FACULTAD DE INGENIERIA U.N.A.M.
DIVISION DE EDUCACION CONTINUA

EDUCACION A DISTANCIA

DIPLOMADO EN CONTROL DE LOS RESIDUOS GENERADOS EN HOSPITALES Y OTROS CENTROS DE SALUD

POR TELECONFERENCIA

MODULO I:

IMPACTO Y RIESGO A LA SALUD Y AL AMBIENTE RELACIONADOS CON EL MANEJO DE RESIDUOS BIOLOGICO-INFECCIOSOS Y ASPECTOS LEGALES

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DIPLOMADO EN CONTROL DE LOS RESIDUOS GENERADOS EN HOSPITALES Y OTROS CENTROS DE SALUD

SITUACIÓN ACTUAL EN EL MUNDO

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AMCRESPAC

En 1983 por ejemplo, el Ministerio de Salud del Brasil, estimó que un número de alrededor de 700,000 perso adquirieron alguna infección vía hospitalaria, en el Brasil.

Asimismo, se ha comprobado también, la presencia en los residuos hospitalarios, de los siguientes microorganismos patógenos:

a) Bacterias
   - Bacilos gram-negativos entéricos
   - Coliformes
   - Salmonella thyphi
   - Shiguella sp
   - Pseudomonas sp.
   - Estreptococos.
   - Staphilococo dorado.

b) Hongos
   - Candida albicans

c) Virus
   - Polio tipo-I
   - Virus de la hepatitis A y B
   - Influenza
   - Vacinia
   - Virus entéricos.

Aunque se piensa de manera general que todos los patógenos sobreviven dentro de los residuos en el ambiente, esto no es tan cierto, lo cual se demuestra con los valores promedio de sobrevivencia en días, de algunos microorganismos.

- Salmonella Thyphi	29 - 70
- Entamoeba Histolytica	8 - 12
- Polio Virus tipo - I	20 - 170
- Mycobacterium tuberculosis	150 - 180

Por otro lado, se debe reconocer la realidad con relación a los microorganismos patógenos, que establecen las siguientes consideraciones:

- Las bacterias patógenas presentes en los residuos, no pueden ser generados por la manipulación inadecuada de ellos.

- La cantidad de materia orgánica presente en los residuos, propicia la proliferación de los microorganismos patógenos.

- Los largos tiempos de transporte entre la fuente generadora y los sistemas de tratamiento y/o disposición final, nos los tiempos de almacenamiento, aumenta la posibilidad de proliferación de los microorganismos patógenos.

- La frecuencia de cierto tipo de bacterias, puede estar relacionada con el tipo de fuente generadora o por el tipo de residuo.

- Una gran cantidad de microorganismos de origen humano, presentes en los residuos, sugiere la presencia de bacterias virulentas y de alta patogenicidad.

- Inventario de todos los generadores de residuos hospitalarios.

- Cuantificar la generación de residuos hospitalarios, en peso, volumen, unidad básica, metros cuadrados o por actividad; de acuerdo a la clasificación que exista.

- Definir normas técnicas regulatorios y/o manuales para obtener las prácticas para un buen manejo de estos residuos.

- Evaluar la situación actual de manejo de los servicios.

- Evaluar las técnicas posibles para el control de estos residuos, técnica, política social, ambiental y econonicamente.

- Generar planes o programas rectores a nivel federal, estatal o local todos ellos coordinados, para el control de estos residuos.

Finalmente, la real peligrosidad de este tipo de residuos, queda manifestada ante la recopilación de importai hechos de afectación a la salud, acaecidos en los últimos 25 años.

- En 1975, la espiroqueta fue identificada como la causante de un nuevo desastre ahora conocido como el Desastre de Lyme.

- En 1978, el Síndrome de Shock Tóxico (TSS), un nuevo síndrome en mujeres entre los 12 y los 52 años, fue descubierta como el resultado de una colonización vaginal, por una bacteria común, S. aureas.

- En 1981, una rara epidemia de inmuno deficiencia fue observada y posteriormente llamada SIDA, que resultó en decenas de miles de muertos alrededor del mundo en un periodo de 15 años.

- Durante los 80's y 90's, Cryptosporidium, un protozoo causante de infecciones en animales y rara vez en humanos, fue el culpable de grandes problemas de salud en los Estados Unidos. 400 mil personas fueron infectadas por Cryptosporidium una Milwaukee, Winsconsin en 1993, después de tomar agua contaminada.

- El Cólera en América Latina, al inicio de los 90's, afectó más de 700,000 personas, de las que murieron más de 6,000.

- En 1992, una inexplicable ola de problemas pulmonares en el suroeste de los Estados Unidos, provocó 44 mueros. El agente patogénico fue identificado como hantavirus.

- El desastre ocasionado por el Virus Ebola en Zaire, Africa en 1995, causó temor mundial, dado que el virus fue identificado también en Liushasa, capital de Zaire. Es aún desconocido donde se originó este virus y como fue la primera infección en un ser humano.

De lo anterior se desprende el siguiente cuadro, que reune a las principales enfermedades derivadas de microorganismos patógenos.

Algunos Patógenos de Importancia Médica y sus Enfermedades Asociadas

Patógenos	Localización de Ocurrencia	Incidencia	Mortalidad si no se Trata	Enfermedades que Causa
Enfermedad Creutzfeldt-Jakob	En todo el mundo	Desconocida	Si	Degeneración de el Sistema Nervioso Central
Hepatitis	En todo el mundo, (particularmente en el Este)	300'000,000	Si	Enfermedades del Higado
Tetanus	Mayormente en Asia, Sudamérica y Africa	Desconocido	Si	Parálisis Espásmica delos Musculos.
Anthrax	Mayormente en Europa, Asia y Africa	Desconocido	Si	Formación de Tejidos Necróticos y Septicemia
Sida	En todo el mundo	8'000,000	Si	El Sistema Inmune es Comprometido
Malaria	Mayormente en Sudamérica, Asia y Africa	150,000,000	Si	Enfermedades de la Sangre y el Higado

4. ALTERNATIVAS PARA EL TRATAMIENTO DE LOS RESIDUOS HOSPITALARIOS

Se puede decir que en términos generales, existen 4 opciones para el tratamiento de los residuos hospitalarios, las cuales son:

- incineración
- microondas
- esterilización
- tratamiento físico-químico

a) Incineración

Es la combustión controlada de los residuos con el fin de eliminar los microorganismos patógenos.

Es el procedimiento comúnmente usado para el tratamiento de los residuos hospitalarios:

Históricamente, los incineraciones han sido usados para quemar residuos patológicos, por razones de salud y percepción poblacional. Recientemente, los hospitales han pretendido incinerar todo tipo de residuos hospitalarios, lo cual ha dado como resultado el que exista un rechazo de la población dado lo riesgoso de esta práctica, si se incluyen residuos hospitalarios y materiales contaminados con agentes patológ sumamente impactantes, como es el virus del SIDA.

Los incineradores más usuales para este tipo de residuos, son los de aire controlado y doble cámara de combustión. Normalmente la temperatura en la cámara primaria, se mantiene entre 1500° F y 1800° F, mientras que en la secundaria, donde se queman los gases de combustión, varía entre los 1800° F y los 2000° F. El tiempo de retención mínimo entre ambas cámaras, debe ser de 2 segundos.

Un buen incinerador, puede quemar prácticamente cualquier tipo de residuo. Los costos de operación de un incinerador moderno y eficiente son de $0.4 a $0.5 USA aproximadamente por kilogramo, sin considerar el transporte.

Cuando el incinerador es ineficiente, es muy probable que se generen dioxinas y furanos.

En la figura 4.1 se presenta un diagrama genérico que muestra el proceso de incineración.

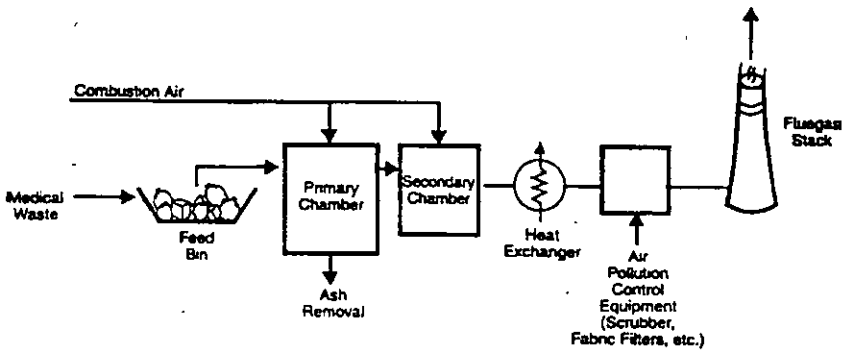

FIGURA 4.1. INCINERACION

b) Tratamiento por microondas.

Este proceso es una opción para el tratamiento de residuos infecciosos. En este proceso, calientan los residuos a 200° F. Dentro del reactor de la cámara, halla un triturador de los residuos para propiciar un mejor contacto con las microondas. El tiempo de residencia en la cámara, varía entre 40 y 45 minutos Este tratamiento, tiene la limitación de no poder recibir partes de cuerpo, navajas, objetos metálicos, ni residuos químicos. Su costo de operación es de aproximadamente un 50% o 60% del costo de la incineración. En la figura 4.2 , aparece un diagrama de flujo con el proceso de las microondas. Con esta técnica, el volumen del residuo, se reduce de un 60 a un 70%.

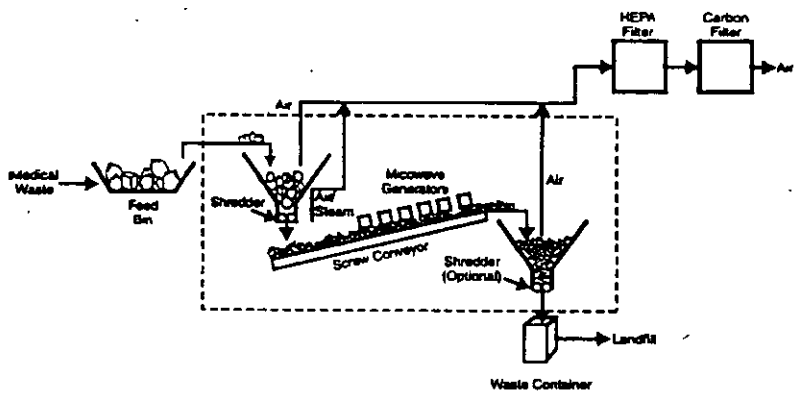

FIGURA 4.2. MICROONDAS

c) Tratamiento de esterilización con vapor.

Este proceso es muy usual para desinfectar o esterilizar residuos médicos ante de disponerlos en rellenos sanitarios. Esta técnica se ha usado ampliamente desde mediados de la década de los 70´s, para la desactivación de cultivos de laboratorio microbiológicos. Sin embargo, aunque puede aceptar metales y navajas, no puede tratar residuos químicos , ni patológicos; excepto si es un sistema esterilizador de alta eficiencia, como los que están usándose actualmente en la ciudad de Berlín.

Con este sistema, se inyecta vapor saturado a una presión que varia de 30 a 40 lb/pulg^2 y a una temperatura del orden de los 310 F . El periodo de retención, es normalmente de 30 a 40 minutos. Si el esterilizador cuenta con triturador interno es posible alcanzar una reducción de hasta un 65%. Se estima que su costo operacional, es de un 50% del costo de la incineración. En la figura No. 4.3, se describe el proceso de esterilización.

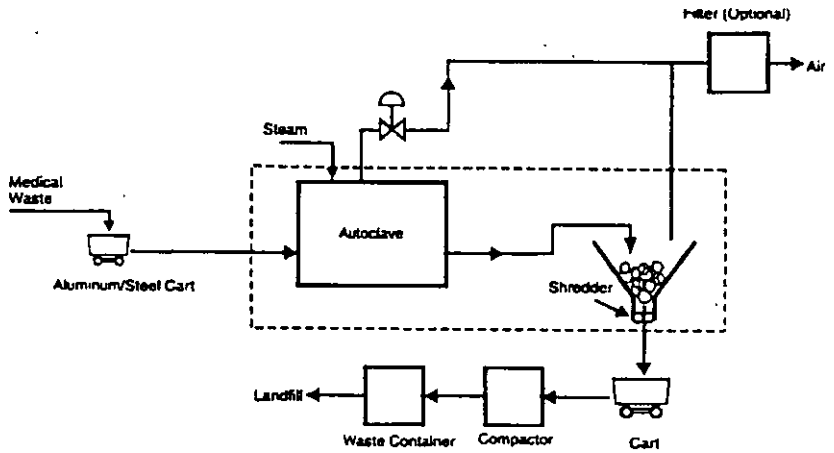

FIGURA 4.3. ESTERILIZACION POR VAPOR

d) Tratamientos físico-químicos

Esta tecnología normalmente involucra una molienda y una inactivación química del desecho, la cual puede hacerse mediante cloro en forma de hipoclorito de sodio; o bien, utilizando peróxido de hidrógeno e incluso ozono. Es más popular el uso de hipoclorito, debido q que el costo de inversión para un ozonizador es muy elevado, mientras que el costo del peróxido es sumamente alto, amén de ser altamente reactivo. La dosificación del reactivo, puede ser de hasta 1500 ppm para asegurar la eficiencia del tratamiento. Esta técnica no acepta residuos químicos, peligrosos, partes de cuerpo, ni partes metálicas. También tiene el

inconveniente de producir lixiviados o residuos líquidos sumamente reactivos, que normalmente requieren ser tratados antes de disponerlos en el drenaje.

El costo aproximado de operación que puede alcanzar este proceso, es de 35 o 45% del costo de la incineración. La reducción del volumen del desecho puede ser de un 60%.

En la figura 4.4., se ilustra el proceso antes descrito.

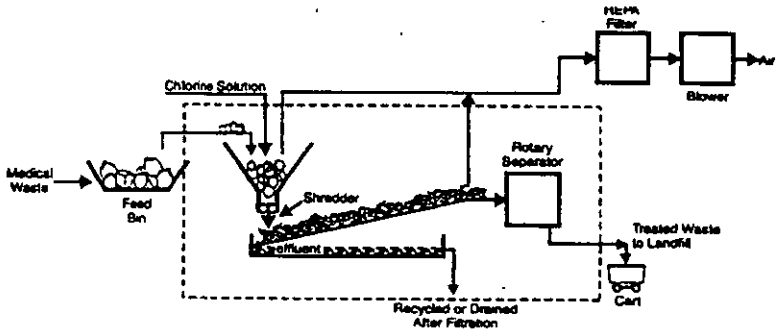

FIGURA 4.4. FISICO-QUIMICO

5. ALGUNAS EXPERIENCIAS EN EL MUNDO

a) Situación Actual en Latinoamérica y el Caribe

Una de las características importantes de los residuos sólidos de hospitales es su heterogeneidad, característica que es consecuencia de la amplia gama de actividades complementarias a la atención médica que se desarrolla al interior de un hospital, todas las cuales, en mayor o menor grado, aportan residuos de diversas calidades.

La composición de los residuos sólidos hospitalarios puede establecerse de acuerdo a diferentes criterios de clasificación de componentes, según sea la utilidad que un determinado criterio de clasificación pueda prestar en la resolución de un problema específico. Es así, como los diversos componentes pueden ser clasificados de acuerdo a su lugar de origen, a su combustibilidad, a su carácter orgánico, a su putrescibilidad, a su peligrosidad, o bien de acuerdo a los compuestos y elementos químicos que conforman los desechos.

Existen diversos criterios de clasificación propuestos o en uso en los países latinoamericanos, los básicamente diferencian los desechos de material médico-quirúrgico, los desechos biológicos, los restos de alimentos, los objetos cortopunzantes y la fracción de desechos similar a los residuos municipales comunes.

Desde el punto de vista del manejo sanitario de los residuos sólidos hospitalarios, interesa especialmente clasificar los desechos de acuerdo a su carácter infeccioso.

La separación de algunas de las diferentes fracciones componentes de los residuos sólidos de hospitales es una práctica común en los establecimientos hospitalarios, si bien tal separación se realiza frecuentemente con el fin de disminuir los costos de manejo interno y externo de los residuos y no con el propósito de reducir los riesgos sanitarios asociados al manejo de las fracciones infecciosas o peligrosas en general

Es práctica muy corriente la separación y comercialización de los residuos provenientes de la preparación, elaboración y servicio de alimentos; de los papeles y cartones provenientes del embalaje de material médico, de laboratorio o de farmacia, así como la separación y comercialización de otras fracciones menores, tales como envases de vidrio y plástico. Sin embargo, el hecho de no contarse con una adecuada práctica de separación de la fracción infecciosa implica la existencia de riesgos para la salud, tanto del personal que manipula estos materiales, como para la salud de la comunidad en general.

Especial mención merecen los objetos punzocortantes, ya que al peligro de accidentes traumáticos que t. objetos ofrecen hay que agregar que, por su misma naturaleza y uso, con frecuencia ellos han estado en contacto con material infeccioso y presentan, por lo tanto, dicha característica. La separación y embalaje adecuado de los residuos cortopunzantes, de manera de prevenir accidentes y evitar el deterioro de los recipientes y bolsas receptoras de desechos, resulta una práctica necesaria para el buen manejo de los residuos de hospitales.

El almacenamiento de los residuos en el lugar de origen representa la primera etapa de un proceso secuencial de operaciones que conforman el sistema de manejo. Para ello, debe contarse con receptáculos de tamaño, forma y material adecuados, de manera de asegurar una capacidad suficiente, un fácil manejo y limpieza y una hermeticidad acorde con los requerimientos sanitarios propios de cada zona. Se considera óptimo el uso de receptáculos cilíndricos o troncocónicos de metal o plástico rígidos, provistos de tapa y asas, y de capacidad no superior a cien litros.

La recolección de los residuos desde las zonas de generación se hace por lo general con carros de tracción manual. Tales carros deben ser de diseño apropiado de manera de impedir el derrame de residuos y evitar molestias innecesarias a la población hospitalaria. De considerarse que es imprescindible transitar por las dependencias interiores del establecimiento, lo cual exige poner especial atención a las condiciones

higiene, rapidez y silencio de esta operación, siendo necesario establecer programas de recolección con horarios y recorridos bien definidos.

La tendencia actual en Latinoamérica y el Caribe, es la de limitar o suprimir el uso de ductos de gravedad para el transporte interno de los residuos debido, fundamentalmente, a los problemas de derrame de residuos tanto en las tolvas de admisión, como en las salas de recepción y a la introducción en el ambiente hospitalario de materiales contaminantes, tales como gases y partículas, e incluso de vectores sanitarios a través de las tolvas las de admisión, cuando ellas se encuentran en malas condiciones o son operadas en forma inconveniente.

El diagnóstico de la situación actual, en cuanto a las condiciones de tratamiento y disposición final de los residuos sólidos de hospitales en los países latinoamericanos y del Caribe es incompleto, disponiéndose en el presente solo de descripciones parciales de la situación imperante en algunos países. En base a estos antecedentes y a la información obtenida directamente en terreno es posible afirmar que , en un gran número de casos, los residuos sólidos de hospitales son derivados en su conjunto a la recolección municipal sin que exista una separación, en muchos casos incompleta, de los restos de tejidos humanos generados en los servicios de cirugía, obstetricia y anatomía patológica.

Ha sido práctica frecuente también en los países latinoamericanos y del Caribe el instalar, en especial en los hospitales y clínicas de gran tamaño, incineradores de grandes dimensiones con el propósito de incinerar en el recinto del establecimiento la mayor parte, y en algunos casos la totalidad, de los residuos sólidos generados.

El resultado de esta práctica ha sido la instalación de equipos sobredimensionados que, además de requerir una importante inversión inicial, tienen altos costos de operación y mantenimiento y que en su mayoría funcionan precariamente o han quedado fuera de uso. Cabe hacer presente además que el diseño original de muchos de estos incineradores no satisface los requerimientos mínimos de un incinerador de residuos hospitalarios por lo que, aún en óptimas condiciones de operación, presentaron deficiencias graves de funcionamiento.

Consecuencias del funcionamiento defectuoso de este tipo de unidades en la emisión de humos, partículas contaminantes y malos olores a la atmósfera, con el consiguiente deterioro de las condiciones ambientales de los sectores aledaños al hospital, y la generación de cenizas no totalmente mineralizadas, y por lo tanto, de difícil manejo posterior.

Existen algunas experiencias interesantes en relación con sistemas de incineración central en donde la municipalidad o alguna empresa presta el servicio de incineración, hasta cuyas instalaciones son trasladados

los residuos sólidos de hospitales, clínicas y establecimientos de salud para su tratamiento. Sistemas de tipo han sido implementados en Brasil, en la ciudad de Sao Paulo y en Ciudad de México.

La incineración central tiene la ventaja de disminuir, tanto los costos totales de inversión, como los de operación y mantenimiento, y de facilitar la obtención de mayores niveles de eficiencia y de suficiencia técnica. En contraste con lo anterior, implica mayores costos de transporte y la introducción de un factor de riesgo sanitario-ambiental adicional asociado al tránsito de desechos infecciosos fuera del recinto del hospital. Por otra parte, esta solución solo resulta aplicable a grandes ciudades en donde la cantidad total de residuos a incinerar permita alcanzar los bajos costos y los niveles de eficiencia buscados.

En países como Chile y Cuba, se practica la separación en origen de las fracciones infecciosas, las que son incineradas, biodigeridas o esterilizadas en unidades de pequeño tamaño especialmente diseñadas para tratar este tipo de residuos. Asimismo, en estos países se promueve la separación de los residuos provenientes de la elaboración de alimentos con el fin de aprovecharlos en la cría y engorda de animales. El resto de los residuos, junto a las cenizas de incineración, son recogidos por el servicio municipal.

b) Situación Actual en los Estados Unidos de Norteamérica

La Asociación Nacional para el Manejo de los Residuos Sólidos, emitió un reporte sobre el estado que guardaba el manejo de los residuos infecciosos en U.S. hasta julio de 1989. Este reporte indicaba que:

- Los estados de Idaho, Mississippi, Montana, South Dakota, Utah y Wyoming no contaban con ningún ordenamiento legislativo para el manejo de los residuos hospitalarios.
- En cambio, Florida, Georgia, Indiana, Maryland, Massachusetts, Michigan y Texas se estaba elaborando un listado de métodos de tratamiento aprobados (usualmente incineración con vapor), el cual sería incluido en sus respectivas legislaciones sobre residuos hospitalarios.

Situaciones Específicas

IOWA.- Al Departamento de Recursos Naturales, le fue solicitada la elaboración de una lista de todas las instalaciones que generan residuos infecciosos y las cantidades de los mismos. Este inventario fue terminado en 1991.

MARYLAND.- Se prohibe la disposición de residuos provenientes de hospitales y de otras instituciones a cargo del cuidado de la salud, en el suelo.

CAROLINA DEL SUR.- Existe un "Acta para el manejo de residuos infecciosos", que establece la creación de un fondo para Contingencias de Residuos Infecciosos con la finalidad de atender las emergencias que se presenten en este campo.

NEW YORK.- La legislación permite tanto la incineración, como la disposición en rellenos sanitarios de residuos infecciosos; sin embargo en la práctica, ningún operador de rellenos sanitarios permite la disposición de residuos infecciosos en sus sitios.

Se generaban 150 ton/día de residuos hospitalarios en el estado de New York, la mitad de estos se incineraban en 300 incineradores en los mismos hospitales y otras instituciones al cuidado de la salud. Comunmente estos incineradores, no estaban contemplados en la legislación de emisiones al ambiente, pero fueron contemplados en 1992.

c) Situación Actual en Japón

- Los residuos hospitalarios son considerados como especiales, por lo que requieren de un tratamiento acorde con sus características. Esto se aplica a los clasificados tanto industriales, como municipales.
- La ley establece que el tratamiento final es la incineración, por lo que antes de realizar este tratamiento es necesario desinfectarlos, utilizando vapor, agua caliente a presión, o bien, oxidación química.
- Se establece como temperatura mínima para la incineración, 800°C.
- El Ministerio de Sanidad y Bienestar, otorga dos tipos de licencia; la primera, para la operación del equipo; la segunda, la autorización al operador de dicho equipo.
- La Agencia del Ambiente, la cual depende del Primer Ministro, evalua el comportamiento de la operación y el cumplimiento de la Normatividad.

d) Situación Actual en los Países en Desarrollo

Al revisar la situación de cualquier país, es importante considerar sus creencias religiosas y el grado de conciencia que tengan respecto a los asuntos relacionados con la salud, sus prácticas y tecnología.

Algunas culturas tienden a mantener el mínimo contacto con los residuos. Esto tiene la ventaja de que hay menor interés de reusar y reciclar y por ello los riesgos inherentes a ciertos componentes peligrosos de los residuos médicos son menores. Sin embargo, esa misma actitud podría desalentar a los profesionales de verse involucrados con el manejo de los residuos y por ello hay muy poco control sobre el almacenamiento, manejo y disposición de los residuos de hospitales. Otras culturas encuentran más aceptable reusar y explotar los residuos y en esas culturas existe más peligro de que los materiales peligrosos y contaminados retornen a la economía. Los residuos médicos constituyen una amenaza a las sociedades que se manifiesta de muchas maneras:

Cuando los desechos tengan un valor de reventa, deberá presentarse mayor atención a la supervisión de los desechos en todas las etapas para verificar que los trabajadores u otras personas no vendan o permitan el acceso a los desechos. El potencial de rentabilidad amplifica enormemente los riesgos inherentes a los desechos médicos.

El grado de educación sanitaria y de concientización sobre la higiene en el público en general es otro fa crucial para decidir los riesgos planteados por los desechos médicos. El público se mostrará renuente a emplear artículos descartados y a recurrir a personal no calificado si es consciente de los riesgos potenciales que afronta. Sin embargo, en muchas sociedades -aún en las que tienen un nivel de educación formal elevado- existe un porcentaje significativo de analfabetos que ignoran los peligros, y son los más expuestos a riesgos mayores. Deberá impedirse que estas personas tengan contacto con desechos médicos peligrosos mediante un control estricto del acceso y una supervisión rigurosa por parte de profesionales responsables.

e) Situación Actual en Otras Regiones

En Africa, algunos hospitales urbanos queman sus residuos al aire libre dentro del mismo local y las aguas residuales a veces se tratan pero no se desinfectan. La clasificación y segregación adecuadas en la fuente de los diferentes tipos de residuos varía de país a país.

La situación en el sudeste asiático fue reportada por el Dr. Bhide, del National Environmental Engineering Research Institute (Instituto Nacional de Investigación en Ingeniería Ambiental) de Nagpur India. Parece ser que los peores problemas se dan en los pequeños hospitales pues no se percatan del cuidado especial que se debe tener al manejar residuos infecciosos. En los grandes hospitales la situación es mejor, sin embarao

la clasificación y recolección separada de los residuos infecciosos está lejos de ser la adecuada. Algunos hospitales grandes tienen incineradores pero no aceptan residuos de otras fuentes. Los residuos líquidos se vierten al alcantarillado sin pretratamiento. Los residuos sólidos, tanto los peligrosos como lo no-peligrosos, a menudo se entierran juntos dentro de los terrenos del hospital. Todo el personal no profesional de los hospitales, necesita urgentemente recibir capacitación en higiene hospitalaria.

Este informe se ha preparado con la intención de discutir los problemas antes mencionados y se presentarán recomendaciones después de revisar las opciones disponibles.

Para expertos en esta actividad, en algunos países del sur o del este de Europa la situación no es mejor que en los países en desarrollo, especialmente en las pequeñas comunidades y en los pequeños establecimientos de salud.

Algunos Aspectos en el Brasil.

× Cuenta con 3 Normas Técnicas para el Manejo de los Residuos Hospitalarios o "de Servicios de la Salud", como les denominan, dichas Normas se indican a continuación:

- Terminología. Con 37 definiciones.
- Clasificación. Que clasifica a los Residuos Hospitalarios en:
  - × Clase "A". Residuos Infecciosos (biológicos, sangre, exsudados, punzocortantes, etc.)
  - × Clase "B". Residuos Especiales (radiactivos, fármacos y residuos químicos peligrosos)
  - × Clase "C". Residuos Comúnes (Residuos no-peligrosos, semejantes a los residuos domésticos y municipales)
- Procedimientos dentro del Hospital, para la segregación, acondicionamiento, colecta interna, almacenamiento interno y externo y características del área del almacenamiento.

Como se observa, no existe ninguna norma que oriente las acciones en materia de tratamiento y disposición final, aunque existe una norma que establece los requisitos para incinerar residuos peligrosos. Es por ello tal vez que actualmente se emplean direferentes técnicas para el tratamiento de los residuos antes de su disposición final, predominando preferentemente la incineración y la esterilización como segunda opción, aunque también es cierto que el tratamiento vía microondas, tiene buena aceptación.

Conceptos Generales en Francia para el Manejo de Estos Residuos

Existen tres tipos de eliminación de los desechos de riesgo:

- × incineración *in situ*, es decir en una instalación en el seno mismo del hospital;
- × incineración en una planta de desechos domésticos, siempre y cuando ésta esté adaptada específica para tal efecto;
- × incineración en una instalación centralizada específica para desechos hospitalarios.

***Incineración* In Situ**

La solución a la cual recurren más seguido los hospitales, alegando principalmente razones de costo (alrededor de 1,200 a 1,500 francos por tonelada), son generalmente, las instalaciones *in situ*. Originan no obstante graves perjuicios, por diferentes razones: por lo general, los hornos de los hospitales son de baja capacidad, inferior a 1 tonelada/hora. Tienen un funcionamiento cíclico que provoca choques términos y contaminación en cada encendido. El tratamiento de humos es un proceso poco eficaz (ausencia de post combustión). La temperatura inferior a 750°C, es insuficiente.

Incineración en las Plantas de Desechos Domésticos

La segunda opción ofrece garantías más amplias que la anterior en términos de salud pública y de protección del medio ambiente. Es una posibilidad mencionada en el decreto del 9 de junio de 1986, el cual especifica la admisión de desechos hospitalarios contaminados está sometida a prescripciones especiales y que debe autorizada por decreto prefectoral.

Actualmente, son pocas las instalaciones de incineración de desechos domésticos que están autorizadas a incineración de desechos domésticos que están autorizadas a incinerar desechos hospitalarios de riesgo.

Incineración Centralizada Específica

La elimiación de los desechos hospitalarios de riesgo en instalaciones centralizadas parece ser más satisfactoria en materia de protección del medio ambiente y de la higiene.

La creación de una instalación centralizada, de gran capacidad, y específica para este tipo de desechos representa una inversión muy fuerte. Por lo tanto, resulta indispensable realizar un estudio minucioso del yacimiento de los desechos y, eventualmente, prever la rentabilidad de la instalación mediante la aportación adicional de otros desechos industriales.

Se pueden considerar dos tipos de instalaciones centralizadas:

- Un horno específico para los desechos hospitalarios, al lado de una planta de incineración de desechos domésticos con el tratamiento conjunto de los humos.

- La construcción de una verdadera instalación autónoma, con su propia instalación de tratamiento de humos.

DIPLOMADO EN CONTROL DE LOS RESIDUOS GENERADOS EN HOSPITALES Y OTROS CENTROS DE SALUD

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INTRODUCCIÓN

Las instituciones encargadas específicamente de la atención de la salud son de tres tipos. En primer lugar para la población abierta se tiene la Secretaría de Salud, la Dirección General de Servicios Médicos del Distrito Federal y el Sistema Nacional para el Desarrollo Integral de la Familia. En segundo lugar, para la población asegurada, se cuenta con el ISSSTE, el IMSS y otras instituciones de seguridad social (PEMEX, SDN y SM). Finalmente, se tiene la medicina privada.

Los criterios para clasificar las unidades por nivel de atención a la salud varían según las instituciones, aunque en términos generales se considera como primer nivel cuando la unidad otorga exclusivamente consulta externa; segundo nivel cuando además de la consulta se cuenta con los cuatro servicios básicos de hospitalización (medicina interna, pediatría, cirugía y gineco-obstetricia); y tercer nivel cuando a lo anterior se agrega cualquier servicio de hospitalización especializada, así como instalaciones de investigación.

Los residuos sólidos generados en hospitales y establecimientos de salud, presentan riesgos y dificultades especiales en su manejo debido, fundamentalmente, al carácter infeccioso de algunas de sus fracciones componentes. Contribuyen también a acrecentar tales riesgos y dificultades, la heterogeneidad de su composición, la presencia frecuente de objetos punzocortantes y la presencia eventual de cantidades menores de sustancias tóxicas, inflamables y radiactivas de baja intensidad. No obstante lo anterior, la mayor parte de los residuos que produce un hospital no ofrece mayores peligros que los asociados a los residuos municipales comunes.

Los riesgos arriba mencionados involucran en primer término, al personal que debe manejar los residuos sólidos tanto dentro como fuera del establecimiento, personal que de no contar con suficiente capacitación, entrenamiento, equipo y herramientas de trabajo o de elementos de protección personal adecuados, puede verse expuesto a gérmenes patógenos o a la acción de objetos punzo-cortantes, tales como agujas de jeringas, trozos de vidrio o bisturíes.

No menos significativos son los riesgos que pueden llegar a afectar al resto de la población hospitalaria y, en particular, al grupo constituido por aquellos pacientes en especial riesgo de contraer infecciones como consecuencia de la exposición a agentes patógenos, cuando el manejo de estos residuos se realiza en forma inadecuada.

La implementación de la norma referente al manejo de los residuos sólidos generados en unidades médicas, plantea la necesidad de que estas instalaciones lleven a cabo una evaluación de cuantificación y dimensionamiento de la cantidad de residuos sólidos que deberán considerarse dentro de un manejo integral en instalaciones de salud.

OBJETIVO GENERAL

Desarrollar una metodología que permita, como primera instancia, cuantificar e identificar los diversos tipos de residuos generados en unidades médicas, y posteriormente establecer una logística para el manejo integral de los residuos sólidos biológico-infeccioso, especiales y municipales, con la finalidad de establecer estrategias económicas que permita dar atención a las necesidades, que demanda el manejo de este tipo de residuos.

1. Índices de Generación

1.1 Antecedentes

De primordial importancia para abordar cualquier programa de control de las situaciones de riesgo derivadas del manejo inadecuado de los residuos sólidos de hospitales, es el caracterizar cualitativa y cuantitativamente el problema.

Ello permitirá dimensionar los espacios físicos necesarios para manejar los diferentes tipos de desechos, decidir acertadamente acerca de qué alternativas técnicas utilizar para el tratamiento de cada una de las fracciones componentes y seleccionar los equipos y dispositivos más convenientes para tal propósito.

Lamentablemente la información disponible a este respecto es aún insuficiente en la mayoría de los casos, y la escasa información existente es, en ocasiones, poco confiable o limitada en su aplicación a situaciones particulares, ello ha conducido a la adopción de soluciones que la experiencia ha demostrado posteriormente que eran inadecuadas y, como consecuencia de ello la agudización de situaciones de riesgo, como las ya antes referidas.

De ahí la importancia de desarrollar una metodología que permita un adecuado manejo de los residuos sólidos generados en unidades médicas, tanto de los residuos biológico-infecciosos como de los residuos municipales, los cuales representan el mayor porcentaje de la generación en unidades médicas.

A la fecha se han realizado una serie de estudios de generación de residuos en diversos hospitales de cada uno de los niveles de atención, los cuales han permitido conocer algunos de los indicadores básicos de los residuos generados en este tipo de establecimientos. Cabe mencionar que a partir de estos estudios se pudo conocer que existe una gran diversidad en la composición de los residuos, así como la cantidad que se genera, originando por el número de pacientes y el tipo de servicio que se ofrece.

1.2 Generación de Residuos Sólidos

La cantidad de residuos sólidos generados en un establecimiento hospitalario está en función de las diferentes actividades que en él se desarrollan y en consecuencia dependerá, entre otros factores, de la cantidad de servicios médicos ofrecidos en el establecimiento de salud, del grado de complejidad de la atención prestada, del tamaño de la unidad médica, de la proporción de pacientes externos atendidos y de la cantidad de personal que labora en las instalaciones; no resulta fácil establecer relaciones que permitan estimar la cantidad de residuos sólidos producidos por un establecimiento hospitalario en función de tal diversidad de factores.

Lo anterior ha conducido a relacionar la cantidad de residuos sólidos generados diariamente con el número de camas sensables del establecimiento, para el caso de las unidades médicas de segundo y tercer nivel, para las unidades de primer nivel, la relación se ha enfocado hacia el número de consultorios, lo mismo sería para las veterinarias, consultorías o particulares, etc. Obteniéndose así cifras que si bien pueden estar sujetas a cierto grado de imprecisión, son de fácil manejo y aplicación.

Las cifras promedio obtenidas en diversas instalaciones de unidades médicas para la generación per cápita fluctúa de la siguiente manera:

FUENTE GENERADORA	GENERACIÓN UNITARIA
U.M. de 1er. Nivel	
- Con laboratorio	1.279 kg/consultorio/día
- Sin laboratorio	0.998 kg/consultorio/día
U.M. de 2o. Nivel	4.730 kg/cama/día
U.M. de 3er. Nivel	5.390 kg/cama/día
Laboratorios Privados	0.580 kg/empleado/día
Veterinarias Privadas	1.700 kg/empleado/día

Tabla 1

Adicionalmente a los indicadores unitarios referenciados al total generado en un hospital como es el kg/cama/día, resulta de interés y de suma importancia para el diseño de un sistema de manejo interno conocer los índices de generación por área, la experiencia nos ha permitido establecer diferentes índices tanto por área como por día de la semana. Estas variaciones se deben al tipo de servicio que se presta y a los pacientes atendidos diariamente. Las fluctuaciones más grandes son en consulta externa, mientras que

en Hospitalización las diferencias son mínimas. En la tabla que a continuación se presenta se puede observar los índices de generación en algunas áreas.

ÁREA GENERADORA	ÍNDICES DE GENERACIÓN PER CAPITA
Consulta Externa	0.064 kg/paciente atendido/día
Hospitalización	1.165 kg/paciente hospitalizado/día
Laboratorios	0.121 kg/muestra analizada/día

Tabla 2

Dicha tasa de generación tiende a aumentar con el tiempo. Tal comportamiento coincide con la evolución mostrada en países desarrollados.

Las principales causas de este progresivo aumento en la tasa de generación de residuos sólidos hospitalarios son el continuo incremento de la complejidad de la atención médica y el uso creciente de materiales desechables.

1.2.1 Comportamiento semanal de la generación por área

En los muestreos realizados a las diversas unidades médicas, se detectó que el comportamiento de la generación era diferente durante todos los días de la semana, en las diferentes áreas que conforman estas instalaciones (fig. 1 a la 7). Esta situación plantea la necesidad de llevar a cabo evaluaciones en cada una de las unidades médicas con el objeto de determinar los índices de generación diaria, tanto de los residuos biológico-infecciosos como de los especiales, así como de los municipales.

Como puede observarse, existe un decrecimiento en la generación el fin de semana, situación que se presenta en las áreas de servicios complementarios, laboratorios, oficinas de gobierno. Por lo que respeta al área de asistencia médica, se presenta una baja producción de residuos el fin de semana, sin embargo, en el área de cuartos de hospitalización la generación se mantiene prácticamente estable durante toda la semana, el área de suministro y preparación de alimentos, reduce su generación el fin de semana, debido a que gran parte del personal que labora realiza sus actividades entre semana y consume alimentos en este periodo.

GENERACIÓN PROMEDIO POR ÁREA GENERADORA

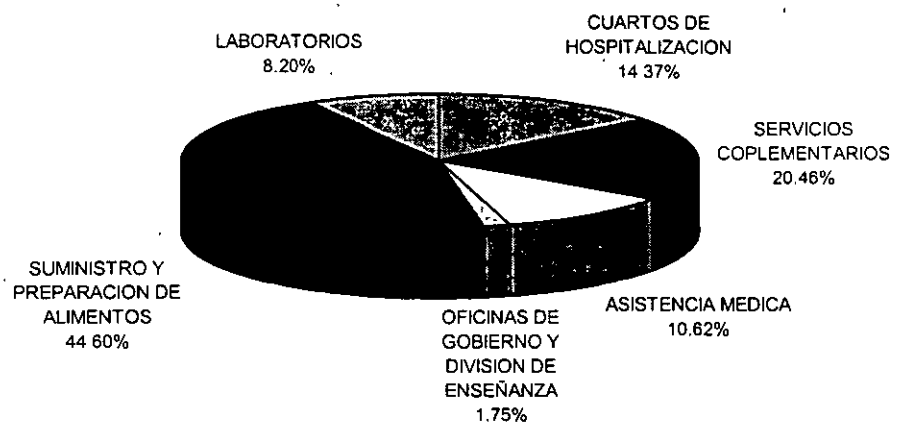


Figura 8

1.2.2 Peso volumétrico "in-situ" por área generadora

ÁREA	PESO VOLUMÉTRICO PROMEDIO KG/M^3
Asistencia Médica	99
Servicios Complementarios	83
Cuartos de Hospitalización	110
Laboratorios	68
Suministro y Preparación de Alimentos	260
Oficinas de Gobierno y División de Enseñanza	58

TABLA 3

Cabe señalar que en el almacenamiento central, el peso volumétrico a considerar deberá contemplar un factor de incremento de 1.40 situación que obedece al acomodo que se da a los residuos por parte del personal de intendencia.

1.2.3 Composición física por área generadora

SUBPRODUCTOS	ASIST. MEDICA	SERV. COMP.	CUARTOS HOSP.	LABORATORIOS	S. Y P. ALIM.	OF. GOB. DIV. ENS.	X
Abatelenguas	0.28	0.14	0.16	0.05	0.00	0.10	0.12
Algodón	2.15	0.05	0.80	0.38	0.00	0.25	0.61
Cartón	7.33	22.59	7.86	9.11	2.74	10.84	10 08
Desechos alimenticios	2.68	4.51	5.91	0.47	77.19	3.75	15 75
Desechos finos (criba # 10)	0.00	0.00	0.004	0.00	0.00	0.00	0.0007
Desechos de jardinería	0.05	0.00	0.52	0.22	0.02	0.37	0 20
Envases de cartón encerado	1.14	0.03	0.73	0.00	3.12	0 20	0 87
Fibra sintética	0.02	1 17	0.02	0.14	0.14	0 25	0 29
Gasas	3.08	2.07	2.41	2 15	0 00	0.81	1.75
Hueso	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hule	0.00	1.04	0.16	0.72	0.00	0.24	0.36
Jeringas desechables	2.88	0.24	2.93	1.30	0.00	0.31	1.28
Lata	0.09	0.17	0.04	0.00	2.32	0 00	0 44
Madera	0.72	0.69	0.03	0.52	0.03	0.06	0 34
Material ferroso	0.53	0.29	0.55	0.27	0.35	0.70	0 45
Material no ferroso	0.18	0.26	0.03	0.07	0.00	0.14	0.11
Pañal desechable	2.54	0.00	8.95	0.00	0.00	0.52	2.00
Papel	31.32	40.88	25.00	43.71	6.93	62.33	35.0
Papel metálico	0.00	0.04	0.02	0.70	0.08	0.09	0.16
Piezas dentales	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Placas radiológicas	0.74	0.04	0.00	0.00	0.03	0.00	0.14
Plástico película	6.20	3.69	4.61	2.64	1.03	2.40	3 43
Plástico rígido	6.80	3.06	12.56	6.70	2 89	2.61	5.77
Poliestireno expandido	0.74	1.71	0.17	0.75	0.22	3 47	1.18
Poliuretano	0.00	0.00	0.00	0.00	0.00	0 00	0.00
Tejido orgánico	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Toalla sanitaria	2.07	0.13	2.55	0.08	0.00	1.40	1.04
Trapo	0.54	3.35	0.50	0.06	0.003	0.51	0.83
Vendas	1.96	0.00	0.09	0.00	0.00	0.00	0.34
Vidrio de color	4.94	1.94	4.25	8.63	0.11	0.95	3.47
Vidrio transparente	19.41	7.71	17.81	18.09	0.95	3.67	11.27
Yeso ortopédico	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cuero	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Loza y cerámica	0.06	0.00	0.00	0.13	0.73	0.39	0.22
Varios	1.55	4 20	1.33	3.11	1.11	3.65	2 49

Tabla 4

La importancia de conocer el tipo de residuos y la calidad que se genera por área, radica en el hecho de poder establecer el tipo y el número de contenedores a emplear por área. así mismo definir las rutas de recolección y finalmente poder dimensionar el sistema de tratamiento a considerar. En la tabla 4 se puede apreciar que la mayor parte de los residuos que se tienen caracterizados, son los considerados como municipales.

1.3 Clasificación de los residuos

Una clasificación adecuada de los residuos que se generan en un centro de atención a la salud permite que su manejo sea eficiente, económico y seguro. La clasificación facilita una apropiada segregación de los residuos, reduciendo riesgos sanitarios y costos en el manejo de los mismos, ya que los sistemas más seguros y costosos se destinarán sólo para la fracción de residuos que lo requieran y no para todos.

Los diversos componentes pueden ser clasificados de acuerdo a su lugar de origen, a su combustiblidad, a su carácter orgánico, a su putrescibilidad, a su peligrosidad, o bien de acuerdo a los compuestos y elementos químicos que conforman los desechos. Existen diversos criterios de clasificación propuestos, según sea la utilidad que un determinado criterio de clasificación puede prestar en la resolución de un problema específico.

Con el objeto de facilitar el manejo de los residuos generados en unidades médicas, en esta propuesta se presenta una forma sencilla y práctica de clasificar los residuos sólidos de acuerdo a sus características (Fig. No. 9).

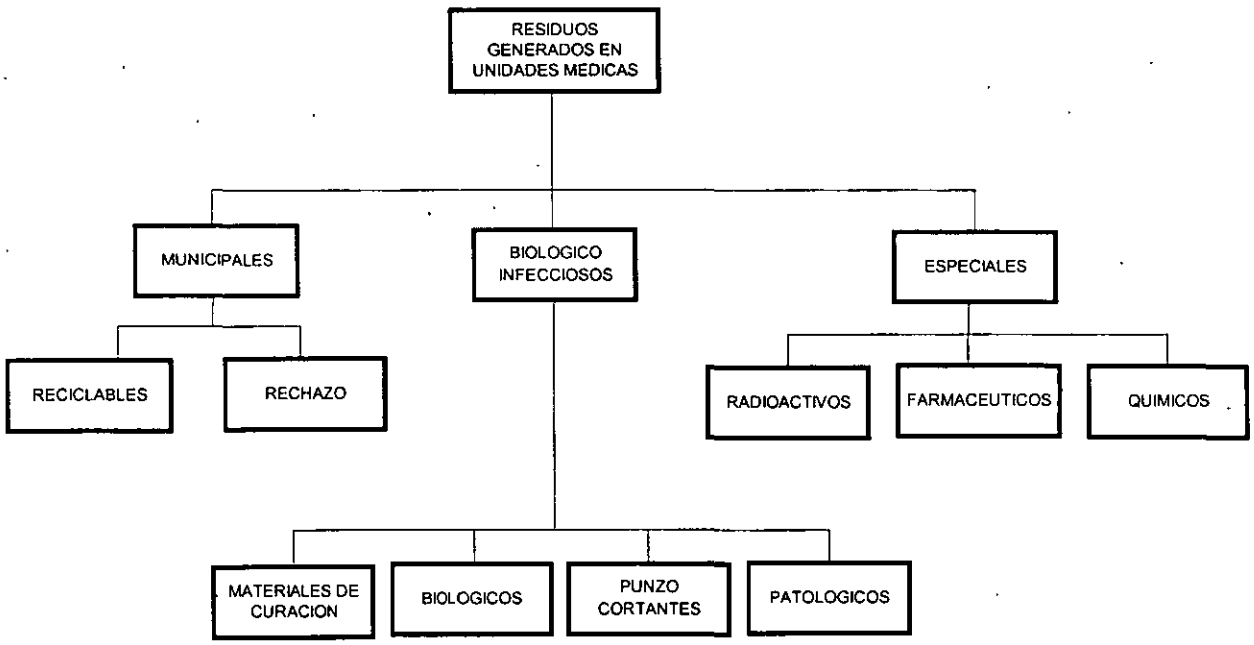


Figura No. 9

Tomando como criterio el riesgo para la salud, considerando los puntos de generación y los tipos de tratamiento y disposición final que se debe dar a los residuos, éstos se clasifican de la siguiente manera:

Residuos municipales (no peligrosos). son los generados en áreas donde no se tiene contacto con pacientes.

Aquellos originados por las actividades administrativas, auxiliares y generales, que no representen peligro para la salud y sus características son similares a los residuos domésticos comunes. Pueden manejarse como los residuos municipales y aunque en algunas otras clasificaciones no los consideran por ser similares a los domésticos. En esta propuesta se incluyen porque comprenden la mayor proporción de los residuos generados en unidades médicas y por lo tanto deben contemplarse dentro del programa integral de manejo interno y externo de los residuos originados en centros de atención a la salud.

Dentro de este grupo podemos encontrar los siguientes tipos de residuos:

- Reciclables. son aquellos que pueden ser transformados en nuevas materias primas para incorporarlos a los mismos procesos productivos para los que fueron creados o bien a procesos alternos para crear otros bienes de consumo.

- Rechazo. Es todo aquel residuo que por no presentar utilidad, beneficio o potencial de recuperación, de ser enviado a un sitio de disposición final.

Residuos biológico-infecciosos (peligrosos). Son definidos como todos aquellos residuos en cualquier estado físico, generados en cualquier unidad médica, que por su carácter biológico-infeccioso representan un peligro para el equilibrio ecológico y salud ambiental.

Estas se pueden agrupar en cuatro categorías, mismas que precisan diferente manejo.

- Materiales de curación y misceláneos. Incluye todos los materiales que hayan estado en contacto con los pacientes, tales como vendas, apósitos, gasas, algodón, compresas, hisopos, equipo para venoclisis (excepto agujas), sondas, bolsas y frascos de recolección de fluidos, guantes, cubrebocas, gorras, ropa quirúrgica desechable, etc.

- Residuos biológicos. Que incluye tanto residuos microbiológicos como líquidos corporales y heces, originados en la toma de muestras de pacientes. También se considera el material generado por la experimentación con animales de laboratorio: Incluyendo muestras de sangre, heces y otros fluidos. Adicionalmente involucra cajas de petri desechables y cepas.

- Punzocortantes. Tales como agujas hipodérmicas, jeringas, pipetas Pasteur, tijeras, hojas de bisturí y de rasurar, cristalería, etc., que hayan estado en contacto con pacientes humanos y animales durante el diagnóstico, tratamiento o investigación. También deben incluirse aquellos objetos punzocortantes que no hayan sido utilizados, pero que tengan que ser desechados por estar en mal estado o cuando se hayan contaminado.

- Patológicos. Incluye partes del cuerpo humano o animal, órganos, tejidos, biopsias etc.

- Residuos especiales. Son aquellos que por sus características de composición y naturaleza, requieren de un manejo y tratamiento especializado. Entre otros se encuentran:

- Residuos radioactivos. Estos residuos son clasificados de acuerdo a su tipo y radioactividad. Involucra cualquier tipo de material empleado y desechado de procesos donde se emplee radioactividad.

- Residuos farmacéuticos. Incluye los fármacos caducos y/o en mal estado o contaminados, que deben eliminarse. Pastillas, suspensiones, soluciones inyectables, etc.

- Residuos químicos. Incluyen reactivos analítico y sustancias utilizadas en los procesos de diagnóstico, y tratamiento de los pacientes (Quimioterapia).

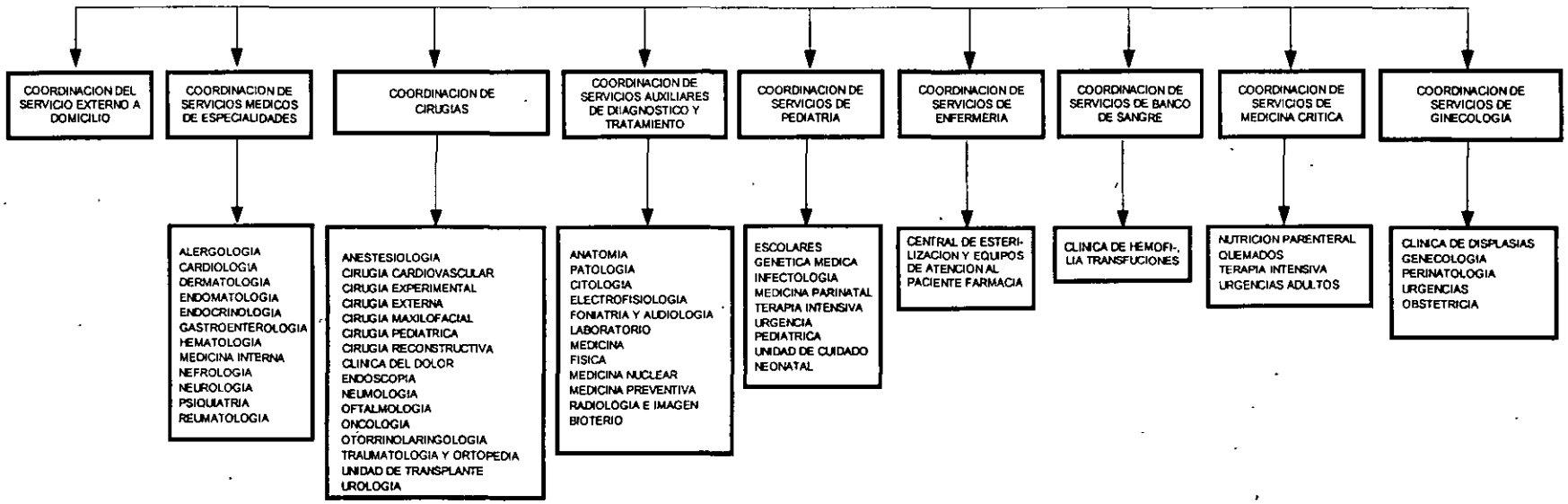
1.4 Clasificación de áreas generadoras

De la misma manera, que es importante conocer el tipo de residuos generados en unidades médicas, para su adecuado manejo, resulta primordial conocer las diversas áreas que generan este tipo de residuos con lo que se estará en posibilidad de diseñar las rutas de recolección interna y cuantificar la cantidad de contenedores y bolsas necesarias, para el manejo interno.

La clasificación que a continuación se presenta (Fig. No. 10) se ha podido definir de la experiencia de varios hospitales, los cuales se han podido visitar, y analizar la distribución de las áreas generadoras de residuos peligrosos y no peligrosos, al realizarse un análisis específico, esta distribución seguramente tendrá variaciones.

DIAGRAMA DE ÁREAS GENERADORAS DE RESIDUOS

RESIDUOS BIOLOGICO-INFECCIOSOS Y ESPECIALES



RESIDUOS MUNICIPALES

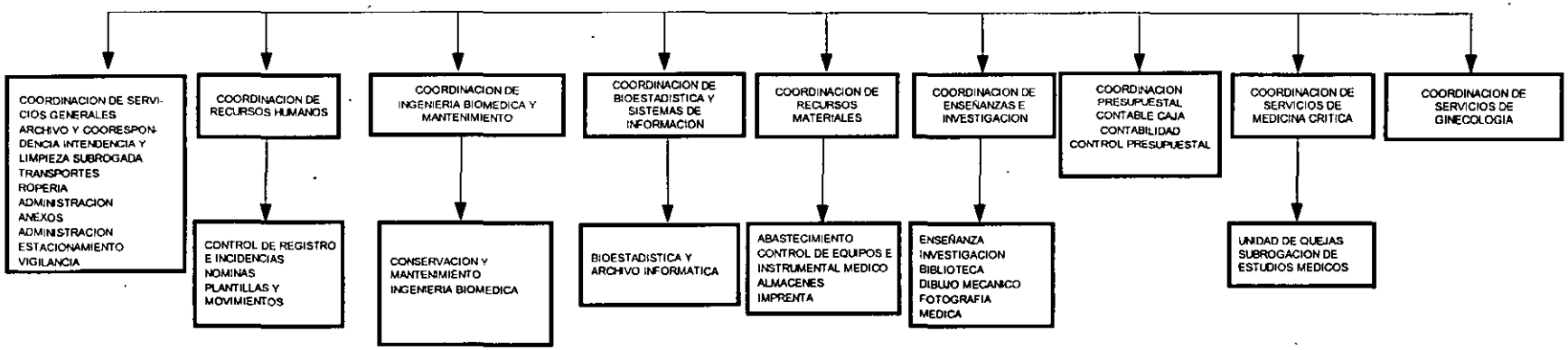


Figura 10

2. IMPLEMETACIÓN DEL PROGRAMA

2.1 Estudio inicial de caracterización de los residuos sólidos

La cantidad y calidad de residuos que producen una unidad médica, es reflejo del tipo de servicio que ofrece y en muchas ocasiones de las especializaciones que tiene. De aquí se desprende, que para diseñar un sistema de manejo en este tipo de instalaciones es necesario caracterizar apropiadamente los residuos que en ella se generan, como ya se había mencionado, y el porcentaje de residuos infecciosos, especiales y comunes, su cantidad actual y proyectada, así como la composición de cada uno de ellos.

Para lo cual es importante desarrollar un estudio de generación de residuos sólidos, el cual debe ser realizado por áreas generadoras, las cuales deben ser catalogadas como factibles de realizar separación de residuos peligrosos biológico-infecciosos y municipales, o no llevar a cabo esta separación por cuestiones operativas.

La verificación de los tonelajes producidos por unidad médica deberá realizarse en diferentes periodos durante el año. Persiguiéndose en este tipo de evaluaciones dos objetivos fundamentales: el primero determinar la cantidad de residuos generados en estas instalaciones y el segundo evaluar el nivel de separación en las diversas áreas generadoras.

2.2 Lineamientos para la supervisión y control del programa de manejo de residuos en estabilidad de salud

Es conveniente señalar que el aplicar y controlar un programa de separación de residuos generados en establecimientos de salud, como lo establece la norma NOM-087-ECOL-1995, demanda una serie de acciones previas para el buen desempeño de cualquier programa, entre estos esta la integración de un grupo de especialistas que sean los encargados de la implementación y supervisión del programa de manejo integral de residuos sólidos. Este grupo debe estar dedicado exclusivamente a las actividades involucradas con el programa, de ninguna manera debe quedar esta responsabilidad en el área de servicios generales, ya que se correría el riesgo de que el cumplimiento del programa se siga viendo como una más de las actividades que debe atender el departamento de mantenimiento. Como se mencionó, el instituir este grupo conformado por diversos especialistas permitirá atender adecuadamente los siguientes rubros.

- Sanidad
- Control de calidad y sanciones
- Capacitación
- Generación de residuos por área
- Mantenimiento de equipo e instalaciones

A partir de la conformación de este grupo el siguiente paso sería, llevar a cabo la capacitación del personal de intendencia, administrativo, médicos y enfermeras con la finalidad de que cada uno conozca su responsabilidad en el programa. Esta función debe quedar permanente para los empleados de intendencia, una vez precisada esta actividad se estará en posibilidad de realizar una rotación del personal, el cual debe obedecer a la destreza y capacidad para realizar su trabajo, manteniendo como prioridad las áreas generadoras de residuos biológicos-infecciosos, es fundamental que una vez definido el sistema de manejo interno se realice un estudio de tiempos y movimientos, el cual aportará los rendimientos promedio por actividad involucrada en el manejo interno.

Este tipo de estudios permitirá evaluar si es necesario contar con mayor número de personal, situación común en muchos hospitales, por lo que los programas de separación no se operan conforme a lo planeado.

Otra actividad que reviste una importancia fundamental, es el implementar un control de peso de los residuos, tanto biológicos-infecciosos como de los residuos municipales.

Contemplándose en esta punto la verificación de la correcta separación de los residuos en las diferentes áreas de la unidad, por lo que sería fundamental que las bolsas o recipientes contaran con claves que permita identificar el área generadora y poder sancionar el personal que no cumpla con las disposiciones señaladas.

No hay que olvidar que de no lograrse un adecuado nivel de separación, se verá incrementado substancialmente el costo que demanda la aplicación de la normatividad en cuanto a tratamiento.

El aspecto económico reviste una importancia fundamental, por lo que el contar con un grupo específico de personal que atienda el manejo de los residuos redituará en ventajas económicas, y evidentemente en el cumplimiento de la normatividad.

Otra actividad que debe contemplarse, es la realización de planes de contingencia, lo que permitiría actuar inmediatamente para resolver la emergencia, por lo que es de gran apoyo el realizar manuales de responsabilidad en los cuales se señale con claridad el ámbito de responsabilidad del personal de acuerdo al área donde parte sus servicios, evaluando el riesgo potencial de los trabajadores.

El especializar esta actividad permitirá por un lado, se garantice la seguridad del personal que participa, así como se logrará garantizar que los residuos municipales que finalmente son competencia de las municipalidades sean entregados sin contener residuos considerados como peligrosos, esta situación de control y verificación será una acción que deberán implementar las autoridades, las cuales deben ejercer una

supervisión de la composición física de los residuos municipales, que serán depositados directamente a los sitios de disposición final.

2.3Dimensionamiento de los Sistemas de Almacenamiento

A partir de la información aportada en los estudios de generación de residuos sólidos se calculó las áreas requeridas para almacenar los diferentes tipos de residuos, además de realizar una propuesta del sitio de almacenamiento central, cabe mencionar que la norma NOM-087-ECOL-1995 no detalla las especificaciones técnicas que debe reunir este tipo de instalaciones, por lo que resulta de interés, el realizar un diseño que permita almacenar los residuos biológico infecciosos, residuos comunes, subproductos reciclables, en un mismo lugar.

El concepto planteado en este trabajo se basa en contar con una instalación central que cuenta con una serie de espacios y equipamiento que garantice un manejo ordenado y seguro.

El almacenamiento central contará con las siguientes áreas:

✓ Área de residuos municipales

Se contará con un anden, en el que se colocaran 2 contenedores, los cuales tendrán una capacidad m^3, los residuos municipales serán vertidos directamente a los contenedores, lo que evitará se tenga que realizar la descarga a piso, lo que origina que los operadores de la recolección tengan que levantar los residuos vertidos.

✓ Área de residuos biológico-infecciosos

En esta área se instaló una cámara de refrigeración. Es importante señalar que contará con un acceso para el personal de intendencia y salida de los contenedores, para ser cargados en el camión recolector especial, antes de ser entregados al vehículo recolector especial, antes de ser entregados al vehículo recolector se pesarán los mismos.

✓ Área de residuos alimenticios

Con el objeto de evitar que en la zona de almacenamiento existan olores desagradables y moscas, los residuos provenientes de la preparación de alimentos constituyen un porcentaje importante en la generación de las unidades médicas y son generados prácticamente durante el transcurso del día.

Por lo que en muchos lugares, los residuos son llevados al almacenamiento central continuamente, es esto que se contempla que estos residuos permanezcan dentro de la cámara fría en espera de ser

depositados en un contenedor que transporte exclusivamente residuos alimenticios, o bien se canalicen como alimento para animales.

✓ Área de residuos aprovechables

Se destinará una zona del almacenamiento central para almacenar temporalmente los subproductos reciclables, con este sistema se espera que la comercialización de subproductos se realice con volúmenes que permitan abatir los costos de transporte.

En la tabla 5 se presenta la generación por área y por tipo de subproducto, para este ejercicio se consideró una generación unitaria de 1 tonelada.

A partir de la información presentada se realizó un análisis que permitirá dimensionar los volúmenes y área necesarios para ser considerados en el diseño del almacenamiento central, el cual se presenta de manera esquemática en la fig 11.

Las principales características técnicas del área de almacenamiento se describen a continuación:

- Contar con elevador de carga o rampa de acceso a la zona de andenes.
- Pendientes del 2% en sentido contrario al acceso de las diversas áreas.
- En el anden de descarga se colocará un tubo perimetral para apoyar los contenedores y vertirlos dentro del contenedor, para evitar que el contenedor caiga en el depósito.
- Sistema de agua y vapor para limpieza de contenedores.
- Iluminación tipo industrial en toda el área de almacenamiento.
- Establecer programas de desinfección y fumigación en la zona.
- Los contenedores de municipales deberán ser cubiertos para su traslado.
- Extinguidor
- Cámara fría
- Señalamiento
- Sistema de comunicación interno
- Debe estar techada la instalación en su totalidad

GENERACIÓN POR TIPO DE RESIDUOS

	Generación		Residuos Biológico Infecciosos				Residuos Municipales			
	%	kg	%	kg	PV	Vol. (m^3)	%	kg	PV	Vol. (m^3)
Suministro y Preparación de Alimentos	44.6	446	20	89.2	150	0.6	80	356.8	260	1 4
Servicios Complementarios	20.5	205	0	0	150	0	36.5	74.9	83	0.9
Cuartos de Hospitalización	14.4	144	30	43.2	150	0.3	70	100.8	110	0.9
Asistencia Médica	10.7	107	30	32.1	150	0.2	70	74.9	99	0.8
Laboratorios	8.2	82	100	82	150	0.6	0	0	68	0
Oficinas de Gobierno y División de Enseñanza	1.6	16	0	0	150	0	100	16	58	0.3
TOTAL			24.6%	246.5	150	1.65	75.4%	623.4	-	4.3

Tabla 5

RESIDUOS SOLIDOS HOSPITALARIOS

Definición:

Recibe el nombre de residuos sólidos hospitalarios el conjunto de materia orgánica e inorgánica que se desechan en el cumplimiento de todas las funciones que se realizan en un establecimiento hospitalario.

Inadecuación del Servicio:

Las deficiencias existentes en relación al manejo de los deshechos se debe principalmente a que no se cuenta con una reglamentación o aplicación de criterios que garantice por una parte que la recolección, el almacenamiento y la disposición de los residuos sólidos esté de acuerdo a la calidad de los mismos, y por la otra que velan por la seguridad de las personas que concurren al hospital.

Generalmente tampoco se cuentan con equipos, ni personal adiestrado para el manejo eficiente y sanitario de los diferentes tipos de deshecho. La gran cantidad de deshechos sólidos y la diversidad de su calidad es causa continua de problemas económicos, adminiestrativos y de saneamiento.

El control de la infección y la contaminación microbiológica preocupa no sólo al personal médico sino también al no médico de los hospitales. Esta preocupación es un poco sorprendente ya que ha transcurrido más de un siglo desde que se tienen claros conceptos de saneamiento y ascepcia hospitalaria.

¿ Por qué es necesario volver a aprender constantemente las leyes básicas de microbiología y no ocurre lo mismo con las de química, física, gramática e historia?. Si los principios de saneamiento introducidos hace un siglo todavía tienen validez, se les debe aprender y poner en práctica de una vez y para siempre. Se debería acabar con las interminables conferencias de introducción, simposios y seminarios en todas las convenciones de ingenieros, personal de limpieza, enfermeras, administradores y demás.

Otra cosa es la redefinición constante de los principios de saneamiento ambiental a la luz de la práctica médica moderna y de sus demandas, como por ejemplo, cirugía a cielo abierto, transplante de órganos y radiaciones ionizantes. En los hospitales todavía hay intenciones y serias deficiencias de saneamiento.

Históricamente, el médico conocía todas esas cosas y en la actualidad sabemucho acerca de ellas, pero no el ingeniero ni el encargado de limpieza, ni la administración. Por eso, encuentra que es difícil relacionar su conocimiento técnico con los diarios problemas prácticos que deben enfrentar otras profesiones.

Muchos de los pacientes hospitalarios de la actualidad, son candidatos con alto riesgo de contraer infecciones, por lo tanto las técnicas que se mantenían para mejorar el medio ambiente en el pasado, podrían ser inadecuadas en las circunstancias actuales.

Forcada, J.G. Universidad de Buenos Aires.
Instituto de Ing. Sanitaria, 1979.

La meta de alcanzar hospitales limpios y seguros desde el punto de vista microbiológico, se puede alcanzar con una combinación de sentido común, experiencia práctica y conocimiento de las leyes fundamentales de biología, física y química.

CONTAMINACION MICROBIOLOGICA

Quizás el primer concepto importante que se debe comprender en una discusión sobre el control de la contaminación microbiológica, es la teoría que indica a las enfermedades como causadas por gérmenes o microbios.

Todas las enfermedades infecciosas son provocadas por microbios: Protozoos, Hongos, Bacterias, Ricketsias y virus. Se les encuentra en todas partes, sobre la piel humana, intestinos, ropas, animales, plantas, en el hogar, en el aire, en el agua. Afortunadamente la mayoría de los microrganismos son inofensivos y muchos beneficiosos (como las levaduras, antibióticos, fertilizantes, etc.). Los que provocan infecciones se denominan gérmenes patógenos. La capacidad que tiene un germen de provocar enfermedad, depende de la capacidad potencial que tenga para multiplicarse en el huesped humano, de la rsistencia de ese husped, de la parte del cuerpo o del tejido en el que el germen penetra y de la cantidad de gérmenes que puedan penetrar.

Desafortunadamente estas circunstancias tienen lugar con bastante frecuencia en los hospitales; resistencia humana disminuida por la edad o enfermedad (niños, ancianos, débiles), la tensión, la exposición a radiaciones o por una enfermedad, concentración del número de gérmenes en ciertos lugares, rotura de las barreras que normalmente separan estos organismos de los tejidos, por ejemplo: por trauma o por una apéndice perforada, heridas, etc.

INFECCION Y CONTAMINACION

La infección se refiere a la entrada y proliferación de microrganismos en el cuerpo de un hombre, de un animal o de una planta. Implica su multiplicación y desarrollo en el huesped que generalmente resulta perjudicado. La infección no siempre provoca síntomas, enfermedades o incapacitación.

La contaminación se refiere a la presencia de microrganismos sobre y dentro de las superficies y materiales inanimados. La presencia de organismos infecciones en el aire, sobre la ropa, en el agua, sobre los muebles, los pisos, en los alimentos, sobre los instrumentos, significa que esos materiales están contaminados. Si se encuentra sobre la superficie de un cuerpo pero no se desarrolla se dice que está contaminado.

Para que se produzca la infección se necesita de los componentes de la cadena infecciosa:

Agente infeccioso
Reservorio
Puerta de salida
Medio de transmisión
Puerta de entrada
Huesped susceptible

Si uno de los eslabones de la cadena falta o se rompe deliberadamente, el brote de la enfermedad se puede controlar con toda efectividad.

ROTURA DE LA CADENA INFECCIOSA

Cualquier brote se puede controlar rompiendo la cadena infecciosa en uno de sus eslabones. Sin embargo, cada enfermedad presenta sus propios problemas y debe atacarse en su eslabón más débil; por inmunización o aislando el reservorio, o antibióticos y quimioterapia. En los hospitales se pone un énfasis extraordinario en el control del eslabón de transmisión de la cadena infecciosa. Las infecciones en general y las infecciones hospitalarias en particular, son un fenómeno muy completo en el que el saneamiento del medio ambiente inanimado, es el factor más importante para un control efectivo.

Para desarrollarse, los microbios necesitan elementos nutritivos, humedad y temperatura. Elementos nutritivos: sangre, alimentos, transpiración, pus, suciedad. Hasta el cuero y la madera pueden servir como elementos nutritivos. La humedad es requisito crítico, una humedad por debajo del 90% inhibe a la mayoría de los gérmenes patógenos; sin embargo, una gota o película de humedad es más que suficiente para su desarrollo. La temperatura puede variar entre 4 y 5 grados centígrados, siendo los más peligrosos los que se desarrollan a la temperatura del cuerpo humano: 36.5 grados centígrados. En condiciones adecuadas muchos gérmenes patógenos duplican su cantidad cada 20 minutos, por lo que en 9 ó 10 horas se proO ducen cientos de millones. En términos prácticos esto significa que debe evitarse el desarrollo bacteriano para el control de la contaminación. Un microbio que se ha aclimatado al ambiente es más difícil de eliminar que uno recien aislado de una herida o de un tubo de ensayo.

Los responsables del saneamiento ambiental y del control de la contaminación, deben tener en cuenta cuatro principios:

1.- Mantener a los gérmenes nocivos fuera de las áreas críticas.

2.- Eliminar los gérmenes que a pesar de todo se filtran.

3.- Prevenir la multiplicación de los que entran y no son destruidos.

4.- Controlar los vehículos y vectores de transmisión.

Todos los que en el hospital quieren destruir la cadena infecciosa en el eslabón de transmisión dependen en última instancia del ingeniero ambiental. Las bases de cualquier programa de saneamiento ambiental abarcaran aspectos de previsión de agua fría y caliente, vapor, refrigeración, depuración de aguas herbidas y depuración también de aguas servidas, ventilación, mantenimiento de equipos y control de residuos sólidos.

DISPOSICION DE LOS RESIDUOS SOLIDOS

Aun en el caso de que los desperdicios hospitalarios no estuvieran contaminados, una consideración estética demandaría su rápida eliminación. Como los provenientes de algunas zonas están muy contaminados, su eliminación es más urgente. Los desperdicios líquidos se eliminan por los conductos cloacales, los desperdicios sólidos se incinerar o se entierran.

Alguno de los problemas en materias de eliminación de los desperdicios hospitalarios, surgen directamente de la aplicación de principios de una ingeniería sanitaria inadecuada. Algunos desperdicios hospitalarios se deben considerar como altamente infectantes y la forma en que se manipulan debe minimizar el riesgo de infección para todos cuantos están en el hospital y en la comunidad donde éste está situado. El papel del ingeniero ambiental en la eliminación de los desperdicios debe abarcar los aspectos del proceso.

- Provisión de espacio adecuado para el almacenamiento sanitario.
- Recolección y manejo de los desperdicios.
- Mantenimiento adecuado de los conductos de incineradores y de eliminación de desperdicios.
- Reparación de eliminadores de residuos.
- Control de los elementos utilizados para el transporte a los lugares de concentración.
- Normas y pautas para el manejo de los residuos.
- Disposición final.
- Control de vectores (insectos y roedores)

TIPOS DE DESHECHOS

Los deshechos producidos pueden ser clasificados de acuerdo con las funciones de las áreas donde son producidos:

- Residuos de la preparación y servicio de alimentos.
- Deshechos producidos por funciones administrativas.
- Deshechos producidos en los servicios de Obstetricia, Cirugía, Emergencia y primeros auxilios. Podrían agregarse también los de Traumatología.
- Deshechos producidos en laboratorios, morgue, patología y autopcias.
- Deshechos producidos en las salas por curaciones a los pacientes y en las áreas de preparación de medicamentos y vendajes.
- Deshechos producidos en cuartos de aislamiento y áreas de tratamiento de enfermos contagiosos.
- Deshechos producidos en áreas de recibo, espera, visita y todas aquéllas procedentes de la limpieza general y de farmacia.
- Deshechos procedentes del servicio de Radiología y Radioterapia.

RESIDUOS DE LA PREPARACION Y SERVICIO DE ALIMENTO

Los deshechos producidos como resultado de la preparación y servicio de los alimentos, en general son manejados independientemente de los deshechos producidos en el resto del hospital. No es costumbre la preparación de comidas para empleados o visitantes, sólo para algunos profesionales médicos.

Los deshechos procedentes del servicio y consumo de alimentos servidos en la sala de pacientes no contagiosos, son manejados en general de la misma manera que los desperdicios de la cocina. El manejo de estos deshechos es considerado seguro y no representa mayores peligros para la salud de las personas que los maneja.

Los deshechos procedentes de alimentos en los servicios de enfermos contagiosos, deberían tratarse en forma especial por el peligro de contagio de ciertas enfermedades.

Todos los utencilios deberán ser lavados en áreas y equipos independientes del resto de los servicios y áreas de preparación de alimentos, asegurándose la completa esterilización de los mismos. Los residuos de alimentos y los removidos de los utencilios no deben ser depositados en lugares accesibles en que pueda entrar en contacto con personal u otros utencilios.

La temperatura del agua de lavado no debe ser menor de 75 grados centígrados durante el proceso de lavado los utencilios tendrán una permanencia de 15 minutos a esa temperatura. De usarse lavadoras automáticas de alta temperatura, las aguas servidas pueden evacuarse con el resto de las del hospital.

Los deshechos sólidos deberán ser esterilizados antes de ser removidos del área de limpieza o incinedados totalmente en incineradores provistos directamente y para este efecto dentro de esta misma área.

DESHECHOS DE FUNCIONES ADMINISTRATIVAS

No ofrecen gran peligro de contaminación. En general son papeles, tarjetas, cajas de cartón y utencilios de oficina.

Es recomendable preveer depósitos de almacenamiento separados del resto del hospital. Como aproximadamente el 90% de estos materiales son secos, no putrescibles y combustibles, podría pensarse en compactarlos para facilitar su remosión o posible venta.

DESHECHOS PRODUCIDOS EN LOS SERVICIOS DE OBSTETRICIAS, CIRUGIA, EMERGENCIA Y PRIMEROS AUXILIOS.

Consisten en vendajes usados, algodón, placentas, ampollas usadas, agujas rotas o deshechables, paños femeninos, mascarillas deshechables, lancetas deshechables y otro gran número de artículos y recipientes. Además son o están impregnados con sustancias rápidamente putrescibles y deben ser manejados y removidos en forma rápida y eficiente. Para ello:

Todos los deshechos deberán ser depositados inmediatamente después de ser producidos en recipientes o bolsas impermeables y deshechables con cierre hermético.

No deben permanecer en las áreas de tratamiento o de trabajo, depositándolos en recipientes contiguos al equipo de incineración o tratamiento previo a su disposición final. Cuando se utilice para la remoción bolsas deshechables de plático podrán utilizarse los conductos de gravedad para el transporte a la disposición final. (Incineración).

El equipo incinerador debe mantener altas temperaturas, la operación debe hacerse tan pronto como sea posible para evitar moelstias, malos olores y peligro de contaminación. Como en general el horario es de mañana en los hospitales del Estado, se adecuará el tiempo de funcionamiento del horno incinerador.

Los residuos provenientes de la incineración de estos materiales deben ser manejados en forma cuidadosa, ya que contienen agujas y otros materiables no combustibles y que pueden ser fuentes de accidentes.

DESHECHOS PRODUCIDOS EN LABORATORIOS, MORGUE, PATOLOGIA Y AUTOPCIAS.

Los deshechos producidos en estas áreas requieren manejo cuidadoso y ordenado. Se deben tener los mismos cuidados que en el Item anterior. Además tener en cuenta que:

- Si bien la cantidad de materiales deshechables puede ser pequeña, deben ser considerada altamente contaminante por lo que se requiere que sea incinerados in-situ o esterilizados previo a su manejo por personas ajenas a la operación de estas áreas.
- Los envases de las muestras deben ser incinerados o esterilizados inmediatamente después de ser usados.
- Las botellas y envases de productos químicos o farmaceúticos y reactivos biológicos pueden ser material combustible (papel, y plástico) o incombustible (metal, y vidrio). Su manejo debe prevenir posibles peligros para el personal o el equipo de disposición usado. Por ejemplo la incineración de envases conteniendo residuos químicos que durante la combustión puedan producir gases venenosos o explosiones.

DESHECHOS PRODUCIDOS EN LAS SALAS POR CURACIONES A LOS PACIENTES Y EN LAS AREAS DE PREPARACION Y MEDICAMENTOS Y VENDAJES.

Especialmente los deshechos de curaciones resultan biológicamente contaminantes. Los de preparción de aderezos, medicamentos y vendajes ofrecen poco peligro de infección, pero representan otro tipo de peligrosidad como los enunciados en el párrafo anterior.

DESHECHOS PRODUCIDOS EN CUARTOS DE AISLAMIENTO Y AREAS DE TRATAMIENTO DE ENFERMOS CONTAGIOSOS

Para estos deshechos son aplicables las mismas recomendaciones para su man ejo y disposición, que las hechas para el manejo de alimentos y deshechos peligrosos mencionados en los párrafos anteriores.

DESHECHOS PRODUCIDOS EN LAS AREAS DE RECIBO, ESPERA, VISITA Y TODAS AQUELLAS PROCEDENTES DE LA LIEMPIEZA EN GENERAL DEL EDIFICIO Y LOS ALMACENES DE RECIBO.

Consiste en papeles o envolturas de regalos para los pacientes, residuos de alimentos o bebidas. Los deshechos provenientes de áreas de recuperación o de enfermos no contagiosos, pueden ser manejados en conjunto con los deshechos de la cocina general.

DESHECHOS PROVENIENTES DE LOS SERVICIOS DE RADIOLOGIA Y RADIOTERAPIA.

Consisten en vendajes o yesos, placas usadas, envases, papel y cartón. Pueden causar algún problema en la operación de incineradores las placas radiográficas arruinadas o descartadas.

Si existiese deshecho de material radioactivo debe ser manejado únicamente por personal experto y autorizado para su manejo. Nunca serán depositados con el resto de los deshechos o en el sistema de aguas servidas.

ESCOMBROS

En los hospitales de cierta complejidad y de antigua data, es frecuente la reparación, modificación o ampliación de servicios que ocasionan cantidades de materiales de construcción que son acopiados, permaneciendo largo tiempo sin disposición final., siendo focos de anidamiento de insectos y ratas. Deben ser removidos inmediatemente después de concluida la obra.

CANTIDAD DE DESHECHOS.

1) Los trabajos respecto a la producción de deshechos hospitalarios citan cifras en peso la mayoría de las veces y en algunas ocasiones en volumen pero relacionadas sólo con el No. de camas o pacientes en los Institutos. Sin embargo, no se ha tenido en cuenta la calidad de los deshechos, la procedencia de los mismos y la influencia que en ello tienen los diferentes servicios existentes en los hospitales, así como el personal que los atiende.

   Los estudios realizados han abarcado diferentes aspectos como producción, manejo y disposición de los deshechos, determiandión de características físicas, químicas y bacteriológicas, estudio virológico y análisis estadístico de los datos experimentales. Se trató de obtener ecuaciones mateméticas sencillas que relacionen la producción de deshechos esperada con los distintos tipos de servicio del hospital. La variable independiente en esas ecuaciones, es el No. de empleados remunerados que trabajan en los diferentes servicios.

2) En un trabajo destinado a conocer la cantidad y calidad de los deshechos producidos en Institutos Hospitalarios realizado entre 1966 y 1970 en Minnesota se llegó a las siguientes concluciones:

   - Tanto el peso como el volumen de los deshechos producidos es notariamente relacionado con la cantidad de camas.

   - La cantidad de deshechos por paciente está relacionado de manera notable por la comunidad a la que rpesta servicio, con el No. de intervenciones quirúrgicas, con el número de pacientes de consulta externa y con el No. de empleados; demostraron que era poco significativo el No. de visitantes al hospital.

   - La producción de deshechos va desde 2.1 kgs. /paciente hasta 7.3 kgs./paciente con un valor medio de 3.9 kgs./paciente (del 40 al 50% de estos deshechos es putrescible).

- En ralación al volúmen se encontró que la producción varía desde 28.3 l/paciente hasta 113.2 l/paciente con promedio de 56.6 l/paciente.

- La forma de transportar los desechos, en carritos, no permite un control sanitario eficiente.

- La forma de operar los incineradores es deficiente y se destaca la falta de personal adecuado

- Es necesario un control efectivo en el manejo y disposición de los desechos debido al grado de peligrosidad que ello representa

3) El Ing. Mario de la Torre Quiroga, en un informe técnico sobre residuos sólidos en un Hospital del Servicio Nacional de Salud, llega a las siguientes conclusiones generales después de realizar el análisis químico de los desechos:

a) La mayoria de los pocentajes de componentes o características químicas varian dentro de un pequeño rango, lo que significa que un ingeniero de diseño puede basar sus parámetros necesarios -- sobre cualquier sección o area del hospital, pero debe tener -- cuidado de considerar aquellas en que la variación es significativa.

b)La húmedad, los sólidos volátiles y cenizas y el poder calorífico, pueden servir para usarse como parámetros de diseño. El contenido de azufre, de nitrógeno y de fósforo ofrecen valores porcentuales de relativa relevancia

c) El valor promedio del poder calorífico de la basura, considerando la totalidad de los residuos del hospital, es de aproximadamente 3.800 kCal/Kg. Esto significa que se debe contar con un sistema de combustible auxiliar, inyectado al incinerador, para asegurar la temperatura requerida para una combustión completa. Conviene recordar que el poder calorífico promedio de la madera es de 4.000 kCal/Kg. ; el del algodón es cerca de 3.500 kCal/Kg. ; el del trapo de 5.000 kCal/Kg. y el del papel 4.100 kCal/Kg.

Hace también una comparación con los resultados obtenidos de un estudio realizado en el Hospital de la Universidad de West Virginia (U.S.A.) y de basuras domiciliarias recogidas por la Municipalidad de Buenos Aires, llegando a la conclusión que los residuos hospitalarios objeto de su estudio, estan más cerca en su composición a los residuos sólidos municipales que a los hospitalarios del país tecnologicamente más avanzado.

Pearce (en 1952) indicaba que para el diseño básico de un incinerador debía utilizarse la cifra de 3.6 kg/cama por día, más 1.4 kg/día por persona de sección de auxiliar, más 0.4 kg/dia por paciente de consulta externa

SISTEMA DE RECOLECCION, MANEJO Y DISPOSICION DE RESIDUOS

Es conveniente seguir el flujo de todos los desechos sólidos desde su origen hasta su disposición final en el establecimiento y tener en cuenta el personal que los maneja en cada puesto de transferencia, ya que esos puntos dan lugar a riesgos de contaminación y accidentes

- Medical wastes means any waste which is generated in the diagnosis treatment or immunization of human beings or animals, in research pertaining thereto, or in the production or testing of biological. (This is the wording and definition used in the USA).

- Clinical wastes means any waste coming out of medical care provided in hospitals or other medical care establishments. (This is the wording and definition used in the Basel Convention regulating transboundary movement of hazardous wastes). Actually this definition neglects medical wastes resulting from medical care in the home.
- Pathological wastes include human tissues, organs, and body parts and body fluids that are removed during surgery or autopsy or other medical procedures, and specimens of body fluids and their containers. (They are part of infectious waste as well as of the three kinds of wastes listed above).

- Infectious wastes include all kind of wastes which may transmit viral, bacterial or parasitic diseases to human beings. In addition to infectious medical wastes it includes infectious animal wastes from laboratories, slaughter-houses, veterinary practices and so on.

This report is concerned with medical wastes according to the American definition quoted above. The term hazardous medical waste will be used to describe wastes that can be defined as hospital, medical or clinical and that are infectious, or hazardous in other ways.

1.2 Sources and generation

Medical wastes generation according to sources:

The following figures were collected in the USA by the Environmental Protection Agency (USEPA 1990a):

Source	Quantities (tons/year)
Hospitals	359,000
Nursing Homes	29,600
Physicians offices	26,400
Clinics	16,700
Laboratories	15,400
Dentists offices	7,600
Veterinarians	4,600
Funeral homes	3,900
Blood Banks	2,400
TOTAL	465,600

The following figures show the total amount of hospital waste (including the non-hazardous component) generated in some industrialized countries:

Managing medical wastes in developing countries. World Health Org., 1994.

Quantity of waste (kg/bed.day)

Type of hospital	Norway	Spain	UK	France	USA	Netherlands
University hospital	3.9	4.4	3.3	3.35	5.24	4.2 to 6.5
General hospital				2.5	4.5	2.7
Maternity		3.4	3.0			
Mental hospital		1.6	0.5			1.3
Geriatric		1.2	9.25			1.7

Source: WHO/EUROPE Publications ERS 97 (Management of waste from hospitals)

Monreal (1991) quoted figures of 1 to 4.5 kg/bed.day for generation of solid wastes from hospitals in Latin America. Figures in more detail are as follows:

Country	Year of study	Generation (kg/bed.day)		
		Minimum	Median	Maximum
Chile	1973	0.97	-	1.21
Venezuela	1976	2.56	3.10	3.71
Brazil	1978	1.20	2.63	3.80
Argentina	1982	0.82	-	4.2
Peru	1987	1.60	2.93	6.00
Argentina	1988	1.85	-	3.65
Paraguay	1989	3.0	3.80	4.50

1.3 Categories of waste

Several classification systems are used for the characterization of the different components of hospital/medical wastes. WHO publication ERS 97 (targeted towards European countries) suggested the following:

- General wastes: all non-hazardous wastes, similar in nature to domestic wastes.
- Pathological waste: tissues, organs, body parts, human foetuses and animal carcasses, and most blood and body fluids
- Radio-active waste: solids, liquids and gases from analysis procedures, body organ imaging and tumour localization, and treatment.
- Chemical waste may be hazardous - toxic, corrosive, flammable, reactive or genotoxic (capable of altering genetic material), or non hazardous
- Infectious waste contain pathogens in sufficient quantity so that they pose a serious threat, such as cultures from laboratories, waste from surgery and autopsies on patients with infectious diseases, waste from

patients in isolation wards or undergoing haemodialysis, and waste associated with infected animals.

- Sharps any item that could cause a cut or puncture, (especially needles and blades).

- Pharmaceutical waste whether surplus, spilled, outdated or contaminated.

- Pressurized containers.

The USA uses the following classification and definitions for regulated medical waste:

- Isolation wastes: Biological waste and discarded materials contaminated with blood, excretion, exudates, or secretions from humans who are isolated to protect others from certain highly communicable diseases, or isolated animals known to be infected with highly communicable diseases. (They may also be called highly infectious wastes).

- Cultures and stocks of infectious agents and associated biological, including cultures from medical and pathological laboratories; cultures and stocks of infectious agents from research and industrial laboratories; wastes from the production of biological; discarded live and attenuated vaccines; and culture dishes and devices used to transfer, inoculate and mix cultures.

- Sharps that have been used in animal or patient care or treatment or in medical research, or industrial laboratories, including hypodermic needles, syringes (with or without the attached needle, pasteur pipettes, scalpel blades, blood vials, needles with attached tubing, and culture dishes (regardless of presence of infectious agents). Also included are the other types of broken or unbroken glassware that were in contact with infectious agents, such as used slides and cover slips.

- Human blood and blood products: (1) Liquid waste human blood; (2) products of blood; (3) items saturated and/or dripping with human blood; or (4) items that were saturated and/or dripping with human blood that are now caked with dried human blood; including serum, plasma, and other blood components, and their containers, which were used or intended for use in either patient care, testing and laboratory analysis or the development of pharmaceuticals. Intravenous bags are also included in this category.

- Animal waste: Contaminated animal carcasses, body parts, and bedding of animals that were known to have been exposed to infectious agents during research (including research in veterinary hospitals), production of biological, or testing of pharmaceuticals.
- Unused sharps: The following unused, discarded sharps: hypodermic needles, suture needles, syringes, and scalpel blades.

- Cytotoxic wastes; which in addition to being toxic are mutagenic and/or teratogenic when discarded or spilled.

- Radio-active waste

Developing countries may wish to use the following simplified classification for practical purposes:

- Non-hazardous hospital waste (general wastes)

- Sharps

- Infectious waste (other than infected sharps)
- Chemical and pharmaceutical wastes
- Other hazardous hospital/medical wastes

This classification system, having five categories instead of eight, is recommended to limit the number of separate waste collection and storage channels that must be set up within a medical establishment.

The general wastes coming from hospitals are no more hazardous than normal domestic wastes, and may be handled and disposed of in the same way. It may often be the case that paper and packaging waste, containers and food waste are sold to merchants for recycling. This practice may pose no problems as far as the general waste is concerned, but there may be problems if the staff who arrange these transactions are tempted to increase their income by selling materials that should be treated as hazardous. For this reason it is recommended that all trading of wastes should be done officially and in a tightly controlled way.

The remainder of this report is concerned with the wastes that may be considered as hazardous, (i.e. not the general wastes).

2. HAZARDS AND RISKS

2.1 Epidemiological impact of medical wastes:

There is strong epidemiological evidence, from Canada, Japan and the USA (see annex for bibliography) that the main concern of infectious hospital waste is the transmission of AIDS/HIV virus and, more often, of Hepatitis B or C virus (HBV) through injuries caused by syringe needles contaminated by human blood. The group most at risk are medical care workers, especially nurses, followed by other hospital workers and by waste management operators outside the hospital. (In places where scavenging or rag picking at disposal sites is common, such people face a grave risk, but no data is available on incidences of injuries and infections in such situations.) It is considered exceptional that victims include patients or the general public. One case has been reported in the USA of a hospital housekeeper who developed staphylococcal bacteraemia and endocarditis after a needle injury. Unfortunately data from developing countries are scarce if not non-existent. (Regarding wastewater discharges, there is a strong suspicion that uncontrolled discharges of sewage from field hospitals in Chile and Peru has contributed to the spreading of cholera.)

In the USA, the Agency for Toxic Substances and Disease Registry, in its paper: The Public Health Implications of Medical Waste, (September 1990) has reported to the US Congress:
HIV has extremely limited viability outside a living host, although live virus survival time may depend upon the environment and virus concentration. Therefore, except for those persons within the health care setting, the potential to develop HIV infection from medical waste contact is remote. Because HBV remains viable for an extended time in the environment, the potential for HBV infection following contact with medical waste is likely to be higher than that associated with HIV.
The workers most frequently injured in the health care industry are nurse's aides, registered nurses, housekeeping and maintenance personnel, and food-preparation workers. The annual injury rates for these occupations vary from 10 to 20 per 1,000 workers.
Of all workers who may contact medical waste, sanitary services workers (e.g., refuse workers) report the highest rate of on-the-job injuries. Their overall injury rate of 180 per 1,000 workers per year is more than double that of the entire US work force combined.

Ranges of estimated medical waste related injuries from sharps occurring annually for non-hospital employees are: nurses 28,000/48,000, emergency medical personnel 12,000, refuse workers 500/7,300, dental assistants 2,600/3,900, physicians 500/1,700, animal technicians 400/1,600, dentists 100/300, and veterinarians 50/200. Corresponding ranges for hospital employees are: nurses 17,700/22,200, housekeepers 11,700/45,300, hospital technicians 12,200, laboratory workers 800/7,500, physicians and dentists 100/400. Estimated annual numbers of medical waste related HBV infections resulting from above quoted injuries are among non-hospital employees in the following ranges: nurses 56/96, emergency medical personnel 24, refuse workers 1/15, dental assistants 5/8, physicians 1/3, and dentists <1. It is estimated that half of infected persons will develop the disease. For hospital employees the estimated numbers of HBV infections are: nurses 26/45, housekeepers 23/91, hospital technicians 24, laboratory workers 2/15, physicians & dentists <1.

It is also estimated that no more than one infection by the AIDS virus will arise yearly in the USA among each professional risk group other than nurses and housekeepers. For each of those 2 groups the risk will be 1.3. According to theoretical calculations the annual number of HBV infections in non-hospital employees as a result of medical waste related to injuries from sharps is between 162 and 321 in the USA compared to a total of 300,000 for all cases. Between 1 and 4 cases of HIV infections in non-hospital employees as a result from medical waste-related injuries from sharps may also occur yearly in the USA against a total of 35,238 cases of HIV infection reported in the USA during 1989. The actual number of infections is probably lower than the maximum theoretical estimates.
Data for other kind of infections due to medical waste as well as data on injuries in the general public from medical waste are insufficient to reach any conclusion.
At least one recommendation that emerges from these findings is that risk groups such as nurses, hospital housekeepers and all personnel who handle medical wastes must be immunized against hepatitis B. Care must be taken in drawing conclusions about risks faced in the developing world, where supervision and training of those with access to medical wastes may much less, and many more people may come into contact with such wastes

At the WHO consultation Professor Shiro Shirato (chairman of the Japanese Society for Research on Medical Waste) reported the following data from Japan:

In July 1987, two young interns in paediatrics - a 25 year old woman and a 28 year old man - were accidentally infected by syringes; these incidents resulted in their deaths from acute hepatitis B. Those syringes had been used on virus-carrying patients and accidentally punctured the interns' fingers. The virus was identified as a virulent mutant of hepatitis B virus. Similar accidents happen in other Japanese hospital - a total of 570 cases were reported in a 3-year period. Fortunately, the victims received immunoglobin injections in time and casualties were avoided. A survey by the public health authorities in 1986 showed that 67.3% of waste handlers inside hospitals had reported injuries from sharps, and that 44.4% of waste disposal workers outside hospitals had also reported wounds when handling hospital wastes. Blood examination among wounded workers showed numerous infections by HBV but also a few by HIV. Other analysis showed that blood infected syringes often contain more than the infective doses for both viruses. These figures should be weighed against the fact that the Japanese population includes only 2% of HBV carriers (compared with 10% in some other Asian countries) and far less than 1% of HIV carriers. In one city children stole discarded syringes from a hospital waste dump and got infected. The first conclusion that was drawn from the case of the infected children is that simple burying of medical waste is not sufficient to prevent the spread of disease. The second conclusion is to point out the specific hazards from discarded cytotoxic drugs, should they be buried. They act as a mutagens to all biological beings.

In total Shirato has documented in the Japanese scientific literature more than 500 cases of infections related to medical waste, more than 500 cases of injury or poisoning with chemical waste from hospitals, and more than 400 cases of bio-hazard from cyto-toxic drugs improperly disposed. It is very important to note that, using data on HBV and HIV survival rates from Resnik tables, Shirato has computed that the amount of each virus surviving in an infected syringe may remain above the infective doses for eight days after it was used on an infected patient.

Shirato's estimate of the time during which infected syringes pose a hazard is of great importance. It is often assumed that HIV quickly becomes inactivated in an unfavourable environment, but it appears that the conditions that exist inside the needle and body of a syringe are much less hostile that might have been presumed. If this information on survival times is coupled with the rate at which injuries occur (as exemplified by the data from the USA) and higher incidences of HIV and HBV in some populations than those found in Japan, the risks of infections from syringes in some situations become alarmingly high.

The case of the infected children shows that simple burying of medical waste is not sufficient to isolate it from the public. Minimal requirements for the safe burial of wastes from hospitals will be discussed later in this report . A further conclusion is the seriousness of the specific hazards from discarded cyto-toxic drugs.

Data on infection or poisoning from medical wastes are scarce, but it is clear that such accidents do happen. According to Shirato, during a 3-year period 671 cases of hospital waste accidents were documented in Japanese hospitals out of which 570 were injuries through infected needles or syringes and 101 were linked to drugs and chemicals.,

Radio-active hospital wastes caused a notorious accident, reported by the international media, in a Brazilian city in 1989. There were fatal and other serious cases of irradiation by radio-active hospital waste in abandoned equipment that was scavenged from a dump.

Cyto-toxic drugs, because of their high potential to kill a variety of organisms, are an acute danger for the environment. Such drugs must be either destroyed by high temperature incineration or stored in sealed containers.

2.2 The situation in developing countries:

When reviewing the situation in any country it is important to consider the cultural beliefs and degree of awareness of health issues, as well as the practices and technology.

Some cultures tend to keep contact with waste to the minimum. This has the advantage that there is less interest in reusing or recycling waste items, and so the risks from certain hazardous components in medical wastes are less. However, the same belief may discourage professionals from being involved in waste management, so that there is very little control over how medical waste is stored, handled and disposed of. Other cultures find reusing wastes and exploiting their potential more acceptable, and in such cultures there is a great danger that contaminated and hazardous materials will be returned to the economy. There are many ways in which hazardous components of medical waste can pose a threat to society:

- There was a case in Central America where used syringes were being sold to schoolchildren as they came out of school. Brightly-coloured sweets were put into the body of the syringe, and the complete syringes (with the needle attached) were sold. Children enjoyed the sweets and then played with the syringes. Of course, this practice was stopped when discovered by public health officials.

- Some people seem to believe that every cure requires an injection. Po people, who have no access to qualified medical personnel, may seek anyone who can give them an injection; it may be administered by an unqualified practitioner using a discarded syringe. Apart from the serious risk of a life-threatening injection, there is also the danger of injecting air into the bloodstream.

- Drug addicts who have no access to sterile syringes may use discarded syringes.

- Discarded drugs may be used inappropriately by unqualified people - some people might believe that any white pill will cure their malady.

- Scavengers or pickers are at risk from sharps, pharmaceuticals, and chemicals, and from direct contact with infected materials. Items, such as containers, that they salvage, may spread contamination to society at large if they are not properly cleaned and sterilized before they are sold.

Where the wastes have a resale value, much greater attention must be given to supervising the waste at all stages, to ensure that labourers or others do not sell, or allow access to, the waste for which they are responsible. The potential for profit from the waste greatly magnifies the risks posed by medical waste.

The degree of health education and hygiene awareness among the public is another crucial factor in deciding the risks posed by medical wastes. The public will be reluctant to use discarded items and unqualified practitioners if they are aware of the potential hazards involved. However, in many societies - even those which have a majority who are educated - there is a significant minority of the population that is illiterate and unaware of the dangers, and it is these people that are most at risk. Barriers must be buil between such people and hazardous medical waste - these barriers will generally involve strict control of access and close supervision by responsible professionals.

No reliable epidemiological data from developing countries related to the health impacts of hospital waste were presented at the Consultation, however the incidents of irradiation by radioactive waste from a hospital in a Brazilian city were mentioned.

In the worst cases, found in countries stricken by civil war, hospitals are often deprived of basic facilities such as a safe water supply or hygienic toilets; in such situations the proper management of hospital wastes appears to be a secondary priority.

The situation in Latin-America and the Caribbean is reviewed in a document of the Pan-American Health Organisation called: Considerations on the management of hospital wastes in Latin-America by J Monreal (1991). The problems identified are:

- infectious injuries from sharps to hospital housekeepers and waste handlers,

- nosocomial infections in patients from poor waste management among other causes, and

- risks of infections outside hospitals for waste handlers, scavengers, and (eventually) the general public.

Technical problems are the poor segregation of hazardous wastes at source due to the low education of personnel in charge; this lack of segregation results in the hazardous component being 10 to 40% of the total instead of less than

10%. There is also a lack of proper storage of sharps, which explains the numerous injuries among waste handlers.

Very frequently hospital wastes are dumped together with municipal garbage, with the common exception however of human body parts which are buried separately for cultural reasons. Hospital incinerators are also used, however they seem to be inappropriate technology in many situations as a high percentage (57 to 92%) do not operate satisfactorily There was a reported use of biological digesters to treat soft infectious wastes; however no data are given on the effectiveness of this process in terms of disinfection, so it cannot be regarded as a proven or satisfactory option at this stage. Chemical disinfection of sharps, particularly needles, should be regarded with suspicion. This matter is discussed more fully in section 6.

The risk of infection is not the only factor that motivates good hospital waste management. There is also the psychological or emotional effect related to recognizable body parts, and the occasional involvement of the police. The following anecdotes illustrate these effects:

- A local newspaper of a large Asian city reported the discovery of a human hand that had been found in a street. The police were called in to investigate. They discovered that the hand came from a local hospital; it had been amputated for medical reasons and thrown into a bin. A passing dog had taken it out and carried it off, and later dropped it in the street.

- Labourers at an incinerator stopped work as a result of seeing a human limb in the waste they were supposed to handle. They refused to continue working until the limb was removed and an undertaking was given that they would not be required to handle such hospital waste in future.

In Africa, some urban hospitals burn their waste in the open air within the hospital premises; liquid wastes are sometimes treated but not disinfected. Whether there is an adequate classification and segregation of the different types of hazardous waste at source seems to vary widely from country to country

The situation in south-eastern Asia was reported by Dr Bhide the chairman of the consultation who was from the National Environmental Engineering Research Institute in Nagpur, India.
It seems that the worst problems arise in small hospitals which are not aware of the need for special care in handling infectious waste. In big hospitals things are better, however the sorting and separate collection of hazardous waste are far from adequate. A few big hospitals operate incinerators but do not accept infectious waste from other sources. Liquid wastes are discharged into municipal sewers without pretreatment. Solid wastes are often buried together - both the hazardous and non-hazardous fractions - inside the hospital premises. There is an acute need for training on hospital hygiene for all non-professional hospital staff.

The situation in the WHO Eastern Mediterranean region has been analyzed as follows by the Regional Office:
Local health authorities are very aware of the hospital waste problem and will deeply appreciate any technical guidance on its solution. Even in high-income countries, hazardous wastes are often not segregated from general hospital waste and both are disposed of together with municipal waste; the disposal method is land-filling (often uncontrolled) but a few incinerators are available. In the western Arab countries the situation regarding sorting and segregation of hazardous hospital waste is better, but most of existing incinerators are out of operation.

In the western Pacific region very primitive and very advanced situations co-exist side by side. It was reported that, in a war stricken country,

hospitals do not even have toilets accessible to patients, but in another nearby country the government is developing its own national guidelines for hospital waste management. Its seems that, in most cases, hospital wastes are adequately segregated at source before storage and transportation, but that hazardous hospital wastes are landfilled together with municipal waste and left exposed to scavenging. Hepatitis B transmission through scavenged infected syringes was reported from countries in this region.

This report has been written to address problems such as those mentioned above, and appropriate recommendations will be presented after a discussion of the available options.

The situation in Europe is out of the scope of this report; however European experts at the Consultation were of the opinion that, in some southern or eastern European countries, the situation is not better than in many developing countries, particularly perhaps in smaller communities and smaller medical establishments.

3. GENERAL HYGIENE

Hospital waste management is part of hospital hygiene and maintenance activities. The importance of hospital hygiene is emphasized in WHO TRS 819, paragraph 6.3:-

The cleanliness of a hospital is often the first thing that a visitor or patient will notice, and it is a sign of its concern for its patients. Cleanliness should not be taken for granted; it reflects the behavioural patterns of health workers, patients, and visitors. In places where patients and visitors may be unaccustomed to the standards of hygiene required in a hospital, health workers need to pay special attention to this matter.

Cleaners and porters, who usually have access to every part of the hospital, should not be overlooked. They need to feel that they are an important part of the hospital's service team and should be given careful training so that they can understand how a lack of cleanliness can affect the outcome of a patient's treatment. Their work requires a sense of duty and responsibility for service, which should be fostered.

This section concludes with a comment about how the example set my medical establishments can influence standards of hygiene in patients' and visitors' homes and workplaces

General hospital hygiene is a prerequisite for good medical waste management; it will be useless in terms of prevention of nosocomial infections to start improving hospital waste management if the hospital does not have a reliable supply of safe water, and basic sanitation facilities accessible to hospital personnel patients and visitors. Whilst it is especially important that the operating theatres should be disinfected and the kitchens be spotless, it is also vital that the whole hospital be kept clean and in a satisfactory state of hygiene. On the other hand, in terms of prevention of the spread of infection outside the hospital, careful management of wastes from the point of generation is of paramount importance.

4. STORAGE

In many ways, the storage of hospital waste is the key to whole management process, because it is at this stage that wastes are segregated into different streams, and incorrect classification of wastes can lead to many problems at a later stage. It is also at this stage that all sharps should be put into containers that will contain them and be resistant to puncture, and failure to do this properly can lead to injury and potentially fatal infections. It is

Consideraciones sobre el manejo de residuos de hospitales en América Latina Montreal Julio, OPS. 1992

SITUACION ACTUAL

Introducción

Los residuos sólidos generados en hospitales y establecimientos de salud presentan riegos y dificultades especiales en su manejo debido, fundamentalmente, al carácter infeccioso de algunas de sus fracciones componentes. Contribuyen también a acrecentar tales riesgos y dificultades la heterogeneidad de su composición, la presencia frecuente de objetos cortopunzantes y la presencia eventual de cantidades menores de sustancias tóxicas, inflamables y radiactivas de baja intensidad. No obstante lo anterior, la mayor parte de los residuos que produce un hospital no ofrece mayores peligros que los asociados a los residuos municipales comunes.

Los riesgos arriba mencionados involucran, en primer término, al personal que debe manejar los residuos sólidos tanto dentro como fuera del establecimiento, personal que, de no contar con suficiente capacitación y entrenamiento o de carecer de facilidades e instalaciones apropiadas para el manejo y tratamiento de los residuos, de equipo y herramientas de trabajo o de elementos de protección personal adecuados, puede verse expuesto contacto directo con gérmenes patógenos o a la acción de objetos cortopunzantes, tales como agujas de jeringas, trozos de vidrio u hojas de rasurar.

No menos significativos son los riesgos que pueden llegar a afectar al resto de la población hospitalaria y, en especial, al grupo constituído por aquellos pacientes que en razón de las características particulares de sus dolencias o de los tratamientos a que han sido sometidos, se encuentran con sus defensas disminuídas. Niños desnutridos, individuos anérgicos, convalecientes de procesos agudos e inmunodeprimidos, entre otros, son ejemplos de pacientes en especial riesgo de contraer infecciones como consecuencia de la exposición a agentes patógenos, cuando el manejo de los residuos sólidos se hace en forma inadecuada.

Finalmente cabe destacar que el manejo deficiente de los residuos sólidos de hospitales no sólo puede crear situaciones de riesgo que amenacen la salud de la población hospitalaria -personal y pacientes-, sino también puede ser causa de situaciones de deterioro ambiental que trasciendan los límites del recinto hospitalario, generando molestias y pérdida de bienestar a la población aledaña al establecimiento y sometiendo a riesgo la salud de aquellos sectores de la comunidad que, directa o indirectamente, lleguen a verse expuestos al contacto con material infeccioso o contaminado, cuando los residuos son trasladados fuera del hospital para su tratamiento o disposición final.

De primordial importancia para abordar cualquier programa de control de las situaciones de riesgo derivadas del manejo inadecuado de los residuos sólidos de hospitales es el caracterizar cualitativa y cuantitativamente el problema.

Ello permitirá dimensionar los espacios físicos necesarios para manejar los diferentes tipos de desechos, decidir acertadamente acerca de qué alternativas técnicas utilizar para el tratamiento de cada una de las fracciones componentes y seleccionar los equipos y dispositivos más convenientes para tal propósito.

Lamentablemente la información disponible a este respecto en Latinoamerica y el Caribe es aún insuficiente en la mayoría de los casos y la escasa información existente es, en ocasiones, poco confiable o limitada en su aplicación a situaciones muy particulares; ello ha conducido, en no pocas oportunidades, a la adopción de soluciones que la experiencia demostró posteriormente eran inadecuadas y, como consecuencia de ello, a la mantención o agudización de situaciones de riesgo como las antes mencionadas.

Generación de Residuos Hospitalarios

La cantidad de residuos sólidos generados en un establecimiento hospitalario es función de las diferentes actividades que en él se desarrollan y en consecuencia dependerá, entre otros factores, de la cantidad de servicios médicos ofrecidos en el establecimiento, del grado de complejidad de la atención prestada, del tamaño del hospital, de la proporción de pacientes externos atendidos y de la dotación de personal; no resultando fácil establecer relaciones simples que permitan estimar la cantidad de residuos sólidos producidos por un establecimiento hospitalario en función de tal diversidad de factores.

Lo anterior ha conducido, en la mayoría de los casos, a relacionar la cantidad promedio de residuos sólidos generados diariamente con el número de camas del hospital, obteniéndose así cifras que, si bien pueden estar sujetas a cierto grado de imprecisión, son de fácil manejo y aplicación.

A partir de los años setenta en adelante los países latinoamericanos han evidenciado un creciente interés sobre la materia, lo que tuvo como resultado la realización de diversos estudios tendientes a conocer la tasa de generación de residuos sólidos en los establecimientos hospitalarios. El análisis comparativo de los resultados obtenidos en estos estudios debe hacerse teniendo presente que las metodologías utilizadas en cada caso, e incluso las definiciones básicas adoptadas respecto de los residuos sólidos hospitalarios, fueron diferentes.

Las cifras promedio obtenidas en diversos países latinoamericanos para la generación de residuos sólidos en hospitales fluctúan entre 1,0 y 4,5 Kg/cama/día, pudiéndose apreciar que dicha tasa de generación tiende a aumentar en el tiempo. Tal comportamiento coincide con la evolución mostrada por la tasa de generación de residuos sólidos hospitalarios en países desarrollados, si bien en estos últimos países las tasas actuales de generación de residuos son significativamente mayores a las que presentan los países en desarrollo. A modo de ejemplo, en Estados Unidos

de Norteamerica se registran cifras del orden de 3,5 kg/cama/día para fines de la década del cuarenta, alcanzándose cifras superiores a 6 u 8 Kg/cama/día para los años ochenta.

Las causas principales de este progresivo aumento de la tasa de generación de residuos sólidos hospitalarios son el continuo incremento de la complejidad de la atención médica y el uso creciente de material desechable.

Tasa de Generación de Residuos Sólidos de Hospitales en algunos Países de Latinoamérica

País	Año del Estudio	Generación (kg/cama/día)		
		Mín	Med	Max
Chile	1973[1]	0.97	-	1.21
Venezuela	1976[2]	2.56	3.10	3.71
Brasil	1978[3]	1.20	2.63	3.80
Argentina	1982[4]	0.82	-	4.20
Perú	1987[5]	1.60	2.93	6.00
Argentina	1988[11]	1.85	-	3.65
Paraguay	1989[6]	3.00	3.80	4.50

Composición de los Residuos

Una de las características importantes de los residuos sólidos de hospitales es su heterogeneidad, caracerística que es consecuencia de la amplia gama de actividades complementarias a la atención médica que se desarrolla al interior de un hospital, todas las cuales, en mayor o menor grado, aportan residuos de diversas calidades.

La composición de los residuos sólidos hospitalarios puede establecerse de acuerdo a diferentes criterios de clasificación de componentes, según sea la utilidad que un determinado criterio de clasificación pueda prestar en la resolución de un problema específico. Es así como los diversos componentes pueden ser clasificados

de acuerdo a su lugar de origen, a su combustibilidad, a su carácter orgánico, a su putrescibilidad, a su peligrosidad, o bien de acuerdo a los compuestos y elementos químicos que conforman los desechos.

Existen diversos criterios de clasificación propuestos ó en uso en los países latinoamericanos, los que básicamente diferencian los desechos de material médico-quirúrgico, los desechos biológicos, los restos de alimentos, los objetos cortopunzantes y la fracción de desechos similar a los residuos municipales comunes.

Desde el punto de vista del manejo sanitario de los residuos sólidos hospitalarios interesa especialmente clasificar los desechos de acuerdo a su carácter infeccioso.

En rigor, un residuo, para ser considerado infeccioso, debe contener gérmenes patógenos en cantidad y con virulencia suficientes como para que la exposición de un huésped susceptible al residuo pueda dar lugar a una enfermedad infecciosa. Dado que resultaría de escasa utilidad práctica y altamente costoso el analizar la presencia efectiva de gérmenes patógenos en los residuos sólidos, la Agencia de Protección Ambiental de los Estados Unidos, US EPA, recomienda establecer como mínimo seis categorías de residuos infecciosos: residuos de salas de aislamiento, cultivos de agentes infecciosos, sangre humana y sus derivados, residuos patológicos, objetos cortopunzantes contaminados y restos animales contaminados.

De acuerdo a los escasos estudios de composición realizados en países latinoamericanos, el contenido de residuos contaminado microbiológicamente fluctua entre un 10% y un 40% del total de residuos sólidos generados por un hospital. Sin embargo, el desarrollo, en países como Chile, de programas de separación en origen de la fracción infecciosa ha permitido demostrar que, conforme se perfecciona la práctica de separación, el porcentaje de residuos infecciosos se mantiene dentro del rango que va del 10% al 20% de dicho total. En los Estados Unidos esta fracción varía de un 5 a un 10% según diversos autores.

Separación de los Residuos

La separación de algunas de las diferentes fracciones componentes de los residuos sólidos de hospitales es una práctica común en los establecimientos hospitalarios, si bien tal separación se realiza frecuentemente con el fin de disminuir los costos de manejo interno y externo de los residuos y no con el propósito de reducir los riegos sanitarios asociados al manejo de las fracciones infecciosas o peligrosas en general.

Es práctica muy corriente la separación y comercialización de los residuos provenientes de la preparación, elaboración y servicio de alimentos; de los papeles y cartones provenientes del embalaje de material médico, de laboratorio o de farmacia, así como la separación y comercialización de otras fracciones menores, tales como envases de vidrio y plástico. Sin embargo, el hecho de no contarse con una adecuada práctica de separación de la fracción infecciosa implica la existencia de riesgos para la salud, tanto del personal que manipula estos materiales, como para la salud de la comunidad en general.

La implantación de una práctica adecuada de separación en origen de las fracciones infecciosas y de otras fracciones peligrosas permite derivar el resto de los residuos hospitalarios hacia la recolección municipal, reservando los sistemas de manejo especiales sólo para aquella porción de residuos que realmente ofrece riesgos. Pese a las ventajas de la separación en origen de las fracciones peligrosas, no resulta fácil implantar este tipo de prácticas en los establecimientos hospitalarios. Ello requiere, en primer término, la colaboración decidida y permanente del personal médico, paramédico y auxiliar, ya que será este personal el que deberá canalizar los residuos, tan pronto se generen, hacia los receptáculos de almacenamiento apropiados. Se requiere además disponer del equipamiento suficiente para almacenar, recolectar, transportar, acumular, tratar y disponer estos residuos en forma totalmente independiente del resto de los residuos del hospital, mientras mantengan sus características de peligrosidad.

Especial mención merecen los objetos cortopunzantes, ya que al peligro de accidentes traumáticos que tales objetos ofrecen hay que agregar que, por su misma naturaleza y uso, con frecuencia ellos han estado en contacto con material infeccioso y presentan, por lo tanto, dicha característica. La separación y embalaje adecuado de los residuos cortopunzantes, de manera de prevenir accidentes y evitar el deterioro de los recipientes y bolsas receptoras de desechos, resulta una práctica necesaria para el buen manejo de los residuos de hospitales.

Almacenamiento de los Residuos en la Zona de Producción

El almacenamiento de los residuos en el lugar de origen representa la primera etapa de un proceso secuencial de operaciones que conforman el sistema de manejo. Para ello debe contarse con receptáculos de tamaño, forma y material adecuados, de manera de asegurar una capacidad suficiente, un fácil manejo y limpieza y una hermeticidad acorde con los requerimientos sanitarios propios de cada zona. Se considera óptimo el uso de receptáculos cilíndricos o troncocónicos de metal o plástico rígidos, provistos de tapa y asas, y de capacidad no superior a cien litros.

El uso de bolsas plásticas como elemento complementario del receptáculo ofrece una serie de ventajas, entre las cuales se puede destacar la reducción de la exposición al contacto directo con los desechos del personal que los manipula y el mejoramiento de las condiciones higiénicas generales del sistema.

Recolección Interna

La recolección de los residuos desde las zonas de generación se hace por lo general con carros de tracción manual. Tales carros deben ser de diseño apropiado de manera de impedir el derrame de residuos y evitar molestias innecesarias a la población hospitalaria. Debe considerarse que es imprescindible transitar por las dependencias interiores del establecimiento, lo cual exige poner especial atención a las condiciones de higiene, rápidez y silencio de esta operación, siendo necesario establecer programas de recolección con horarios y recorridos bien definidos.

La tendencia actual en Latinoamérica y el Caribe es la de limitar o suprimir el uso de ductos de gravedad para el transporte interno de los residuos debido, fundamentalmente, a los problemas de derrame de residuos tanto en las tolvas de admisión como en las salas de recepción y a la introducción en el ambiente hospitalario de materiales contaminantes, tales como gases y partículas, e incluso de vectores sanitarios a través de las tolvas las de admisión, cuando ellas se encuentran en malas condiciones o son operadas en forma inconveniente.

Tratamiento y Disposición Final

El diagnóstico de la situación actual en cuanto a las condiciones de tratamiento y disposición final de los residuos sólidos de hospitales en los países latinoamericanos y del Caribe es incompleto, disponiéndose en el presente sólo de descripciones parciales de la situación imperante en algunos países. En base a estos antecedentes y a la información obtenida directamente en terreno es posible afirmar que, en un gran número de casos, los residuos sólidos de hospitales son derivados en su conjunto a la recolección municipal sin que exista una separación previa de las fracciones infecciosas, practicándose sólo una separación, en muchos casos incompleta, de los restos de tejidos humanos generados en los servicios de cirugía, obstetricia y anatomía patológica.

Desde el punto de vista sanitario esta forma de eliminar los desechos hospitalarios resulta absolutamente inaceptable, ya que implica someter a alto riesgo la salud y seguridad del personal encargado de recolectar los residuos. A lo anterior debe agregarse que muy frecuentemente los residuos municipales son dispuestos en basurales a cielo abierto en los cuales, por regla general, se practican actividades de recuperación de materiales sin ningún control, quedando las personas que se dedican

a tales actividades expuestas al contacto directo con material contaminado microbiológicamente.

El manejo de los restos de tejidos humanos separado por el hospital es también, en muchos casos, objetable. Los procedimientos usados van desde la correcta cremación en unidades especialmente diseñadas para estos efectos hasta el enterramiento en el recinto del hospital, la introducción a la red de alcantarillado con o sin trituración previa, la quema directa con agregado de combustible en recipientes metálicos a el envío al cementerio local.

Ha sido práctica frecuente también en los países latinoamericanos y del Caribe el instalar, en especial en los hospitales y clínicas de gran tamaño, incineradores de grandes dimensiones con el propósito de incinerar en el recinto del establecimiento la mayor parte, y en elgunos casos la totalidad, de los residuos sólidos generados.

El resultado de esta práctica ha sido la instalación de equipos sobredimensionados que, además de requerir una importante inversión inicial, tienen altos costos de operación y mantenimiento y que en su mayoría funcionan precariamente o han quedado fuera de uso. Cabe hacer presente además que el diseño original de muchos de estos incineradores no satisface los requerimientos mínimos de un incinerador de residuos hospitalarios por lo que, aún en óptimas condiciones de operación, presentaron deficiencias graves de funcionamiento.

Resultados Obtenidos en Diversos Estudios sobre Condiciones de Funcionamiento de Incineradores de Residuos Sólidos Hospitalarios en Algunos Países Latinoamericanos

PAIS	AÑO DE ESTUDIO	TOTAL ESTUDIADO	NUMERO DE INC. CON FUNCIONAMIENTO DEFECT. O FUERA DE USO	
		No.	No.	%
Mexico[8]	1975	-	-	90
Argentina[4]	1982	9	7	78
Brasil[7]	1985	14	8	57
Perú[5]	1985	25	23	92

Consecuencias del funcionamiento defectuoso de este tipo de unidades en la emisión de humos, partículas contaminantes y malos olores a la atmósfera, con el consiguiente deterioro de las condiciones ambientales de los sectores aledaños al hospital, y la generación de cenizas no totalmente mineralizadas, y por lo tanto, de difícil manejo posterior.

Existen algunas experiencias interesantes en relación con sistemas de incineración central en donde la municipalidad o alguna empresa presta el servicio de incineración, hasta cuyas instalaciones son trasladados los residuos sólidos de hospitales, clínicas y establecimientos de salud para su tratamiento. Sistemas de este tipo han sido implementados en Brasil, en la ciudad de Sao Paulo y en Ciudad de México aunque se reconoce que la separación de la basura es muy deficiente o no se hace.

La incineración central tiene la ventaja de disminuir, tanto los costos totales de inversión, como los de operación y mantenimiento, y de facilitar la obtención de mayores niveles de eficiencia y de suficiencia técnica. En contraste con lo anterior, implica mayores costos de transporte y la introducción de un factor de riesgo sanitario-ambiental adicional asociado al tránsito de desechos infecciosos fuera del recinto del hospital. Por otra parte esta solución sólo resulta aplicable a grandes ciudades en donde la cantidad total de residuos a incinerar permita alcanzar los bajos costos y los niveles de eficiencia buscados.

Existe también la alternativa de usar este sistema mediante la habilitación de un incinerador sobre dimencionado de algún hospital grande, al que se lleven los residuos de otros hospitales y clínicas.

La factibilidad técnica y económica de dar adecuado tratamiento y disposición final a los residuos hospitalarios esta directamente relacionada con la posibilidad de implementar una efectiva separación en origen de las fracciones peligrosas. Tal como se ha señalado anteriormente, el mezclar los residuos infecciosos con el resto de los residuos obliga a tratar al conjunto con los mismos procedimientos y precauciones aplicables a los residuos infecciosos, encareciendo y dificultando la operación del sistema. Por el contrario, una buena separación en origen permite derivar la mayor parte de los residuos sólidos producidos en un hospital a la recolección municipal y reservar los procedimientos especiales y de alto costo sólo para los residuos peligrosos. Lo anterior es válido tanto si el tratamiento se hace en el propio recinto del hospital como si se realiza fuera de él.

Este enfoque ha sido aplicado en países como Chile y Cuba, en donde se practica la separación en origen de las fracciones infecciosas, las que son incineradas, biodigeridas o esterilizadas en unidades de pequeño tamaño especialmente diseñadas

para tratar este tipo de residuos. Así mismo en estos países se promueve la separación de los residuos provenientes de la elaboración de alimentos con el fin de aprovecharlos en la cría y engorda de animales. El resto de los residuos, junto a las cenizas de incineración, son recogidos por el servicio municipal.

Legislación

Por regla general, la legislación, reglamentación y normativa existente en los países latinoamericanos y del Caribe en relación con el manejo de los residuos sólidos de hospitales es insuficiente, demasiado general en muchos casos y demasiado rígida en otros. Ejemplo de este último son las disposiciones legales que obligaban a incinerar los residuos hospitalarios en el propio establecimiento, como es el caso del municipio de Rio de Janeiro (Dec.498/76), sin posibilitar la adopción de soluciones conjuntas, tales como la incineración centralizada o el uso de otras técnicas de tratamiento.

Sin perjuicio del ejemplo anterior, en la mayor parte de los países la legislación y reglamentación vigente sólo establece principios generales sin definir claramente las responsabilidades de las diferentes instituciones involucradas, sin identificar convenientemente las diferentes categorías de desechos y sin instituir los requisitos de manejo ni los mecanismos de vigilancia y control.

Aspectos Institucionales

Si bien en la mayoría de los países de la Región existe cierto concenso tácito en cuanto a que la responsabilidad de manejar adecuadamente los residuos sólidos hospitalarios es del propio hospital, en la práctica tal responsabilidad se extiende sólo al tiempo en que los residuos permanecen dentro del predio del establecimiento. Una vez que los residuos son retirados, sea por la recolección municipal o por empresas particulares, el hospital se desentiende de la suerte que corran posteriormente los desechos, responsabilidad que, salvo excepciones, tampoco es asumida por el recolector.

Aún dentro del mismo hospital el manejo de los residuos sólidos es una función anexa asignada al administrador o al encargado de servicios generales, quien usualmente no dispone de suficiente personal capacitado ni de implementos o equipo para desarrollar adecuadamente su labor.

El vacío administrativo anterior se ve agravado debido a que usualmente el personal encargado de ejercer vigilancia y control sobre los factores ambientales capaces de afectar la salud de la población pertenece al propio sector salud, al igual

que parte importante de los establecimientos hospitalarios, lo que muchas veces inhibe a dicho personal para ejercer eficazmente sus atribuciones.

El esquema diseñado en Brasil en cuanto a estructurar un Sistema de Vigilancia Sanitaria al margen de la tuición directa de las autoridades locales de salud parece ser una alternativa institucional que permite superar las limitantes arriba mencionadas.

ALTERNATIVAS DE MANEJO DE RESIDUOS SOLIDOS DE HOSPITALES

Las alternativas disponibles para el manejo de los residuos sólidos de un hospital están estrechamente ligadas al tamaño del establecimiento y al tamaño de la localidad urbana en que éste esta inserto: Un hospital de gran tamaño podrá estimar conveniente instalar un incinerador para tratar los desechos infecciosos que genera, incluídos los restos de cirugía y obstetricia, en tanto que un hospital pequeño ubicado en una localidad aislada podrá optar por enviar los restos de tejidos humanos, junto con otros desechos infecciosos, al cementerio local y por descontaminar los objetos cortopunzantes y otros objetos contaminados para enviarlos, convenientemente acondicionados, a la recolección municipal. Por su parte, un hospital de tamaño medio ubicado en las cercanías de otro hospital mayor podrá encontrar interesante establecer un convenio con este último para utilizar sus facilidades de incineración. Similarmente, la posibilidad de adoptar una solución centralizada para el tratamiento o disposición final de los residuos hospitalarios dependerá directamente del tamaño del conglomerado urbano.

En todo caso, cualquiera sea el tamaño del establecimiento y de la localidad, la separación en origen de los residuos peligrosos, en especial de los residuos infecciosos, y de los objetos cortopunzantes es una práctica necesaria que le permitirá seleccionar las mejores alternativas de manejo a costos razonables.

Separación de los Desechos

La separación de los residuos infecciosos requiere del uso de receptáculos diferenciados, claramente identificables por su color. La cantidad y capacidad de los receptáculos dependerá de las actividades que en cada área del hospital se desarollen y podrá ser estimada aplicando tasas de producción conocidas o por inspección directa. La implementación de un sistema de separación implica disponer además de facilidades de recolección interna y de almacenamiento independientes del resto de los residuos.

Es importante definir muy claramente cuales serán los residuos considerados infecciosos y poner en conocimiento del personal médico, paramédico, auxiliar y de servicio esta definición.

La separación de los objetos cortopunzantes debe hacerse también en origen. Una vez separados estos objetos deben embalarse convenientemente en cajas de cartón rígido o en envases plásticos resistentes para evitar la ocurrencia de accidentes y la rotura de las bolsas de desechos. Para estos efectos pueden utilizarse cajas y envases sobrantes de bodega, farmacia y laboratorio. Los objetos cortopunzantes, convenientemente embalados, deberán manejarse junto con los residuos infecciosos, a menos que se los someta a un proceso de esterilización, caso en el cual podrán manejarse junto con los residuos comunes.

Tratamiento de los Desechos Infecciosos

En hospitales de gran tamaño el procedimiento recomendado, cuando se opta por tratar los residuos dentro del recinto del establecimiento, es la incineración.

Cuando no se dispone de facilidades de incineración en el recinto del hospital los residuos pueden ser trasladados hasta otro hospital que disponga de incinerador, siempre que las condiciones de localización y acceso a esta unidad permitan hacerlo sin riesgo para la población hospitalaria. En todo caso esta alternativa requiere disponer de un vehículo de transporte cerrado, estanco, lavable y de fácil desinfección que en ningún caso podrá utilizarse para transportar personas, alimentos, ropas o medicamentos.

Si no existe la posibilidad de utilización conjunta de facilidades de incineración y la localidad dispone de un relleno sanitario que cumpla cabalmente con los requisitos propios de este tipo de instalaciones, en especial lo referente a cubrimiento oportuno de los residuos, ausencia de recuperadores y control de líquidos percolados, puede establecerse, siempre que la autoridad sanitaria local lo autorice, un convenio para disponer en el relleno sanitario los residuos infecciosos. Esta alternativa requiere de la habilitación de zonas especiales de descarga, retape inmediato y de un sistema de transporte de los residuos sujeto a las mismas restricciones consignadas en el párrafo anterior.

Evidentemente, tratándose de localidades urbanas de gran tamaño debe estudiarse la conveniencia de establecer soluciones centralizadas, las que pueden formularse sobre la base de incineración o de rellenamiento sanitario en una instalación especialmente diseñada y habilitada para este propósito, todo lo cual debe estar sujeto a estricta reglamentación y vigilancia.

A los hospitales de tamaño medio y pequeño usualmente les resulta muy onerosa la instalación y operación de un incinerador, en especial cuando en razón

de su ubicación, lejos de los grandes centros urbanos, no pueden acceder fácilmente a los servicios de mantenimiento y reparación. En estos casos una alternativa para el tratamiento de los residuos infecciosos es el enterramiento en el cementerio local, previo establecimiento de un convenio entre ambas instituciones, o su disposición en el relleno sanitario de la localidad, siempre que este reuna los mismos requisitos señalados más arriba.

También se han empleado con éxito en estos casos digestores biológicos, tanto de tipo seco como de tipo húmedo. Este tipo de unidades es de muy bajo costo y permite tratar los residuos de cirugía, obstetricia, laboratorio y demás desechos infecciosos biodegradables. Los biodegestores húmedos se han utilizado con o sin triturador. Los objetos cortopunzantes y otros objetos no biodegradables contaminados con sangre o sus derivados se someten a esterilización, en autoclave y se derivan a la recolección municipal, convenientemente embalados, junto al resto de residuos del hospital. De acuerdo a la literatura técnica disponible, el uso de soluciones desinfectantes para tratar estos desechos no ofrece suficientes garantías de esterilización, en especial cuando hay objetos con orificios de pequeño diámetro o con zonas que favorezcan la formación de burbujas, como es el caso las agujas de jeringa.

El uso de trituradores para eliminar placentas y otros tejidos blandos a través de la red de alcantarillado ofrece reservas desde el punto de vista sanitario, aún en el caso de existir un sistema de tratamiento de aguas servidas en la localidad.

LINEAMIENTOS PARA LA FORMULACION DE PLANES DE MANEJO INTERNO

El propósito fundamental al formular y aplicar un plan de manejo de residuos sólidos al interior de un hospital es de reducir, tanto como sea posible, los riesgos que para la salud de la población hospitalaria derivan del manejo de los diferentes tipos de desechos que genera el hospital, en especial de aquellos desechos que por su carácter infeccioso o por sus propiedades físicas y/o químicas presentan un alto grado de peligrosidad.

Un plan de este tipo debe ser formulado de acuerdo a las características particulares de cada hospital y a la reglamentación y normativa vigente, debiendo quedar claramente establecido en el documento respectivo las opciones de manejo seleccionadas, los recursos necesarios y el funcionario responsable de implementar el plan.

La elaboración de planes para el manejo interno de los residuos sólidos hospitalarios puede verse facilitada al considerar los aspectos señalados a continuación:

- Caracterización cualitativa y cuantitativa del problema, estableciendo con la mayor precisión posible las cantidades de residuos producidos en cada servicio de especialidad médica y unidad de apoyo, así como las características de peligrosidad de cada fracción componente, de acuerdo a la clasificación establecida al respecto por las normas vigentes, o, en su defecto, a la clasificación adoptada por el hospital.

- Selección de las alternativas técnicas y procedimientos más convenientes para el manejo interno de los residuos, incluyendo separación, almacenamiento en las zonas de producción, acondicionamiento, recolección interna, acumulación, tratamiento y eliminación de los residuos tratados, identificando, en cada caso, los responsables de ejecutar cada acción, los recursos humanos y materiales necesarios y los requerimientos de espacio físico para ejecutarlas.

- Diseño de un plan de emergencia para hacer frente en forma eficaz y oportuna a situaciones accidentales como derrame de líquidos infecciosos, ruptura de bolsas plásticas y recipientes, fallas de equipos, etc.

- Diseño de programas de capacitación y entrenamiento permanentes, tanto para el personal encargado de manejar los residuos como para aquel que los genera.

- Elaboración de normas de procedimiento escritas para la ejecución de cada una las labores correspondientes al sistema de manejo seleccionado.

- Elaboración de un presupuesto para la implementación y el funcionamiento del sistema para su presentación a la autoridad competente.

- Coordinación con el Comité de Prevención y Control de Infecciones Intrahospitalarias del establecimiento con el fin de asignar responsabilidades, establecer programas de información, capacitación y entrenamiento a todos los niveles y de implementar programas de fiscalización.

LINEAMIENTOS PARA LA FORMULACION DE PLANES DE MANEJO EXTERNO

Al igual que el manejo interno de los residuos sólidos hospitalarios, el manejo externo de los residuos generados por un hospital debe obedecer a un plan previamente concebido cuyos objetivos principales deben ser, en primer término, el evitar que los residuos que salen del hospital generen situaciones de riesgo para la

salud de la población y, en segundo término, el lograr que el manejo ambientalmente adecuado de los residuos se haga utilizando los recursos comprometidos tan eficientemente como sea posible.

Como se ha señalado anteriormente, no siempre resulta posible ni conveniente el tratar dentro del establecimiento la totalidad de los residuos infecciosos producidos en un hospital. Si bien ello puede representar ventajas para grandes complejos hospitalarios, puede no ser practicable o económico en hospitales de menor tamaño.

En estos casos una solución conjunta que permita aprovechar eficientemente las instalaciones de un determinado hospital o una solución centralizada que abarque una determinada área geográfica puede resultar mucho más conveniente.

La formulación de un plan de manejo externo de los residuos sólidos hospitalarios requerirá de la participación a nivel local de los diferentes sectores involucrados y deberá contemplar al menos de lo siguiente:

- Realización de un acabado estudio de la localización de los hospitales en el área, su tamaño, características de la atención proporcionada, etc. Así mismo se deberá conocer los planes de expansión de los establecimientos existentes y los proyectos de nuevas instalaciones hospitalarias.

- Evaluación técnica y económica de la conveniencia de establecer soluciones centralizadas, conjuntas o individuales, tomando en cuenta la capacidad del equipamiento existente y la posibilidad de optimizar su aprovechamiento. Esta evaluación debe contemplar, entre otros, aspectos sanitarios, ambientales y de seguridad en la operación y continuidad del servicio:

- Definición de una política clara en cuanto al rol que desempeñará en el esquema de solución adoptado el productor de los residuos, el sector público y el sector privado. Al respecto cabe señalar que cualquiera de las etapas del manejo externo puede ser ejecutada tanto por el sector público como por el sector privado y que en ambos casos hay ventajas e inconvenientes que deben ser evaluados en función de las condicionantes locales específicas.

- Elaboración de cuerpos reglamentarios acordes la política definida y con el esquema de solución adoptado. Esta reglamentación deberá incluir aspectos sanitario-ambientales del manejo externo, sistemas tarifarios, responsabilidades de cada institución y sector involucrado y mecanismos de vigilancia y fiscalización.

- Análisis del marco legal existente en relación con el tema y elaboración de leyes y reglamentos necesarios para el correcto desarrollo del plan.

ASPECTOS RELEVANTES A SER ABORDADOS POR LA LEGISLACION Y REGLAMENTACION.

La legislación y reglamentación en materia de manejo de residuos sólidos de hospitales debe abordar, entre otros, los siguientes tópicos:

- Definición de residuos sólidos de hospitales incluyendo la definición de las diferentes fracciones componentes, en especial de aquellas que por su peligrosidad requerirán de un manejo especial.

- Establecimiento de normas para el control de los riesgos ocupacionales, sanitarios y ambientales asociados al manejo de los residuos sólidos hospitalarios así como de normas de procedimiento para atender situaciones de emergencia.

- Establecimiento de incentivos para lograr disminuir la cantidad de desechos producida y promoción de la recuperación y el reciclado de materiales, cuando ello pueda hacerse sin riesgo para la salud del personal de servicio, población hospitalaria y comunidad en general.

- Normalización de los requisitos exigibles en cada una de las alternativas técnicas aplicables al manejo de los residuos sólidos hospitalarios.

- Establecimientos de un sistema tarifario en relación con los servicios prestados por terceros.

- Establecimiento de sistemas eficaces de vigilancia y control del manejo sanitario de los residuos sólidos de hospitales.

EUROPEAN COMMISSION
DIRECTORATE-GENERAL XI
ENVIRONMENT, NUCLEAR SAFETY AND CIVIL PROTECTION
Industry and the Environment
Waste Management Policy

Org. EN
Brussels, 9 January 1996
Unit E.3

PRIORITY WASTE STREAMS

HEALTHCARE WASTE

PROPOSAL FROM THE PROJECT GROUP

TO THE EUROPEAN COMMISSION

FOR A

STRATEGY DOCUMENT

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1.0 INTRODUCTION

Strategy Document

1.01 This Strategy Document is one of the series of documents produced during the Healthcare Waste Priority Waste Stream Project. The Strategy Document, Information Document, Information Summary and Executive Summary form the main final products of the project.

1.02 The important issues for healthcare waste management have been identified by the Project Group and the strategies for each have been developed by open discussion. The strategies are presented in this report as a statement for each issue together with supporting text. The strategies are listed in the tables in Section 2.0.

1.03 The aim of this document is to provide recommendations to the European Commission for the development of community action on the measures and procedures necessary to control the risks to human health and harm to the environment caused by healthcare waste management. The basic concept is to minimise resources used without prejudicing healthcare itself.

Aim and Background of the Project

1.04 In September 1989 the European Commission delivered a community strategy for waste management to the Council of Ministers and European Parliament. On March 22, 1990 the EC Council of Environment Ministers expressed its approval of the Commission's strategy and endorsed it with a Resolution of the Council concerning waste management (OJ C122, 18.5.1990).

1.05 In its strategy the Commission states that the central focus of this source-oriented policy has to be products as well as production processes. The main aim is to apply a "cradle to grave" perspective on the product since it is only such a policy that will lead to "sustainable development". Wherever possible, it is necessary to look for environmentally acceptable solutions with groups that directly influence the production and consumption patterns ahead of the waste stage.

1.06 The aims of the EC Treaty, Action Programmes and Policy Statements in the field of waste management ar characterised by the "ladder principle", a broad hierarchy of waste management options. Highest priority is given to prevention, followed by recovery (re-use, recycling, combustion with energy recovery), incineration and, finally, landfill of waste.

1.07 A new form of working called the "strategic discussion" method has been employed, involving open discussion at Community level and allowing active involvement on the part of those who have not hitherto had a sufficient role in the early development of strategic solutions.

1.08 Healthcare waste is one of a series of "priority waste streams" identified for "strategic discussion".

1.09 The Healthcare Waste Project commenced in June 1992 and progress has been made in a systematic manner. The project phases have been developed by the Project Group comprising key actors in the field of healthcare waste production and disposal. Initially the work involved developing a programme of work together with aims and objectives. The basis for further work has been developed from information on the current situation and analysis identified problems and opportunities. Strategies have been selected from a shortlist of options developed for each key issue of healthcare waste management.

1.10 Healthcare waste (HCW) refers to all waste arising from healthcare practices. Only a small proportion of this waste poses any greater risk than normal household, or municipal waste. Segregation of healthcare risk waste (HCRW) for separate treatment and disposal is, therefore, a key issue for this project.

1.11 The Group has developed a definition for HCRW and this is given in section 3.0. The main aim is to minimise risk to human health whilst at the same time minimising the resources used for healthcare or disposal. As such the "ladder principle" needs to be modified in its application to this waste stream.

1.12 Incineration with energy recovery is only one aspect of the wider concept of safe healthcare waste disposal with the least use of environmental resources, such as energy. It is more important to follow this basic

concept of minimising resources use, without prejudicing healthcare and the environment, rather than to slavishly follow the ladder principle.

1.13 The strategies in this document represent qualitative targets for improvements in the management of healthcare waste. The Project Group considered that quantitative targets based on the ladder principle are not appropriate for this waste stream at this stage because:

- advancing healthcare practices and minimising the risk to human health take priority over environmental factors;
- there is great diversity in the management, treatment and disposal practices in operation in different Member States; and
- there is no common system of categorisation and recording of HCRW quantities on which to base and monitor implementation of targets although these should be produced in time.

2.0 STRATEGY SUMMARY

ISSUE	STRATEGY
GENERAL STRATEGIES	
Definition	Adopt definition produced by the Project Group.
Prevention of waste	Prevention is to be encouraged. Prevention must not present a barrier to technological innovation or to ensuring high standards of healthcare.
Recycling of waste	If a suitable market exists then the recycling of suitable fractions of healthcare waste should be encouraged providing that recycling does not compromise healthcare standards, or standards for handling healthcare risk waste (HCRW).
Re-use	Re-use of products should be encouraged, but guidance must be provided on those products suitable for re-use and those that are not. Re-use of products must not compromise healthcare standards or standards for handling HCRW.
Education and training/health and safety at work	Compulsory education and training for healthcare and waste management staff, linked to the risks involved for all aspects of healthcare waste management, should be introduced, together with a system of assessment of competence.
Public perception	The public perception of risk should be actively addressed to promote the reality of the situation. Relevant, understandable and correct information should be made available in order to achieve an improvement in understanding.

ISSUE	STRATEGY
Research policy	Research projects should be promoted, but selected on the basis of the priorities set out in the strategy statements for healthcare waste.
Waste management planning	Member States' waste management plans should detail the provisions, related to European Directives, to be made for HCRW management and disposal.

ISSUE	STRATEGY
STRATEGIES FOR HEALTHCARE PRACTICES	
Selection of Product	Medical product selection should be based on healthcare performance, with consideration of the life cycle environmental effect.
Segregation	HCRW should be strictly segregated at source and the appropriate disposal route chosen in accordance with the waste management plan.
Packaging	Guidance should be produced for a common system of packaging HCRW taking legislation into account.
Labelling	Guidance should be produced on how to apply a common system of labelling and coding for HCRW taking legislation into account.
Transport and storage	Guidance should be developed for storage on site, transport and storage prior to pre-treatment and disposal taking legislation into account.
Standards for pre-treatment and disposal	Minimum performance standards for pre-treatment of HCRW prior to disposal should be developed and enforced where they do not exist.
Pre-treatment	The use of validated methods of pre-treatment should be encouraged if a decrease in the risk of harm to human health or pollution or a reduction in costs will result.
Quantities (record keeping)	A system of record keeping for HCW should be developed. Record keeping should be in accordance with the Waste Framework Directive.
Responsibility	Responsibilities, including those on individuals, for all aspects of healthcare risk waste management should be defined and enforced by legislation.

ISSUE	STRATEGY
STRATEGIES FOR TREATMENT AND DISPOSAL	
Choice of methods	The choice of method or methods of pre-treating and disposing of healthcare risk waste should be left to the Member State providing that performance standards are met.
Disposal of non-risk healthcare waste via municipal waste stream	Disposal of non-risk healthcare waste and risk HCW treated to make it non-risk may be carried out via the municipal waste stream if appropriate quality assurance systems are in place.
Disposal of human tissue via crematoria or burial	When disposal of recognisable human organs or tissues (not including blood) takes place via the whole body disposal route, it must conform to national law and be under the responsibility of medical, environmental and ethical authorities. If crematoria are used they should comply with performance standards for incineration of HCRW.
Disposal of healthcare risk waste via municipal waste incinerators with special design features	Provided that spread of infection is prevented through validated and audited procedures, the use of specifically designed or adapted municipal waste incinerators should be encouraged. Mandatory conditions must be applied and monitored, and specific approval given. The disposal of toxic and radioactive wastes through municipal waste incinerators should not be allowed.
Energy recovery	Assessment of the potential for energy recovery from healthcare waste should be encouraged, with consideration of the overall cost and environmental benefits.
Proximity principle	Guidance should be developed for the implementation of the proximity principle in relation to the treatment and disposal of healthcare risk waste.

3.0 DEFINITION

3.01 One of the first tasks of the Project Group was to formulate a definition for healthcare waste as there is considerable variation between Member States. The definition took the draft European Waste Catalogue (EWC) - developed from the Waste Framework Directive 75/442/EEC (and adopted on 20 December 1993) - as a basis and adopted an existing classification system for infectious waste. It is recommended that the definition, which is reproduced below, is adopted at a Community level.

a) **Healthcare** : Medical activities such as diagnosis, monitoring, treatment, prevention of disease or alleviation of handicap in humans or animals, including related research (see note 1), performed under the supervision of a medical practitioner or veterinary surgeon (see note 2).

b) **Healthcare Waste** : The solid or liquid waste arising from healthcare.

c) **Healthcare Risk Waste** :
- Biological (recognisable anatomical waste)
- Infectious (see note 3)
- Chemical, toxic or pharmaceutical including cytotoxins
- Sharps (eg. needles, scalpels)
- Radioactive (refer to Radioactive Waste Directive(s))

Note 1 : Wherever appropriate and applicable, waste from basic and fundamental biomedical and other research shall be managed according to the principles set out for healthcare waste and healthcare risk waste.

Note 2: The above mentioned supervision may also be carried out by any other person authorised by virtue of their professional qualifications to do so.

Note 3 : Infectious waste is any Healthcare Waste known or clinically assessed to be at risk of being contaminated with:

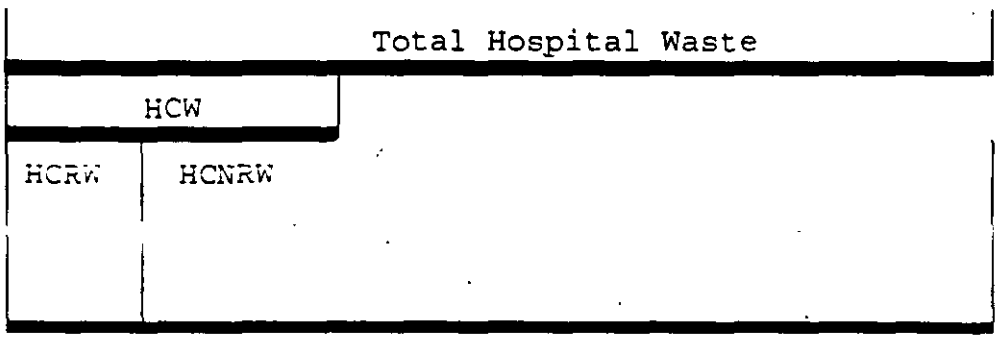
a) any of the biological agents mentioned in Article 2(d) Groups 3 and 4 or identified through the procedure set out in Article 3 of the Council Directive (90/679/EEC) of 26 November 1990 (amended by Directive 93/88/EEC) on the protection of workers from risks related to exposure of biological agents of

Article 16(1) of Directive 89/391/EEC or

b) with other viable biological agents artificially cultivated to significantly elevated numbers.

3.02 This project has been concerned mainly with healthcare risk waste. It has not addressed the issue of genetically modified micro-organisms which is covered by Council Directive 90/219/EEC. Figure 1 illustrates how healthcare risk waste relates to the total amount of waste produced at a hospital but the system can also be applied to other sites of healthcare risk waste production. Figure 2 illustrates the strategy for dealing with healthcare waste following segregation between risk and non-risk waste.

Figure 1 : Relationship of healthcare waste to the total waste produced at a hospital.



HCW = Healthcare Waste
HCRW = Healthcare Risk Waste
HCNRW= Healthcare Non Risk Waste

4.0 GENERAL STRATEGIES

Definition

4.01 The first step towards the regularisation of healthcare waste management practices within the European Community should be the production of a Europe-wide definition of healthcare waste. The definition produced by the Project Group is given in Section 3.0.

Statement:

4.02 **Adopt the definition produced by the Project Group.**

Prevention of Waste

4.03 The aims of the EC Treaty Action Programmes and Policy Statements are characterised by the "ladder" principle, a broad hierarchy of preferred waste management options. Prevention is given highest priority in the "ladder".

4.04 Issues contributing to prevention include segregation, re-use, recycling and selection of medical products and devices by users.

Statement:

4.05 **Prevention is to be encouraged, but must not present a barrier to technological innovation or to ensuring high standards of healthcare.**

Recycling of Waste

4.06 Recycling is defined, for the purpose of this project, as "using waste as a raw material".

4.07 Recycling of healthcare risk waste without pre-treatment is not an option. Even with pre-treatment it is not recommended.

4.08 The basis of successful and effective recycling of

healthcare waste is effective segregation. Some raw materials, not classified as healthcare risk waste (eg. glass, paper, cardboard, metal etc.), are already recycled as a matter of course. Others are not recycled because of ineffective segregation systems or lack of healthcare personnel motivation or both. It is essential, however, to establish the size and reliability of the market for the raw materials **before** comprehensive recycling schemes are introduced.

Statement:

4.09 **If a suitable market exists the recycling of suitable fractions of healthcare waste should be encouraged; but recycling must not compromise healthcare standards or standards for handling healthcare risk waste.**

Re-use

4.10 There are three principal aspects of re-use: re-use of single use medical devices and equipment for the same purpose; re-use of medical equipment for non- medical purposes; and re-use of items designed for re-use.

4.11 The re-use of medical devices and equipment intended for single use for the same purpose and the extended re-use of re-usable items both entail potential safety problems. In some European countries, legal tests for product liability claims are based on reasonable foreseeability or expectation that a product will cause injury.

4.12 Re-use of medical devices and equipment for non-medical purposes (eg. re-use of scalpel blades for craft purposes,) is less problematic. However, the success of such schemes depends on effective segregation and the availability of suitable, cost effective treatment to remove the health risk.

4.13 Re-use is directly below prevention in the hierarchy of preferred waste management options: it is an option that the healthcare waste Project Group would wish to see encouraged. However, the re-use of items designed for single use is not acceptable. Only items designed for re-use should be re-used: even then, treatment and quality assurance systems should be introduced to ensure that risks to patients and healthcare workers

are not increased. Items should be selected for re-use according to the levels of risk associated with such practices and the environmental benefits.

Statement:

4.14 **Re-use of products should be encouraged, but guidance must be provided on those products suitable for re-use and those that are not. Re-use of products must not compromise healthcare standards or standards for handling of HCRW.**

Education and Training/Health and Safety at Work

4.15 The issue of education and training is closely connected to health and safety. Education and training of personnel involved in all aspects of healthcare waste management are related to the safety of those personnel and protection of the environment.

4.16 Community legislation requires the protection at work of all handlers of healthcare waste , including professional and non-professional staff. Many Member States provide guidance to enable employers to develop policies for handling and disposing of healthcare waste that will safeguard their employees and others. Council Directive 89/391/EEC introduces measures to encourage improvements in the safety and health of workers at work and requires designated individuals to carry out activities related to protection and prevention of occupational risks. Responsibility is also placed on each worker to take care, as far as possible, of his own safety and health and that of other persons affected by his acts.

4.17 Responsibility for waste management must be defined, both in and outside the production site. Within the production site it is the responsibility of the healthcare institution; outside the production site (transport, treatment, disposal) it is the responsibility of the waste management operators.

4.18 Adequate health and safety legislation exists but needs to be enforced, particularly in accordance with the defined responsibilities for all those parties involved in the management of HCW.

Statement:

4.19 **Compulsory education and training for healthcare and waste management staff should explain the risks involved in all aspects of healthcare waste management. A system of assessment of competence should be introduced.**

Public Perception

4.20 Public perception covers a wide range of issues:

- The management and disposal of healthcare waste
- Fears and concerns of the public about the hazards to themselves and the environment from healthcare waste exposure
- Pressure from local planners and authorities on producers of healthcare waste, developers of disposal plant, and others
- Management of healthcare waste arising in the home due to the increase in home care.

4.21 Healthcare risk waste must be adequately defined i.e. by type of risk. Clear, logical and effective segregation systems need to be in place and suitable methods of disposal adopted for each type of waste in order to relieve the fears, concerns and pressures outlined above. The public must be reasonably assured that healthcare risk waste is being dealt with in the most appropriate and environmentally acceptable way.

Statement:

4.22 **The public perception of risk should be actively influenced to promote the reality of the situation. Correct, relevant, and understandable information should be made public in order to achieve an improvement in understanding.**

Research Policy

4.23 Research (public and private sectors) on healthcare waste covers areas such as risk analysis, recovery and disposal, pre-treatment/treatment, and creation of data-bases. Changes in medical practices and products also come under this general heading.

Statement:

4.24 **Research projects should be promoted. Selection of projects should be on the basis of the priorities set out in the strategy statements for healthcare waste.**

Waste Management Planning

4.25 The Waste Framework Directive requires Member States to prepare national waste management plans. These plans should include the management and disposal of healthcare risk waste. (Council Directive 75/442/EEC on Waste amended by Directives 91/156/EEC and 91/692/EEC.)

Statement:

4.26 **Member States' waste management plans should detail the strategic provisions, related to European Directives, to be made for healthcare risk waste management and disposal.**

5.0 STRATEGIES FOR HEALTHCARE WASTE PRACTICES

Selection of Product

5.01 The quantity and type of materials, including packaging, entering the healthcare waste stream can be significantly influenced by careful selection of products used for medical purposes. Changes are taking place in the manufacture of many products, e.g. changes in the composition of products. Producers need to recognise and understand these changes if they are to select the most environmentally acceptable product .

5.02 Primarily the selection of products should be based on the criteria in the Medical Devices Directive, (93/42/EEC) e.g, efficiency, side effects, security .

5.03 Packaging of products can influence waste quantities and product selection. The proposed EC Directive on Packaging and Packaging Waste (COM(93) 416 final - SYN 436)) will place a requirement on Member States to achieve recovery and recycling targets for packaging waste. It will also provide for harmonisation of the criteria for packaging and packaging materials .

5.04 Accessible information is needed on the relative benefits and costs of different products and materials. Life Cycle Analysis is one method of appraising different environmental options.

Statement:

5.05 **Medical product selection should be based on healthcare performance, with consideration of the life cycle environmental effect (including value for money).**

Segregation

5.06 Segregation is the key to effective healthcare waste management. It ensures that the correct disposal routes are taken, personnel safety is maintained, environmental harm is minimised and the least resources are used (see Figure 2).

5.07 Segregation is the responsibility of the waste producer. Each healthcare institution should prepare and follow a waste plan. Segregation should be undertaken on the basis of the two types of waste listed in the definition for healthcare waste, i.e. (1) Healthcare risk waste and its components and (2) other (non-risk) waste.

5.08 Healthcare risk waste should be segregated at source from other waste and treated in an appropriate manner. Where healthcare waste is not segregated it should be treated as risk waste. The healthcare institution should identify the most appropriate disposal route(s) for liquid and solid healthcare wastes.

5.09 Segregation of waste must reflect the risks : see Figure 2. The initial segregation must allow the choice of a disposal route that minimises the use of resources.

5.10 Correct and efficient segregation will only be achieved through rigorous training and education of employees, supervisors and managers. Policies should take this into account.

Statement:

5.11 **Healthcare risk waste should be strictly segregated at source and the appropriate disposal route chosen in accordance with the waste management plan.**

Packaging

5.12 Healthcare Risk Waste is packaged or contained between the time of generation and the time of treatment/disposal. In most Member States, guidance exists for the selection of the most appropriate packaging materials and methods.

5.13 From 1st January 1995 infectious waste from healthcare will be included in the Annex to the European Agreement concerning the International Carriage of

Dangerous Goods by Road (ADR). An EC Directive entitled 'The transport of dangerous goods by road' will incorporate the provisions of the ADR.

Statement:

5.14 **Guidance should be produced for a common system of packaging HCRW taking legislation into account.**

Labelling

5.15 A common system of labelling and coding of packaging needs to be developed for healthcare risk waste.

5.16 Labelling requirements for infectious waste are put forward in annex A to the proposed EC Directive on the Approximation of the Laws of Member States with regard to the Transport of Dangerous Goods by Road.

5.17 Healthcare risk waste should be labelled to comply with its requirements .

Statement:

5.18 **Guidance should be produced on a common system of labelling and coding for healthcare risk waste, taking legislation into account.**

Transport and storage

5.19 Some Member States have existing guidelines that cover safety during the transport and storage of healthcare waste. These relate to aspects such as design of storage containers, length of storage, and design of vehicles .

5.20 All Member States have some form of special collection and transport system for HCRW. The exact form depends on the kind of facility, or the defined hazardous nature of the waste, or both. Specific conditions of transport of some HCRW are put forward in the proposed Directive on the Approximation of the

Laws of Member States with regard to the Transport of Dangerous Goods by Road.

5.21 Healthcare risk waste requires specialised transport methods: specially designed, purpose-built vehicles should transport the waste safely and hygienically between the production point and the disposal point.

5.22 Guidance should be provided on :

- storage facilities at the point of arising
- length of storage (from time of arising to time of treatment or disposal)
- transport on and off site
- specifications for containers and vehicle
- storage facilities prior to treatment or disposal

5.23 Guidance should take into account the differences in conditions existing in Member States, and between small and large producers.

Statement:

5.24 **Guidance should be developed for storage on site, transport and storage prior to pre-treatment and disposal, taking legislation into account.**

Standards for Pre-Treatment and Disposal (Treatment).

5.25 Pre-treatment is usually carried out to remove the risk from HCRW but can have other functions. With the exception of incineration, there are no common European standards for treatment methods for healthcare risk waste. If validated pre-treatment methods are to be encouraged and utilised more widely, standards should be produced and commonly agreed. The terms treatment and pre-treatment overlap and have been defined as follows:

> **Pre-treatment** is the initial treatment of waste materials to make them safe to handle, or precondition them for subsequent processing or

disposal. (Source: ISWA)

Treatment is any method, technique or process, including neutralisation, designed to change the physical, chemical or biological character or composition of any waste, or to recover energy or material resources from the waste, or to render such waste non-hazardous or less hazardous; safer to transport, store or dispose of; or amenable for recovery, amenable for storage, or reduced in volume. (Source: ISWA)

5.26 The standards for pre-treatment methods need to be commonly agreed but individually implemented by the Member States.

Statement:

5.27 **Harmonised performance standards for pre-treatment of HCRW prior to disposal should be developed where they do not exist.**

Pre-treatment

5.28 A number of methods of pre-treating healthcare risk waste to remove the risk are in use. One such method is steam treatment. Others exist or are being developed. Their development and use should be encouraged where they produce environmental or economic benefits without prejudicing human health.

Statement:

5.29 **The use of validated methods of pre-treatment should be encouraged if a decrease in the risk of harm to human health, or pollution, or a reduction in costs will result.**

Quantities (record-keeping)

5.30 Quantities of healthcare risk waste arising vary among Member States and are related to current policies, definitions and perceived sources in each. Some data

and statistics are available but there are many gaps - filling some of these gaps is fundamental to establishing good waste management practices.

5.31 The Waste Framework Directive 91/156/EEC requires record keeping for wastes, including HCRW.

5.32 The keeping of records is already in place in some Member States, particularly at the point of disposal. Record-keeping is required for the following reasons:

- it allows manufacturers to demonstrate that they are striving to prevent waste;
- it enables producers of waste to establish whether systems of standards are working;
- it is an effective method of setting and measuring targets to promote the waste disposal hierarchy;
- for economic reasons - because of the variation in costs between HCRW, domestic and inert waste disposal, it provides a means of improving financial management.
- it assists in legislation, control and planning.

Statement:

5.33 **A system of record keeping for healthcare waste should be developed. Record keeping should be in accordance with the requirements of the Waste Framework Directive.**

Responsibility

5.34 The responsibility for all aspects of healthcare risk waste management must be statutorily defined. All HCRW producers need to be bound by a responsibility for its disposal. The responsibility must extend to each person who accepts the waste, from the point of arising to the point of disposal. Council Directive 89/391/EEC imposes obligations on employers (for the provision of protective and preventive services) and on workers' .

Statement:

5.35 **Responsibilities, including those on individuals, for all aspects of healthcare risk waste management should be defined and enforced by legislation, where this has not already been done.**

6.0 STRATEGIES FOR TREATMENT AND DISPOSAL

Choice of methods

6.01 Standards must be established for acceptable performance of pre-treatment and disposal (treatment) methods. These criteria should cover :

- effectiveness
- health & safety
- environmental impact, and
- quality control.

6.02 If these criteria are met individual choices of treatment should be made by the relevant Authority in each Member State.

Statement:

6.03 **The choice of method or methods of pre-treating and disposing of healthcare risk waste should be left to the Member State, providing that minimum acceptable performance standards are met.**

Disposal of non-risk healthcare waste via municipal waste stream

6.04 Non risk healthcare waste (which includes risk healthcare waste treated to make it non-risk) can be disposed of via the normal municipal waste stream. This method of disposal is used at present in many Member States and has major economic benefits: municipal waste disposal, including incineration, is, at present, much less expensive than specialist disposal.

6.05 Central to this issue is the definition of risk waste and whether or not infectious "risk" waste, once pre-treated in validated processes, can be disposed of via the municipal waste stream.

6.06 Healthcare waste other than risk waste could be disposed of via the municipal waste stream providing there are adequate quality assurance systems in place. Segregation schemes must be adequately controlled to ensure that it is **only** the non-risk or suitably treated waste being disposed of via this route.

Statement:

6.07 **Disposal of healthcare non riskwaste (including healthcare risk waste treated to make it non-risk) may be carried out via the municipal waste stream if appropriate segregation and quality assurance systems are in place.**

Disposal of human tissue via the whole body disposal route (WBDR)

6.08 The usual whole body disposal route is cremation or burial. Cremating or burying strictly segregated human tissue would conform with the proximity principle, prevent duplication of facilities and complement treatment methods that are generally unsuitable for human tissue. This already occurs for practical and religious reasons in some areas but can cause concern and where acceptable must be done in an ethical manner.

6.09 The quantities involved would be small. Packaging should be designed to take environmental impact into account. If crematoria are used for the disposal of the human tissue component of HCRW, the same standards of incineration as for HCRW should be met.

Statement:

6.10 **When disposal of recognisable human organs or tissue (not including blood) takes place via the whole body disposal route, it must conform to national law and be under the responsibility of medical, environmental and ethical authorities. [If crematoria are used they should comply with the performance standards for HCRW].**

Disposal of healthcare risk waste via municipal incinerators with special design features

6.11 In the management of infectious health care risk waste through incineration, due consideration should be given to prevention of spread of infection during transport and pre-incineration handling (including the feeding of the waste into the incinerator). Appropriate packaging and labelling, and a validated Quality System, are necessary. Use of municipal waste incinerators would reduce the need for specialist health care waste incineration facilities. Incineration of health care risk waste is practised at some sites without measurable impact on the environment or health of employees.

6.12 Municipal waste incinerators are not normally suitable for the disposal of anatomical, toxic or radioactive HCRW. If used for the disposal of anatomical waste, the municipal incinerator should be equipped to ensure the total destruction of the waste.

Statement:

6.13 **Provided that spread of infection is prevented through validated and audited procedures, the use of specifically designed or adapted municipal waste** incinerators should be encouraged. Mandatory **conditions must be applied and monitored, and specific approval given. The disposal of toxic and radioactive wastes through municipal waste incinerators should not be allowed.**

Energy recovery

6.14 The use of combustion with energy recovery is one of the aims of the waste disposal hierarchy.

6.15 When considering the benefits of recovering energy from healthcare waste it is worth noting that the quantity of waste produced is very small, less than 1% of the total quantity of solid waste produced by the Community as a whole.

6.16 In some circumstances energy recovery from healthcare waste incineration is not a viable option. For instance, the throughput of waste may be insufficient,

or energy required to clean exhaust gases may exceed the amount of energy obtained from the waste. Energy recovery should not itself be mandatory, but an assessment of the potential for energy recovery should be. The assessment should consider, among other things, the balance of resources used in a process.

Statement:

6.17 **Assessment of the potential for energy recovery from healthcare waste should be encouraged, with consideration of the overall cost and environmental benefits.**

Proximity principle

6.18 Application of the proximity principle for the disposal of wastes is mandatory under Art 5 of the Waste Framework Directive (91/156/EEC).

6.19 For the management of healthcare risk waste, a balance needs to be achieved between the benefits of treating waste at the point of arising and the economics of [illegible] In many countries, there is a move towards closure of small hospital incinerators.

6.20 Guidance is needed on the optimum application of the proximity principle to this waste stream.

Statement:

6.21 **Guidance should be developed on applying the proximity principle in relation to the treatment and disposal of healthcare risk waste.**

EUROPEAN COMMISSION
DIRECTORATE-GENERAL XI
ENVIRONMENT, NUCLEAR SAFETY AND CIVIL PROTECTION
Industry and the Environment
Waste Management Policy

XI/15/96
Org. EN
Brussels, 9 January 1996
Unit E.3

PRIORITY WASTE STREAMS

HEALTHCARE WASTE

PROPOSAL FROM THE PROJECT GROUP

TO THE EUROPEAN COMMISSION

FOR AN

WAY FORWARD DOCUMENT

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ANALYSIS OF PRIORITY WASTE STREAMS

HEALTHCARE WASTE

WAY FORWARD DOCUMENT

(issues for implementation of the

STRATEGY DOCUMENT)

OCTOBER 1995

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7.0 THE FUTURE - THE REFERENCE NETWORK

7.1 The role of the Reference Network as a Group
7.2 The role of individuals
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1.0 THE WAY FORWARD DOCUMENT - ITS CONTENT AND STATUS

1.1 This Document forms part of the final product of the Healthcare Waste Priority Waste Stream Project. The other final documents are the Information Document, Information Summary and the Strategy Document.

1.2 This document presents possible, but not concluded, ideas for actions for the issues identified during the course of the Project Group discussions.

1.3 Unlike the case of the other final documents, this one does not reflect a consensus reached from the normal process of strategic discussion employed to develop the other documents for this Priority Waste stream. The timescale for the project was shortened by some twelve months. The Project Group did not have time to work with the Way Forward Document in discussion. Therefore, it was not possible to develop these ideas into agreed implementation and for future action.

1.4 This document also explores the possible future roles of the Project Group and the Reference Network. It sets out the proposals for presentation of the final documents to the Commission and for future action.

1.5 Many of the actions, identified by the Project Group, already form part of other initiatives, draft Directives or Directives yet to be implemented. The probable implications of recent EC Directives on healthcare work are included in the Information Document. This may be compared to the actions proposed in this document. This document gives possible actions identified by the Project Group during the last meeting on 15/16 November 1993, as subsequently formulated by a smaller "Extended Core Group" of Project Group members and a final round of consultation by correspondence with the whole group. Responsibility for the final editing rested with the Project Leader.

1.6 At the final Project Group meeting the members were also asked to indicate what strength of action should be taken by the Commission on each strategic issue.. Either mandatory action or guidance was chosen. The results of this exercise are given at the beginning of each section.

POSSIBLE ACTIONS FOR GENERAL STRATEGIES

2.1 Prevention

Strategy: Prevention is to be encouraged. Prevention must not present a barrier to technological innovation, or to high standards of healthcare.

*ACTION BY COMMISSION: the majority of the Project Group considered that the main action by the Commission for this issue should be **GUIDANCE**.*

The possible actions are:

Governments

- Ban the use of materials which are of proven harmfulness to the environment, the effects of substitute materials should be understood.
- Introduce a statutory requirement to provide environmental information with all purchases.

Economic Measures

- Increase the costs of waste disposal

Guidance/Promotion

- Educate healthcare professionals to raise awareness of environmental problems and waste disposal.
- Encourage manufacturers to minimise the use of materials in packaging and products.
- Promote good practice for prevention, re-use and recycling through journal articles, conferences etc.

Practices

- Reduce waste by miniaturisation and non-invasive technology.
- Continue to reduce the amount of materials used in products and packaging.
- Develop products which are safe to use and safe for disposal.

2.2 Recycling

Strategy: If a suitable market exists then healthcare and healthcare waste personnel should be encouraged to recycle suitable fractions of waste as a matter of course, providing that recycling does not compromise healthcare standards.

*ACTION BY COMMISSION: the majority of the Project Group considered that the main action by the Commission for this issue should be **GUIDANCE.***

The possible actions are:

Governments

- Introduce a statutory requirement to identify all components of a product where physically feasible.

Economic Measures

- Provide funding from the EU to develop a methodology for assessing the potential for re-cycling healthcare products and waste materials.
- EU to sponsor the development of recycling technology
- Co-operation between health authorities, municipal authorities and business to develop markets for recyclable products.
- EU or Member State action to encourage and promote the recycling industry and secure end markets.
- Encourage waste audits by experienced contractors or consultants to find out where cost effective changes may be made.

Guidance/Promotion

- Inform potential recycling industries what materials healthcare waste contains.

Practices

- Devise standard designs for disposable products to aid recycling.
- Investigate techniques to use the waste as a raw material for a wide range of products.

- Accelerate the development of techniques to assess the eco-balance of recycling alternatives.

- In suitable cases design products specifically for recycling.

- Develop the technology for disassembling products into different components to aid recycling.

2.3 Re-use

Strategy: Re-use of used products should be encouraged, but guidance must be provided on those products suitable for re-use and those that are not. Re-use of products must not compromise healthcare standards.

*ACTION BY COMMISSION: the majority of the Project Group considered that the main action by the Commission for this issue should be **GUIDANCE.***

The possible actions are:

Governments

- Introduce standards for quality control

- Introduce environmental auditing for hospital and health authorities to cover issues such as purchasing and waste disposal routes.

- Each Member State to develop a list of devices which are allowed to be re-used.

Economic Measures

- Provide Government funding in association with industry to develop a data-base for re-useable products.

- Assist with finance for investigations and revenue costs of re-using waste products.

Guidance/Promotion

- Encourage staff responsible for purchasing supplies to periodically consider whether there are economic alternatives to disposable items.

- Develop standard techniques to fully assess the costs and environmental benefits of re-using healthcare waste.

- Produce a list of items for re-use in order of priority with regard to patient risk.

- Provide guidance at EU level to identify the type of re-use and types of device which may be re-used.
- Provide guidance on how different Healthcare facilities and practitioners may be able to re-use products and the difficulties that may be encountered.
- Develop an information data base on a generic basis for products and devices.

2.4 **Education and Training/Health and Safety at Work**

Strategy: Compulsory education and training for healthcare and healthcare waste management staff, linked to the risk involved for all aspects of healthcare waste management should be introduced, together with a system of assessment of competence.

*ACTION BY COMMISSION: the majority of the Project Group considered that the main action by the Commission for this issue should be **MANDATORY**.*

The possible actions are:

Governments

- Enforce health and safety legislation that concerns education and training on medical practices.
- Define health & safety responsibilities for all concerned with healthcare waste and those concerned with education and training.
- Implement mandatory education for healthcare waste management.
- Extend existing Health and Safety Officer's responsibilities to include environmental matters.

Economic Measures

- Provide education for producers by contractors or consultants.

Guidance/Promotion

- Provide guidance on the level of education needed for each kind of professional.
- Develop training programmes which can be adopted by each Health Authority.

- Develop policies, procedures and guidelines for training.
- Introduce training units for waste management in medical training courses.
- Provide guidance through Health and Safety and nursing journals.
- Consider ideas and procedures from other countries.
- Establish a common education scheme with minimum topics that should be covered.
- Train healthcare professionals in waste management either at work or during higher education.
- Develop systems of training units which can be assessed and qualifications obtained.

2.5 Public Perception

The public perception of risks should be actively addressed to promote the reality of the situation. Relevant and correct information should be promoted in order to achieve an improvement in understanding.

ACTION BY COMMISSION: the majority of the Project Group considered that the main action by the Commission for this issue should be ***GUIDANCE.***

The possible actions are:

Governments

- Member States to introduce compulsory education on waste management.
- Introduce total quality management with certification for healthcare waste to manage the risks.
- Ensure that legislation and standards are enforced.
- Require hospitals to develop environmental policy statements and annual reports on performance that are publicly open for discussion.

Economic Measures

- Influence public perception through media involvement, and presentation of real situations.
- Develop an active public relations campaign to address the fears and

concerns.

- Encourage healthcare and waste/environmental professionals to respond to exaggerated media reports of healthcare waste incidents.

2.6 **Research Policy**

Strategy: Research projects should be promoted, but selected on the basis of the priorities set out in the strategy statements for healthcare waste.

ACTION BY COMMISSION the majority of the Project Group considered that the main action by the Commission for this issue should be ***GUIDANCE.***

The possible actions are:

Governments

- Initiate a search of all related research undertaken in all Member States.
- Set up a small technical group to develop a programme of relevant research.
- Establish a data-base for prevention, recycling and re-use of non-risk healthcare waste.
- Develop an EU research policy which directs research to meaningful practical projects.

Economic Measures

- Establish a funding source for key healthcare waste research.
- Invite Tenders for relevant research.

Guidance/Promotion

- Encourage doctors to adopt quality assurance programmes for changes in medical practices.

Practices

- Research the situations and activities in waste management which present the actual risks to health or harm to the environment.
- Develop risk analysis techniques specifically for healthcare waste.

- Develop a life cycle analysis model or code of practice for medical devices taking into account medical performance.

2.7 **Waste Management Plans**

Strategy: Member State's Waste Management Plans should detail the provisions to be made for healthcare waste management and disposal.

Note: This strategy statement replaced a statement relating to licensing and controls after the final Project Group meeting.

3.1 **Selection of Product**

The following actions were identified but not fully discussed or agreed by the Project Group at its final meeting.

Strategy: Medical product selection should be based on healthcare performance, with consideration of the environmental effect of the waste produced.

ACTION BY COMMISSION: the majority of the Project Group considered that the main action by the Commission for this issue should be ***GUIDANCE.***

The possible actions are:

Governments

- Develop a central database for users

Economic Measures

- Provide funding from industry and Government for database development.
- Provide incentives for the manufacturers to produce more environmentally acceptable products.
- EU funding for generic eco-balance methodologies such as life cycle analysis.

Guidance/Promotion

- Produce guidance on the criteria for selection which sets quality and security before costs.
- Provide more information on life cycle analysis.

Practices

- Development and application of generic eco-balance methodologies such as life cycle analysis (LCA).

3.2 **Segregation**

Strategy: Healthcare risk waste should be strictly segregated at source and the appropriate disposal route taken in accordance with the Producers' Waste Management Plan.

ACTION BY COMMISSION: the majority of the Project Group considered that the main action

*by the Commission for this issue should be **MANDATORY**.*

The possible actions are:

Governments

- Continue with the development of a common definition for healthcare waste and healthcare risk waste.
- Develop standards for good segregation practices at EU level.
- Introduce mandatory rules for which parts of healthcare waste should and should not be segregated.
- Introduce standard colour coding for waste and devices to aid identification for segregation
- Develop plans and audit systems for healthcare waste.

Guidance/Promotion

- Develop practical guidelines for staff at working level to increase awareness of the need for, and benefits of, segregation.
- Develop guidance on procedures and facilities which take into account the differences in Member States.

Practices

- Adopt Quality Management systems (ISO 9000 and CEN 2900) to the segregation of healthcare risk waste.

3.3 Packaging

Strategy: The controls on the packaging of healthcare risk waste should be enforced and guidance produced for other waste types. Guidance should be provided for implementation of the Directive on Packaging and Packaging Waste.

*ACTION BY COMMISSION: the majority of the Project Group considered that the main action by the Commission for this issue should be **GUIDANCE**.*

The possible actions are:

Governments

- Develop a single system of packaging for all Member States.
- Develop a European standard on the minimum requirements for

properties and validation of healthcare waste packaging and medical device packaging.

Economic Measures

- Make staff aware of the existing requirements for packaging of wastes.

Practices

- Develop Packaging systems and materials to reduce the amount of waste for the same standard of security.

3.4 Labelling

Guidance should be produced for a common system of labelling and coding for healthcare risk waste.

*ACTION BY COMMISSION: the majority of the Project Group considered that the main action by the Commission for this issue should be **GUIDANCE.***

The possible actions are:

Governments

- Develop a positive labelling policy to support waste minimisation.
- Produce a European standard on minimum labelling requirements for the various types of healthcare waste.

Guidance/Promotion

- Make staff aware of the existing requirements for packaging of wastes.

3.5 Transport and Storage

Strategy: Guidance should be developed for storage on site, transport to the point of treatment and disposal and storage prior to treatment or disposal taking legislation into account.

*ACTION BY COMMISSION: the majority of the Project Group considered that the main action by the Commission for this issue should be **GUIDANCE.***

The possible actions are:

Governments

- Develop protocols and standards for the minimum standards for collection, transport and storage.
- Standardise the colour of vehicles for healthcare waste.
- Consider the requirements for small quantities of waste produced outside healthcare establishments.
- Separate the standards for what is done within healthcare establishments and what is done outside healthcare establishments.
- Introduce a system of designated individuals, with defined responsibilities and a method of assessment.

Economic Measures

- Consider the effect of onerous costs on compliance.

Guidance/Promotion

- Identify all the types of transport and storage within the hospital and outside the hospital and produce guidance at EC level to help the Member States enforce the obligations.

3.6 Pre-Treatment

Strategy: Validated methods of pre-treatment should be encouraged if a decrease in the risk of harm to health or pollution or a reduction in costs will result.

ACTION BY COMMISSION: the majority of the Project Group considered that the main action by the Commission for this issue should be ***GUIDANCE.***

The possible actions are:

Governments

- Produce European standards on validation of pre-treatment methods for healthcare risk wastes.
- Establish a common concept for the validation of waste disinfection processes to change healthcare risk waste to non-risk waste.
- Establish what pre-treated waste may be disposed of via the municipal waste stream.
- Develop a system whereby when a Member State approves a pre-

treatment method, an expert committee reviews it as soon as possible so that it can be endorsed at EU level without undue delay.

- Determine the design criteria for all pre-treatment technologies.

Economic Measures

- Sponsor development of pre-treatment methods for various types of risk waste.

Guidance/Promotion

- Encourage the use of pre-treatment methods.
- Provide guidance on the pre-treatment methods for hospitals.

Practices

- Prepare an authoritative and independent technical appraisal of the strengths and weaknesses of actual and potential pre-treatment methods.
- Prepare a comparison of two methods of disposing of healthcare risk waste i.e.

  1. pre-treatment, then incineration in an ordinary incinerator for healthcare waste
  2. incineration in specially designed incinerators capable of accepting both municipal waste and healthcare risk waste.

3.7 Quantities

Strategy: A system of record keeping specifically for healthcare waste should be developed.

*ACTION BY COMMISSION: the majority of the Project Group considered that the main action by the Commission for this issue should be **MANDATORY**.*

The possible actions are:

Governments

- Develop as soon as possible a European statistical model for healthcare waste.
- Ensure that record keeping is made mandatory across the EC.

- Agree on the common definitions for healthcare waste and healthcare risk waste so that quantities can be measured on a common basis throughout the EC.

Guidance/Promotion

- Provide guidance for data collection in the form of minimum requirements or model documents.

Practices

- Devise systems of record keeping that are simple.

3.8 **Responsibility**

Strategy: Responsibilities for all aspects of healthcare waste management should be defined and enforced by legislation.

*ACTION BY COMMISSION: the majority of the Project Group considered that the main action by the Commission for this issue should be **MANDATORY**.*

The possible actions are:

Governments

- Introduce a legal responsibility of care for all concerned with the management of waste.
- Devise a European wide text for the understanding of the "Duty of Care" as introduced in the UK.
- Differentiate between responsibilities inside and outside healthcare establishments.

Economic Measures

- Prevent "externalisation of costs (i.e. environmental costs) to make the total price comparable.

4.0 POSSIBLE ACTIONS FOR TREATMENT AND DISPOSAL

4.1 Choice of Methods

Strategy: The choice of method or methods of pre-treating and disposing of healthcare risk waste should be left to the Member State providing that minimum performance standards are met.

*ACTION BY COMMISSION: the majority of the Project Group considered that the main action by the Commission for this issue should be **GUIDANCE.***

The possible actions are:

Governments

- Develop performance standards and standards for the measurement of performance.

4.2 Standards for Pre-Treatment

Strategy: Harmonised performance standards for pre-treatment of healthcare risk waste should be developed and enforced where they do not exist.

*ACTION BY COMMISSION: the majority of the Project Group considered that the main action by the Commission for this issue should be **MANDATORY.***

The possible actions are:

Governments

- Develop general standards for healthcare risk waste treatment which can be easily controlled.
- Ensure that the standards do not suppress new ideas.
- Member States set minimum standards for the various treatment methods.

Guidance/Promotion

- Provide guidance from EU for the total costs/impacts (LCA) of treatment methods.
- Provide clear concise guidance for small producers.

- Publish the outcome of performance tests.
- Produce policies and protocols for different treatment methods.
- Introduce training and assessment of appropriate personnel.
- Develop audit techniques for the waste stream.

4.3 Disposal of non-risk waste via the municipal waste stream

Strategy: Disposal of healthcare waste that is not risk waste via the municipal waste stream is acceptable if suitable quality assurance is in place.

ACTION BY COMMISSION the majority of the Project Group considered that the main action by the Commission for this issue should be ***GUIDANCE.***

The possible actions are:

Governments

- Define and introduce Quality Assurance schemes to allow the disposal of non-risk waste via the municipal waste stream but link the rules on disposal via the municipal waste stream to segregation policies and practices.

Guidance/Promotion

- Increase acceptance by Local Authorities of strategy through information.
- Consider public perception of the issues when landfill is used to dispose of healthcare waste and develop quality assurance procedures accordingly

Practices

- Continue to develop methods to prove that healthcare risk waste has been effectively segregated and treated to render it safe, i.e. non-risk waste.

4.4 Disposal of Human Tissue via the Whole Body Disposal Route

Strategy: When disposal of recognisable human organs or tissues (not including blood) takes place via the whole body disposal route, it must conform to national law and be under the responsibility of medical, environmental and ethical authorities.

*ACTION BY COMMISSION. the majority of the Project Group considered that the main action by the Commission for this issue should be **GUIDANCE.***

The possible actions are:

Governments

- Restrict the disposal of waste to approved waste disposal plant and only use crematoria for religious or ethical reasons.

Guidance/Promotion

- Develop guidance on the medical and religious ethics for when this is acceptable.

4.5 **Disposal of Risk Waste via Municipal Waste Incinerator**

Strategy: The use of specifically designed Municipal Waste Incinerators should be encouraged for the disposal of healthcare risk waste but mandatory conditions must be applied and specific approval given.

*ACTION BY COMMISSION: the majority of the Project Group considered that the main action by the Commission for this issue should be **GUIDANCE.***

The possible actions are:

Governments

- Develop standards for incineration in municipal waste incineration covering the management of all types of risk waste.
- Develop standards to ensure efficiency but avoid too high legal requirements.
- Introduce an EU directive for such treatment
- Ban the use of municipal waste incinerators unless the plant is specifically modified and the staff are trained.

- Disposal of toxic and radioactive waste through municipal waste incinerators should not be allowed.

- Develop enclosed feed and ash sterility criteria for municipal incinerators.

Guidance/Promotion

- Organise a meeting at EU level to clarify the design and legal aspects.

4.6 Energy Recovery

Strategy: Assessment of the potential for energy recovery and use from healthcare waste should be encouraged, with consideration of the overall costs and benefits.

*ACTION BY COMMISSION: the majority of the Project Group considered that the main action by the Commission for this issue should be **MANDATORY**.*

The possible actions are:

Governments

- Define the energy policy for this area.

- Do not involve EU policy in this area as energy recovery is not the prime purpose of an incinerator and the potential for recovery from healthcare waste is very small.

Economic Measures

- Provide joint funding with industry for research in this area.

Guidance/Promotion

- Undertake studies of the energy and other resources used in the different healthcare waste disposal routes and publicise the results.

4.7 Proximity Principle

Strategy: Guidance should be developed for the implementation of the

Proximity Principle in relation to the treatment and disposal of healthcare risk waste.

ACTION BY COMMISSION: the majority of the Project Group considered that the main action by the Commisston for this issue should be ***GUIDANCE.***

The possible actions are:

Governments

- Implement the proximity principle to the waste stream and ban waste tourism where the local facility is appropriate for the waste.
- Determine the methods to implement the proximity principles for healthcare waste facilities.

Economic Measures

- Consider the implications of the proximity principle for a free-market trade practice.

5.1 Actions at Community Level and by Member States

The Commission will develop the work into a draft proposal, the legal form of which could be decided as a result of a meeting with Member States. Once the text of the draft proposal is ready, it will be submitted to inter-service and inter-DG consultations within the Commission, and the proposal revised as necessary. Following those consultations, it will be submitted to the written procedure (ie. consideration by the cabinets) and finally to adoption by the Commission.

Once adopted, the proposal will be published in the official journal and presented to the appropriate Community bodies (Economic and Social Committee, European Parliament and European Councils) for discussion and adoption. It is difficult to estimate how long this final stage will take.

Actions by Member States will depend to a large extent on the approach taken by the European Commission. However, there will be initiatives which could be taken at Member State level.

5.2 Presentation to the European Commission

The Project Group will present to the Commission its final product: an Information Document, a Strategy Document and this issues Document. These documents will be taken by the Commission as a basis for future Community action.

6.1 Future Role of the Project Group

The Project Group consisted of representatives of different groups, including European Commission, Member States, manufacturers, and users (or waste producers). In view of the fact that there were no more Strategic Discussion meetings, the work of the main Project Group was completed in November 1993. However, the Core Group was extended in order to increase the amount of representation on work undertaken after November 1993.

The original task of the Project Group was to produce and agree a set of documents. One view is that, having completed the documents, the project is complete. Other members of the Project Group would wish to see the work continued through professional bodies; the International Solid Waste Association may be one such organisation.

Reasons for continuing the Project Group, in some form, would be

* to monitor, and maybe assist, progress of the Commission in developing these proposals
* to continue to build on the commitment to European cooperation generated as a result of the discussions and
* to assist in furthering the actions for example: by information exchange and the development and harmonisation of standards

6.2 Administration/Commitment by Project Group Members

Informal communication from the Commission on the progression of the work, would be circulated to the Project Group via the Project Leader every six months, or more frequently if there were any major actions.

It would then be the responsibility of the Project Group to publicise, through their organisations, results of projects.

7.1 The Role of the Reference Network as a Group

The role of the Reference Network has been, and will continue to be, to carry news and information about the work of the Project Group. There are currently some 300 members in the Reference Network. They have received newsletters throughout the duration of the project and have been invited to attend the poster sessions held at Project Group meetings. In return, the Project Group have received information and queries pertaining to the project.

The Reference Network will each receive a copy of the Executive Summary, Information Document Summary, Strategy Document and this Document.

7.2 The Role of Individuals

One proposal is to identify the subjects of interest of each member of the Reference Network and circulate names and addresses to any organisation interested in making contact. In this way, the flow of specific information can be facilitated.

7.3 Administration/Commitment by Project Group and Reference Network Members

At EU level, a core group should be established to manage the list of the members of the Reference Network and the preparation and circulation of the Newsletter to members of the Project Group.

At National level, at least one member of the Project Group in each Member State would be responsible for sending a newsletter to all national members of the Reference Network and for sending information about the existence of the Reference Network with the Member State.

Some organisations are interested in developing the Network and continuing the project beyond its specified close. Funding may be a problem and it may therefore be necessary for several organisations to join together.

7.4 Continuation of The Healthcare Waste Priority Waste Stream Newsletter

The newsletter was found to be a valuable means of communication to the wider network of those interested in this Priority Waste Stream. Maintaining contact with the Reference Network would be one of the primary functions of the newsletter.

The aims of the newsletter would be to:

- inform about the future of the project
- act as a link between all persons interested in HCW
- inform about the progress of the Healthcare Waste PWS within the

European Commission

- give information about HCW meetings and lectures
- inform about HCW research and practices
- inform about new devices and systems of treatment or pre-treatment

The structure of delivery of the Newsletter would need to be at EU level and national level.

EUROPEAN COMMISSION
DIRECTORATE-GENERAL XI
ENVIRONMENT, NUCLEAR SAFETY AND CIVIL PROTECTION
Industry and the Environment
Waste Management Policy

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Brussels, 9 January 1996
Unit E.3

PRIORITY WASTE STREAMS

HEALTHCARE WASTE

PROPOSAL FROM THE PROJECT GROUP

TO THE EUROPEAN COMMISSION

FOR AN

INFORMATION DOCUMENT

- SUMMARY -

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ANALYSIS OF PRIORITY WASTE STREAMS
HEALTHCARE WASTE
INFORMATION SUMMARY

Contents

1.0 INTRODUCTION

Information Summary

1.01 This Information Summary is one of the series of documents produced during the Healthcare Waste Priority Waste Stream project. It is a concise version of the Information Document, which together with the Strategy Document and the Executive Summary form the final products of the project. An associated report *The Way Forward* describes how the work of the Healthcare Waste Project Group may be continued.

Aims and Background of the Project

1.02 In September 1989, the European Commission delivered a proposed Community strategy for waste management to the Council of Ministers and European Parliament. On 22 March 1990 the Community's Council of Environment Ministers endorsed the proposals. Under the strategy, some waste streams were to be dealt with individually. They were identified as requiring particular attention because of their complex nature and potential attention from the general public and effect on the environment: among them was healthcare waste.

1.03 To be successful, waste management strategies must often take account of, and interact with, the processes that produce the wastes. Strategies should seek to provide medically and environmentally acceptable solutions by influencing the attitudes of the waste producers: the emphasis should be on personal responsibility for sustainable development. To develop this new kind of strategy, the Commission proposed a new method of working. Called "Strategic Discussion", it uses open - but structured - discussion at Community level.

The Healthcare Waste Project

1.04 Concern over the safe management and disposal of healthcare waste has resulted from the perceived or real risk of potential transmission of infectious diseases through accidental injury or contact with infected body fluids. The disposal of sharps (needles, scalpels etc) has attracted particular interest because the small number of occupationally acquired hepatitis and HIV infections suffered by healthcare workers have been the result of sharps injuries. The majority of sharps injuries however, do not result in infection.

1.05 Hospital Waste is a term used for all waste arising from healthcare establishments. Healthcare waste can briefly be described as waste from medical or other related practices. In reality only a small proportion of this waste presents a higher risk than normal household or municipal waste. It is proposed that this fraction is defined as "healthcare risk waste". This project is concerned mainly with healthcare risk waste.

1.06 Whenever healthcare waste causes infection, injury, apprehension or distaste. It attracts substantial attention from the media. Public perception of risk therefore varies markedly from a technical appraisal of risk. The recommendations of this project will recognise the strength of public opinion. Clearly all waste that presents a real risk must be dealt with using the appropriate and controlled methods and technology. In considering these technologies, it must be remembered that, as social values, proprieties and economic conditions vary from Member State to Member State some latitude should be allowed in the method of treatment and disposal to accord with local circumstances, customs and economic conditions.

2.0 DEFINITION OF HEALTHCARE WASTE

2.01 The Project Group took the view that the first step towards the regularisation of healthcare waste management practices within the European Community should be the production of a Europe-wide definition of healthcare waste and that this should be linked to the European Waste Catalogue, developed from the Framework Directive 75/442/EEC.

2.02 The Project Group, aided by a specific definition task group, formulated and adopted the following definitions:

a) **Healthcare**: Medical activities such as diagnosis, monitoring, treatment, prevention of disease or alleviation of handicap in humans or animals, including related research (see note 1), performed under the supervision of a medical practitioner or veterinary surgeon (see note 2).

b) **Healthcare Waste**: The solid or liquid waste arising from healthcare.

c) **Healthcare Risk Waste**:

- Biological (recognisable anatomical waste)
- Infectious (see note 3)
- Chemical, toxic or pharmaceutical waste including cytotoxins
- Sharps (eg. needles, scalpels)
- Radioactive waste (refer to Radioactive Waste Directive(s))

Notes:

(1) Wherever appropriate and applicable, waste from basic and fundamental biomedical and other research shall be managed according to the principles set out for healthcare waste and healthcare risk waste.

(2) The above mentioned supervision may also be carried out by any other person authorised by virtue of their professional qualifications to do so.

(3) Infectious waste is any Healthcare Waste **known** or **clinically assessed** to be at risk of being contaminated with:

a) any of the biological agents mentioned in Article 2(d) groups 3 and 4 or identified through the procedure set out in Article 3 of the Council Directive (90/679/EEC) of 26 November 1990 (amended by Directive 93/88/EEC) on the protection of workers from risks related to exposure to biological agents, of Article 16 (1) of Directive 89/391/EEC, or,

b) with other viable biological agents artificially cultivated to significantly elevated numbers.

3.0 SOURCES

3.01 Sources of healthcare waste can include:

- Hospitals
- General Practitioners and dental surgeries
- Outpatient/healthcare centres
- Laboratories (such as anatomy, pathology, biology, chemistry and microbiology laboratories)
- Mortuaries
- Veterinary sources
- Pharmacies
- Other healthcare establishments
- Community healthcare in the home (district nursing)

Note:

At the time of the study, variations in definition meant that some Member States would class only some of the establishments listed above as sources of healthcare waste.

4.0 QUANTITIES

4.01 Information on the quantities of healthcare waste produced in Member States is summarised in Table 1. The records only relate to healthcare risk waste as this is the only waste type for which records are kept in many countries. Non-risk waste is not normally recorded separately from municipal waste.

4.02 The quantities of waste per head vary appreciably between Member States: the variation is probably due to differences in definitions and data quality as well as differences in healthcare practices and healthcare waste segregation.

MEMBER STATE	HEALTHCARE RISK WASTE (tonnes/annum)	DATE OF SURVEY	POPULATION	HEALTHCARE RISK WASTE kg/headpop/annum
Belgium	13,700	1992	9,863,374	1.4
Denmark	10,000	1989	5,116,275	1.95
France	105,000	1990	56,614,493	1.9
Germany	33,000	1990	79,753,000	0.4
Greece	14,600	1987	9,970,000	1.4
Ireland	9,000	1992	3,443,403	2.6
Italy	50-60,000	1991	57,128,000	1.0
Luxembourg	-	-	365,900	-
Netherlands	8,500	1992	14,453,833	0.6
Portugal	15,000	NOT KNOWN	10,128,893	1.5
Spain	23,000	-	38,818,355	0.6
United Kingdom	308,000	1991	55,776,422	5.5

TABLE 1: Quantities of healthcare waste arising

5.0 LEGISLATION

5.01 Legislation within the Member States is often derived from EC Regulations and Directives. A list of relevant Directives, Regulations and Member State legislation is given in the reference section at the end of this summary.

5.02 Member States control the collection, transport and disposal of healthcare waste by different means. Some have specific statutes directly controlling the management of healthcare waste whilst others control healthcare waste under general waste regulations.

5.03 European air pollution legislation now influences the economics of combustion-based waste disposal. A European Directive on landfill is under discussion; meanwhile, standards for waste treatment and landfilling are generally under Member State control.

6.0 WASTE MANAGEMENT SYSTEMS AND PRACTICES

6.01 Policies on the issues identified below vary between Member States. Some national non-statutory codes of practice and guidelines are listed in the reference section at the end of this Summary.

6.02 The issues include:

	Paragraphs
• Prevention	6.03 - 6.06
• Segregation	6.07 - 6.08
• Packaging and Labelling	6.09 - 6.10
• Storage	6.11
• Handling	6.12
• Transport	6.13
• Education and Training	6.14
• Responsibility	6.15
• Licensing	6.16
• Treatment and Disposal	Section 7.0.

6.03 **Prevention** The guidelines in the Community Strategy on Waste Management (May 1990) incorporate a " ladder principle", a hierarchy of preferred waste management options. The sequence, adapted from the general ladder principle, is:

- Prevention
- Re-Use
- Recycling
- Pre-treatment
- Incineration with energy recovery
- Incineration
- Landfill

6.04 The quantity of healthcare waste produced is very small (less than 1%) compared to the total amount of solid waste produced by the community For this waste stream the priorities for management systems are health and safety issues, but environmental issues should also be taken into account.

6.05 Waste minimisation is a form of waste prevention. It begins at the manufacturing level, and can thus be encouraged by the purchasing policies of healthcare providers. Manufacturers of healthcare products are also continually considering product design and the types and amounts of materials they use for manufacture and packaging.

6.06 Healthcare waste producers could reduce the amount of waste they produce. Some Member States have set targets for prevention and minimisation and produced practical ideas to enable these targets to be met. The use of devices specifically designed for reuse and, to a certain extent, recycling can play an important role in waste reduction.

6.07 **Segregation** (6.08 of Inf Doc) Effective segregation is essential: it reduces the amount of waste requiring special treatment and consequently the resources needed for disposal. Normally segregation is based on material type. Health care risk waste segregation can be based on risk of infection or injury whereas non-risk health care waste can be segregated according to the material.

6.08 Healthcare risk waste can be segregated at source. The personnel who segregate the waste at source are trained healthcare staff: they know how to identify potentially dangerous material and separate it out. Their involvement reduces the risks to people further down the waste stream and some form of quality assurance system is desirable.

6.09 **Packaging and labelling of waste** (6.11 of Info Doc) All healthcare risk waste can be kept in containers from creation to final disposal. Containers for healthcare waste should be compatible with the type of waste and the methods used for handling, transportation, storage and treatment. Advice on this aspect of waste management is contained in the existing codes of many Member States, and for risk waste is covered in the proposed EC Directive on the Carriage of Dangerous Goods by Road, (see transport below.)

6.10 Packages containing healthcare risk waste should carry labels that allow the contents to be clearly identified and traced to its source. The package must also carry the international Biohazard sign (Article 6(b) of Council Directive [90/679/EEC] of 26 November 1990).

6.11 Storage [illegible] To reduce the risks associated with storage of healthcare waste, certain design criteria can be met, and wastes stored only for as long as the storage conditions allow. These aspects of waste management are often covered by existing codes in many Member States Storage at transfer stations and treatment plants is likely to be on a larger scale, with design and operation correspondingly more demanding.

6.12 **Handling** (6.18 of Inf Doc) Under Article 6(h and i) of Council Directive 90/679/EEC [of 26 November 1990], an employer must provide methods of collecting, storing and disposing of waste that ensure workers' safety. Member States' existing codes usually include requirements for, and advice on the safe handling of healthcare risk waste.

6.13 **Transport** (6.14 of Inf Doc) On-site transport can be designed for the purpose - ie. easily loaded and unloaded, and easily cleaned. Transport of healthcare risk waste off-site for eventual disposal is the subject of specific provisions in legislation. The Commission is currently proposing legislation that will incorporate the provisions of the ADR (Carriage of Dangerous Goods by Road) Agreement into a Directive: it would apply from 1995, and would set standards for the construction of packages or containers intended for the off-site carriage of healthcare risk waste.

6.14 **Education and Training** Education and training in healthcare waste management can be extended to everybody who manage and handle healthcare waste: responsibility lies primarily with the healthcare institutions and the transport, treatment and disposal operators. Effective training plans are likely to depend upon the introduction of set waste management standards and a responsibility to take care of safety and health. Standards of safety will only be maintained if training, the assessment of competence, and some form of quality assurance system are mandatory.

6.15 **Responsibility** In some Member States waste producers and managers are obliged to satisfy themselves that suitable waste management systems are in place for wastes under their control. Responsibility extends to each person who handles the waste in the system from producer to disposer.

7.0 TRANSFER, TREATMENT AND FINAL DISPOSAL METHODS

7.01 Incineration (paras 7.19-7.29) is still the most common form of treatment[1] for healthcare waste. In many Member States small quantities of healthcare risk waste are landfilled (para. 7.30). A number of newer technologies for treatment or pre-treatment[2] have entered the market place and are gaining recognition within the industry. Healthcare risk waste treated to remove the risk can usually be disposed of with municipal waste.

7.02 In all Member States the healthcare sector is moving away from local hospital waste disposal facilities towards group disposal systems. Only grouped facilities can support the cost of incorporating adequate controls for minimising environmental pollution. This change is being largely driven by the implementation of Community law in Member States.

[1] Treatment is defined as "any method, technique or process, including neutralisation, designed to change the physical, chemical or biological character or composition of any waste, or so as to recover energy or material resources from the waste, or so as to render such waste non-hazardous or less hazardous, safer to transport, store or dispose of; or amenable for recovery, amenable for storage, or reduced in volume". (Source: ISWA)

[2] Pre-treatment is defined as the initial treatment of waste materials to make them safe to handle or precondition them for subsequent processing or disposal. (Source: ISWA)

7.03 Grouping of disposal facilities will often increase the distances travelled by healthcare risk waste from the point of arising to the point of disposal. Bulk transport from transfer station to disposal facility reduces the unit cost of transport.

7.04 Some healthcare waste fractions are suitable for disposal with municipal wastes.

Disposal of municipal wastes is usually achieved by less costly techniques and therefore the inclusion of healthcare wastes is likely to be advantageous, provided that it does not threaten health or the environment, or give rise to offence.

7.05 Different healthcare waste fractions ideally require different disposal methods. In Member States final processing of waste is determined by the content of that waste and the type of treatment facilities available. Strict segregation systems in Sweden appear to work effectively, allowing appropriate methods of disposal for each fraction.

Technologies for pre-treatment of healthcare waste

7.06 Most methods for pre-treating healthcare waste destroy the pathogens in the waste, but may not lessen other potential hazards, such as those due to chemicals, pharmaceuticals, radioactivity and sharps (although some special systems are being developed for sharps). Recognizable body parts can be perceived as a risk. Because of these limitations, pre-treatment methods should be combined with strict segregation of the waste components.

7.07 The increasing costs of specialist healthcare waste incineration are stimulating research and development work on methods of pre-treatment to reduce risk, and thus allow disposal with municipal waste. Historically such pre-treatment has usually only been applied on a small scale, using autoclaves. The concept of mass pre-treatment of healthcare waste is relatively new, and has been accepted more readily in some countries than in others.

7.08 The advantage of these pre-treatment methods is that, since local pre-treatment permits local disposal, transport costs are reduced; and disposal in combination with municipal waste is cheaper than specialised disposal. Mobile pre-treatment systems have also been developed.

7.09 Designers of systematic arrangements for healthcare waste disposal consider compatibility and trade-offs between pre-treatment processes and final disposal methods. For example, a process which produces wet material may be cheaper; but it will impose extra energy requirements, and extra cost, if final disposal is by incineration. Resource use - to the extent that it is not directly reflected in cost - is an important factor in disposal route assessments.

7.10 Although there are existing EC regulations and standards for incineration, there are currently no standards for the methods of pre-treatment outlined below. Most pre-treatment methods involve changing the condition of the waste by heat. The oldest and most commonly used is steam treatment (7.11). Other forms of heat treatment that have been used are microwave and radio frequency irradiation (7.13-7.14). Chemical exposure (7.15) has been used to treat waste, although this is not effective for all potential risks and can cause environmental problems. Other

treatment processes are being developed and may become accepted as they are validated.

7.11 **Steam Treatment** These methods have been developed from established steam autoclaving systems. There are two main groups of steam processes: those - generally the more effective - that use evacuation or increased pressure or both, and those that rely purely on exposure to steam. Machines in the first group

- remove air from the chamber and the waste by repeated evacuation alternating with the admission of saturated steam
- disinfect by saturated steam, and then
- dry the disinfected material by evacuation.

7.12 **Microwave treatment** The disinfection of healthcare waste with microwaves requires certain conditions:

- waste must be shredded
- wetted with steam
- exposed to the microwaves for an adequate period of time

The treated waste can usually be disposed of with municipal waste.

7.13 **Gamma irradiation** Micro-organisms exposed to gamma irradiation cannot reproduce. Gamma irradiation is used to sterilise heat-sensitive disposable medical supplies; but is only practical where levels of contamination and infection are low. The waste must be shredded before treatment.

7.14 **Radio frequency irradiation** Radio frequency irradiation heats the waste by exposing it to high intensity, low frequency shortwave radiation. The heated waste is then stored to maintain the heat and complete the treatment.

7.15 **Chemical exposure** The chemical can be in liquid or gaseous form. Combinations of chemical and mechanical systems have been used to render the waste unrecognisable and non-infectious. However, the efficiency of chemical treatment is accepted in some member states and not in others. Environmental problems can be caused when the waste or chemicals are disposed of.

7.16 Chemical treatment systems generally are not used on a large scale, but are restricted to individual clinics and surgeries.

7.17 **Other methods** Numerous other treatment methods have been tried and are being developed: for example, dry heat (in Sweden) and pyrolysis. Methods that reduce volume are also being researched: they include plastics densification and other forms of compaction. Small devices are also available, designed specifically for healthcare workers or for specific uses eg., for the disposal of dialysis waste, syringes and needles.

Incineration

7.18 The three main broad types of incinerator used for healthcare waste are: the municipal waste incinerator, the hazardous waste incinerator, and the specially designed HCW incinerator. Each of these types has its own design characteristics.

7.19 Municipal wastes are very varied: municipal waste incinerators are designed accordingly. If specifically designed, they can accept healthcare risks wastes: for safety, the waste should be fed in with its packaging intact and the ash should be sterile. The advantage is that unit costs can be lower than those at specialised healthcare waste incinerators. Municipal waste incinerators are widely used for no-risk healthcare waste and pre-treated healthcare risk waste.

7.20 Hazardous waste incinerators run at high temperatures. They can therefore accept pharmaceutical wastes and other chemicals for treatment. Pharmaceuticals are the only component of healthcare risk waste **not** excluded from the proposed Directive on Hazardous Waste Incineration.

7.21 Healthcare waste incinerators are generally designed to take all the components of the healthcare waste stream (with the exception of medical radioactive waste). Some components of the waste stream impose difficult and expensive requirements: some pharmaceuticals (including cytotoxins) demand high temperatures; human tissue requires long residence times. The design of the incinerator is conditioned by these specialised requirements, even though the largest proportion of the wastes going through the incinerator does not require them.

7.22 At present some Member States allow several types of incinerator to accept healthcare waste; others increasingly insist on dedicated plant.

7.23 In the United Kingdom, for example, some municipal incinerators are permitted to accept healthcare waste providing it does not contain human tissue. Many small-scale healthcare waste incinerators are still in use at individual hospitals (although most will shortly have to close, because they are not able to meet new emission standards).

7.24 In France, healthcare waste is accepted at specially adapted municipal incinerators with the proviso that it does not constitute more than 10% of the total waste throughput or include chemical, explosive or radioactive wastes. Nevertheless, more incinerators are being dedicated to healthcare waste.

7.25 In Germany, hazardous waste and municipal waste incineration plants are generally used for the disposal of healthcare waste.

7.26 In Italy, hazardous wastes, including healthcare waste, are incinerated in municipal

waste incineration plant or other plant with similar characteristics.

7.27 In the Netherlands there are several incineration plants capable of processing healthcare waste. The central government's stated preference is to incinerate specific hospital waste at one central plant.

7.28 In Denmark, there is a move towards the closure of small plants at hospitals, and the transport of healthcare waste to municipal incinerators. These must have special facilities for healthcare risk waste including special feed systems and and/or special hearth systems. Alternatively the waste is incinerated in special healthcare risk waste incinerators.

7.29 This study did not reveal any specific European standards for the incineration of infectious waste.

Landfill

7.30 In general, the practice of landfilling healthcare waste without pre-treatment is declining. The process of compacting waste releases the contents of bags and containers. This causes potential hazards from exposed sharps for delivery drivers, landfill workers, and scavengers (human and animal). Some landfilling, under specified controlled conditions, is likely to continue. A draft European Directive on landfill is currently under discussion.

8 0 EDUCATION AND TRAINING HEALTH AND SAFETY AT WORK

8.01 Council Directive 89/391/EEC places responsibilities for health and safety on employers and employees. Employers have a duty to conduct an assessment of risk and to inform and train their staff. .They have a duty to develop policies which cover technology and organisation of work. Emphasis is placed on protective and preventive services and requires the designation of one or more competent workers to carry out such services.

8.02 Some Member States (eg. Netherlands, Spain and Germany) have specific training courses for people working in healthcare waste management. Typical courses cover waste segregation and waste handling, recycling, and waste minimisation. Other Member States (eg. Belgium, UK and France) produce guidelines.

8.03 The Project Group was not aware of any existing obligatory training programmes, with assessment, that are aimed specifically at healthcare waste.

9.0 COSTS

9.01 The prices charged for the treatment and disposal of healthcare waste vary tremendously throughout the Community. These differences can be due to the varying definitions and classifications for waste. They also differ depending on whether the full costs of treatment and disposal are taken into account. The lowest price quoted for the disposal of healthcare waste by incineration is £118/tonne, the highest is £1,900/tonne. This compares to a price range of £17 to £75/tonne for the incineration of municipal waste and £7 to £45/tonne for landfilling of municipal waste.

9.02 **For incineration**, the largest single influence is probably the aggregation of costs for new plant (built to new standards) with costs for old plant. Specialist healthcare waste incineration with its special requirements is substantially more expensive (unit cost basis) than municipal waste incineration with its economies of scale. Even for incineration, however, there are other key factors: haulage distances, pre-sorting and calorific values of the feedstock, disposal cost for residues, and the accounting régime for the disposal operation as a whole (including the contributions from sales of steam and electricity).

9.03 **For landfill**, the key factors are likely to be haulage distances, competition, site geology, and the regulatory régime.

9.04 There is limited information available on pre-treatment costs; but they are usually highly dependent on the throughput of wastes and the cost of handling and transport. Nevertheless, there is currently considerable commercial interest in pre-treatment. Prices in the range of £300-£400/tonne have been quoted for steam treatment and [illegible] healthcare waste.

10.0 RISK

10.01 There is some degree of public anxiety about healthcare waste but there is no common understanding about the hazards inherent in this waste and the risks derived from those hazards. The Project Group considered risk in the sense the term is generally used to mean "**the probability of a future negative event**".

10.02 Probabilities, and hence risks, can be considered to be **actual** or **perceived**. The actual probability of an event occuring depends on observations of the prior occurrence of sufficiently similar events. The perceived probability is a subjective judgment about the past and the future.

10.03 Some events - such as the consequences of a needlestick injury - possess both actual and perceived risk. The injured person perceives the event through his fears of the harm that may result; but harm may in fact result.

10.04 By definition, people who have no specialised knowledge rely upon perceived probability for their judgments: hence excessive (though not wholly unwarranted) fear of dying in an air crash, and altogether insufficient fear of horrific injury in a road accident.

Perceived Risks

10.05 In the opinion of the Group, members of the public appear to perceive healthcare waste as hazardous. They perceive major risks in used syringes, needles, blood packs, catheters, dialysis consumables, dressings, and the like; and in medicines and medicine containers and packages. The perception is, in part, based on aesthetics.

10.06 Members of the public also perceive risks to health and to the environment in the processing of healthcare wastes. Their perception of risk to the environment is shared by healthcare workers and environmental professionals.

10.07 Healthcare workers' perceptions of health risks, however, are more precisely focused. They fear infection, either from needlestick injury or from contact with materials carrying pathogens. Environmental professionals concur in this perception; they add that risks to waste disposal workers arise also from the way that waste disposal is carried out, as well as from the particular characteristics of healthcare wastes.

Actual Risks

10.08 Few scientific studies have measured the risks associated with handling healthcare waste. The probability of HIV or hepatitis B virus infection of employees in the healthcare sector following pricking or cutting has, however, been estimated in the US.

10.09 Under indiscriminate landfilling, healthcare wastes have been dumped in landfills without precaution. The Group is not aware of any occasion when the resultant harm has extended beyond the individuals directly affected.

10.10 **The Group's Consensus on Risk**

1. Quantification of the actual risks from healthcare waste must begin from observation, hypothesis and experiment. It must take account of the characteristics of the known pathogens.

2. Those responsible for the disposal of healthcare wastes must manage the risks by selecting a disposal method suited to the character of each kind of

waste.

3. If members of the public know about the actual risks from healthcare waste, they may accept that it is right to scale the response to the risk.

4. Professionals in healthcare, healthcare management, and waste disposal need a forum for discussing methods of risk audit, the resistance of pathogens in wastes, the risks of infection and harm, and the risks to the environment from healthcare wastes and healthcare waste disposal.

11.0 RESEARCH AND DEVELOPMENT

Risk Research

11.01 As stated above, risk needs further research: it should include the handling of actual and perceived risk and the controlled targeting of information activities.

Re-use

11.02 Re-use of medical devices is widely practised in many Member States for reasons of economy and convenience. The facts do not yet establish whether or not re-use is safe; for example, reuse of equipment may be practical where a single patient is involved but not for a number of patients. A well-designed single-use device must realistically be expected to have failure modes when treated and re-used. If re-use is desired, the equipment must be designed from the outset to suit the cycle of use and re-use; and the cost must be paid.

11.03 Further studies must clarify the technical, ethical and legal issues associated with re-use.

Recycling

11.04 Hospitals have generally concentrated on helping the recycling non-patient contact materials such as glass, scrap metal, aluminum cans, cardboard and other packaging materials, including plastics. A variety of other worthwhile materials and products can be recycled or recovered from hospitals: they include silver from developers and fixing baths in x-ray departments, and organic materials (food, flowers).

11.05 The contribution of plastics to waste minimisation through lightweighting can be enhanced by a further examination of its recycling potential which is difficult to achieve in ways that produce an adequate return. Recycled plastics products are mainly but not exclusively manufactured from specific and unmixed material. Infusion sets, for example, consist of 4 or 5 different plastics. To improve the opportunity for recycling, the number of individual plastics used in any given healthcare artefact should be minimised.

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DIPLOMADO EN CONTROL DE LOS RESIDUOS
GENERADOS EN HOSPITALES
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MICROBIOLOGÍA CLÍNICA

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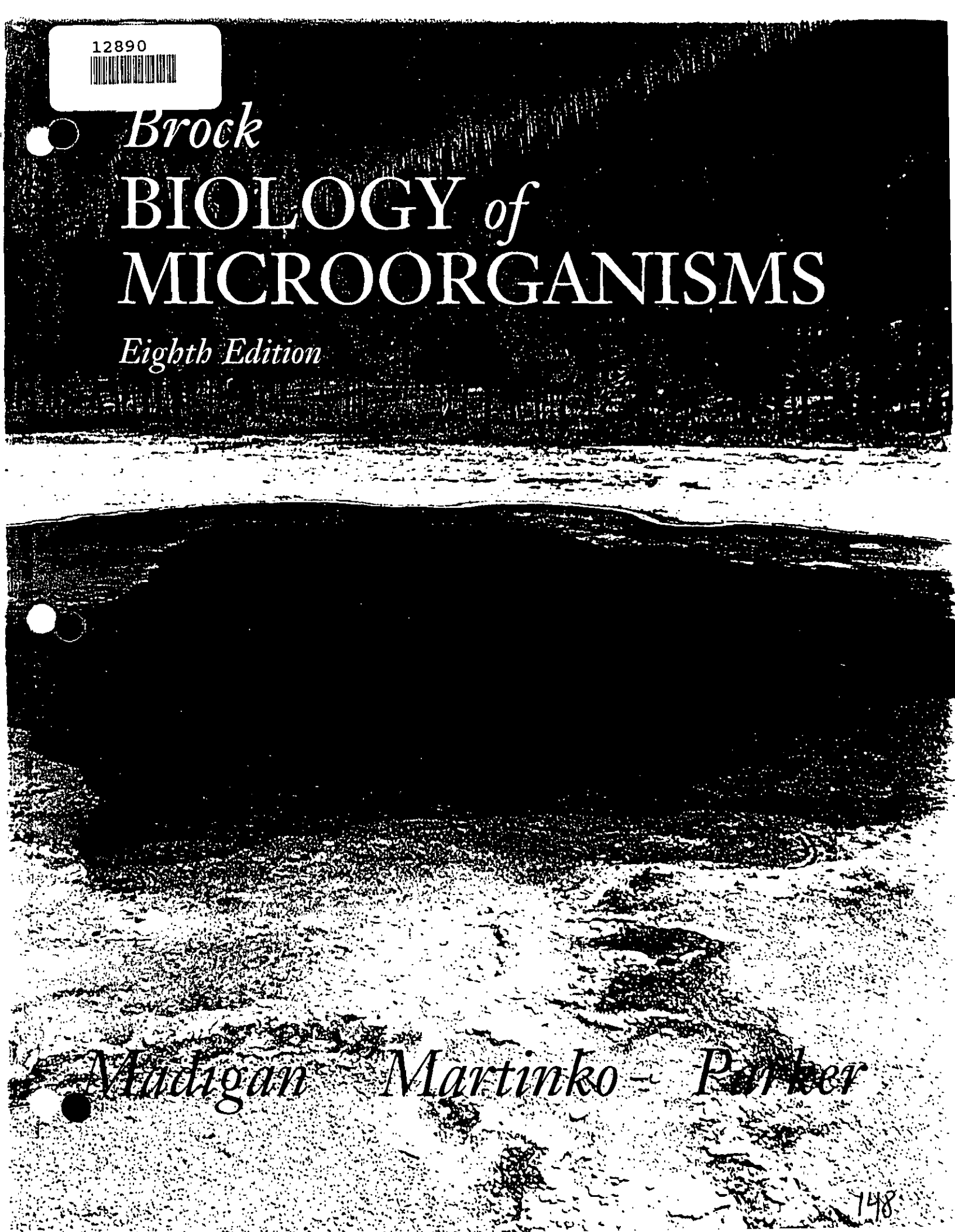
BIOLOGY *of* MICROORGANISMS

Eighth Edition



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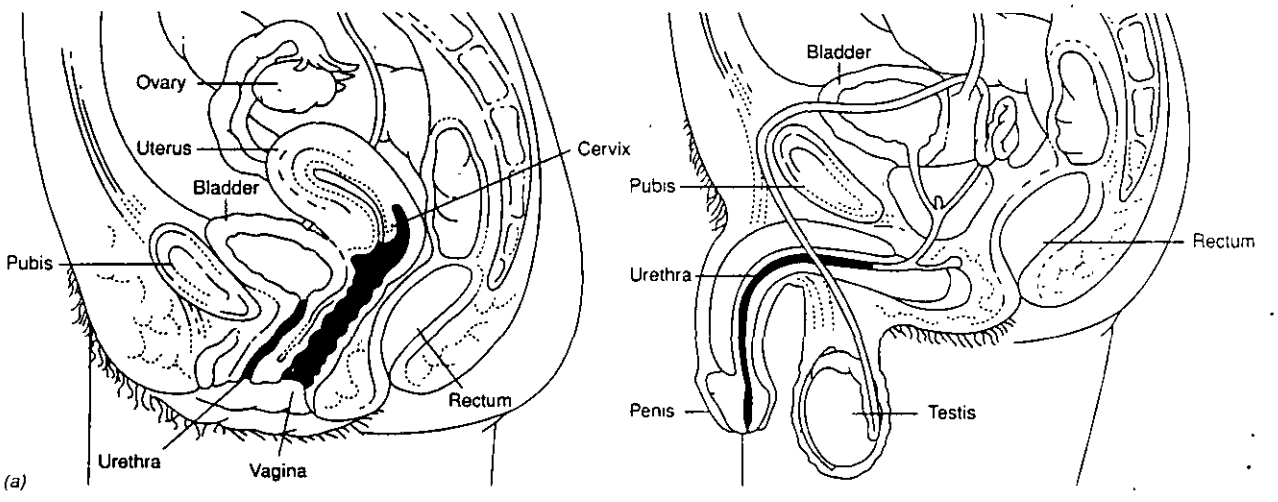

Figure 19.12 (a) The genitourinary tracts of the human female and male, showing regions (color) where microorganisms often grow. (b) Gram stain of *Lactobacillus acidophilus*, the predominant organism in the vagina of women. Individual rods are 3–4 μm in length.

not produce glycogen, *L. acidophilus* is absent, and the flora consists predominantly of staphylococci, streptococci, diphtheroids, and *E. coli*. After menopause, glycogen disappears, the pH rises, and the flora again resembles that found before puberty.

19.6 Entry of the Pathogen into the Host

We now start discussion of mechanisms used by pathogens to alter host function. The steps of *pathogenesis*, the progression of a disease state, include entry, colonization and growth, and the use of several strategies to establish *virulence*, the relative ability of a pathogen to cause disease in the host (Figure 19.13). We will start our discussion by considering the factors responsible for entry of a pathogen into a host.

A pathogen must usually gain access to host tissues and multiply before damage can be done. In most cases, this requires that the organism penetrate the skin, mucous membranes, or intestinal epithelium, surfaces that normally act as microbial barriers. Passage through the skin into subcutaneous layers almost always occurs through wounds; in rare instances pathogens penetrate through the unbroken skin.

Specific adherence

Most microbial infections begin on the mucous membranes of the respiratory, alimentary, or genitourinary tract. There is considerable evidence that bacteria or viruses able to initiate infection can adhere specifically to epithelial cells (Figure 19.14). The evidence for specificity is of several types. First, there is *tissue specificity*. An infecting microorganism does not adhere to all epithelial cells equally but selectively adheres to cells in the particular region of the body where it normally gains entrance. For example, *Neisseria gonorrhoeae*, the causative agent of the sexually transmitted disease gonorrhea, adheres much more strongly to urogenital epithelia than to other tissues. Second, there is *host specificity*. A bacterial strain that normally infects humans adheres more strongly to the appropriate human epithelial cells than to similar cells in another animal (for example, the rat), whereas a strain that specifically colonizes the rat adheres more firmly to rat cells than to human cells.

Many bacteria possess specific surface macromolecules that bind to complementary receptor molecules on the surfaces of certain animal cells, thus promoting specific and firm adherence. Certain of these macromolecules are polysaccharide in nature and form a sticky meshwork of fibers called the bacterial **glycocalyx** (Figure 19.14*b*). The glycocalyx is important not only in attaching bacterial cells to host cell surfaces but also in adherence between bacterial cells (Figure 19.14*b*). In addition, fimbriae (◦ Section 3.11) may be important in

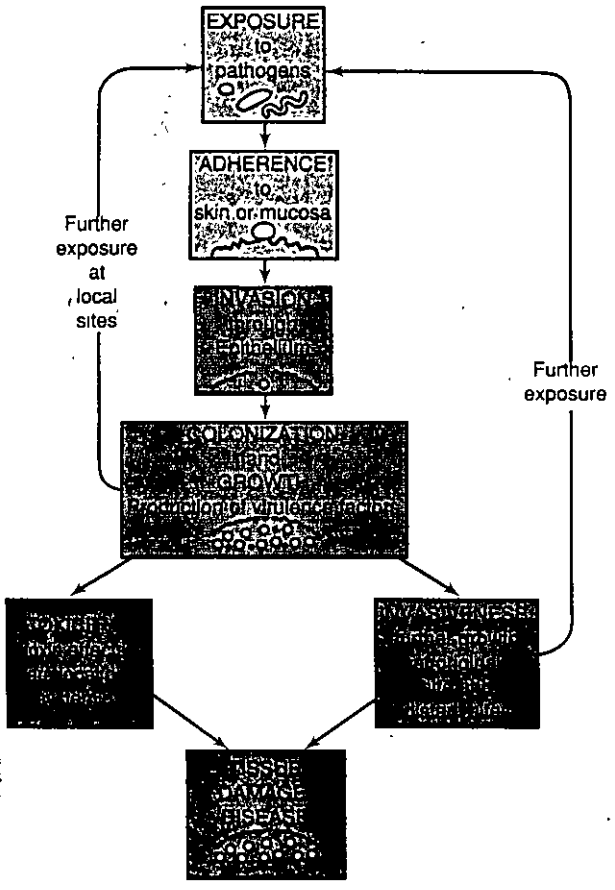

Figure 19.13 Microorganisms and pathogenesis. The presence of microorganisms on the host does not always lead to disease.

he attachment process. For instance, the fimbriae of *N. gonorrhoeae* play a key role in the attachment of this organism to urogenital epithelium, and fimbriated strains of *Escherichia coli* (Figure 19.15) are much more frequent causes of urinary tract infections than strains lacking fimbriae. Among the best-characterized fimbriae are the so-called *type I fimbriae* of enteric bacteria (*Escherichia, Klebsiella, Salmonella, Shigella*). Type I fimbriae are 0.2–1 μm in length and 7 nm wide and are uniformly distributed on the surface of cells. Type I fimbriae function in attachment by binding mannose residues of specific host cell glycoproteins to initiate the attachment event.

Evidence of the specific interaction between mucosal epithelium and the pathogen comes from studies of diarrhea caused by *Escherichia coli*. Most strains of *E. coli* are nonpathogenic and are part of the normal flora of the *large* intestine. A few strains (only a handful of the 160 different *E. coli* serotypes known) are *enteropathogenic*, possessing the ability to colonize the *small* intestine and initiate diarrhea. Such strains possess specific surface structures, the **colonization factor antigens (CFA)**, which are fimbrial proteins involved in specific attachment to intestinal mucosa. Thus, two kinds of *E. coli* can be recognized: pathogenic strains, which are able to adhere to the mucosal surface of the small intestine and cause disease symptoms, and "normal" *E. coli* strains, which are unable to adhere to the small intestine or produce enterotoxin (see Section 19.9). The normal *E. coli* strains grow in the large intestine (cecum and colon), and often enter into a long-lasting symbiotic relationship with the mammalian host. A summary of major factors in microbial adherence is given in Table 19.3.

Invasion

A few microorganisms are pathogenic solely because of the toxins they produce. These organisms do not need to gain access to host tissues, and we will discuss them separately (see Sections 19.8 and 19.9). However, most pathogens penetrate the epithelium to initiate pathogenicity, a process called *invasion*. At the point of entry, usually at small breaks or lesions in the skin or in mucosal surfaces, growth is often established in the

(a)

(b)

Figure 19.14 Adherence of pathogens to animal tissues. (a) Transmission electron micrograph of a thin section of *Vibrio cholerae* adhering to the brush border of rabbit villi. Note the absence of the outer layer (glycocalyx). (b) Enteropathogenic *Escherichia coli* in a fatal model infection in the newborn calf. The bacterial cells are attached to the brush border of calf villi via an extensive glycocalyx. The rods are about 0.5 μm in diameter.

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submucosa. Growth may also be established on intact mucosal surfaces, especially if the normal flora is altered or eliminated, for example, by antimicrobial chemotherapy. Pathogens may then more readily colonize the tissue and begin the invasion process. Pathogen growth may also be established at sites distant from the original point of entry. Access to distant, usually interior, sites is through the blood or lymphatic circulatory system (∞ Section 20.1).

CONCEPT CHECK 19.6

Pathogens may first gain access to host tissues by adherence to specific host molecules, usually on mucosal surfaces. Invasion starts at the site of adherence and may spread throughout the host via the circulatory systems.

- ✔ *Distinguish between* adherence *and* invasion.
- ✔ *Why is invasion usually necessary to establish pathogenicity?*

19.7 Colonization and Growth

If a pathogen gains access to tissues, it must multiply, a process called *colonization*. Colonization requires that the pathogen bind to specific tissue surface receptors and overcome any nonspecific or immune host defenses (see Section 19.12 and Chapter 20). The initial inoculum is rarely sufficient to cause damage; a pathogen must *grow* within host tissues in order to produce a disease. If the pathogen is to grow, it must find appropriate nutrients and environmental conditions in the host. Temperature, pH, and reduction potential are environmental factors that affect pathogen growth, but the availability of microbial nutrients in host tissues is most important. Although a vertebrate host might seem to be

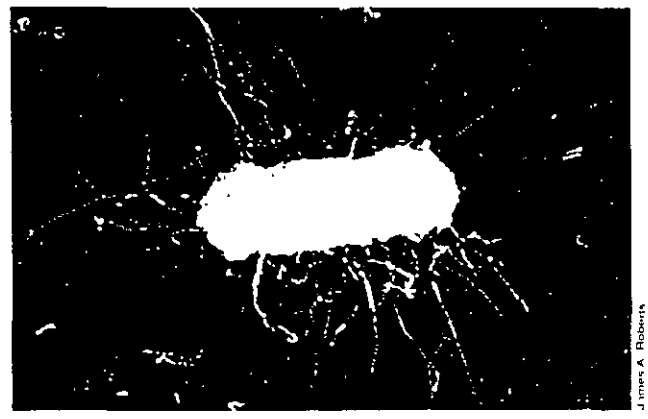

Figure 19.15 Shadow-cast electron micrograph of the bacterium *Escherichia coli*, showing type P fimbriae. Type P fimbriae resemble type I fimbriae but are somewhat longer. The cell shown is about 0.5 μm wide.

a nutritional paradise for microorganisms, not all nutrients are plentiful. Soluble nutrients such as sugars, amino acids, and organic acids may often be in short supply, and organisms able to utilize complex nutrient sources such as glycogen may be favored. Not all vitamins and other growth factors are necessarily in adequate supply in all tissues at all times. *Brucella abortus*, for example, can grow slowly in most tissues of infected cattle but grows very rapidly in the placenta, where it causes abortion. This specificity is due to the elevated concentration of erythritol found in the placenta, a nutrient that greatly stimulates growth of *B. abortus* (see Table 19.6).

Trace elements may also be in short supply and can influence establishment of the pathogen. For example, considerable evidence exists for the influence of **iron** on microbial growth. Specific proteins called *transferrin* and *lactoferrin*, present in animals, bind iron tightly and transfer it through the body. Such is the affinity of these proteins for iron that microbial iron deficiency may be common; indeed, administration of

TABLE 19.3 Major adherence factors used to facilitate attachment of microbial pathogens to host tissues[a]

Factor	Example
Sticky outer capsule (glycocalyx)	Enterotoxic *Escherichia coli* (ETEC)—glycocalyx promotes adherence to the brush border of intestinal villi
	Dental caries—binding to tooth surface by *Streptococcus mutans*
Adherence proteins	M-protein on surface of *Streptococcus pyogenes* binds receptor on respiratory mucosa
Lipoteichoic acid	Along with M-protein of *Streptococcus pyogenes*—facilitates binding to respiratory mucosal receptor
Fimbriae (pili)	Gonorrhea—pili on *Neisseria gonorrhoeae* facilitate binding to urogenital epithelium
	Salmonellosis—type I fimbriae facilitate binding to small intestinal epithelium
	Enterotoxic *Escherichia coli*—colonization factor antigens (CFAs), which are fimbrial, facilitate binding to small intestinal epithelium

[a]For the most part, receptor sites on host tissues are glycoproteins or complex lipids such as gangliosides or globosides

a soluble iron salt to an infected animal may greatly increase the virulence of some pathogens. As we noted in Section 4.2, many bacteria produce iron-chelating compounds (siderophores), which help them to obtain iron from the environment. Some iron chelators isolated from pathogenic bacteria are so efficient that they can actually remove iron from animal iron-binding proteins. For example, a siderophore called *aerobactin*, produced by certain strains of *Escherichia coli* and encoded by the Col V plasmid (∞ Section 9.8), readily removes iron bound to transferrin.

Localization in the body

After initial entry, the organism often remains localized and multiplies, producing a small focus of infection such as the boil, carbuncle, or pimple that commonly arises from *Staphylococcus* infections of the skin. Alternatively, the organisms may pass through the lymphatic vessels and be deposited in lymph nodes. If an organism reaches the blood, it will be distributed to distant parts of the body, usually concentrating in the liver or spleen. Spread of the pathogen through the blood and lymph systems can result in a generalized (systemic) infection of the body, with the organism growing in a variety of tissues. If extensive bacterial growth in tissues occurs, some of the organisms are usually shed into the bloodstream in large numbers, a condition called **bacteremia.** Generalized infections of this type almost always start as a localized infection at a specific organ site but fortunately are quite rare.

Virulence factors

A number of pathogen-produced extracellular proteins aid in the establishment and maintenance of disease. These proteins, which are mostly enzymes, are called *virulence factors*. For example, streptococci, staphylococci, pneumococci, and certain clostridia produce **hyaluronidase** (Table 19.4), an enzyme that promotes spreading of organisms in tissues by breaking down hyaluronic acid, a polysaccharide that functions in the body as a tissue cement. Production of this enzyme enables these organisms to spread from an initial focus. Streptococci and staphylococci also produce a vast array of proteases, nucleases, and lipases that serve to depolymerize host proteins, nucleic acids, and fats, respectively. Clostridia that cause gas gangrene produce **collagenase,** or κ-toxin (Table 19.4), which breaks down the collagen network supporting the tissues; the resulting dissolution of tissue is a factor in enabling these organisms to spread through the body. Fibrin clots are often formed by the host in a region of microbial invasion and wall off the organism, preventing its spread through the body. Some organisms are able to produce fibrinolytic enzymes to dissolve these clots and make further invasion possible. One such fibrinolytic substance, produced by *Streptococcus pyogenes,* is known as **streptokinase** (Table 19.4). On the other hand, some organisms produce enzymes that actually promote fibrin clotting, which causes localization of the organism rather than its spread. The best-studied fibrin-clotting enzyme is **coagulase** (Table 19.4), produced by pathogenic *Staphylococcus aureus,* which causes the fibrin material to be deposited on the cocci and may offer them protection from attack by host cells. The fibrin matrix produced as a result of coagulase activity probably accounts for localization of many staphylococcal infections in boils and pimples (∞ Figure 23.6).

Various pathogens produce proteins that are able to act on the animal cytoplasmic membrane, causing cell lysis and hence cell death. The action of these toxins is most easily detected with red blood cells (erythrocytes), hence they are often called **hemolysins** (Table 19.4); in probably all cases, however, they also work on cells other than erythrocytes. The production of such toxins is most readily demonstrated in the laboratory by streaking the organism on a *blood agar plate.* During growth of the colonies, some of the hemolysin is released and lyses the surrounding red blood cells, typically clearing a zone of hemolysis (Figure 19.16*a*). Some hemolysins are enzymes that attack the phospholipid of the host cytoplasmic membrane. Because the phospholipid lecithin (phosphatidylcholine) is often used as a substrate, these enzymes are called **lecithinases** or **phospholipases** (Figure 19.16*b*). Since the cytoplasmic membranes of all organisms, both prokaryotes and eukaryotes, contain phospholipids, hemolysins that are phospholipases sometimes destroy bacterial as well as animal cytoplasmic membranes. Some hemolysins are not phospholipases, however. Streptolysin O, a hemolysin produced by streptococci, affects the sterols of the host cytoplasmic membrane, and its action is neutralized by addition of cholesterol or other sterols. **Leukocidins** (Table 19.4) are lytic agents capable of lysing white blood cells and hence serve to decrease host resistance (∞ Section 20.1).

CONCEPT CHECK 19.7

The disease process requires that a pathogen gain access to host-provided nutrients, followed by colonization and growth in substantial numbers in host tissue. A number of pathogen-produced extracellular virulence factors are designed to protect the pathogen from host defenses or to provide increased access to nutrients.

- ✔ *Why is colonization necessary for the success of most pathogens?*
- ✔ *Why do bacterial enzymes attack structural components of host cells?*

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TABLE 19.4 Exotoxins and extracellular virulence factors produced by certain bacteria pathogenic for humans

Organism	Disease	Toxin or factor	Action
Clostridium botulinum	Botulism	Neurotoxin	Flaccid paralysis (see Figure 19.18*a*)
Clostridium tetani	Tetanus	Neurotoxin	Spastic paralysis (see Figure 19.18*b*)
Clostridium perfringens	Gas gangrene, food poisoning	α-Toxin	Hemolysis (lecithinase, see Figure 19.16*b*)
		β-Toxin	Hemolysis
		γ-Toxin	Hemolysis
		δ-Toxin	Hemolysis
		θ-Toxin	Hemolysis (cardiotoxin)
		κ-Toxin	Collagenase
		λ-Toxin	Protease
		Enterotoxin	Alters permeability of intestinal epithelium
Corynebacterium diphtheriae	Diphtheria	Diphtheria toxin	Inhibits protein synthesis in eukaryotes and in Archaea (see Figure 19.17)
Staphylococcus aureus	Pyogenic (pus-forming) infections (boils, and so on), respiratory infections, food poisoning, toxic shock syndrome, scalded skin syndrome	α-Toxin	Hemolysis
		Toxic shock syndrome toxin	Systemic shock
		Exfoliating toxins A and B	Peeling of skin, shock
		Leukocidin	Destroys leukocytes
		β-Toxin	Hemolysis
		γ-Toxin	Kills cells
		δ-Toxin	Hemolysis, leukolysis
		Enterotoxins A, B, C, D, and E	Induce vomiting, diarrhea, shock
		Coagulase	Induces fibrin clotting
Streptococcus pyogenes	Pyogenic infections, tonsillitis, scarlet fever	Streptolysin O	Hemolysin
		Streptolysin S	Hemolysin
		Erythrogenic toxin	Causes scarlet fever rash
		Streptokinase	Dissolves fibrin clots
		Hyaluronidase	Dissolves hyaluronic acid in connective tissue
Vibrio cholerae	Cholera	Enterotoxin	Induces fluid loss from intestinal cells (see Figure 19.19)
Escherichia coli (enteropathogenic strains only)	Gastroenteritis	Enterotoxin	Induces fluid loss from intestinal cells
Bacillus cereus	Food poisoning	Enterotoxin	Induces fluid loss from intestinal cells
Shigella dysenteriae	Bacterial dysentery	Neurotoxin	Paralysis, hemorrhage
Yersinia pestis	Plague	Plague toxin	Kills cells
Bordetella pertussis	Whooping cough	Whooping cough (Pertussis) toxin	Kills cells
Pseudomonas aeruginosa	Various *P. aeruginosa* infections	Exotoxin A	Kills cells

19.8 Exotoxins

The ways in which pathogens bring about damage to the host are diverse. Only rarely are symptoms of a disease due simply to the presence of large numbers of microorganisms. Although a large mass of cells can block vessels or heart valves or clog the air passages of the lungs, in many cases pathogens produce *toxins* that are responsible for host damage.

Toxins released extracellularly as the organism grows are called **exotoxins.** These toxins may travel from a focus of infection to distant parts of the body

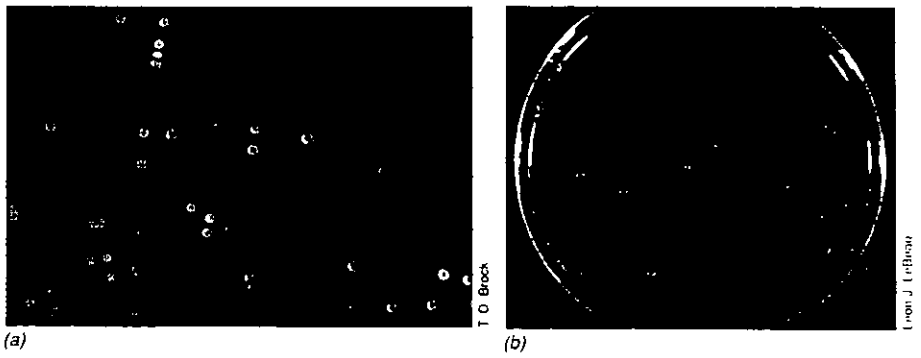


Figure 19.16 (a) Zones of hemolysis around colonies of *Streptococcus pyogenes* growing on a blood agar plate. (b) Action of lecithinase, a phospholipase, around colonies of *Clostridium perfringens*, growing on an agar medium containing egg yolk.

and cause damage in regions far removed from the site of microbial growth. Table 19.4 provides a summary of the properties and actions of some of the best-known exotoxins.

Diphtheria toxin

The toxin produced by *Corynebacterium diphtheriae*, the causal agent of diphtheria, was the first exotoxin to be discovered. It differs markedly in its action on different animal species; rats and mice are relatively resistant, whereas humans, rabbits, guinea pigs, and birds are susceptible. Diphtheria toxin is very potent; only a single molecule is required to kill a single cell. The toxin binds irreversibly to the cell, and within a few hours the cell loses its ability to synthesize protein because the toxin interferes with protein synthesis by blocking transfer of an amino acid from a transfer ribonucleic acid (tRNA) to the growing peptide chain. The toxin specifically inactivates one of the elongation factors (elongation factor 2) involved in growth of the polypeptide chain (Figure 19.17) by catalyzing the attachment of the adenosine diphosphate (ADP) ribose moiety of NAD^+ to the elongation protein. The elongation protein is ADP-ribosylated at a single amino acid residue, a modified histidine molecule called *diphthamide*; following ADP-ribosylation, the activity of elongation factor 2 drops dramatically and protein synthesis stops.

Diphtheria toxin is formed by strains of *C. diphtheriae* that are lysogenized by a bacteriophage called phage β, and the toxin production is encoded in the phage genome. Nontoxigenic and hence nonpathogenic strains of *C. diphtheriae* can be converted to pathogenic strains by infection with the β phage (the process of phage conversion) (☞ Section 9.7).

The toxin as excreted by *C. diphtheriae* cells is a single polypeptide of 62,000 molecular weight containing 535 amino acids. Following binding to the host cell, the polypeptide is cleaved by a protease into two fragments. Fragment A (193 amino acids) enters the cell and disrupts protein synthesis, whereas the remaining piece, Fragment B (342 amino acids), is discarded. Before cleavage, Fragment B promotes specific binding of the toxin to the host cell, and following cleavage it assists in the entry of Fragment A into the host cytoplasm.

A factor in toxin production is the concentration of *iron* present in the environment. In media containing sufficient iron for optimal growth, no toxin is produced

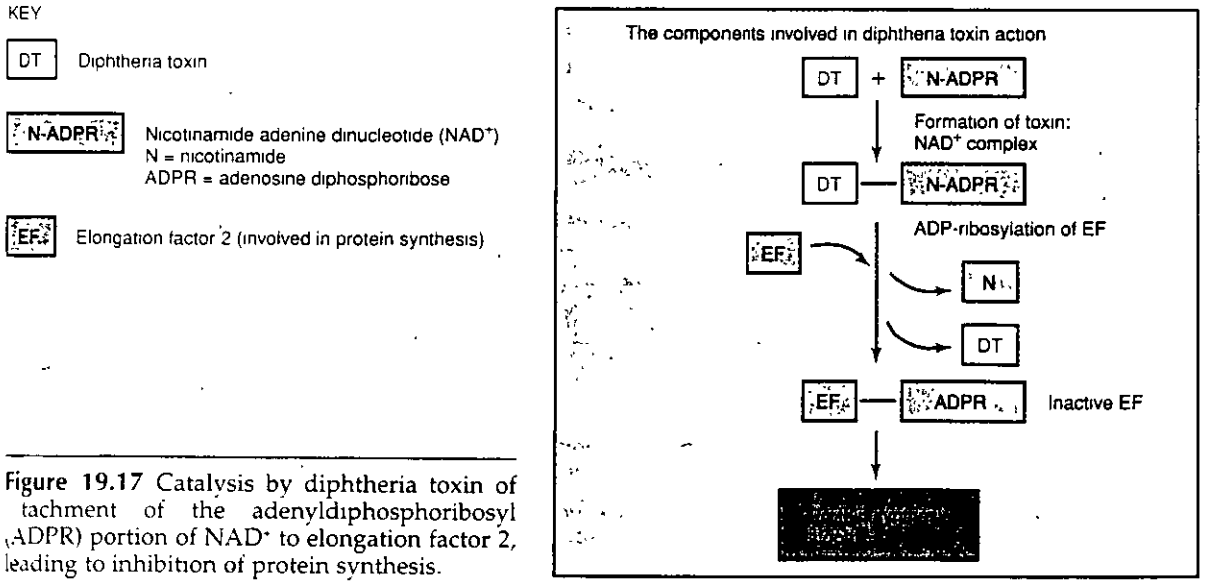


Figure 19.17 Catalysis by diphtheria toxin of tachment of the adenyldiphosphoribosyl (ADPR) portion of NAD^+ to elongation factor 2, leading to inhibition of protein synthesis.

When the iron concentration is reduced to growth-limiting levels, toxin production occurs. The role of iron is to bind to a regulatory protein in *C. diphtheriae* (that is, act as a negative control element) (∞ Section 7.3). The iron-binding protein then combines with a control region of the DNA of β phage and prevents expression of the diphtheria toxin gene. When iron is absent, the regulatory protein does not act, and toxin synthesis can occur. The disease diphtheria is discussed in Section 23.2. This strategy for toxin production may also be found in other microorganisms. For example, exotoxin A of *Pseudomonas aeruginosa* (Table 19.4) has an action quite similar to that of diphtheria toxin, also transferring the ADP-ribosyl portion of NAD^+ to elongation factor 2.

Tetanus and botulinum toxins

These toxins are produced by two species of obligately anaerobic bacteria, *Clostridium tetani* and *C. botulinum*, which are normal soil organisms that occasionally become involved in disease situations in animals. *C. tetani* grows in the body in deep wound punctures that become anaerobic, and although *C. tetani* does not invade the body from the initial site of infection, the toxin it produces can spread and cause severe neurological symptoms that can result in death. *C. botulinum* rarely grows directly in the body, but it does grow and produce toxin in improperly preserved foods. Ingestion of toxin-containing food results in neurological disease and death.

However, in *infant botulism*, infection of the intestinal tract from a *C. botulinum*-containing food product such as raw honey results in chronic infection by the toxin-producing organism. Elaboration of the toxin then causes the disease. *C. botulinum* infection is rare in normal adults because the normal flora and the immune response are developed and prevent colonization of the intestinal tract by the pathogen.

Tetanus toxin is a protein of molecular weight 150,000, containing two polypeptides. On entry into the central nervous system, this toxin becomes fixed to nerve synapses, binding specifically to a ganglioside lipid. This binding blocks the release of glycine, a factor that induces relaxation of the muscles. Thus, the toxin allows constant firing of the motor neurons and continual contraction. This is very different from the normal muscle action pattern (Figure 19.18). Usually, two neurons innervate each muscle fiber. One neuron transmits activation (contraction) signals from the central nervous system. The other neuron transmits inhibition (relaxation) signals. Muscles throughout the body are arranged in opposing pairs. Thus, when one muscle of each pair has received an activation signal and is contracted, the other has received an inhibition signal and is relaxed. However, if tetanus toxin is bound to the inhibitory motor neurons as described above, it blocks the inhibitory signal, resulting in the simultaneous contraction of both of the paired muscles. The outcome is a spastic, twitching paralysis, with both muscles contracted and opposing one another at the same time. If the muscles of the mouth are involved, the prolonged spasm restricts the mouth's movement, resulting in the condition known as *lockjaw*. If the respiratory muscles are involved, death may be due to asphyxiation.

Botulinum toxin is a series of seven related toxins that are the most poisonous substances known. One milligram of pure botulinum toxin is enough to kill more than 1 million guinea pigs. Of the seven distinct botulinum toxins described, at least two of these are encoded on lysogenic bacteriophages specific for *Clostridium botulinum*. The major toxin is a protein of about 150,000 molecular weight, which readily forms complexes with nontoxic botulinum proteins to give an active form of the toxin of almost 10^6 molecular weight. Toxicity occurs because the toxin binds to presynaptic membranes at the nerve–muscle junction, blocking the release of acetylcholine. Because transmission of the nerve impulse to the muscle is by means of acetylcholine action, muscle contraction is inhibited, causing a flaccid paralysis. The fatality rate from botulism poisoning can approach 100% but can be significantly reduced by quick administration of an antitoxin antibody (∞ Section 20.17) and by use of an artificial respirator to prevent respiratory failure. Death in cases of botulism is usually due to respiratory or cardiac failure. The mode of action of tetanus and botulinum toxins is contrasted in Figure 19.18.

CONCEPT CHECK 19.8

The most potent biological toxins are the exotoxins produced by pathogens. Each exotoxin acts on specific host cells or molecules.

- ✔ *What key features are shared by all exotoxins?*
- ✔ *What factors make botulinum toxin so lethal?*

19.9 Enterotoxins

Enterotoxins are exotoxins that act on the *small* intestine, generally causing massive secretion of fluid into the intestinal lumen, leading to the symptoms of diarrhea. Enterotoxins are produced by a variety of bacteria, including the food-poisoning organisms *Staphylococcus aureus, Clostridium perfringens,* and *Bacillus cereus,* and the intestinal pathogens *Vibrio cholerae, Escherichia coli,* and *Salmonella enteritidis.* The *E. coli* enterotoxin is plasmid-encoded. It is likely that this plasmid also encodes synthesis of the specific surface antigens that are essential for attachment of enteropathogenic *E. coli* to intestinal epithelial cells (see Section 19.6).

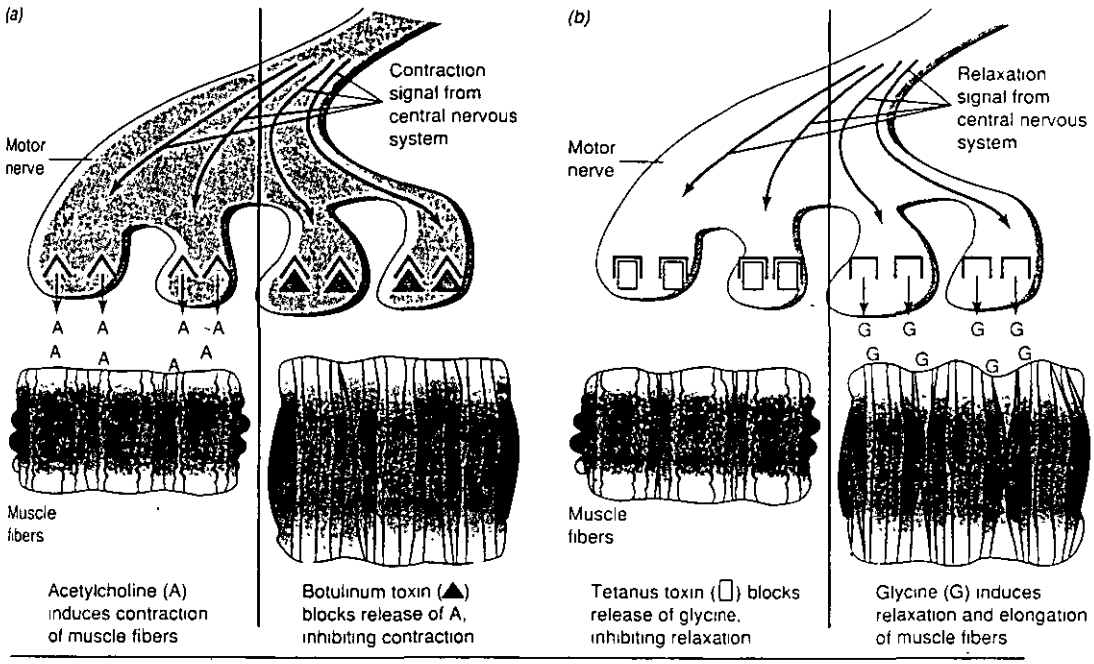


Figure 19.18 Actions of neurotoxins on the motor end plate at the muscle fiber–motor nerve junction. (a) Botulinum toxin from *Clostridium botulinum* This toxin results in irreversible relaxation and flaccid paralysis in the affected muscles. (b) Tetanus toxin from *Clostridium tetani* This toxin results in irreversible contraction and spastic paralysis in the affected muscles.

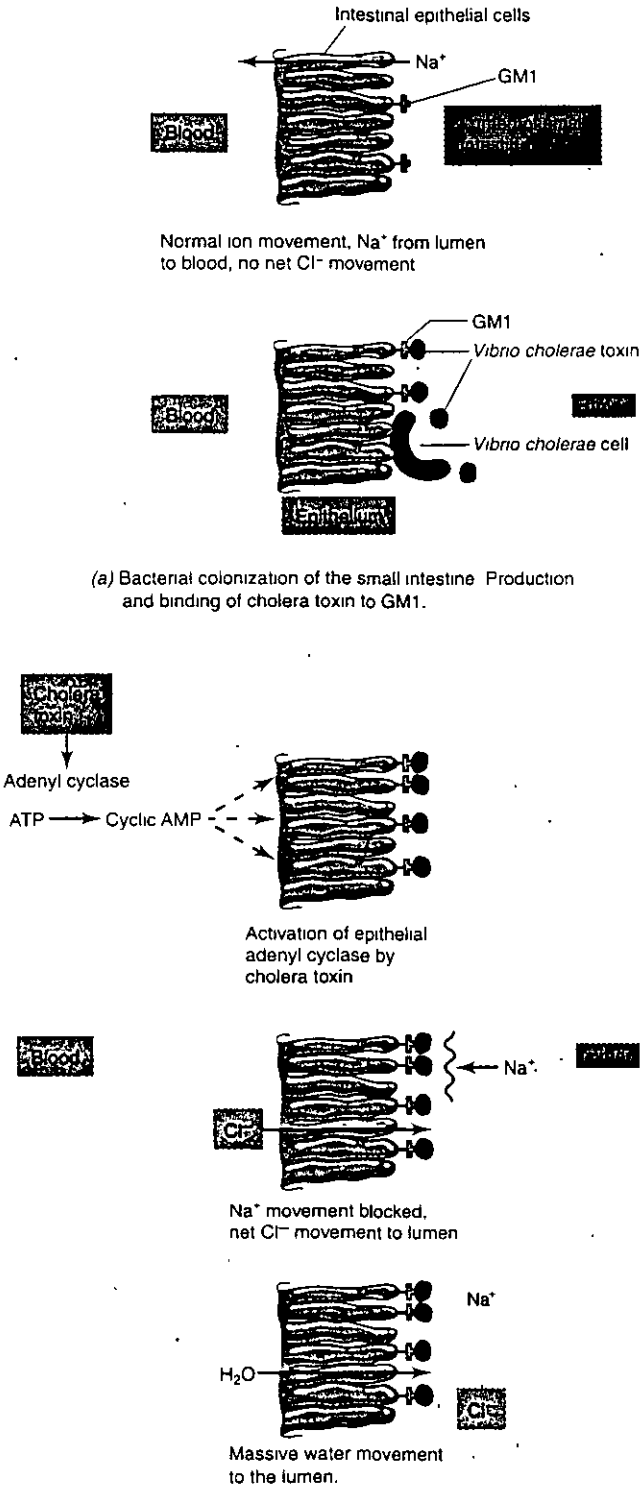
Cholera toxin

The enterotoxin produced by *Vibrio cholerae*, the causal agent of cholera, is the best understood. Cholera toxin is a protein consisting of three polypeptides, the A_1, A_2, and B polypeptide chains of 82,000 total molecular weight. Chains A_1 and A_2 are covalently connected by a disulfide bridge to make a dimer called subunit A, and this is loosely associated with a variable number of B chains. The B subunit contains the binding site by which the cholera toxin combines specifically with the ganglioside GM1 (a complex glycolipid) in the epithelial cytoplasmic membrane (Figure 19.19*a*), but the B subunit itself does not cause an alteration in membrane permeability. Rather, the toxic action is in the A_1 chain, which activates the cellular enzyme *adenyl cyclase*, causing the conversion of adenosine triphosphate (ATP) to cyclic adenosine monophosphate (cAMP).

As we discussed in Section 7.6, cyclic AMP is a specific mediator of a variety of regulatory systems in cells. In mammals, cyclic AMP is involved in the action of a variety of hormones, as well as in synaptic transmission in the nervous system, and in inflammatory and immune reactions of tissues, including allergies. Although the A_1 subunit of cholera toxin is responsible for activation of adenyl cyclase, A_1 must first be activated by a cellular enzyme that requires NAD^+ and ATP. In the action of cholera enterotoxin, the increased cyclic AMP levels bring about the active secretion of chloride and bicarbonate ions from the mucosal cells into the intestinal lumen. This change in ionic balance leads to the secretion of large amounts of water into the lumen (Figure 19.19*b*). In the acute phase of cholera, the rate of water loss into the small intestine is greater than reabsorption of water by the large intestine, and so massive net fluid loss occurs. Cholera victims generally die from extreme dehydration, and the best treatment for the disease is the oral administration of electrolyte solutions containing solutes (Figure 19.19*c*) to replace the lost fluid and ions.

At the molecular level, cholera enterotoxin has a mode of action (formation of cyclic AMP) identical to that of some normal mammalian hormones, and it has been suggested that cholera toxin may represent an ancestral hormone. Because cholera enterotoxin activates adenyl cyclase in a variety of cells and tissues, pathological manifestations of cholera toxin are related more to the specific site at which it binds, the epithelial cells of the small intestine, than to toxin activation of adenyl cyclase. Indeed, purified B subunits devoid of adenyl cyclase activity can actually *prevent* the action of cholera enterotoxin, if they are administered first, because they bind to the specific cholera receptors on the mucosal cells and block the binding of the complete toxin.

Genetic studies of cholera toxin have shown that the cholera enterotoxin is encoded by two genes, *ctxA* and *ctxB*. Expression of *ctxA* and *ctxB* is controlled by a positive regulatory element, a protein encoded by the *toxR* gene. The *toxR* gene product is a transmembrane protein



igure 19.19 Action of cholera enterotoxin.

that controls not only cholera toxin production but also several other important virulence factors, such as outer membrane proteins and pili required for successful colonization of *Vibrio cholerae* in the small intestine.

Other enterotoxins

There is good evidence that the enterotoxins produced by enteropathogenic *Escherichia* and *Salmonella* have modes of action similar to that of cholera toxin, and antibody against cholera enterotoxin also inactivates these other enterotoxins, suggesting a similar structure. The sequence of the cholera toxin genes *ctxA and B* further supports this relationship: cholera toxin genes show greater than 75% sequence homology with the genes encoding the heat-labile enterotoxin produced by enteropathogenic *Escherichia coli*. Also, the active component of *Escherichia* enterotoxin is activated by a cellular enzyme system requiring ATP and NAD^+. As discussed in Section 9.8, *Escherichia* enterotoxin is controlled by a conjugative plasmid, but the enterotoxin gene of *Vibrio cholerae* is chromosomal, although transmissible by conjugation. However, the enterotoxins produced by the food-poisoning bacteria (*Staphylococcus aureus, Clostridium perfringens, Bacillus cereus*) may be quite different in their modes of action (see Section 20.16 for a discussion of *S. aureus* toxic mechanisms) because their action is at least partly systemic and cannot be explained by alterations in intestinal permeability alone.

CONCEPT CHECK 19.9

Enterotoxins are exotoxins that act specifically on the small intestine, causing changes in intestinal permeability that lead to diarrhea. Many food-poisoning microorganisms produce enterotoxins.

- ✔ *Are all enterotoxins also exotoxins?*
- ✔ *Do all enterotoxins share a common mechanism of action?*

19.10 Endotoxins

Gram-negative Bacteria produce lipopolysaccharides as part of the outer layer of their cell walls (see Figures 3.33 and 3.34), which under many conditions are toxic. These are called **endotoxins** because they are generally cell-bound and released in large amounts only when cells lyse. In most cases, *endotoxin* can be equated with lipopolysaccharide toxin. Endotoxins have been studied primarily in the genera *Escherichia, Shigella,* and especially *Salmonella*. The major differences between exotoxins and endotoxins are listed in Table 19.5.

TABLE 19.5 Basic properties of exotoxins and endotoxins

Property	Exotoxins	Endotoxins
Chemical properties	Proteins, excreted by certain gram-positive or gram-negative Bacteria; generally heat-labile	Lipopolysaccharide–lipoprotein complexes (see Figures 3.33 and 3.34), released on cell lysis as part of the outer membrane of gram-negative Bacteria, extremely heat-stable
Mode of action; symptoms	Specific; either cytotoxin, enterotoxin, or neurotoxin with defined specific action on cells or tissues	General; fever, diarrhea, vomiting
Toxicity	Highly toxic, often fatal	Weakly toxic, rarely fatal
Immunogenicity	Highly immunogenic; stimulate the production of neutralizing antibody (antitoxin)	Relatively poor immunogen; immune response not sufficient to neutralize toxin
Toxoid potential	Treatment of toxin with formaldehyde will destroy toxicity, but treated toxin (toxoid) remains immunogenic	None
Fever potential	Do not produce fever in host	Pyrogenic, often produce fever in host

Endotoxin structure and function

When injected into an animal, endotoxins cause a variety of physiological effects. *Fever* is an almost universal symptom because endotoxin stimulates host cells to release proteins called *endogenous pyrogens*, which affect the temperature-controlling center of the brain. In addition, however, the animal may develop diarrhea, experience a rapid decrease in lymphocyte, leukocyte, and platelet numbers, and enter into a generalized inflammatory state. Large doses of endotoxin can cause death, primarily through hemorrhagic shock and tissue necrosis. However, the toxicity of endotoxins is much *lower* than that of exotoxins. For instance, in the mouse the amount of endotoxin required to kill 50% of a population of test animals (the so-called LD_{50}) is 200–400 μg per mouse, whereas the LD_{50} for botulinum toxin is about 25 picograms (pg) per mouse, about 10 million times less! (A picogram is 10^{-12} g or 10^{-6} μg.)

The overall structure of lipopolysaccharide (LPS) was diagrammed in Figure 3.34. Lipopolysaccharide consists of lipid A, a core polysaccharide, which in *Salmonella* is the same for many species, consisting of ketodeoxyoctonate, seven-carbon sugars (heptoses), glucose, galactose, and *N*-acetylglucosamine, and the *O-polysaccharide*, a highly variable molecule that usually contains galactose, glucose, rhamnose, and mannose and generally contains one or more unusual dideoxy sugars such as abequose, colitose, paratose, or tyvelose. The sugars of the *O*-polysaccharide are connected in four- to five-sugar sequences (often branched), which then repeat to form the complete molecule (∞ Figures 3.33 and 3.34). Lipid A is not a normal glycerol lipid, but instead the fatty acids are connected by ester linkage to *N*-acetylglucosamine. Fatty acids frequently found in the lipid include β-hydroxymyristic, lauric, myristic, and palmitic acids.

Purification of lipopolysaccharide fractions has shown that it is the *lipid A complex* that is responsible for toxicity and that the polysaccharide acts mainly to render the lipid water-soluble. However, animal studies have shown that the entire endotoxin complex, which contains both polysaccharide and lipid, is required to obtain a response.

Limulus *assay for endotoxin*

Because endotoxins are fever inducers, pharmaceuticals such as antibiotics and intravenous solutions must be endotoxin-free. An endotoxin assay of very high sensitivity has been developed using lysates of amebocytes from the horseshoe crab, *Limulus polyphemus*. Although the mechanism of this assay is not understood, endotoxin specifically causes lysis of amebocytes (Figure 19.20). In a commercial assay, amebocyte extracts are mixed with the solution to be tested. If endotoxin is present, the amebocyte extract gels and precipitates, causing a marked change in turbidity. This reaction can be measured quantitatively with a spectrophotometer. A measurable reaction can be obtained with as little as 10–20 pg/ml of lipopolysaccharide. Apparently the active component of the *Limulus* extract reacts with the lipid component of lipopolysaccharide. The *Limulus* assay has been used to detect the presence of minute quantities of endotoxin in serum, cerebrospinal fluid, drinking water, and fluids used for injection.

The *Limulus* test is so sensitive that considerable care must be taken to avoid contamination of the equipment, solutions, and reagents with the gram-negative Bacteria in the laboratory and clinical environment, for example, as contaminants in the distilled water. In clinical work, detection of endotoxin by the *Limulus* assay in serum or cerebrospinal fluid is presumptive evidence of gram-negative infection of these body fluids.

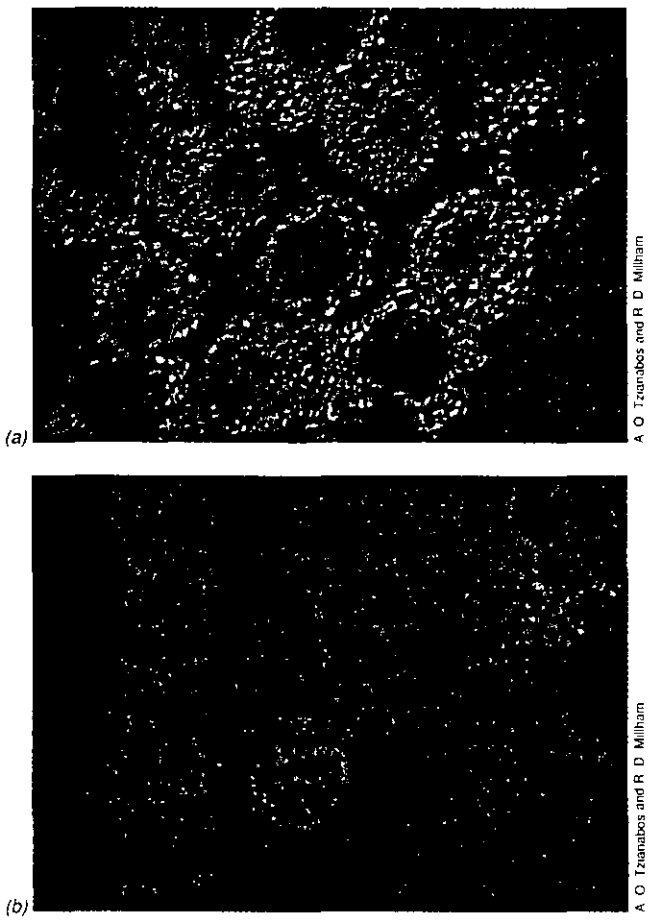


Figure 19.20 Photomicrographs of *Limulus* amebocytes. (a) Normal amebocytes. (b) Amebocytes following exposure to bacterial lipopolysaccharide. Treatment with lipopolysaccharide causes degranulation of the cells, and this response can be used as an assay for lipopolysaccharide content

CONCEPT CHECK *19.10*

Endotoxins are toxic outer cell wall components derived from gram-negative Bacteria. Host fever is a symptom of endotoxin action.

- ✔ *Why do gram-positive Bacteria not produce endotoxins?*
- ✔ *Are endotoxins generally as potent as exotoxins? Why or why not?*

19.11 Virulence

Virulence is the relative ability of a parasite to cause disease. In the last five sections, we described several specific virulence factors, all of which dealt with the ability of a pathogen either to *invade* a host or to cause damage by producing *toxins*. In this section, we will deal with specific examples of particularly virulent organisms and we will apply our knowledge of virulence factors to explain the virulence of these organisms.

Both *invasiveness* and *toxigenicity* are quantitative properties and may vary over a wide range from very high to very low. An organism that is only weakly invasive may still be virulent if it is highly toxigenic. A good example of this is the organism *Clostridium tetani*. The cells of this organism rarely leave the wound where they were first deposited; yet they are able to bring about death of the host because they produce the potent tetanus exotoxin, which can move to distant parts of the body and initiate paralysis. On the other hand, a weakly toxigenic organism may still be able to produce disease if it is highly invasive. *Streptococcus pneumoniae* is not known to produce any toxin but is able to cause extensive damage and even death because it is highly invasive, being able to grow in lung tissues in enormous numbers and initiate host responses that lead to disturbance of lung function. These two organisms exemplify the extremes of invasiveness and toxigenicity; most pathogens fall somewhere between these two extremes.

We have discussed several virulence factors used by pathogens, including the toxins (see Sections 19.8–19.10). Several other virulence factors have also been identified in pathogenesis. In *Salmonella*, for example, a genus in which genetic studies can be readily done, a variety of virulence factors are known. Toxin production contributes to the virulence of *Salmonella* sp., and at least three toxins are produced: enterotoxin, endotoxin, and *cytotoxin*. Cytotoxin acts by inhibiting host cell protein synthesis, and because it is associated with the cell surface, it may also be involved in *adherence*, which allows *Salmonella* to bind to epithelial cells. Other factors involved in adherence are the cell surface polysaccharide O antigen (Figure 3.33) and the flagellar Vi antigen. Fimbriae may also enhance adherence. *Invasion factors* include the O and Vi antigens These invasion factors are important because they prevent killing by *phagocytes*, a group of white blood cells that normally ingest and kill bacteria (Section 20 3) *Salmonella* is thought to establish infections through *intracellular parasitism*, the practice of residing in host cells, eventually growing and destroying those cells, and spreading to other cells. A plasmid-borne virulence factor is responsible for intracellular persistence and spread in most species of *Salmonella*. Thus, *Salmonella*, and probably most other pathogens, use several virulence factors simultaneously to initiate infection. Figure 19 21 summarizes the known virulence factors in *Salmonella*

The virulence of a pathogen can be estimated from experimental studies of the LD_{50}. Highly virulent pathogens frequently show little difference in the number of cells required to kill 100% of the population as compared to the number required to kill 50% of the population. This is illustrated in Figure 19.22 for exper-

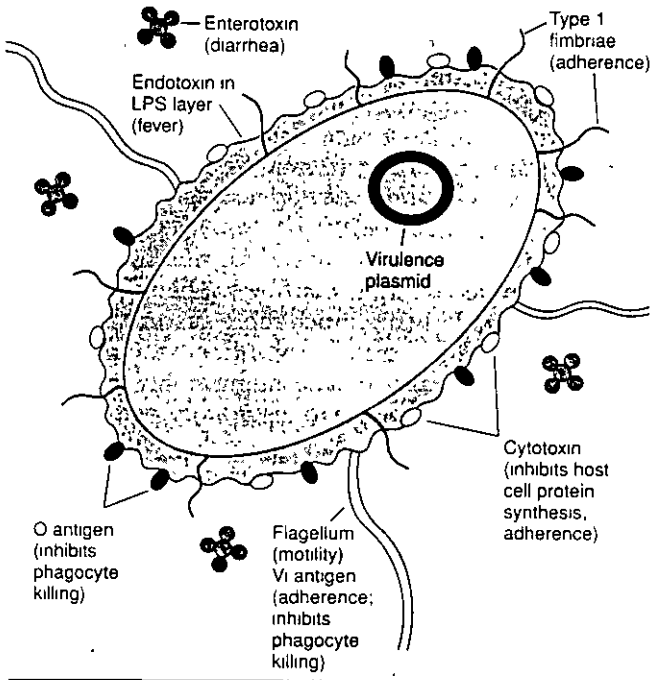


Figure 19.21 Summary of virulence factors important in *Salmonella* pathogenesis. See text for discussion.

imental *Streptococcus* and *Salmonella* infections in mice. Only a few cells of *Streptococcus pneumoniae* are required to establish a fatal infection in mice. Fewer than 100 cells per mouse are necessary to kill every member of a test population once the virulence of a particular strain has been established. In fact, the LD_{50} for this organism is hard to ascertain because so few organisms are needed to produce a lethal infection. By contrast, the LD_{50} for *Salmonella typhimurium*, also a mouse pathogen but a much less virulent one, is much higher than for *S. pneumoniae*, and the number of cells required to kill 100% of the population is much higher than the LD_{50}.

When pathogens are kept in laboratory culture and not passed through animals for long periods, their virulence is often decreased or even completely lost. Such organisms are said to be **attenuated.** Attenuation probably occurs because nonvirulent mutants may grow faster and, through successive transfers to fresh media, such mutants are selectively favored. Attenuation often occurs more readily when culture conditions are not optimal for the species. If an attenuated culture is reinoculated into an animal, virulent organisms are sometimes reisolated, but in many cases loss of virulence is permanent. Attenuated strains find frequent use in the production of vaccines, especially viral vaccines (Section 20.17). Measles and mumps vaccines, for example, are composed of attenuated viruses, as is the rabies vaccine given to domesticated animals.

CONCEPT CHECK 19.11

Virulence is determined by the invasiveness and toxigenicity of a pathogen. In most pathogens, a number of factors contribute to virulence. Attenuation is loss of virulence.

- ✔ *Why is* Streptococcus pneumoniae *highly virulent even though it produces no toxins?*
- ✔ *Suggest a method for producing an attenuated pathogen.*

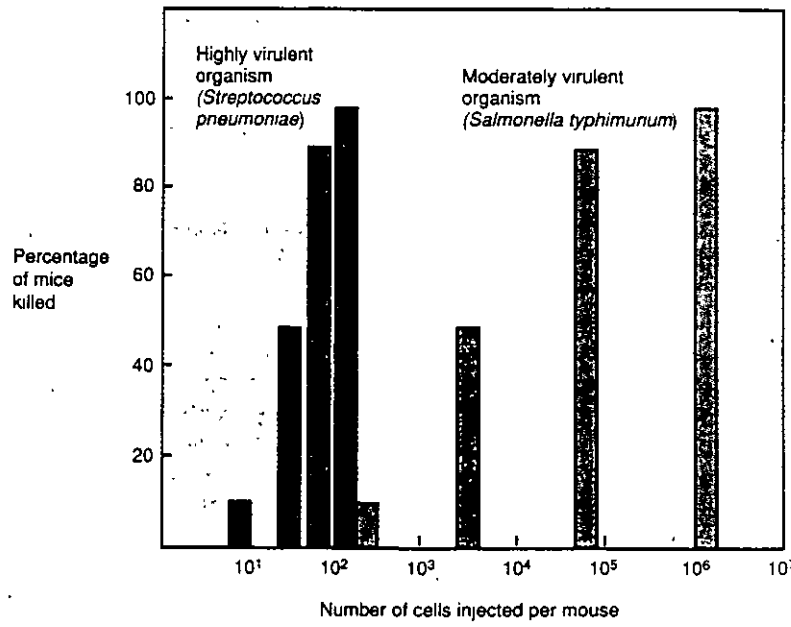


Figure 19.22 An example of differences in microbial virulence as shown by the number of cells of *Streptococcus pneumoniae* or *Salmonella typhimurium* required to kill a mouse population.

19.12
Nonspecific Host Defenses

Many of the mechanisms responsible for the suppression of pathogens are innate "resistance factors." These resistance factors can be divided into two categories: *specific* host defenses, which are directed against individual species or strains of pathogens, and *nonspecific* host defenses, directed against a variety of pathogens. In this chapter we consider the major *nonspecific* host defenses that have been identified as important in preserving the healthy state of the host. In the following chapter we consider *specific* host defenses—the immune response.

Natural host resistance

The ability of a particular pathogen to cause disease in different animal species is highly variable. In *rabies*, for instance, death usually occurs in all species of mammals once symptoms of the disease develop. Nevertheless, certain animal species are much more susceptible to rabies than others. Raccoons and skunks, for example, are extremely susceptible to rabies infection as compared to opossums, which are rarely linked to cases of rabies in wild animals. *Anthrax* infects a variety of animals and causes disease symptoms varying from mild pustules in humans to a fatal blood poisoning in cattle. However, birds are totally resistant to anthrax. Finally, diseases of warm-blooded animals are rarely transmitted to cold-blooded species, and vice versa. Why should this be so?

Resistance to certain diseases and susceptibility to others is an innate property of a given species and is governed by complex and interdependent factors. Differences in physiology and nutrition as well as anatomical differences are important, as is variation in tissue surface receptors, as discussed later. The net result is that different animal species, even very closely related species, may show completely different susceptibilities to the same disease agent.

Age, stress, and diet

Age is an important factor in susceptibility to infectious disease. Infectious diseases are more common in the very young and in the aged. In the infant, for example, development of an intestinal microflora occurs quite quickly, but the normal flora of a young infant is not the same as that of the adult. Before the development of an adult flora, and especially in the days immediately following birth, pathogens have a greater opportunity to become established and produce disease. Thus, diarrhea caused by enteropathogenic strains of *Escherichia coli* (∞ Section 23.13) or *Pseudomonas aeruginosa* is frequently encountered in infants under the age of 1 year. These organisms can be transmitted from the mother where they may be causing no ill effects because they have established a stable residence as part of the mother's flora. The undeveloped state of the infant's microflora provides poor competition for pathogenic species. As we discussed previously, infant botulism is encountered only in very young infants because establishment of the intestinal normal flora in older children precludes intestinal infection with *Clostridium botulinum*, which causes the disease (see Section 19.8).

In individuals over the age of 65, infectious diseases are much more common than in younger adults. For example, the elderly are much more susceptible to respiratory infections, particularly influenza (Section 23.4), probably because of a declining ability to make an effective immune response to respiratory pathogens In addition, anatomical changes associated with age may also encourage infection. Enlargement of the prostate gland, a common condition in men over the age of 50, frequently leads to a decreased urine flow. This, in turn, allows pathogens to colonize the male urinary tract (Figure 19.12) more readily, leading to an increase in these infections in elderly men.

Stress can predispose a normally healthy individual to disease. In studies with rats and mice, fatigue, exertion, poor diet, dehydration, or drastic climatic changes, all sources of physiological stress, increase the incidence and severity of infectious diseases. For example, rats subjected to intense physical activity for long periods of time show a higher mortality rate from experimental *Salmonella* infections than well-rested control animals. The interaction of hormones that are produced under stress with the immune system may play a role in stress-mediated disease. Hormonal balances change dramatically when an animal is placed under stressful conditions. The hormone *cortisone*, for example, is produced at much higher levels in times of stress than during calm periods, and this hormone is an effective anti-inflammatory agent. Suppression of inflammation removes one of the normal defenses against disease (see Section 19.13).

Diet plays a role in host resistance. The correlation between famine and infectious disease has been known for centuries. Protein shortages may alter the composition of the normal flora, thus allowing opportunistic pathogens a better chance to multiply. For example, cholera is much more prevalent in malnourished individuals than in well-nourished ones. On the other hand, the number of *Vibrio cholerae* required to cause infection is drastically reduced when the *V. cholerae* is ingested in food, presumably because the food neutralizes the stomach acids that would normally destroy the pathogen (∞ Section 23.14). Overeating may be harmful as well. Studies on clostridial diseases of sheep, in particular bloats caused by excessive gas accumulation, indicate that constant overeating affects the composition of the normal flora, leading to massive growth of bacterial species normally present in low numbers.

Not eating a particular substance needed by a pathogen may serve to prevent disease. The best exam-

ple here is the effect sucrose has on the development of dental caries. As explained in Section 19.3, absence of sucrose from the diet (along with good oral hygiene) virtually eliminates tooth decay. In the absence of sucrose, the highly cariogenic bacteria *Streptococcus mutans* and *S. sobrinus* are unable to synthesize the gummy outer surface polysaccharide needed to keep the bacterial cells attached to the teeth.

Anatomical defenses

The structural integrity of tissue surfaces poses a barrier to penetration by microorganisms. In the skin and mucosal tissues potential pathogens must not only bind to tissue surfaces but also grow at these sites before traveling elsewhere in the body. Intact surfaces form an effective barrier to colonization, but microbial access to damaged surfaces is more easily obtained. Resistance to colonization and invasion is due to the production of host defense substances and to various mechanical actions that disrupt colonization. A summary of the major anatomical defenses is shown in Figure 19.23.

The **skin** is an effective barrier to the penetration of microorganisms. *Sebaceous glands* in the skin (Figure 19.2) secrete fatty acids and lactic acid, which lower skin pH and inhibit colonization of pathogenic bacteria. Microorganisms inhaled through the *nose* or *mouth* are removed by the action of ciliated epithelial cells in mucous surfaces of the nasopharynx and tracheal regions. Cilia push bacterial cells upward until they are caught in oral secretions and either are expectorated or are swallowed and killed in the stomach. Potential pathogens entering the host via the oral route must first survive the *acidity* of the stomach (which is about pH 2) and then successfully compete with the increasingly abundant resident microflora present in the small intestine (which is about pH 5) and finally in the large intestine (pH 6–7). The latter organ contains bacterial numbers of about 10^{10} per gram of intestinal contents in a normal adult (see Section 19.4).

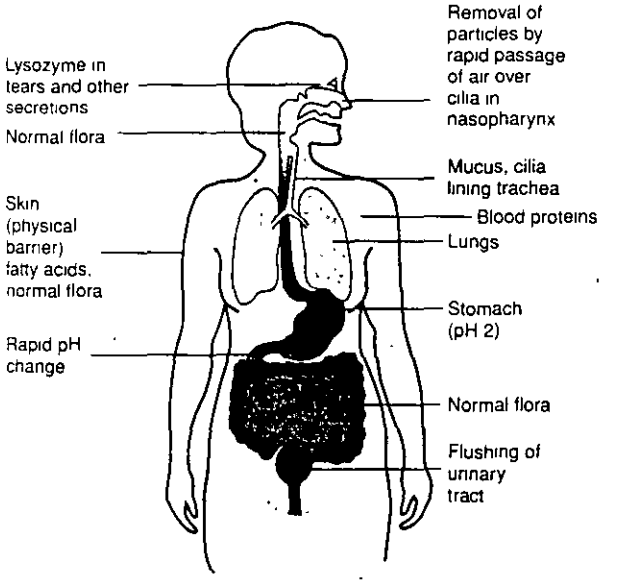


Figure 19.23 Anatomical barriers to infection.

In a healthy adult, the kidney and the surface of the eye are constantly bathed with secretions containing *lysozyme* that markedly reduce microbial populations. Extracellular fluids such as blood plasma also contain bactericidal substances. For example, blood proteins called β-lysins bind and destroy microbial cells. β-Lysins are basic proteins that act by disrupting the bacterial cytoplasmic membrane, leading to leakage of cytoplasmic constituents and cell death.

However effective these defenses may be, damage to physical barriers and changes in other nonspecific defenses can quickly lead to growth of the pathogen and initiation of disease.

Tissue specificity

Most pathogens must first establish themselves at the site of infection. If the site is not compatible with their nutritional and environmental needs, the organisms cannot multiply. Thus, if *Clostridium tetani* were ingested, it would not bring about tetanus because the pathogen is killed by the acidity of the stomach. If, on the other hand, *C. tetani* cells were introduced into a deep wound, the organism would grow in the anaerobic zones created by localized tissue destruction and produce tetanus toxin (see Section 19.8). By contrast, enteric bacteria such as *Salmonella* and *Shigella* do not cause wound infections but successfully colonize the intestinal tract. Table 19.6 summarizes a number of examples of tissue specificity.

The compromised host

The term *compromised host* refers to hosts in which one or more resistance mechanisms are malfunctioning and in which the probability of infection is therefore increased.

Hospital patients are often compromised hosts. Many hospital procedures such as catheterization, hypodermic injection, spinal puncture, and biopsy can also introduce pathogens into the patient. Surgical procedures expose highly susceptible parts of the body to sources of contamination. The stress of surgery also diminishes the resistance of the patient to infection. Finally, in organ transplant procedures (∞ Section 20.7), drugs are used that suppress the immune system to prevent rejection of the transplant. Immunosuppressive drugs greatly increase susceptibility to infection. Thus, many hospital patients with noninfectious primary ailments (for example, cancer and heart disease) die of microbial infection because they are compromised hosts (∞ Section 22.7).

Compromised hosts exist even outside the hospital. Smoking, excess consumption of alcohol, intravenous drug usage, lack of sleep, poor nutrition, and infection itself are condition that compromise a host.

TABLE 19.6 Tissue specificity as a factor in infectious disease

Disease	Tissue infected	Organism
Diphtheria	Throat epithelium	*Corynebacterium diphtheriae*
Gonorrhea	Urogenital epithelium	*Neisseria gonorrhoeae*
Cholera	Small intestine epithelium	*Vibrio cholerae*
Pyelonephritis	Kidney medulla	*Proteus* sp.
Dental caries	Oral epithelium	*Streptococcus mutans, S. sobrinus, S. sanguis, S. mitis*
Spontaneous abortion (cattle)	Placenta	*Brucella abortus*
Acquired immunodeficiency syndrome (AIDS)	T helper lymphocytes	Human immunodeficiency virus (HIV)
Malaria	Blood (erythrocytes)	*Plasmodium* sp

For instance, the virus causing acquired immunodeficiency syndrome (AIDS) destroys one type of cell involved in the immune response (T helper cells). Therefore, AIDS patients are unable to mount effective resistance to infection; death is generally due to some infectious agent (∞ Sections 22.4 and 23.7).

Finally, there are certain genetic conditions that may compromise the host, such as genetic diseases that eliminate important parts of the immune system. Individuals with such conditions frequently die at an early age, not from the genetic condition itself but from microbial infection.

CONCEPT CHECK 19.12

Nonspecific physical, anatomical, and chemical barriers prevent colonization of the host by most pathogens. Breakdown in these defenses results in a compromised host who is more susceptible to infection.

- ✔ *How can diet influence host resistance to a pathogen?*
- ✔ *How might smoking compromise an otherwise healthy host?*

19.13 Inflammation and Fever

Inflammation is a general nonspecific reaction to foreign particles and other noxious stimuli such as toxins and pathogens. The characteristic inflammatory response results in redness, swelling, pain, and heat, all localized at the site where the host contacted the noxious stimuli (∞ Section 23.3 and Figure 20.32). The mediators of inflammation include a group of proteins called *cytokines* (∞ Section 20.8), which are produced by white blood cells or *leukocytes* (∞ Section 20.3). Leukocytes are also involved in pathogen-specific responses to noxious stimuli in the immune response, which we will discuss in Chapter 20. The most important outcome of the inflammatory response is the immediate localization of the noxious agent, often by the production of a fibrin clot at the site of inflammation.

Inflammation is one of the most important and ubiquitous aspects of host defense against invading microorganisms. However, inflammation is also an important aspect of microbial pathogenesis because the inflammatory response elicited by an invading microorganism can result in considerable host damage.

Fever

The healthy human body maintains a surprisingly constant temperature. Over an average 24-hr period, body temperature varies over the narrow range of 1–1.5°C. However, individuals vary in their "normal" temperatures, and although 37°C is considered the standard normal temperature, the actual normal temperature in some individuals may be as low as 36°C or as high as 38°C. Also, body temperature varies with the amount of physical activity and can be as much as 2°C below normal in sleep and as much as 4°C above normal during strenuous exercise.

Fever is defined as an abnormal increase in body temperature. Although fever can be caused by noninfectious disease, most fevers are caused by infection. At least one reason why fever occurs during many infections is that certain products of pathogenic organisms are *pyrogenic* (fever-inducing). The most well-studied pyrogenic agents are the endotoxins of gram-negative Bacteria (see Section 19.10). However, many organisms that do not produce endotoxins are able to cause fever on infection. In these organisms, proteins known as *endogenous pyrogens* are released when leukocytes destroy them (∞ Section 20.3). Slight temperature increases benefit the host by accelerating phagocytic and antibody responses, while strong fevers of 40°C (104°F) or greater may benefit the pathogen if host tissues are further damaged.

Three kinds of characteristic fever patterns have been recognized in infectious disease. (1) *Continuous fever* is that condition in which the body temperature

remains elevated over a whole 24-hr period and the total range of variation in temperature is less than 1°C. Continuous fever is seen in *typhoid fever* (∞ Section 23.13) and *typhus fever* (∞ Section 23.9). (2) A *remittent fever* is one in which the body temperature is abnormal over the whole of a 24-hr period and the daily range shows swings greater than 1°C. This occurs in some *pyogenic infections* (∞ Section 23.2) and in *tuberculosis* (∞ Section 23.3). (3) An *intermittent fever* is one in which the temperature is normal for part of the day and then rises above normal. Most infectious diseases elicit some intermittent fever, and the condition is a diagnostic characteristic of malaria (∞ Section 23.11), a protozoan infection. *Relapsing fever,* caused by various *Borrelia* species (∞ Sections 23.9 and 16.12) is an intermittent fever in which the temperature remains normal for a long period of time, followed by a new attack of fever. This is characteristic of an incomplete recovery from an infectious disease, the fever arising when the infection periodically reestablishes itself.

CONCEPT CHECK 19.13

Inflammation and fever are nonspecific responses to noxious stimuli such as pathogens. These host responses can result in accelerated isolation and destruction of the pathogen.

- ✔ *Describe the chief symptoms of inflammation.*
- ✔ *Describe the three types of fever*

Material for Review

REVIEW QUESTIONS

1. Distinguish between a parasite and a pathogen. Distinguish between infection and disease.
2. Which parts of the human body are normally heavily colonized with microorganisms? Which body parts are normally devoid of microorganisms?
3. Distinguish between the resident and transient microorganisms at a body site. How could you distinguish between resident and transient microorganisms experimentally?
4. Why are members of the genus *Streptococcus* instrumental in forming dental caries?
5. What region of the gastrointestinal tract has the highest concentrations of bacteria? What region has the lowest concentrations? Why?
6. Describe the relationship between *Lactobacillus acidophilus* and glycogen in the vaginal tract.
7. Give two examples of adherence factors important for pathogen attachment. At least one example should not be a protein.
8. What do hyaluronidase, collagenase, streptokinase, and coagulase have in common? What is the mode of action of each in promoting disease?
9. Define and contrast exotoxin, enterotoxin, and endotoxin. Give two examples of each and the name of an organism producing each.
10. For each of the exotoxins listed below, describe (i) the producing organism, (ii) the mode of action in the host, (iii) its role in pathogenicity, and (iv) how its effects can be counteracted. (a) Diphtheria toxin, (b) tetanus toxin, (c) botulinum toxin, (d) cholera toxin.
11. Give an example of a microorganism that is pathogenic almost solely because of its toxin-producing ability. Give an example of a microorganism that is pathogenic almost solely because of its invasive characteristics.
12. How do temperature and pH work to limit bacterial infections? What organisms might be susceptible to either of these agents?
13. Distinguish between a continuous fever and an intermittent fever. Which type most commonly occurs in infectious diseases?

APPLICATION QUESTIONS

1. Describe experiments to demonstrate the effects of mucus in protection against bacterial colonization.
2. What steps are involved in the formation of dental plaque? Describe and discuss experiments that demonstrate the buildup of plaque on toothlike surfaces and discuss experiments designed to illustrate biological methods for removal of plaque.
3. Obligately anaerobic bacteria are very common in the large intestine, yet they are able to grow there only if facultatively aerobic bacteria are also present. Explain. How could you test the validity of your answer in the laboratory?
4. Certain antibiotics, even antibiotics whose mode of action is bacteriostatic instead of bactericidal, sterilize

the intestinal tract. How could a bacteriostatic antibiotic bring about this result?

5. Design an experiment to demonstrate the likely route of infection of a urinary tract pathogen in a catheterized patient.
6. Describe how enteropathogenic strains of *Escherichia coli* differ from normal strains of *E. coli*. Include a discussion of structural and ecological variables.
7. Although mutants incapable of producing exotoxins are relatively easy to isolate, mutants incapable of producing endotoxin are much harder to isolate. From what you know of the structure and function of these types of toxins, explain the differences in mutant recovery.
8. Should fever always be treated? Give reasons for your answer based on your knowledge of the importance of the inflammatory response in limiting the spread of infection

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On-line resources for this chapter are on the World Wide Web at:
http://www.prenhall.com/~brock (click on the table of contents link and then select Chapter 19).

MINIGLOSSARY for Chapter 21

Agglutination reaction between antibody and particle-bound antigen, resulting in visible clumping of the particles

Bacteremia the presence of bacteria in the blood

Complement Fixation the consumption of complement by an antibody–antigen reaction

ELISA *e*nzyme-*l*inked *i*mmunosorbent *a*ssay

Fluorescent Antibody covalent modification of an antibody molecule with a fluorescent dye; the dye makes the antibody visible under fluorescent light

Gonococcus *Neisseria gonorrhoeae*, the gram-negative diplococcus that causes gonorrhea

Immunoblot (Western Blot) electrophoresis of proteins followed by transfer to a membrane and detection by addition of specific antibodies

Nucleic Acid Probe in clinical microbiology, a short oligonucleotide of unique sequence used as a hybridization probe for identifying pathogens (see Chapter 6 for general usage)

Precipitation reaction between antibody and a soluble antigen resulting in a visbible, insoluble complex

RIA *r*adio*i*mmuno*a*ssay

Septicemia blood infection

Titer in an immunological context, the quantity of antibody present in a solution

The most important activity of the microbiologist in medicine is to isolate and identify the agents that cause infectious disease. This major area of microbiology is called **clinical** or **diagnostic microbiology.** There is increasing awareness of the importance of precise identification of the pathogen for proper treatment of infectious disease, and new sophisticated methods are being continually developed. Clinical laboratories are generally able to isolate, identify, and determine the antibiotic sensitivity of most routinely encountered pathogenic bacteria within 48 hr of sampling. However, recent advances in rapid diagnostic methods have made it possible to identify some pathogens in minutes and antibiotic susceptibility patterns in hours. Diagnostic methods based on immunological and molecular biology methods make it possible to identify many pathogens without culturing the organism at all. This is particularly important for the diagnosis of viral and protozoal infections, diseases that are typically difficult to identify because of the difficulty of culturing the agent. The clinical microbiologist works with and advises the physician in matters relating to the diagnosis and treatment of infectious diseases.

21.1

Isolation of Pathogens from Clinical Specimens

The physician, following clinical examination of the patient, may suspect that an infectious disease is present. Samples of infected tissues or fluids are then collected for microbiological, immunological, and molecular biological analyses (Figure 21.1). Depending on the kind of infection, materials collected may include blood, urine, feces, sputum, cerebrospinal fluid, or pus. A sterile swab may be passed across a suspected infected area (Figure 21.2). The swab is then streaked over the surface of an agar plate or placed directly in a liquid culture medium. In some cases, small pieces of living tissue may be aseptically removed (biopsy) for culture. Table 21.1 summarizes current recommendations for culture of organisms isolated from typical clinical specimens.

If clinically relevant organisms are to be isolated and a correct diagnosis made, care must be taken in obtaining samples of clinical specimens. The phy ı must ensure that the specimen is removed fro ɛ *actual site of the infection.* Recovery or detection of pathogens may not be possible if insufficient inoculum is available. The sample must also be taken under aseptic conditions so that contamination is avoided. Care must also be taken to ensure that metabolic requirements for certain organisms, such as anoxic conditions, are maintained. Once taken, the sample is analyzed as soon as possible. If it cannot be analyzed immediately, it is usually refrigerated to slow down deterioration In the rest of this section, we describe some of the most common microbiological procedures used to obtain and culture microorganisms in the clinical laboratory.

Blood cultures

Bacteremia means the presence of bacteria in the blood (Section 19.7). Bacteria are normally cleared from the bloodstream rapidly. Therefore, bacteremia is uncommon in healthy individuals, and the presence of bacteria in the blood is generally indicative of systemic infection. The most common pathogens found in blood include *Pseudomonas aeruginosa*, enteric bacteria, especially *Escherichia coli* and *Klebsiella pneumoniae*, and the gram-positive cocci *Staphylococcus aureus* and *Streptococcus pyogenes*. The classic type of blood infection is **septicemia,** resulting from a virulent org ı entering the blood from a focus of infection, multiplying, and traveling to various body tissues to initiate

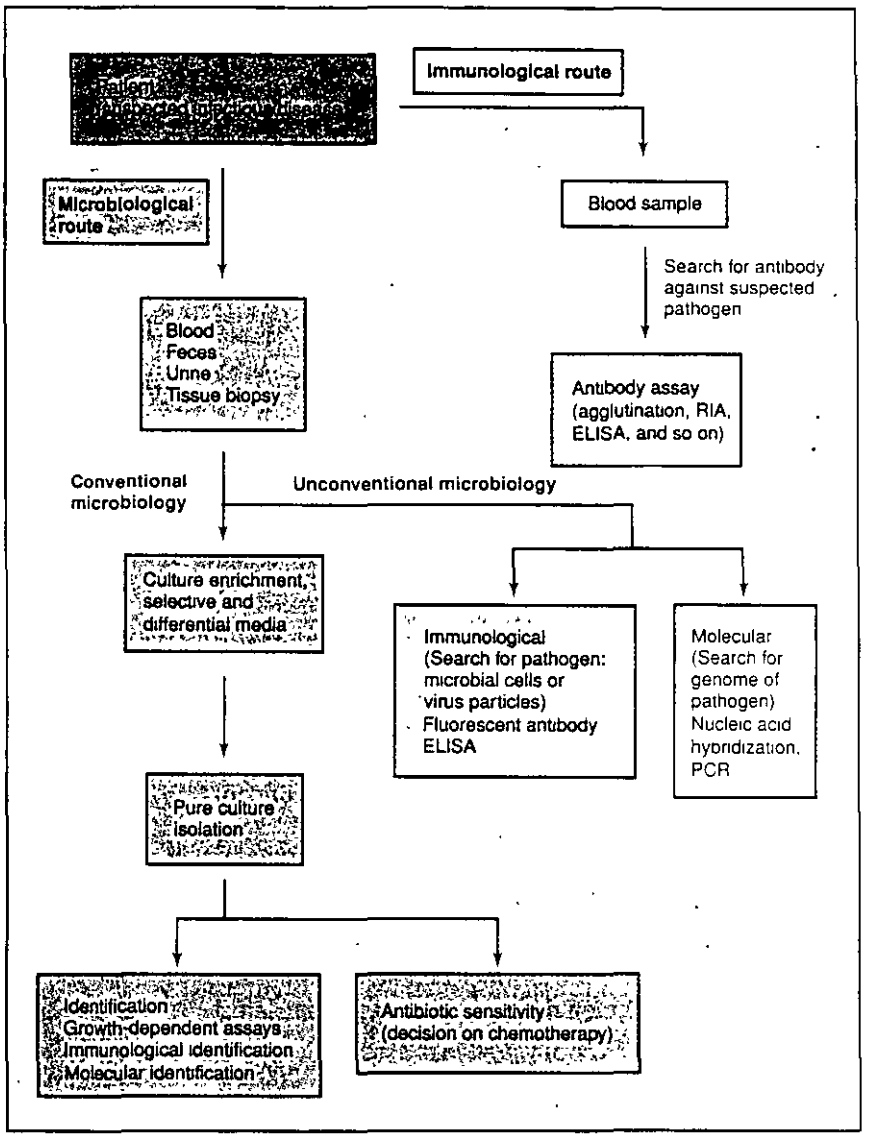

Figure 21.1 Clinical and diagnostic methods used for isolation and identification of infectious pathogens.

new infections. Septicemia is indicated by the presence of severe systemic symptoms, usually with fever and chills, followed by prostration. In many disease situations, culture of the blood provides the only immediate way of isolating and identifying the causal agent, and diagnosis therefore depends on careful and proper blood culture.

The standard blood culture procedure is to remove 10 ml of blood aseptically from a vein and inject it into a blood culture bottle containing an anticoagulant and

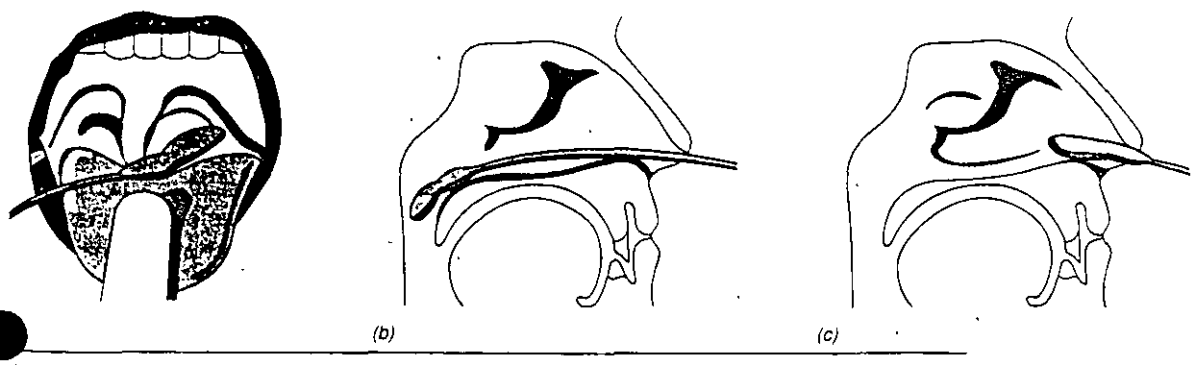

Figure 21.2 Methods for obtaining specimens from the upper respiratory tract. (a) Throat swab. (b) Nasopharyngeal swab passed through the nose. (c) Swabbing the inside of the nose.

TABLE 21.1 Recommended enrichment media for primary isolation purposes in a clinical microbiology laboratory[a]

Specimen	Media[b]				
	Blood agar	Enteric agar	CA	TM	Anaerobic agar
Fluids: chest, abdomen, pericardium	+	+	+	−	+
Feces: rectal swabs	+	+	+	−	−
Surgical tissue biopsies: lung, lymph nodes	+	+	−	−	+
Throat: swabs, sputum, tonsil, nasopharynx	+	+	+	−	−
Genitourinary swabs: urethra, vagina, cervix	+	+	+	+	−
Urine	+	+	−	−	−
Blood	+	−	−	−	+
Swabs: wounds, abscesses, exudates	+	+	+	−	+

[a]Data from Murray, P. R., E. J. Baron, M. A. Pfaller, F. C. Tenover, and R. H. Yolken. 1995. *Manual of Clinical Microbiology*, 6th edition. American Society for Microbiology, Washington, DC.

[b]Blood agar, 5% whole sheep blood added to trypticase soy agar; enteric agar, either eosin–methylene blue (EMB) agar or MacConkey agar; CA, chocolate (heated blood) agar; TM, Thayer–Martin agar; anaerobic agar, thioglycolate-containing blood agar or supplemented thioglycolate agar incubated anaerobically.

an all-purpose culture medium. Two cultures are set up with one bottle being incubated aerobically and one anaerobically. Media used are all relatively rich, containing protein digests and other complex ingredients. Blood culture bottles are incubated at 35°C and examined daily for up to 7 days. Most clinically significant bacteria are recovered within this period. Some blood isolation systems employ a chemical that lyses red and white blood cells, releasing potential intracellular pathogens that might otherwise be overlooked. Microorganisms in blood cultures are commonly detected by visual inspection (turbidity), microscopic examination, and subculture. Automated blood culture systems detect growth by continuously monitoring carbon dioxide production and turbidity.

Because a certain amount of skin contamination is unavoidable during initial drawing of the blood, a contamination rate of 2–3% can be expected. Contamination may be indicated if certain organisms commonly found on the skin are isolated, such as *Staphylococcus epidermidis*, coryneform bacteria, or propionibacteria, although even these organisms can occasionally cause infection of the wall of the heart (subacute bacterial endocarditis). Thus, considerable microbiological and clinical experience is necessary when interpreting blood cultures.

Urine cultures

Urinary tract infections are very common, and because the causal agents are often identical or similar to bacteria of the normal flora (for example, *Escherichia coli*), considerable care must be taken in the bacteriological analysis of urine. Since urine supports extensive bacterial growth under many conditions, fairly high cell numbers are often found in urinary infection. In most cases, the infection occurs as a result of an organism ascending the urethra from the outside. Occasionally, even the bladder may become infected. Urinary tract infections are the most common form of *nosocomial* (hospital-acquired) infection (∞ Section 22.7).

Significant urinary infection generally results in bacterial counts of 10^5 or more organisms per milliliter of a clean-voided midstream specimen, whereas in the absence of infection, contamination of the urine from the external genitalia (almost unavoidable to some extent) results in less than 10^3 organisms per milliliter. The most common urinary tract pathogens are members of the enteric bacteria, with *E. coli* accounting for about 90% of the cases. Other urinary tract pathogens include *Klebsiella, Enterobacter, Proteus, Pseudomonas, Staphylococcus saprophyticus,* and *Enterococcus faecalis. Neisseria gonorrhoeae,* the causal agent of gonorrhea, does not grow in the urine itself, but in the urethral epithelium, and must be diagnosed by different methods (see later).

Direct microscopic examination of urine may be used to indicate *bacturia*, the presence of abnormal numbers of bacteria in the urine. However, because nearly all urine contains some level of bacterial growth, significant bacturia is most commonly monitored by using a variety of commercially available dipstick tests. For example, one dipstick test monitors the reduction of nitrate by detecting the reduction product, nitrite. A positive test is indicated by a color change on the dipstick (Figure 21.3). Since nitrite production occurs only when significant numbers ($>10^5$ per milliliter) of enteric organisms are present, the method is a virtually instantaneous check for urinary tract infections. Other dipstick tests for urinary tract infections, often used in conjunction with nitrate reduction, detect esterase (produced by leukocytes) (∞ Section 20.3) and peroxidase (produced by a variety of bacteria) (∞ Sections 5.11 and 13.24). A positive dipstick test is then followed by a urine culture.

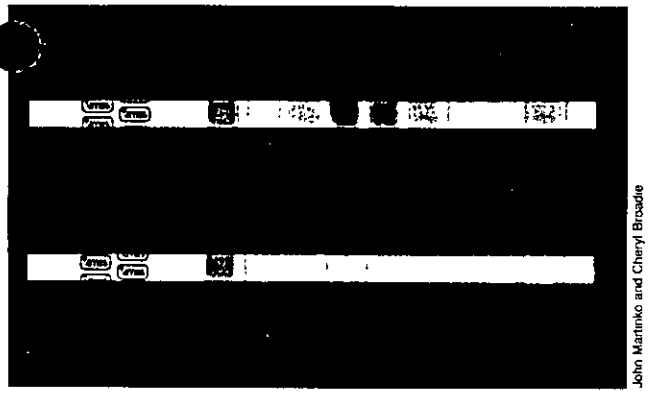

Figure 21.3 Urinalysis dipstick test. A control strip is shown underneath the test strip. From left to right, the strip measures abnormal levels of glucose, bilirubin, ketones, specific gravity, blood, pH, protein, urobilinogen, nitrite, and leukocytes (esterase) in a urine sample. Abnormal readings for esterase (trace positive, far right) and nitrite (strong positive, second from right) indicate bacturia. Subsequent culture of this sample indicated the presence of *Escherichia coli*.

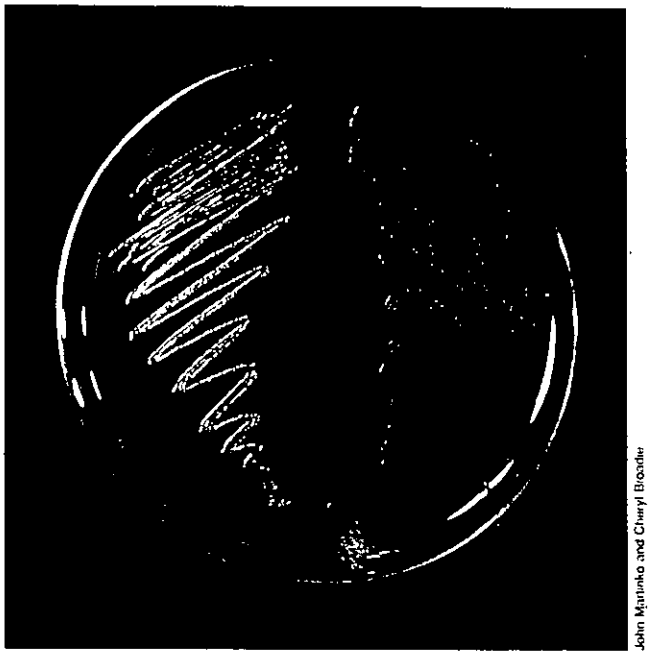

Figure 21.4 An eosin–methylene blue (EMB) agar plate showing a lactose fermenter, *Escherichia coli* (left), and a nonlactose fermenter, *Pseudomonas aeruginosa* (right). Note the green metallic sheen of the *E. coli* colonies.

To culture potential urinary tract pathogens, two media are used: blood agar as a nonselective general medium, and a medium selective for enteric bacteria, such as MacConkey or eosin–methylene blue agar (EMB) (see Section 21.2 and Figure 21.4). These specialized media permit the initial differentiation of lactose fermenters from nonfermenters, and the growth of gram-positive organisms such as *Staphylococcus* spp. (common skin contaminants) is inhibited. Organisms isolated can be identified, and antibiotic susceptibility tests performed. Experienced clinical microbiologists may make a tentative identification of an isolate by observing the color and morphology of colonies of the suspected pathogen grown on various selective media as described in Table 21.2. Such an identification must be followed up with more detailed analyses, but clinical microbiologists use this information in conjunction with more detailed test results, discussed throughout the remainder of this chapter, to make a positive identification.

Finally, if no bacterial growth is obtained in spite of persistent urinary tract infection symptoms, a clinician may request direct cultures for a number of fastidious organisms, especially *Neisseria gonorrhoeae, Chlamydia trachomatis, Branhamella* spp., mycoplasma, or several anaerobic organisms (∞ Section 23.6).

Fecal cultures

Proper collection and preservation of feces is important in the isolation of intestinal pathogens. During storage, the pH of feces drops, and thus an extended delay between sampling and sample processing must be avoided. This is especially critical for the isolation of *Shigella* and *Salmonella* species, both of which are rather sensitive to acid pH. Samples, collected from feces freshly voided into a sterile plastic cup, are placed in a vial containing phosphate buffer for transport to the lab. If a patient has a bloody or pus-containing stool, this material is always sampled; such discharges generally contain a large number of the organisms of interest. In the case of suspected foodborne or waterborne infections, fecal samples should be inoculated into a variety of selective media (see Section 21.2) for the isolation of specific bacteria or characterization of intestinal parasites. Positive identifications are made by the techniques described in later sections.

Wounds and abscesses

Infections associated with traumatic injuries such as animal or human bites, burns, cuts, or the penetration of foreign objects, must be carefully sampled in order to recover the relevant pathogen. This is because wound infections and abscesses are frequently contaminated with members of the normal flora. Swab samples of such lesions are frequently misleading. The best sampling method is to aspirate purulent (pus-containing) lesions with a sterile syringe and needle following disinfection of the skin surface with 70% ethyl or isopropyl alcohol. Internal purulent discharges are usually sampled by biopsy or from tissues removed in surgery.

A variety of pathogens can be associated with wound infections, and because some of these are anaerobes, samples should be transported from the collection site under anaerobic conditions. A common pathogen

TABLE 21.2 Colony characteristics of frequently isolated gram-negative rods cultured on various clinically useful media[a]

Organism	Agar media[b]			
	EMB	MC	SS	BS
Escherichia coli	Dark center with greenish metallic sheen (see Figure 21.4)	Red or pink	Red to pink	Mostly inhibited
Enterobacter	Similar to *E. coli*, but colonies are larger	Red or pink	White or beige	Mucoid colonies with silver sheen
Klebsiella	Large, mucoid, brownish	Pink	Red to pink	Mostly inhibited
Proteus	Translucent, colorless	Transparent, colorless	Black center, clear periphery	Green
Pseudomonas	Translucent, colorless to gold (see Figure 21.4)	Transparent, colorless	Mostly inhibited	No growth
Salmonella	Translucent, colorless to gold	Translucent, colorless	Opaque	Black to dark green
Shigella	Translucent, colorless to gold	Transparent, colorless	Opaque	Brown or inhibited

[a]Adapted from Murray, P. R., E. J. Baron, M. A. Pfaller, F. C. Tenover, and R. H. Yolken 1995. *Manual of Clinical Microbiology*, 6th edition American Society for Microbiology, Washington, DC.

[b]BS, Bismuth sulfite agar; EMB, eosin–methylene blue agar; MC, MacConkey agar; SS, *Salmonella–Shigella* agar.

associated with purulent discharges is *Staphylococcus aureus*, but enteric bacteria, *Pseudomonas aeruginosa*, and the anaerobes *Bacteroides* and *Clostridium* species are also commonly encountered. The major isolation media are blood agar, several selective media for enteric bacteria (Tables 21.1 and 21.2), and blood agar containing additional supplements and reducing agents for obligate anaerobes. Smears from such specimens should also be examined directly by microscopy.

Genital specimens and the laboratory diagnosis of gonorrhea

In males, a purulent urethral discharge is the classic symptom of the sexually transmitted disease gonorrhea (∞ Section 23.6). If no discharge is present, a suitable sample can be obtained using a sterile narrow-diameter cotton swab that is inserted into the anterior urethra, left in place a few seconds to absorb any exudate, and then removed for culture of *Neisseria gonorrhoeae*, the causative agent of gonorrhea. Alternatively, a sample of the first early morning urine of an infected individual usually contains viable cells of *N. gonorrhoeae*. In females suspected of having gonorrhea or other genital infections, samples are usually obtained by swab from the cervix and the urethra.

Gonorrhea is one of the most common infectious diseases in adults, and clinical microbiological procedures are central to its diagnosis. *N. gonorrhoeae* (referred to clinically as the *gonococcus*) colonizes mucosal surfaces of the urethra, uterine cervix, anal canal, throat, and conjunctiva. The organism is quite sensitive to drying and therefore is transmitted almost exclusively by direct person-to-person contact, usually by sexual intercourse. The major goal of public health measures to control gonorrhea involves identification of asymptomatic carriers, and this requires microbiological analysis.

Because the gonococcus is a gram-negative coccus, usually observed as diplococci, and similar organisms are not very common in the normal flora of the urogenital tract, direct microscopy of Gram-stained material is of value. For example, observation of gram-negative diplococci in a urethral discharge or in a vaginal or cervical smear is presumptive evidence for gonorrhea. In acute gonorrhea, microscopy usually reveals phagocytized gram-negative diplococci in the polymorphonuclear leukocytes (∞ Section 20.3), with virtually no other organisms present (Figure 21.5*a*).

Cultural procedures have a higher degree of sensitivity than microscopic analyses. Most media for the culture of *N. gonorrhoeae* contain heated blood or hemoglobin (referred to as *chocolate agar* because of its deep brown appearance), the heating causing the formation of a precipitated material, which is quite effective in absorbing toxic products present in the agar and other media constituents. A second primary isolation medium, called *Thayer–Martin agar*, also is used for isolation of *N. gonorrhoeae* (Figure 21.5*b*). This medium incorporates the antibiotics vancomycin, nystatin, and

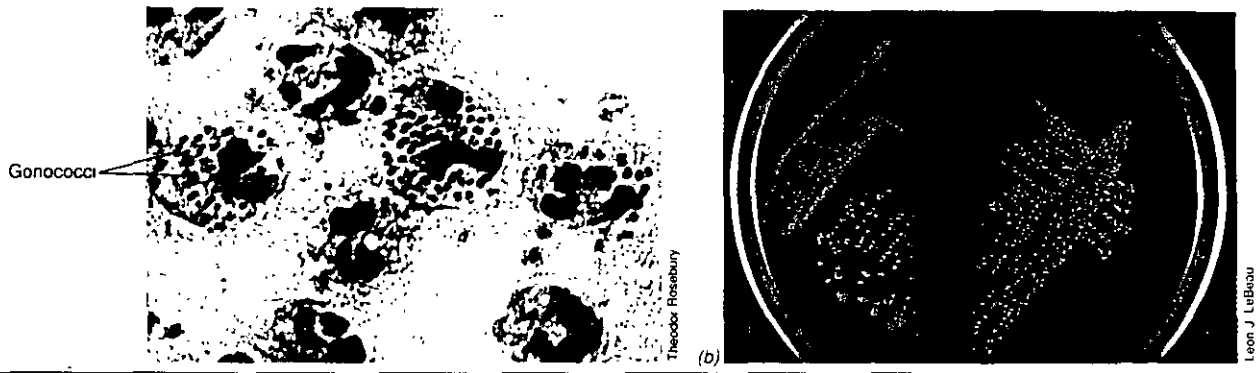

Figure 21.5 (a) Photomicrograph of *Neisseria gonorrhoeae* within human polymorphonuclear leukocytes from a cervical smear. Note how many cells are in pairs as diplococci (arrows). (b) Colonies of *N. gonorrhoeae* growing on Thayer–Martin agar. The plate has been stained in the middle with a reagent that turns colonies blue if cells contain cytochrome *c* (the oxidase test).

colistin, to which most clinical isolates of *N. gonorrhoeae* are naturally resistant.

After streaking, the plates must be incubated in a humid environment in an atmosphere containing 3–7% CO_2 (CO_2 is required for growth of gonococci). The plates are examined after 24 and 48 hr, and portions of colonies should be immediately tested by the oxidase test because all *Neisseria* are oxidase-positive (see Section 21.2). Oxidase-positive gram-negative diplococci growing on chocolate agar can be presumed to be gonococci if the culum was derived from genitourinary sources, but definitive identification requires determination of carbohydrate utilization patterns or immunological or nucleic acid probe tests (see Sections 21.4–21.10).

A rapid test employing chromogenic substrates has been developed for differentiating *N. gonorrhoeae* from other species of *Neisseria*. With the use of colonies on plates, various species can be differentiated by the substrate color reaction obtained following incubation of the test medium with bacterial cells. The test is designed to detect the presence of specific enzymes present in one species of *Neisseria* but absent in the others. The enzymes act on substrates that yield colored products. A simple, sensitive, highly specific nucleic acid probe test (see Section 21.10) has also been developed for identifying *N. gonorrhoeae*.

Culture of anaerobes

Obligately anaerobic bacteria are common causes of infection and are completely missed in clinical diagnosis unless special precautions are taken for their isolation and culture. We have discussed anaerobes in general in Section 5.11, and we noted that many anaerobes are extremely susceptible to oxygen. Because of this, specimen collection, handling, and processing require special if an obligate anaerobe may be involved. There are al habitats in the body (for example, the oral cavity and the intestinal tract) (∞ Sections 19.3 and 19.4) that are generally anoxic and in which obligately anaerobic bacteria can be found as part of the normal flora. However, other parts of the body can become anoxic as a result of tissue injury or trauma, which results in reduction of blood supply to the injured site. These anaerobic sites are then available for colonization by obligate anaerobes. In general, pathogenic anaerobic bacteria are part of the normal flora and are only opportunistic pathogens, although two important pathogenic anaerobes, *Clostridium tetani* (causal agent of tetanus) and *C. perfringens* (causal agent of gas gangrene and one type of food poisoning), both endospore-forming Bacteria, are predominantly soil organisms.

With anaerobic culture, the microbiologist is presented not only with the usual problems of obtaining and maintaining an uncontaminated specimen but also with ensuring that the specimen not come in contact with air. Samples, collected by suction or biopsy, must be immediately placed in a tube containing oxygen-free gas, preferably containing a small amount of a dilute salts solution with a reducing agent such as thioglycolate and the redox indicator resazurin. This dye is colorless when reduced and becomes pink when oxidized, thus quickly indicating any oxygen contamination of the specimen. If a proper anaerobic transport tube is not available, the syringe itself can be used to transport the specimen, the needle being inserted into a sterile rubber stopper so that no air is drawn into the syringe.

For anaerobic incubation, agar plates are placed in a sealed jar, which is made anoxic by either replacing the atmosphere in the jar with an oxygen-free gas mixture (a mixture of N_2 and CO_2 is frequently employed) or by adding some compound to the enclosed vessel that removes O_2 from the atmosphere. For example, as shown in Figure 21.6, H_2 is generated and, in the presence of a suitable catalyst, usually palladium, the H_2 is combined with free O_2 to form H_2O, thus removing the contaminating oxygen. Alternative means for providing

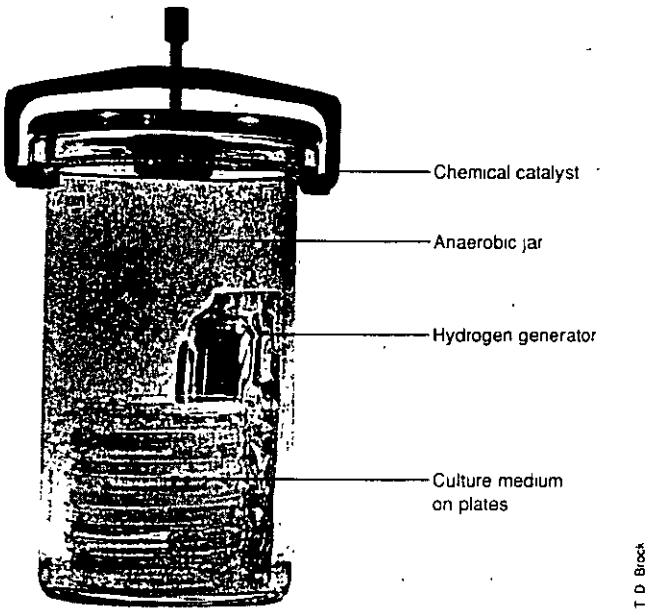

Figure 21.6 Sealed jar for incubating cultures under anoxic conditions.

anaerobic conditions include the use of culture media containing reducing agents and the use of anaerobic glove boxes. The latter are large gas-impermeable bags filled with an oxygen-free gas such as nitrogen or hydrogen that are fitted with an airlock for inserting and removing cultures (∞ Figure 5.22). The advantage of an anaerobic glove box is that manipulations can be done as one would normally perform them on a laboratory bench. However, because of their expense, anaerobic glove boxes are not employed extensively in clinical laboratories but are in widespread use in research laboratories that specialize in anaerobic microorganisms.

In general, media for anaerobes do not differ greatly from those used for aerobes, except that they are generally richer in organic constituents, and contain reducing agents (usually cysteine or thioglycolate) and a redox indicator such as resazurin. Once positive cultures have been obtained, they must be characterized and identified, to be certain that the isolate is not a member of the normal flora.

CONCEPT CHECK 21.1

Culture of the suspected pathogen is the most reliable way to identify an organism that causes a disease. For successful microbial culture, the growth needs of the organisms must be met. This requires knowledge of bacterial physiology and nutrition. A variety of rapid tests that do not require microbial culture are also being developed and used to identify pathogens.

- ✔ *Why are urine cultures almost always positive for bacterial growth?*
- ✔ *Describe the specialized methods and precautions necessary for successful isolation of anaerobic pathogens.*

21.2 Growth-Dependent Identification Methods

If the inoculation of a primary medium results in bacterial growth, the clinical microbiologist must identify the organism or organisms present. Identification of a clinical isolate can frequently be made using a variety of growth-dependent assays. We discuss some of these methods here.

Growth on selective and differential media

On the basis of growth characteristics in primary isolation media, a clinical microbiologist subcultures an unknown pathogen on perhaps several of the dozens of available, diagnostically useful culture media. In many large hospitals and clinics, media are purchased from commercial sources, which ensures quality control and reliable testing in different clinical settings (Figure 21.7). Many of these media are available in miniaturized kits containing a number of different media in separate wells, all of which can be inoculated at one time (Figure 21.7*d* and *e*).

The battery of media employed are selective, differential, or both. A *selective medium* is one to which compounds have been added to selectively inhibit the growth of certain microorganisms but not others. A *differential medium* is one to which some sort of indicator, usually a dye, has been added, which allows the clinician to differentiate between various chemical reactions carried out during growth. Eosin–methylene blue (EMB) agar, for example, is a widely used selective *and* differential medium. EMB agar is used for the isolation of gram-negative enteric Bacteria. The methylene blue is present to inhibit gram-positive Bacteria; although the mechanism is unclear, small amounts of this dye effectively inhibit the growth of most gram-positive Bacteria. Eosin is a dye that responds to changes in pH, going from colorless to black under acidic conditions. EMB agar medium contains lactose and sucrose, but not glucose, as energy sources. Lactose-fermenting (generally enteric) bacteria, such as *Escherichia coli*, *Klebsiella*, and *Enterobacter*, acidify the medium and the colonies appear black with a greenish sheen. Colonies of lactose nonfermenters, such as *Salmonella*, *Shigella*, and *Pseudomonas*, are translucent or pink (Figure 21.4).

In the battery of tests performed to help identify an organism, many different biochemical reactions can be

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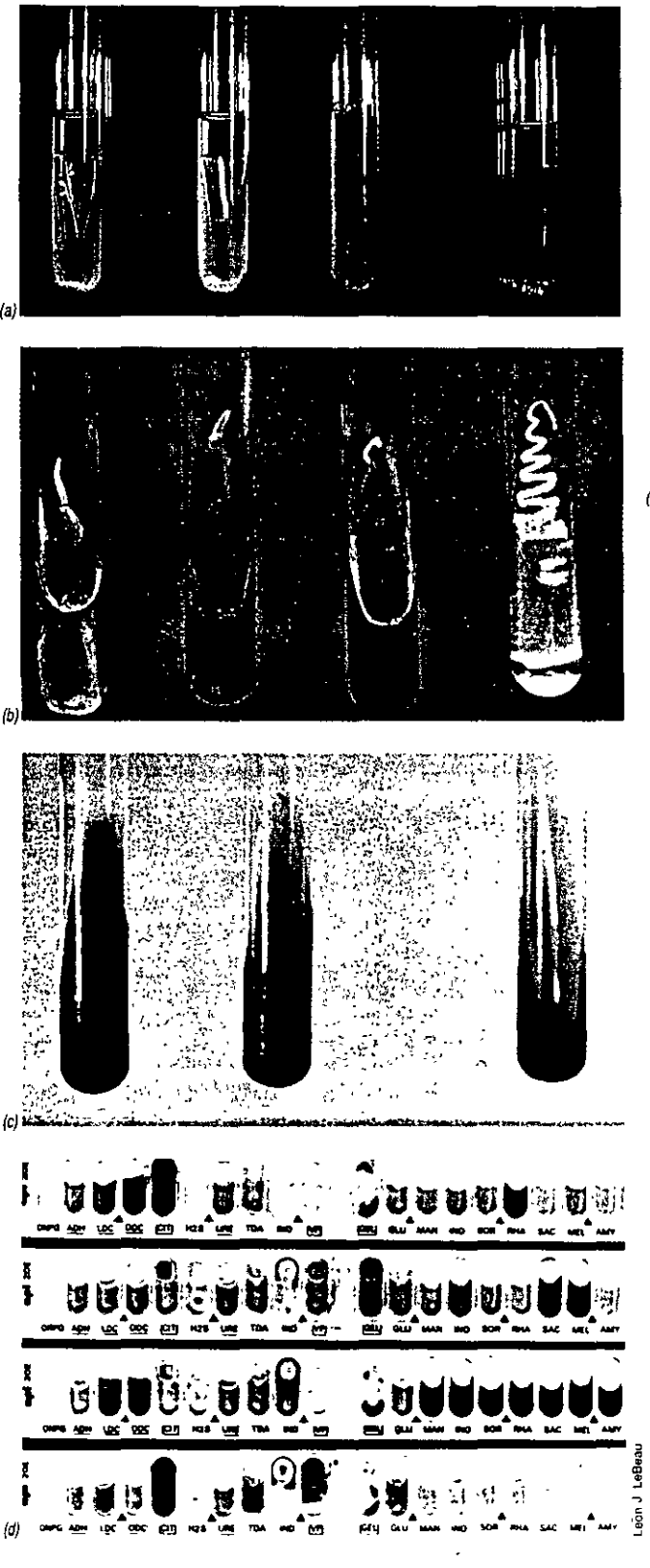

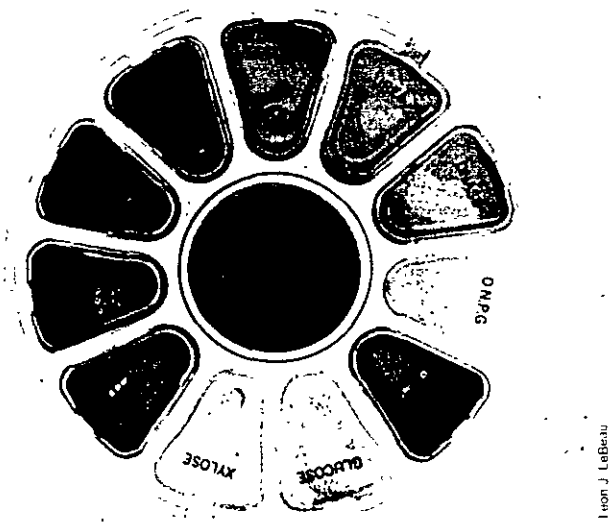

Figure 21.7 Growth-dependent diagnostic methods used for the identification of clinical isolates by color changes in various diagnostic media. (a) Use of a differential medium to assess sugar fermentation. Acid production is indicated by color change of the pH-indicating dye added to the liquid medium. If gas production occurs, a bubble appears in the inverted vial in each tube. From left to right. acid, acid and gas, negative, uninoculated. (b) A conventional diagnostic test for enteric bacteria in a medium called *triple sugar iron (TSI) agar.* The medium is inoculated both on the surface of the slant and by stabbing into the butt. The medium contains a small amount of glucose and a large amount of lactose and sucrose. Organisms able to ferment only the glucose cause acid formation only in the butt, whereas lactose or sucrose-fermenting organisms also cause acid formation in the top. Gas formation is indicated by the breaking up of the agar in the butt. Hydrogen sulfide formation (either from protein degradation or from reduction of thiosulfate in the medium) is indicated by a blackening due to reaction of the H_2S with ferrous iron in the medium. From left to right: fermentation of glucose only; no reaction; hydrogen sulfide formation; fermentation of glucose and another sugar. (c) Measurement of citrate utilization by *Salmonella* on Simmons citrate agar. The change in pH causes a change in the color of the indicating dye. From left to right: positive, negative, uninoculated. (d) Media kits used for the rapid identification of clinical isolates. The principle is the same as in (a), but the whole arrangement has been miniaturized so that a number of tests can be run at the same time. Four separate strips, each with a separate culture, are shown. (e) Another arrangement of a miniaturized test kit. This one defines sugar utilization in nonfermentative organisms.

measured. The most important tests are summarized in Table 21.3. These tests measure the presence or absence of *enzymes* involved in catabolism of the substrate or substrates added to the differential medium. Fermentation of sugars is measured by incorporating pH indicator dyes that change color on acidification (Figure 21.7*a*). Production of hydrogen gas and/or carbon dioxide during sugar fermentation is assayed by observing gas production either in gas collection vials or in agar (Figure 21.7*a* and *b*). Hydrogen sulfide production is indicated following growth in a medium containing ferric iron. If sulfide is produced, ferric iron complexes with H_2S to form a black precipitate of iron

TABLE 21.3 Important clinical diagnostic tests for bacteria

Test	Principle	Procedure	Most common use
Carbohydrate fermentation	Acid and/or gas produced during fermentative growth with sugars or sugar alcohols	Broth medium with carbohydrate and phenol red as pH indicator; inverted tube for gas	Enteric bacteria differentiation (also several other genera or species separations with some individual sugars) (Figure 21.7)
Catalase	Enzyme decomposes hydrogen peroxide, H_2O_2	Add drop of H_2O_2 to dense culture and look for bubbles (O_2) (Figure 5.25)	*Bacillus* (+) from *Clostridium* (−); *Streptococcus* (−) from *Micrococcus–Staphylococcus* (+)
Citrate utilization	Utilization of citrate as sole carbon source, results in alkalinization of medium	Citrate medium with bromthymol blue as pH indicator. Look for intense blue color (alkaline pH)	*Klebsiella–Enterobacter* (+) from *Escherichia* (−), *Edwardsiella* (−) from *Salmonella* (+) (Figure 21.7)
Coagulase	Enzyme causes clotting of blood plasma	Mix dense liquid suspension of bacteria with plasma, incubate, and look for fibrin clot	*Staphylococcus aureus* (+) from *S. epidermidis* (−)
Decarboxylases (lysine, ornithine, arginine)	Decarboxylation of amino acid releases CO_2 and amine	Medium enriched with amino acids. Bromcresol purple pH indicator becomes purple (alkaline pH) if there is enzyme action	Aid in determining bacterial group among the enteric bacteria
β-Galactosidase (ONPG) test	Orthonitrophenyl-β-galactoside (ONPG) is an artificial substrate for the enzyme. When hydrolyzed, nitrophenol (yellow) is formed	Incubate heavy suspension of lysed culture with ONPG. Look for yellow color	*Citrobacter* and *Arizona* (+) from *Salmonella* (−). Identifying some *Shigella* and *Pseudomonas* species
Gelatin liquefaction	Many proteases hydrolyze gelatin and destroy the gel	Incubate in broth with 12% gelatin. Cool to check for gel formation. If gelatin is hydrolyzed, tube remains liquid on cooling	To aid in identification of *Serratia, Pseudomonas, Flavobacterium, Clostridium*
Hydrogen sulfide (H_2S) production	H_2S produced by breakdown of sulfur amino acids or reduction of thiosulfate	H_2S detected in iron-rich medium from formation of black ferrous sulfide (many variants: Kliger's iron agar and triple sugar iron agar, also detect carbohydrate fermentation)	In enteric bacteria, to aid in identifying *Salmonella, Arizona, Edwardsiella,* and *Proteus* (Figure 21.7)
Indole test	Tryptophan from proteins converted to indole	Detect indole in culture medium with dimethyl-aminobenzaldehyde (red color)	To distinguish *Escherichia* (+) from *Klebsiella* (−) and *Enterobacter* (−); *Edwardsiella* (+) from *Salmonella* (−)
Methyl red test	Mixed-acid fermenters produce sufficient acid to lower pH below 4.3	Glucose-broth medium. Add methyl red indicator to a sample after incubation	To differentiate *Escherichia* (+, culture red) from *Enterobacter* and *Klebsiella* (usually −, culture yellow)
Nitrate reduction	Nitrate as alternate electron acceptor, reduced to NO_2^- or N_2	Broth with nitrate. After incubation, detect nitrite with α-naphthylamine-sulfanilic acid (red color). If negative, confirm that NO_3^- still present by adding zinc dust to reduce NO_3^- to NO_2^-. If no color after zinc, then $NO_3^- \rightarrow N_2$	To aid in identification of enteric bacteria (usually +)

TABLE 21.3 (continued)

Test	Principle	Procedure	Most common use
Oxidase test	Cytochrome *c* oxidizes artificial electron acceptor: tetramethyl (or dimethyl)-*p*-phenylenediamine	Broth or agar. Oxidase-positive colonies on agar can be detected by flooding plate with reagent and looking for blue or brown colonies	To separate *Neisseria* and *Moraxella* (+) from *Acinetobacter* (−) To separate enteric bacteria (all −) from pseudomonads (+). To aid in identification of *Aeromonas* (+)
Oxidation–fermentation (O/F) test	Some organisms produce acid only when growing aerobically	Acid production in top part of sugar-containing culture tube; soft agar used to restrict mixing during incubation	To differentiate *Micrococcus* (acid produced aerobically only) from *Staphylococcus* (acid produced anaerobically). To characterize *Pseudomonas* (aerobic acid production) from enteric bacteria (acid produced anaerobically)
Phenylalanine deaminase test	Deamination produces phenylpyruvic acid, which is detected in a colorimetric test	Medium enriched in phenylalanine. After growth, add ferric chloride reagent and look for green color	To characterize the genus *Proteus* and the *Providencia* group
Starch hydrolysis	Iodine-iodide gives blue color with starch	Grow organism on plate containing starch Flood plate with Gram's iodine and look for clear zones around colonies	To identify typical starch hydrolyzers such as *Bacillus* spp.
Urease test	Urea ($H_2N—CO—NH_2$) split to 2 NH_3 + CO_2	Medium with 2% urea and phenol red indicator. Ammonia release raises pH, intense pink-red color	To distinguish *Klebsiella* (+) from *Escherichia* (−) To distinguish *Proteus* (+) from *Providencia* (−)
Voges–Proskauer test	Acetoin produced from sugar fermentation	Chemical test for acetoin using α-naphthol	To separate *Klebsiella* and *Enterobacter* (+) from *Escherichia* (−) To characterize members of genus *Bacillus*

sulfide (Figure 21.7*b*). Utilization of citric acid, a six-carbon acid containing three carboxylic acid groups, is accompanied by a pH rise, and a specific dye incorporated into this test medium changes color as conditions become alkaline (Figure 21.7*c*). Hundreds of differential tests have been developed for clinical use, but only about 20 are used routinely (Figure 21.7*d*).

The typical reaction patterns for large numbers of strains of various pathogens have been published, and in the modern clinical microbiology laboratory, all this information is stored in a computer. The results of the differential tests on an unknown pathogen are entered, and the computer makes the best match by comparing the characteristics of the unknown with the species in the data bank. For many organisms, as few as three or four key tests are all that are required to make an unambiguous identification. In cases of a dubious match, however, more sophisticated identification procedures may be called for, especially if the chemotherapy regimens are different for several pathogens with similar growth characteristics.

Clinical diagnosis

Many companies market their own versions of growth-dependent rapid identification systems (Figure 21.7*d* and *e*). Such systems are frequently designed for use in identifying enteric bacteria because enterics are frequently implicated in routine urinary tract and intestinal infections (see Section 21.1).

Other growth-dependent rapid identification kits are available for other bacterial groups or even for single bacterial species. For example, commercial kits containing a battery of tests have been developed for *Staphylococcus aureus*, *Streptococcus pyogenes*, *Neisseria gonorrhoeae*, *Haemophilus influenzae*, and *Mycobacterium tuberculosis*. Other kits are available for identification of the pathogenic fungi *Candida albicans* and *Cryptococcus neoformans* (∞ Section 23.16).

The decision to use a specific diagnostic test is usually made by the clinical microbiologist. This individual takes into consideration the nature of the clinical specimen, basic characteristics (especially the Gram

stain) of pure cultures obtained, and previous experience with similar cases. For example, an enteric identification kit would be useless in identifying a gram-positive coccus isolated from an abscess. Instead, a *Staphylococcus aureus* or *Streptococcus pyogenes* kit would be used to make a positive identification.

CONCEPT CHECK 21.2

Traditional methods for identifying pathogens depend on observing metabolic changes induced as a result of growth. These growth-dependent methods provide rapid and reasonably accurate means of diagnosing many infectious diseases.

- ✔ *Distinguish between* selective *and* differential *identification methods. Give an example of a medium used for each purpose.*
- ✔ *What parameters would a clinical microbiologist use to prescribe a specific diagnostic test kit for identification of an infectious agent?*

21.3 Testing Cultures for Antibiotic Sensitivity

In medical practice, microbial cultures are isolated from diseased patients to confirm diagnoses and to aid in decisions on therapy. Determination of the sensitivity of microbial isolates to antimicrobial agents is one of the most important tasks of the clinical microbiologist.

We discussed the principles for the measurement of antimicrobial activity in Chapter 11. The sensitivity of a culture can be most easily determined by an agar diffusion method or by using a tube dilution technique to determine the *minimum inhibitory concentration* (MIC) of an agent that is necessary to inhibit growth (∞ Section 11.4). Food and Drug Administration (FDA) regulations now control the procedures used for sensitivity testing in the United States, and similar regulations exist in other countries. A recommended agar diffusion procedure is called the *Kirby–Bauer method*, named after the workers who developed it (Figure 21.8). A plate of suitable culture medium is inoculated by spreading a sample of culture evenly across the agar surface. Filter paper discs containing known concentrations of different antimicrobial agents are then placed on the plate. The concentration of each agent on the disc is specified, and after incubation, the presence and size of inhibition zones around the discs of the different agents are noted. Table 21.4 presents typical zone sizes for several antibiotics. Zones observed on the plate are measured and compared to standard data to determine if the isolate is truly sensitive to a given antibiotic.

The MIC procedure for antibiotic sensitivity testing involves an *antibiotic dilution assay*, either in culture tubes (∞ Figure 11.11) or in the wells of a microtiter plate (Figure 21.8*e*). A series of twofold dilutions of each antibiotic are made in the wells, and then all wells are inoculated with a standard amount of the same test organism. After incubation, the inhibition of growth by the various antibiotics can be observed by measuring turbidity. Sensitivity is usually expressed as the *highest dilution* (lowest concentration) of antibiotic that completely inhibits growth. The dilution assay, because it can be performed in microtiter plates, is readily automated.

Because of the widespread occurrence of antibiotic resistance (∞ Section 11.13), an antibiotic sensitivity test is essential for pathogens isolated from each patient. Data such as those in Table 21.4 are useful to the physician in choosing the best antibiotic for a specific bacterial infection. Fortunately, many potentially serious pathogens are susceptible to a number of different antibiotics, and this allows the physician considerable latitude in the course of treatment. However, some pathogens, for example, *Pseudomonas aeruginosa*, are sensitive to very few drugs. Other pathogens, such as some encountered in hospital environments, have developed antibiotic resistance (∞ Sections 22.7 and 11.13). Thus; antibiotic sensitivity testing for these organisms is absolutely essential for effective chemotherapy. Using the drug sensitivity information gathered in this fashion, the clinical microbiologist generates periodic reports to the physician and pharmacist. These reports, called *antibiograms*, indicate the sensitivity of clinically isolated organisms to the antibiotics in current use. This report is particularly valuable for tracking the emergence of antibiotic-resistant strains of pathogens in facilities such as hospitals and nursing homes.

CONCEPT CHECK 21.3

Antibiotics are in wide use for the treatment of infectious diseases. Pathogens must be tested for sensitivity to individual antibiotics *before treatment* to ensure appropriate chemotherapy.

- ✔ *Describe the Kirby–Bauer technique. What does it indicate?*
- ✔ *Why is antibiotic sensitivity testing important for the clinical microbiologist, the physician, and the patient?*

21.4 Immunodiagnostics

In this section, we will apply the principles of immunity to the diagnosis of infectious diseases. First, we will briefly review the immune response to pathogens. Next, we will observe the immune response in a normal individual. Finally, we will examine immunologi-

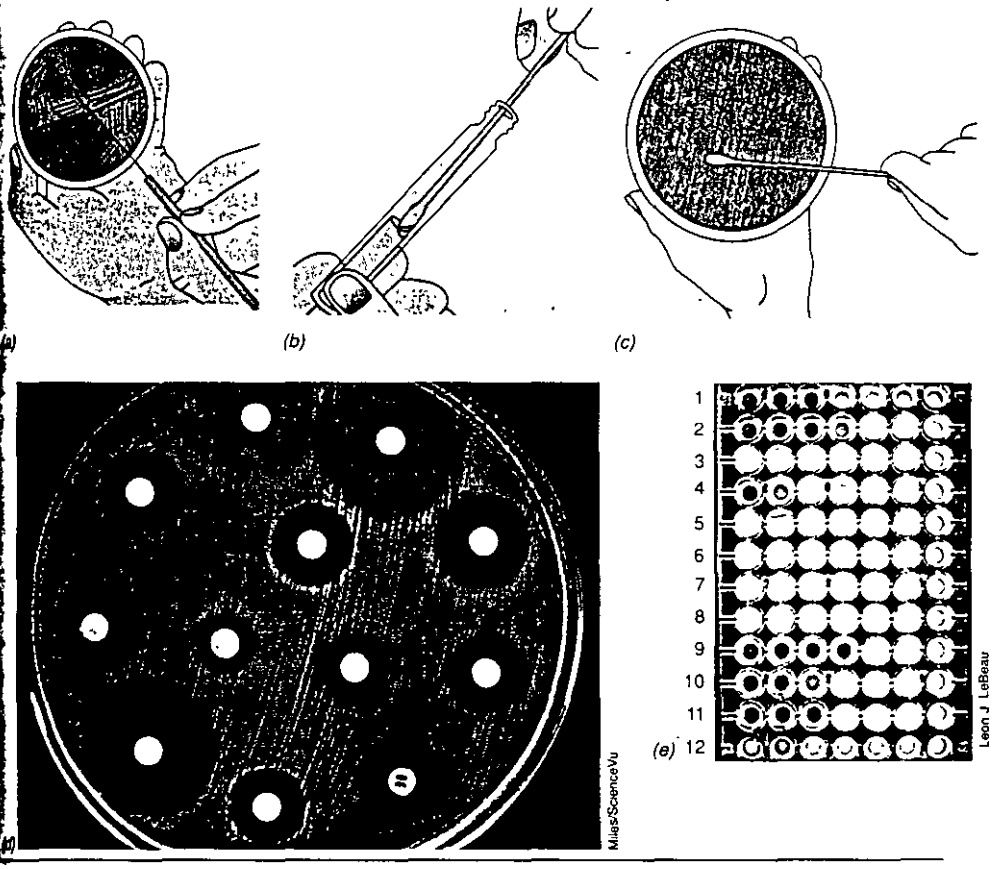

Figure 21.8 Antibiotic sensitivity testing. (a–d) the Kirby–Bauer procedure for determining the sensitivity of an organism to antibiotics. (a) A colony is picked from an agar plate. It is inoculated into a tube of liquid culture medium and allowed to grow to a specified density. (b) A swab is dipped in the liquid culture. (c) The swab is streaked evenly over a plate of sterile agar medium. (d) Discs containing known amounts of different antibiotics are placed on the plate. After incubation, inhibition zones are observed. The susceptibility of the organism is determined by reference to a chart of zone sizes (Table 21.4). (e) Antibiotic sensitivity determined by the dilution method. The organism is *Pseudomonas aeruginosa*. Each row has a different antibiotic. The use of the microtiter plate enables automation of these tests. The end point is read as the well with the lowest concentration of antibiotic that shows no evidence of bacterial growth. The highest concentration of antibiotic is in the well at the left; serial dilutions are made in the wells to the right. For example, in rows 1 and 2, the end point is the third well. In row 3, the antibiotic is ineffective at the concentrations tested, since there is bacterial growth in all the wells. In row 4, the end point is in the first well. The lowest concentration of antibiotic that completely inhibits bacterial growth defines the minimum inhibitory concentration (MIC) for that agent (∞ Section 11.4).

cal reagents that are useful for diagnostic applications. In the following sections, we will examine specific applications of these reagents.

Immunity to infection: Overview and review

The immune response was discussed in Chapter 20. A summary of the major aspects of immunity is shown in Figure 20.1. The body responds to pathogens in a three-step process. For a pathogen that the body has never before encountered, the pathogen must first be recognized. This is usually accomplished by a group of cells called phagocytes (∞ Section 20.3), which constitute the first line of defense against any pathogen that gains access to body tissues. Fortunately, phagocytes ingest and destroy most pathogens (a process called *phagocytosis*). Phagocytosis is *nonspecific*, and the target may be any foreign substance, including the pathogens and their components.

In the second phase of immunity, the phagocytes present pathogen-derived *antigens* (proteins obtained from the destroyed pathogen) to antigen-specific immune lymphocytes known as T cells (∞ Section 20.7). Some T cells known as T helper (T_H) cells do not act directly on the pathogen but recruit and stimulate (help) another group of antigen-specific cells known as B cells.

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TABLE 21.4 Zone sizes for some antimicrobial disc susceptibility tests

Antibiotic	Amount on disc	Inhibition zone diameter (mm)[a]		
		Resistant	Intermediate	Sensitive
Ampicillin[b]	10 μg	11 or less	12–13	14 or more
Ampicillin[c]	10 μg	28 or less	—	29 or more
Cephoxitin	30 μg	14 or less	15–17	18 or more
Cephalothin	30 μg	14 or less	15–17	18 or more
Chloramphenicol	30 μg	12 or less	13–17	18 or more
Clindamycin	2 μg	14 or less	15–16	17 or more
Erythromycin	15 μg	13 or less	14–17	18 or more
Gentamicin	10 μg	12 or less	13–14	15 or more
Kanamycin	30 μg	13 or less	14–17	18 or more
Methicillin[c]	5 μg	9 or less	10–13	14 or more
Neomycin	30 μg	12 or less	13–16	17 or more
Nitrofurantoin	300 μg	14 or less	15–16	17 or more
Penicillin G[d]	10 units	28 or less	—	29 or more
Penicillin G[e]	10 units	11 or less	12–21	22 or more
Polymyxin B	300 units	8 or less	9–11	12 or more
Streptomycin	10 μg	11 or less	12–14	15 or more
Tetracycline	30 μg	14 or less	15–18	19 or more
Trimethoprim-sulfamethoxazole	1.25/23.75 μg	10 or less	11–15	16 or more
Tobramycin	10 μg	12 or less	13–14	15 or more

[a]See Figure 21.8*d* for an illustration of a typical test.

[b]For gram-negative organisms and enterococci.

[c]For staphylococci and highly penicillin-sensitive organisms.

[d]For staphylococci.

[e]For organisms other than staphylococci. Includes some organisms, such as enterococci and some gram-negative rods, that may cause some systemic infections treatable with high doses of penicillin G.

The B cells then respond by producing soluble, antigen-specific binding proteins known as *antibodies* (∞ Sections 20.5 and 20.11). A *primary antibody response* generally occurs within 5 days, but antibodies do not reach peak quantities for several weeks. The antibody proteins, because they are antigen-specific, and thus pathogen-specific, are critical components of the immune response.

The antibodies interact specifically with the antigen on target cells, but cannot kill the cells. A group of nonspecific enzyme proteins, known collectively as complement (∞ Section 20.13), may attach to antibodies bound to the pathogen and lyse all cells with attached antibody. For example, antibodies specific for cell surface proteins of *Salmonella* spp. interact only *Salmonella:* complement causes lysis of the antibody-sensitized *Salmonella* cell, but not of an *Escherichia coli* cell that is not antibody-sensitized. Thus, the immune response is *specific* for individual antigens, by virtue of specific antibodies, but may be mediated or enhanced through nonspecific mechanisms such as complement.

In many cases, antibody-mediated immunity is not an effective mechanism for controlling the spread of infection. Some infectious agents parasitize the body from *within* cells. For example, animal viruses reproduce using host cell systems and, therefore, spend a large portion of their life cycle within the host cells (∞ Section 8.14). Likewise, bacteria such as *Mycobacterium tuberculosis*, the causative agent of tuberculosis, take up residence preferentially within phagocytes (∞ Sections 20.3 and 23.3). Because antibodies are geared to recognize the free pathogen in the blood or at mucosal cell surfaces, the infected host cells must be identified and destroyed by other means, usually involving the cell-to-cell interactions of the *cell-mediated immunity.* Fortunately, the internal pathogens all produce antigens that are in turn presented on the surface of infected target cells. A T cytotoxic cell (T_C) recognizes the antigen (∞ Section 20.7) and acts directly on the infected target cell by secreting cytolytic proteins called *perforins*, which destroy the infected cell (∞ Section 20.9).

No useful specific immunity exists before exposure to antigen, but after the first antigen exposure specific immune T and B cells are present and some level of detectable circulating antibody may persist for years. More importantly, the cells that are capable of making antibody are now present in large numbers; a second antigen stimulation through reinfection generates a very rapid and very strong immune response which peaks within several days, often at a level several orders of magnitude higher than the primary response (∞ Section 20.11). This *secondary antibody response* quickly targets and destroys the pathogen. Thus, the immune response has *memory.* Memory is characterized by a rapid rise in antibody *titer*, or quantity, and we will now use this principle to track infections.

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Antibody titers and the diagnosis of infectious disease

In the diagnosis of an infectious disease, isolation of the pathogen is not always possible. One alternative is to measure antibody titer to a suspected pathogen. As we discussed earlier, if an individual is infected with a suspected pathogen, the antibody titer to that pathogen should be elevated. Antibody titer can be measured by agglutination, precipitation, enzyme-linked immunosorbent assay (ELISA), immobilization methods, or radioimmunoassay (RIA), depending on the situation. The general procedure is to set up a series of dilutions of serum (usually twofold dilutions: 1:2, 1:4, 1:8, 1:16, 1:32, and so on) and to determine the *highest* dilution at which the antigen–antibody reaction occurs.

A *single* measure of antibody titer does not indicate active infection. Many antibodies remain at high titer for long times after infection; to establish that an acute illness is due to a particular pathogen, it is essential to show a *rise* in antibody titer in successive samples of serum from the same patient. Frequently, the antibody titer is low during the acute stage of the infection and rises during convalescence (Figure 21.9). Such a rise in antibody titer is the best indication that the illness is due to the suspected agent and is also useful in diagnosis of infectious diseases of a rather chronic nature, such as typhoid fever and brucellosis. In some cases, however, the mere presence of antibody may be sufficient to indicate infection. This is the case for a pathogen that is quite rare in a population, and so the presence of antibody is sufficient to indicate that the individual has experienced an infection. A relevant example here is acquired immunodeficiency syndrome (AIDS). As will be discussed in Section 21.8, an extremely sensitive and highly reliable ELISA test is now available for detecting antibodies to human immunodeficiency virus (HIV), the AIDS virus. After infection with HIV, an antibody response occurs but, unlike the case in most diseases where antibody titers *increase* in the later stages of the disease, the loss of T helper cell function (∞ Section 23.7) actually causes HIV-specific antibody titers to *decrease* in the later stages of AIDS. Nevertheless, the exquisite sensitivity of ELISA allows detection of even very low antibody titers, and the HIV-ELISA is used to routinely screen blood samples for evidence of HIV infection.

Unfortunately, not all infections result in formation of systemic antibody. If a pathogen is extremely localized, there may be little induction of an immunological response and no rise in antibody titer even if the pathogen is proliferating profusely at its site of infection. A good example is the disease gonorrhea. Infection with *Neisseria gonorrhoeae*, the causative agent of gonorrhea, does not elicit a systemic immune response, and thus reinfection of a cured individual is not uncommon (see Sections 21.1 and 23.6). In other cases, the presence of antibody in the serum may have been due to vaccination. In fact, measurement of the rise in antibody titer following vaccination is one of the best ways of determining that the vaccination is effective.

Some of the most common clinical immunological procedures are outlined in Table 21.5.

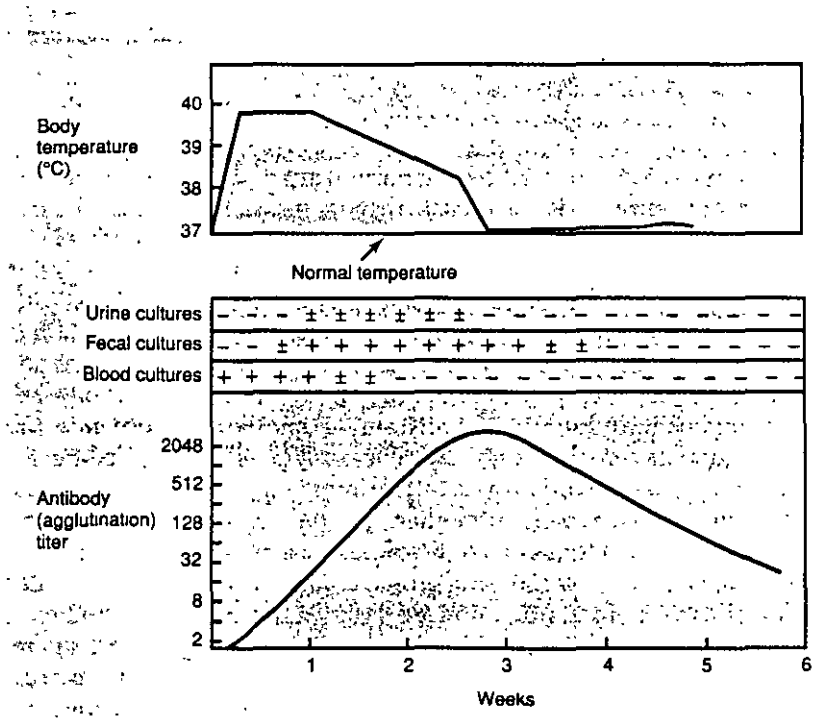


Figure 21.9 The course of infection in a typical untreated typhoid fever patient. Measurement of body temperature provides a measure of the course of clinical symptoms. The antibody titer was measured by determining the highest dilution (twofold series) causing agglutination of a test strain of *Salmonella typhi*. Presence of viable bacteria in blood, feces, and urine was determined from periodic cultures. Note that the pathogen clears from the blood as the antibody titer rises, and clearance from feces and urine requires longer time. Body temperature gradually drops to normal as the antibody titer rises. The data given do not represent a single patient but are a composite of the picture seen in large numbers of patients.

TABLE 21.5 Some clinical immunological procedures for identification of infectious agents

Pathogen or disease	Antigen	Serological procedure[a]
Streptococcus (group A)	Streptolysin O (exotoxin)	Neutralization of hemolysis
	DNase (extracellular protein)	Neutralization of enzyme
Neisseria meningitidis	Capsular polysaccharide	Passive hemagglutination (*N. meningitidis* polysaccharide adsorbed to red cells)
	N. meningitidis cells	Indirect fluorescent antibody
Salmonella	O or H antigen	Agglutination (Widal test)
		ELISA
Vibrio cholerae	O antigen	Agglutination
		Bactericidal test (in presence of complement)
		ELISA
Borrelia burgdorferi (Lyme disease)	Flagellin	ELISA
	Surface proteins	Immunoblot
		Bactericidal test (⊂⊃ Section 23.10)
Brucella	Cell wall antigen	Agglutination
		ELISA
Corynebacterium diphtheriae	Toxin	Skin test (Schick test)
Mycobacterium tuberculosis	Tuberculin (partially purified bacterial proteins, PPD)	Skin test (tuberculin test)
		ELISA
Syphilis (*Treponema pallidum*)	Cardiolipin-lecithin-cholesterol	Flocculation [Venereal Disease Research Laboratory (VDRL) test]
	T. pallidum antigens	ELISA
	T. pallidum cells	Indirect fluorescent antibody (FTA)
Rickettsial diseases (Q fever, typhus, Rocky Mountain spotted fever)	Killed rickettsial cells	Complement-based assay or cell agglutination tests
		ELISA
Influenza virus	Influenza virus suspensions	Complement-based assay
	Nasopharynx cells containing influenza virus	Immunofluorescence
AIDS	Human immunodeficiency virus (HIV)	ELISA
		Immunoblot
Pneumocytis carinii	*P. carinii* cells	Immunofluorescence

[a]Except for the skin tests and the immunofluorescent tests, the serum of the patient is assayed for antibody against the specific antigen by the methods shown.

Monoclonal antibodies for immunodiagnostics

As we discussed in Section 20.14, the normal antibody response to an antigen is *polyclonal*; that is, many B cells are stimulated to produce antibodies to a complex antigen. The resulting antiserum consists of a mixture of different antibodies. Although this antibody population can give adequate immune protection to the host, it is usually not specific for a single, defined antigen and is not precisely reproducible because it was produced in a single individual animal at a single time. For immunodiagnostic procedures, these types of antibodies, while they may be very potent, are extremely hard to standardize. *Monoclonal* antibodies, on the other hand, are products of clones of single cells, and because the cell clones can be stored and grown indefinitely, reproducibility and standardization are easily attained. Monoclonal antibody technology, therefore, has supplanted standard polyclonal techniques for many immunodiagnostic applications.

A monoclonal antibody is generally highly specific for a *single* antigenic determinant and hence is very useful in immunodiagnostics. For example, fluorescent antibodies (see Section 21.7) against *Chlamydia trachomatis* membrane proteins can be used to detect this organism in host tissues (*C. trachomatis* causes a variety of sexually transmitted diseases as well as trachoma, a serious eye disease) (⊂⊃ Section 23.6). These monoclonal antibodies react with *C. trachomatis* but are so specific they fail to react with even the closely related species *C. psittaci*. *C. trachomatis* is also an obligate intracellular parasite and is not easily cultured because it is dependent on the host cell to complete its life cycle. Use of the fluorescent anti-*C. trachomatis* monoclonal antibody on cervical scrapings or urethral or vaginal exudates makes positive identification of chlamydial infections almost routine.

Other monoclonal antibodies have been developed against outer membrane proteins of *Neisseria gonorrhoeae*. These probes are not only monospecific, reacting only with *N. gonorrhoeae*, but are also capable

of differentiating *strains* of *N. gonorrhoeae*. The use of fluorescent monoclonal antibodies therefore eliminates much of the cross-reactivity problem observed when polyclonal sera are used.

With presently available technology, it is possible to generate monoclonal antibodies that react with only a certain bacterial species or even with only a certain *strain* of a species. In addition, viral antigens can be detected with the appropriate monoclonals. For example, both fluorescent and enzyme-conjugated monoclonal antibodies (subsequently assayed by ELISA) (see Section 21.9) have been developed for the diagnosis of herpes infections and the typing of herpes virus obtained from clinical specimens. Hence, monoclonal antibodies are useful for broad screening purposes as well as highly detailed analyses. Monoclonal antibodies have also been widely used in noninfectious disease diagnoses as well (for example, see Figure 21.15).

CONCEPT CHECK 21.4

An immune response is a natural outcome of infection. A specific immune response to a pathogen can be used as a diagnostic aid. Monoclonal antibodies are widely used for immunodiagnostic applications.

- ✔ *How might a patient develop an antibody titer to an organism?*
- ✔ *Why does the antibody titer to an organism rise during convalescence?*
- ✔ *What advantages do* monoclonal *antibodies have over* polyclonal *antibodies in immunodiagnostic tests?*

21.5 Agglutination

Agglutination is due to the binding of a particulate antigen by antibody. Agglutination reactions were discussed in Section 20.15, with the well-known ABO blood grouping reaction serving as a prime example of direct agglutination. However, many other agglutination reactions are used for the detection of antigens or antibodies associated with certain disease. Although not as sensitive a test as some other immunoassays (Table 21.6), agglutination remains useful in clinical diagnostics as an inexpensive, highly specific, rapid immunoassay.

Coated-particle agglutination

The agglutination of antigen-coated or antibody-coated latex beads by complementary antibody or antigen from a patient is a typical method of rapid diagnosis. Small (0.8-μm) latex beads coated with a specific antigen or antibody are mixed with patient serum on a microscope slide and incubated for a short period. If the antibody complementary to the molecule bound to the bead surface is present in the patient's serum, the milky-white latex suspension will be visibly clumped, indicative of the agglutination reaction. Latex agglutination is also used to detect bacterial surface antigens by mixing a small amount of a bacterial colony with antibody-coated latex beads. For example, a commercially available suspension of latex beads containing antibodies to protein A and clumping factor, two molecules found exclusively on the surface of *Staphylococcus aureus*, is virtually 100% accurate in identifying clinical isolates of *S. aureus*. Unlike traditional tests for *S. aureus*, many of which are growth-dependent assays, identification of *S. aureus* by the latex bead assay takes only 30 seconds (Figure 21.10). Other latex bead agglutination assays have been developed to identify *Streptococcus pyogenes, Neisseria gonorrhoeae, Haemophilus influenzae, Campylobacter* spp. and the yeasts *Cryptococcus neoformans* and *Candida albicans*.

A very widely employed latex agglutination assay is that used for detecting specific serum antibodies for *rheumatoid factor*, an antibody directed against the body's own immunoglobulins and associated with the autoimmune disease *rheumatoid arthritis* (Section 20.16). Latex beads coated with human immunoglobulin are mixed with whole blood or serum, and agglutination scored versus positive and negative control sera run in parallel. Latex bead assays are simple and specific. In addition, the inexpensive nature of the assays makes them suitable for large-scale screening purposes; the widespread use of the rheumatoid test is a good example of this. Because they require no expensive equipment or particular expertise, they are in wide use in virtually all clinical settings.

Some agglutination assays use a suspension of activated charcoal as the carrier. For example, a rapid diagnostic test for detection of the virus *Herpes simplex*, fre-

TABLE 21.6 Sensitivity of immunodiagnostic assays

Assay	Sensitivity (μg antibody/ml)[a]
Precipitin reaction	
In fluids	24–160
In gels (double immunodiffusion)	24–160
Agglutination reactions	
Direct	0.4
Passive	0.08
Radioimmunoassay (RIA)	0.0008–0.008
Enzyme-linked immunosorbent assay (ELISA)	0.0008–0.008
Immunofluorescence	8.0

[a]The smallest amount of antibody necessary to give a positive reaction in the presence of antigen.

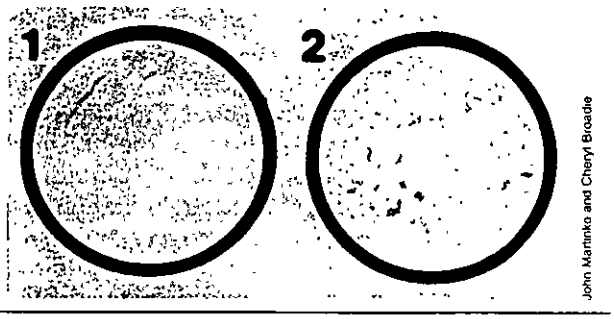


Figure 21.10 Latex bead agglutination test for *Staphylococcus aureus*. Panel 1 shows a negative control. Note the uniform pink color of the suspended latex beads coated with antibodies to protein A and clumping factor, two antigens found exclusively on the surface of *S. aureus* cells. Panel 2 shows the same suspension after a loopful of material from a bacterial colony was mixed into the suspension. The bright red clumps indicate a positive agglutination reaction took place and indicates that the colony is *S. aureus*.

quently associated with oral fever blisters or genital sores (∞ Section 23.6), employs anti-*H. simplex* virus antibodies adsorbed to small particles of activated charcoal. Cotton swabs used to sample suspected herpes lesions are placed in a buffer solution, and samples of the buffer solution, possibly now containing virus, are used to test for charcoal agglutination. A positive test is indicated by visible clumping of the charcoal into large, black aggregates. Because of the specificity of the antiserum used (and here, naturally, monoclonal antibodies are ideal), complicating cross-reactions with related pathogens are not a problem. Like latex beads, charcoal agglutination tests can be rapid and cost-effective diagnostic tools.

Coated-particle tests are *passive* agglutination reactions and are up to five times more sensitive than the direct agglutination tests we discussed in Section 20.15 (Table 21.6).

CONCEPT CHECK 21.5

A number of clinically useful agglutination tests are available. These tests are rapid, relatively sensitive, and inexpensive methods for identifying a variety of pathogens.

- ✔ *Distinguish between* direct *and* passive *agglutination. Which tests are more sensitive?*
- ✔ *What advantages do agglutination tests have over other immunoassays? What disadvantages?*

21.6 Immunoelectron Microscopy

Antibodies to which heavy metals have been chemically conjugated can be used to locate antigens in cells by electron microscopy. This is possible because heavy metals scatter the electron beam of the electron microscope. This technique, called *immunoelectron microscopy*, is used primarily in research where there is a need to determine where a specific antigen (usually a protein) is localized in a particular region of the cell (Figure 21.11). Cells, following chemical fixation and other preparations necessary for observation by the electron microscope, are treated with antibodies covalently conjugated to a heavy metal, usually gold or platinum. The electron-dense metals scatter electrons, and thus the presence of bound antibody can be detected by dense black spots in photographs of the preparation.

In immunoelectron microscopy, although the cell is dead and chemically fixed, most protein antigens retain sufficient native structure and antibodies still react with little nonspecific cross-reaction. Immunoelectron microscopy has been used extensively to pinpoint the location of enzymes in cells, especially those suspected to be associated with the cytoplasmic membrane or some other internal structure (Figure 21.11).

Although immunoelectron microscopy can be used for identifying pathogens such as human immunodefi-

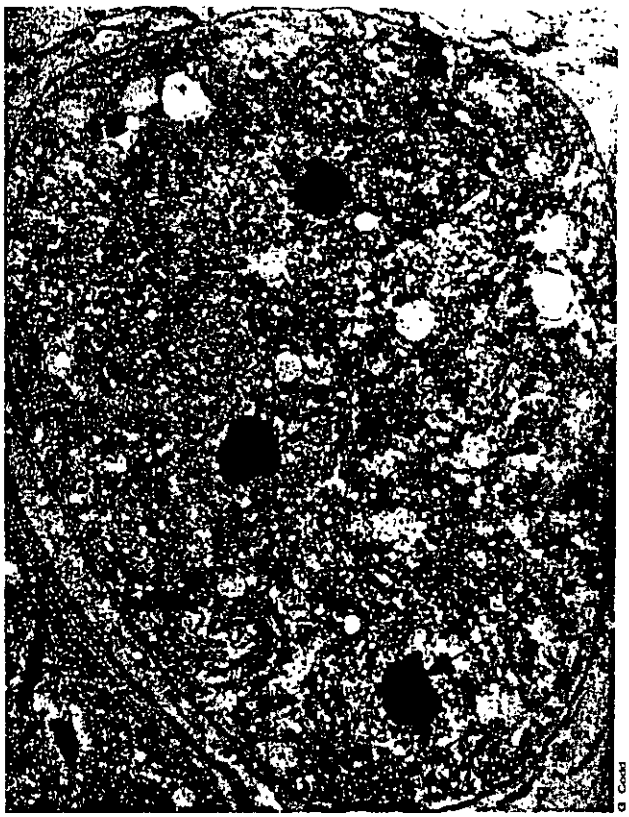


Figure 21.11 Immunoelectron microscopy. Antibodies made in rabbits to the enzyme ribulose-1,5-bisphosphate carboxylase from the cyanobacterium *Chlorogloeopsis fritschii* were added to thin sections of *C. fritschii* and the preparation treated with goat anti-rabbit IgG conjugated to 20-nm colloidal gold particles. The concentration of the particles around large inclusions called carboxysomes (arrows) indicate that these are sites of large amounts of the enzyme.

ciency virus (HIV) in cells (∞ Figure 23.32), the time, expense, expertise, and specialized equipment involved make it impractical for diagnostic procedures in all but the most specialized clinical research settings.

CONCEPT CHECK 21.6

Immunoelectron microscopy is a research tool used for localizing antigens in cells.

✔ *Why are heavy metal–antibody conjugates used for immunoelectron microscopy?*

21.7 Fluorescent Antibodies

In addition to heavy metals, there are a number of other chemical methods for covalently modifying antibodies that make them readily detectable. In this section, we will discuss the use of antibodies chemically modified with fluorescent dyes. This procedure makes it possible to detect reactions of antibodies with single cells. Virtually all well-equipped clinical laboratories make extensive use of fluorescent antibodies for clinical diagnostic procedures.

Fluorescent methods

Antibody molecules can be made fluorescent by covalently attaching them to fluorescent organic compounds such as rhodamine B, which fluoresces red, or fluorescein isothiocyanate, which fluoresces yellow-green. This does not alter the specificity of the antibody but makes it possible to detect the antibody bound to cell or tissue surface antigens by use of the fluorescence microscope (Figure 21.12). Cells to which fluorescent antibodies have bound emit a bright fluorescent color, usually red or yellow-green, depending on the dye used. Fluorescent antibodies have been of considerable utility in diagnostic microbiology because they permit the study of immunological reactions on single cells. The fluorescent antibody technique is also very useful in microbial ecology as one of the few methods for directly identifying microbial cells in natural environments.

Two distinct fluorescent antibody procedures, the **direct** and the **indirect** staining methods, are used (Figure 21.13). In the direct method, the antibody

Figure 21.12 Fluorescent antibody reactions. Cells of *Clostridium septicum* were teated with antibody conjugated with fluorescein isothiocyanate, which fluoresces yellow-green. Cells of *Clostridium chauvei* were stained with antibody conjugated with rhodamine B, which fluoresces red.

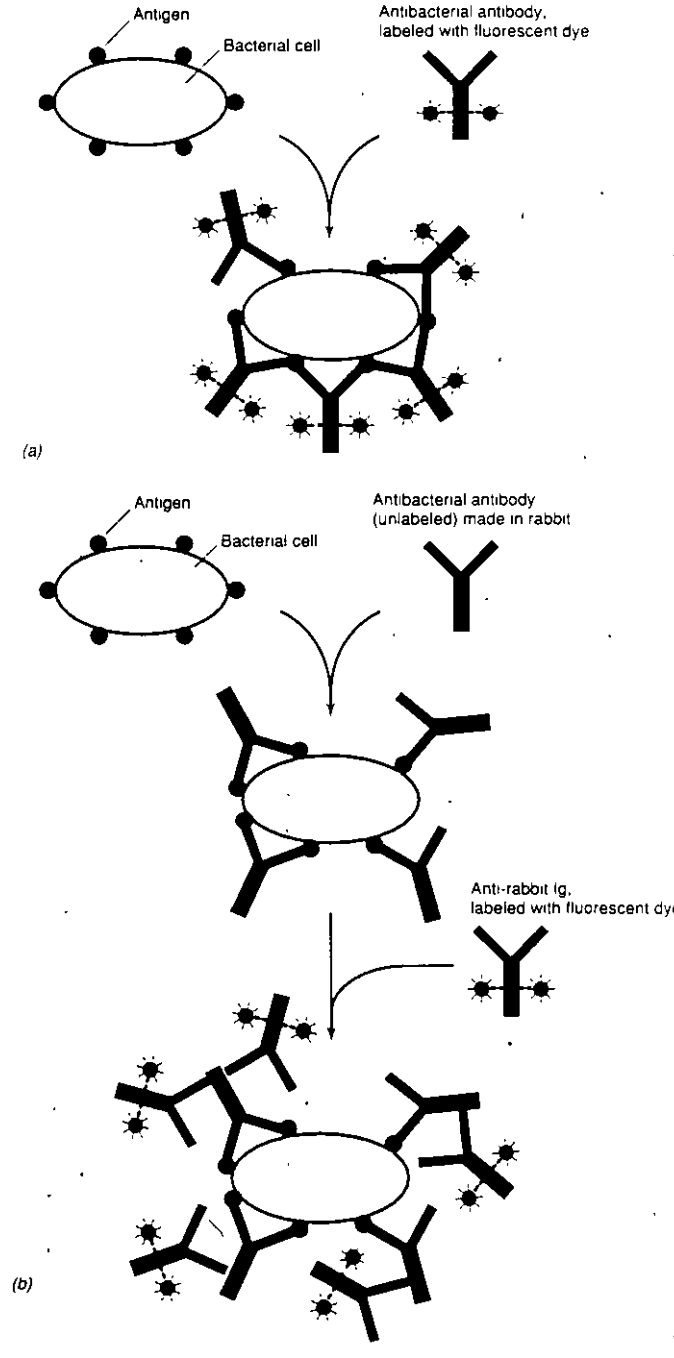


Figure 21.13 Methods of using fluorescent antibodies t detect bacterial surface antigens. (a) Direct staining metho (b) Indirect staining method.

against the organism itself is fluorescent. In the indirect hod, the presence of a nonfluorescent antibody on surface of the cell is detected by the use of a fluorescent antibody directed against the nonfluorescent antibody (Figure 21.13). This is done by immunizing one animal species, for example, a goat, with antibodies from a second species, for example, a rabbit, and then conjugating the fluorescent dye to the goat antibodies. The fluorescent goat anti-rabbit antibodies can then be used to detect the presence of rabbit immunoglobulin previously bound to cells. One of the advantages of the indirect staining method is that it eliminates the need to make a fluorescent antibody for each antigen of interest.

Clinical applications

In a typical clinical test using fluorescent antibodies, a smear of material containing a suspected pathogen is allowed to react with a specific fluorescent antibody and observed with a fluorescent microscope. If the pathogen contains surface antigens against which the fluorescent antiserum was prepared (that is, the suspected pathogen is identical to or immunologically closely related to the cells used to generate the antibodies), the cells will fluoresce (Figure 21.14). Organisms immunologically unrelated to the control organism generally do not react or react only weakly.

Fluorescent antibodies can also be applied directly infected host tissues, permitting diagnosis long before primary isolation techniques yield a suspected organism. For example, in diagnosing legionellosis (∞ Section 23.2) a positive diagnosis can be made by staining biopsied lung tissue with fluorescent antibodies prepared against cell walls of *Legionella pneumophila*, the causative agent of legionellosis (Figure 21.14*a*). Likewise, a fluorescent antibody against the capsule of *Bacillus anthracis* can be used in the microscopic diagnosis for anthrax. Fluorescent antibody reactions can also be used in diagnosis of viral infection (Figure 21.14*b*) and in a variety of noninfectious diseases. For example, in identifying cell types expressing a particular antigen, such as malignant cells, fluorescent antibodies may be very valuable in following the course of the disease (Figure 21.15).

Fluorescent antibodies can also be used to separate mixtures of cells into relatively pure populations or to define the numbers of certain cell types in complex mixtures such as blood. Fluorescent-labeled monoclonal antibodies directed against the CD4 and CD8 surface antigens of T lymphocytes (∞ Section 20.4) are routinely used to identify and enumerate these cells in the blood leukocyte population (Figure 21.16). For

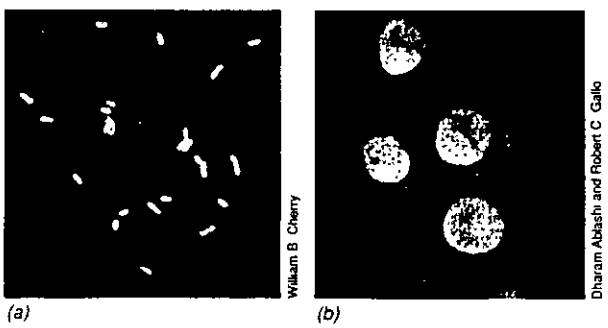


Figure 21.14 Examples of the use of fluorescent antibodies in clinical microbiology. (a) Immunofluorescent stained cells of *Legionella pneumophila*, the cause of legionellosis. The individual organisms are 2–5 μm in length. (b) Detection of virus-infected cells by immunofluorescence. Human B lymphotrophic virus (HBLV)-infected spleen cells were incubated with serum containing antibodies to HBLV from a patient with a lymphoproliferative disorder. Cells were then treated with fluorescein isothiocyanate-conjugated anti-human IgG antibodies. HBLV-infected cells fluoresce bright yellow. Cells in background did not react with the patient's serum. Individual cells are about 10–15 μm in diameter.

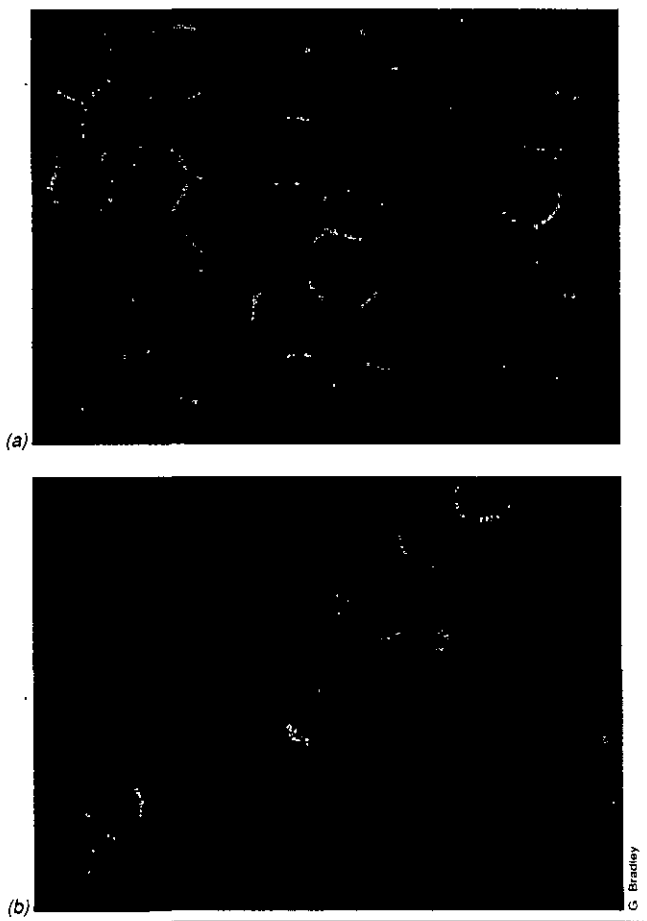


Figure 21.15 Use of fluorescent antibodies in nonnfectious disease diagnostics. (a) Human leukemic cells, some of which are sensitive to a toxic anticancer drug and some of which are not, appear indistinguishable. (b) When the cells in (a) are treated with a fluorescent monoclonal antibody that binds specifically to a protein found only on the surface of drug-resistant cells, the latter fluoresce whereas drug-sensitive cells do not.

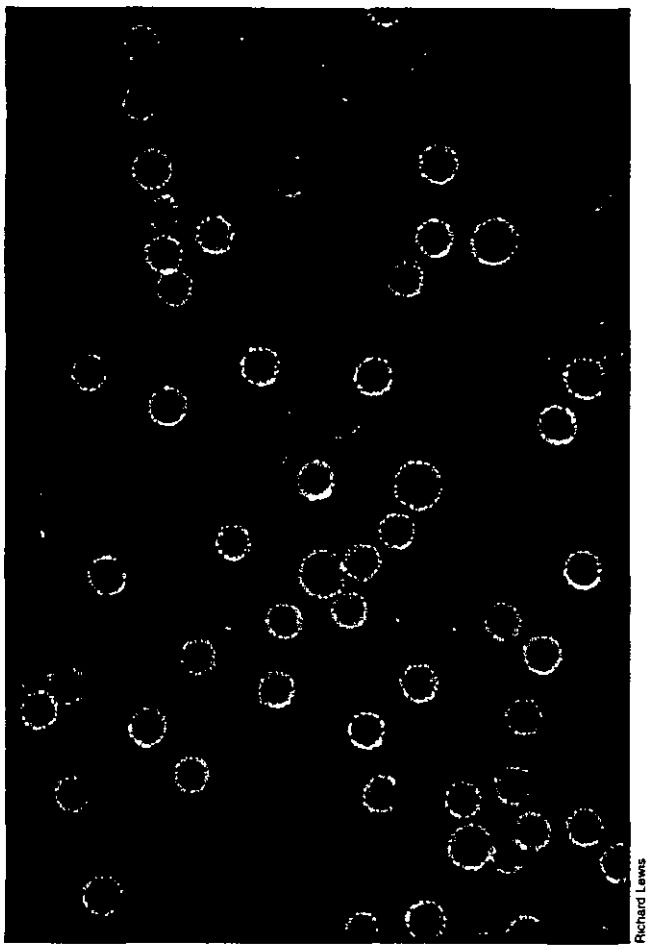


Figure 21.16 T lymphocytes stained with fluorescent-tagged monoclonal antibodies to specific surface markers. Yellow-green cells are cytotoxic (CD8) T cells; red cells are T helper (CD4) cells. The different-colored cells can be separated from one another by a fluorescence-activated cell sorter to yield enriched populations of different cell types. Reprinted with permission from *Science 239:* Cover (Feb. 12, 1988), © AAAS.

example, the definition of acquired immunodeficiency syndrome (AIDS) includes a reduction in CD4 cells. In addition, the CD4:CD8 ratio changes during the progression of AIDS. Thus, by defining the CD4 and CD8 numbers, the clinician can identify the reduction in CD4 cells and, with successive assays over time, can follow the progress of the disease (∞ Section 23.7).

Fluorescing cells can be visualized, counted, and separated with an instrument called a *fluorescence spectrometer,* often referred to as a fluorescence-activated cell sorter (FACS). The FACS uses a laser beam to activate the fluorescent molecules (in this case, fluorescent antibody bound to cells), placing a charge on the labeled cells. Following laser exposure, an electric field is applied to the cell mixture. The fluorescing and nonfluorescing cells are then deflected to opposite ends of the electric field where each cell population is counted and deposited in a tube. The use of several antibodies, each labeled with a different fluorescent dye, can result in the simultaneous identification of several cell markers. A typical application used for identifying CD3 and CD4 positive T cells in normal and AIDS patients is shown in Figure 21.17. FACS analysis is also useful for research applications. For example, immunologists routinely use FACS methods to separate complex mixtures of immune cells. They can then study the properties of the highly enriched cell populations.

Under appropriate conditions, fluorescent antibodies yield rapid, highly specific, useful information about a variety of clinical conditions. However, immunodiagnoses using fluorescent antibody techniques are not without their pitfalls. Nonspecific staining can be a problem because of surface antigens that may *cross-react* between various bacterial species, some of which may be members of the normal flora. This is a major problem among enteric bacteria, where antigens derived from lipopolysaccharides are frequently sufficiently similar among species to cause binding or partial binding of the fluorescent probe. The clinical microbiologist must therefore be careful to perform controls using nonspecific sera and confirm all positive immunofluorescent findings by other immunological or microbiological tests.

CONCEPT CHECK 21.7

Fluorescent antibodies can be employed for quick, accurate identification of pathogens and other antigenic substances in tissue samples and other complex environments. Through use of cell sorting, fluorescent antibodies can be used for quantitative enumeration of a variety of cell types, including pathogens.

- ✔ *Are fluorescent antibodies more sensitive for detecting antigens than normal antibodies?*
- ✔ *How are fluorescent antibodies used to identify specific cells in complex mixtures like blood?*

21.8 Enzyme-Linked Immunosorbent Assay and Radioimmunoassay

The specificity of antibodies is such that the limiting factor in most of the immunological reactions discussed thus far is not *specificity* but *sensitivity* (Table 21.6). Because of their exquisite sensitivity, radioimmunoassay (RIA) and enzyme-linked immunosorbent assay (ELISA) are two widely used immunological techniques. These methods employ radioisotopes and enzymes, respectively, to detect antibody molecules. Because radioactivity and the products of certain enzymatic reactions can be measured in very small amounts, the attachment of radioactive or enzyme ligands to anti-

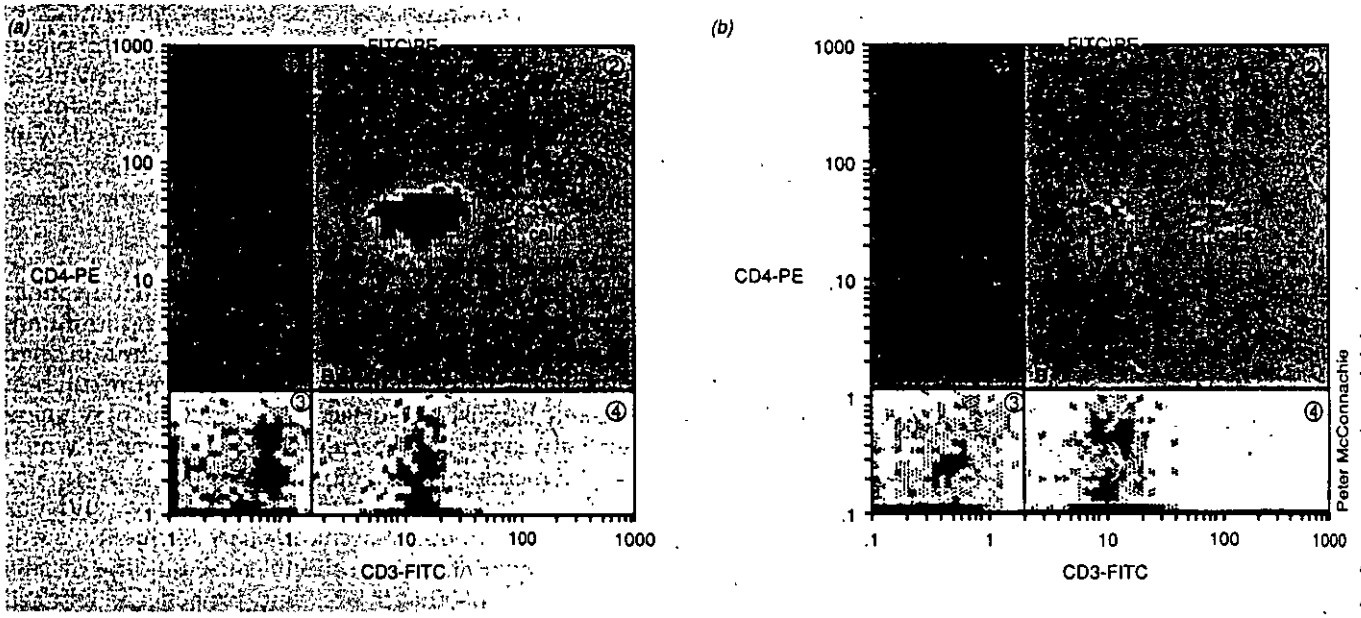


Figure 21.17 CD3 and CD4 cell enumeration from a healthy human (a) and from a human with acquired immunodeficiency syndrome (AIDS) (b) using a fluorescence-activated cell sorter (FACS). Peripheral blood cells were simultaneously labeled with monoclonal antibody to CD4 conjugated to phycoerythrin (PE) and with monoclonal antibody to CD3 conjugated to fluorescein isothiocyanate (FITC). CD3 is found on all T cells. CD4 is found on T helper (T_H) cells only. Quadrant 3 shows cells that were stained with neither antibody. Quadrant 1 shows cells stained with only anti-CD4. Quadrant 4 shows cells stained with only anti-CD3. Quadrant 2 shows cells stained with both anti-CD3 and anti-CD4. (a) Results from a healthy human. In this case, 56.3% of the T cells were T_H cells. Thus, quadrant 2 shows a dense staining pattern. (b) Results from a patient with clinical AIDS. In this case, only 2.7% of the total T cells are T_H cells. This is indicated by the very light staining pattern in quadrant 2. [Original data from Peter McConnachie used with permission.]

body molecules serves to decrease the amount of antigen–antibody complex required to detect a reaction. This increased sensitivity has been extremely helpful in clinical diagnostics and research and has opened the door to the development of a variety of new immunological tests, previously impossible because the methods available were not sufficiently sensitive (∞ Urine Testing for Drug Abuse, and Over-the-Counter Immunodiagnostic Kits, Chapter 20).

ELISA

The covalent attachment of enzymes to antibody molecules creates an immunological tool possessing both high specificity and high sensitivity. The technique, called **ELISA** (for *e*nzyme-*l*inked *i*mmuno*s*orbent *a*ssay), makes use of antibodies to which enzymes have been covalently bound such that the enzyme's catalytic properties and the antibody's specificity are unaltered. Typical linked enzymes include peroxidase, alkaline phosphatase, and β-galactosidase, all of which catalyze reactions whose products are colored and can be measured in very low amounts.

Two basic ELISA methodologies have been developed, one for detecting antigen (*direct* ELISA) and the other for detecting antibodies (*indirect* ELISA). For detecting antigens such as virus particles from a blood or fecal sample, the direct ELISA method is used. In this procedure the antigen is "trapped" between two layers of antibodies (Figure 21.18). Thus, this method is sometimes called the "sandwich ELISA." The specimen is added to the wells of a microtiter plate (see the box, The Microtiter Plate and Immunoassays) previously coated with antibodies specific for the antigen to be detected. If the antigen (virus particle) is present in the sample, it will be trapped by the antigen binding sites on the antibodies. After washing unbound material away, a second antibody containing a conjugated enzyme is added. The second antibody is also specific for the antigen, and so it binds to any remaining exposed determinants. Following a wash, the enzyme activity of the bound material in each microtiter well is determined by adding the substrate of the enzyme. The color formed is proportional to the amount of antigen present (Figure 21.18).

To detect *antibodies* in human serum, an indirect ELISA is employed. An indirect ELISA test is widely used to detect antibodies to human immunodeficiency

virus (HIV), and we will discuss this test in detail because the principles involved are applicable to all indirect ELISA tests.

The HIV-ELISA

The causative agent of AIDS, the human immunodeficiency virus (HIV) (∞ Section 23.7), is transmitted by bodily fluids including blood. Rapid, efficient, cost-effective screening tools are needed to test blood samples to ensure that HIV is not being inadvertently transmitted during blood transfusions or through the transfer of blood products. An ELISA test is used for the routine screening of blood for signs of exposure to HIV (and hence possible AIDS).

The HIV-ELISA test is an *indirect* ELISA designed to measure *antibodies* to HIV present in serum. Initial infection with HIV leads to the production of antibod-

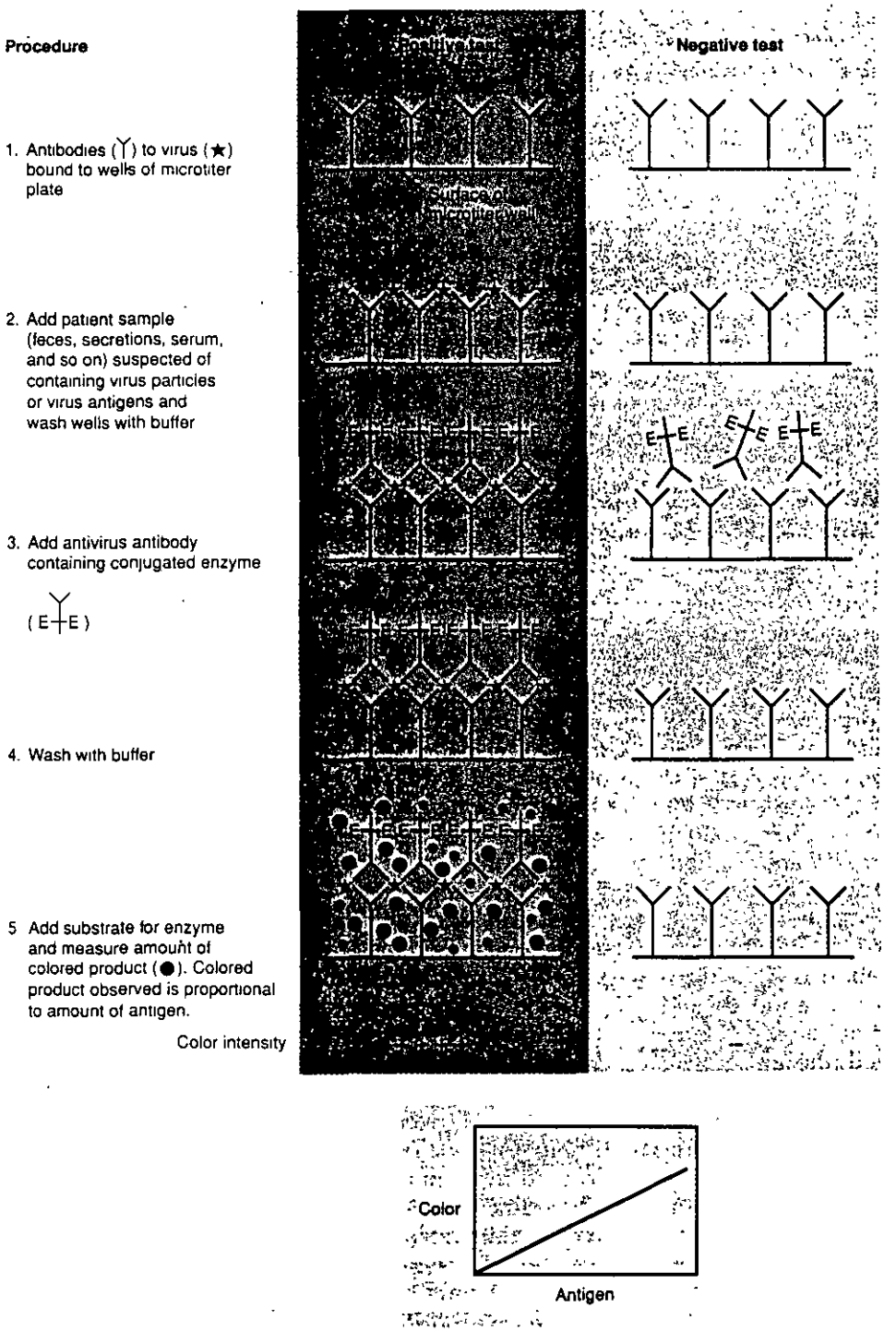
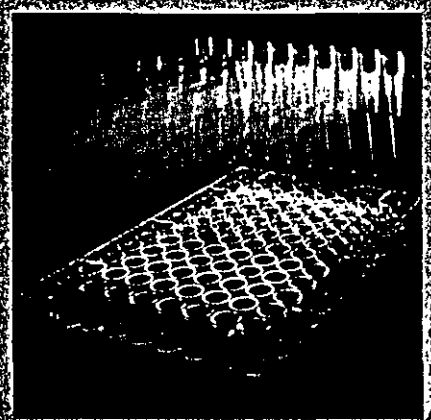


Figure 21.18 Detection of viruses by a direct ELISA test.

A FOCUS ON . . .

The Microtiter Plate and Immunoassays

A number of immunoassays have been developed requiring that either the antigen or the antibody be bound to a solid support. A variety of solid phase carriers such as latex beads or plastic tubes have been used, but the plastic disposable *microtiter plate*



has been the most successful solid support in modern immunoassays.

Microtiter plates are small, plastic trays containing a number of wells. The plates are made of polystyrene or polypropylene, both of which are transparent plastics. Proteins, either antigens or antibodies, adsorb to the plastic surface of the microtiter plate as a result of interactions between hydrophobic regions of the protein and the nonpolar plastic surface. Once bound, the proteins are not easily removed by washing or other manipulations, and thus bound proteins can be treated with various reagents and washed repeatedly without being removed from the plate surface. The standard microtiter plate contains 96 wells, which allows for several replicates of each sample to be run. For quantitation, several dilutions are prepared. Although only small amounts of protein can be adsorbed to each well, the sensitivity of ELISAs and radioimmunoassays are such that only small amounts of antigen or antibody are needed anyway.

Automatic machines are available for adding reagents and preparing dilutions. Depending on whether the microtiter plate assay is an ELISA or a radioimmunoassay, special machines are available to read the absorbance of a colored product (ELISA) or amount of radioactivity (radioimmunoassay) in each of the wells of the plate. Such automation allows these immunoassays to be performed both rapidly and routinely at relatively low cost. The microtiter plate has therefore helped to revolutionize research and diagnostic immunoassays. ELISAs in particular have become part of the everyday activities of the clinical laboratory. ■

ies to several HIV antigens, in particular those of the HIV envelope. These antibodies can be detected by the HIV-ELISA test (Figure 21.19).

To carry out an HIV-ELISA test, microtiter plates are first coated with a disrupted preparation of HIV particles; about 200 ng of disrupted HIV is required in each well. Following a brief incubation period to ensure binding of the antigens to the surface of the microtiter wells, a diluted serum sample is added and the mixture incubated to allow HIV-specific antibodies to bind to HIV antigens. To detect the presence of antigen–antibody complexes, a second antibody is then added. This second antibody is an enzyme-conjugated anti-human IgG preparation. Following a brief incubation period with the second antibody and a washing step to remove any unbound second antibody, the enzyme activity is assayed (the anti-human IgG antibodies bind to any HIV-specific IgG antibodies previously bound to the HIV antigen preparation). A color is obtained in the enzyme assay in proportion to the amount of anti-human IgG antibody bound (Figure 21.19). The binding of the second antibody is an indication that antibodies from the patient's serum recognized the HIV antigens, the patient has antibodies to HIV, and the patient has been exposed to HIV. Control sera (known to be HIV-negative) are assayed in parallel with any samples to measure the extent of background absorbance in the assay.

The HIV-ELISA test is a rapid, highly sensitive, specific method for detecting exposure to HIV. Since ELISAs in general are highly adaptable to mass screening and automation, the HIV-ELISA test is used as a standard screening method for blood. However, this test method can give erroneous results under certain circumstances.

For example, the test occasionally gives false positive results. Because a number of factors can contribute to these results, none of which are related to exposure to HIV, all positive HIV-ELISA tests *must* be confirmed by another independent test, usually the Western blot (immunoblot) test (see Section 21.9). A positive HIV Western blot test after a positive HIV-ELISA test is considered proof of HIV infection.

A final drawback to the HIV-ELISA test is the possibility of obtaining false negative results. As we learned in Section 20.11, it takes the immune system some time to develop an effective antibody response with a detectable antibody titer. In the case of HIV infection, this lag time is estimated to be 6 weeks to a year. Therefore, individuals who have been recently infected with HIV may not yet be producing detect-

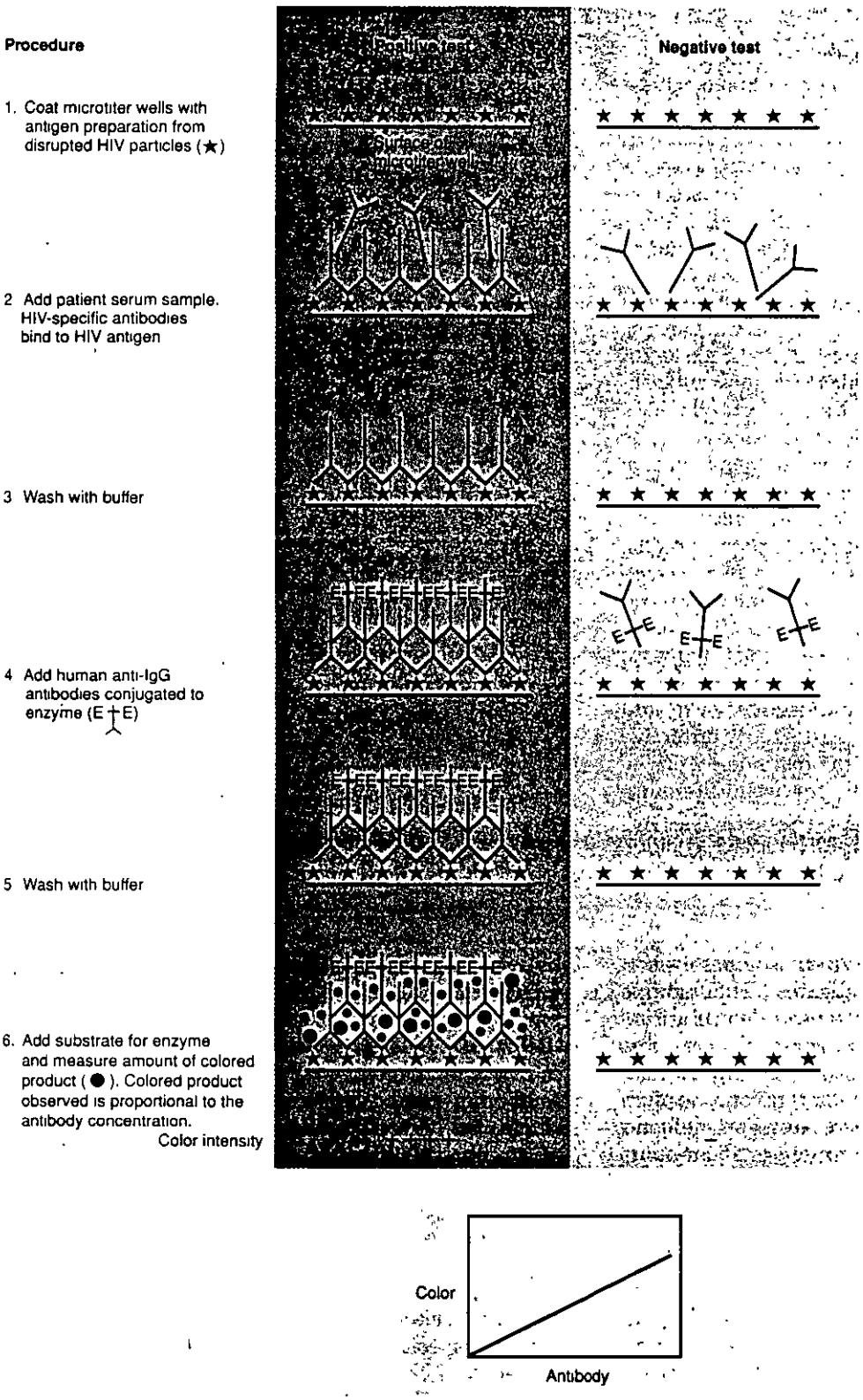


Figure 21.19 Indirect ELISA test for detecting antibodies to human immunodeficiency virus (HIV), the causal agent of acquired immunodeficiency syndrome (AIDS).

able amounts of antibody when they are tested. Another reason for a false negative result in the HIV-ELISA test is the total destruction of the immune system seen in advanced cases of AIDS; if no immune cells are left in the body, no antibodies can be made and the ELISA test is not useful. However, at this stage of disease, a clinical diagnosis is possible and the ELISA test is useful only as a confirmatory indicator.

Other ELISA tests of clinical importance

Besides the ELISA test for HIV, literally hundreds of clinically useful ELISAs have been developed. Some of these are direct ELISAs for detecting antigens. Direct ELISAs for detecting bacterial toxins such as cholera toxin, enteropathogenic *Escherichia coli* toxin, and *Staphylococcus aureus* enterotoxin have been developed. Viruses currently detected using direct ELISA techniques include rotavirus, hepatitis viruses, rubella virus, bunyavirus, measles and mumps viruses, and parainfluenza virus.

Indirect ELISAs have been developed for detecting antibodies to a variety of clinically important bacteria. Although not meant to be a complete list, ELISAs for detecting serum antibodies to *Salmonella* (gastrointestinal diseases), *Yersinia* (plague), *Brucella* (brucellosis), a variety of rickettsias (Rocky Mountain spotted fever, typhus, Q fever), *Vibrio cholerae* (cholera), *Mycobacterium tuberculosis* (tuberculosis), *Mycobacterium leprae* (leprosy), *Legionella pneumophila* (legionellosis), *Borelia burgdorferi* (Lyme disease), and *Treponema pallidum* (syphilis) have been developed. ELISAs have also been developed for detecting antibodies to *Candida* (yeast) and antibodies to a variety of parasites, including those causing amebiasis, Chagas' disease, schistosomiasis, toxoplasmosis, and malaria.

The speed, low cost, lack of radioactive waste, and long shelf life make ELISA tests particularly attractive for many laboratories. But it is the extreme *sensitivity* of ELISAs that really make them important immunodiagnostic tools. New ELISA tests are marketed each year, and many of them are rapidly replacing older, less-sensitive methods such as agglutination.

Radioimmunoassay

Radioimmunoassay (RIA) employs radioisotopes instead of enzymes as antibody conjugates. The isotope iodine-125 is the most commonly used detecting system, as proteins can be readily iodinated without disrupting their specificity. RIA is used clinically to measure rare serum proteins such as human growth hormone, glucagon, vasopressin, testosterone, and insulin present in humans in extremely small amounts (Figure 21.20) and also in some urine tests for drug abuse (∞ Urine Testing for Drug Abuse, Chapter 20). In most cases a *direct* RIA is employed. The direct assay is a two-step procedure. First, radioactive antigen-specific antibodies are added to a series of microtiter wells containing known concentrations of pure antigen (such as a hormone), which is first bound to the wells. The radioactivity in each of these standard wells is then measured. Next, the antigen sample from a patient is allowed to bind to another well, and radioactive antibodies are added and measured, as before. The amount of radioactivity bound by the patient sample is then compared to a standard plot generated from the binding data obtained using the pure antigen, and the concentration of antigen in the patient serum is interpolated from the standard plot (Figure 21.20).

RIA has the same sensitivity range as ELISA and can also be performed very rapidly. However, the instruments used to detect radioactivity are quite specialized and expensive. RIA generates a considerable amount of radioactive waste, and the radioactive decay time (half life) of the radioisotopes used for detection may limit the useful life of the test kit. As a result, RIA is often used only when ELISA is not sufficiently accurate or sensitive. For example, RIA is often more useful than ELISA for detecting serum protein levels (as described earlier) because some serum components may inhibit ELISA enzyme–substrate reactions. Thus, for certain applications, each test system has clear advantages over the other.

CONCEPT CHECK 21.8

ELISA and RIA methods are the most sensitive known immunoassay techniques. Both involve linking a detection system, either an enzyme or a radioactive molecule, to an antibody or antigen, enhancing sensitivity. ELISA and RIA are used for clinical and research work; tests have been designed to detect either antibody or antigen in a vast number of applications.

- ✔ *Why are ELISA and RIA techniques more sensitive than standard immunoassays such as precipitation and agglutination?*
- ✔ *What hazards are associated with radioimmunoassays?*

21.9 Immunoblot Procedures

Antibodies can be also used in clinical diagnostics to identify individual specific *proteins* associated with specific pathogens. The procedure employs three techniques discussed previously: (1) the separation of proteins on polyacrylamide gels, (2) the transfer (blotting) of proteins from gels to nitrocellulose paper (∞ Working with Nucleic Acids: The Tools, Chapter 6), and (3) identification of the proteins by specific antibodies. Protein blotting and the subsequent identification of the proteins by specific antibodies is sometimes called the "Western" blot technique to distinguish it from the (DNA) "Southern" blot technique.

The immunoblot is a very sensitive method for detecting specific proteins in complex mixtures. In the first step of an immunoblot, a protein mixture is subjected to electrophoresis on a polyacrylamide gel. This separates the proteins into several distinct bands, each of

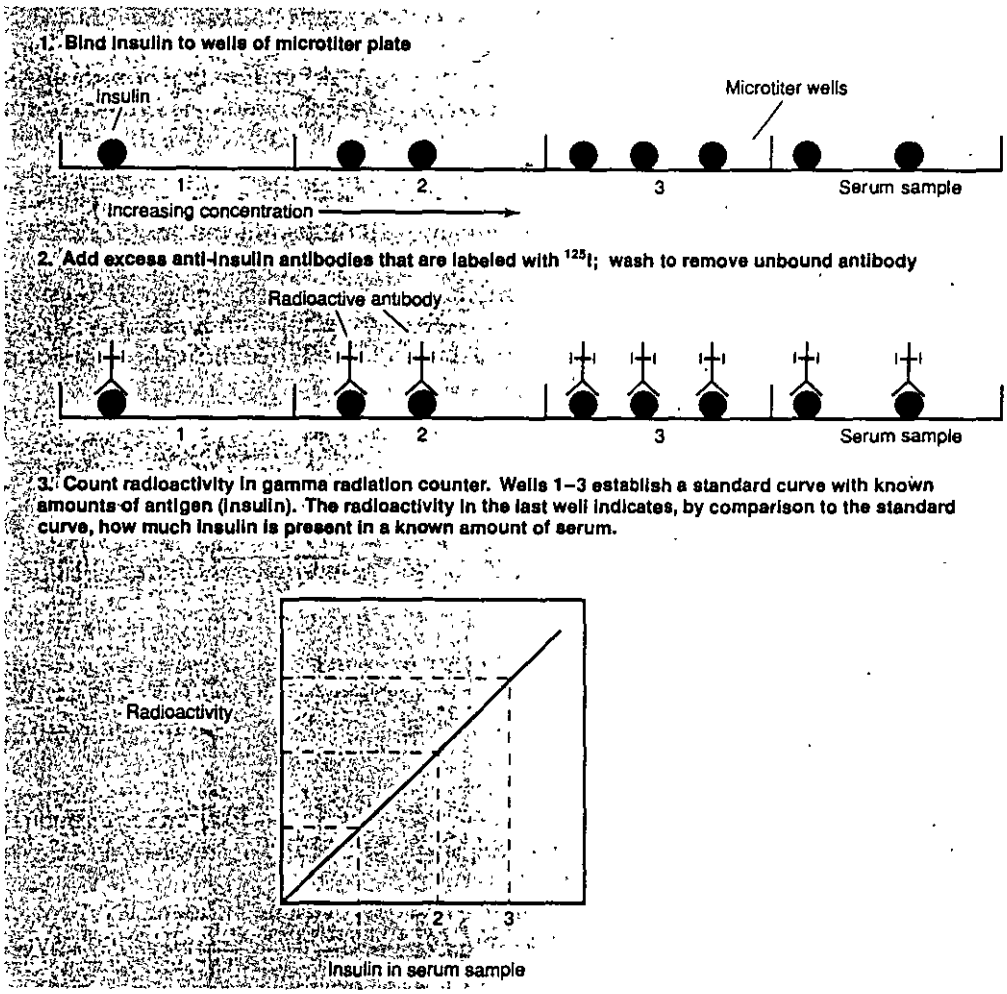


Figure 21.20 Radioimmunoassay (RIA). Using RIA to detect insulin level human serum Follo establishment of a stan curve, the insulin concentration in a serum sample can be estimated

which represents a single protein of specific molecular weight (Figure 21.21). The proteins are then transferred to nitrocellulose paper by an electrophoretic transfer process that forces the proteins out of the gel and onto the paper. At this point, antibodies raised against a protein or group of proteins from a pathogen are added to the nitrocellulose blot. Following a short incubation period to allow the antibodies to bind, a radioactive marker that binds antigen–antibody complexes is added. The most common radioactive marker used is *Staphylococcus* protein A iodinated with radioactive iodine, ^{125}I. Protein A has a strong affinity for antigen–antibody complexes and binds firmly to them. Once the radioactive marker has bound, its vertical position on the blot can be detected by exposing the nitrocellulose blot to X-ray film; the gamma rays emitted by the ^{125}I expose the film only in the region where the radioactive antibody has bound to antigen–antibody complexes (Figure 21.21).

For many clinical applications, immunoblots employ enzyme-linked immunosorbent assay (ELISA) technology (see Section 21.8) for detection of bound antigen–antibody complexes. Following treatment of the blotted proteins with specific antibody, the paper is washed and then treated with a second antibody, which binds to the first. For example, if antibodies from a human were used in the first step, then the second antibody could be a rabbit anti-human antibody. Covalently attached to this second antibody is an enzyme. The original antigen–antibody complexes are visualized when the enzyme is assayed because the product of the enzyme reaction leaves a colored product on the nitrocellulose filter at any spot where rabbit antibodies are bound to the human antibodies. By comparing the location of the color bands on the nitrocellulose paper with the position of colored bands from control samples, a protein associated with a given pathogen can be positively identified.

The immunoblot procedure can be used to detect either antigen (*direct* evidence for pathogen presence) or antibody (*indirect* evidence for pathogen exposure). Thus, this very sensitive, extremely accurate method is analogous to the direct and indirect ELISA procedures detailed in Section 21.8. We now examin widely used immunoblot test designed to ident exposure to HIV.

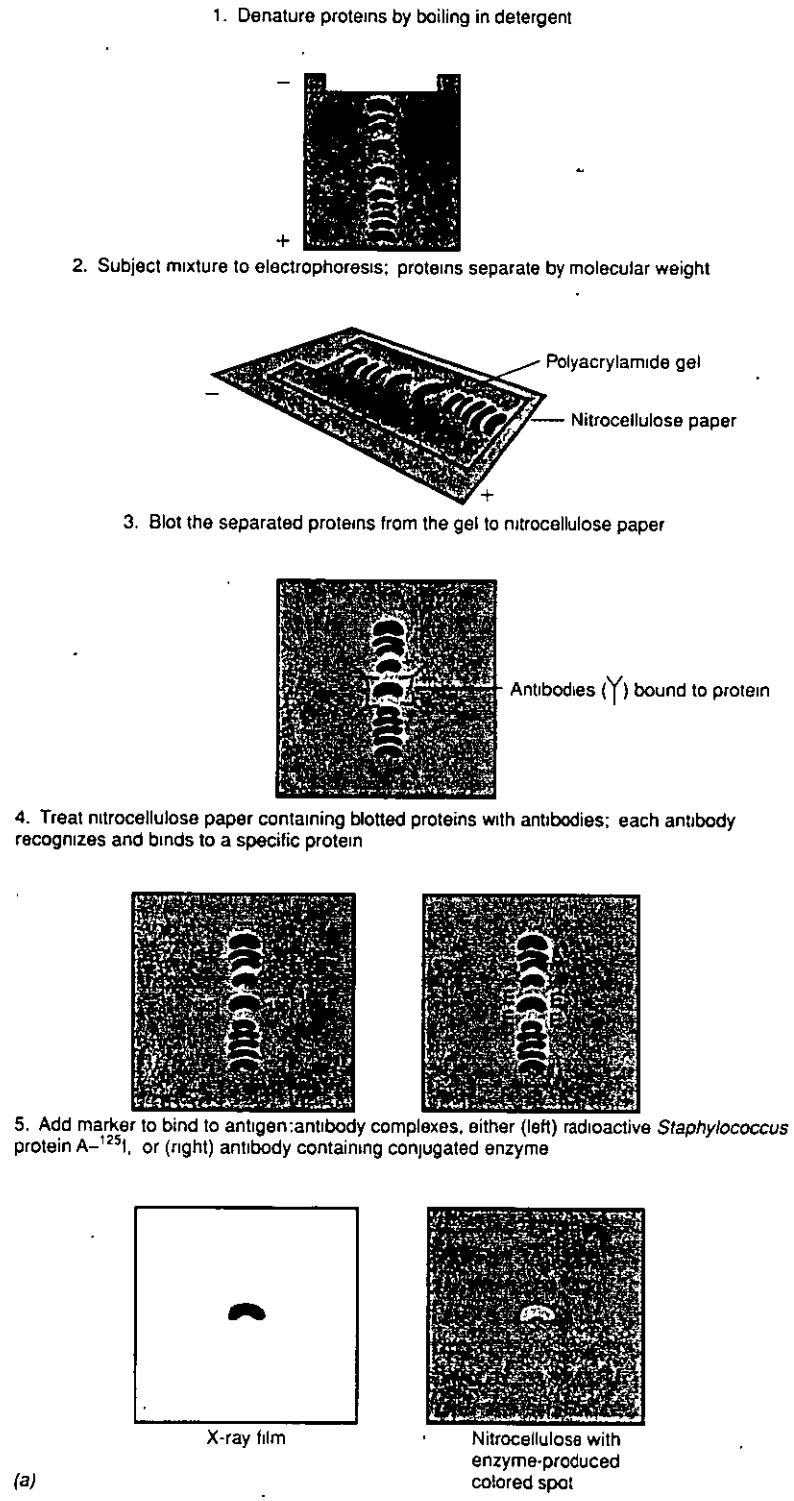


Figure 21.21 The Western blot (immunoblot) and its use in the diagnosis of human immunodeficiency virus (HIV) infection. (a) Protocol for an immunoblot. (b) Developed HIV immunoblot. The proteins P24 and GP41-45 are coat proteins of the virus and are diagnostic for HIV. Lane 1, Positive control serum (from known AIDS patients); lane 2, negative control serum (from healthy volunteer); lane 3, strong positive from patient sample; lane 4, weak positive from patient sample; lane 5, reagent blank to check for background binding.

The HIV immunoblot

Immunoblots have had a significant clinical impact on the diagnosis and confirmation of cases of AIDS. Because an immunoblot is more laborious, time-consuming, and costly than the ELISA test, HIV-ELISA tests have been widely used for screening purposes. However, the HIV-ELISA test occasionally yields false positive results. Thus, an immunoblot is virtually always used to confirm positive ELISA results.

Like the HIV-ELISA, the HIV immunoblot is designed to detect the presence of *antibodies* to HIV in

a serum sample. To perform the immunoblot, a purified preparation of HIV is treated with the detergent sodium dodecyl sulfate (SDS), which solubilizes HIV proteins and also renders the virus inactive. HIV proteins are then resolved by polyacrylamide gel electrophoresis. The HIV proteins are then blotted from the gel onto sheets of nitrocellulose paper (Figure 21.21). At least seven major HIV proteins are resolved by electrophoresis, and two of them, designated P24 and GP41-45, are used as specific diagnostic proteins in the AIDS immunoblot. Protein P24 is the HIV core protein, and proteins GP41-45 are HIV coat proteins (∞ Section 8.22).

Following blotting of the proteins, the nitrocellulose strips are incubated with a serum sample previously identified as HIV-positive (a positive control) by HIV-ELISA. If the sample is truly HIV-positive, antibodies against HIV proteins will be present and will bind to the HIV proteins separated on the nitrocellulose paper (Figure 21.21). To detect whether antibodies from the serum sample have bound to HIV antigens, a *detecting antibody*, anti-human IgG conjugated to the enzyme peroxidase, is added to the strips. If detecting antibody binds, the activity of the conjugated enzyme will form a brown band on the strip at the site of antibody binding after addition of substrate. The serum from the HIV-ELISA-positive patient is assayed in parallel with the positive control serum. The patient can be confirmed as HIV-positive if the position of the bands in the patient and the positive control sera are identical; negative control sera are also analyzed in parallel and must show no bands (Figure 21.21).

Although the intensity of the bands obtained in the HIV immunoblot varies somewhat from sample to sample (Figure 21.21*b*), the interpretation of an immunoblot is generally unequivocal, and thus the test is valuable for confirming HIV-ELISA positives and eliminating HIV-ELISA false positives. To make the HIV immunoblot clinically accessible, nitrocellulose strips containing inactivated HIV antigens (previously separated by electrophoresis) are available commercially. Separate strips can be incubated directly with the patient and control serum samples and subsequently treated with the detecting antibody. In addition to standardizing the assay, this eliminates the need for clinical microbiology laboratories to produce HIV as a source of antigen for the HIV immunoblot.

The immunoblot technique is considered the definitive test for serodiagnosis of HIV infection and is virtually always used to confirm positive HIV-ELISA tests. This technique is also used to confirm the specificity of screening tests for the Lyme disease antibody (see Table 21.5). However, because of the expense, technical requirements, and time involved, immunoblot tests are not likely to supplant the rapid, low cost ELISA methods for general screening purposes.

CONCEPT CHECK *21.9*

Immunoblot procedures can be used to detect antibodies to specific antigens or to detect the presence of the antigens themselves. The antigens are electrophoresed, transferred (blotted) to a filter, and exposed to antibody. Immune complexes are visualized through the use of enzyme-labeled or radioactive second antibodies. Immunoblots are extremely sensitive *and* accurate, but procedures are complex and time-consuming.

✔ *What advantage does the immunoblot have over immunoassays such as ELISA and RIA?*

✔ *What alternative labeling methods are used for immunoblot detection systems?*

21.10 Nucleic Acid Probes in Clinical Diagnostics

The emergence of molecular biology has given rise to new molecular tools that are rapidly being adapted to the field of diagnostic microbiology. *DNA diagnostics*, as this area has come to be known, is revolutionizing the whole approach to identifying and monitoring infectious diseases, genetic and malignant diseases, and other medical conditions such as coronary artery disease and diabetes. This new approach uses *genotypic* rather than *phenotypic* factors to identify specific pathogens. The power of DNA diagnostics is a consequence of two facts: (1) nucleic acids can be rapidly and sensitively measured, and (2) the *sequence* of nucleotides in a given DNA molecule is so specific that hybridization analyses can be used for reliable clinical diagnoses.

Automation is helping to make DNA analysis virtually routine in the clinical setting. Automated DNA extractors, polymerase chain reaction (PCR) machines (∞ Section 10.9), DNA sequencers, and pulse field gel electrophoresis equipment (for separating large DNA segments such as whole chromosomes) (∞ Working with Nucleic Acids: The Tools, Chapter 6) are all available for use in the diagnosis of diseases. The **nucleic acid probe** is now a major molecular tool in clinical laboratories.

Nucleic acid probes

One of the most powerful analytical tools available to clinical microbiologists is *nucleic acid hybridization*. Instead of detecting a whole organism or its products (for example, antigens), hybridization detects the presence or absence of *specific DNA sequences* associated with a specific organism. To identify a microorganism through

DNA analysis, the clinical microbiologist must have available a *nucleic acid probe* to that microorganism, a *single strand* of DNA containing sequences unique to the organism. The probe may be up to several kilobases in length, but many synthetic oligonucleotides consist of 20 bases or less and are still highly specific. If a microorganism in a clinical specimen contains DNA sequences complementary to the probe, the two sequences can hybridize (following appropriate sample preparation to yield single-stranded DNA from the microorganism), forming a *double-stranded* molecule (Figure 21.22). To detect that a reaction has occurred, the probe is labeled with a *reporter molecule*, a radioisotope, an enzyme, or a fluorescent compound that can be measured in small amounts following hybridization. Depending on the reporter used (radioisotopes are the most sensitive), as little as 0.25 μg of DNA per sample can be detected.

Nucleic acid probes offer many advantages over clinical immunological assays. Nucleic acids are much more stable than proteins to high temperatures, high pH, organic solvents, and other chemicals. This means that a clinical sample can be treated in a relatively harsh manner so as to destroy most interfering material, leaving behind the nucleic acid. In addition, nucleic acid probes are more defined entities than antibodies; the composition of a probe can be accurately checked by sequence analysis, and new molecules of the short probes can be produced in DNA synthesizers whenever necessary.

Nucleic acid probes are also very sensitive. With current technology it is possible to detect less than 1 μg of nucleic acid per sample. This translates into about 10^6 bacterial cells or virus particles. Although probes used in this fashion are not as sensitive as direct culture (where as few as 1–10 cells per sample can be detected), probe methods can be useful in situations where culture of the organism is difficult or even impossible.

Perhaps one of the most promising methods for clinical diagnostics involves the use of sequence-specific probes for polymerase chain reaction amplification of DNA or ribonucleic acid (RNA) from specific pathogens. As we discussed in Section 10.9, PCR uses two sequence-specific oligonucleotides to amplify target DNA. A DNA amplification of a millionfold or more increases the probe sensitivity and theoretically makes this procedure capable of detecting DNA from a single bacterial cell. For example, probes for a pathogen might be used to examine DNA derived from suspected infected tissue, even in the absence of an observ-

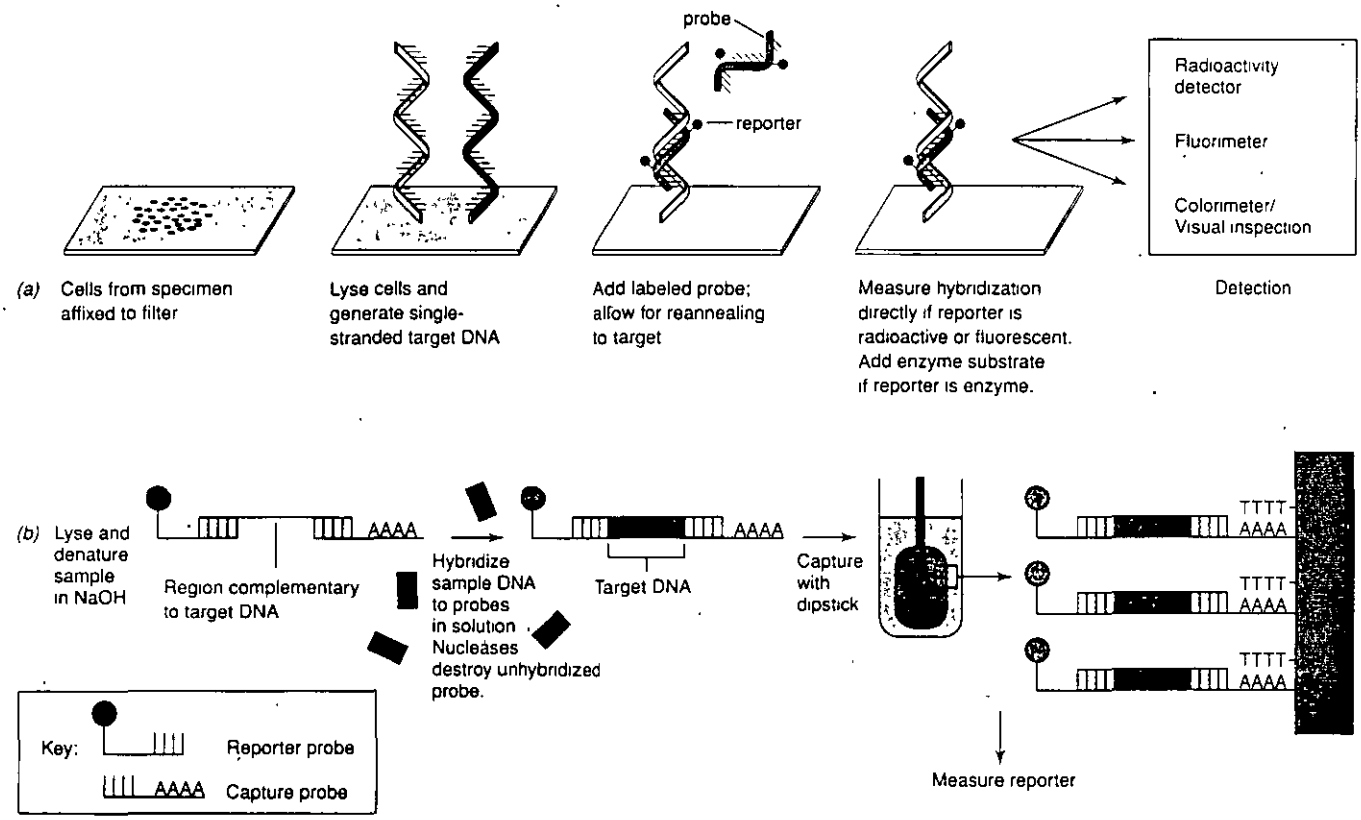


Figure 21.22 Nucleic acid probe methodology in clinical diagnostics. (a) Membrane filter say. The detecting system (reporter) can be a radioisotope, a fluorescent dye, or an zyme. (b) Dipstick assay. In the dipstick assay a dual reporter or capture probe is used. The capture probe contains a poly-dA tail that hybridizes to a poly-dT oligonucleotide affixed to the dipstick.

able, culturable pathogen. These methods are particularly useful for identifying viral and intracellular infections. The presence of the appropriate amplified gene segment (Figure 21.23) confirms the presence of the pathogen. Several of the specific organisms for which either hybridization or PCR methods are in use are listed in Table 21.7. We now consider several specific examples of nucleic acid probes and discuss some applications in more detail.

Probes in the clinical laboratory

In most clinical probe assays, colonies from plates or pieces of infected tissue are treated with strong alkali, usually NaOH, to lyse the cells and partially denature the DNA, forming single-stranded molecules (Figure 21.22). This mixture is then affixed to a filter or left in solution (for dipstick assays, see later), and the labeled probe added. Hybridization is allowed to occur at a temperature at which considerable sequence homology between target DNA and probe DNA is necessary to form a stable duplex (the actual temperature used in a given probe assay is governed by the length and nucleic acid composition of the probe and target DNA). Following a wash to remove any unhybridized probe DNA, the extent of hybridization that occurred is measured using the reporter molecule attached to the probe. Depending on how the probe was labeled, this involves measurement of radioactivity, enzyme activity, or fluorescence from an attached dye.

Nucleic acid probes have been marketed for the identification of several major microbial pathogens and are in widespread use for the detection of *Neisseria gonorrhoeae* and *Chlamydia trachomatis* (see Table 21.7 and Section 23.6). However, in addition to their clinical usefulness, probes are finding widespread application in food industries and in food regulatory agencies. Probe detection systems can be used to routinely monitor foods for their content of important pathogens such as *Salmonella* and *Staphylococcus*. In probe assay of food, an enrichment period is usually employed to allow low numbers of cells in the food to multiply to a sufficient number to be detectable by the probe. However, the use of PCR gene amplification techniques eliminates the need for the enrichment period.

Probes designed for use in the food industry employ probe dipsticks to remove hybridized DNA from solution. Two component probes are used here, one serving as a *reporter probe* and the other as a *capture probe* (Figure 21.22). Following hybridization of the reporter or capture probe to target DNA, the dipstick, which contains a sequence complementary to the capture probe (usually poly dT to capture poly dA on the probe) (see Figure 21.22*b*) is inserted into the hybridization solution, and it traps hybridized DNA for removal and measurement.

Probes for detecting certain cancer viruses are also being developed. For example, a probe is now available to detect DNA sequences unique to human papilloma viruses. These viruses sometimes cause skin and cervical cancer in humans (∞ Section 8.14), and a specific group of papilloma viruses causes genital warts (∞ Section 23.6). In women, an increased incidence of genital papilloma virus infection is associated with an increased risk of cervical cancer. The DNA probe developed for papilloma viruses can be used to search by hybridization for papilloma virus sequences in tissues removed during a cervical exam. Early detection and treatment of papilloma virus infections decreases the risk of cervical cancer.

The development of new nucleic acid probes is a major activity in pharmaceutical, biotechnology, and clinical diagnostic companies. Although developing probes for diseases for which no probe yet exists is a top priority, a major goal of probe research and development is to make existing probes even more specific and to continue to simplify the procedures necessary for implementing probe-based assays in the clinical setting.

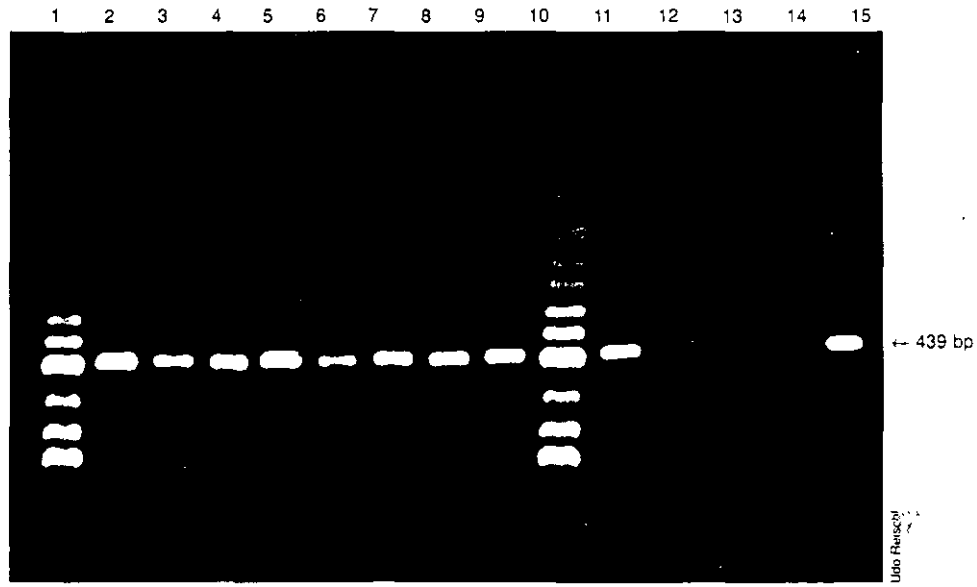


Figure 21.23 Polymerase chain reaction (PCR) analysis of patient sputum for *Mycobacterium tuberculosis* in the diagnosis of tuberculosis. Sputum samples from patients were used as a source of DNA. Amplification was initiated with a primer pair, which produced the indicated 439-base pair product when a pure culture of *M. tuberculosis* was used as the DNA source (lane 15). Lanes 2–9, 11 and 12 are from sputums positive for *M. tuberculosis* (lane 12 is only a weak positive). Lanes 13 and 14 are from *M. tuberculosis*-negative sputum samples. Lanes 1 and 10 are molecular weight reference markers.

TABLE 21.7 Pathogens that can be identified with nucleic acid probes

Pathogen	Disease
Bacteria	
Campylobacter spp.	Food infections
Chlamydia trachomatis	Venereal syndromes; trachoma
Escherichia coli (enteropathogenic strains)	Gastrointestinal disease
Haemophilus influenzae	Infectious meningitis
Legionella pneumophila	Pneumonia
Listeria monocytogenes	Listeriosis
Mycobacterium avium	Tuberculosis
Mycobacterium tuberculosis	Tuberculosis
Mycoplasma hominis	Urinary tract infection; pelvic inflammatory disease
Mycoplasma pneumoniae	Pneumonia
Neisseria gonorrhoeae	Gonorrhea
Salmonella spp.	Gastrointestinal disease
Shigella spp.	Gastrointestinal disease
Staphylococcus aureus	Purulent discharges (boils, blisters, pus-forming skin infections)
Streptococcus pyogenes	Scarlet, rheumatic fever; "strep throat"
Fungi	
Blastomyces dermatitidis	Blastomycosis
Coccidioides immitis	Coccidioidomycosis
Histoplasma capsulatum	Histoplasmosis
Viruses	
Cytomegalovirus	Congenital viral infections
Epstein–Barr virus	Burkitt's lymphoma, mononucleosis
Hepatitis viruses A, B, C, delta	Hepatitis
Herpes virus (types I and II)	Cold sores; genital herpes
Human immunodeficiency virus (HIV)	Acquired immunodeficiency syndrome (AIDS)
Human papilloma virus	Genital warts; cervical cancer
Protozoa	
Leishmania donovanii	Leishmaniasis
Plasmodium spp.	Malaria
Pneumocystis carinii	Pneumonia
Trypanosoma spp.	Trypanosomiasis

A major impediment to more extensive use of nucleic acid probes is the high cost per test, both for special reagents and for trained personnel. However, as automated methods and new tests become available, these problems will be overcome. Another problem is the lack of specific probes for many pathogens. However, recent advances in our understanding of bacterial phylogenetics based on 16S ribosomal RNA (rRNA) sequencing (∞ Section 15.7) now allow new and more specific nucleic acid probes to be constructed.

For example, *ribotyping* is a new method based on DNA probes that recognize conserved RNA operon genes. Ribotyping is essentially a Southern blot analysis in which strains are characterized for restriction fragment length polymorphisms (RFLPs; ∞ DNA Fingerprinting, Chapter 10) of their individual ribosomal genes. Within a species, and particularly within a strain, the DNA sequences and restriction digest patterns of genes encoding 5 rRNA, 25S rRNA and tRNAs are highly conserved and serve as a molecular fingerprint for that organism. Since *all* organisms have ribosomal genes, this technique is universally applicable and is finding wide acceptance as a clinical and phylogenetic tool.

CONCEPT CHECK 21.10

Nucleic acid hybridization is a powerful tool for disease diagnosis. A nucleic acid sequence specific for the virus or microbial pathogen must be available to design a probe. In addition to their use in clinical diagnosis, probes are also finding wide application in food and environmental monitoring.

✔ *What advantage does nucleic acid hybridization have over standard culture methods for identification of microorganisms? What disadvantages?*

✔ *Cite an example where identification of a pathogen can be made with a nucleic acid probe that cannot be made with standard culture techniques.*

21.11
Diagnostic Virology

Because of their unique characteristics as cellular parasites, identification and diagnosis of pathogenic viruses pose significantly different problems from the bacterial pathogens on which we have focused (∞ Chapter 8). For example, viruses cannot be directly cultured on artificial media, but they can be grown in host cells. Thus, viral growth-dependent assays are extremely complex. However, immunodiagnostic methods (see Sections 21.4–21.9) and nucleic acid hybridization methods (see Section 21.10) are widely used for viral identification, using the same principles applied to bacterial identification schemes. Finally, electron microscopy is often used for direct examination of viral specimens. In this section, we will concentrate on specific methods useful for viral identification, especially for the pathogenic viruses we will discuss in Chapter 23.

First, laboratory cultivation of viruses from clinical materials is more difficult, time-consuming, and specialized than the cultivation of most bacterial pathogens. This is because viruses grow only in living cells. We discussed the use of cell cultures for the growth of viruses in Section 8.3, and such cultures are commonly used in diagnostic virology. A common cell line is a human diploid fibroblast culture called WI-38, which grows rapidly and reproducibly in cell culture medium. Another cell line sometimes used is HeLa, a cell culture derived initially from a human cancer. This cell line has been maintained *in vitro* for so many successive transfers that it has greatly changed its character (for instance, it is no longer diploid). In addition to these two cell lines, which can be maintained in the laboratory indefinitely, cultures are also made from Rhesus monkey kidneys. Monkey kidney cell lines are called *primary* because they are not maintained by successive transfer in the laboratory. Primary monkey kidney cells support growth of a number of pathogenic viruses and are therefore of value in initial isolation of unknown viruses, but are not routinely used in most clinical laboratories. Because of the technical expertise and expense involved (for example, laboratories that do primary culture must maintain or purchase Rhesus monkeys), most diagnostic virology laboratories are located at specialized government facilities or major clinical research institutions.

Although the best diagnostic technique for most viral infections is actual isolation, growth, and identification of the virus, this is not practical in most clinical settings. Instead, several immunological tests and nucleic acid probes for viruses have been developed. Most of the immunological tests are either direct enzyme-linked immunosorbent assays (ELISAs) that detect viral particles (see Section 21.8 and Figure 21.18) or fluorescent antibody methods in which antibodies made against viral antigens are used to detect cells containing viruses (see Section 21.7 and Figure 21.14*b*). Viruses currently detectable by direct ELISA include rotavirus, hepatitis viruses, rubella virus, bunyavirus, measles virus, mumps virus, and parainfluenza virus. Agglutination tests are also available in which antiviral antibodies conjugated to latex beads or activated charcoal (see Section 21.5) are used to test for agglutination of viral antigens released from lysed tissue samples. Nucleic acid probes for detection and identification of clinically significant viruses are also becoming a major diagnostic tool in clinical virology (see Section 21.10).

Electron microscopy

In addition to the tools described previously, diagnostic virology can be done by electron microscopy. Because many viruses have distinctive morphologies (∞ Chapter 8), their presence in clinical specimens can often be detected by observing the sample under the electron microscope (Figure 21.24). In most specimens the virus particles must first be concentrated and separated from human tissues, and a variety of techniques, generally employing centrifugation and filtration, are used to obtain a sample enriched in virus particles. Although not as reliable as immunological or nucleic acid probe methods, the observation of virus particles of a specific morphology in a particular type of human tissue can often serve as presumptive evidence for a disease. Treating the sample with antibodies prepared against particular viruses can be used to increase the sensitivity and specificity of this method; such antibodies may cause the viral particles to agglutinate, and this makes them easier to distinguish from cellular

Figure 21.24 Electron microscopic observation of clinical specimens to detect viruses. Human rotavirus from a fecal sample. The distinct spherical nature of the virus, coupled with the source, is a highly diagnostic criterion. Eac rotavirus particle is approximately 75 nm in diameter.

debris under the electron microscope. Viruses can also be visualized following treatment of specimens with antiviral antibodies containing conjugated heavy metals (see Section 21.6). The electron microscope can thus serve as a provisional means of identifying viruses directly from patient specimens and offers the major advantage of speed. With the use of negative staining techniques (Figure 21.24), results from electron microscopic analysis can be available 20 minutes after collection of the specimen.

A summary of a few laboratory procedures used in diagnostic virology is given in Table 21.8. Most of these procedures are used only under special circumstances. For routine virus infections, diagnoses are made by assessing symptoms or by immunological or other indirect means. For example, testing for human immunodeficiency virus (HIV) infection involves the ELISA test and the immunoblot test. Both these methods detect the presence of *antibodies* to HIV, not HIV itself; as is the case for most viruses, there is currently no *routine* method used to detect the presence of HIV directly.

CONCEPT CHECK 21.11

Virus culture can be accomplished only in susceptible tissue or organs. Therefore, most diagnostic techniques for viral identification are not growth-dependent but routinely rely on immunoassays and nucleic acid hybridization techniques. Electron microscopy techniques are useful for direct observation of virus in host samples.

✔ *Why must viruses be grown in tissue or organ culture and not on artificial, inert media?*

✔ *How can individual pathogenic viruses be identified?*

21.12
Safety in the Clinical Laboratory

By their very nature, clinical laboratories are areas in which potentially dangerous biological specimens must be handled on a routine basis. Hence, a defined protocol for handling clinical samples must be established to avoid laboratory accidents. In the United States, every clinical and research institution that deals with human or primate tissue is required by law to have an occupational exposure control plan in place for the handling of all bloodborne pathogens. This law was specifically designed to protect workers from infection by hepatitis B virus (HBV) (☞ Section 23.13) and human immunodeficiency virus (HIV) (☞ Section 23.7) but effectively protects workers from infection by virtually all pathogens because of the stringent precautions.

Studies of laboratory-associated infections have indicated that most such infections do not result from known exposures or accidents but instead from routine handling of patient specimens. The two most common causes of laboratory accidents are ignorance and carelessness. Infectious aerosols, generated during processing of the specimen, are the most likely cause of laboratory infections. In attempts to minimize the exposure of clinicians to infectious agents and to thereby reduce the number of nonaccident-associated laboratory infections, well-run clinical laboratories stress the safety rules outlined here. These rules, if applied stringently, ensure the prevention of pathogen spread and meet the legal requirements of the United States law.

1. Laboratories handling hazardous materials must restrict access to laboratory and support personnel. These individuals must have knowledge of the bio-

TABLE 21.8 Some laboratory procedures used in diagnostic virology[a]

Condition	Possible viral cause	Sample source	Inoculation procedure
Upper respiratory infection	Rhinovirus Coronavirus Adenovirus	Nasopharyngeal or tracheal fluid (aspirate)	Human fibroblast culture
Pneumonia	Influenza	Nasopharyngeal fluid or swab	Human fibroblast cultures or embryonated eggs
Measles	Measles virus	Nasopharyngeal fluid or swab	Monkey kidney cells
Vesicular rash	Herpes simplex	Vesicular fluid by aspiration	Human fibroblast culture
Diarrhea	Rotavirus (infants) Norwalk agent (adults)	Feces or rectal swab	Look for characteristic virus particles with the electron microscope (Figure 21.24)
Nonbacterial meningitis	Enterovirus Mumps Herpes simplex	Spinal fluid	Human fibroblast or monkey kidney cultures

[a] Immunological methods and nucleic acid probe methods are also widely used in the diagnosis of viral infections (see Sections 21.4–21.10).

logical risks involved in the clinical laboratory and act accordingly.

2. Effective procedures for decontaminating infectious materials or wastes, including specimens, syringes and needles, inoculated media, bacterial cultures, tissue cultures, experimental animals, glassware, instruments, and surfaces must be in place and be practiced without compromise. A 5.25% (full strength) chlorine bleach solution or other approved disinfectant is recommended for decontaminating spilled infectious material. All potentially infectious waste must be burned in a certified incinerator or handled by a licensed waste handler.
3. Personnel working with hazardous infectious agents or vaccines (for example, rabies, polio, or diphtheria-pertussis-tetanus vaccines) must be properly vaccinated against the agent. Persons working with human or primate tissue must be vaccinated against HBV.
4. All clinical specimens should be considered potentially infectious and handled in the appropriate manner. This is especially important for preventing laboratory-acquired hepatitis because of the relative frequency with which hepatitis viruses are present in clinical specimens.
5. All pipetting must be done with automatic pipetting devices (not by mouth), and devices such as syringes, needles, and clinical centrifuges must always be used with proper biological containment equipment.
6. Animals should be handled only by trained laboratory personnel, and anesthetics or tranquilizers should be used to avoid injury to both personnel and animals.
7. Laboratory personnel must wear laboratory coats or gowns, sealed shoes, rubber gloves, masks, eye protection, respiratory devices when needed, and other barrier protection as deemed appropriate by the level of exposure and the severity of the potential infection. These barrier devices must also be properly stored and decontaminated after use. Laboratory personnel must also practice good personal hygiene with respect to hand washing. Eating and drinking, applying lip balm, or wearing contact lenses is never permitted in the clinical laboratory.
8. Because of the special risks associated with AIDS, all clinical specimens should be treated as if they contain HIV (which they might). Latex or vinyl gloves should be worn whenever handling specimens of *any* kind. Masks must be worn any time there is a possibility of generating an aerosol during specimen preparation. Needles must not be resheathed, bent, or broken; they should be placed in a labeled container designated expressly for this purpose that can be sealed and autoclaved before disposal.

These safety rules should be the norm for all clinical laboratories. Specialized clinical laboratories may have additional rules to ensure a safe work environment. For example, if laboratory personnel handle extremely hazardous airborne pathogens (such as the causative agent of tuberculosis, *Mycobacterium tuberculosis*) on a routine basis, the laboratory should be fitted with special features, such as negatively pressurized rooms, biological safety cabinets (∞ Figure 11.4), and air filters, to prevent accidental release of the pathogen from the laboratory. In the final analysis, however, it is the attitude of the personnel that makes the laboratory a safe or an unsafe place to work. Any clinical laboratory is a potentially hazardous place for untrained personnel or those unwilling to take the necessary steps to prevent laboratory-acquired infection.

CONCEPT CHECK 21.12

Safety in the clinical laboratory requires effective training, planning, and care to prevent the infection of laboratory workers with pathogens. Materials such as inoculated culture media, needles, and patient specimens require specific precautions for safe handling.

✔ *What are the major precautions necessary to prevent spread of a bloodborne pathogen to laboratory personnel?*

Material for Review

REVIEW QUESTIONS

1. Describe the standard procedure for obtaining and culturing a blood sample for bacteria.
2. Why is the *number* of bacterial cells in urine, rather than simply the *presence* of bacteria in urine, of significance? What organism is responsible for most urinary tract infections? Why?
3. Describe the procedures used for culturing anaerobic microorganisms. Why is it important to process all clinical specimens quickly? What special procedures and precautions are necessary for the isolation and culturing of anaerobes?
4. Differentiate between *selective* and *differential* media. Is eosin–methylene blue (EMB) agar selective or differential? How and why is it used in a clinical laboratory?
5. Describe the Kirby–Bauer test for antibiotic sensitivity. Why should potential pathogens from patient isolates be tested by this method?
6. Why does the antibody titer *rise* after infection? Why is it necessary to draw two serum samples to monitor infections?
7. How are fluorescent antibodies used for the diagnosis of viral diseases?
8. Agglutination tests are significantly more sensitive than precipitation tests. Why might this be the case?
9. Likewise, radioimmunoassay (RIA) and enzyme-linked immunosorbent assay (ELISA) tests are extremely sensitive, as compared to agglutination. Why?
10. What advantages do *monoclonal* antibodies have over *polyclonal* antibody preparations, especially with regard to standardization of antibody preparations?
11. Why is the immunoblot (Western blot) procedure used to confirm positive human immunodeficiency virus (HIV)-ELISA results?
12. What information is essential for the design of a pathogen-specific nucleotide probe? Where can one obtain such information? Is this information available for all pathogens?
13. What is a primary cell line? Why do some animal viruses grow in primary cell lines but not in cell lines such as HeLa cells?
14. How are most laboratory-associated infections contracted? What actions can be taken to prevent them?

APPLICATION QUESTIONS

1. From a blood culture, you obtain a culture positive for *Staphylococcus aureus*. Interpret and explain the results. Is it likely that the patient has a *S. aureus* bacteremia? Why or why not?
2. Describe the microscopic and cultural evidence that would support a diagnosis of gonorrhea. Why is Thayer–Martin agar a "better" medium than chocolate agar for the isolation of *Neisseria gonorrhoeae*?
3. Compare and contrast the changes in color due to pH-sensitive dyes in tests for carbohydrate fermentation and citrate utilization. Is the same dye used in both tests? Why or why not?
4. Why should it not be a common medical practice to treat an infectious disease with antibiotics before isolating the suspected pathogen? What further steps should be taken before antibiotic therapy is initiated? Why are these steps seldom taken outside a hospital environment?
5. What are the advantages of rapid identification systems such as agglutination tests as compared to standard clinical diagnostic procedures? Also discuss the potential disadvantages of rapid, non-culture-based tests.
6. Design a fluorescent antibody assay for confirming an initial diagnosis of "strep throat" (*Streptococcus pyogenes* is the causative agent of strep throat). Discuss all aspects of the assay, including preparation of antisera, necessary controls, and clinical interpretation.
7. Design an ELISA test for detecting hepatitis A virus in feces. Likewise, design an *indirect* hepatitis A virus test for detection of exposure. Would either test require anti-human IgG antibodies? Why or why not?
8. What are the major advantages of using DNA probes in diagnostic microbiology? Discuss at least four aspects of probe technology that benefit clinical medicine. Where can you find information to design polymerase chain reaction (PCR) assay probes for the hepatitis A virus in Question 7? Remember, the probes must be sequence-specific for the virus.
9. As a new professional in a clinical laboratory, you are assigned the task of formalizing the laboratory safety requirements to prevent infectious diseases. Explain how you would monitor and enforce the recommendations outlined in Section 21.12.

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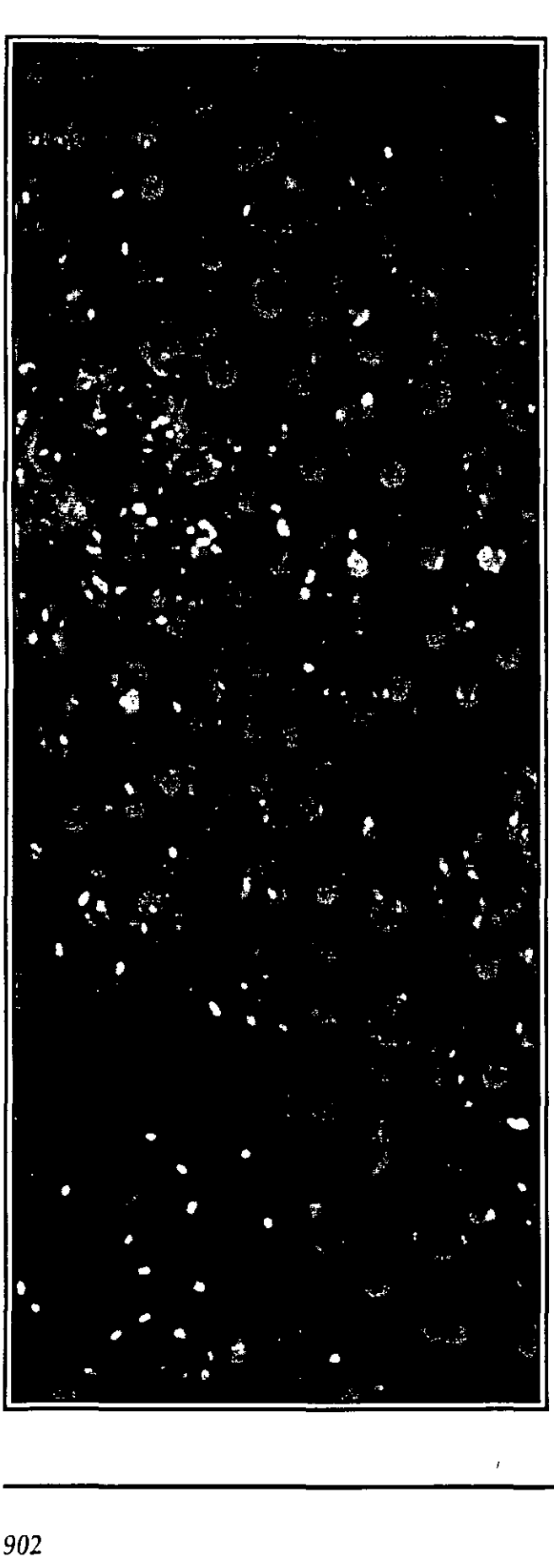
On~line resources for this chapter are on the World Wide Web at:
http://www.prenhall.com/~brock (click on the table of contents link and then select Chapter 21).



CHAPTER 22

Epidemiology and Public Health Microbiology

Many human pathogens exist as normal inhabitants of the environment. Shown here are cells of *Vibrio cholerae* (green) attached to the surface of *Volvox* (red), a freshwater alga. The *V. cholerae* organism causes cholera. This isolate was found in a water source in Bangladesh. The ability of these organisms to exist outside the human host makes their eradication as pathogens nearly impossible.

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GLOSSARY for Chapter 22

Acute short-term infection usually characterized by dramatic onset and rapid recovery

Carrier subclinically infected individuals who may spread a disease

Chronic long-term infection

Common-Source Epidemic an epidemic resulting from infection of a large number of people from a single contaminated source

Emerging Infections infectious diseases whose incidence has increased in the past 20 years or whose incidence threatens to increase in the near future

Endemic disease constantly present, usually in low numbers

Epidemic the occurrence of a disease in unusually high numbers in a localized region

Epidemiology the study of the occurrence, distribution, and control of infectious diseases

Fomites inanimate objects that, when contaminated with a viable pathogen, can transfer the pathogen to a host

Herd Immunity resistance of a group to a pathogen as a result of the immunity of a large portion of the group

...t-to-Host Epidemic an epidemic resulting from ...son-to-person contact, characterized by a gradual rise and fall in numbers of cases

Incidence the number of cases of disease in a population

Morbidity incidence of illness in a population

Mortality incidence of death in a population

Nosocomial Infection hospital-acquired infection

Outbreak the occurrence of a large number of cases of a disease in a short period of time

Pandemic a worldwide epidemic

Prevalence the proportion or percentage of individuals in the population having a disease

Public Health the health of the population as a whole

Quarantine the practice of restricting the movement of individuals with highly contagious serious infections to prevent spread of the disease

Reservoir sites in which viable infectious agents remain and from which infection of individuals may occur

Resurgent Infections infectious diseases, thought to be under control, that reemerge

Surveillance observation, recognition, and reporting of diseases as they occur

Vector a living agent that transfers a pathogen (note alternative usage in Chapter 8)

Vehicle nonliving source of pathogens that infect large numbers of individuals; common vehicles are food and water

Zoonosis a disease that occurs primarily in animals but can be transmitted to humans

In Chapters 19 and 20 we considered the general principles of how microorganisms cause infectious disease and how the host responds to microbial onslaught. In Chapter 21, we discussed the methods for diagnosis of infectious diseases. In this chapter, we consider how a pathogen spreads from an infected individual to others in a population. Thus, we are dealing here with *public health*. In the next chapter we consider the diseases themselves. The principles put forward in this chapter are vital for controlling the spread of infectious disease.

One measure of our success in the control of infectious disease was shown by the data presented in Figure 1.18, which compared the present causes of death in the United States with those at the beginning of the twentieth century. Many microbial diseases are no longer the th... to public health they once were in developed c... es. However, we will discuss a number of infectio... diseases that are emerging as important public health problems, even in developed countries. In developing countries, which include about 75% of the world's population, infectious diseases are still a major problem. Worldwide, infectious diseases account for nearly 40% of the total of 50 million annual estimated deaths. Table 22.1 shows the most prevalent causes of death. Note that, for many of these diseases (for example, measles and whooping cough), effective vaccines are manufactured (∞ Section 20.17) but are often not available or are not used outside of developed countries. Clearly, infectious diseases will remain an important public health problem throughout the world. The current acquired immunodeficiency syndrome (AIDS) epidemic, which has apparently spread worldwide in 20 years or less, is only one example of the devastating consequences of an infectious disease in a global theater. Eradication or even effective control of infectious diseases must involve scientific, economic, political, and educational solutions, and ultimately, global cooperation.

TABLE 22.1 Infectious diseases: The leading human killers

Cause of death	Estimated yearly deaths[a]	Infectious agents
Acute respiratory infections	6,900,000	Bacteria, viruses, protozoa, fungi
Diarrheal diseases	4,200,000	Bacteria, viruses
Tuberculosis	3,300,000	Bacteria
Acquired immunodeficiency syndrome (AIDS)	1,000,000–2,000,000	Virus
Malaria	1,000,000–2,000,000	Protozoa
Hepatitis	1,000,000–2,000,000	Viruses
Measles	220,000	Virus
Meningitis, bacterial	200,000	Bacteria
Schistosomiasis	200,000	Parasitic worm
Pertussis (whooping cough)	100,000	Bacterium
Amebiasis	40,000–100,000	Protozoa
Hookworm	50,000–60,000	Parasitic worm
Rabies	35,000	Virus
Yellow fever	30,000	Virus
African trypanosomiasis (sleeping sickness)	20,000 or more	Protozoan

[a]Data represent estimates for yearly worldwide total deaths each year from each disease. There are approximately 50 million deaths per year, worldwide, from all causes. Over 20 million deaths are caused by infectious disease each year

Source: World Health Organization.

22.1
The Science of Epidemiology

The most visible aspect of microbial disease is the actual diseased individual. However, individuals do not live alone, and when we consider infectious diseases in populations, some new factors arise. The study of the occurrence, distribution, and control of disease in populations is the field of **epidemiology.**

To continue existing in nature, a pathogen must be able to grow and reproduce. For this reason, an important aspect of the epidemiology of any disease is a consideration of the natural history of the pathogen. In many cases the pathogen cannot grow outside the host, and if the host dies, the pathogen will also die. Pathogens that kill the host before they are transmitted to a new host would thus become extinct. This raises the question of why pathogens occasionally kill their hosts. Actually, a well-adapted parasite lives in synchrony with its host, taking only what it needs for existence and causing only a minimum of harm. However, serious host damage often occurs when new varieties of pathogens arise for which the host has not developed resistance, or when the resistance of the host changes because of the factors discussed in Chapter 19. Pathogens are selective forces in the evolution of the host, just as hosts are selective forces in the evolution of pathogens. When equilibrium between host and pathogen exists, both coexist in a stable relationship.

The epidemiologist traces the spread of a disease to identify its origin and mode of transmission. The epidemiologist relies heavily on data obtained from clinical studies, disease reporting surveys, insurance questionnaires, and interviews with patients to define common factors that constitute a disease. The science of epidemiology has been referred to as "medical ecology" because the study of a disease in populations is really a study of a disease in its natural environment. This is in contrast to the clinical or laboratory study of disease, where the focus is on treating the individual patient. Knowledge of both the clinical aspects and ecological aspects of a given disease are important if public health measures to control diseases are to be effective.

CONCEPT CHECK 22.1

Epidemiology follows the spread of disease in populations. For infectious disease, the epidemiologist develops methods for the control of infectious disease by defining the interactions of the pathogen in the host population.

- ✔ *How does an epidemiologist differ from a microbiologist?*
- ✔ *What data do epidemiologists acquire for infectious diseases?*

22.2
Epidemiological Terminology

A number of terms having specific meanings are used by the epidemiologist to describe patterns of disease. The **prevalence** of a disease in a population is defined as the proportion (or percentage) of diseased individuals in a population at any one time. The **incidence** of a disease is the *number* of diseased individuals in a popu-

...on at risk. A disease is said to be **epidemic** when it ...s in an unusually high number of individuals in ... immunity at the same time; a **pandemic** is a widely distributed epidemic (Figure 22.1). By contrast, an **endemic** disease is one that is constantly present, usually at low incidence, in a population. In an endemic disease, the pathogen may not be highly virulent, or the majority of the individuals may be immune, and so the incidence of disease is low. However, as long as an endemic situation lasts, a few individuals remain who serve as reservoirs of infection.

Sporadic cases of a disease occur when individual cases are recorded in geographically separated areas, implying that the incidents are not related. A disease **outbreak,** on the other hand, occurs when a number of cases are observed, usually in a relatively short period of time, in an area previously experiencing only sporadic cases of the disease. Finally, *subclinical infection* is used to describe diseased individuals who show no or only mild symptoms. Subclinically infected individuals are frequently identified as **carriers** of a particular disease, because even though they themselves show few or perhaps no symptoms, they may still be actively carrying and shedding the pathogenic agent (see Section 22.3).

Mortality and morbidity

In practice, the incidence and prevalence of disease is ...rmined from statistics of illness and death. From ... data a picture of the public health in a population can be obtained. The population under consideration could range in size from the total global population of humans down to the population of a localized region of a country or district. Public health varies from region to region, as well as with time; thus, assessment of public health at a given moment provides only a snapshot of the situation. By continuing to examine health statistics over many years, it is possible to assess the value of various public health policies that may influence the incidence of disease.

Mortality expresses the incidence of *death* in the population. Infectious diseases were the major causes of death in 1900 in developed countries (☞ Figure 1.18), whereas currently they are of much less significance; noninfectious diseases such as heart disease and cancer are of greater importance. However, the current situation could rapidly change if a breakdown in public health measures were to occur and, in fact, does not mirror the worldwide situation. In developing countries, infectious diseases are still the major killers (Table 22.1).

Morbidity refers to the incidence of *disease* in populations and includes both fatal and nonfatal diseases. Clearly, morbidity statistics define the health of the population more precisely than mortality statistics because many diseases that affect health in important ways have only a low mortality. The major causes of illness are quite different from the major causes of death. Major illnesses are acute respiratory diseases (the common cold, for instance) and acute digestive system conditions, which are generally due to infectious agents.

Disease progression

In terms of clinical symptoms, the course of a typical disease can be divided into stages:

1. *Infection:* the organism begins to grow in the host.
2. *Incubation period:* the time between infection and the appearance of disease symptoms. Some diseases, like influenza (∞ Section 23.4), have short incubation periods, measured in days; others, like AIDS, have longer ones, measured in years (∞ Section 23.7). The incubation period for a given disease is determined by inoculum size, virulence of the pathogen, resistance of the host, and distance of the site of entrance from the focus of infection (☞ Sections 19.6 and 19.7). At the end of incubation, the first symptoms, such as headache and a feeling of illness, appear.

(a) Endemic disease (b) Epidemic disease (c) Pandemic disease

Figure 22.1 Classification of ...se by incidence. Each dot ...sents several cases of a particular disease.

3. *Acute period:* the disease is at its height, with overt symptoms such as fever and chills.
4. *Decline period:* disease symptoms are subsiding, the temperature falls, usually following a period of intense sweating, and a feeling of well-being develops. The decline may be rapid (within 1 day), in which case it is said to occur by *crisis*, or it may be slower, extending over several days, in which case it is said to be by *lysis*.
5. *Convalescent period:* the patient regains strength and returns to normal.

During the later stages of the infection cycle, the immune mechanisms of the host become increasingly important, and in most cases complete recovery from the disease requires and results in active immunity.

CONCEPT CHECK 22.2

An endemic disease is constantly present in a population in low numbers. In epidemics, an unusually high incidence of disease occurs. An infection may cause morbidity (disease) or mortality (death) in a population. A disease follows a predictable clinical pattern in the host.

- ✔ *Distinguish between* morbidity *and* mortality.
- ✔ *What is the normal course of an infectious disease?*

22.3 Disease Reservoirs

Reservoirs are sites in which viable infectious agents remain alive and from which infection of individuals may occur. Reservoirs may be either animate or inanimate. Table 22.2 lists some common human diseases and their reservoirs. Some pathogens are primarily saprophytic (living on dead matter) and only incidentally infect and cause disease. For example, *Clostridium tetani* (the causal agent of tetanus) normally inhabits the soil. Infection of animals by this organism is an accidental event; infection of a host is not essential for its continued existence and even if there were no susceptible hosts, *C. tetani* would still survive in nature.

However, many pathogens have other living organisms as their only reservoirs. In these cases, the reservoir is an essential component of the natural life cycle of the infectious agent. Some infections occur only in humans, and maintenance of the cycle involves person-to-person transmission. This type of pathogen cycle is common for viral and bacterial respiratory diseases, sexually transmitted diseases, staphylococcal and streptococcal infections, diphtheria, typhoid fever, and mumps.

Zoonosis

A number of infectious diseases that occur in humans also occur in animals. A disease that occurs primarily in animals but is occasionally transmitted to humans is called a **zoonosis.** Because public health measures for animal populations are much less developed than for humans, the infection rate for many diseases is much higher in animals, and animal-to-animal transmission is the rule. However, occasionally transmission is from animal to human. It is less likely for transmission to also occur from person to person in such diseases. Thus, maintenance of the pathogen in nature depends on animal-to-animal transfer. However, control of a zoonosis in the human population in no way eliminates it as a public health problem. Indeed, more effective human control can generally be achieved through elimination of the disease in the animal reservoir. Marked success has been achieved in the control of two diseases that were often transferred to humans from domestic animals, bovine tuberculosis and brucellosis. Control was achieved primarily by identifying and destroying infected animals. Pasteurization of milk was also of considerable importance in the prevention of the spread of bovine tuberculosis to humans because milk was the main vehicle of transmission.

Certain infectious diseases have more complex cycles, involving an obligate transfer from animal to human to animal. These are due to organisms with complex life cycles like metazoans (for example, tapeworms) or protozoa (for example, malaria, ☜ Section 23.11). In such cases, control of the disease in the population can be either through control in humans or in the alternate animal host.

Carriers

A carrier is an infected individual with no obvious signs of clinical disease. Carriers are potential sources of infection for others and are important for understanding the spread of disease. Carriers may be individuals in the incubation period of the disease, in which case the carrier state precedes the development of actual symptoms. Carriers of this sort are prime sources of infectious agents for respiratory infections because they are not yet aware of their infection and so are not taking any precautions against infecting others. Such persons are **acute carriers** because the carrier state lasts for only a short time. Also significant from the public health standpoint are chronic carriers, who may remain infected for long periods of time. **Chronic carriers** may be either individuals who had a clinical disease and recovered, or they may have a subclinical infection that has remained inapparent. These individuals may be perfectly healthy, but they harbor and spread viable pathogens (see the box, The Tragic Case of Typhoid Mary).

TABLE 22.2 Epidemic diseases: Agents, sources, reservoirs and control

Disease	Causative agent[a]	Infection sources	Reservoirs	Control measures
Common-source epidemics[b]				
Anthrax	*Bacillus anthracis* (B)	Milk or meat from infected animals	Cattle, swine, goats, sheep, horses	Destruction of infected animals
Bacillary dysentery	*Shigella dysenteriae* (B)	Fecal contamination of food and water	Humans	Detection and control of carriers; oversight of food handlers; decontamination of water supplies
Botulism	*Clostridium botulinum* (B)	Soil-contaminated food	Soil	Proper preservation of food
Brucellosis	*Brucella melitensis* (B)	Milk or meat from infected animals	Cattle, swine, goats, sheep, horses	Pasteurization of milk, control of infection in animals
Cholera	*Vibrio cholerae* (B)	Fecal contamination of food and water	Humans	Decontamination of public water sources; vaccination
Giardiasis	*Giardia* spp. (P)	Fecal contamination of water	Wild mammals	Decontamination of public water sources
Hepatitis	Hepatitis A, B, C, D, E (V)	Infected humans	Humans	Decontamination of contaminated fluids and fomites, vaccination if available (A and B only)
Paratyphoid	*Salmonella paratyphi* (B)	Fecal contamination of food and water	Humans	Decontamination of public water sources, oversight of food handlers; vaccination
Typhoid fever	*Salmonella typhi* (B)	Fecal contamination of food and water	Humans	Decontamination of public water sources, oversight of food handlers; pasteurization of milk; vaccination
Host-to-host epidemics				
Respiratory diseases				
Diphtheria	*Corynebacterium diphtheriae* (B)	Human cases and carriers; infected food and fomites	Humans	Vaccination; quarantine of infected individuals
Hantavirus pulmonary syndrome	*Hantavirus* (V)	Inhalation of contaminated fecal material	Rodents	Control rodent population and exposure
Meningicoccal meningitis	*Neisseria meningitidis* (B)	Human cases and carriers	Humans	Exposure treated with sulfadiazine for susceptible strains
Pneumococcal pneumonia	*Streptococcus pneumoniae* (B)	Human carriers	Humans	Antibiotic treatment; isolation of cases for pe- [illegible]
Tuberculosis	*Mycobacterium tuberculosis* (B)	Sputum from human cases; contaminated milk	Humans, cattle	Treatment with isoniazid; pasteurization of milk
Whooping cough	*Bordetella pertussis* (B)	Human cases	Humans	Vaccination; case isolation
German measles	Rubella virus (V)	Human cases	Humans	Vaccination; avoid contact between infected individuals and pregnant women
Influenza	Influenza virus (V)	Human cases	Humans, animals	Vaccination (recommended only in certain cases)
Measles	Measles virus (V)	Human cases	Humans	Vaccination

TABLE 22.2 (continued)

Disease	Causative agent[a]	Infection sources	Reservoirs	Control measures
Sexually transmitted diseases[c]				
Acquired immunodeficiency syndrome (AIDS)	Human immunodeficiency virus (HIV)	Infected body fluids, especially blood and semen	Humans	Treatment with viral replication inhibitors (not curative)
Chlamydia	*Chlamydia trachomatis* (B)	Urethral, vaginal, and anal secretions	Humans	Testing for organism during routine pelvic examinations, chemotherapy of carriers and potential contacts; case tracing and treatment
Gonorrhea	*Neisseria gonorrhoeae* (B)	Urethral and vaginal secretions	Humans	Chemotherapy of carriers and potential contacts; case tracing and treatment
Syphilis	*Treponema pallidum* (B)	Infected exudate or blood	Humans	Identification by serological tests; antibiotic treatment of seropositive individuals
Trichomoniasis	*Trichomonas vaginalis* (P)	Urethral, vaginal, prostate secretions	Humans	Chemotherapy of infected individuals and contacts
Vector-borne diseases				
Epidemic thyphus	*Rickettsia prowazekii* (B)	Bite by infected louse	Humans, lice	Control louse population
Lyme disease	*Borrelia burgdorferi* (B)	Bite from infected tick	Rodents, deer, ticks	Avoid tick exposure, treat infected individuals with antibiotics
Malaria	*Plasmodium* spp. (P)	Bite from *Anopheles* mosquito	Humans, mosquito	Control mosquito population; treat infected humans with antimalarial drugs
Plague	*Yersinia pestis* (B)	Bite by flea	Wild rodents	Control rodent populations
Rocky Mountain spotted fever	*Rickettsia rickettsii* (B)	Bite by infected tick	Ticks, rabbits, mice	Avoid tick exposure; treat infected individuals with antibiotics
Direct-contact diseases				
Psittacosis	*Chlamydia psittaci* (B)	Contact with birds or bird excrement	Wild and domestic birds	Avoid contact with birds, treat infected individuals with antibiotics
Rabies	Rabies virus (V)	Bite by carnivores	Wild and domestic carnivores	Avoid animal bites; vaccination of animal handlers and exposed individuals
Tularemia	*Franciscella tularensis* (B)	Contact with rabbits	Rabbits	Avoid contact with rabbits; treat infected individuals with antibiotics

[a]B, Bacteria; V, virus; P, protozoan.
[b]Some common-source diseases can also be spread from host to host.
[c]Sexually transmitted diseases can also be controlled by effective use of condoms and by sexual abstinence.

Carriers can be identified by routine surveys of populations using cultural, radiological (chest X-ray), or immunological techniques. In general, carriers are sought only among groups of individuals who may be sources of infection for the public at large, such as food handlers and health care workers.

Diseases in which carriers are important for the spread of infection include hepatitis (∞ Section 23.13), tuberculosis (∞ Section 23.3), and typhoid fever (see the box, The Tragic Case of Typhoid Mary). Surveys of food handlers and health care workers are sometimes made to detect inapparent cases of these infections.

CONCEPT CHECK 22.3

To understand how diseases develop, the pathogen reservoir must be known. Some pathogens exist in soil, water, or animals. Other pathogens are restricted to humans and are maintained solely by person-to-person contact. An understanding of disease carriers is critical for controlling disease.

- ✔ *What is a disease reservoir?*
- ✔ *Distinguish between* acute *and* chronic *carriers.*

LEARNING FROM THE PAST

THE TRAGIC CASE OF TYPHOID MARY

The classic example of a chronic carrier was the woman known as "Typhoid Mary," a cook in New York City and Long Island in the early part of the twentieth century. Typhoid Mary (her real name was Mary Mallon) was employed in a number of households and institutions, and as a cook she was in a central position to infect large numbers of people. Extensive epidemiological investigation of a number of typhoid outbreaks by Dr. George Soper revealed that Mary was the likely source of contamination. When her feces were examined bacteriologically, she had very high numbers of the typhoid bacterium, *Salmonella typhi*. She remained a carrier for many years, probably because her gallbladder was infected, and organisms were continuously being excreted from there into her intestine. Public health authorities offered to remove her gallbladder, but she refused the operation, and to prevent her from continuing to serve as a source of infection, she was imprisoned. After almost 3 years in prison, she was released on the pledge that she would not cook or handle food for others and that she was to report to the health department every 3 months. She promptly disappeared, changed her name, and cooked in hotels, restaurants, and sanitariums, leaving behind a wake of typhoid fever. After 5 years she was captured as a result of the investigation of an epidemic at a New York hospital. She was again arrested and imprisoned and remained in custody on North Brother Island in the East River of New York City for 23 years. She died in 1938, 32 years after epidemiologists had first discovered she was a chronic typhoid carrier. ■

22.4
Epidemiology of AIDS: An Example of How Epidemiological Research Is Done

Cases of acquired immunodeficiency syndrome (AIDS), the virus-mediated infectious disease that severely cripples the body's immune system (∞ Section 23.7), were first reported in the United States in 1981. Since then, the number of new AIDS cases in the United States has risen dramatically nearly every year (Figure 22.2). The extraordinary rise for 1993–1994 was probably due to a change in the definition of AIDS (∞ A Definition of AIDS, Chapter 23) but *about 50,000 new cases of AIDS will be diagnosed every year in the* United States for the foreseeable future. *Worldwide, 30 to 40 million individuals will be infected with human immunodeficiency virus* (HIV) (∞ Section 23.7) *by the year 2000. At least 1 million people now die each year from AIDS.* A vast majority of the new infections and deaths will occur in developing countries.

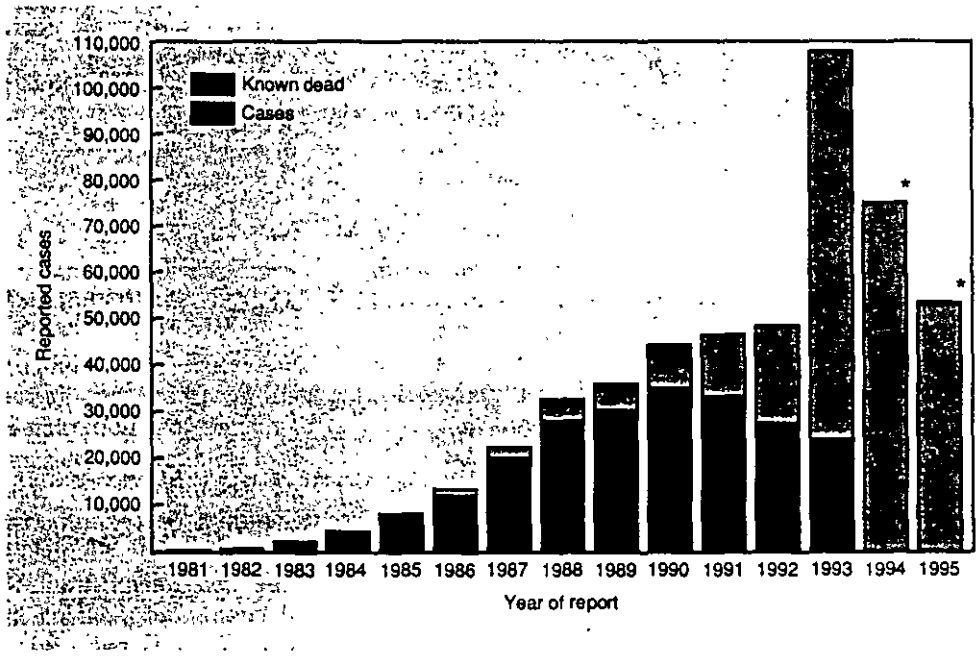


Figure 22.2 Number of total cases of acquired immunodeficiency syndrome (AIDS) in the United States since 1981. The numbers of known deaths are also shown. Cumulatively, there were about 500,000 cases of AIDS and about 300,000 [illegible]e to AIDS from 1981 [illegible] *Data for deaths in these years are incomplete.

Tracking an epidemic

Initial case control studies suggested an unusually high AIDS prevalence among homosexual men and intravenous drug abusers. This in turn strongly implicated a transmissible agent, presumably transferred during sexual activity or by contaminated needles. The finding that individuals requiring blood or blood products were also at high risk strengthened the case for a transmissible agent (Figure 22.3).

Soon after the discovery of HIV, laboratory tests were developed to detect antibodies to the virus in serum (∞ Sections 21.8 and 21.9). This made possible more extensive surveys of the incidence of HIV infection in different populations and also served as a screening method to ensure that new cases of AIDS were not transmitted by blood transfusions. Such tests revealed a fourth group of individuals at high risk for AIDS—the children of mothers who are themselves at high risk for AIDS.

The pattern illustrated in Figure 22.3 is typical of an agent transmissible by sexual activity or by blood, and the association of AIDS cases with *specific* groups was an important epidemiological finding. The identification of certain well-defined high risk groups implied that AIDS was *not* transmitted from person to person by casual contact, such as the respiratory route, or by contaminated food or water. Instead, epidemiological findings pointed clearly to bodily fluids, primarily blood and semen, the major vehicles for transmission of HIV.

In the United States AIDS has affected mainly homosexual men (Figure 22.3*a*), but intravenous drug users represent an increasing proportion of AIDS cases. Subsequent epidemiological surveys have shown that homosexual men with multiple sexual partners are more likely to contract AIDS than monogamous homosexual males. In addition, the fastest growing category for new AIDS cases is the heterosexual contact group. This group is already a major risk group among women (Figure 22.3*b*). This undoubtedly reflects the increased probability of contacting an HIV-infected individual when engaging in sexual activity with multiple partners.

The incidence of AIDS in hemophiliac transfusion recipients has been reduced greatly in recent years (Figure 22.3). This is due not only to screening of the blood supply but also because many blood clotting factors needed by hemophiliacs can withstand a heat treatment sufficient to inactivate HIV. Pediatric AIDS cases are still a major concern. In 1993, there were 958 new cases among this group. HIV can be transmitted to the fetus by infected mothers and probably also in mother's milk. All infants born to HIV-infected mothers have maternally derived antibodies to HIV in their

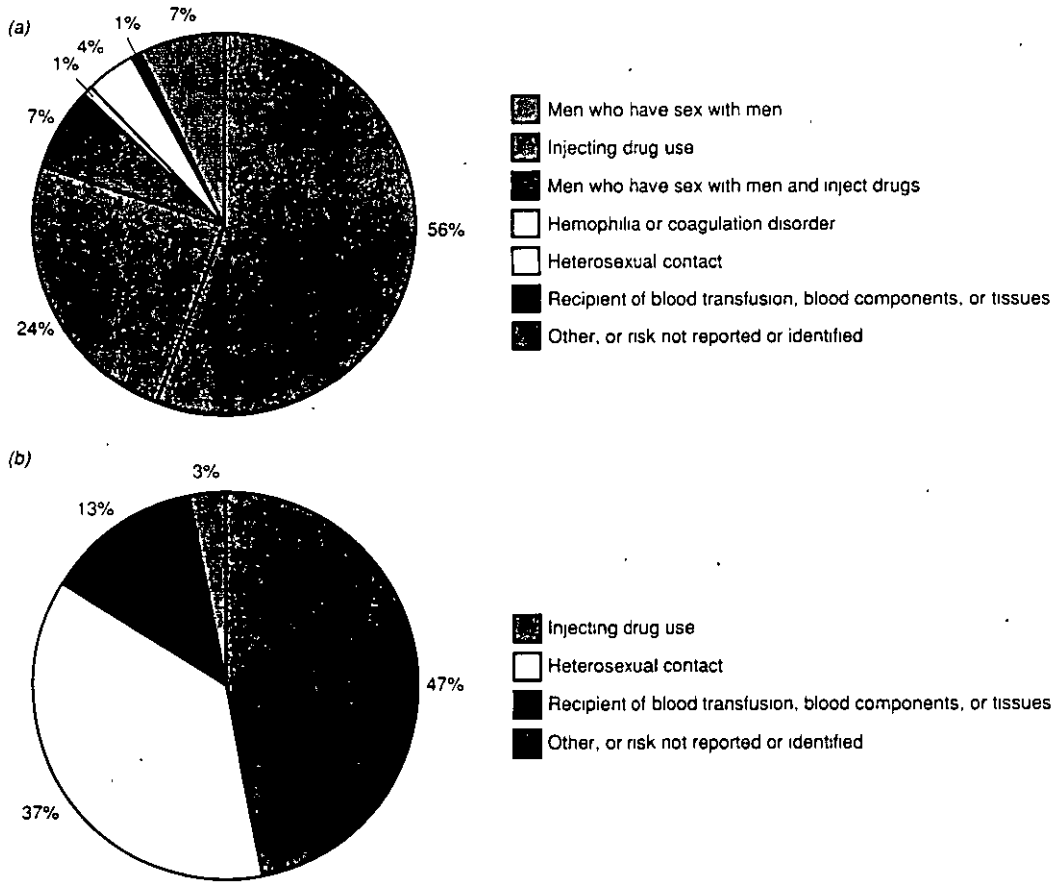


Figure 22.3 Distribution of AIDS cases by risk group and sex in the United States, 1993. The total number of cases reported was 105,989. (a) AIDS in men. N 89,165 (b) AIDS women. N = 16,824.

blood, but a clear diagnosis of AIDS in infants must wait a year or more after birth because about 70% of infants showing maternal HIV antibodies at birth do not go on to develop HIV infection.

Epidemiological studies of AIDS in Africa, where the disease is thought to have originated, have clearly shown that transmission of AIDS is not linked to particular sexual practices, such as homosexuality, but instead to person-to-person transfer of HIV-infected fluids. In Africa heterosexual transmission of AIDS seems the norm, with about equal numbers of men and women infected. Unfortunately, reliable global statistics on AIDS are not available because of differences in reporting in various countries. Current estimates are about 10 million AIDS cases worldwide with up to 40 million infected people who do not (yet) show clinical symptoms; that is, they are carriers. The identification of high risk groups through epidemiological studies led to the development of health education campaigns to inform the public of how AIDS is transmitted and what activities constitute high risk behavior (∞ Sexual Activity and AIDS, Chapter 23). Because no cure for AIDS is yet available, public health education offers the most effective approach to the control of AIDS and is the major weapon for preventing the spread of infection. We discuss the pathology and therapy of AIDS in Section 23.7.

CONCEPT CHECK 22.4

AIDS is one of the newest and most studied pandemics. Current information suggests that AIDS will continue to be a major public health problem, especially in developing countries, although we now know a great deal about its pathology and spread.

- ✔ *Describe the major risk factors for acquiring AIDS.*
- ✔ *Estimate the total number of individuals in the United States who now have AIDS and make a prediction for this number in the year 2000.*

22.5 Infectious Disease Transmission

Epidemiologists follow the incidence of a disease by correlating geographical, seasonal, and age group distribution of a disease with possible modes of transmission. A disease limited to a restricted geographical location may suggest a particular vector; malaria, for example, is transmitted by a mosquito found mainly in tropical regions. A marked seasonality to a disease is often indicative of certain modes of transmission, such as the case of measles and chickenpox, where the number of cases jumps sharply when children enter school and come in close contact (∞ Figure 23.21). The age group distribution of a disease can also be an important epidemiological statistic, frequently suggesting or eliminating particular routes of transmission.

Different pathogens have different modes of transmission, which are usually related to the habitats of the organisms in the body. For instance, respiratory pathogens are generally airborne, whereas intestinal pathogens are spread by food or water. If the pathogen is to survive, it must undergo transmission from one host to another. Even environmental factors may play a role in survival of the pathogen, and such variables as weather conditions may influence exposure to a pathogen. For example, aseptic meningitis, caused by any of a group of more than 60 different enteroviruses, is most prevalent in the summer (Figure 22.4) and is thought to be spread via fecal contamination of water sources such as public swimming areas.

Thus pathogens generally are associated with specific features or mechanisms that permit or ensure transmittal. Transmission involves three stages: (1) escape from the host, (2) travel, and (3) entry into a new host. We give here a brief overview of transmission mechanisms. Several of these will be discussed in detail for certain diseases in the next chapter.

Direct host-to-host transmission

Host-to-host transmission occurs whenever an infected host transmits the disease to a susceptible host. Transmission by the respiratory route and by direct contact is very common. Transmission by infectious droplets is the most frequent means by which upper respiratory infections such as the common cold and influenza are propagated. However, some pathogens are so sensitive to environmental influences that they are unable to survive for significant periods of time away from the host and must be transmitted from host to host by direct contact. The best examples of pathogens transmitted in this way are those responsible for sexually transmitted diseases, such as *Treponema pallidum* (syphilis) and *Neisseria gonorrhoeae* (gonorrhea). These agents are extremely sensitive to drying and do not survive away from the body, even for a few moments. Intimate person-to-person contact, such as kissing or sexual intercourse, provides a direct means for the transmission of such pathogens. However, such intimate transfer can occur only if the viable pathogen is present on the transmitting person at the body site that comes in direct contact with that of the recipient. Thus, pathogens causing sexually transmitted diseases live in genitalia, the mouth, or the anus because these are the sites involved in sexual contact.

Direct contact is also involved in the transmittal of skin pathogens, such as staphylococci (boils and pimples) and fungi (ringworm). However, these pathogens are relatively resistant to environmental influ-

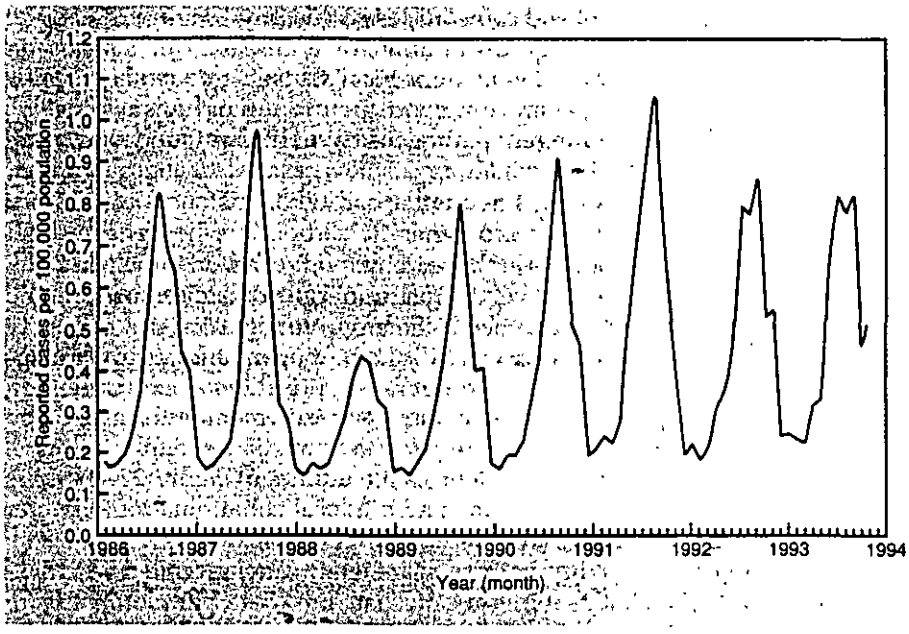


Figure 22.4 The incidence of aseptic (viral) meningitis in the United States. Note the marked summer rise and annual cyclical nature of disease incidence.

ences such as drying, and intimate person-to-person contact is not the only means of transmission. Many respiratory pathogens are also transmitted by direct means because they are spread by droplets resulting from sneezing or coughing. However, many of these droplets do not remain airborne for long. Transmission, therefore, requires close, although not necessarily intimate, person-to-person contact.

Indirect host-to-host transmission

Indirect transmission can occur by either living or inanimate means. Living agents transmitting pathogens are called **vectors;** they are generally arthropods (for example, insects, mites, or fleas) or vertebrates (for example, dogs, rodents). Arthropod vectors may not be hosts for the disease but simply carry the agent from one host to another. Large numbers of arthropods obtain nourishment by biting, and if the pathogen is present in the blood, the arthropod vector may ingest the pathogen and transmit it when biting another individual. In some cases, the pathogen actually replicates in the arthropod, which is then considered an alternate host. Such replication leads to a buildup of the inoculum, increasing the probability that a subsequent bite will lead to infection.

Inanimate agents such as bedding, toys, books, and surgical instruments can also transmit disease. These inanimate objects are collectively referred to as **fomites.** Food and water are referred to as disease **vehicles.** Fomites can also be disease vehicles, but major epidemics originating from a single source are usually traced to food or water because these are actively consumed in large amounts by a number of individuals in a population.

Epidemics

Two major types of epidemics can be distinguished: common-source and host-to-host. These two types are contrasted in Figure 22.5. A **common-source epidemic** arises as the result of infection (or intoxication) of a large number of people from a contaminated common source, such as food or water. Usually such contamination occurs because of a malfunction in the sanitation of a central distribution system. Foodborne and waterborne diseases are primarily *intestinal* diseases; the pathogen leaves the body in fecal material, contaminates food or water via improper sanitary procedures, and then enters the intestinal tract of the recipient during ingestion. Because foodborne and waterborne diseases are some of those that are most amenable to control by public health measures, we shall discuss them in some detail in Chapter 23 (also see the boxes, Snow on Cholera, and The Tragic Case of Typhoid Mary in this chapter). The disease incidence for a common-source outbreak is characterized by a rapid rise to a peak because a large number of individuals succumb within a relatively brief period of time (Figure 22.5). The common-source outbreak also declines rapidly, although the decline is less rapid than the rise. Cases continue to be reported for a period of time approximately equal to the duration of one incubation period of the disease.

In a **host-to-host epidemic,** the disease incidence shows a relatively slow, progressive rise (Figure 22.5) and a gradual decline. Cases continue to be reported over a period of time equivalent to several incubation periods of the disease. The epidemic may have been initiated by the introduction of a single infected individual into a susceptible population, and this individual has infected one or more people in the population. The pathogen then repli-

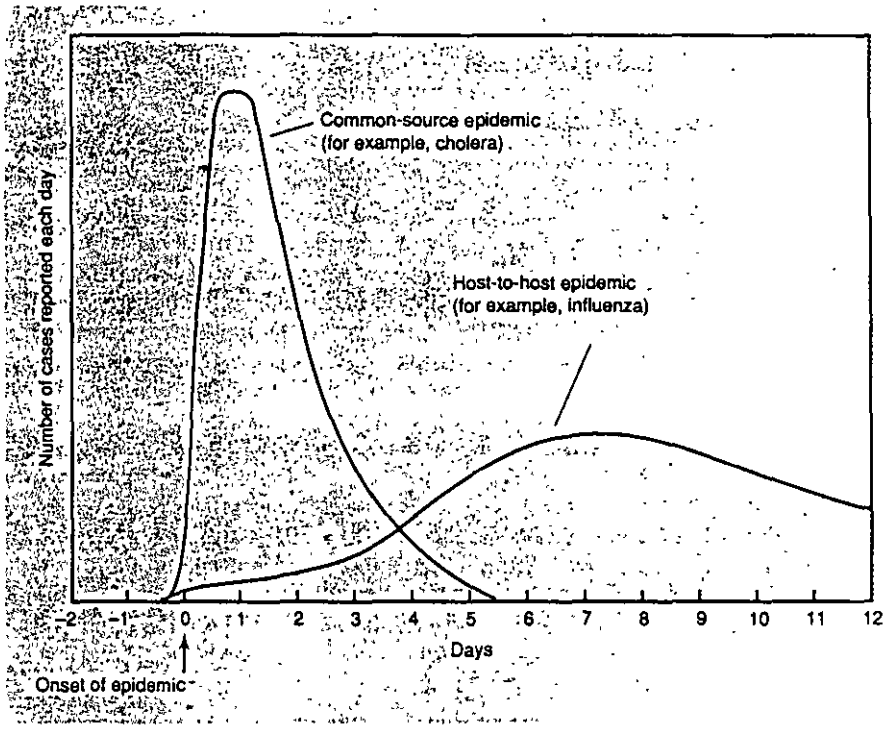


Figure 22.5 Origins of epidemics. The shape of the epidemic curve helps to distinguish the likely origin. In a common-source epidemic, such as from contaminated food or water, the curve is characterized by a sharp rise to a peak, with a rapid decline, which is less abrupt than the rise. Cases continue to be reported for a period approximately equal to the duration of one incubation period of the disease. In a host-to-host epidemic, the curve is characterized by a relatively slow, progressive rise, and the cases continue to be reported over a period equivalent to several incubation periods of the disease.

cated in the susceptible individuals, reached a communicable stage, and was transferred to others, where it replicated and again became communicable. Table 22.2 sum- s some of the key epidemiological features of sc .najor epidemic diseases observed today.

CONCEPT CHECK 22.5

A pathogen can be transmitted directly from one host to another, or indirectly by means of another living agent called a vector. Pathogens can also be transmitted by inanimate objects (fomites) and common vehicles such as food and water. Epidemics may be of common-source or host-to-host origin. By observing disease incidence over time, the type of epidemic can be determined.

- ✔ *Compare a* common-source *epidemic to a* host-to-host *epidemic. Cite at least one example of each.*
- ✔ *Suggest one method for halting the spread of a common-source epidemic and a host-to-host epidemic.*

22.6 The Host Community

The colonization of a susceptible, unimmunized host by a parasite may first lead to an explosive infection and an ep ic. As the host population develops resistance, ; the spread of the parasite is checked, and eventu *balance* is reached in which host and parasite are in equilibrium. A subsequent genetic change in the parasite could lead to the formation of a more virulent form, which would then initiate another explosive epidemic until the host again responds and another balance is reached. In effect, the host and parasite are affecting each other's evolution; that is, the host and parasite are *coevolving.*

Coevolution of a host and a parasite

An excellent experimental example of coevolution of host and parasite occurred when a virus was intentionally introduced for purposes of population control in the wild rabbits of Australia.

Wild rabbits were introduced into Australia from Europe in 1859 and quickly spread until they were overrunning large parts of the continent. Myxoma virus was discovered in South American rabbits, which are a different species from the European rabbits in Australia. In South America the virus and its hosts are apparently in equilibrium, and the virus causes only a minor disease. However, this same virus is extremely virulent in the European rabbit and almost always causes a fatal infection. The virus is spread from rabbit to rabbit by mosquitoes and other biting insects, and is capable of rapid spread in areas with appropriate insect vectors.

Myxoma virus was introduced into Australian rabbits in 1950 to control the rabbit population. Within several months, the virus was well established in the population and spread over an area in Australia as large as all of Western Europe. The disease showed a marked seasonal pattern, rising to a peak in the sum-

LEARNING FROM THE PAST

Snow on Cholera

The importance of drinking water as a vehicle for the spread of cholera was first shown in 1855 by British physician John Snow, who at that time had no knowledge of the bacterial causation of the disease. Snow's study is one of the great classics of epidemiology and serves as a model for how a careful study can lead to clear and meaningful conclusions.

In London, the water supplies to different parts of the city were from different sources and were transmitted in different ways. In a large area south of the Thames River, across the river from Westminster Abbey and the Parliament Building, the water was supplied to houses by two competing private water companies, the Southwark and Vauxhall Company, and the Lambeth Company. It was the water of the former company that was the major vehicle for the transmission of cholera. When Snow began to suspect the water supply of the Southwark and Vauxhall Company, he made a careful survey of the residence of every cholera death in this district and determined which company supplied the water to that residence. In some parts of the area served by these two companies, each had a monopoly, but in a fairly large area the two companies competed directly, each having run independent water pipes along the various streets. Houses had the option of connecting with either supply, and the distribution of houses between the two companies was random. The clear-cut results of Snow's survey were completely convincing, even to those skeptical about the importance of polluted water in the transmission of cholera. In the first seven weeks of the epidemic, there were 315 deaths per 10,000 houses supplied by the Southwark and Vauxhall Company, and only 37 per 10,000 houses supplied by the Lambeth Company. In the rest of London, there were 59 deaths per 10,000 houses, showing that those supplied by the Lambeth Company had fewer deaths than the general population. In the districts where each company had exclusive rights, it could of course be argued that it was not the water, but some other factor (soil, air, general layout of houses, and so on), that might have been responsible for the differences in disease incidence, but in the districts where the two companies competed, all of these other factors were the same, yet the incidence was high for those supplied with Southwark and Vauxhall water and low for those supplied with Lambeth water. Snow attempted to relate these differences in disease incidence to the sources of the waters used by the two companies. Since he suspected that the excrement and evacuations from cholera patients were highly infectious, he considered that sewage contamination of the water supply might exist. In those days, sewage treatment did not exist and raw sewage was dumped directly into the Thames River. The Southwark and Vauxhall Company obtained its water supply from the Thames right in the heart of London, where sewage contamination could occur, while the Lambeth Company obtained its water from a point on the river considerably above the city, and hence was relatively free of pollution. It was this difference in source that accounted for the difference in disease incidence. In Snow's words:

> As there is no difference whatever, either in the houses or the people receiving the supply of the two Water Companies, or in any of the physical conditions with which they are surrounded, it is obvious that no experiment could have been devised which would more thoroughly test the effect of water supply on the progress of cholera than this. . . . The experiment, too, was on the grandest scale. No fewer than three hundred thousand people of both sexes, of every age and occupation, and of every rank and station, from gentlefolk down to the very poor, were divided into two groups without their choice, and, in most cases, without their knowledge; one group being supplied with water containing the sewage of London, and, amongst it, whatever might have come from cholera patients, the other group having water quite free from such impurity. ■

mer when the mosquito vectors were present and declining in the winter. The epidemiology of myxoma virus was studied as a model of a virus-induced epidemic by Australian scientists. Virus was isolated from wild rabbits, and the isolated strains were characterized for virulence with laboratory rabbits. At the same time, baby rabbits were removed from their dens before infection could occur and reared in the laboratory. Then these wild rabbits were challenged with standard virulent strains of myxoma virus to determine their susceptibility. The results of this large-scale model study are shown in Figure 22.6.

During the first year of the epidemic, over 95% of the infected rabbits died. However, within 6 years both the virus and the rabbit population had changed. Over this interval, rabbit mortality dropped to about 84%, and the virus isolated was of decreased virulence. In addition, changes were noted in the resistance of th

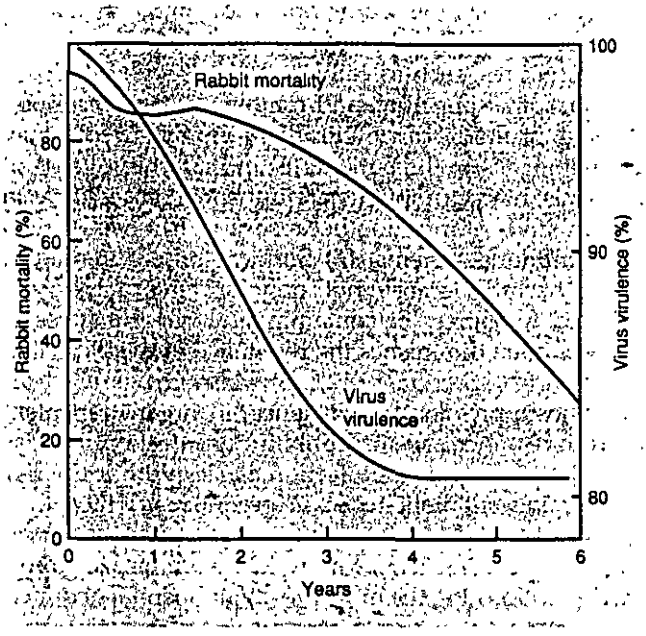


Figure 22.6 Changes in virulence of myxoma virus and in susceptibility of the Australian rabbit during the years after the virus was introduced into Australia in 1950. Virus virulence is given as the average mortality in standard laboratory rabbits for virus recovered from the field each year. Rabbit susceptibility was determined by removing young rabbits from their dens and challenging with a virus strain of 'erately high virulence, which killed 90–95% of normal atory rabbits.

rabbit. In parts of Australia where the virus was first introduced, the remaining rabbit population had been subjected to selective pressure by the virus for several years. As seen in Figure 22.6, within years the resistance of the rabbits had increased dramatically. This resistance was due to innate changes in the rabbit population and not to immunological responses, for the rabbits tested had been removed from their mothers at birth and had never been in contact with the virus. Their resistance was due to some genetic change in the animal that made it less susceptible to myxoma virus.

As a result of the introduction of myxoma virus, the Australian rabbit population was controlled, but the genetic changes in virus and host prevented complete eradication of the rabbit from Australia. A steady-state rabbit population of about 20% of that present before the introduction of myxoma virus was observed (Figure 22.6). The virus was thus a major factor in population control but did not totally eliminate rabbits because of coevolutionary events in both host and parasite. The Australian experiment reveals how quickly an equilibrium is reached between host and site. The manner in which the malaria parasite has ted biochemical evolution in humans is another example of host–parasite coevolution and will be discussed in Section 23.11.

Herd immunity

An analysis of the immune state of a group is of great importance in understanding the role of immunity in the development of epidemics. **Herd immunity** is the resistance of a group to invasion and spread of an infectious agent resulting from immunity of a high proportion of the members of the group. If the proportion of immune individuals is sufficiently great, then the whole population will be protected. The fraction of resistant individuals necessary to prevent an epidemic is higher for a highly virulent agent or one with a long period of infectivity, and lower for a mildly virulent agent or one with a brief period of infectivity.

The proportion of the population that must be immune to prevent infection of the rest of the population can be estimated from data on poliovirus immunization in the United States. From epidemiological studies of the incidence of polio in large populations, it appears that if a population is 70% immunized, polio will be essentially absent in the population. Clearly, these immunized individuals protect the rest of the population. For a highly infectious disease such as influenza, the proportion of immune individuals necessary to confer herd immunity is higher, about 90–95%. A value of about 70% has also been estimated for diphtheria, but further study of several small diphtheria outbreaks has shown that in densely settled areas a much higher proportion must be immunized to prevent development of an epidemic. Apparently, in dense populations, person-to-person transmission can occur even if the agent is not highly infectious. In the case of diphtheria, an additional complication arises because immunized persons can still harbor the pathogen (inapparent infection) and thus act as chronic carriers, serving as potential sources of infection.

Cycles of disease

The concepts of propagated epidemics and herd immunity can also explain why certain diseases occur in *cycles*. A good example of a cyclical disease is chickenpox, which occurs in a high proportion of school children. Because the chickenpox virus (⊂⊂ Section 8.19) is transmitted by the respiratory route, its infectivity is high in crowded situations such as schools. On entry into school at age 5, most children are susceptible, so that on the introduction of virus into the school, an explosive propagated epidemic results. Virtually every individual becomes infected and develops immunity, and as the immune population builds up, the epidemic dies down. Chickenpox shows an annual cycle (∞ Figure 23.21) probably because a new group

of nonimmune children arrives each year; the phasing of the epidemic is related to the time of the year at which school begins after the summer vacation.

CONCEPT CHECK 22.6

Hosts and pathogens coevolve with time and arrive at a steady state that favors the continued survival of both. With herd immunity, a large fraction of a population is immune to a given disease, and it is difficult for the disease to spread. Disease cycles occur when a large, recurring, nonimmune population such as children entering school is exposed to a pathogen.

- ✔ *Explain coevolution of host and pathogen. Cite a specific example.*
- ✔ *How does herd immunity work to prevent a nonimmune individual from acquiring a disease?*

22.7 Hospital-Acquired (Nosocomial) Infections

A hospital may not only be a place where sick people get well but may also be a place where sick people get sicker. Cross-infection from patient to patient or from hospital personnel to patients presents a constant hazard. Hospital infections are often called *nosocomial infections* (*nosocomium* is the Latin word for "hospital") and occur in about 5% of all patients admitted. In certain clinical services, such as intensive care units, up to 10% of the patients acquire a nosocomial infection. In all, there are about 2 million nosocomial infections each year in the United States, leading directly or indirectly to 80,000 deaths. Hospital infections are partly due to the prevalence of diseased patients but are often due to the presence of pathogenic microorganisms that are selected for and maintained within the hospital environment. Most nosocomial infections are endemic rather than epidemic. These infections result from organisms already in the hospital environment. Even multiple-drug-resistant organisms are often spread from host to host as normal flora. Therefore, virtually all the important nosocomial pathogens are normal flora in either patients or hospital staff.

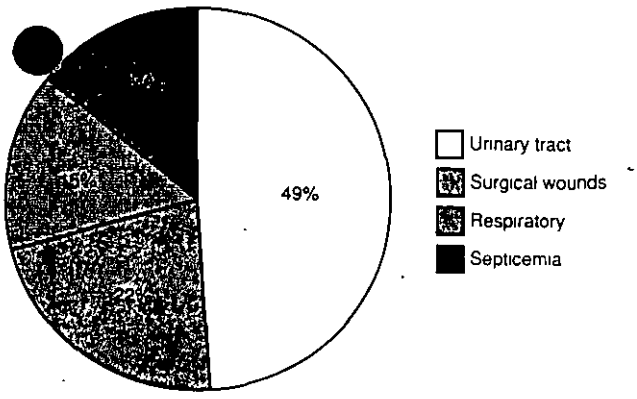
The hospital environment

Hospitals are special environments. Infectious diseases are spread easily and rapidly in hospital environments for several reasons. (1) Many patients have weakened resistance to infectious disease because of their illness (compromised hosts) (∞ Section 19.12). (2) Hospitals treat patients suffering from infectious disease, and these patients may be reservoirs of highly virulent pathogens. (3) The crowding of patients in rooms and wards increases the chance of cross-infection. (4) Hospital personnel move from patient to patient, increasing the probability of transfer of pathogens. (5) Many hospital procedures, such as catheterization, hypodermic injection, spinal puncture, and removal of tissue samples (biopsy) or fluids, carry with them the risk of introducing pathogens to the patient. (6) In maternity wards of hospitals, newborn infants are unusually susceptible to certain kinds of infection because they lack well-developed immune systems. (7) Surgical procedures are a major hazard because not only are internal organs exposed to sources of contamination but the stress of surgery often diminishes the resistance of the patient to infection (∞ Section 19.12). (8) Many drugs used for immunosuppression (for instance, in organ transplant procedures) increase susceptibility to infection. (9) Use of antibiotics to control infection carries with it the risk of selecting antibiotic-resistant organisms, which then may not be easily controlled if they cause further infection (∞ Section 11.13). Figure 22.7 summarizes information concerning the most prevalent hospital-acquired infections.

Hospital pathogens

A relatively limited number of organisms cause the majority of hospital infections. *Escherichia coli*, presumably introduced from the normal flora, is the most common cause of urinary tract infections in hospitals, but other gram-negative bacteria and *Pseudomonas aeruginosa* (see later) are often implicated as well. *Enterococcus* is also a common urinary tract pathogen; the yeast *Candida* is also encountered (Figure 22.7).

One of the most important and widespread hospital pathogens is *Staphylococcus aureus*. It is most commonly associated with blood (septicemia), surgical (wound), and lower respiratory tract infections and is a particular problem in infections acquired by newborns in the hospital (Figure 22.7). Certain strains of unusual virulence have been widely associated with hospital infections. Although only the coagulase-positive strains of *S. aureus* were normally considered as pathogens in the past, a number of other strains of *Staphylococcus* spp. (most of which are coagulase-negative) are now collectively the most common cause of hospital-acquired septicemia (an acute host response due to the presence of organisms in the blood) (∝ Section 23.2) and are also very prominent as agents of wound infections (Figure 22.7). The habitat of these staphylococci is the upper respiratory tract, usually the nasal passages, and they often become established as normal flora in hospital personnel. In healthy personnel the organism may cause no disease, but these symptomless carriers may be a source of infection for patients. Because staphylococci are resistant to drying, they survive for long periods on dust particles and other fomites and can subsequently infect patients. Because of the potential seriousness of infection with hospital



Pathogen	Urinary tract infection (%)	Surgical wound (%)	Respiratory tract (%)	Septicemia (%)
Escherichia coli	26	10	6	6
Enterococcus	16	3	2	8
Pseudomonas aeruginosa	12	8	17	4
Staphylococcus aureus	2	17	16	16
Staphylococcus spp.[a]	4	12	2	27
Candida spp.	9	2	5	8
S' ·occus s.	0	3	1	4
Other gram-negative organisms	20	18	26	12
All other organisms	11	27	25	15

[a]Coagulase-negative staphylococci.

Figure 22.7 Major sites and pathogen distribution for nosocomial infections.

staphylococci, careful adherence to proper hospital sanitation procedures is necessary.

Pseudomonas aeruginosa is important in causing infections of the lower respiratory and urinary tracts (Figure 22.7). It is also an important cause of infections in burn patients who have lost their primary barrier to skin infection. *P. aeruginosa* exhibits one of the most significant features complicating the treatment of nosocomial infections, *antibiotic resistance.* Isolates of this bacterium from patients with hospital infections are commonly resistant to many antibiotics. A somewhat lower degree of resistance has been noted among *Staphylococcus aureus* isolates (with occasional highly resistant strains not uncommon), whereas *Escherichia coli* isolates generally em sensitive to antibiotics. Antibiotic-resistant pathogenic acteria in hospitals generally contain plasmids encoding *multiple antibiotic resistance* (∞ Section 11.13).

CONCEPT CHECK 22.7

Hospital patients often have impaired immune systems or are unusually sensitive to infectious disease. Certain organisms that are ordinarily not important pathogens in normal populations cause serious disease in hospitals.

- ✔ *Why are hospital patients more susceptible than normal individuals to pathogens?*
- ✔ *Why are antibiotic-resistant staphylococci a major problem in hospital settings?*

22.8 Public Health Measures for the Control of Epidemics

An understanding of the epidemiology of an infectious disease makes it possible to develop methods for control of the disease. **Public health** refers to the health of the population as a whole and to the activities of public health authorities in the control of disease. However, the incidence of many infectious diseases has dropped dramatically, especially in developed countries, over the past 100 years not because of public health efforts but because of general increases in the well-being of the population. Better nutrition, less crowded living quarters, and lighter work loads have probably done as much as public health measures to control diseases such as tuberculosis, primarily by reducing the risk factors related to disease (∞ Section 19.12). However, diseases such as typhoid fever, diphtheria, brucellosis, and poliomyelitis owe their low incidence to active and specific public health measures.

Overall public health depends on application of control measures to prevent the spread of infectious disease, and we discuss these here.

Controls directed against the reservoir

If the disease occurs primarily in *domestic animals,* then infection of humans can be prevented if the disease is eliminated from the infected animal population. Immunization procedures or destruction of infected animals may be used to eliminate the disease in animals. These procedures have been quite effective in eliminating brucellosis and bovine tuberculosis from humans. Not incidentally, the health of the domestic animal population is also enhanced, with likely economic benefits to the farmer.

When the reservoir is a *wild animal,* then eradication is much more difficult. **Rabies** is a disease that occurs in both wild and domestic animals but is transmitted to domestic animals primarily by wild animals. Thus *control* of rabies can be achieved by immuniza-

tion of domestic animals, although this will never lead to complete *eradication* of the disease. The majority of rabies cases are in wild rather than domestic animals, at least in the United States (∞ Figure 23.36). Therefore, eradication of rabies would require the immunization or destruction of all wild animal reservoirs, which includes such diverse species as raccoons, bats, skunks, and foxes. Although oral rabies immunization is practical and recommended for rabies control in limited animal populations, its efficacy is untested in large, diverse animal populations.

If the reservoir is an *insect* (such as a mosquito in the case of malaria), effective control of the disease can be accomplished by eliminating the reservoir with chemical insecticides or other lethal agents. However, such use must be balanced with environmental concerns about the use of toxic or carcinogenic chemicals—in some cases the elimination of one public health problem only creates another. For example, the insecticide dichlorodiphenyl trichloroethane (DDT) (∞ Figure 14.51) is very effective against mosquitoes and is credited with eradicating yellow fever and malaria in North America. However, its use is currently banned in the United States because of environmental concerns. DDT is still widely used in many developing countries to control mosquito-borne diseases.

When *humans* are the reservoir (for example, AIDS), then control and eradication are much more difficult, especially if there are asymptomatic carriers.

Controls directed against transmission of the pathogen

If the organism is transmitted via food or water, then public health procedures can be instituted either to prevent contamination of these vehicles or to destroy the pathogen in the vehicle. Water purification methods (∞ Section 23.15) have been responsible for dramatic reductions in the incidence of typhoid fever, and the pasteurization of milk has helped in the control of bovine tuberculosis in humans. Food protection laws have been devised that greatly decrease the probability of transmission of a number of enteric pathogens to humans (∞ Section 23.13). Transmission of respiratory pathogens is much more difficult to prevent. Attempts at chemical disinfection of air have been unsuccessful. In Japan, many individuals wear face masks when they have upper respiratory infections to prevent transmission to others, but such methods, although effective, are voluntary, and would be difficult to institute as public health measures.

Vaccination

Immunization of the host has been the prime means by which smallpox, diphtheria, tetanus, pertussis (whooping cough), and poliomyelitis have been controlled. As we discussed in Section 22.6, 100% immunization is not necessary in order to control the disease in a population, although the percentage needed to ensure disease control varies with the virulence of the pathogen and with the condition of the population (for example, crowding).

Over the past several decades, the proportion of children vaccinated for diphtheria, tetanus, pertussis, measles, mumps, rubella, and polio has been decreasing, apparently because the public has become less fearful of contracting these diseases because of their very low incidence in the population. However, because none of these diseases has been eradicated from the United States (indeed, the reservoir of tetanus is the soil, and so it will never be eradicated), and with a decrease in the proportion of individuals immunized, the protection afforded by herd immunity (see Section 22.6) can be overcome, and these infectious diseases could reappear in epidemic form. For example, Table 22.3 shows the vaccination rate for measles in selected countries in the Americas. In the United States, nearly 30,000 cases of measles were reported in 1990 (∞ Section 23.4), but renewed efforts to increase vaccination levels in preschool children have reversed this alarming trend (∞ Figure 23.19). Presumably, as the percentage of the immunized preschool population approached 70% in the United States, the benefits of herd immunity disappeared but have now been reestablished as the result

TABLE 22.3 Infants immunized against measles in the Americas (1990)[a]

Country	Immunized (%)
Panama	99
Chile	98
Dominican Republic	96
Argentina	94
Cuba	94
Honduras	91
Bahamas	86
Costa Rica	85
Colombia	82
Uruguay	82
Belize	81
Nicaragua	81
Brazil	77
Paraguay	77
El Salvador	75
Jamaica	74
United States	70
Guatemala	68
Mexico	66
Peru	64
Venezuela	64
Ecuador	62
Bolivia	53
Haiti	31

[a]Data are for children less than 2 years of age.

of aggressive immunization program. In countries s s Haiti, measles remains a significant cause of morbidity and mortality because of inadequate vaccination standards.

Many *adults* are inadequately immunized to a variety of infectious agents, either because they received low titer vaccines when they were children or because their immunity has gradually disappeared with age. In the United States, up to 80% of adults may lack solid immunity to important childhood diseases. When these so-called childhood diseases occur in adults,they can have severe effects. If a woman contracts rubella (a viral disease) (∞ Section 23.4) during pregnancy, the unborn child can be seriously impaired. Measles and polio are also much more serious diseases in adults than in children.

All adults are advised to review their immunization status, checking their medical records (if available) to ascertain dates of vaccinations. *Tetanus* vaccinations should be renewed at least every 10 years. Surveys of adult populations have shown that more than 10% of adults under the age of 40 and over 50% of those over 60 are not protected. *Measles* immunity in adults also needs to be reviewed. People born before 1957 probably had measles as children and are immune. Those born after 1956 may have been vaccinated, but the effectiveness of early vaccines was variable and solid immunity may not be present, especially if the vaccine was given before 1 year of age. Revaccination for polio is not recommended for adults unless they are traveling to countries in Africa and Asia where polio is still prevalent.

Vaccination practices and procedures have been discussed in Section 20.17, and those for particular infections will be discussed in Chapter 23.

Quarantine

Quarantine involves restricting the movement of individuals with active infections to prevent spread of disease to other members of the population. The time limit of quarantine is the longest period of communicability of the given disease. Quarantine must be done in such a manner that the infected individual cannot contact individuals who have not been exposed. Quarantine is not as severe a measure as strict isolation, which is used for unusually infectious diseases in hospital situations.

By international agreement, six diseases are considered quarantinable: smallpox, cholera, plague, yellow fever, typhoid fever, and relapsing fever. Although smallpox has been eliminated from the world, quarantine for the other five diseases is still mandated. Each of them is considered a highly serious, particularly unicable disease. Thus, it is essential to quarantine infected individual for the period of communicability.

Surveillance

Surveillance is the observation, recognition, and reporting of diseases as they occur. The diseases that are under surveillance in the United States are listed in Table 22.4. Note that several of the epidemic diseases listed in Table 22.2 are not on the surveillance list. Several diseases like influenza are, however, surveyed through regional laboratories that identify *index cases*—those cases that exhibit new syndromes, characteristics, or pathogens indicating high potential for new epidemics.

CONCEPT CHECK 22.8

Food and water purity regulations, vector control, vaccination, quarantine, and disease surveillance are public health measures that play a major role in reduction of disease incidence.

- ✔ *Compare public measures for controlling infectious disease caused by insect reservoirs and by human carriers.*
- ✔ *What public health methods can be used to halt the spread of an epidemic disease once it has begun?*

22.9 Global Health Considerations

The United States is typical of countries where public health protection is highly developed. Other countries with similar characteristics include Japan, Australia, New Zealand, Israel, and the European countries. However, only about one-quarter of the nearly 6 billion people in the world live in these developed countries. In quite another category as far as infectious disease is concerned are the developing countries, a category that includes most of the countries in Africa, Central and South America, and Asia. In these countries, infectious diseases are still major causes of death (Figure 22.8).

Infectious disease in developing countries

There is a sharp contrast in the degree of importance of infectious diseases as causes of death in developing versus developed nations. In developing regions of the world, infectious diseases account for about 40% of deaths, whereas infectious diseases account for about 4% of deaths in developed regions (Figure 22.8). Diseases that were leading causes of death in the United States nearly a century ago, such as tuberculosis and gastroenteritis, are still leading causes of death in developing countries today (see Figures 22.8 and 1.18). Furthermore, the majority of deaths due to infectious disease in developing regions occur among infants and

TABLE 22.4 Reportable infectious diseases in the United States

Diseases caused by Bacteria
- Anthrax
- Botulism
- Brucellosis
- Chancroid
- Chlamydia
- Cholera
- Diphtheria
- *Escherichia coli* 0157:H7
- Gonorrhea
- Granuloma inguinale
- *Haemophilus influenzae*
- Hansen disease (leprosy)
- Legionellosis
- Leptospirosis
- Lyme disease
- Lymphogranuloma venereum
- Meningococcal infections
- Murine typhus fever
- Pertussis
- Plague
- Psittacosis
- Rheumatic fever
- Rocky Mountain spotted fever
- Salmonellosis
- Shigellosis

Diseases caused by Bacteria (cont.)
- Syphilis
- Tetanus
- Toxic shock syndrome
- Tuberculosis
- Tularemia
- Typhoid fever

Diseases caused by viruses
- Acquired immunodeficiency syndrome (AIDS)
- Aseptic meningitis
- Hepatitis
- Measles
- Mumps
- Poliomyelitis, paralytic
- Rabies, animal
- Rabies, human
- Rubella
- Varicella (chicken pox)

Diseases caused by protozoa
- Amebiasis
- Malaria

Disease caused by a helminth
- Trichinosis

children. Thus, the average age of individuals dying as a result of infectious diseases in developing versus developed countries is also dramatically different.

The distinct differences in the health status of people in different regions of the world are due in part to general nutritional deficiency in individuals in developing countries and to a lower overall standard of living. As discussed in Section 19.12, factors such as physical stress and diet play important roles in the ability of the host to ward off infection. Thus, it is not surprising that in developing countries death from infection is about 10-fold more likely. In addition, the generally lower levels of public health protection and lack of economic resources for implementing widespread vaccination and food and water purity programs in developing countries make infection more likely in the first place. Statistics on disease in developed countries show that control of many diseases is possible. However, statistics on the worldwide incidence of disease show that infectious disease remains an important public health problem.

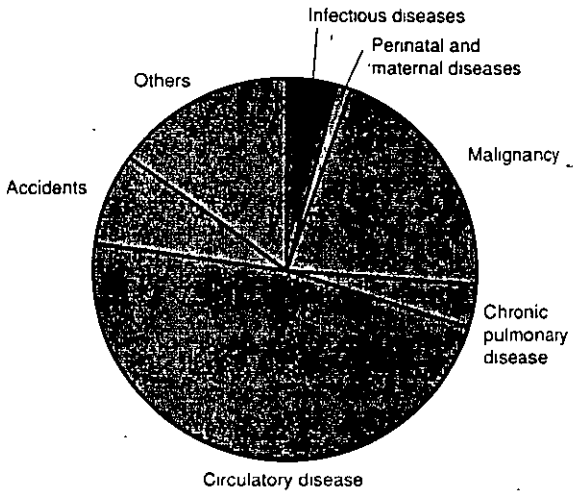
Travel to endemic areas

The high incidence of disease in many parts of the world is also a concern for people traveling to such areas. It is possible to be immunized against many of the diseases that are endemic in foreign countries. Some typical recommendations for immunization for those traveling abroad are shown in Table 22.5. Many foreign countries currently require immunization certificates for yellow fever, but most other immunizations are recommended only for people who are expected to be at high risk. There is also risk in many parts of the world of exposure to diseases for which there is no effective vaccine available. These include amebiasis, dengue fever, encephalitis, giardiasis, malaria, and typhus. Travelers are advised to take reasonable precautions such as avoiding insect and animal bites, drinking only water that has been properly treated and eating food properly stored and prepared, and undergoing chemotherapeutic programs when exposure is suspected.

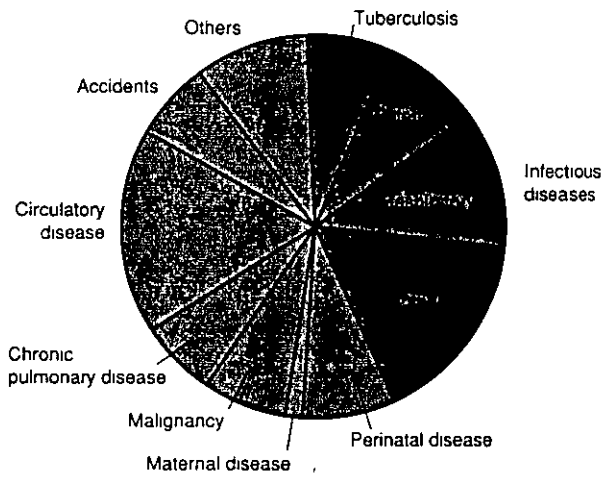
CONCEPT CHECK 22.9

Infectious diseases account for over one-third of all deaths, worldwide. Control measures such as adequate immunizations are important for maintaining health, especially when traveling in developing countries.

- ✔ *Contrast the morbidity and mortality due to infectious diseases in developing and developed countries.*
- ✔ *List a series of infectious diseases for which you have not been immunized and with which you could come into contact next year.*



(a) Developed countries



(b) Developing countries

Figure 22.8 Leading causes of death in developed and developing countries. Infectious diseases are shown in pink, and noninfectious diseases are shown in blue. (a) Developed countries. Of approximately 11.5 million deaths per year, about 500,000 are attributed to infectious disease, with nearly all deaths in this category due to pneumonia. (b) Developing countries. Of approximately 38.5 million deaths per year, about 17.5 million are attributed to infectious disease. Major infectious disease categories are shown.

22.10

Emerging and Resurgent Infectious Diseases

Infectious diseases are *global* health problems, and the scope and focus of these problems are constantly ging. In this section, we will examine some recent ges in patterns of infectious disease outbreaks, the reasons for the changing patterns, and the methods used by epidemiologists to identify and deal with new threats to public health.

The worldwide distribution of diseases can change dramatically and rapidly. Alterations in the pathogen, the environment, or the host population can contribute to the rapid spread of new diseases, with potential for high morbidity and mortality among infected individuals. We refer to diseases that suddenly become prevalent as *emerging* diseases. Emerging infections are not limited to "new" diseases but also include *resurgence* of diseases thought to be controlled, especially as antibiotics become less effective and public health systems fail. Some of the most recent, dramatic examples of emerging and resurgent disease are shown in Figure 22.9 on a global scale.

The phenomenon of suddenly emerging diseases of epidemic proportions is not new. Some of the diseases that suddenly emerged into prominence in the past were syphilis (caused by *Treponema pallidum*) (∞ Section 23.6) and plague (caused by *Yersinia pestis*) (∞ Section 23.12). In the Middle Ages, up to one-third of all living humans were killed by the plague epidemics that swept Europe, Asia, and Africa. More recently, influenza (∞ Section 23.4) became a major public health threat in the early part of the twentieth century. In the 1980s, legionellosis (caused by *Legionella pneumophila*) (∞ Section 23.2), acquired immunodeficiency syndrome (AIDS) (∞ Section 23.7), and Lyme disease (∞ Section 23.10) became major epidemic diseases.

Emergence factors

Some factors responsible for the emergence of new pathogens are (1) human demographics and behavior, (2) technology and industry, (3) economic development and land use, (4) international travel and commerce, (5) microbial adaptation and change, (6) breakdown of public health measures, and (7) abnormal natural occurrences that upset the usual host–pathogen balance.

The *demographics* of human populations have changed dramatically in the last two centuries. In 1800, less than 2% of the world's population lived in urban areas. By contrast, today nearly one-half of the world's population lives in cities. The numbers, sizes, and population densities of modern urban centers make disease transmission much easier. For example, dengue fever (Figure 22.9 and Table 22.6) is now recognized as a serious hemorrhagic disease in tropical cities, largely because of the spread of dengue virus by the mosquito *Aedes aegypti*. The disease now spreads as an epidemic in tropical urban areas. Prior to 1950, dengue fever was rare, presumably because the virus was not easily spread among a more dispersed, smaller population.

Human behavior, especially in large population centers, also contributes to disease spread. For example, sexual promiscuity and the use of injectable drugs, centered mainly in large urban areas, have been a

TABLE 22.5 Immunizations required or recommended for travel to developing countries[a]

Disease	Destination	Recommendation
Cholera	Many central African nations, India, Pakistan, South Korea, Albania, Malta, endemic areas in South America	*Vaccination recommended* if entering from or continuing to endemic areas
Yellow fever	Tropical and subtropical countries, worldwide	*Vaccination often required* for entry; or if entering from or continuing to endemic areas
Plague	Mostly rural mountainous and upland areas of Africa, Asia, and South America	*Vaccination recommended* if direct contact with rodents is anticipated
Infectious hepatitis (A)	Specific tropical areas and many developing countries	*Vaccination recommended*
Serum hepatitis (B)	Africa, Indochina, eastern and southern Europe, countries in the former Soviet Union, Central and South America	*Vaccination recommended*
Typhoid fever	Many African, Asian, Central and South American countries	*Vaccination recommended*

[a]*Current Health Information for International Travelers*, U.S. Department of Health and Human Services.

Vaccinations are also recommended for diphtheria, pertussis, tetanus, polio, measles, mumps, and rubella. Most U.S. citizens are already immunized through normal immunization practices.

major contributing factor to the spread of AIDS and hepatitis (Table 22.6; ∞ Sections 23.6 and 23.7).

Although *technological advances* and *industrial development* have had a generally positive impact on living standards worldwide, in some cases these advances have contributed to the spread of diseases. For example, one of the chief technological advances of the twentieth century has been in the health care area. However, as we noted in Section 22.7, the health care environment, especially in hospitals, has resulted in an explosive increase in nosocomial infections. For example, during the 1980s there was a threefold rise in hospital-associated bacteremias in the United States (see Section 22.7 and Figure 22.7). Antibiotic resistance in microorganisms is another negative outcome of modern health care practices; vancomycin-resistant

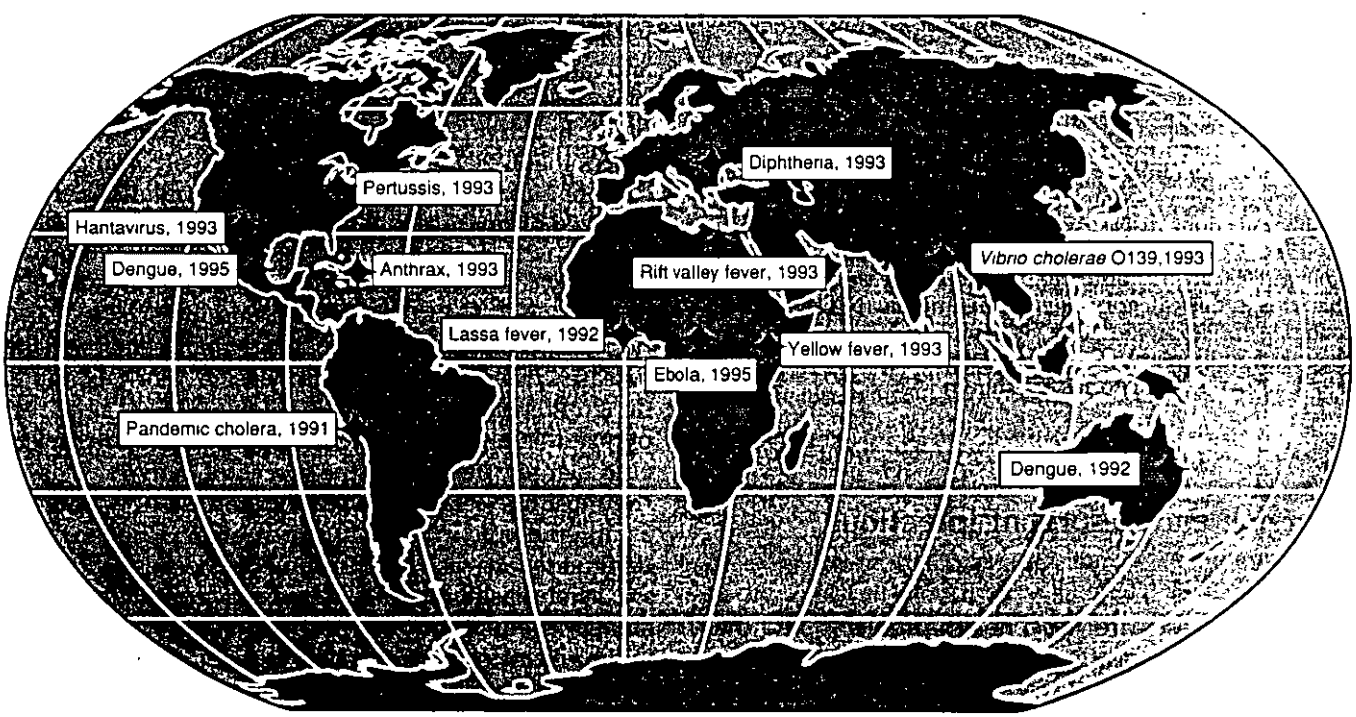


Figure 22.9 Recent outbreaks of emerging and resurgent infectious diseases on a global scale.

TABLE 22.6 Some emerging and resurgent infectious diseases

Agent	Disease and symptoms	Mode of transmission	Cause(s) of emergence
Bacteria, Rickettsias, and Chlamydias			
Borrelia burgdorferi	Lyme disease: rash, fever, neurological and cardiac abnormalities, arthritis	Bite of infective *Ixodes* tick	Increase in deer and human populations in wooded areas
Campylobacter jejuni	Campylobacter enteritis: abdominal pain, diarrhea, fever	Ingestion of contaminated food, water, or milk; fecal-oral spread from infected person or animal	Increased recognition; consumption of undercooked poultry
Chlamydia trachomatis	Trachoma, genital infections, conjunctivitis, infant pneumonia	Sexual intercourse	Increased sexual activity; changes in sanitation
Escherichia coli O157:H7	Hemorrhagic colitis; thrombocytopenia; hemolytic uremic syndrome	Ingestion of contaminated food, especially undercooked beef and raw milk	Development of a new pathogen
Haemophilus influenzae biogroup *aegyptus*	Brazilian purpuric fever: purulent conjunctivitis, fever, vomiting	Discharges of infected persons; flies are suspected vectors	Possible increase in virulence due to mutation
Helicobacter pylori	Gastritis, peptic ulcers, possibly stomach cancer	Contaminated food or water, especially unpasteurized milk; contact with infected pets	Increased recognition
Legionella pneumophila	Legionnaires' disease: malaise, myalgia, fever, headache, respiratory illness	Air-cooling systems, water supplies	Recognition in an epidemic situation
Mycobacterium tuberculosis	Tuberculosis: cough, weight loss, lung lesions; infection can spread to other organ systems	Sputum droplets (exhaled through a cough or sneeze) of a person with active disease	Immunosuppression, immunodeficiency
Staphylococcus aureus	Abscesses, pneumonia, endocarditis, toxic shock	Contact with the organism in a purulent lesion or on the hands	Recognition in an epidemic situation; possibly mutation
Streptococcus pyogenes	Scarlet fever, rheumatic fever, toxic shock	Direct contact with infected persons or carriers, ingestion of contaminated foods	Change in virulence of the bacteria; possibly mutation
Vibrio cholerae	Cholera: severe diarrhea, rapid dehydration	Water contaminated with the feces of infected persons; food exposed to contaminated water	Poor sanitation and hygiene; possibly introduced via bilge water from cargo ships
Viruses			
Dengue	Hemorrhagic fever	Bite of an infected mosquito (primarily *Aedes aegypti*)	Poor mosquito control; increased urbanization in tropics; increased air travel
Filoviruses (Marburg, Ebola)	Fulminant, high mortality, hemorrhagic fever	Direct contact with infected blood, organs, secretions, and semen	Unknown; in Europe and the United States, virus-infected monkeys shipped from developing countries via air
Hantaviruses	Abdominal pain, vomiting, hemorrhagic fever	Inhalation of aerosolized rodent urine and feces	Human intrusion into virus ecological niche
Hepatitis B	Nausea, vomiting, jaundice; chronic infection leads to hepatocellular carcinoma and cirrhosis	Contact with saliva, semen, blood, or vaginal fluids of an infected person; mode of transmission to children not known	Probably increased sexual activity and intravenous drug abuse; transfusion (before 1978)
Hepatitis C	Nausea, vomiting, jaundice; chronic infection leads to hepatocellular carcinoma and cirrhosis	Exposure (percutaneous) to contaminated blood or plasma; sexual transmission	Recognition through molecular virology applications; blood transfusion practices, especially in Japan
Hepatitis E	Fever, abdominal pain, jaundice	Contaminated water	Newly recognized
Human immunodeficiency viruses: HIV-1 and HIV-2	HIV disease, including AIDS: severe immune system dysfunction, opportunistic infections	Sexual contact with or exposure to blood or tissues of an infected person; vertical transmission	Urbanization; changes in lifestyle or mores; increased intravenous drug use; international travel; medical technology (transfusions and transplants)

TABLE 22.6 (continued)

Agent	Disease and symptoms	Mode of transmission	Cause(s) of emergence
Viruses (cont.)			
Human papillomavirus	Skin and mucous membrane lesions (often, warts); strongly linked to cancer of the cervix and penis	Direct contact (sexual contact or contact with contaminated surfaces)	Newly recognized; perhaps changes in sexual lifestyle
Human T-cell lymphotrophic viruses (HTLV-I and HTLV-II)	Leukemias and lymphomas	Vertical transmission through blood or breast milk; exposure to contaminated blood products; sexual transmission	Increased intravenous drug abuse; medical technology (transfusion and transplantation)
Influenza pandemic	Fever, headache, cough, pneumonia	Airborne; especially in crowded, enclosed spaces	Animal–human virus reassortment, antigenic shift
Lassa	Fever, headache, sore throat, nausea	Contact with urine or feces of infected rodents	Urbanization and conditions favoring infestation by rodents
Measles	Fever, conjunctivitis, cough, red blotchy rash	Airborne, direct contact with respiratory secretions of infected persons	Deterioration of public health infrastructure supporting immunization
Norwalk and Norwalk-like agents	Gastroenteritis; epidemic diarrhea	Most likely fecal-oral; vehicles may include drinking and swimming water, and uncooked foods	Increased recognition
Rabies	Acute viral encephalomyelitis	Bite of a rabid animal	Introduction of infected host reservoir to new areas
Rift Valley	Febrile illness	Bite of an infective mosquito	Importation of infected mosquitoes and/or animals; development (dams, irrigation)
Rotavirus	Enteritis: diarrhea, vomiting, dehydration, and low grade fever	Primarily fecal-oral; fecal-respiratory transmission can also occur	Increased recognition
Venezuelan equine encephalitis	Encephalitis	Bite of an infective mosquito	Movement of mosquitoes and hosts (horses)
Yellow fever	Fever, headache, muscle pain, nausea, vomiting	Bite of an infective mosquito (*Aedes aegypti*)	Lack of effective mosquito control and widespread vaccination; urbanization in tropics; increased air travel
Protozoa and Fungi			
Candida	Candidiasis: fungal infections of the gastrointestinal tract, vagina, and oral cavity	Endogenous flora; contact with secretions or excretions from infected persons	Immunosuppression; medical management (catheters), antibiotic use
Cryptococcus	Meningitis; sometimes infections of the lungs, kidneys, prostate, liver	Inhalation	Immunosuppression
Cryptosporidium	Cryptosporidiosis: infection of epithelial cells in the gastrointestinal and respiratory tracts	Fecal-oral, person to person, waterborne	Development near watershed areas; immunosuppression
Giardia lamblia	Giardiasis: infection of the upper small intestine, diarrhea, bloating	Ingestion of fecally contaminated food or water	Inadequate control in some water supply systems, immunosuppression; international travel
Microsporidia	Gastrointestinal illness, diarrhea; wasting in immunosuppressed persons	Unknown; probably ingestion of fecally contaminated food or water	Immunosuppression; recognition
Plasmodium	Malaria	Bite of an infective *Anopheles* mosquito	Urbanization; changing parasite biology; environmental changes; drug resistance; air travel
Pneumocystis carinii	Acute pneumonia	Unknown; possibly reactivation of latent infection	Immunosuppression
Toxoplasma gondii	Toxoplasmosis: fever, lymphadenopathy, lymphocytosis	Exposure to feces of cats carrying the protozoan; sometimes foodborne	Immunosuppression; increase in cats as pets

enterococci and multiple-drug-resistant *Streptococcus pneumoniae* have become important emerging diseases, especially in developed countries.

Transportation, bulk processing, and central distribution methods have become an important factor for quality assurance and economy in the food industry. However, these same factors can increase the potential for common-source epidemics when sanitation measures fail. For example, a single meat processing plant spread *Escherichia coli* O157:H7 (Table 22.6) to at least 500 individuals in four states in the United States. Finally, the food source, ground beef, was recalled and the epidemic was curtailed, but not before several people died (∞ Section 23.13).

Economic development and changes in land use also have potential implications for promoting disease spread. For example, Rift Valley fever, a mosquito-borne viral infection, has been on the increase since completion of the Aswan High Dam in Egypt in 1970. The dam created 2 million acres of flooded land, which dramatically increased mosquito breeding grounds at the edge of the new reservoir. The first major epidemic of Rift Valley fever occurred in Egypt in 1977 when an estimated 200,000 people became ill and 598 died. Several epidemic outbreaks have occurred since then including a major outbreak in 1993 (Figure 22.9), and the disease has become endemic near the reservoir.

Lyme disease, the most common vector-borne disease in the United States, is probably on the rise because of *changes in land use*. Reforestation and the concomitant increase in the numbers of deer (the natural host for the disease-producing *Borrelia burgdorferi*) have resulted in greater numbers of infected ticks, the arthropod vector (∞ Section 23.10). In addition, increasing numbers of people are building homes and pursuing recreational activities in and near forests, resulting in increased contact between the infected ticks and humans and, consequently, increased disease.

International travel and commerce can also affect the spread of pathogens. For example, filoviruses (Filoviridae), a group of ribonucleic acid (RNA) viruses, (∞ Section 8.16), cause fevers culminating in hemorrhagic disease in infected hosts. These diseases, because of their viral origin, are not treatable. They generally have a mortality rate higher than 20%. Most outbreaks of these diseases have been restricted to equatorial central Africa, where the still-unidentified natural hosts and vectors undoubtedly live (Figure 22.9). Travel of potential hosts to or from endemic areas is usually implicated in disease transmission. For example, one of these viruses was imported into Marburg, Germany, with a shipment of African green monkeys, a species used for laboratory work. The virus quickly spread from the primate vector to some of the human handlers. Twenty-five people were initially infected, and six more developed disease as a result of contact with the human cases. Seven people died in this outbreak of what came to be known as the Marburg virus. Another shipment of laboratory monkeys brought a filovirus to the United States. At least four individuals who worked with the imported monkeys were infected with what is now called the Reston virus (named for Reston, Virginia, the site of the outbreak). The Reston virus was highly contagious and spread through the monkeys, presumably by a respiratory route. However, only four humans were infected and none developed clinical disease. Fortunately, this virus did not cause significant human disease. These two filoviruses are closely related to the Ebola virus (Table 22.6 and Figure 22.9). Recent Ebola outbreaks in central Africa, characterized by mortality rates of greater than 50%, have again underscored the existence of highly virulent human pathogens for which there is little or no immunity. These pathogens could potentially be disseminated via air travel throughout the world in a matter of days. A single agent that combines the highly contagious respiratory transmission route of the Reston virus and the high mortality rate of the Ebola virus could start a major pandemic that could devastate population centers worldwide in a matter of weeks.

Microbial adaptation and change also contribute to pathogen emergence. For example, nearly all RNA viruses, including influenza and human immunodeficiency virus (HIV), undergo genetic mutations. Hepatitis B virus, a deoxyribonucleic acid (DNA) virus known for rapidly mutating, also uses reverse transcriptase to replicate (∞ Section 8.14). These viruses lack correction mechanisms for replication steps, and so they incorporate genomic mutations at an extremely high rate compared to most DNA viruses. RNA viruses are considered to be major epidemiological problems because of their constantly changing genomes.

Bacteria also have genetic mechanisms that enhance virulence and promote emergence of new epidemics. One group of virulence-enhancing mechanisms are the mobile genetic elements: bacteriophages, plasmids, and transposons (∞ Sections 8.7, 9.8, and 9.10, respectively). Table 22.7 shows some representative virulence factors that are carried on these mobile genetic elements and contribute to pathogen emergence.

Antibiotic resistance is also a major factor in bacterial pathogen resurgence (∞ Section 11.13). Drug resistance is also a factor for virus emergence. Although several drugs are effective against certain viral diseases (∞ Section 11.11), resistance to these drugs is very common, especially among the RNA viruses. For example, most strains of HIV develop resistance to azidothymidine very rapidly unless it is used in combination with other drugs (∞ Section 23.7).

A breakdown of public health measures is sometimes responsible for the emergence or resurgence of diseases. For instance, cholera (caused by *Vibrio cholerae*) (see Figure 22.9 and Section 23.14) can be adequately controlled, even in endemic areas, by providing proper sanitation, especially for water sources. However, contaminated municipal water supplies in Peru led to a

TABLE 22.7 Virulence factors encoded by bacteriophages, plasmids, and transposons

Genetic element	Organism	Virulence factors
Bacteriophage	*Streptococcus pyogenes*	Erythrogenic toxin
	Escherichia coli	Shiga-like toxin
	Staphylococcus aureus	Enterotoxins A, D, E, staphylokinase, toxic shock syndrome toxin-1 (TSST-1)
	Clostridium botulinum	Neurotoxins C, D, E
	Corynebacterium diphtheriae	Diphtheria toxin
Plasmid	*Escherichia coli*	Enterotoxins, pili colonization factor, hemolysin, urease, serum resistance factor, adherence factors, cell invasion factors
	Bacillus anthracis	Edema factor, lethal factor, protective antigen, poly-D-glutamic acid capsule
	Yersinia pestis	Coagulase, fibrinolysin, murine toxin
Transposon	*Escherichia coli*	Heat-stable enterotoxins, aerobactin siderophores, hemolysin and pili operons
	Shigella dysenteriae	Shiga toxin
	Vibrio cholerae	Cholera toxin

major cholera pandemic, involving nearly 400,000 people by 1991, with almost 4000 deaths. In another case, the municipal water supply of Milwaukee, Wisconsin, was contaminated with the chlorine-resistant protozoan *Cryptosporidium* in 1993. The contamination resulted in 370,000 cases of intestinal disease, 4000 of which required hospitalization. More effective treatment procedures including enhanced filtration systems were required to rid the water supply of the pathogen.

Inadequate public vaccination programs are an important potential reason for the resurgence of some previously controlled diseases. For example, recent outbreaks of diphtheria (caused by *Corynebacterium diphtheriae*) (see Figure 22.9 and Section 23.2) in the former Soviet Union are the result of inadequate immunization of susceptible children resulting from the breakdown of the formerly centralized public health infrastructure. Pertussis, another vaccine-preventable childhood respiratory disease (caused by *Bordetella pertussis*) (see Figure 22.9 and Section 23.2), has increased recently in the United States because of inadequate immunization and record keeping. As we mentioned in Section 22.8, the incidence of measles was also on the rise in the United States owing to a lack of effective, timely vaccination programs.

Finally, *abnormal natural occurrences* such as rapid environmental changes sometimes upset the usual host–pathogen balance. For example, hantavirus is a well-known human pathogen that occurs in many rodent populations, even in laboratory animals. Over the last decade, several isolated cases of hantavirus infection have occurred in laboratory animal handlers. However, a number of lethal cases of hantavirus infection were reported in 1993 in the American Southwest and were linked to exposure to wild animal droppings. Abundant rainfall and a long growing season, coupled with a mild winter, caused a tremendous increase in the number of mice in 1993. Virtually everyone who acquired the hantavirus infection had been exposed to rodents or their droppings. Thus, increased human contact with the larger-than-normal mouse population resulted in propagation and transfer of a deadly virus to a large number of human hosts, all because of abnormally mild weather conditions.

Addressing emerging diseases

Many of the emerging diseases we have discussed are absent from the official notifiable disease list for the United States (Table 22.4). How then do public health officials define and deal with emerging diseases to prevent major epidemics? The key features for addressing emerging diseases are *recognition* of the disease and *intervention* to prevent spread of the disease.

The first step in disease *recognition* is surveillance: *Epidemic* diseases that exhibit particular *clinical syndromes* warrant intensive public health surveillance. These syndromes are (1) acute respiratory diseases, (2) encephalitis and aseptic meningitis, (3) hemorrhagic fever, (4) acute diarrhea, (5) clusterings of high fever cases, (6) unusual clusterings of any disease or deaths, and (7) resistance to common drugs or treatment. Thus, new diseases are recognized because of their epidemic incidence, clusterings, and syndromes. As the prevalence and pathology of an emerging disease are recognized, it is added to the notifiable disease list. For example, AIDS was recognized as a disease in 1981 and was added to the notifiable disease list in 1984. Lyme disease was first recognized as a separate clinical disease in the 1980s and added to the notifiable disease list in 1991. Likewise, outbreaks of gastrointestinal disease due to enteropathogenic *Escherchia coli* O157:H7 have been increasing in recent years, and the strain was added to the notifiable disease list in 1995.

Intervention to prevent spread of emerging infections must be a public health response involving a variety of methods. General strategies such as

strengthening the public health system and supporting research and training are useful, but disease-specific intervention is the key to controlling individual outbreaks. Public health methods such as vector control and quarantine were discussed in Section 22.8. In addition, intervention must include drug and vaccine development (∞ Sections 12.5 and 20.17) to prevent and treat specific diseases. Finally, a number of the emerging diseases are propagated in nonhuman hosts, or vectors. We must identify the alternate hosts and vectors and develop means to intervene in the life cycle of the pathogen to prevent disease propagation.

In the following chapter, we will examine a number of infectious diseases, including several emerging and resurgent diseases. We will define their individual effects on the host and identify specific intervention strategies.

CONCEPT CHECK 22.10

Emerging and resurgent diseases are of major global concern. Changes in host, vector, or pathogen conditions, whether natural or artificial, can result in conditions that encourage the explosive emergence of certain infectious diseases. Global surveillance and intervention programs must be maintained and enhanced to prevent major new epidemics and pandemics.

- ✔ *What factors are important in the emergence or resurgence of potential pathogens?*
- ✔ *Indicate general and specific methods that would be useful for dealing with perceived and actual emerging infectious diseases.*

Material for Review

REVIEW QUESTIONS

1. What are the most common causes of death due to infectious diseases throughout the world?
2. Describe the stages involved in a typical infectious disease in which the host recovers.
3. Explain the difference between a chronic carrier and an acute carrier of an infectious disease.
4. Identify the major risk factors for acquiring human immunodeficiency virus (HIV) infection. Does this indicate a common-source or a host-to-host epidemic?
5. Give examples of host-to-host transmission of disease via direct contact. Also give examples of indirect host-to-host transmission of disease.
6. Some diseases produce high mortality on introduction to a susceptible population, but after time these diseases usually generate much lower mortality. Explain this phenomenon.
7. Hospitals are particularly hazardous environments for the spread of infectious diseases. Review the reasons for the enhanced spread of infection in hospitals.
8. Many factors that can control the spread of infection are important considerations for public health personnel. Describe the major methods used to control the spread of infectious diseases.
9. Compare the role of infectious diseases on mortality in developed and developing countries.
10. Review the major reasons for the emergence of new infectious diseases. Review the major methods available for controlling the emergence of new infectious diseases.

APPLICATION QUESTIONS

1. How would an epidemiologist acquire data concerning a potential common-source epidemic? What resources are currently at the epidemiologist's disposal and what resources must be enhanced to better define serious infectious disease outbreaks?
2. If an infectious disease causes high *mortality*, then *morbidity* may be quite low. On the other hand, diseases characterized by high morbidity often induce very low mortality. Explain these statements and present examples to support your explanation. Can you identify any infectious diseases that do not fit these generalizations?
3. Smallpox, a disease that was limited to humans, was eradicated. Plague, a disease with a zoonotic reservoir in rodents (Table 22.2) will never be eradicated. Explain this statement and why you agree or don't agree with the possibility of eradicating plague. Could you eradicate plague in limited environments (that is, individual cities)? Why or why not?
4. Acquired immunodeficiency syndrome (AIDS) transmission is considered to be person to person. How did epidemiologists determine this fact? AIDS is a candidate for a disease that can be eliminated because it is propagated by person-to-person contact and there are no known animal reservoirs. Design a program for eliminating AIDS in a developed country and in a developing country. How would these programs differ from one

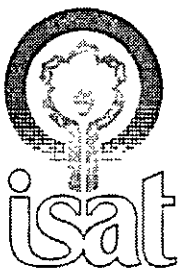
DIPLOMADO EN CONTROL DE LOS RESIDUOS
GENERADOS EN HOSPITALES
Y OTROS CENTROS DE SALUD

EVALUACIÓN DE RIESGOS A LA SALUD

Dr. Carlos Santos Burgoa

DIVISIÓN DE EDUCACIÓN CONTINUA
FACULTAD DE INGENIERIA
UNAM

AMCRESPAC



INSTITUTO DE SALUD AMBIENTE Y TRABAJO

MATERIALES DE APOYO

CURSO DE DIPLOMADO EN DESECHOS HOSPITALARIOS

PROFESORES:

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COORDINADOR DE DOCENCIA
MSP. JUAN PABLO VILLA BARRAGÁN

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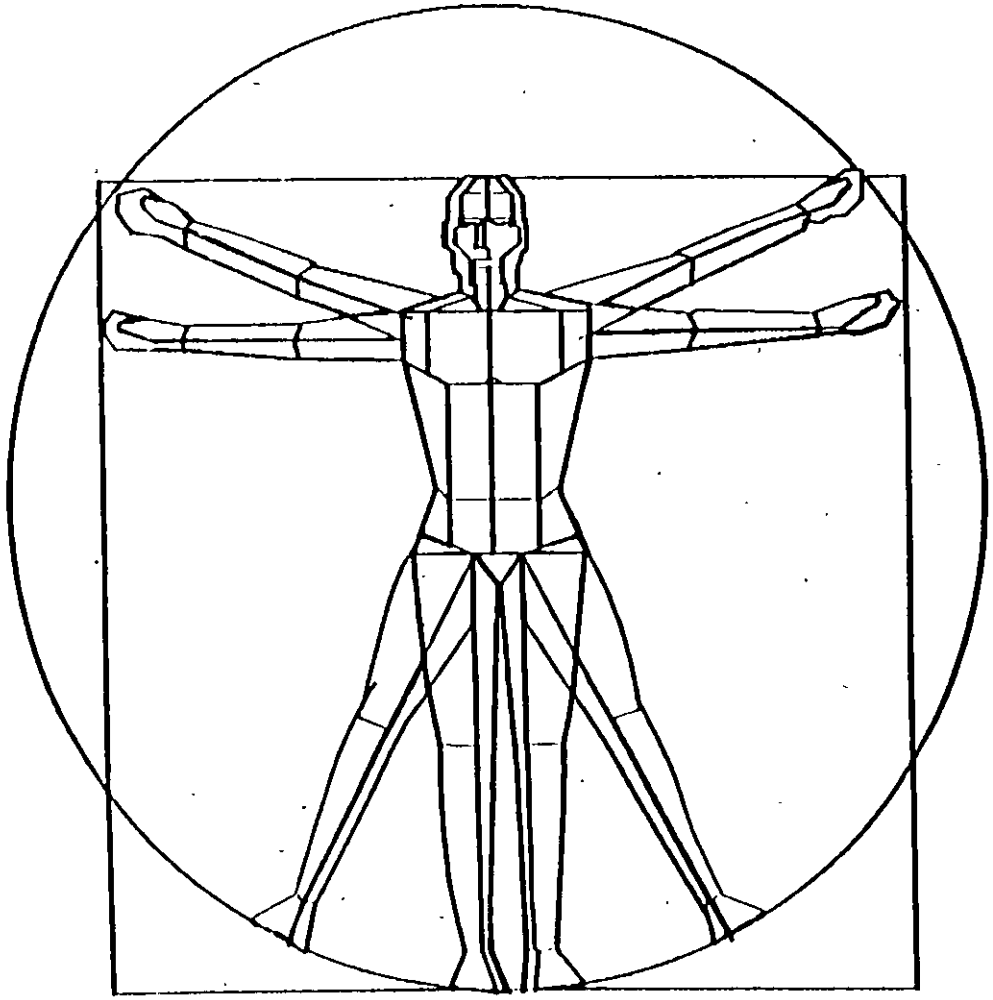
¿CUALES SON LOS COMPONENTES DE LA EVALUACION DE RIESGOS?

- Identificación del Peligro
- Evaluación Dosis-Respuesta
- Evaluación de la Exposición Humana
- Caracterización del Riesgo

IDENTIFICACION DEL PELIGRO

- Revisar y analizar datos de toxicidad
- Sopesar la evidencia de que una sustancia produce varios efectos tóxicos
- Evaluar si los efectos tóxicos de un lugar pueden ocurrir en otros sitios

EVIDENCIA EN HUMANOS



Suficiente
Limitada
Inadecuada
No hay datos
No hay evidencia

Estudios de Toxicidad en Animales

Se fundamentan en el hecho de que en algunos casos, los efectos en humanos pueden inferirse de los efectos observados en estudios en animales de laboratorio

IDENTIFICACIÓN DEL PELIGRO

Propósito de obtener y evaluar información relacionada con propiedades tóxicas inherentes a cada sustancia (potencial para causar daño biológico, enfermedad o muerte), bajo ciertas condiciones de exposición.

Información recolectada se origina en cuatro fuentes principales:

1) Estudios epidemiológicos.
2) Estudios en modelos experimentales en animal íntegro.
3) Pruebas de corta duración *in vitro*.
4) Estudio de las relaciones

FUENTES DE DATOS DE TOXICIDAD

Estudios en Humanos

Reportes de casos
Estudios epidemiológicos
- Transversal
- Casos y Controles
- Cohorte

Estudios en animales

Estudios de toxicidad general
- Agudos
- Crónicos

Estudios de toxicidad especializados
- Teratogenicidad
- Mutagenicidad

Estudios in vitro

- Microbiológicos
- En células de mamíferos

ALGUNOS TIPOS DE ESTUDIOS DE TOXICIDAD

Tipo de estudio	Período de exposición	Propósito
Agudo	Usualmente una dosis única	Determinar la dosis letal Identificar órganos que pueden ser objetivos potenciales Indicar toxicidad comparativa
Subcrónico	Dosis repetidas durante varias semanas	Identificar órganos o sistemas que puedan ser dañados y el nivel de exposición en el cual no se observen efectos adversos
Crónico	Dosis repetidas durante la mayor parte del ciclo de vida	Identificar anormalidades y/o enfermedades que pueden ser producidas por sustancias y caracterizar las condiciones de exposición y la dosis para producir formas específicas de daño o enfermedad
Metabólico y farmacocinético	Dosis única o repetida, usualmente durante cortos períodos	Identificar las características de la absorción, distribución y eliminación de una sustancia en el organismo e identificar los procesos metabólicos que la afectan

Identificación del Peligro

- Validez y significado de la información toxicológica
- Solidez científica de la evidencia de que una sustancia causa efectos tóxicos
- Probabilidad de que los efectos observados en la población X puedan ocurrir en la población Y

E l baile es un ejercicio
saludable, pero cuando es
violento y de larga duración
en una habitación abarrotada,
puede ser peligroso y ha
acelerado la muerte de
mucha gente joven

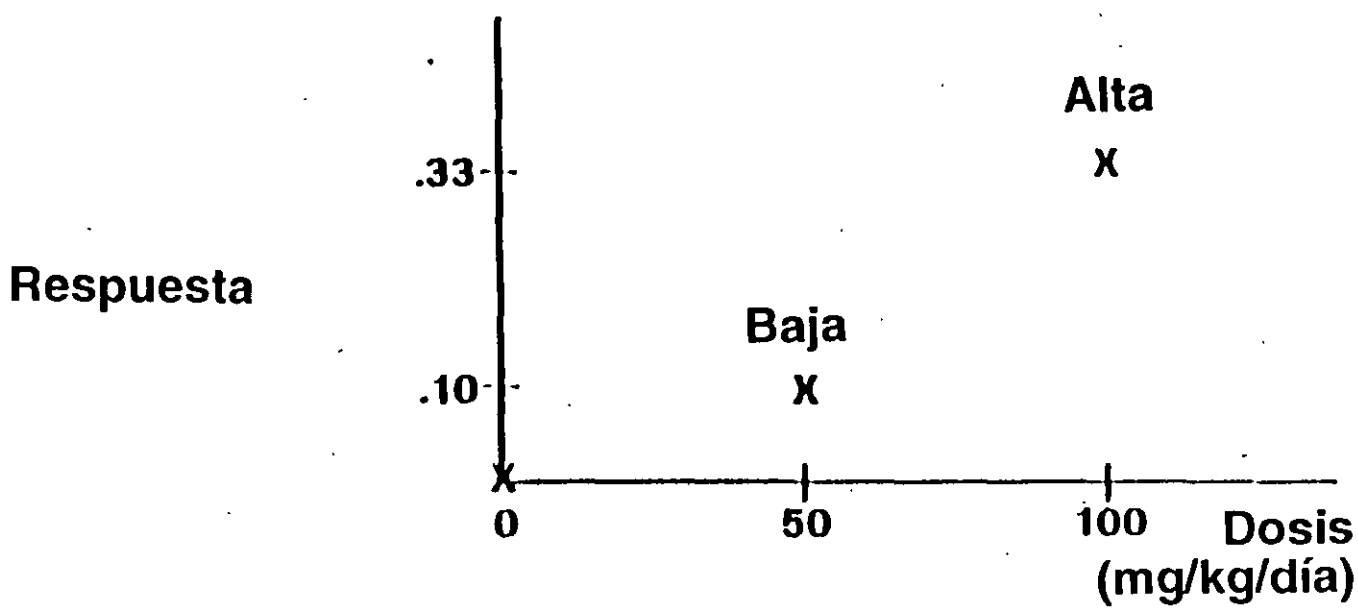
Dr. A. Murray
1826

LD_{50} ORAL IN RATAS PARA DIFERENTES SUSTANCIAS QUIMICAS

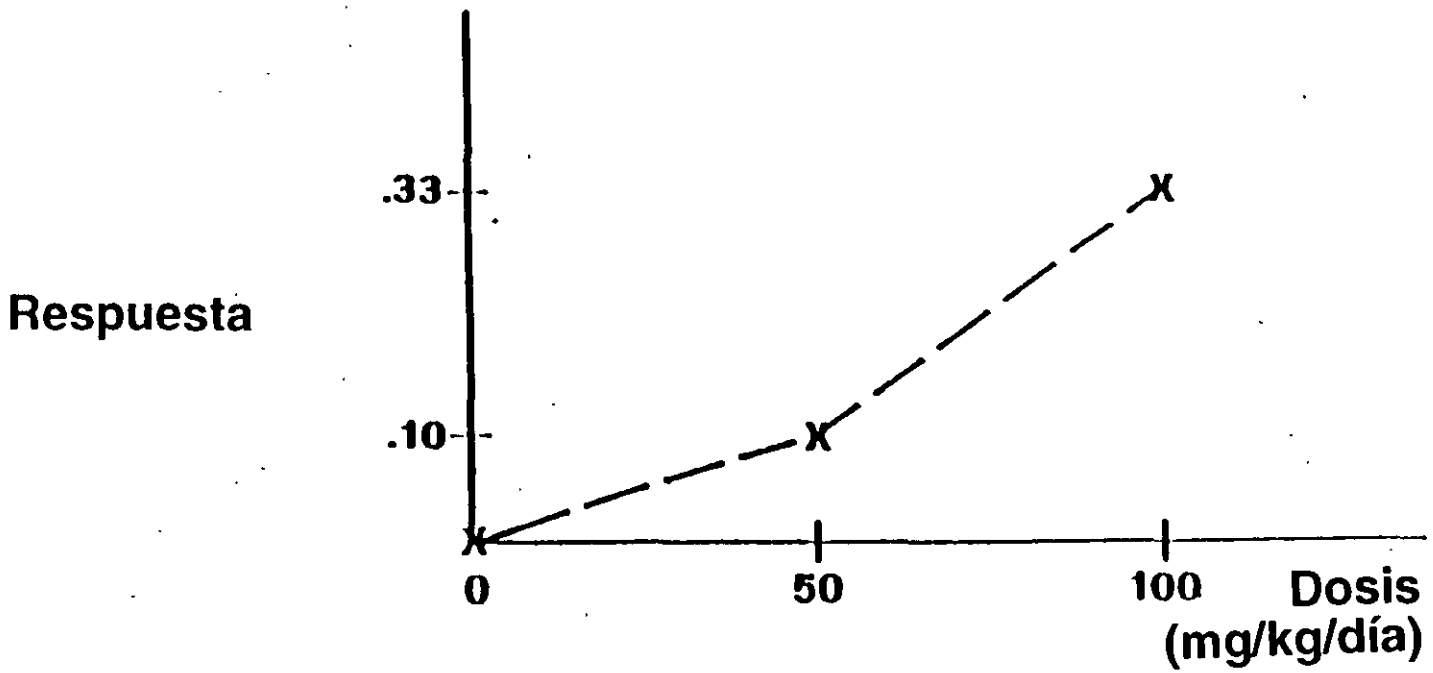
Sustancia	LD_{50} (mg/kg)
Sacarosa azúcar de mesa)	25,700
Alcohol etílico	14,000
Cloruro de sodio (sal común)	3,000
Vitamina A	2,000
Vainillina	1,580
Aspirina	1,000
Cloroformo	800
Sulfato de cobre	300
Cafeína	192
Fenobarbital, sal de sodio	162
DDT	113
Nitrito de Sodio	85
Nicotina	53
Aflatoxina B1	7
Cianuro de sodio	6.4
Estricnina	2.3

EVALUACION DOSIS-RESPUESTA

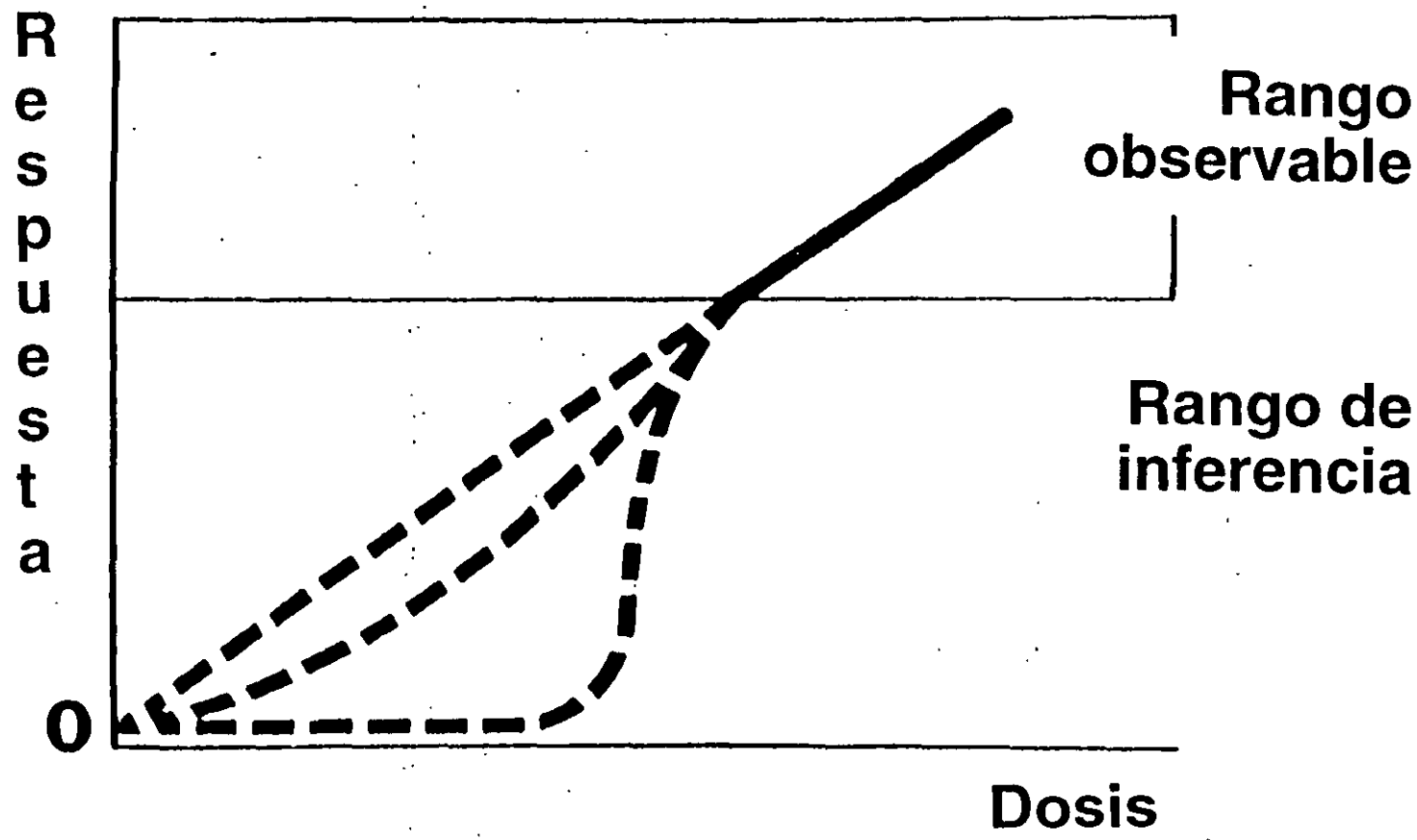
Se lleva a cabo para estimar la frecuencia del efecto adverso como una función de la magnitud de la exposición humana a una sustancia



CURVA DOSIS-RESPUESTA



CURVA DOSIS-RESPUESTA



DOSIS

DOS TIPOS DE MEDICION

1.- Medición de la cantidad de la sustancia en el medio (aire, dieta, etc.) en el que está presente o se admnistra

2.- Medición de la cantidad recibida por el sujeto, sea humano o un animal

DOSIS

Ejemplo:

→ **La sustancia HC-BAD está presente en el agua de bebida a una concentración de 10 mg/l**

Medición tipo 1

→ **¿Cuál es la dosis (diaria) para un adulto?**
Supuestos: Un adulto pesa 70 kg.
Bebe 2l de agua por día

$$\text{DOSIS} = \frac{10\text{mg}}{\text{l}} \times \frac{2\text{l}}{\text{día}} \times \frac{1}{70\text{kg}} = 0.29\ \text{mg/kg/día}$$

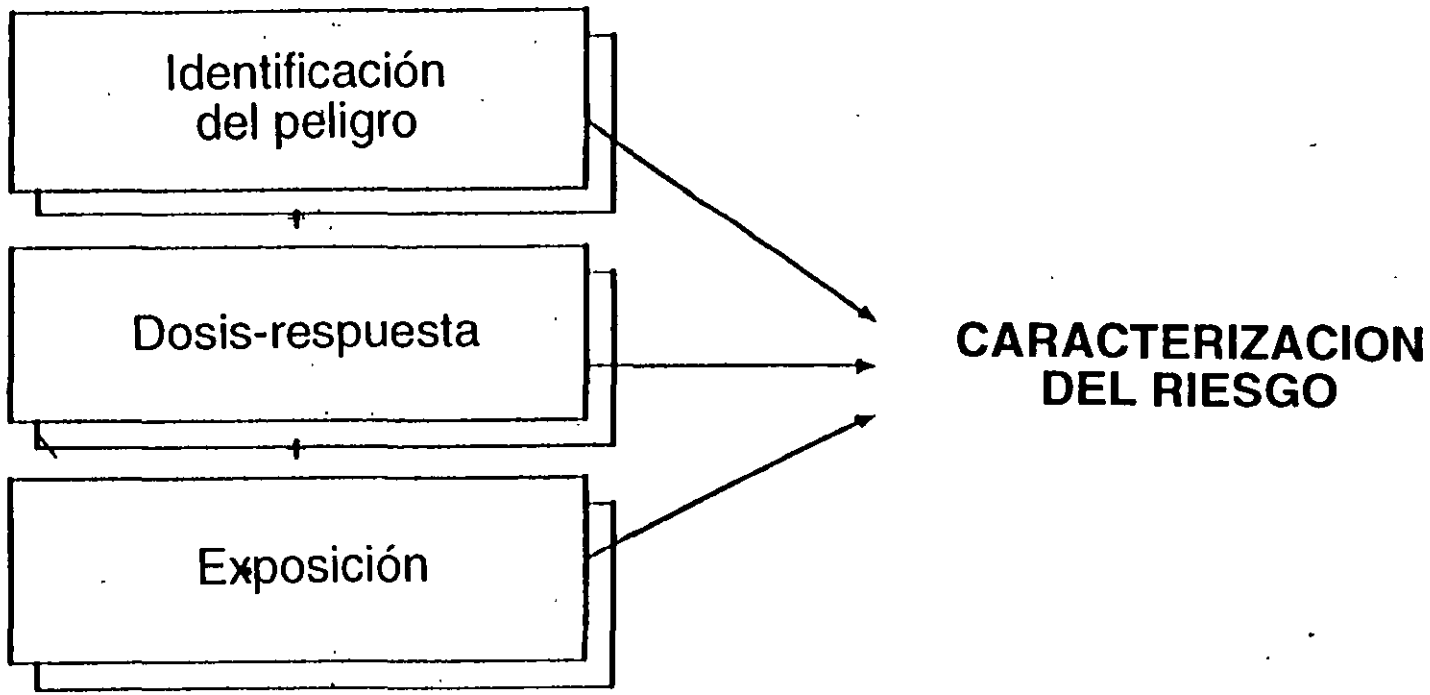
Medición tipo 2

ASPECTOS DE EXPOSICION

- **Grado y frecuencia de la exposición humana**
  - **¿A cuánto?**
  - **¿Qué tan a menudo?**
  - **¿Con qué certeza?**
- **Número de gente expuesta**
- **Grado de absorción por varias rutas de exposición**
- **Uso de individuos promedio o típicos**
- **Uso de grupos de alto riesgo**


FORMAS DE
EXPOSICION HUMANA
Inhalación
Ingestión
Contacto en la piel

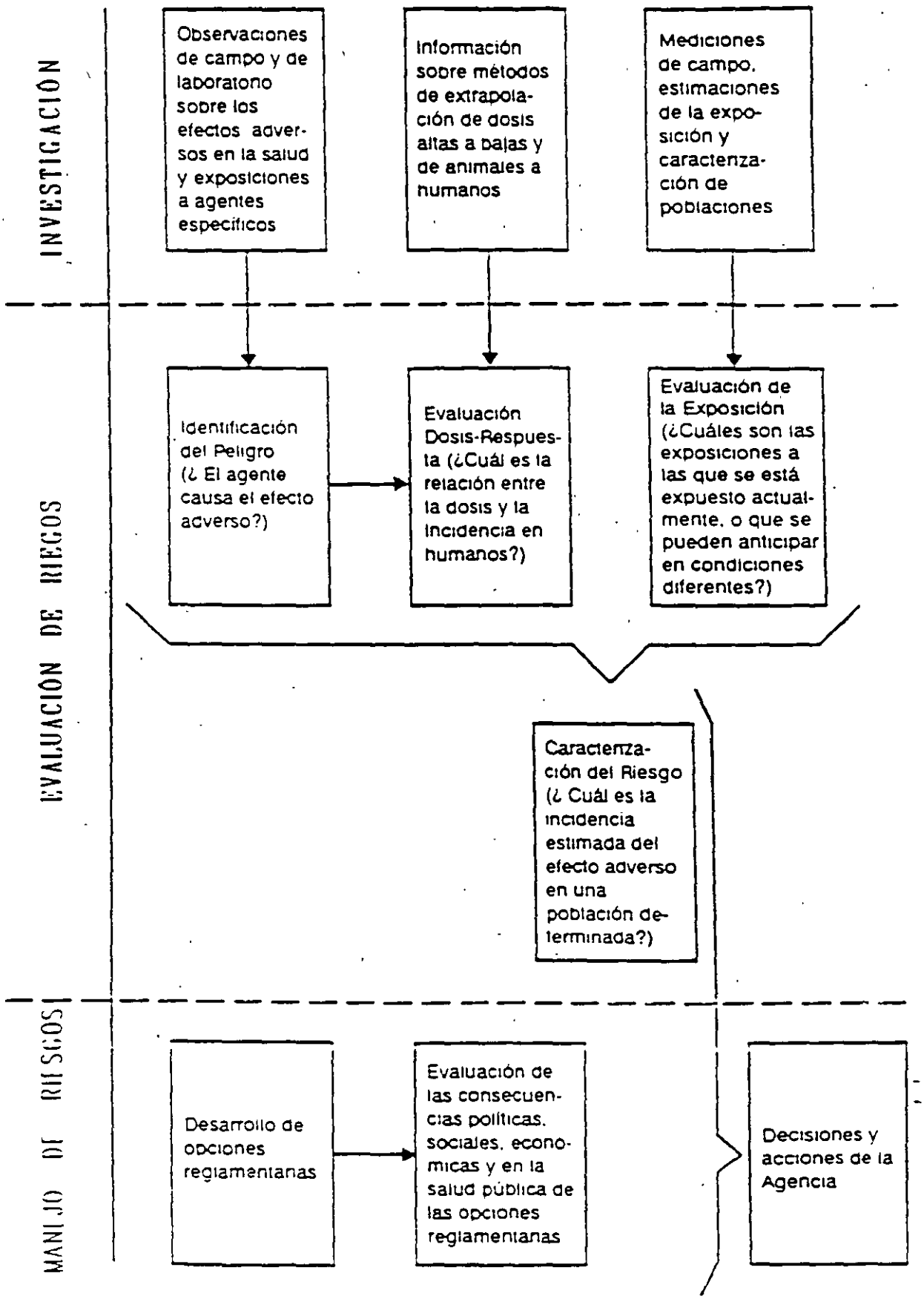
COMPONENTE 4
CARACTERIZACION DEL RIESGO



Caracterización del Riesgo

- Integrar la identificación del peligro, la evaluación dosis respuesta y la evaluación de exposición
- Desarrollar estimadores de riesgo para la salud pública
- Desarrollar un marco de referencia para definir la significancia del riesgo
- Presentar los supuestos, incertidumbre y juicios científicos

ELEMENTOS DE EVALUACIÓN DE RIESGOS Y MANEJO DE RIESGOS



DIPLOMADO EN CONTROL DE LOS RESIDUOS
GENERADOS EN HOSPITALES
Y OTROS CENTROS DE SALUD

EVALUACIÓN DOSIS RESPUESTA

Dr. Horacio Riojas

DIVISIÓN DE EDUCACIÓN CONTINUA
FACULTAD DE INGENIERIA
UNAM

AMCRESPAC

EVALUACION DE RIESGOS

La estimación científica del riesgo que se obtiene al combinar los resultados de una evaluación de exposición con los resultados de la evaluación de toxicidad de una sustancia química

MANEJO DE RIESGOS

El juicio y análisis que combina los resultados científicos de una Evaluación de Riesgos con factores de tipo económico, político, legal y social, para generar una decisión que lleve a una acción ambiental

COMUNICACION DE RIESGOS

La comunicación de la información de la Evaluación/Manejo de Riesgos al Público, a la prensa y a los tomadores de decisiones

¿QUE ES LA EVALUACION DE RIESGOS?

"Un proceso cualitativo o cuantitativo que se lleva a cabo para caracterizar la naturaleza y magnitud de los riesgos potenciales para la salud pública, de la exposición a sustancias peligrosas, contaminantes o agentes liberados de sitios de residuos peligrosos"

EPA, 1986

¿QUE ES RIESGO?

La probabilidad de daño, enfermedad o muerte

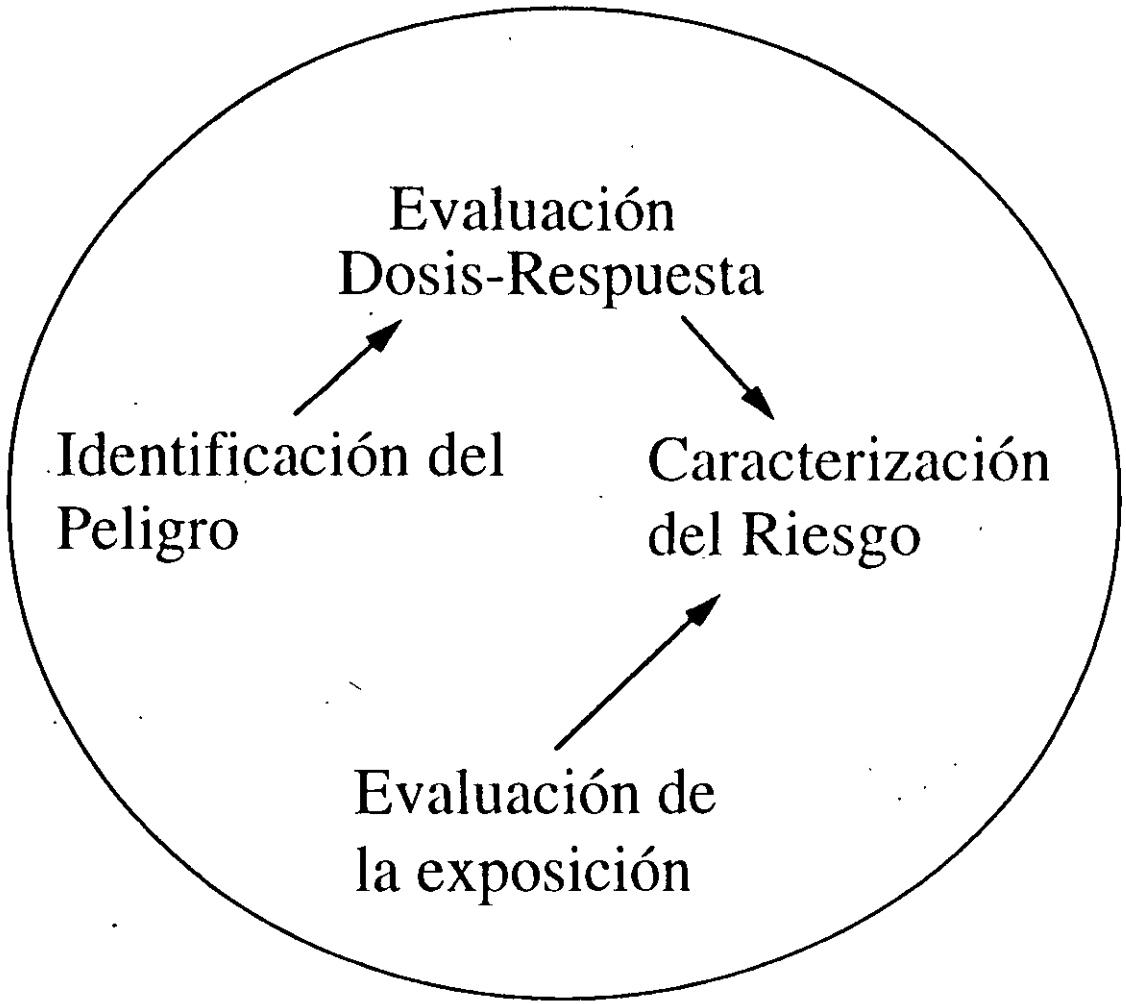
¿QUE ES RIESGO AMBIENTAL?

La *probabilidad* de daño, enfermedad o muerte que resulta de la exposición a un peligro ambiental

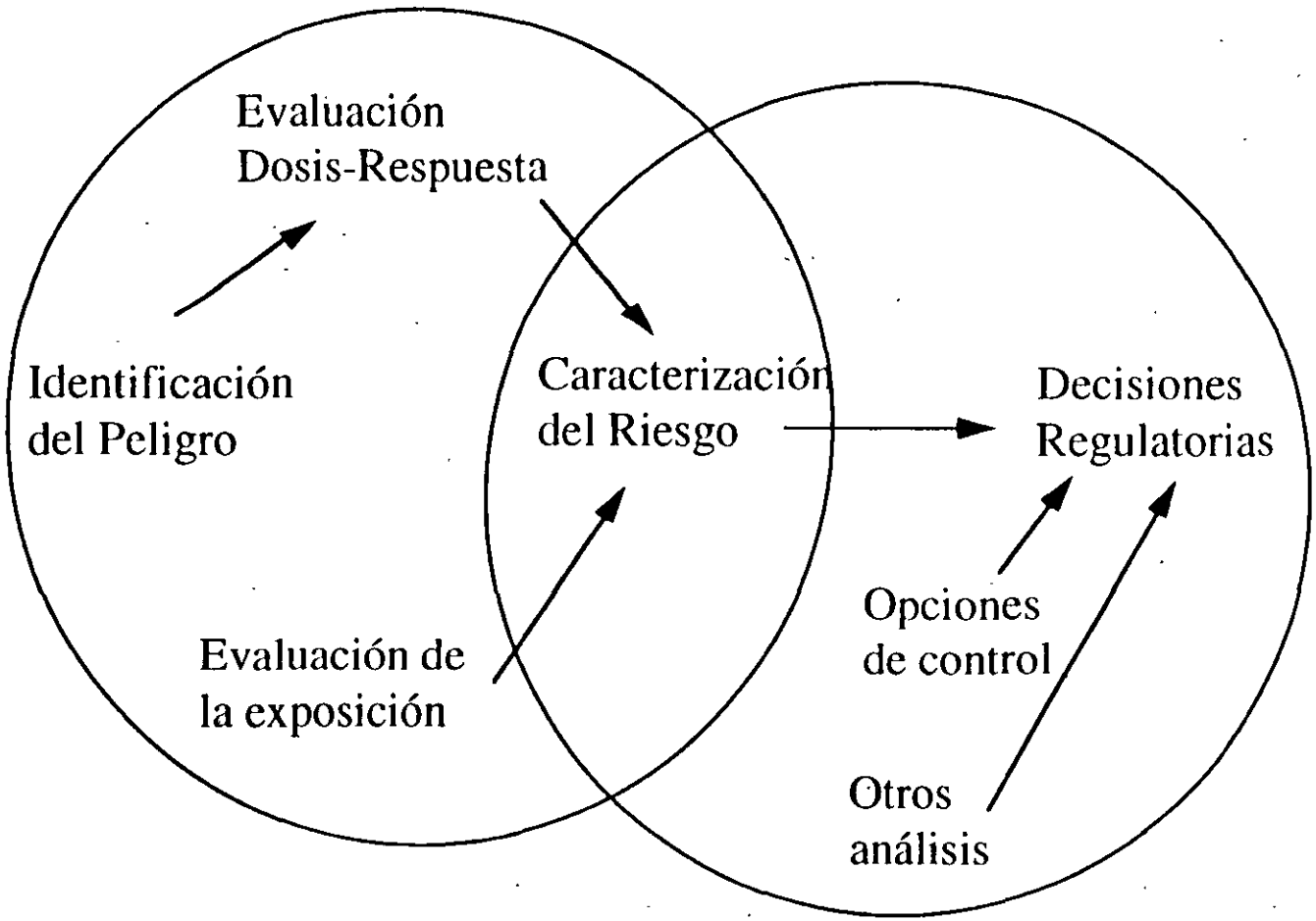
RIESGOS COMPARATIVOS DE MUERTE

	Número de muertes/año	Riesgo en toda la vida
○ Accidentes en vehículos automotores	46,000	1/65
○ Accidentes en el hogar	25,000	1/130
○ Muerte por Cancer pulmonar en fumadores	80,000	1/12

EVALUACION DE RIESGOS

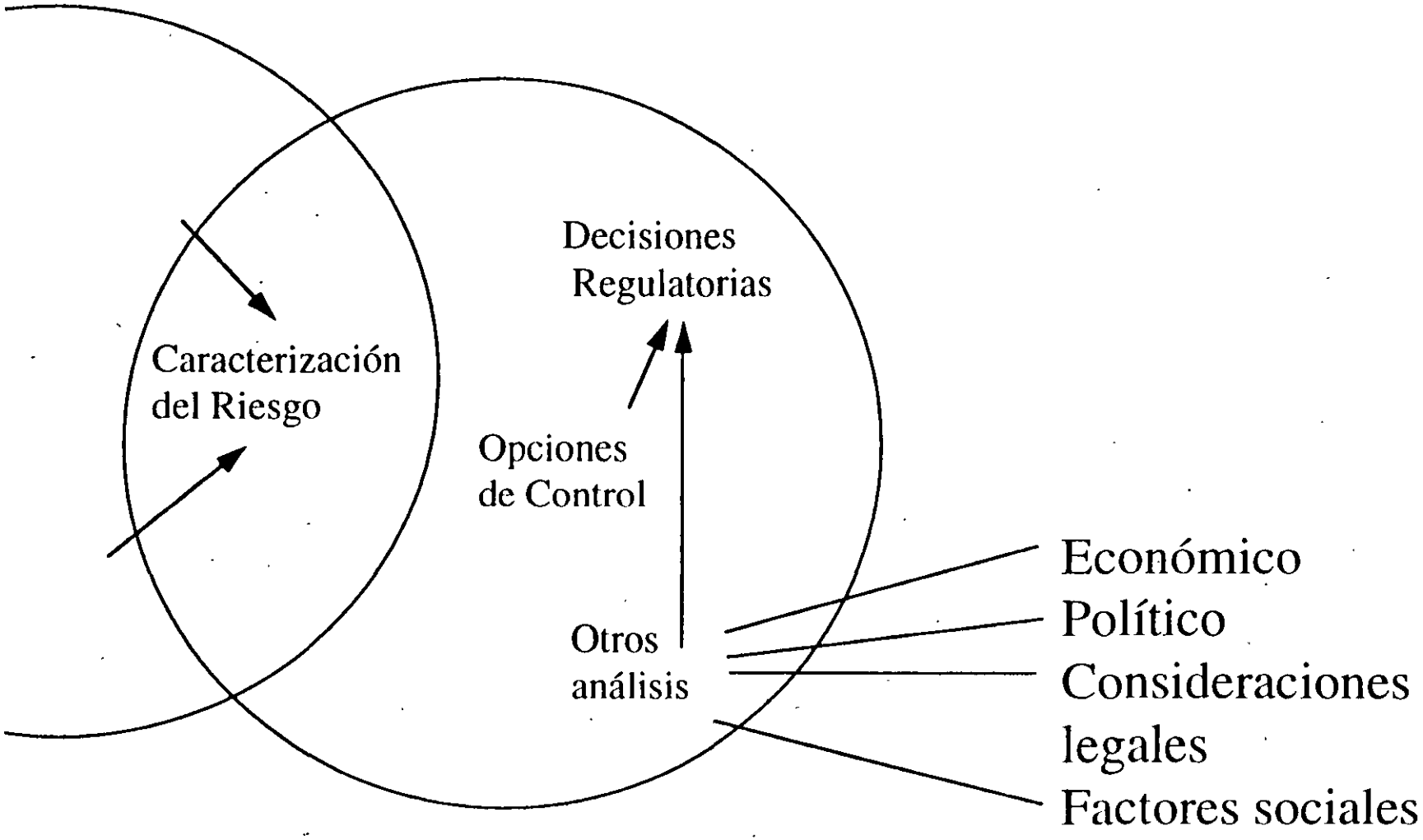


EVALUACION DE RIESGOS



MANEJO DE RIESGOS

OTROS ANALISIS



EVALUACIÓN DE RIESGOS (NAS, 1983)

Caracterización de los efectos adversos potenciales derivados de la exposición humana a factores ambientales peligrosos.

Incluye los siguientes elementos:

- **describir efectos adversos posibles sobre la base de evaluar resultados epidemiológicos, clínicos, toxicológicos y ambientales;**

- **extrapolar resultados anteriores para predecir tipo y magnitud de efectos en salud humana bajo condiciones dadas de exposición;**

- **evaluar número y características de personas expuestas a diferentes intensidades y duraciones;**

- **apreciar presencia y magnitud global del problema de salud pública;**

- **caracterizar incertidumbres inherentes al proceso de inferencia de los riesgos.**

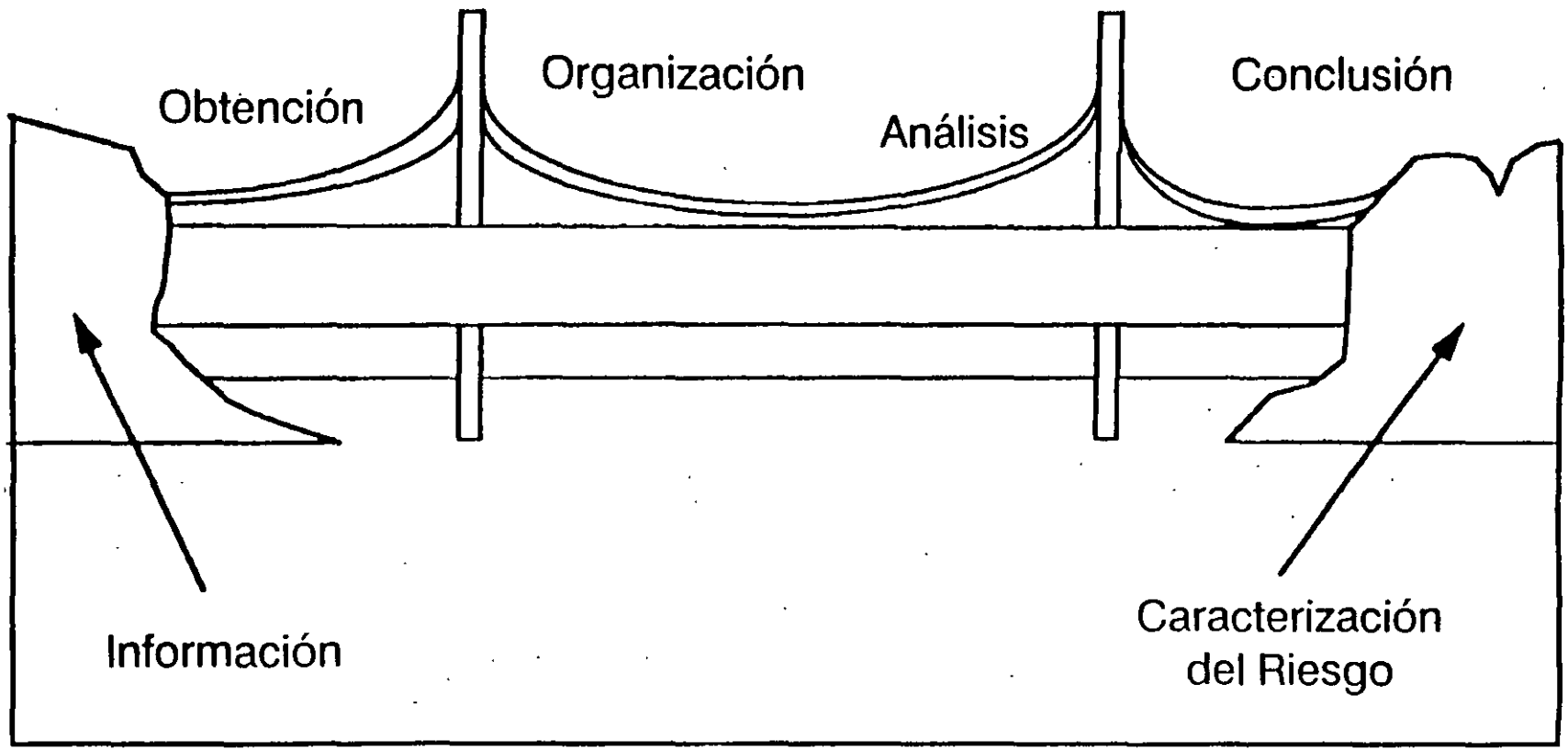
El proceso debe apuntar a reducir al mínimo los juicios de valores y las apreciaciones subjetivas de los científicos.

EVALUACIÓN DE RIESGOS
- PROPÓSITOS -

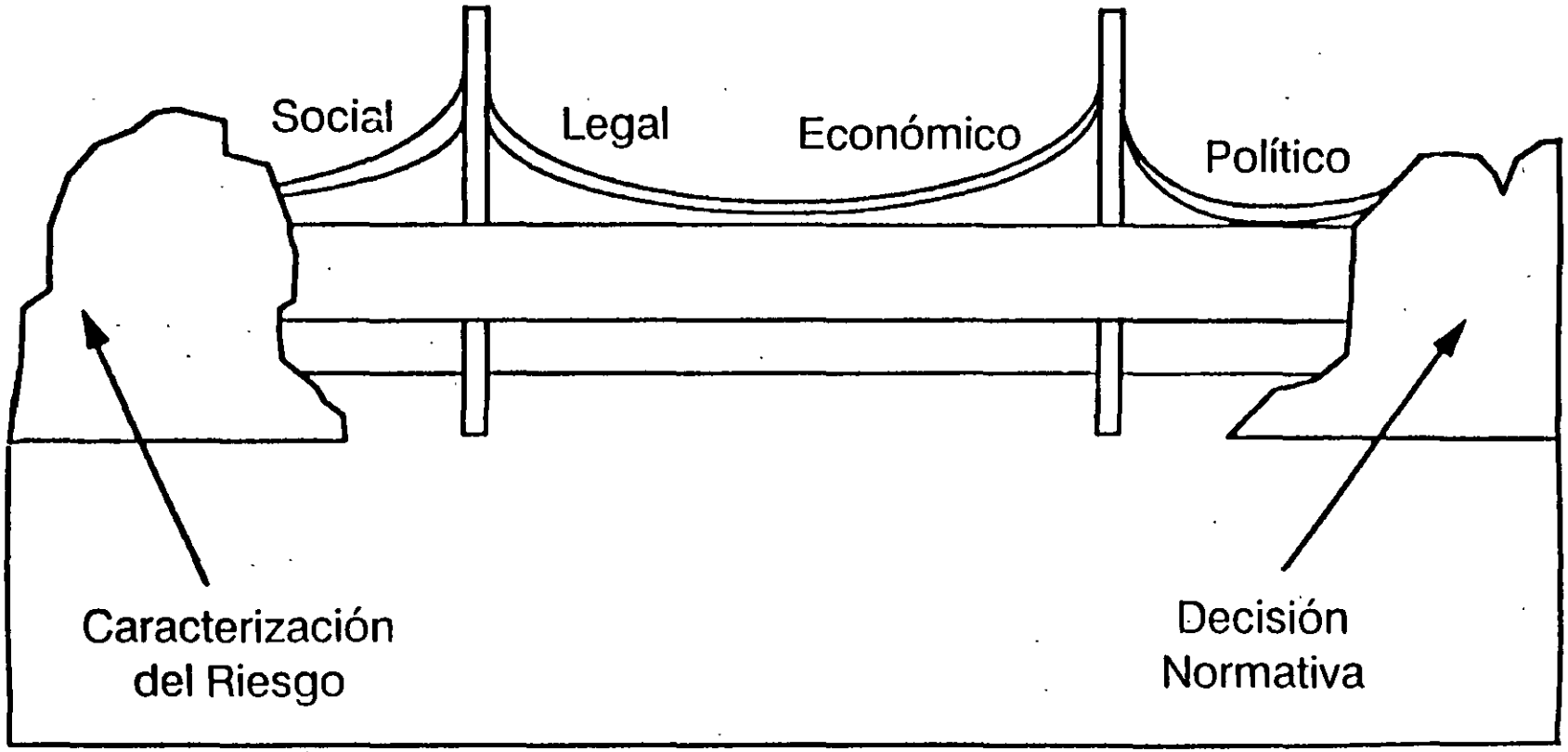
a) determinar posibilidad de efectos adversos en humanos, otras especies y ecosistemas ante la presencia de un agente químico o físico; y

b) proporcionar la más completa información posible a encargados de controlar los riesgos, específicamente a quienes establecen políticas y establecen las normas.

Materialmente una evaluación de riesgos se expresa en un documento escrito en donde se reúne, se critica y se interpreta la información científica pertinente relacionada con la toxicología, las situaciones en humanos, la dinámica ambiental y la exposición en cuanto a un agente determinado.


Obtención
Organización
Análisis
Conclusión
Información
Caracterización
del Riesgo

Manejo de Riesgos



DIPLOMADO EN CONTROL DE LOS RESIDUOS
GENERADOS EN HOSPITALES
Y OTROS CENTROS DE SALUD

RUTAS DE EXPOSICIÓN

Biol. Rocío Alatorre

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FACULTAD DE INGENIERIA
UNAM

AMCRESPAC

EVALUACION DE EXPOSICION

EXPOSICION

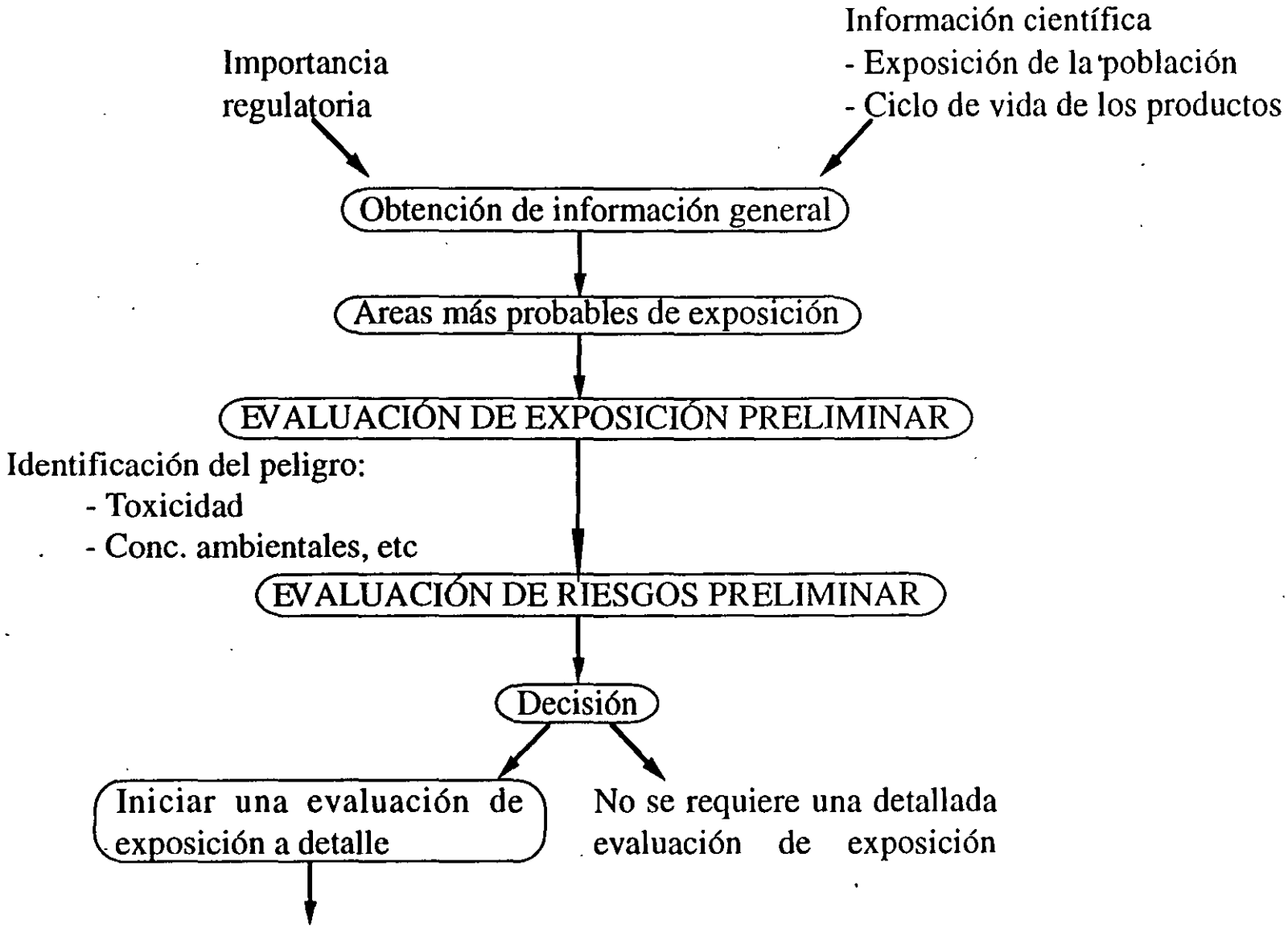
Contacto con un agente químico o físico

EVALUACION DE EXPOSICION

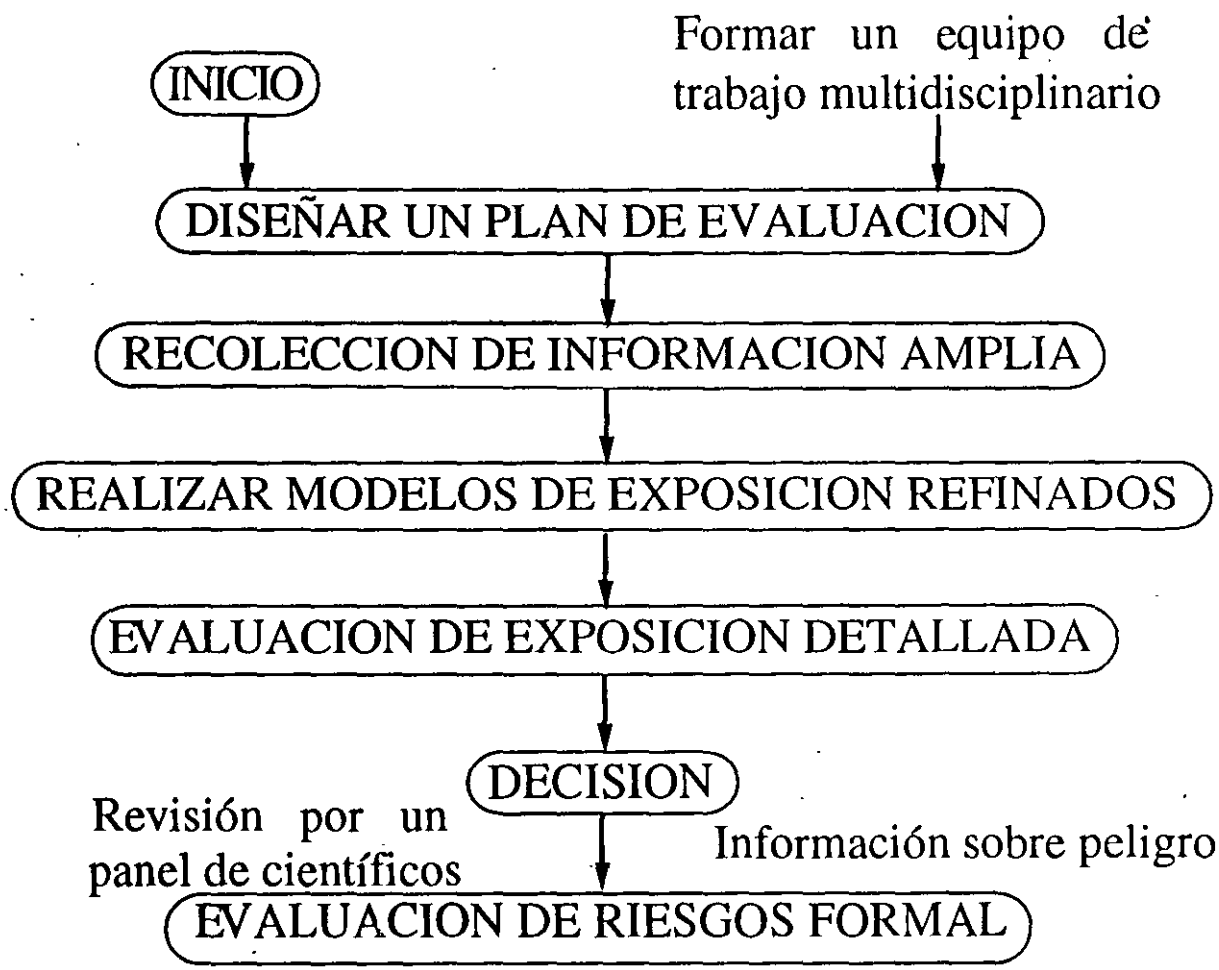
Determinación o estimación de la magnitud, duración y ruta de exposición

Referencia:
Federal Register Vol. 51, No. 185,
pp.34042-34054, Miércoles 24
de septiembre de 1986.

EVALUACION DE EXPOSICION PRELIMINAR



EVALUACION DE EXPOSICION DETALLADA



COMPONENTES DE UNA EVALUACION DE EXPOSICION

- ✔ Caracterización del sitio de exposición
- ✔ Identificación de las rutas de exposición
- ✔ Cuantificación de la exposición

PROTOCOLO DE UNA EVALUACION DE EXPOSICION

1. Síntesis ejecutiva

2. Introducción
    a. Objetivos
    b. Metas

3. Información general para cada sustancia o mezcla
    a. Identidad
        (1) Fórmula molecular y estructura, sinónimos y número CAS (Chemical abstracts service)
        (2) Descripción de grados, contaminantes y aditivos
        (3) Otras características de identificación
    b. Propiedades físicas y químicas

4. Fuentes
    a. Caracterización de la producción y distribución
    b. Usos
    c. Desechos
    d. Resumen de su liberación ambiental

PROTOCOLO (continuación)

5. Rutas de exposición y destino ambiental
    a. Transporte y transformación
    b. Identificación de las principales rutas de exposición
    c. Predicción de la distribución ambiental

6. Concentraciones medidas o estimadas
    a. Usos de las mediciones
    b. Estimación de las concentraciones ambientales

7. Poblaciones expuestas

    a. Poblaciones humanas
        (1) Tamaño y características de la población
        (2) Ubicación de la población
        (3) Hábitos de la población

    b. Poblaciones no humanas (cuando sea apropiado)
        (1) Tamaño y características de la población
        (2) Ubicación de la población
        (3) Hábitos de la población

PROTOCOLO (continuación)

8. Análisis de Exposición Integrado
    a. Cálculo de exposición
        (1) Identificación de la población expuesta y de elementos críticos del ecosistema
        (2) Identificación de rutas de exposición
    b. Dosimetría humana y mediciones biológicas
    c. Desarrollo de escenarios y perfiles de exposición
    d. Evaluación de incertidumbre
        (1) Introducción
        (2) Evaluaciones basadas en la información inicial
        (3) Evaluaciones basadas en estimadores subjetivos de la distribución de la variable seleccionada
        (4) Evaluaciones basadas en la información de las variables introducidas en el modelo
        (5) Evaluaciones basadas en datos de exposición
        (6) Resumen

METODOS PARA CARACTERIZAR LA INCERTIDUMBRE DE LA EXPOSICION ESTIMADA

- TIPO DE INFORMACION
  Medición de exposición en una muestra grande de miembros de una población.

- CARACTERISTICA ESTIMADA EN LA POBLACION
  Distribución de exposición

- METODOS PARA CARACTERIZAR LA INCERTIDUMBRE
  A. CUALITATIVOS
     1. Limitaciones en el diseño de la encuesta y en las técnicas de medición.
  B. CUANTITATIVOS
     1. Estimación del intervalo de confianza para los percentiles de la distribución de exposición.
     2. Bondad de ajuste de los modelos de exposición, si es que han sido postulados.

CARACTERIZACION DE LA INCERTIDUMBRE

(Continuación)

- TIPO DE INFORMACION
  Medición de exposición en una muestra pequeña de miembros de una población.

- CARACTERISTICA ESTIMADA EN LA POBLACION
  Parámetros descriptivos de la distribución de la exposición, p. ej., medias o percentiles.

- METODOS PARA CARACTERIZAR LA INCERTIDUMBRE
  A. CUALITATIVOS
     1. Limitaciones en el diseño de la encuesta y en las técnicas de medición.
  B. CUANTITATIVOS
     1. Estimación del intervalo de confianza de los parámetros descriptivos.
     2. Bondad de ajuste de los modelos de exposición, si es que han sido elaborados.

CARACTERIZACION DE LA INCERTIDUMBRE

(Continuación)

TIPO DE INFORMACION

Medición de variables de un modelo para una muestra grande de miembros de una población.

CARACTERISTICA ESTIMADA EN LA POBLACION

Distribución de exposición

METODOS PARA CARACTERIZAR LA INCERTIDUMBRE

A. CUALITATIVOS

1. Limitaciones en el diseño de la encuesta y de las técnicas de medición.
2. Validez del modelo de exposición.

B. CUANTITATIVOS

1. Estimación del intervalo de confianza para los percentiles de la distribución de exposición.
2. Bondad de ajuste para las funciones de distribución de las variables, si han sido elaboradas.
3. Distribución de exposición estimada, basada en modelos alternativos.

¿Por qué los Modelos?

* Proporcionan cálculos poco costosos de niveles de exposición.

* Son buenos para análisis de sensibilidad o para otros análisis en caso de duda.

* Cuando monitoreo no puede efectuarse o es inapropiado

Limitaciones de los Modelos

* Simplifican la realidad

* Puede ser difícil desarrollar u obtener parámetros para incorporar al modelo

* Posible uso inadecuado

Uso Inadecuado de los Modelos

* Usar valores incorrectos de los parámetros
* Usar modelos incorrectos o inadecuados
* Uso incompleto de los datos de monitoreo
* No reconocer ni considerar las limitaciones del modelo.

ELEMENTOS DE UNA EVALUACION DE EXPOSICION

- ✔ Analizar la liberación de contaminantes
- ✔ Identificar las poblaciones expuestas
- ✔ Identificar las rutas de exposición potenciales
- ✔ Estimar la magnitud de la exposición para esas rutas
- ✔ Estimar la cantidad que ingresa al organismo por esas rutas

INFORMACION SOBRE EL SITIO

- ✔ Identidad de los contaminantes
- ✔ Concentración de los contaminantes en fuentes y medios de interés
- ✔ Características de las fuentes, en especial la información relacionada con el potencial de liberación
- ✔ Características ambientales que puedan afectar el destino, transporte y persistencia de los contaminantes

ESTRATEGIA ANALITICA

- Estrategia de muestreo
- Almacenamiento de la muestra
- Preparación de la muestra
- Métodos de detección
- Sensibilidad requerida
- Análisis/reporte de los resultados
- Control/garantía de la calidad

MUESTRAS REQUERIDAS

A. AMBIENTALES

1. Suelo, sedimento
2. Agua
3. Aire, partículas
4. Polvo de superficies
5. Controles (no contaminados)

B: BIOLOGICAS

1. Fluídos corporales (p. ej. sangre)
2. Desechos corporales (p. ej. orina)
3. Biopsias de tejido (p. ej. adiposo)
4. Controles (no expuestos)

CONTROL DE CALIDAD / GARANTIA DE CALIDAD

1. Contar con personal capacitado, métodos escritos y validados, y laboratorios con construcción, equipo y manejo adecuados.

2. Proporcionar muestras y controles representativos.

3. Uso de cristalería, solventes y reactivos de alta calidad.

4. Calibración, ajuste y mantenimiento del equipo.

5. Uso de muestras de control, referencia y estándar, con registros adecuados.

6. Observar directamente el desarrollo de ciertas pruebas críticas.

CONTROL DE CALIDAD / GARANTIA DE CALIDAD

(Continuación)

7. Revisión y análisis crítico de los resultados.

8. Pruebas de desempeño interno y externo.

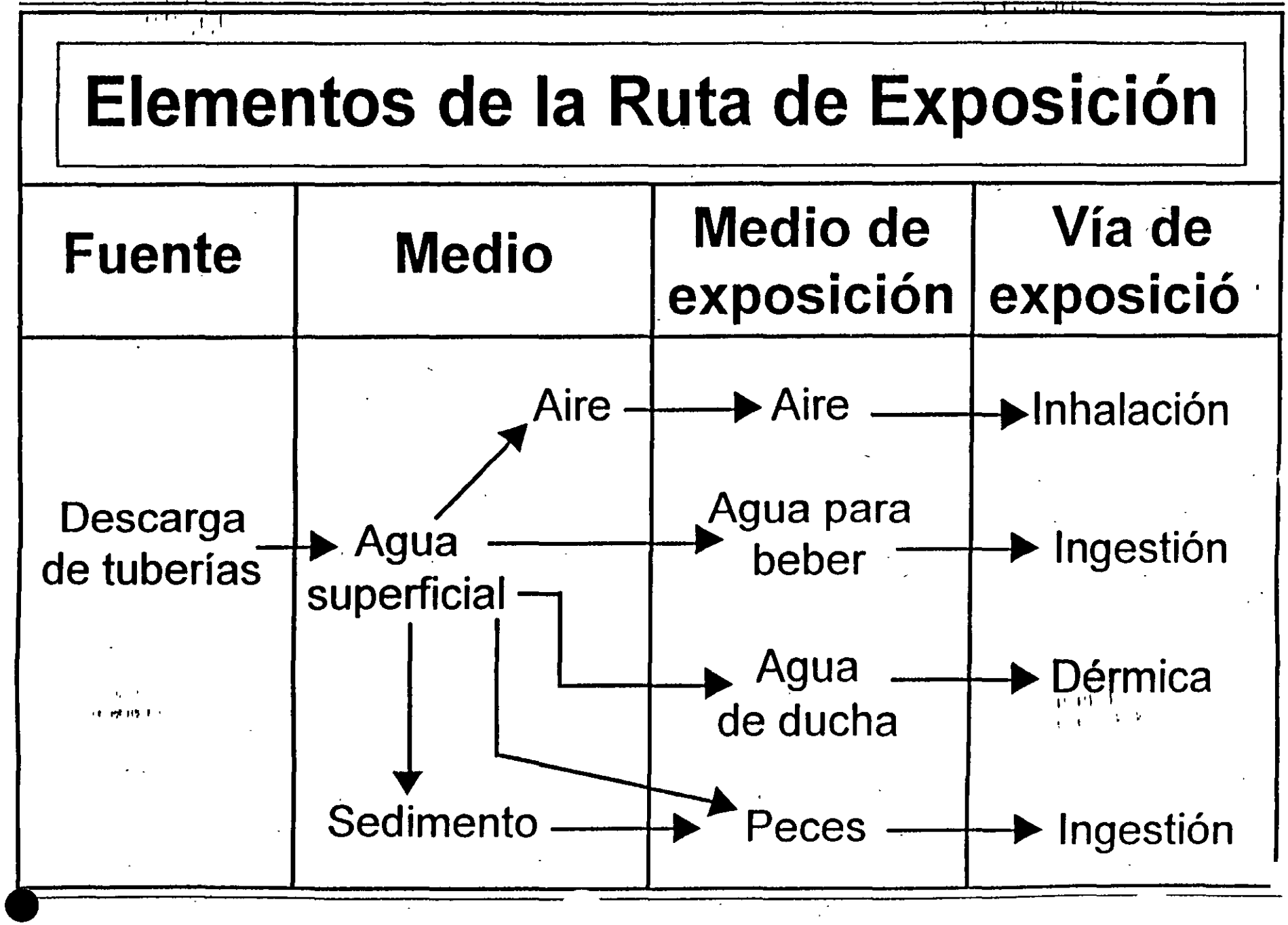
9. Uso de muestras duplicadas.

10. Comparación de los resultados duplicados con otros laboratorios.

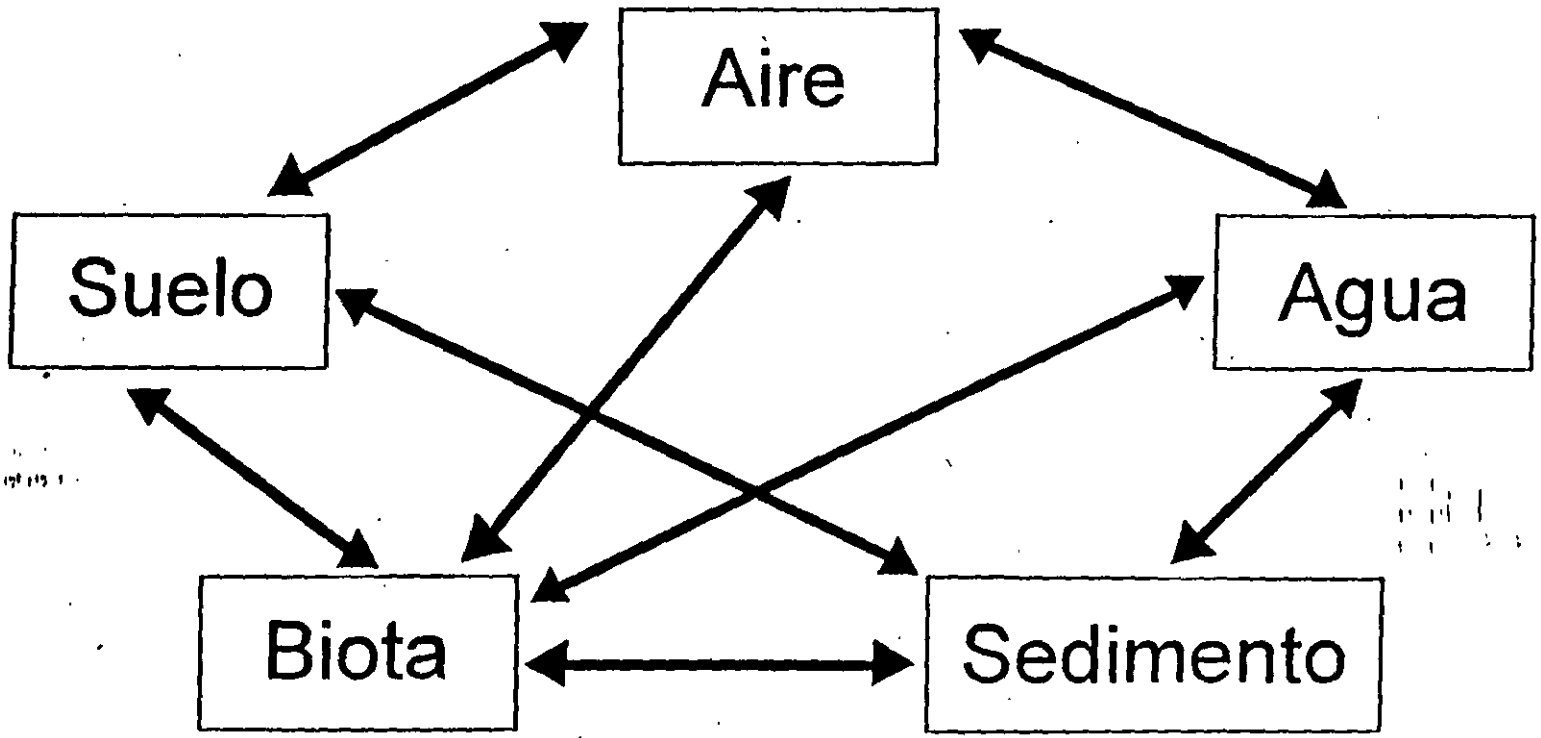
11. Responder a las quejas de los usuarios.

12. Monitoreo de los resultados.

13. Corrección de desviaciones de los estándares de calidad.


Elementos de la Ruta de Exposición
Fuente
Medio
Medio de exposición
Vía de exposició
Descarga de tuberías
Agua superficial
Aire
Sedimento
Aire
Agua para beber
Agua de ducha
Peces
Inhalación
Ingestión
Dérmica
Ingestión

Vías de Transferencia entre los Medios



CARACTERIZACION DEL SITIO DE EXPOSICION

→ Caracterización física

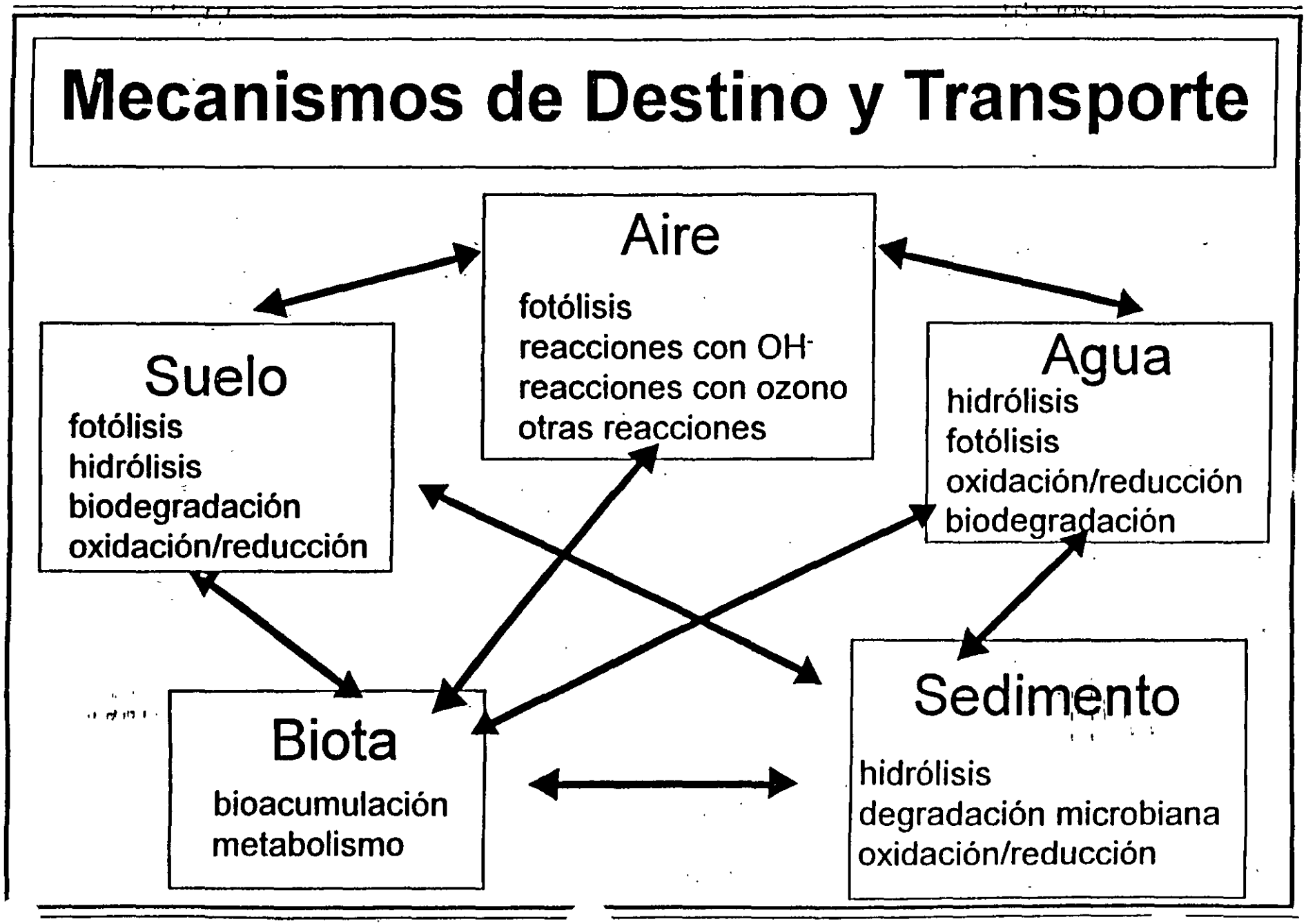
Clima, metereología, características geológicas, vegetación, tipo de suelo, hidrología subterranea y superficial.

→ Caracterización de poblaciones potencialmente expuestas.

Localización relativa al sitio, patrones de actividad, presencia de grupos sensibles.

TRANSPORTE Y DESTINO AMBIENTAL

- Transporte en matriz (aire, agua, partículas [suelo sedimento, polvo])
- Transformación física (volatilización, precipitación)
- Transformación química (fotólisis, hidrólisis, oxidación, reducción, etc.)
- Transformación biológica (biodegradación, bioacumulación)


Mecanismos de Destino y Transporte
Aire
fotólisis
reacciones con OH-
reacciones con ozono
otras reacciones
Suelo
fotólisis
hidrólisis
biodegradación
oxidación/reducción
Agua
hidrólisis
fotólisis
oxidación/reducción
biodegradación
Biota
bioacumulación
metabolismo
Sedimento
hidrólisis
degradación microbiana
oxidación/reducción

IDENTIFICACION DE LAS RUTAS DE EXPOSICION

- ✔ Fuente y mecanismo de liberación de la sustancia
- ✔ Matriz de retención o transporte (aire, agua, suelo, polvo, etc.)
- ✔ Punto de contacto humano potencial con la matriz contaminada
- ✔ Ruta de exposición (dérmica, inhalación o ingestión) en el punto de contacto

Mecanismos de Transporte Ambiental

* Volatilización
* Escurrimiento superficial/erosión
* Depósito seco y húmedo
* Lixiviación/transporte por agua subterránea
* Transporte por agua superficial/resuspensión y depósito en sedimentos
* Bioacumulación

Procesos de Transformación

* Hidrólisis/fotólisis
* Oxidación/reducción
* Biodegradación
* Reacciones de precipitación
* Metilación/Alquilación

Factor de Bioacumulación

Bioacumulación - Captación de una sustancia por parte de la biota a partir de los diferentes medios (por ejemplo, agua, suelo, alimento). FBA - factor de bioacumulación.

Factor de bioconcentración (FBC) - Medida de la tendencia que muestra una sustancia contaminante presente en el agua para acumularse en los tejidos de los peces.

Margen típico del FBC para compuestos orgánicos en el agua = de 1 a más de 10^5.

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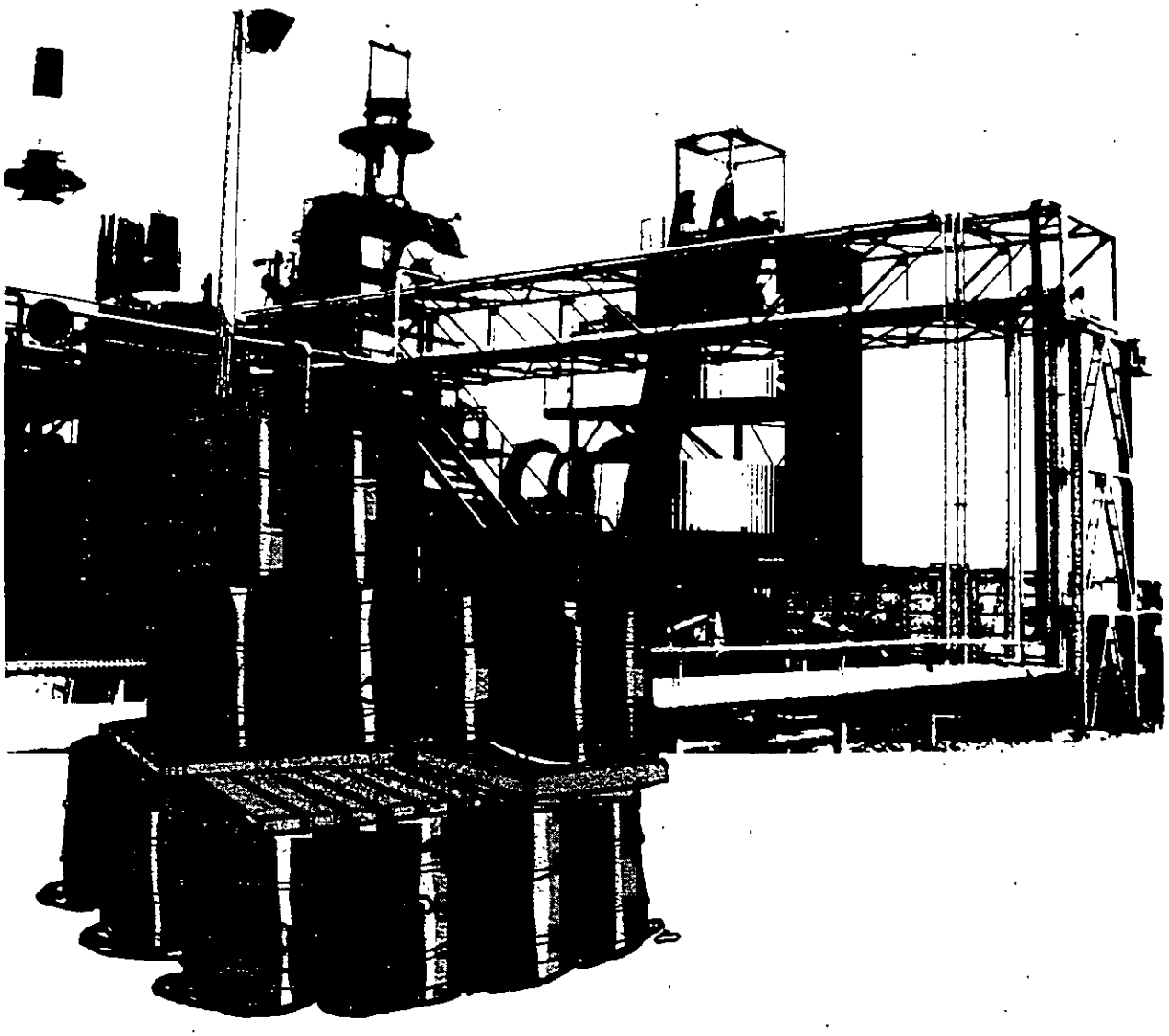
The Safe Disposal of Hazardous Wastes

The Special Needs and Problems of Developing Countries

Volume I

Roger Batstone, James E. Smith, Jr., and David Wilson, editors



A joint study sponsored by the World Bank, the World Health Organization (WHO), and the United Nations Environment Programme (UNEP).

CHAPTER 1 - Introduction

1.1 What are Hazardous Wastes?

This manual presents systems for the control, reduction, storage, treatment and disposal of those wastes that contain highly persistent elements, chemicals and compounds with attendant chronic and acute impacts on human health and the environment.

Hazardous wastes are generated from a wide range of industrial, commercial, agricultural and even domestic activities (Chapter 2). Table 1-1 illustrates the widespread distribution of hazardous wastes.

Hazardous wastes may take the form of solids, liquids or sludges. Most definitions exclude domestic solid wastes and aqueous effluents; however, a major source of hazardous wastes is from the pretreatment of effluents in order to meet water pollution controls, an example being heavy metal sludges from electroplating, sludges from treating tannery wastes, etc.

The **degree of hazard** posed by hazardous wastes varies widely. A useful distinction is between those wastes which pose a potentially high risk to human health and those wastes where the hazard is much less, but the quantities are perhaps much greater. Typical wastes in the first category might include low flashpoint flammable solvents, highly toxic pesticides or persistent chlorinated materials such as PCBs, while the latter includes such large volume mineral wastes as metaliferous slags, mine tailings, phosphogypsum or lime sludges. These distinctions are discussed further in Chapter 2.

1.2 Why are we Concerned with Hazardous Wastes?

Hazardous wastes have only come to be recognized as a priority problem over the past 10-15 years. Action to control hazardous wastes has too often been precipitated by an actual or potential environmental disaster.

- Japan was one of the first countries to introduce comprehensive hazardous waste controls, following the Minamata incident in the late 1960s when many people died from eating fish contaminated with mercury which had been discharged to the sea.

- In the UK, a high level committee had been investigating the problem of hazardous wastes for a number of years when, in February 1972, public outrage arose over the discovery of drums containing heat treatment cyanide salts on vacant land where children were playing. Ten days later legislation was enacted.

- The rigid control system on hazardous wastes in the United States which has evolved since 1976 has been driven largely by public outcry over the widespread discovery of pollution caused by past uncontrolled dumping of hazardous wastes.

TABLE 1-1

Some Illustrative Examples of Hazardous Wastes

Sector	Source	Hazardous Waste
Commerce & Agriculture	Vehicle servicing	Waste oils
	Airports	Oils, hydraulic fluids etc.
	Dry cleaning	Halogenated solvents
	Electrical transformers	Polychlorinated Bipheryls (PCBs)
	Hospitals	Pathogenic/infectious wastes
	Farms/Municipal parks etc.	Unused pesticides, "empty" containers
Small-scale industry	Metal treating (electro-plating, etching, anodizing, galvanizing)	Acids, heavy metals
	Photofinishing	Solvents, acids, silver
	Textile processing	Cadmium, mineral acids
	Printing	Solvents, inks and dyes
	Leather tanning	Solvents, chromium
Large-scale industry	Bauxite processing	Red muds
	Oil refining (Petrochemical manufacture)	Spent catalysts Oily wastes
	Chemical/pharmaceutical manufacture	Tarry residues, solvent
	Chlorine production	Mercury

Note: A classification system for hazardous wastes is introduced in Chapter 2.

Hazardous wastes can cause immediate, short-term, public health problems as well as long-term environmental pollution. Proper control of hazardous wastes does cost money, but experience in a number of developed countries suggests that cleaning up the "sins of the past" is much more expensive in the long term. For instance, in the United States clean up of improperly managed wastes has been estimated to cost 10-100 times as much as proper early management. It is therefore important that all developing countries institute controls over hazardous wastes to avoid such excessive costs in the future.

Even though the definition of hazardous waste excludes domestic wastes, in many countries **it may be difficult to totally separate industrial and domestic wastes**. Developing countries will need some strategy to identify and quantify the risks posed by hazardous wastes in order to arrive at a list of priorities for action within their limited resources. Some factors affecting the degree of risk are:

- o reactivity (fire, explosion, leaching);
- o biological effect (toxicity, short and long, exotoxicity);
- o persistence (fate in environment, detoxification potential, multiple factors);
- o indirect health risks (pathogens, vectors); and
- o actual amounts and local conditions (temperature, soil, water, humidity, light, receiving systems, their use pattern, etc.).

1.3 Aspects of a Control System for Hazardous Wastes

Every country needs a national control system for hazardous waste management. Such a system must provide four vital components if it is to be successful:

- o **legislation** and **regulations**;
- o proper **implementation** and **enforcement** procedures;
- o the provision of **adequate facilities** for hazardous waste recycling, treatment and disposal and measures to encourage their use;
- o introduction of **training schemes** for government enforcement officers and plant operators and managers and/or public awareness educational programs.

All four aspects are vital to the proper working of a national control system. No matter how perfect a system may appear on paper, it is worthless if it is not enforced. Similarly, control cannot be enforced if adequate facilities are not available or if enforcement officers are not adequately trained. Thus development of legislation and provision of adequate facilities must proceed in parallel. A few general points may be made regarding the introduction of a control system:

- o Good information on present quantities of waste and on present practices is essential so that priorities may be identified.

- o A national strategy for hazardous waste management needs to be developed including a plan for the provision of facilities.

- o A control system should encompass all aspects of hazardous waste management, from generation through storage, transport and treatment to disposal.

- o All parties involved -- generators, transporters, disposers, and government -- have their role and responsibilities.

1.4 Previous International Efforts on Hazardous Waste Management

A number of international organizations have taken an interest in hazardous waste management.

- o In 1983, the World Health Organization (WHO) and the United Nations Environment Program (UNEP) published policy guidelines and a code of practice, which sets out the principles of formulating and implementing a hazardous waste management policy. (Suess and Huismans 1983)

- o In late 1985, an ad hoc working group on environmentally sound management of hazardous wastes meeting under the auspices of UNEP adopted the 'Cairo guidelines' on policies and legislation. (UNEP 1985)

- o UNEP's International Register of Potentially Toxic Chemicals (IRPTC) published a Waste Management File in 1985, which contains information on treatment and disposal options for wastes containing specific chemicals. (IRPTC 1985)

- o A workshop in May 1986 organized by ASEAN, UNEP and CDG developed guidelines for establishing policies and strategies for hazardous waste management in Asia and the Pacific. (UNEP 1986)

- o The Organization for Economic Cooperation and Development (OECD) and the Commission of the European Communities (CEC) have been preparing an international convention on the transfrontier movement of hazardous wastes. Much work has focused on standardizing a list of hazardous wastes. (OECD 1988)

- o The UN Economic Commission for Europe (ECE) and the Council for Mutual Economic Assistance (CMEA) have focused in particular on low-waste and non-waste technologies. (ECE 1979-1987)

Where these efforts have been of particular relevance to developing countries, the focus has generally been on formulating policies and strategies and developing legislation (ECE 1979-1987). Recently, increasing focus is being given to the dumping of hazardous wastes in developing countries where there are inadequate controls to ensure the safe disposal of their wastes.

1.5 Quantities of Hazardous Waste

Obtaining reliable information on the quantities or types of hazardous wastes produced by any country is very difficult. International comparisons are almost impossible because of differences in the classification and definition of hazardous wastes from country to country.

An attempt has been made to estimate the quantities of hazardous waste produced in different countries (Yakowitz 1985). It was estimated that for a number of western European countries, hazardous waste production is about 5,000 tons per billion US$ of gross domestic products (GDP). The figure for the USA is approximately 75,000 tons; the figure for the USA is higher because certain high volume waste water streams are included in the calculations. The corresponding figure for Canada is 10,000 tons.

On the basis of very limited data, it was assumed that waste production in the USSR could be estimated at 10,000 tons per billion US$ GDP, that in other countries with mature industry at 5,000 tons, in newly industrialized countries 2,000 tons and in developing countries 1,000 tons.

Such estimates can at best indicate relative orders of magnitude of hazardous waste production in different countries. Figure 1-1 summarizes the numbers of countries within each of four "bands" of likely hazardous waste production, namely less than 10,000 tons per annum (tpa) 10-100,000 tpa, 100,000 - 1 million tpa and more than 1 million tpa.

From these estimates it appears that around two-thirds of all countries produce less than 10,000 tpa of hazardous wastes. For many developing countries the estimates are in the range of a few hundred or a few thousand tons. While this puts the overall problem in context, it should be remembered that a single heavy industrial plant can produce hundreds of thousands of tons per annum of bulk wastes, although most of these are in the 'grey' region between hazardous and non-hazardous wastes.

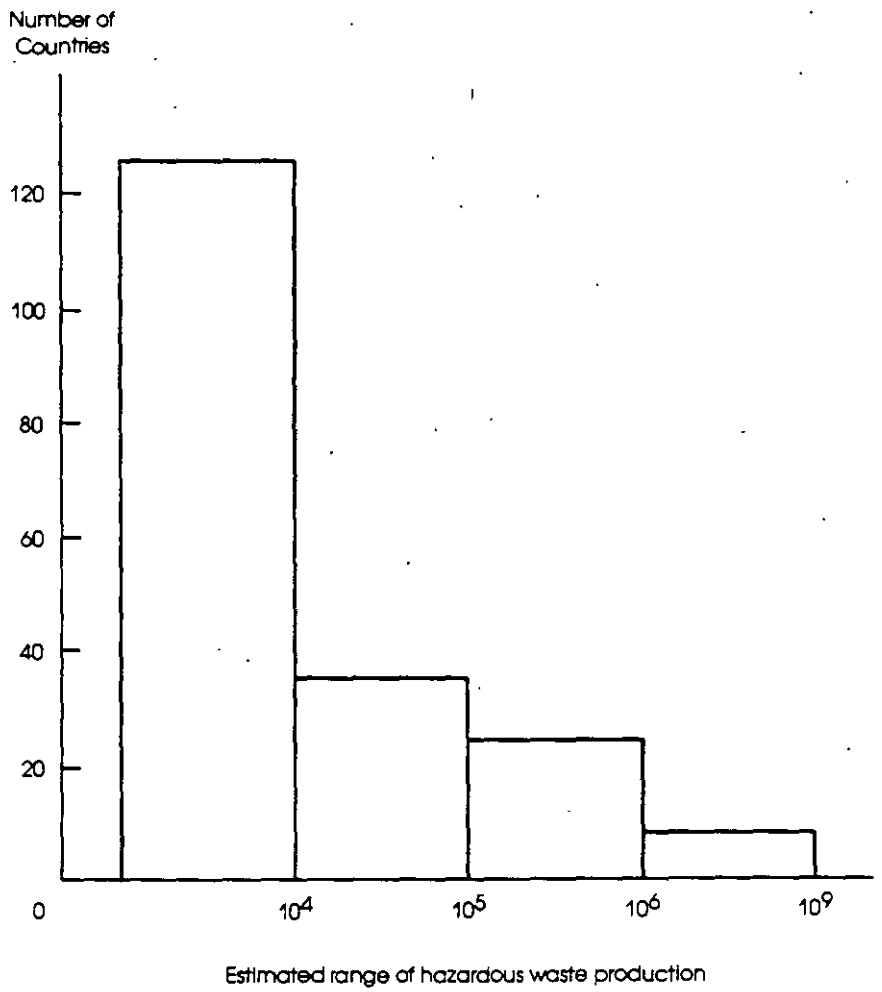
1.6 Progress in Controlling Hazardous Wastes

Considerable progress has been made over the last 10 years in controlling hazardous wastes in a number of developed countries (Forester and Skinner 1987). Progress varies considerably from country to country, but in some countries:

- effective legislation is in place;
- effective manifest systems are being introduced to control waste transport;
- an increasing percentage of operators of hazardous waste treatment and disposal facilities have been licensed;
- in some cases, well engineered and well managed facilities have been provided for hazardous waste treatment, incineration, and landfill is controlled;

FIGURE 1-1

Order of Magnitude of Hazardous Waste Production in Individual Countries



- o in a few cases, good collection and transfer systems have been established.

Hazardous waste disposal is a dynamic problem, and there is on-going work in these countries on standards and licensing procedures. Present priorities vary depending on the stage of development and implementation of the control systems.

- o In those cases where the process is only just beginning, an effective system is a priority (1.8).

- o In other places, continuing implementation of regulations and provision of adequate facilities, either for landfill or for treatment of hazardous wastes, or both, are seen as high priorities.

- o In a number of countries it is not the absence of facilities that presents a problem, but rather competition between landfill and treatment facilities. Landfill tends to be less expensive than waste treatment, so that given a free market, landfills tend to predominate, even though treatment would be better for environmental reasons. In these cases government control of competition is necessary.

- o Almost all countries see a need to improve enforcement of and compliance with the regulations that are in place.

1.7 Specific Problems of Developing Countries

Developing countries face a number of specific problems in tackling hazardous wastes.

(i) General control over pollution and waste disposal is often poor

In many countries open dumps predominate, and in the absence of controls hazardous wastes continue to find their way into such dumps. Scavengers may live and work among the wastes, and many dumps are already causing water pollution. Proper management of dumpsites is a high priority in developing countries.

Controls over water and air pollution are often poor, and when such controls are implemented, the treatment sludges and dusts are often hazardous wastes.

Isolated efforts to control specific hazardous wastes are often ineffective without an overall upgrading of waste management practices. Coordination of controls over air and water pollution and hazardous waste is particularly important.

(ii) Generators may be unaware of the hazard of their waste

Ignorance of the potential harm of hazardous wastes is encountered in all countries, but it is a particular problem among small generators in developing countries. Even though the quantities they produce may be small, the potential problems are not insignificant. For example, the

improper disposal of surplus pesticides or pesticide containers may poison humans or pollute sensitive ground water resources. (See Annex 7.1B)

(iii) Stockpiles of waste awaiting treatment or disposal

In some countries, new industries may stockpile their waste on site in the absence of proper facilities for treatment or disposal. After 5, 10 or 15 years space begins to run out or pollution problems arise, and suddenly the problem becomes urgent.

(iv) Limited resources

Some developing countries lack the financial resources and skilled manpower to adequately dispose of hazardous waste. Restrictions on foreign exchange and limited access to hard currencies make it difficult to finance such facilities. A shortage of skilled manpower will impede planning, management, operation and maintenance of facilities, and enforcement of regulations.

(v) Socio-political reasons

Without public education on the issues and a general awareness of the dangers of improper disposal of hazardous waste there is too often insufficient public demand for action. Developing countries may focus on other very real and seemingly more urgent problems and not see hazardous waste disposal as a pressing need and immediate political goal.

Developing countries need to set priorities in controlling hazardous wastes. The available resources must be focused on the most significant problems and short-term solutions implemented to bring immediate problems under control.

It may be necessary to distinguish between long-term solutions, which may involve the establishment of centralized treatment/disposal facilities and short-term solutions which aim to eliminate the worst current practices.

Even in the longer term, there will be a need to develop solutions which are compatible with the limited resources available. Such 'appropriate' solutions are required particularly for small quantities of waste or for those wastes which would appear on the agenda for action.

1.8 Purpose of this Manual

The World Bank, WHO and UNEP have each identified the need for guidance on the assessment and planning aspects of hazardous waste management, with specific reference to developing countries. Among the topics discussed in this manual are the following:

- o setting priorities for control;
- o establishing an appropriate definition and classification scheme;

- o developing a plan to provide the necessary facilities for waste treatment and disposal;

- o choosing a short-list of options for treatment and disposal appropriate to the needs of specific countries;

- o the economics and financing of facilities.

The manual is aimed at meeting the needs of three distinct but overlapping target audiences.

(i) The first is the most senior technical level within government and industry in developing countries. The aim is to provide sufficient information to enable them to undertake a study of the needs and requirements of their own country, region or community, and to select a short list of potential options for more detailed examination.

(ii) Within funding organizations, the manual will be used to assist in the identification, preparation and appraisal of countrywide hazardous waste management programs and 'stand alone' projects.

(iii) It is envisaged that the manual will form the basis for national and international training courses aimed both at senior and middle management levels within government and industry in developing countries.

1.9 Guide to this Manual

The remaining chapters in the manual are outlined briefly below.

- o **Chapter 2** gives a review of health and environmental effects, which aims to give guidance on setting of priorities, and examines the difficult questions of defining and classifying hazardous wastes. A practical classification scheme, which can be adapted to the needs of a particular country, is outlined.

- o **Chapter 3** provides a framework for developing a national, regional or local plan to provide the necessary facilities for recycling, treating or disposing of hazardous wastes.

- o **Chapter 4** examines methods for waste avoidance, reduction at source, recovery, recycling and reuse.

- o **Chapter 5** gives details of the infrastructure required for establishing a hazardous waste management system as well as addressing economic, financial and institutional arrangements.

- o **Chapter 6** includes a discussion of the choice of appropriate recycling and treatment technologies.

- o **Chapter 7** provides information on final disposal options.

1.10 References 1.1 - 1.9

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CHAPTER 2 - The Health and Environmental Effects of Hazardous Wastes

2.1 Introduction

In the last few years, considerable attention has focused on the question of what constitutes a "hazardous waste." National systems differ both in the methods used for defining wastes and the type of wastes included. These differences arise partly from variations in the institutional and legal frameworks of different countries.

International organizations like the OECD and CEC are currently attempting to establish a cross-reference list of hazardous wastes, as a first step towards harmonization of definitions. The main concern, at present, is to implement stricter controls over the transfrontier movement of hazardous wastes.

For the purpose of this manual, however, we are more concerned with evolving a practical definition of hazardous waste, which can then be adapted to the legal system of any particular country.

Equally important, the possible health and environmental effects of hazardous wastes must be understood and dealt with. In order to do this, we need to understand the chemical and physical properties of hazardous wastes and their potential pathways through ecosystems to man.

Subsequent sections of this chapter consider the following:

- o a working definition of the terms "waste" and "hazardous waste";
- o broad types of waste which should be included within the scope of "hazardous wastes," and those which should be excluded;
- o approaches to the identification and classification of hazardous wastes, which can be used to give a proper working definition;
- o details of our proposed classification scheme;
- o factors affecting the environmental behavior of chemicals;
- o a detailed discussion of the effect of hazardous wastes on human health;
- o categorizing hazardous wastes by degree of hazard; and
- o environmental effects of hazardous waste disposal.

2.2 Working Definitions

Typically, the concept of "waste" refers to something which no longer has any further value or use.

This definition, however, has been complicated by the issue of wastes versus products; in other words, if a waste can be recycled or can be used in some way, it has acquired value and is no longer considered a waste. This, in turn, requires a definition of what is recyclable. There is some evidence that relaxation of controls for recyclable wastes may increase the risk of environmental damage resulting from the mismanagement of recyclable wastes. Examples of such mismanagement abound and include the use of contaminated waste oil for dust control; the long-term, uncontrolled storage of materials pending recycling; using metaliferous

wastes as building or road construction materials; or using wastes as fuel substitutes, burning them under uncontrolled conditions.

For these reasons, the definition of waste adopted in this manual makes little reference to recycling and does not suggest that any relaxation of controls be considered for recyclable wastes.

A waste is thus defined as a moveable object which has no direct use and is discarded permanently.

All wastes must receive proper treatment and disposal so as to protect the environment and enhance the quality of life. Hazardous wastes are a special category of wastes which, due to their toxicity, persistence, mobility, flammability, etc., require more stringent regulatory and technical controls when compared to wastes such as municipal refuse. Later in this chapter, the range of possible health and environmental problems that can arise because of the improper management of hazardous wastes are discussed.

The following definition of hazardous wastes was prepared under UNEP auspices by the Ad Hoc Working Group of Experts on the Environmentally Sound Management of Hazardous Wastes in December 1985:

"Hazardous wastes means wastes other than radioactive wastes which by reason of their chemical reactivity or toxic, explosive, corrosive or other characteristics causing danger or likely to cause danger to health or the environment, whether alone or when coming into contact with other wastes, are legally defined as hazardous in the State in which they are generated or in which they are disposed of or through which they are transported."

2.2.1 Inclusions and Exclusions from the Definition

Thus defined, hazardous wastes can include solids, liquids, gases, sludges, containerized gases or contaminated containers, and can originate from a wide range of commercial, agricultural, and industrial sources. In general, hazardous wastes cannot be handled safely and effectively by the existing wastewater treatment or domestic waste disposal systems.

A number of specific exclusions are mentioned within the definition:

- Radioactive wastes are considered hazardous, but are excluded from the definition, since most countries control and manage these material in a separate organizational framework;

- Domestic refuse can cause significant environmental pollution and may also contain small quantities of hazardous substances (e.g., mercury from dry cell batteries, solvents from paint residues, etc.). Again, these wastes are normally controlled by a separate, though interrelated, organizational framework. However, some countries with well developed control systems are now turning attention to separating and/or eliminating the hazardous components in domestic waste.

The UNEP Working Group also gave consideration to the quantity of waste:

- For small quantities, all countries have chosen to exclude "hazardous wastes" from household waste. At the same time, some countries also exclude small generators of hazardous waste as well. The cutoff point for regulation is important. The United States, for example, recently reduced the threshold for control from 1000 kg/month to 100 kg/month, thereby increasing the number of regulated generators of hazardous waste by tenfold;

- For large quantities, regulators may wish to control wastes containing relatively low concentrations of pollutants, since the volume will still render them hazardous to the environment. However, because of the practical problems in implementing controls over such wastes, some countries exclude certain large volume wastes, such as mining or agricultural wastes, from control under hazardous waste legislation.

As mentioned above, most countries choose to control waste-water effluents separately from hazardous wastes. However, in the United States, wastewater stored or treated in surface impoundments, settling ponds, lagoons, etc. is controlled within the regulations governing the management and handling of hazardous wastes. The reason for this is simple: there is growing concern that such effluents contain hazardous substances that can leave with the wastewater stream percolating into groundwater reservoirs or appearing in sludge which may later be landfilled in municipal dumps or other areas not equipped to handle potentially toxic or hazardous material. This is another factor contributing to the large amounts of toxic waste reported for the US (See Chapter 1, Section 1.5).

Wastes listed in Annex 2 are considered hazardous according to current standards and knowledge. This list, however, is not static and has evolved over time, as more toxicological, and other data, have been gathered on the health effects of various wastes, particularly chemical wastes.

2.3 Identification and Classification of Hazardous Wastes

In developing an organized approach to hazardous waste assessment and management, a system of waste identification and classification must be formulated (see Table 2-1). In many countries, such a system is an integral part of a legal definition of hazardous waste. Most countries have used a definition based on an inclusive listing of the following factors:

- particular types of hazardous wastes;
- industrial processes from which the wastes are defined as hazardous; and
- substances, either specific or classes, the presence of which is indicative of a potential human health and or environmental hazard.

TABLE 2-1

A Proposed Waste Classification Scheme

Industrial/Waste Groups	Agriculture Forestry and Food Production A	Mineral Extraction B	Energy Generation C	Metal Manufacture D	Manufacture of Non-metal Mineral Products E	Chemical & Related Industries F	Metal Goods Engineering and Vehicle G
I Inorganic Wastes							
Acids and Alkalis	x		x	x		x	x
Cyanide Wastes				x			
Heavy Metal Sludges and Solutions				x	x	x	x
Asbestos Wastes					x	x	
Solid Residues n.o.s.				x		x	x
II Oily Wastes							
III Organic Wastes							
Spent Halogenated Solvents						x	x
Non-halogenated Solvent Wastes	x					x	x
PCB Wastes						x	x
Paint and Resin Wastes						x	x
Biocide Wastes	x				x	x	x
Organic Chemical Residues			x	x		x	
IV Putrescible Organic Wastes	x					x	
V High Volume/Low Hazard Wastes		x	x			x	
VI Miscellaneous Wastes							
Infectious Wastes	x						
Laboratory Wastes						x	
Explosives Wastes						x	x

Note: n.o.s. = not otherwise specified

TABLE 2-1 (continued)

A Proposed Waste Classification Scheme

Industrial/Waste Groups	Textile Leather and Timber Industries H	Manufacture of Paper Printing and Publishing J	Medical and Other Health Services K	Commercial Personal Services L
I **Inorganic Wastes**				
Acids and Alkalis	x	x		
Cyanide Wastes				
Heavy Metal Sludges and Solutions	x			
Asbestos Wastes				
Solid Residues n.o.s.				
II **Oily Wastes**	x			
III **Organic Wastes**				
Spent Halogenated Solvents	x			x
Non-halogenated Solvent Wastes	x	x		
PCB Wastes				
Paints and Resin Wastes	x	x		
Biocide Wastes	x	x		
Organic Chemical Residues n.o.s.				
IV Putrescible Organic **Wastes**	x			
V High Volume/Low Hazard **Wastes**				
VI **Miscellaneous Wastes**				
Infectious Wastes			x	
Laboratory Wastes			x	
Explosives Wastes				x

Note: n.o.s. = not otherwise specified

In some cases, a listing of one or more of these criteria is used as a definition. In other cases, reference is also made to a particular concentration level for each hazardous substance.

Other criteria may include the toxicity of an extract of the waste, usually obtained by means of a specific leaching test. Toxicity is generally defined by reference to concentrations of specific substances in the extract:

- o the ignitability or flammability of the waste;
- o the corrosiveness of the waste; and
- o the reactivity of the waste.

Each of these approaches have their advantages and disadvantages. The use of inclusive lists provides a relatively simple approach, requiring no testing and also give a certain flexibility to the waste controlling authorities in making qualitative judgements with respect to an individual waste disposal option. It has the disadvantage, however, of placing the burden of decision on the waste controlling authorities as to which of the industrial process wastes should be controlled.

Supplementing (or replacing) such lists with testing procedures and/or concentration limits has the advantage of presenting a clear and accurate description of wastes, theoretically leaving no doubt as to whether the waste should be classified as hazardous or not. These precise definitions, however, require detailed testing protocols and a surveillance system which, in practice, may pose problems as regards manpower, laboratory facilities, etc. for both waste generators and controlling authorities.

The U.S. Toxicity Characteristic Leaching Procedure (TCLP) is designed to identify wastes likely to leach hazardous concentrations of toxic constituents into the groundwater as a result of improper management. During the procedure, constituents are extracted from the waste in a manner designed to simulate the leaching actions that occur in landfills. The extract is then analyzed to determine if it possesses any of the toxic contaminants listed in Table 2-2. If the concentrations of a particular toxic constituent exceeds the level listed in Table 2-2, the waste is classified as hazardous.

In the TCLP test (Federal Register 1986) , a 100 gm sample is employed. For wastes containing less than 0.5% solids, the waste--after filtration through a 0.6-0.8 um glass fiber filter, is defined as the TCLP extract. Separation is accomplished with pressures of up to 50 psi. The particle size of the solid phase is reduced, if necessary, to a size of about 9.5 mm. The sample is then weighed and extracted with an amount of extraction fluid equal to 20 times the weight of the solid phase. The extraction fluid employed is a function of the alkalinity of the solid phase of the waste. If the sample after mixing with distilled deionized water has a pH <5.0, the extraction fluid is made by adding 5.7 ml of 1.0 N Glacial acetic acid to 500 ml of distilled deionized water, adding 64.3 ml of 1.0 N NaOH and diluting to a liter. If the sample after mixing with distilled deionized water has a pH >5.0, add 3.5 ml 1.0 N HCl, slurry for 30

TABLE 2-2

Toxicity Criteria

Contaminant	MCL (ppm)
Arsenic	5.0
Barium	100.0
Cadmium	1.0
Chromium (total)	5.0
Lead	5.0
Mercury	0.2
Selenium	1.0
Silver	5.0
Endrin	0.02
Lindane	0.4
Methoxychlor	10.0
Toxaphene	0.5
2,4-D	10.0
2,4,5-TP Silvex	1.0

seconds, cover with a watchglass, heat to 50 degrees C and hold for 10 minutes. If the sample after cooling has a pH <5.0, the extraction fluid previously described is used. If the pH is >5.0, the fluid is made by diluting 5.7 ml glacial acetic acid with distilled deionized water to a volume of 1 liter. A special extractor vessel is used when testing for volatiles. Following extraction, the liquid extract is separated from the solid phase by 0.6-0.8 um glass fiber filter filtration.

If compatible, the initial liquid phase of the waste is added to the liquid extract and these liquids are analyzed together.

The characteristic of ignitability/flammability is a concern because these wastes could cause fires during transport, storage or disposal. Typical examples are waste oils and used solvents. These wastes often have the properties of:

(a) being a liquid, except for aqueous solutions containing less than 24% alcohol, that has a flash point less than 60 degrees C;

(b) a non-liquid capable, under normal conditions, of spontaneous and sustained combustion;

(c) an ignitable compressed gas; or

(d) an oxidizer.

Materials that might be considered hazardous because of corrosivity are: an aqueous material with pH <2.0 or pH >12.5; or a liquid that corrodes steel at a rate greater than one-quarter inch per year at a temperature of 55°C. Wastes with high or low pH can react dangerously with other wastes or cause toxic contaminants to migrate from certain wastes. Wastes capable of corroding steel can escape from their containers and liberate other wastes. Examples of such corrosive wastes include acidic wastes and used pickle liquor.

A reactive waste might be expected to have one or more of the following properties:

(a) normally unstable and reacts violently without detonating;

(b) reacts violently with water;

(c) forms an explosive mixture with water;

(d) generates toxic gases, vapors or fumes when mixed with water;

(e) contains cyanide or sulfide and generates toxic gases, vapors, or fumes at a pH of between 2 and 12.5;

(f) is capable of detonation if heated under confined conditions or subjected to a strong initiating force; and

(g) capable of detonation at standard temperature and pressure. Examples of reactive wastes include water from TNT operations and used cyanide solvents.

The choice of the most appropriate system depends upon the use to which the classification system will ultimately be put. For the purpose of this manual, three objectives are considered of particular importance:

- o to allow the waste controlling authority to use its knowledge of industry to draw up a short-list of wastes;
- o to identify wastes in a way that is consistent with the discussion of technologies for recovery, treatment and disposal; and
- o to provide the waste controlling authority with a framework appropriate for establishing their own hazardous waste control system.

To achieve these objectives, the classification scheme proposed here is a qualitative listing, using a combination of some specific types of waste with classes of substances specific substances and industrial processes to identify waste types.

2.4 Proposed Classification Scheme--Notation of Health/Ecological Concerns

A proposed waste classification scheme linking waste types to industrial categories is shown in Annex 2. The purpose of the annex is to enable planners to identify the major types of wastes associated with broad industrial groups. The industrial groups used for the waste classification scheme are defined in Table 2-3.

Further details of each waste type including examples of particular waste streams are included in Table 2-1. These listings are examples of the most important waste streams likely to be encountered.

A brief description of each waste type including major subcategories and sources of generation, is given below.

(A) Inorganic Wastes

Acids and alkalis are among the major components of the total amount of hazardous waste generated. They occur in many sectors of industry, although in terms of quantity, acid wastes come mainly from the surface preparation and finishing of metals.

The major hazard with acids and alkalis is their corrosive action, complicated--in some cases--by the presence of toxic constituents.

Cyanide wastes are generated primarily in the metal finishing industry and in the heat treatment of certain steels.

The principal hazard associated with cyanide waste is their acute toxicity.

TABLE 2-3

Industrial Groups

A Agriculture, Forestry and Food Production

- o agriculture, forest management, fisheries;
- o animal and vegetable products from the food sector;
- o drink industry;
- o manufacture of animal feed.

B Mineral Extraction (excluding Hydrocarbons)

- o mining and quarrying of non-metallic minerals;
- o mining and quarrying of metallic minerals.

C Energy

- o coal industry, including mineral extraction, gasworks and coking;
- o petroleum and gas industry including oil and gas extraction, and refined products;
- o production of electricity;
- o production of water;
- o distribution of energy.

D Metal Manufacture

- o ferrous metallurgy;
- o non-ferrous metallurgy;
- o foundry and metal working operations.

E Manufacture of Non-Metal Mineral Products

- o construction materials, ceramics and glass;
- o salt refining;
- o asbestos goods;
- o abrasive products.

F Chemical and Related Industries

- o petrochemicals;
- o production of primary chemicals and chemical feedstocks;
- o production of inks, varnish, paints and glues;
- o fabrication of photographic products;
- o perfume industry and fabrication of soap and detergent products
- o finished rubber and plastic materials;
- o production of powders and explosives;
- o production of biocides.

TABLE 2-3 (continued)

Industrial Groups

G	**Metal Goods, Engineering and Vehicle Industries**
	o mechanical engineering; o manufacture of office machinery and data processing of equipment; o electronic and electrical engineering; o manufacture of motor vehicle and parts; o manufacture of other transport equipment; o instrument engineering; o other metal good manufacturing industries n.o.s.
H	**Textile, Leather, Timber and Wood Industries**
	o textile, clothing and footware industry; o hide and leather industry; o timber, wood and furniture industry; o other non-metallic manufacturing industries n.o.s.
J	**Manufacture of Paper and Products, Printing and Publishing**
	o paper and cardboard industry; o printing, publishing and photographic laboratories.
K	**Medical, Sanitary and other Health Services**
	o health; hospitals, medical centres and laboratories; o veterinary services.
L	**Commercial and Personal Services**
	o laundries, dyers and dry cleaners; o domestic services; o cosmetic institutions (e.g., hairdressers); o other personal services n.o.s.

Heavy metal sludges and solutions of most concern are those containing the toxic metals, arsenic, cadmium, hexavalent chromium, lead, mercury, nickel, zinc, and copper. These wastes are generated from a wide range of manufacturing processes, including chlorine production, pigment production, wood preserving, battery production, textiles, metal plating and tanning.

Asbestos wastes normally arise from lagging wastes, power stations, industrial manufacturing plants, gas works, dock yards, hospitals and educational establishments. Materials containing asbestos may also appear as waste from the demolition or rebuilding of locomotives and railway carriages, and from building and demolition sites.

The health hazards associated with inhalation of asbestos fibers and dust stem from the carcinogenic potential of the material. Asbestos cement pipes and sheets are typically much less of a problem than loose fibers or dust.

Other solid residues are generated from a variety of sources of which the most significant is the smelting and refining of metals. Dusts and sludges generated from these processes typically contain toxic metals including nickel, arsenic, zinc, mercury, cadmium and lead.

(B) Oily Wastes

Oily wastes are generated primarily from the processing, use and storage of mineral oils. Examples include waste lubrication and hydraulic fluids, bottom sludges from oil storage tanks, waste cutting oils and interceptor waste. In some cases, these materials may be contaminated with toxic metals (e.g. sludges from leaded petrol storage tanks, etc.).

(C) Organic Wastes

Halogenated solvents are generated primarily from dry cleaning operations, metal cleaning in the engineering industry and, to a much smaller extent, from degreasing and deoiling processes in the textile and leather industries. The hazards associated with these wastes are a result of their toxicity, mobility, and relatively high persistence in the environment.

Non-halogenated solvent wastes include a large number of hydrocarbons and oxygenated hydrocarbons, of which some of the most commonly used are white spirit, toluene, methanol, isopropanol, and ethanol. They find wide application throughout industry in the production of paints, inks, adhesives, resins, solvent-based wood preservatives, toiletries, food flavorings, cosmetics, and also for plant and equipment cleaning and as thinners. They are also used as degreasants in the engineering and vehicle manufacturing industries and are used for the extraction of natural products from animal and vegetable sources.

The toxicity of these materials varies greatly, and in many cases the major hazard posed is flammability.

PCB wastes are generated from the manufacture of PCBs and from the decommissioning of equipment in which PCBs are used, principally as dielectric fluids in transformers and capacitors, and also as hydraulic fluids and heat transfer fluids. The major concerns with PCBs is associated with their high persistence and bioaccumulation potential.

Paint and resin wastes are generated from a variety of formulation and other tertiary chemical processes, and also in the application of paints and resins to finished products. They are typically combinations of solvents and polymeric materials including, in some cases, toxic metals.

Biocide wastes are generated both in the manufacture and formulation of biocides and in the use of these compounds in agriculture, horticulture and a variety of other industries. The range of biocides used runs into several thousand compounds. (For information on their classification, see Annex 2).

In addition to the concentrated organic waste streams described above, organic chemical residues are also generated from coal carbonization and by-products operations; and from the manufacture or primary, secondary, and tertiary chemical products. Distillation residues and filter materials are common components. These waste streams include both halogenated and non-halogenated chemicals, and are generated by a broad range of industries, including petroleum refining and the manufacture of chemicals, dye stuffs, pharmaceuticals, plastics, rubbers, and resins.

(D) Putrescible Organic Wastes

Putrescible organic wastes include wastes from the production of edible oils, as well as leftovers from slaughter houses, tannaries, and other animal-based products. The proper handling of putrescible wastes is of particular importance in developing countries where extreme climatic conditions can exacerbate the possible health hazard associated with these organic wastes.

(E) High Volume/Low Hazard Wastes

High volume/low hazard wastes include those wastes which, based on their intrinsic properties, present relatively low hazards, but may pose problems because of their high volumes. Examples include: drillings muds from petroleum and gas extraction, and fly ash from fossil fuel-fired power plants, mine tailings, or metaliferous slags.

(F) Miscellaneous Wastes

In addition to the waste classes described above, there are a number of other miscellaneous waste types which have not been addressed. These include: infectious wastes associated with diseased human or animal tissues; redundant chemicals, which may have deteriorated or exceeded their shelf-life, and come from retail shops, commercial warehouses, and governmental and industrial stores; laboratory wastes from manufacturing and research facilities; and explosive wastes from manufacturing operations or surplus munitions. Although these wastes typically do not

represent a large proportion of total hazardous waste generation, special provision should be made to ensure their safe and proper disposal.

2.5 Potential Pathways of Release to the Environment

The potential pathways by which hazardous wastes can enter the human environment are summarized in Figure 2-1. Some pathways correspond to a direct input to an environmental compartment, such as the evaporation of a chemical to the atmosphere. Other pathways represent indirect inputs, such as the atmospheric deposition of wind-borne particulate matter to surface waters. The relative importance of each pathway is not only dependent on the physical, chemical, and biological properties described earlier but also on the characteristics of both the disposal site and the underlying geology.

2.5.1 Groundwater Movement and Contamination

The characteristics of the subsurface environment have a major influence on the aqueous transport of chemical contaminants and micro-organisms from disposal sites. Of particular importance is the presence of an unsaturated zone beneath the land disposal site. This is the zone, above the water table, where water generally moves vertically until it encounters the groundwater flow (when the movement becomes horizontal). It is an advantage to have an unsaturated zone beneath the landfill because this severely restricts leachate movement from the site and therefore increases the opportunity for attenuation by chemical and biochemical processes.

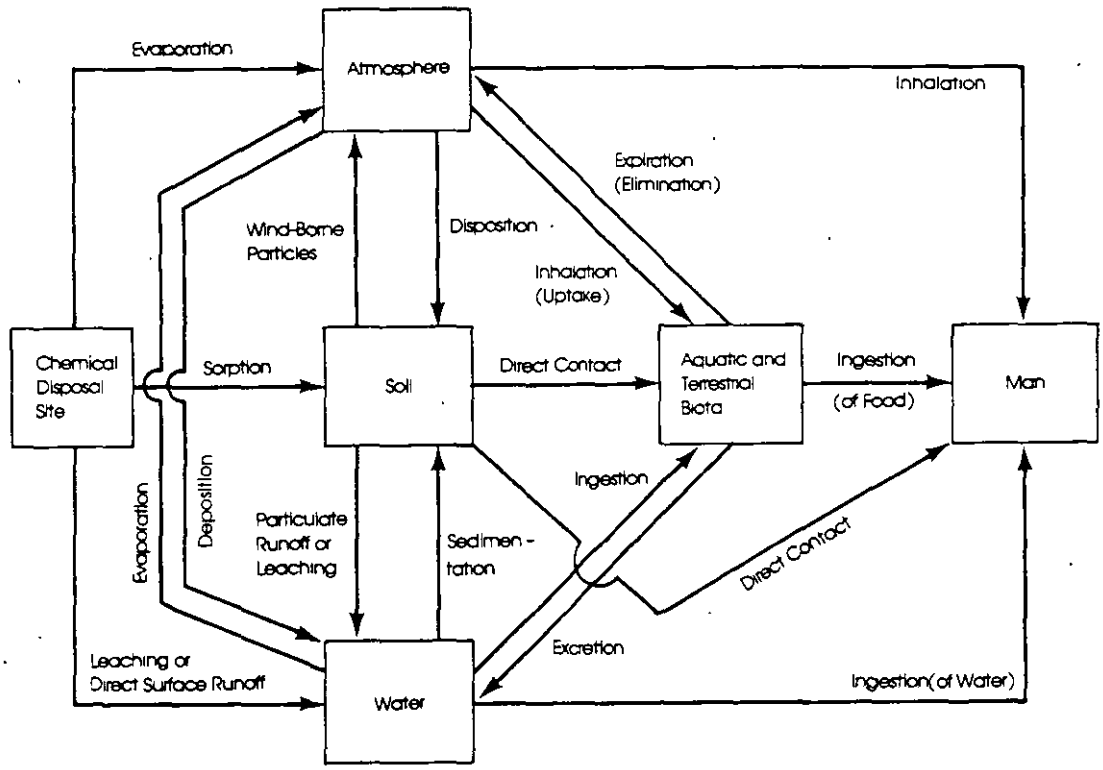
In recent years much attention has been paid to the transport of contaminants, particularly organic compounds, in the saturated zone. It is important to note that some chemicals will dissolve/dilute in water, while others--with low chemical solubility--will lead to compounds that are called "floaters." It has been found that some organic solvents can migrate through the sub-surface environment, particularly those with a lower density than water. Appropriately, the "floaters" spread across the top of the water table. By contrast, dense organic liquids, called "sinkers," migrate vertically down the aquifer. Contaminant flow rates in the saturated zone are highly variable and depend to a large extent on the characteristics of the aquifer. Transport times are generally shorter in a sand aquifer than a clay one, but transport can be more rapid in the latter if the clay is fractured. The actual time scales regarding the movement of contaminants out of a waste site are generally very long. It can take decades for a contaminant to migrate from a disposal site to nearby drinking wells. Once the chemical appears in the well water, however, it may remain there, in elevated amounts, for many years, even if remedial action is taken at the disposal site. Furthermore, the arrival of one pollutant in well water may signal the arrival of dozens more contaminants, entering the water over the course of many years.

2.5.2 Surface Water Contamination

Open water bodies near to disposal sites can receive hazardous wastes directly from surface runoff. In addition, the groundwater flow of

FIGURE 2-1

Physical and Biological Routes of Transport of Hazardous Substances, their Release from Disposal Sites, and Potential for Human Exposure



chemicals may also lead to inputs of contaminants to surface waters. Aerobic conditions, which generally prevail, can facilitate the chemical and biological degradation of organic compounds, while volatilization will also be more pronounced in surface waters than in groundwater. One must be concerned about bioaccumulation and the toxicity of some wastes--at low concentrations--to fish and other aquatic biota.

2.5.3 Other Pathways of Release

Those organic compounds with a high vapor pressure will show a tendency to be released to the atmosphere from disposal sites. The vaporization rates of chemicals from buried wastes in landfill sites are much smaller than when wastes are spread over the land, or placed in surface impoundments. Nevertheless, the quantities of volatile wastes lost to the atmosphere at landfill sites can be very large on an annual basis. Fires at disposal sites will lead to an increase in the vaporization of volatile compounds.

Wind-blown dispersal is another potential pathway of release to the environment (affecting people through inhalation). Certain solid wastes, asbestos for example, are particularly susceptible to wind-blown dispersal. The mobilization of contaminated soil or the contaminants themselves may be a particular problem at poorly managed sites, or where remedial activities require the use of many large vehicles.

It is conceivable that vegetation growing on land near waste sites, or on rehabilitated (former) landfill sites, will take up hazardous chemicals via root absorption either from contaminated soil or from the waste itself. Some chemicals may be translocated from the roots to the upper parts of the plant. The deposition of wind-blown contaminated soil particles onto the surface of the plant is another potential exposure pathway (particularly for vegetation growing in the vicinity of poorly managed landfills.

2.6 Factors Affecting the Environmental Behavior of Chemicals

This section describes the major physical, chemical, and biological processes which can affect the environmental behavior of hazardous chemicals at waste disposal sites. Reference will be made to a variety of chemicals.

Most attention is paid in this section to the behavior of chemicals at land disposal sites as these are the predominant methods of hazardous waste disposal. The wastes encountered at these sites can be complex mixtures of organic and inorganic hazardous chemicals in combination with other non-hazardous wastes. Such wastes can be in the form of solids, sludges or liquids or mixtures of all three. Major environmental risks include the leaching of chemicals and subsequent contamination of water sources as well as release to the air. In this respect, the geology and hydrogeology of the site, as well as local climatic conditions, are all important factors which influence the behavior of hazardous waste.

2.6.1 Physical and Chemical Factors

A number of physical and chemical factors are important in determining the behavior of chemicals in the environment. They are:

- o Leaching;
- o Adsorption/Desorption;
- o Volatilization; and
- o Bioaccumulation, etc.

These factors can act in a complex and interrelated series of reactions which may themselves be dependent on the geochemical characteristics of the disposal area.

Generally, the higher the water solubility of a compound, the greater the potential for leaching from the landfill site. Many hazardous organic compounds display low water solubilities. However, the presence of partially water miscible solvents, such as chloroform, can enhance the leaching of organic compounds from landfill sites, as can the formation of emulsions. Many inorganic chemicals ionize on contact with water to produce dissolved ions. In the case of trace metals, solubility is controlled mainly by speciation, but it can be further reduced by adsorption and ion exchange. In some cases, the metal can form complexes which enhance solubility. Cyanide may also enhance the solubility of trace metals. The fatty acids produced by bacterial degradation of domestic wastes can also form soluble complexes with metals.

The adsorption of compounds onto soil particles or waste material is an important phenomenon which tends to restrict the movement of both organic and inorganic chemicals from the landfill site. In addition, the process of adsorption maybe an important factor in retarding the migration of oil wastes. The soil adsorption coefficient of a chemical describes its potential for binding to soil particles. For organic compounds it appears that the partitioning between water and organic carbon is the most important factor. A compound with a low soil adsorption coefficient will generally tend to migrate from the landfill site. For example, phenol is not only highly water soluble but also has a low soil adsorption coefficient; these characteristics are reflected by rapid leaching of phenol in many landfill sites.

Volatilization, as noted previously, is a potential route by which hazardous wastes migrate out of landfills. This phenomenon may be particularly important for certain organic compounds and can occur at a significant rate for chemicals such as chloroform, which have a high vapor pressure. Conversely, leaching can be expected to be more important for those chemicals with a low vapor pressure, particularly if the compound also has a low soil adsorption coefficient. It should be stressed that factors other than the vapor pressure, such as the diffusion coefficient, can also have an important influence on the transport of compounds in a landfill. For example, disposal site characteristics such as temperature, soil moisture, and soil pH, as well as the water solubility of the compound, all influence the extent of volatilization. Thus, the elevated temperatures encountered at many disposal sites--the product of microbial

activity--will enhance the upward movement and evaporation of many volatile organic compounds. Nevertheless, the downward migration of these compounds has still been found to be important, particularly when large quantities are disposed of, as occurs for waste solvents.

Some chemicals, like methylene chloride and ethylene dichloride, have high vapor pressures and high solubilities and thus can be lost by leaching and volatilization.

For organic compounds, the octanol/water partition coefficient 'P' is often used as an index of the bioaccumulation potential for a chemical in the aquatic environment. This coefficient is somewhat correlated with a compound's molecular weight. Thus, a chemical such as DDT, which has a high P value, displays a marked potential for bioaccumulation in aquatic organisms. This coefficient is also proportional to the soil adsorption coefficient, although not linearly, reflecting the importance of the soil organic matter in the adsorption of organic compounds. Therefore, this coefficient also provides an insight into the importance of a compound's ability to bind with soil particles. This is of particular relevance for particle transport from the landfill site, either by wind-blown dispersal, or by runoff during heavy rainfall.

2.6.2 Degradation of Chemicals

The persistence of hazardous organic chemicals is an important determinant of their environmental fate. Certain compounds can undergo either chemical or biological degradation at land disposal sites, while others are resistant to any transformation and may even be toxic to soil micro-organisms. The pattern of degradation is not only influenced by the conditions in the landfill. Degradation may also be initiated during the transport of chemicals in the leachate, surface water, or groundwater. The major chemical processes associated with the degradation of organic contaminants at disposal sites have been identified as hydrolysis, biodegradation, photolysis, and oxidation; the latter is thought to be of particular importance in the degradation of phenols and aromatic amines. Nevertheless, the overall significance of chemical reactions in degrading toxic substances at disposal sites is largely unknown. For this reason, simply because a contaminant undergoes efficient chemical degradation in the laboratory, it should not be assumed that degradation will occur to the same extent--if at all--in disposal areas.

In certain instances, reactive chemicals can come into contact at the same disposal site, resulting in fires or explosions. Figure 2-2 summarizes the undesirable reactions which can occur when incompatible wastes containing hazardous compounds are mixed together. These reactions include:

- o Exothermic reactions which may result in fires or explosions; these may be caused by alkali metals and strong oxidizing agents.
- o Production of toxic gases such as arsine, hydrogen sulphide, hydrogen cyanide, and chlorine.
- o Production of flammable gases such as hydrogen and acetylene.

FIGURE 2-2

Compatibility of Selected Hazardous Wastes

1	Oxidising Mineral Acids	1										
2	Caustics	H	2									
3	Aromatic Hydrocarbons	H F		3								
4	Halogenated Organics	H F GT	H GF		4							
5	Metals	GF H F			H F	5						
6	Toxic Metals	S	S				6					
7	Sat Aliphatic Hydrocarbons	H F						7				
8	Phenols and Cresols	H F							8			
9	Strong Oxidising Agents		H	H F		H F		H		9		
10	Strong Reducing Agents	H F GT			H GT				GF H	H F E	10	
11	Water and Mixtures containing Water	H			H E		S				GF GT	11
12	Water Reactive Substances	← Extremely reactive, do not mix with any chemical or waste material →										12

E	Explosive
F	Fire
GF	Flammable Gas
GT	Toxic Gas
H	Heat Generation
S	Solubilisation of Toxins

Hazards are also associated with certain types of wastes which are unstable under ambient conditions or with motion (e.g. silane metal hydrides, alkalis metals/alloys, and organic peroxides).

Photodegradation is commonly identified as an important mechanism for the breakdown of organic compounds in the environment. However, this process will only be of any significance in the top few centimeters of the disposal site surface which is exposed to UV light. Photodegredation may be of greater importance for those compounds which have vaporized from the site, or entered surface waters.

It is currently considered that biological transformation is a significant degradation pathway for many contaminants in disposal sites. These microbial transformations may take place either at the land disposal site or in groundwater. Microbial activity may lead to the degradation of a contaminant to harmless, or less hazardous products, but may also result in the biosynthesis of persistent and toxic compounds. For example, microbial transformation of three solvents--trichloroethylene, perchloroethylene, and 1,1,1-trichloroethane--can lead to the formation of vinyl chloride, a compound resistant to further breakdown and a proven carcinogen. The degradation of many contaminants is most efficient under aerobic conditions, but these conditions only arise at the surface of the disposal site. The environmental conditions required for biodegradation are well known for some chemicals. In the case of cyanide these are: temperatures in excess of 10 degrees C, a pH of 6-7.5, and a maximum cyanide concentration of 100 mg/l.

The anaerobic conditions which predominate in landfill sites favor the bacterial reduction of sulphates, nitrates, and carbohydrates. Sulphate is reduced to sulphide and nitrate is reduced to nitrite or ammonia. The microbial production of sulphide under anaerobic conditions can cause a marked reduction in the concentration of dissolved metals in leachate by the precipitation of insoluble sulphides. This attention mechanism is particularly important for some metals, notably inorganic mercury.

In anaerobic conditions, bacterial activity is also responsible for the production of "landfill gas." Although landfill gas is generally associated with the disposal of domestic wastes, it may still occur at sites receiving hazardous wastes in combination with domestic refuse. Generally, the major components of landfill gas are carbon dioxide and methane, but hydrogen sulphide can also be a minor constituent. Several factors influence the rate of landfill gas production and its composition; the main parameters being temperature, moisture content, waste density, and pH value of the waste material. The optimum pH range for methane production is 6.4-7.4 and the optimum temperature range for anaerobic decomposition is 29-37 degrees C. The decomposition of some organic components in waste is so slow that significant concentrations of methane may be produced for many years after the waste has been deposited. The major problem associated with landfill gas is the serious risk of fire and explosion which occurs when the concentration of methane falls within the range of 5-15%. Proper precautions must be taken. In addition, landfill gas can also be a factor in flushing volatile organics from the fill.

2.7 Effects of Hazardous Wastes on Health and the Environment

Mixing chemical wastes containing incompatible chemicals may cause explosions and fires (see Figure 2-2). Contact with strong acids or alkali may cause corrosion and etching of the skin as well as severe corneal damage. Skin absorption of certain pesticides may cause acute poisoning. Most empty containers or jars for hazardous chemicals can--if not properly disposed of--result in incidents of severe poisoning if left unguarded at waste storage or dumping sites. Children are especially vulnerable. In the developed world, one of the main causes of child mortality--between the ages of 1 and 10--are accidents which involve accidental poisoning. If chemicals are introduced on the consumer market and no provisions made to collect the empty containers, bottles, or jars, they are likely to be stored in households or disposed of in an uncontrolled way. This has resulted in a substantial number of poisoning cases involving small children.

As previously noted, the release of chemical waste into the environment may result in long-term exposure of the population, causing adverse health effects due to poisoning. The following example is illustrative. Water containing a large amount of cadmium was discharged from the Kamioka zinc mine in Japan into a river that was used for drinking water downstream from the mine. The river water was also used for irrigating paddy rice. Because of the large amounts of cadmium in the water used for both drinking and irrigation purposes, the long-term exposure of the local population to this chemical resulted in serious kidney malfunctions in a large percentage of the population. The effects, which were most severe in pregnant women with low calcium intakes, as well as those women suffering from close-spaced births, included de-calcification of the skeleton, multiple bone fractures, invalidity, and death (Itai-itai disease).

The cadmium intake interfered with normal calcium metabolism, resulting in the de-calificaiton of bone tissue (osteomalacia). In many industrial countries both the body burden and the kidney content of cadmium have been considerably raised due to environmental exposure from chemical waste or cadmium impurities in fertilizers. However, so far no adverse health effects have been reported. These increased levels have, nontheless, caused a great deal of concern and measures have been taken to limit population exposure until a satisfactory safety margin has been identified between cadmium levels present in the kidneys and levels at which impaired function is likely to occur.

In other areas of Japan, industrial use of mercury catalysts resulted in the presence of mercury in the effluents from wastewater treatment plants entering coastal waters. The mercury was then converted, by micro-organisms present in seawater, into methylmercury, a highly toxic form of mercury. At Minamata Bay and the Agano River at Niigata, methylmercury accumulated in fish and shellfish. As seafood is an important part of the Japanese diet, many local inhabitants were poisoned and developed severe neurological symptons, such as impaired vision and hearing loss and difficulties in walking or standing. Children exposed *in utero* exhibited cerebral palsy syndrome or retarded psycomotor development. These

Japanese outbreaks of methylmercury poisoning are still the best documented cases on record. Nevertheless similar outbreaks have occurec in other countries.

In some regions, the body burden of methylmercury has increased due to t regular consumption of contaminated fish and shellfish. Measures have therefore been taken to regulate both the intake and the mercury content of fish, as well as limiting the amount of mercury discharged into the environment. Chemical elements, like mercury, are indestructable and hence can only be redistributed into the environment. By contrast, organic chemicals are often degraded in the environment to elemental components or simple organic compounds such as carbon dioxide and water. However, some chlorinated or halogenated organic compounds are extremely persistent in the environment and tend to accumulate in the food chain o in the biosphere in general. Examples of such compounds include: PCBs, dioxins, and chlorinated hydrocarbons; the latter being used extensively in the past as pesticides (e.g. DDT, dieldrin, and aldrin). PCBs and dioxins may be formed by incineration of waste containing hydrocarbons an chlorides. They are spread with atmospheric emissions and precipitate in the environment. Once released, they often end up in human food chains, lodging in fatty tissues in the bodies of humans and animals. It is know that in some industrialized countries, notably Sweden and Japan, levels o PCBs and dioxins in breast milk and human fat are on the increase. The health significance of this increase is still uncertain, as the body burden at which adverse health effects might occur is still unknown. However, experience from accidental high level exposures has shown that these compounds may cause serious effects on human health.

Leakages from landfills and dumping sites often contain large amounts of nitrates. This has often resulted in high levels of nitrates in adjacent drinking water wells. Levels of nitrates in drinking water exceeding 45 mg/l run a risk of methemoglobinemia in infants. This condition, which interferes with the oxygen transportation in the bloodstream, can be fatal. There are several reports in the literature about severe methemoglobinemia in infants caused by contaminated drinking water.

Another important consequence of finding nitrate in leachate from landfills, is the simple fact that the site is leaching contaminants into the environment. If industrial residuals are being placed in the site as well, then the possibility exists for a whole host of contaminants to find their way into drinking water (including some which are considerably more deadly than nitrate).

Other land disposal catastrophes can be noted. For instance, at Love Canal in New York State, chemicals and vapors began to leak into homes and schools causing adverse health effects and eventually resulting in the complete evacuation of the town. In the United Kingdom, drums containing heat treatment cyanide salts were discovered on waste land used by children as a playground.

2.7.1 Hazard Identification and Risk Assessment

To prevent and/or control adverse effects on health and the environment,

it is necessary to control all chemical and infectious materials introduced into the human environment. The chemical nature of each product should be determined, together with impurities, by-products and degradation products. The potential effects of these substances on health and the environment should then be assessed together with a quantitative estimation of levels occuring in the environment. Exposure commitments for human populations, as well as other organisms, should be undertaken in the final risk evaluation. From such an evaluation, measures should then be taken to ensure that unacceptable adverse effects are avoided. The effectiveness of these control measures should then be monitored on a continuous basis.

Hazard Identification

Each waste material should be assessed for organisms that are pathogenic to man and animals. Such an assessment can usually be made and verified from information regarding the source of the waste. The chemical composition of each waste material must also be determined in order to evaluate potential systemic toxicity together with other effects, such as mutagenic, cytogenetic, and carcinogenic effects, as well as effects on reproduction and foetal/neonatal growth and development. In most cases, such information can be found in the literature, such as the World Health Organization's health criteria documents, national safety data sheets available from ILO or other sources of toxicological literature. When the required information is lacking it may then be necessary to perform laboratory tests.

As can be seen from Table 2-2, all the contaminants studied in the TCLP test are of concern in drinking water because of their adverse health effects. The MCLs set are approximately 100 times the drinking water guidelines for those contaminants. Arsenic, cadmium, chromium, and lead, for example, are of concern because of their possible carcinogenicity, while barium effects the muscles and can cause gastroenteritis or muscle paralysis. Endrin is a potent teratogen and reproductive toxin. Chronic exposure to it can effect the nervous system, heart, lungs, liver and kidneys.

Once a substance is identified in waste, a good place to look for information first is the Guidelines for Drinking-Water Quality (World Health Organization 1984). They will tell you the health effects and provide a recommended safe concentration in water.

Table 2-4 lists the 25 most frequently identified substances that were found at a large number of hazardous waste sites. Table 2-5 lists some health effects information that may prove useful when working with wastes. Again, the recommended levels are for drinking water. Designations are as follows: Cancer Group A = human carcinogens; B = probable human carcinogens; B1 = at least limited evidence of carcinogenicity in humans; B2 = usually a combination of sufficient evidence in animals and inadequate data for humans; C = possible human carcinogen (limited evidence of carcinogenicity in animals in the absence of data on humans); D = not classified (inadequate data); and E = no evidence of carcinogenicity for humans.

TABLE 2-4

25 Most Frequently Identified Substances at 546 Superfund Sites

Rank	Substance	Percent of Sites
1	Trichloroethylene	33
2	Lead and compounds	30
3	Toluene	28
4	Benzene	26
5	Polychlorinated biphenyls (PCBs)	22
6	Chloroform	20
7	Tetrachloroethylene	16
8	Phenol	15
9	Arsenic and compounds	15
10	Cadmium and compounds	15
11	Chromium and compounds	15
12	1,1,1-Trichloroethane	14
13	Zinc and compounds	14
14	Ethylbenzene	13
15	Xylene	13
16	Methylene chloride	12
17	trans-1,2-Dichloroethylene	11
18	Mercury	10
19	Copper and compounds	9
20	Cyanides (soluble salts)	8
21	Vinyl chloride	8
22	1,2-Dichloroethane	8
23	Chlorobenzene	8
24	1,1-Dichloroethane	8
25	Carbon tetrachloride	8

Source: Adapted from McCoy and Associates. 1985. Hazardous Waste Consultants 3(2):2-20. Lakewood, Colorado.

TABLE 2-5

HA Summary Table

Cancer Chemical	10-kg Child			70-kg Adult					
	One-day HA(ug/L)	Ten-day HA(ug/L)	Longer-term HA(ug/L)	Longer-term HA(ug/L)	RfD (ug/kg/day)	DWEL (ug/L)	Lifetime HA (ug/L)	ug/L at 10^{-4} Cancer Risk	Group
Acrylamide	1,500	300	20	70	0.2	7	--	1	B2
Alachlor	100	100	100	100	10	350	--	15	B2
Aldicarb	10	10	10	40	1.25	40	10	NA	E
Barium	1,500	1,500	1,500	1,500	51	1,800	1,500	NA	D
Benzene	235	235	--	--	--	--	--	70	A
Cadmium	43	43	5	20	0.5	18	5	NA	D
Carbofuran	50	50	50	180	5	180	36	NA	E
Carbon Tetrachloride	4,000	160	71	250	0.7	25	--	27	B2
Chlordane	63	63	0.5	0.5	0.045	2	--	2.7	B2
Clorobenzene	4,300	4,300	4,300	15,000	43	1,500	300	NA	D
Chromium	1,400	1,400	240	840	4.8	170	120	NA	D
Cyanide	200	200	200	800	22	770	154	NA	D
2,4-D	1,100	300	100	350	10	350	70	NA	D
DBCP	200	50	--	--	--	--	--	2.6	B2
Dichlor-o-,m-	9,000	9,000	8,900	31,250	89.3	3,125	620	NA	D
Benzenes p-	10,700	10,700	10,700	37,500	107	3,750	75	175	C

TABLE 2-5 (continued)

HA Summary Table

Cancer Chemical	10-kg Child One-day HA(ug/L)	10-kg Child Ten-day HA(ug/L)	10-kg Child Longer-term HA(ug/L)	70-kg Adult Longer-term HA(ug/L)	70-kg Adult RfD (ug/kg/day)	70-kg Adult DWEL (ug/L)	70-kg Adult Lifetime HA (ug/L)	70-kg Adult ug/L at 10^{-4} Cancer Risk	Group
1,2-Dichloro-ethane	740	740	740	2,600	--	--	--	38	B2
1,1-Dichloro-ethylene	2,000	1,000	1,000	3,500	10	350	7	NA	C
cis-1,2-DCE	4,000	1,000	1,000	3,500	10	350	70	NA	D
trans-1,2-DCE	20,000	1,430	1,430	1,430	10	350	70	NA	D
Dichloro-methane	13,300	1,500	--	--	60	1,750	--	480	B2
1,2-Dichloro-propane	--	90	--	--	--	--	--	111	B2
p-Dioxane	4,120	412	--	--	--	--	--	700	B2
2,3,7,8-TCDD Dioxin)	0.001	0.0001	0.00001	3.5×10^{-5}	1×10^{-8}	3.5×10^{-5}	--	2.2×10^{-5}	B2
Endrin	20	5	4.5	16	0.045	1.6	0.32	NA	E
Epichloro-hydrin	140	140	70	70	2	70	--	354	B2
Ethylbenzene	32,000	3,200	971	3,400	97	3,400	680	NA	D
Ethylene dibromide	8	8	--	--	--	--	--	0.05	B2

TABLE 2-5 (continued)
HA Summary Table

Cancer Chemical	10-kg Child One-day HA(ug/L)	10-kg Child Ten-day HA(ug/L)	10-kg Child Longer-term HA(ug/L)	70-kg Adult Longer-term HA(ug/L)	70-kg Adult RfD (ug/kg/day)	70-kg Adult DWEL (ug/L)	70-kg Adult Lifetime HA (ug/L)	ug/L at 10^{-4} Cancer Risk	Group
Ethylene Glycol	19,100	5,500	5,500	19,250	1,000	35,000	7,000	NA	D
Heptachlor/	10	10	5	5	0.5	17.5	--	7.6	B2
Heptachlor-epoxide	10	--	0.13	0.13	0.013	0.4	--	3.8	B2
Hexachloro-benzene	50	50	50	175	0.8	28	--	2	B2
Hexane	13,000	4,000	4,000	14,000	--	--	--	NA	D
Legionella	--	--	--	--	--	--	--	NA	--
Lindane	1,200	1,200	33	120	0.3	10	0.2	2.65(CAG) 5.5(NAS)	B2/C
Mercury	1.58	1.58	1.58	5.5	0.158	5.5	1.1	NA	D
Methoxychlor	6,400	2,000	500	1,700	50	1,700	340	NA	D
Methyl ethyl ketone	75,000	7,500	2,500	8,600	24.7	860	170	NA	D
Nickel	1,000	1,000	150	150	10	350	150	NA	D
Nitrate/	10,000[a]	1,000[a]	10,000	10,000	--	10,000	10,000	NA	D
Nitrite	1,000[b]	1,000[b]	1,000	1,000	--	1,000	1,000	NA	D
Oxamyl	175	175	175	175	25	875	175	NA	E

a= Value given is for 4-kg infant; One-day and Ten-day HAs for all other populations is 111,000 ug/L.
b= Value given is for 4-kg infant; One-day and Ten-day HAs for all other populations is 11,000 ug/L.

TABLE 2-5 (continued)

HA Summary Table

Cancer Chemical	10-kg Child			70-kg Adult					
	One-day HA(ug/L)	Ten-day HA(ug/L)	Longer-term HA(ug/L)	Longer-term HA(ug/L)	RfD (ug/kg/day)	DWEL (ug/L)	Lifetime HA (ug/L)	ug/L at 10^{-4} Cancer Risk	Group
Pentachloro-phenol	1,000	300	300	1,050	30	1,050	220	NA	D
Styrene	22,500	2,000	2,000	7,000	200	7,000	140	3	C
Tetrachloro-ethylene	2,000	2,000	1,400	5,000	14.3	500	10	66	B2
Toluene	21,500	3,460	3,460	12,100	346	12,100	2,420	--	D
Toxaphene	500	40	--	--	--	--	--	3.1	B2
1,1,1-Tri-chloroethane	140,000	35,000	35,000	125,000	35	1,000	200	NA	D
Trichloro-ethylene	--	--	--	--	7.35	260	--	260	B2
2,4,5-TP	200	200	70	260	7.5	260	52	NA	D
Vinyl chloride	2,600	2,600	13	46	--	--	--	1.5	A
Xylenes	12,000	7,800	7,800	27,300	62	2,200	400	NA	D

On the other hand, some dangerous compounds are not included in health advisories. PCBs, chloroform, tetrachloroethylene, phenol and methylene chloride are all carcinogens and recommended safe levels for these compounds in drinking water are as follows: 12.6 ng/l; 0.10 mg/l (total trihalomethanes); 0.88 ug/l; 3.5 mg/l and 0.15 mg/l (long-term Health Advisory), respectively (USEPA 1986).

An analytical investigation may be structured according to known information regarding sources of the waste. Hazard identification should be followed by quantification and an exposure commitment calculation. If these procedures indicate a possible human health risk, then it becomes necessary to measure exposure levels. Biological monitoring of the exposed population is the preferred method as this quantifies the actual intake of the toxic agent. If this is not feasible, intake can be estimated from measured exposure levels in drinking water, food, or air.

Exposure to Man and Animals

Hazardous waste can affect human and animal health through different mechanisms and routes of exposure. The most obvious route is direct contact with the hazardous agent during handling of the waste, or waste adsorbed to oil matter or via empty containers, jars or bags left at disposal sites, dropped during transportation or reused without proper cleaning. This could also be a source of disease as well as chemical contamination. Children are an especially vulnerable group as they are likely to play around waste bins etc., and may put fingers or contaminated articles in their mouths. Inhalation of dust from waste storage and dumping sites may also constitute a hazard. This is, for example, the case for asbestos-containing material. Inhalation of vaporized chemical waste is also a potential exposure pathway, but is only likely to be of significance to the on-site workforce.

Groundwater can be contaminated from dumping sites and landfills. Hazardous agents, such as bacteria, viruses, and chemicals can be transferred to drinking water wells in this way. Certain viruses and bacteria may survive for weeks to months in soil and/or inadequately treated sewage sludge, thus increasing the risk of such agents being transferred to drinking water supplies.

The transport of contaminants in surface waters results in a rapid and extensive dispersion which can greatly increase the size of the exposed population. Drinking water can also be contaminated by direct transfers from disposal sites or by animals (e.g., birds) to surface reservoirs. Seabirds can also transfer bacteria from coastal sewage outlets and treatment plants to drinking water reservoirs. Other animals (e.g., rates and insects) may also transfer contagious diseases or dangerous chemicals from dumping sites to households in the community.

Chemicals from hazardous waste may be taken up by crops from soil-bound particles or contaminated surface- or groundwaters, or if contaminated water is used for irrigation purposes. The spreading of wastes on agricultural land and deposition of air emissions from smoke stacks and a variety of industrial point sources constitute other pathways for chemical

contamination of vegetation and crops. Consumption of contaminated vegetation by animals can result in the tropic transfer of hazardous chemicals. Livestock may ingest large quantities of soil when feeding on pasture and this is often a significant source of exposure in areas with contaminated soils.

Finally, release of waste materials into the sea and via freshwater sources leaching from disposal sites and treatment plants as well as atmospheric deposition, may lead to the uptake of chemicals by aquatic organisms. Those compounds with high partition coefficients tend to bioaccumulate in aquatic food chains. This is of particular significance for compounds which are persistent in the environment as these show marked accumulation in fish. Consumption of contaminated seafood can be a significant source of human exposure, particularly for fishing communities. Figure 2-2 summarizes the different exposure pathways of hazardous wastes back to human populations.

Assessment of Health Risks

With identification of a hazard, accessing health effects data-including dose-response information on the particular contaminant(s)--and determination of public exposure to the hazard, a risk assessment can then be made. The risk of adverse effects on human health and the environment from the presence of hazardous chemicals or pathogenic organisms present in waste is fully assessed by quantifying target organism exposure. This will determine whether there is a potential adverse health risk and whether there is a sufficient safety margin between exposure levels and levels known to cause adverse health effects. The safety margin required varies between a factor of 2 to an order of magnitude greater, depending on factors such as the type of effect induced, the number of people at risk, or the extent of environmental damage. A substance causing irreversible injury and/or death will require a larger safety margin than a substance which may induce mild skin irritation, for example. Similarly, if thousands of people are at risk, the safety margin has to be larger than if just a few individuals are at risk. If the risk assessment reveals that the hazardous waste will impose an unacceptable risk to human health or the environment, then measures must be taken to limit the risk to an acceptable level.

During the period 1964-1972 an estimated 300,000 barrels of liquid and solid wastes were buried in shallow trenches at a 200 acre dump site in Hardeman County, Tennessee (U.S.A.). In 1972, a nearby test well was found to be contaminated with hazardous chemicals, and the site was closed. An analysis of water from private wells close to the dump showed no contamination. However, five years later, in 1977, the situation changed dramatically. Residents in the area of the dump became alarmed by the unusual and unpleasant odor and taste of their well water. Some people experienced skin and eye irritation, weakness in the upper and lower extremities, severe gastrointestinal symptoms including nausea, diarrhea, and abdominal cramps. The local authorities launched an investigation. Analysis of the well water revealed high concentrations of carbon tetrachloride and small amounts of other organic compounds known to have been dumped at the site by a pesticide manufacturer. The highest

concentration of carbon tetrachloride found in one well was 18.7 mg/l. As no method for biological monitoring of carbon tetrachloride was available, it was decided to look for effects on liver function, as this is the main target organ in carbon tetrachloride toxicity. Liver function tests were performed on 36 exposed individuals and compared to a reference population of 56 people. A higher prevalence of enlarged liver and impaired function tests was observed in the exposed group. All signs returned to normal after cessation of exposure when examined a year later in a follow-up study.

It is important that in any case where potential exposure is discovered from hazardous wastes, the public is informed immediately about the source of exposure and the potential health risks involved. Such risks should then be compared with other risks, such as those associated with smoking, traffic accidents, alcohol consumption, and other estimable risk factors. An information system should be set up to ensure that the progress of ongoing investigations is being reported adequately. Such information is necessary in order to prevent the public from over-reacting and falling victim to political exploitation.

2.8 Degree of Hazard Concept

In identifying and classifying hazardous wastes, it is important to recognize that there are varying degrees of hazard associated with different waste streams. To reflect these differences, regulations in a number of countries have examined methods of ranking wastes according to how great a hazard they present.

There are strong economic arguments for doing this: It enables resources to be allocated so that the most dangerous wastes can be tightly controlled. In a number of European countries, this type of approach has been adopted in national regulations using concentrations of constituents to indicate whether or not a waste should be subjected to a high degree of monitoring and control. Other "degrees of hazard" schemes have considered the mobility of wastes as a criterion for establishing the degree of hazard.

There are, however, a number of difficulties in implementing this type of quantitative approach to degree of hazard assessments. In the first place, the amount of information needed is daunting. For this reason (and others) an alternative approach is recommended here. Under this system, three main categories of waste are defined.

- The first category includes those wastes of priority concern (Category 1) known to contain significant concentrations of constituents that are highly toxic, mobile, persistent, or bioaccumulative. Examples of Category I wastes would include the following:

  - chlorinated solvent wastes from metal degreasing. These are included because of their toxicity, mobility, and--to some extent --persistence in the environment;
  - cyanide wastes are included because of their acute toxicity;
  - PCB wastes are on the list because of their persistence and bioaccumulative properties.

- o Most wastes not singled out for special attention would be designated as Category 2 wastes. These would include metal hydroxide sludges (excluding hexavalent chromium) for which the toxic metals are in a relatively insoluble physical form with low mobility.

- o Category 3 includes primary large volume, low hazard wastes and some putrescible wastes, for which the cut-off between a 'hazardous' and 'non-hazardous' waste is least clear-cut.

It is emphasized, however, that this scheme is not intended to diminish the concern for the proper handling of Category 2, or even Category 3 wastes. Rather, it is an attempt to identify those waste streams for which a consensus has been reached that a particularly high degree of hazard is present, and accordingly for which a high degree of attention is warranted. It also allows certain related low hazard (Category 3) wastes to be brought under scrutiny, since in some local circumstances their control may assume high priority.

In Annex 2, an attempt has been made to categorize various types of waste. However, in some cases more specific information on concentrations and on properties--such as flashpoint--is required. These factors should be taken into account in assigning a waste to a particular category of hazard.

As new substances of concern surface and the need for additional health/environmental effects information develops, please consult your local/national health department. If necessary, they will in turn contact their local UNEP/WHO representative for assistance.

2.9 Environmental Effects of Hazardous Waste Disposal

Adverse effects on biota can arise at disposal sites as a result of construction activities and the subsequent release of toxic chemicals to the environment. In addition, the plants and animals living in the vicinity of such sites can be used to evaluate the geographical extent and intensity of contamination resulting from hazardous waste release. This activity, termed biological monitoring, generally relies on measurement of the concentration of the contaminant(s) in the species selected for examination. The presence of sub-lethal effects may also be investigated, but these are often difficult to relate in a causal manner to a specific chemical. Biological monitoring offers the advantage that containment levels in biota are often much higher than in the physical environment. This is of particular importance in the aquatic environment, where pronounced bioaccumulation results in markedly elevated levels of certain organics in fish, even in waters which contain low levels of these compounds. In the case of food crops or livestock, measurement of the pollutant concentration will not only provide an insight into the extent of environmental contamination, but will also allow an estimation of the potential exposure resulting from the consumption of such food items.

Increased mortality of biota, particularly large animals, can provide an early warning of contaminant release from a disposal site. An example is the numerous cases of fish deaths resulting from episodic inputs of

chemicals to surface waters. Such events can be caused by surface run-off from disposal sites--landfills and impoundments--during periods of heavy rainfall or due to dike failure. Adverse effects can also extend from the individual or population level to effects on the functioning of the ecosystem itself. This may result in changes in nutrient cycling or reduced primary production in the impacted area.

2.9.1 Effects on the Terrestial Environment

Effects on the terrestial environment at disposal sites tend to be of a localized nature. One effect of importance, however, is that the production of landfill gas depletes the oxygen supply in the upper layer of the landfill, causing vegetation to die off. This effect can produce problems when re-vegetation of the site is being carried out. Metal-rich wastes can also inhibit the re-vegetation of disposal sites. Those areas of the site lacking vegetation will be susceptible to erosion; wind-blown dispersal, and episodic flooding can result in the environmental release of contaminants. Land spreading of certain industrial wastes can result in significant inputs of metals and organic chemicals to agricultural land. Certain metals are phytotoxic and if soil levels are sufficiently high these can reduce crop productivity. Other metals can accumulate in the edible portions of crops, which may lead to problems of exposure for human consumers.

2.9.2 Effects on the Aquatic Environment

The efficient dispersal which occurs when pollutants enter surface waters is an important feature of this environmental compartment. Thus, widespread contamination may arise from a single source of discharge, particularly in rivers, drainage canals, and coastal waters. As mentioned earlier, fish deaths resulting from contaminant inputs are often the most visible sign of an environmental impact. In addition, attention has recently focused on sub-lethal effects observed in button-dwelling commercial fish species caught near waste dump sites in coastal waters. The effects observed include epidermal lesions and liver neoplasms; in some coastal waters these effects have been related to elevated levels of aromatic hydrocarbons in the sediments.

2.10 Summary

A working definition for hazardous waste(s) is developed in this chapter and examples of such wastes are given. The range of possible industries for a country to have are listed together with the wastes they typically produce; and a classification is made. Movement of waste components in the environment is discussed together with their varied effects on human health and the environment. A scheme for classifying hazardous wastes by the degree of hazard they pose is proposed.

2.11 References 2.1 - 2.10

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USEPA. 1986. Superfund Public Health Evaluation Manual, EPA/540/1-86/060 (October). Washington, D.C.: Office of Emergency and Remedial Response.

World Health Organization. 1984. Guidelines for Drinking-Water Quality, 3 Vols. Geneva.

ANNEX 2 - Waste Types for Proposed Classification Scheme

I INORGANIC WASTES

ACIDS AND ALKALIS

Waste Streams	Industry/Process	Industrial Groups
Acid		
Spent sulphuric acid	Galvanizing	D
Spent ferrous pickle liquor	Steel pickling	D
Acid strip solution	Metal finishing	D
Spent nitrating acid	Organic synthesis	F
Spent chromic acid	Anodising	D
Spent brightener for stainless steel	Metal finishing	D
Acid tars	Coking	C
Spent reagents	Pesticide manufacture	F
Alkalis		
Alkaline cleaning agents	Metal degreasing	D
Spent ammoniacal etchants	Electronics	G
Spent caustic baths	Metal finishing	D
Waste ammonia	Photocopying shops, chemical synthesis	F/L
Caustic sludge	Oil re-refining	F
Spent caustic	Oil refining	C
Ammonia still lime sludge	Coking operations/gas works	C

CYANIDE WASTES

Untreated rinse water	Electroplating	D
Spent electro-plating process solutions		D
Heat treatment wastes	Steel production	D
Spent concentrates and semi-concentrates	Hydrometallurgy	D
	Chemical synthesis	F
	Fumigation	L

HEAVY METAL SLUDGES AND SOLUTIONS

Lead sludges from diaphragm cell process	Chlorine production	F
Wastewater treatment sludge from the mercury cell process		
Brine purification muds from the mercury cell process		
Wastewater treatment sludges	Chrome pigments	F
	Wood preserving (1)	H
Surface impoundment dredged solids	Lead smelting (2)	D
Emission control sludge	Lead smelting (3)	D
Treatment process wastewater sludges	Zinc production	D
Acid plant blowdown		

Waste Streams	Industry/Process	Industrial Groups
Electrolic anode sleeves and sludges Cadmium plant leachate residue Lead sludges	Battery production	G
Sludge	Tin plating mill operations Galvanizing mill operations	D
Acid plant blowdown slurry sludges	Copper production (2)	D
Wastewater treatment sludges	Copper rolling and drawing	D
Spent pickle liquor and sludge	Copper production	D
Zinc and other heavy metal sludges	Textiles industry	H
Emission control sludge	Production of steel in electric furnace (2)	D
Spent pickle liquor	Steel finishing operations	D
Untreated wastewater	Manufacture of explosives	F
Wastewater treatment sludges	Manufacture/processing of explosives	F
Mixed metal sludges	Paint production	F
	Ink formulation	F
Waste sludges	Photographic processing	F
Spent reagents	Electronics industry	G
Etching solutions/rinse waters	Plastic plating	G
Grinding and polishing residues	Metal finishing	D
Lead sludge	Glassmaking	E
ASBESTOS WASTES		
Asbestos powder	Preparation and processing of asbestos	E
Lagging materials	Power stations, industrial manufacturing, gasworks dockyards, hospitals and educational establishments	Various
Asbestos diaphragms	Chlorine production	F
SOLID RESIDUES N.O.S.		
Emission control dust	Production of steel in electric furnaces (2)	D
Dust and sludge	Ferromanganese furnaces	D
	Silicomanganese electric furnaces	D
	Ferrochrome electric furnaces	D
	Iron and steel foundries	D
Waste sand	Iron and steel foundries	D

Waste Streams	Industry/Process	Industry/ Group
Emission control dust	Lead smelting (3)	D
Blast furnace slag	Copper smelting (3)	D
Spent catalysts	Chemical synthesis	F
Solid residues	Rubber production	F
Spent activated carbon wastes	Manufacture of sulphuric acid, chemical synthesis	F
Scrap batteries	Miscellaneous sources	Various
Spent iron oxide	Gas purification/coking	C

Notes: (1) using chromated copper arsenate
(2) Primary
(3) Secondary

II OILY WASTES

OILY WASTES

Waste Streams	Industry/Process	Industry/ Group
Used oil wastes	Vehicle repair shops, petrol stations	G/L
Acid waste oils	Textiles	H
Contaminated fuel oils	Oil tanks and reservoirs	Various
Compressor condensates	Compressors	Various
Sand trap and interceptor wastes	Manufacture of building materials	E
	Chemical synthesis	F
	Sand traps, storage tanks	Various
Oily sludges containing cyanide	Surface treatment of metals	G
Oily sludges	Oil recovery/cleansing	F
	Oil prospecting and mining	C
	Petroleum refining	C
Bottom sludges from tanks API separator sludge Heat exchanger sludge Dissolved air floatation float Silt/storm water runoff		
Oily sludges	Coking plants and gasworks	C
Caustic sludge	Oil re-refining	F
Drilling and cutting emulsions	Metal working	G
Waste vegetable oils	Production of vegetable oils	A

III ORGANIC WASTES

ORGANIC CHEMICAL RESIDUES N.O.S.

Waste Streams	Industry/Process	Industrial Group
Halogenated		
Propylene dichloride in admixture with lime slurry	Propylene Oxide/ Propylene Glycol	F
Distillation residues containing 1-10% chlorinated hydrocarbons (e.g., chlorinated toluenes from manufacture of benzaldehyde)	Ethers and Aldehydes	F
Residue with low concentration of o-dichlorobenzene	Isocyanates	F
Phosphoric acid contaminated with brominated hydrocarbons	Alkylated Bromides	F
Tarry residue (m.p. 60°C) containing chlorinated aromatic compounds	Dyestuff intermidieates and Dyestuffs	F
Aqueous waste containing low concentrations of mono-and tri-chlorobenzene		
Tarry residues of 1-2% halogen (chlorine, fluorine, bromine) content	Pharmaceuticals and Fine Chemicals	F
Spent filter cake of approximately 0.1% chlorine content		
Chlorinated hydrocarbon in admixture with toluene and dissolved solids (chlorine content 1%)		
Contaminated mixtures of chlorinated solvents (e.g., methylene chloride, chloroform, ethylene dichloride, chlorobenzene, with non-halogenated hydrocarbon solvents)		
Solvent waste containing small amounts of methylene chloride and and alkyl chloride		
Aqueous streams of about 0.1% chlorinated xylenes and terpene alcohols		
Still residues containing up to 2% films and disposables		
Aqueous stream containing about 40 ppm chlorinated hydrocarbons with traces of brominated and iodated compounds		
PVC (with or without additives) off-cuts, films and disposables: waste from machining of PTFE/Graphite products	Plastics and Rubbers	F
PVC granules from processing operations		
Slurry of chlorinated rubber and rubber in carbon tetrachloride		
Waste stream containing chlorinated hydrocarbons (10% chlorine content)	Dyeline intermediate products	F

Waste Streams	Industry/Process	Industrial Group
Epichlorohydrin wastes	Epoxy and phenolic resin	F
Contaminated chlorinated hydrocarbon solvents (e.g., methylene chloride, chloroform)	Products (research)	F
Ethylene dichloride tars	Chlorocarbon production	F

Source: Her Majesty's Stationary Office. 1979. Halogenated Organic Wastes, Waste Management Paper No. 15, Annex 2. London.

III ORGANIC WASTES

ORGANIC CHEMICAL RESIDUES N.O.S.

Waste Streams	Industry/Process	Industrial Groups
Non-halogenated		
Spent aqueous caustic soda solution	Oil refining operations	C
Distillation residues containing 45 per cent aromatic hydrocarbons (xylene to methyl naphthalene)	Petroleum refining	C
Still bottoms containing octyl phenyl naphthylamine and polyisobutylene		
Tars containing polymerized methyl-methacrylate, alkylated phenols, cyanovaleramide and condensation products, hexamethylene triamine	Heavy organic chemicals manufacture	F
Filter press cake containing 8 per cent naphthenates, 4 per cent naphthenic acid and metallic oxides	Chemical manufacture	F
Still residues containing: diphenylamine, aromatic amines, inorganic compounds, 2-naphthol and oxidation products, phenol decomposition products and amine decomposition products	Dyestuffs and intermediates manufacture	F
Distillation residues containing phenylamines, nitrated phenylamines and phenyl ethers	Production of chemical intermediates	F
Glycol and glycol ether residues in admixture with hydrocarbon sludge, plastic powder and water	Petrochemicals manufacture	F
Liquid cyclopentadiene residue	Petrochemicals manufacture	F
Dimethylformamide residues	Pharmaceuticals manufacture	F
Residue containing up to 20 per cent organic amines		
Liquid comprising 70 per cent toluene, 6 per cent chlorphenol + 20 per cent by-products		
Distillation residues - terpene hydrocarbons and weak acid stabilizers	Fine chemicals manufacture	F
Waste from hydroquinone processing, containing 0.2 per cent insoluble tars and 35 per cent soluble tars		
Caprolactam residues	Fibers manufacturing	F
Still bottoms containing spent caustic, alcohols	Lube oil additive manufacture	F
Tar slurry (1 per cent coal tar + water)	Aluminum smelting	D

Waste Streams	Industry/Process	Industrial Groups
Phenol-formaldehyde and epoxy resins, varnish blends and solvent	Plastics fabrication	F
Propylene polymerization residues; polymerized ethylene granules	Plastics manufacture	F
Tar emulsions	Town gas manufacture (coal carbonization)	C
Acid tar washing of BTX fraction	(coal carbonization)	C
Distillation bottom tars	Phenol production	F
Centrifuge and distillation residues	Toluene diisocyanate production	F

Source: Her Majesty's Stationary Office. 1977. Tarry and Distillation Wastes and Other Chemical-Based Residues, Waste Management Paper No. 13, Annex 3. London.

III ORGANIC WASTES

HALOGENATED SOLVENTS

Waste Streams	Industry/Process	Industry/ Group
1,1,2 - trichloro - 1,2,2, -trifluoroethane	Dry cleaning	L
Perchlorethylene, Perchloroethylene, trichloroethylene	Textiles and leather	H
Trichloroethylene, 1,1,1, - trichloroethane	Metal cleaning	G
1,1,2 - trichloro -, 1,2,2, - trifluoroethane		
Dichloromethane	Paint stripping	L
Chloroform, carbon tetrachloride	Industrial and domestic cleaning	L
Chlrobenzene; 1,2 - dichlorobenzene	Chemical synthesis	F

NON-HALOGENATED SOLVENTS

Methyl ethyl ketone, "Special Boiling Point" aliphatic hydrocarbons toluene	Adhesive manufacture	F
"Special Boiling Point" aliphatic hydrocarbons, xylene, toluene, white spirit, kerosene, esters	Motor vehicle manufacture	G
White spirit, kerosene, refined paraffin, "Special Distillates"	Cleaning materials and polishes	F
Kerosene and white spirit (with significantly greater quantities of chlorinated hydrocarbon solvents).	Engineering industries	G
n-Hexane, ethanol, methanol, isopropanol	Extractive industries (essential oils, etc.)	F
Propylene glycol, isopropanol, diacetin, glycerol triacetate	Food flavorings, essences, perfumes cosmetics and toiletries manufacture	
"Special Boiling Point" solvents, paraffin, glycerol triacetate	Industries where large fleets of vehicles require maintenance - including road, rail and air transport	G
White spirit, kerosene	Leather industry	H
Petroleum fractions of the white spirit type	Organic wood preservatives	H
Methanol, Industrial Methylated Spirit, acetone, various glycols, ethanol, ethyl acetate, cyclohexane	Photographic industry	J
White spirit, "Special Boiling Point" solvents, kerosene, ethanol, isopropanol, ethyl acetate, butyl acetates, acetone, methyl ethyl ketone, toleuene, xylene, methyl isobutyl ketone	Printing industry	J

Waste Streams	Industry/Process	Industry Group
Toluene, xylene, white spirit, cellosolves, isobutanol, methyl ethyl ketone, methyl isobutyl ketone	Shipbuilding and refitting	G
Petroleum hydrocarbons	Tyre manufacture	F

Source: Adapted from Department of the Environment. 1977. Waste Management Paper No. 14, Annex 1. London: Her Majesty's Stationary Office.

POLYCHLORINATED BIPHENYL WASTES

Solid and liquid wastes	Manufacture of PCBs	F
Dielectric fluid/solid wastes	Scrap transformers	G
Dielectric fluid/solid wastes	Scrap capacitors	G
Hydraulic fluids	Mining equipment, aircraft	G
Heat transfer fluids	Chemical industry	F
Plasticiser residues	Chemical processing	F
	Plastics processing	F

III ORGANIC WASTES

BIOCIDE WASTES

Chemical Classes	Waste Types	Industry/Process	Industrial Groups
Insecticides	Still bottoms	Manufacture of biocides	F
o Organophosphorus compounds	Filter media	Biodice formulaltors	F
o Organochloride compounds	Extraction units	packers	F
o Carbamates	Packaging	importers	F
	Clothing	wholesalers	F
Herbicides	Effluent treatment sludge	distributor	F
o Phenolics	Sweepings		
o Phenoxyacids	Spill clean ups		
o Substituted ureas	Washings		
o Triazines			
o Benzoic acids			
o Dinitroanilines	Empty containers	Agriculture users	A
o Anilides	Unused products	Animal husbandry users (dips)	A
o Others	Spills	Horticulture users	A
Fungicides		Industrial users	
		o wood preservation	H
o Dithiocarbamates		o paint industry	F
o Phthalimides		o paper and board	J
		o textiles (not wool)	H
		o electric cable	G
		o tobacco	A
		o adhesives	F
		o building industry	E
		Public sector users	L
		Home and garden users	L
		Drum reconditions	G
		Service companies (rodent/bird control)	L

BIOCIDE WASTES

Waste Streams (1)	Industry/Process	Industrial Groups
Lacquering residues	Lacquering shops	G/H
Old lacquers	Paint/lacquer shops (trade)	G/H
Old paints	Paint/lacquer shops	G/H
Lacquer sludge		
Paint sludge		
Coating material residues	Manufacturing of coating mats	F
Printing ink residues	Manufacturing of printing inks	F
	Printing works	J
Resin residues	Plastics processing	F
	Manufacturing of coating mats	F
	Manufacturing of synthetic resin	F
Resin oil residues		F
	Manufacture of resin	H
Paint residues	Paint production	F

(1) Wastes typically contain mixtures of aliphatic solvents, resins and may also include heavy metals.

IV PUTRESCIBLE ORGANIC WASTES

Waste Streams	Industry/Process	Industrial Groups
Spoiled vegetable oils	Production of edible oils	A
	Production of edible fats	A
Esterified oil residues	Production of pharmaceuticals	F
	Production of articles of personal hygiene	F
Butchering wastes; including blood, offal and intestines	Slaughter houses,	A
	meat processing	A
	meat packing	A
	fish processing	A
Poultry	Poultry and feather processing	A
Fish wastes	Fish processing	A
Animal carcasses	Livestock raising	A
	Pharmaceutical industry	F
Hideglue Fleshings Residues Hide liming sludge Tanyard sludge	Tanyards and fur industry	H
Sludge and residues	Processing of natural gut	A
Boiling out residues	Processing of animal products	A

V HIGH VOLUME/LOW HAZARD WASTES

Waste Streams	Industry/Process	Industrial Groups
Drilling muds	Petroleum/gas extraction	C
Fly ash	Power generation	C
Mine tailings	Mineral extraction	B
Contaminated soil	Miscellaneous	Various
Flue gas desulphurization sludges	Power generation	C
Phosphogypksum sludges	Fertilizer production	F
Titanium dioxide wastes	Pigment production	F

VI MISCELLANEOUS WASTES

Waste Streams	Industry/Process	Industrial Groups
INFECTIOUS WASTES		
Special faeces	Livestock raising	A
	Veterinary quarantine	K
Contagious wastes Animal and human tissue	Human and animal health institutes	K
	Microbiological laboratories	K
	Contagious hospitals	K
	Microbiological industries	K
	Microbiological institutions	K
Dressing wastes Disposable linen Disposable hospital wastes	Hospitals	K
	Therapeutic institutions	K
LABORATORY WASTES		
Waste pharmaceuticals	Pharmacies	L
Laboratory chemical residues	Manufacture of pharmaceuticals/ fine chemicals	F
	Research institutes	Various
	Factory laboratories	Various
EXPLOSIVE WASTES		
Waste munitions	Armaments	F/G
TNT, azides	Manufacture of explosives	F
Nitrated organic chemical wastes	Chemical synthesis	F

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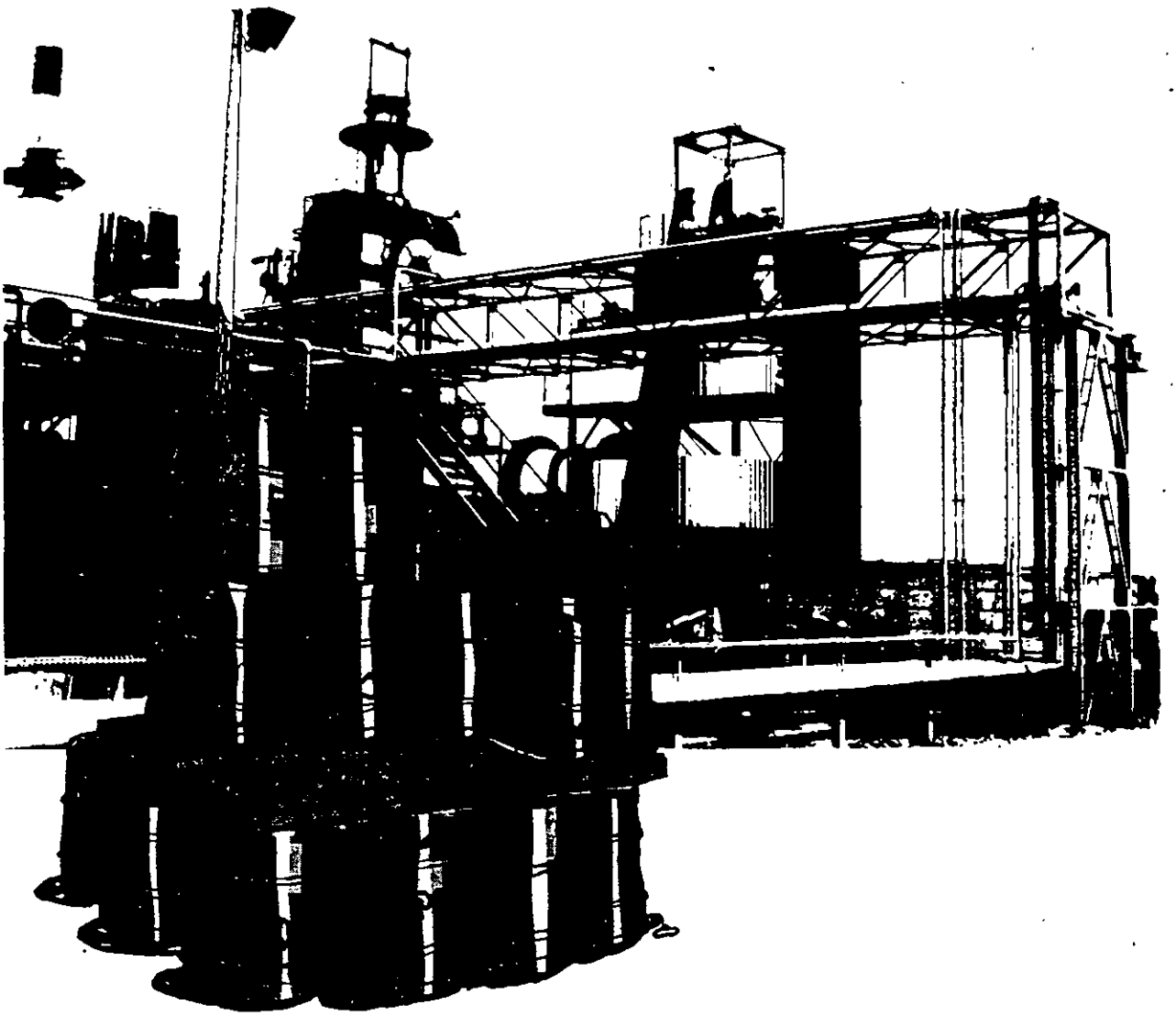
The Safe Disposal of Hazardous Wastes

The Special Needs and Problems of Developing Countries

Volume III

Roger Batstone, James E. Smith, Jr., and David Wilson, editors



A joint study sponsored by the World Bank, the World Health Organization (WHO), and the United Nations Environment Programme (UNEP).

ANNEX 7.4 - Biomedical Waste

Annex 7.4 was prepared by the Ontario Ministry of the Environment in Toronto, Ontario and Trecan Combustion Limited in Mississauga, Ontario.

Introduction

The criteria expressed in this document supersede those stipulated in the June 1974 Ontario Ministry of the Environment "Criteria for Incinerator Design and Operation for pathological waste incineration. Part of the need to update the existing criteria has been the change in the composition of waste generated in hospitals and other health care facilities. To reflect current waste composition, the Ontario Ministry of the Environment now uses the term "biomedical" waste to replace the existing definitions of "pathological" and "institutional" wastes. The criteria presented in this document were developed for application to biomedical waste.

Scope of Document

The topics covered in this document are summarized as follows:

(i) Characterization of the biomedical waste generated in Ontario, including the component proportion, moisture content, and heating value for each type of biomedical waste;

(ii) Overview of the current technology for the incineration of biomedical waste; and

(iii) Recommendation of design and operating criteria for biomedical waste incinerators.

Biomedical Waste

Introduction

"Biomedical" waste refers to any waste that includes anatomical waste, pathological waste, infectious waste, hazardous waste, and other waste generated in health care facilities and medical laboratories that require special handling. Previously, the terms "pathological" and "institutional" wastes were used to refer to what is now considered "biomedical" waste.

Classifications

The Ministry will classify biomedical waste according to the categories presented in Table 7.4A-1. The Ministry recommends that biomedical waste be segregated and packaged in leakproof, color-coded plastic bags to facilitate identification, handling, storage, decontamination and transportation.

The surveys carried out for these institutions also reflect the situation in Ontario hospitals. This was confirmed in a study carried out by Sirman in 1985 in which he found that the biomedical waste generation rate in Ontario hospitals ranged from 2.3 to 7.7 kg/bed/day (Sirman and Ivan 1985).

TABLE 7.4A-1

Ministry Classification and Colour Coding for Biomedical Waste

Classification		Description	Colour Code
Type A, Class 1		Human anatomical	red
Type A, Class 2		Animal anatomical, infected	orange
Type A, Class 3	a)	Non-anatomical, infected	yellow
	b)	Laboratory wastes	yellow
	c)	Wastes from DNA work	yellow
Type B, Class 1		Animal anatomical, non-infected	blue

The total biomedical waste stream also includes infectious waste generated from special care beds in surgical rooms, isolation wards and special medical procedure rooms. A 1985 survey sponsored by the Ontario Hospital Association showed that the average-size Ontario hospital generates approximately 0.75 kg/day of infectious waste for each special care bed. This value is based on 75 responses from 164 facilities surveyed (Health Care Occupational Health and Safety Association 1985).

Collection and Handling in Hospitals and Other Health Care Facilities

Waste collection and handling at most hospitals in Ontario involve the transport of waste by employees from the point of generation (patients' beds, operating rooms, laboratories, etc.) to initial storage points (usually enclosed containers in utility rooms) in each hospital unit. At some hospitals, waste considered to be "contaminated," such as urine containers, histology laboratory cuttings, tubes and bags containing blood, spinal fluid containers, and waste from isolation patients' rooms, are placed in color-coded plastic bags for separate handling.

To minimize the potential risk of public exposure to hospital waste, some hospitals use rigid containers for transporting the color-coded bags along routes within the hospital that are accessible to the general public. The use of rigid containers in this situation is considered good practice and is recommended for all hospitals.

Existing waste collection and handling procedures vary from hospital to hospital in Ontario and the practice of color coding the disposal bags for separate handling is not consistent. It is therefore recommended that the color-coding system presented in Table 7.4A-1 be adopted so that all biomedical waste can be immediately identified. The use of the colorcode should be exclusive to biomedical waste to preclude public exposure during general purpose disposal.

Waste Generation Rate

(i) Hospitals

Hospital facilities are among the largest generators of solid waste today on a per capita basis. Much of the waste from hospitals comes from the trash basket at the side of the patient's bed, and includes newspapers, magazines, paperbacks, packaging and discarded flowers. In addition, broken syringes, discarded splints, masks, rubber gloves and broken glass ampoules, etc., generated by other routine activities add to the daily waste stream.

During the last decade, there has been an increasing trend towards the use of disposable products or single-purpose items, which now account for more than one-half of the total hospital waste generated. Nightgowns, sheets, bed pads, pillow cases, etc., which used to be sterilized and reused have been replaced with one-time-use, throw-away articles. Depending on the institution's or hospital's preference for using throw-away materials, the waste generation rate can vary substantially from hospital to hospital.

Pollock (1978) and Airan et al. (1980) conducted studies on waste generation rates in some US hospitals between 1968-1980. In addition, McCrate (1980) carried out a similar study at the Royal Jubilee Hospital located in British Columbia during 1980. The findings of these studies are summarized in Table 7.4A-2. As can be seen from the Table, the waste generation rates in these studies fall within a range of 1.5-7.5 kg/bed/day.

The surveys carried out for these institutions also reflect the situation in Ontario hospitals. This was confirmed in a study carried out by Sirman in 1985 in which he found that the biomedical waste generation rate in Ontario hospitals ranged from 2.3 to 7.7 kg/bed/day (Sirman and Ivan 1985).

The total biomedical waste stream also includes infectious waste generated from special care beds in surgical rooms, isolation wards and special medical procedure rooms. A 1985 survey sponsored by the Ontario Hospital Association showed that the average-size Ontario hospital generates approximately 0.75 kg/day of infectious waste for each special care bed. This value is based on 75 responses from 164 facilities surveyed (Health Care Occupational Health and Safey Association 1985).

(ii) Medical Laboratories

The waste produced from private and diagnostic laboratories (Type A, Class 3(b) in Table 7.4A-1 is considered infectious. The waste generation rate is estimated to be 0.2 kg/patient/day and the total quantity of infectious waste from these facilities is higher than that generated in all Ontario hospitals on an annual basis.

Medical laboratory waste contains a very high percentage of plastics (50-60%), the majority of which are non-halogenated. The balance is composed of wet materials such as bodily fluids, blood and used diagnostic reagents, as well as small quantities of paper and cellulose. Most of the medical laboratory waste currently generated is being shipped out of Ontario for disposal. The remaining portion is either incinerated or steam autoclaved and then disposed of in a landfill.

(iii) Summary

Depending on an institution's practice of using throw-away materials, the biomedical waste generation rate varies from hospital to hospital. It is recommended that each facility review and document its own practice in order to more accurately determine its waste generation rate. If the actual rate is not available, the Ministry recommends that the following values be used for sizing the capacity of a new biomedical waste incinerator:

(iv) Predicted Waste Generation Rate From:

(a) Hospitals

- Total biomedical waste* - 6 kg/bed/day
- Special care waste - 1 kg/special care bed/day

(b) Medical laboratories

TABLE 7.4A-2

Summary of Waste Generation Rates at Selected Hospitals in the United States and Canada

Source	Generation Rate (kg/bed/day)
Pollock (1978)	
o 1968 survey	3.0
o 1974 survey	4.1
o 1975 survey	4.3
o West Coast Teaching Hospital	3.7
o 1978 estimate	7.5
o conclusion of Pollock	3.0-7.5
Airan et al. (1980)	
o 1980 survey	4.3-5.8
McCrate (1980)	
o 1980 survey	1.5-3.9

° Total laboratory waste - 0.2 kg/patient/day

Characterization of Biomedical Waste

Introduction

This section discusses the physical and chemical characteristics of biomedical waste generated in Ontario, with emphasis on the human and animal anatomical components, moisture content, proportion of plastics and heating value (as fired).

Physical and Chemical Characteristics

Tables 7.4A-3 and 7.4A-4 summarize the properties of the biomedical waste in terms of higher heating value (HHV), moisture content, component weight percent and bulk density expressed in metric and imperial units, respectively. The breakdown of the waste classifications and color coding in the tables are based on the Canadian Standards Association guidelines for "Handling of Waste Materials within Health Care Facilities" (1981). The ranges of weight percent are based on field measurements as well as data provided by the institutions. The values in Column 7 in each table reflect the weighted HHV range of the waste components (as-fired) under each classification and have been calculated from the data given in columns 3, 4 and 6. The last column (Column 8) represents typical values based on interpretation of actual findings from an Ontario facility.

* This includes special care waste, but excludes kitchen waste.

As can be seen from the wide range of HHV, discretion should be exercised in using the data for the design of a biomedical waste incinerator. A thorough evaluation of the waste should be carried out to identify its characteristics to facilitate the proper design of the incinerator.

Based on the data from Table 7.4A-3 the typical higher heating values for each type of biomedical waste are summarized in Table 7.4A-5. It can be seen that yellow-bag waste generally has a heating value of 21,000 kJ/kg or greater. All other color coded bags 6,700 kJ/kg or less and may require the use of auxiliary fuel when being incinerated.

It may be possible to blend different color coded bags of waste to modify the overall composition of the waste charged into the incinerator. In this way, waste with a low heat content can be combined with waste of higher heat content to form a waste capable of self-sustaining combustion. If all waste types in Table 7.4A-5 are combined equally, the average HHV would be 13,877 kJ/kg, which is higher than that of typical municipal solid waste (11,140 kJ/kg). However, the possibility of blending must be evaluated on a case-by-case basis.

The typical chemical composition of animal anatomical waste and the associated combustion data are given in Table 7.4A-6. It should be noted that this is only one type of biomedical waste and does not include components such as plastics and cellulose gauzes, which have a higher heat content than anatomical waste.

TABLE 7.4A-3

Characterization of Biomedical Waste (Metric Units)

Waste Class	Component Description	Typical Component Weight Percent (as fired)	HHV Dry Basis (kJ/kg)	Bulk Density as Fired (kg/m^3)	Moisture Content of Component (Weight Percent)	Weighted Heat Value Range of Waste Component (kJ/kg)	Typical Component Heat Value of Waste as Fired (kJ/kg)
A1	Human Anatomical	95-100	18600-27900	800-1200	70-90	1770[a]-8370[b]	2800
(Red Bag)	Plastics	0-5	32500-46400	80-2300	0-1	0-2300	400
	Swabs, Absorbants	0-5	18600-27900	800-1000	0-30	0-1400	200
	Alcohol, Disinfectants	0-0.2	25500-32500	800-1000	0-0.2	0-70	50
							3450
A2	Animal Infected Anatomical	80-100	20900-37100	500-1300	60-90	1670-14840	3500
(Orange Bag)	Plastics	0-15	32500-46400	80-2300	0-1	0-6960	1000
	Glass	0-5	0	2800-3600	0	0	0
	Beddings, Shavings Paper, Fecal Matter	0-10	18600-20900	320-730	10-50	0-1880	1400
							5900
A3 (a)	Gauze, Pads, Swabs	60-90	18600-27900	80-1000	0-30	7810-25110	15000
(Yellow Bag)	Garments, Paper Cellulose						
	Plastics, PVC, Syringes	15-30	22500-46400	80-2300	0-1	3340-13920	7540
	Sharps, Needles	4-8	140	7200-8000	0-1	6-10	10
	Fluids, Residuals	2-5	0-23200	1000-1020	80-100	0-230	70
	Alcohols, Disinfectants	0-0.2	16200-32500	800-1000	0-50	0-70	30
							22650
A3 (b)	Plastics	50-60	32500-46400	80-2300	0-1	16090-27840	21000
(Yellow Bag)	Sharps	0-5	140	7200-8000	0-1	0-10	0
Lab Waste	Cellulosic Materials	5-10	18600-27900	80-1000	0-15	790-2790	1500
	Fluids, Residuals	1-20	0-23200	1000-1020	95-100	0-230	70
	Alcohols, Disinfectants	0-0.2	25500-32500	800-1000	0-50	0-70	50
	Glass	15-25	0	2800-3600	0	0	0
							22620

TABLE 7.4A-8 (continued)

Waste Class	Component Description	Typical Component Weight Percent (as fired)	HHV Dry Basis (kJ/kg)	Bulk Density as Fired (kg/m^3)	Moisture Content of Component (Weight Percent)	Weighted Heat Value Range of Waste Component (kJ/kg)	Typical Component Heat Value of Waste as Fired (kJ/kg)
A8 (c)	Gauze, Pads, Swabs	5-30	18600-27900	80-1000	0-30	650-8370	2300
(Yellow Bag)	Plastics, Petri Dishes	50-60	32500-46400	80-2300	0-1	16090-27840	21000
R & D	Sharps, Glass	0-10	140	7200-8000	0-1	0-10	0
on DNA	Fluids	1-10	0-23200	1000-1020	80-100	0-460	230
							23530
B1	Non-Infected						
	Animal Anatomical	90-100	20900-37100	500-1300	60-90	1880-14840	3000
(Blue Bag)	Plastics	0-10	32500-46400	80-2300	0-1	0-4640	2300
	Glass	0-3	0	2800-3600	0	0	0
	Beddings, Shavings, Fecal Matter	0-10	18600-20900	320-730	10-50	0-1880	1400
							6700

TABLE 7.4A-4

Characterization of Biomedical Waste (Imperial Units)

Waste Class	Component Description	Typical Component Weight Percent (as Fired)	HHV Dry Basis (BTU/lb)	Bulk Density as Fired (lb/ft^3)	Moisture Content of Component (Weight Percent)	Weighted Heat Value Range of Waste Component (BTU/lb)	Typical Component Heat Value of Waste as Fired (BTU/lb)
A1	Human Anatomical	95-100	8000-12000	50-75	70-90	760[a]-3600[b]	1200
(Red Bag)	Plastics	0-5	14000-20000	5-144	0-1	0-1000	180
	Swabs, Absorbants	0-5	8000-12000	5-62	0-30	0-600	80
	Alcohol, Disinfectants	0-0.2	11000-14000	48-62	0.02	0-28	20
							1480
A2	Animal Infected Anatomical	80-100	9000-16000	30-80	60-90	720-6400	1500
(Orange Bag)	Plastics	0-15	14000-20000	5-144	0-1	0-3000	420
	Glass	0-5	0	175-225	0	0	0
	Beddings, Shavings Paper, Fecal Matter	0-10	8000-9000	20-46	10-50	0-810	600
							2520
A3 (a)	Gauze, Pads, Swabs	60-90	8000-12000	5-62	0-30	3360-10800	6400
(Yellow Bag)	Garments, Paper, Cellulose,						
	Plastics, PVC, Syringe	15-30	9700-20000	5-144	0-1	1440-6000	3250
	Sharps, Needles	4-8	60	450-500	0-1	3-5	5
	Fluids, Residuals	2-5	0-10000	62-63	80-100	0-11	30
	Alcohols, Disinfectants	0-0.2	7000-14000	48-62	0-50	0-28	15
							9700
A3 (b)	Plastics	50-60	14000-20000	5-144	0-1	6930-12000	9000
(Yellow Bag)	Sharps	0-5	60	450-500	0-1	0-3	0
Lab Waste	Cellulostic Materials	5-10	8000-12000	5-62	0-15	340-1200	650
	Fluids, Residuals	1-20	0-10000	62-63	95-100	0-100	30
	Alcohols, Disinfectants	0-0.2	11000-14000	48-62	0-50	0-28	20
	Glass	15-25	0	175-225	0	0	0
							9700

TABLE 7.4A-4 (continued)
Characterization of Biomedical Waste (Imperial Units)

Waste Class	Component Description	Typical Component Weight Percent (as Fired)	HHV Dry Basis (BTU/lb)	Bulk Density as Fired (lb/ft^3)	Moisture Content of Component (Weight Percent)	Weighted Heat Value Range of Waste Component (BTU/lb)	Typical Component Heat Value of Waste as Fired (BTU/lb)
A3 (c)	Gauze, Pads, Swabs	3-30	8000-12000	5-62	0-30	280-3600	1000
(Yellow Bag)	Plastics, Petri Dishes	50-60	14000-20000	5-144	0-1	6930-12000	9000
R & D	Sharps, Glass	0-10	60	450-500	0-1	0-6	0
on DNA	Fluids	1-10	0-10000	62-63	80-100	0-200	100
							10100
B1	Non-infected Animal Anatomical	90-100	9000-16000	30-80	60-90	810-6400	1400
(Blue Bag)	Plastics	0-10	14000-20000	5-144	0-1	0-2000	1000
	Glass	0-3	0	175-225	0	0	0
	Beddings, Shavings, Fecal Matter	0-10	8000-9000	20-46	10-50	0-810	600
							3000

TABLE 7.4A-5

Typical Higher Heating Values for Various Biomedical Waste Classifications (as Fired)

Classification		Colour Code	Typical HHV (kj/kg)
Type A, Class 1		Red	3,450
Type A, Class 2		Orange	5,900
Type A, Class 3	a)	Yellow	22,650
	b)	Yellow	22,620
	c)	Yellow	23,530
Type B, Class 1		Blue	6,700

TABLE 7.4A-6

Chemical Composition of Animal Anatomical Waste and Combustion Data

Ultimate Analysis (Whole Dead Animal)

Constituent	As Charged % by Weight	Ash and Moisture Free Combustible % by Weight
Carbon	14.7	50.80
Hydrogen	2.7	9.35
Oxygen	11.5	39.85
Water	62.1	-
Nitrogen	Trace	-
Mineral (ash)	9.0	-

Dry combustible empirical formula - $C_5 H_{10} O_3$

Combustion Data
(Based on 1 kg of Dry Ash-free Combustible)

Constituent		Quantity kg	Volume Nm^3
Theoretical air		7.03	5.77
40% sat at 15.5°C		7.06	5.81
Flue gas with	CO_2	1.86	1.00
Theoretical	N_2	5.40	4.57
Air 40%	H_2O formed	0.76	1.00
Saturated	H_2O air	0.03	0.04
Products of Combustion total		8.05	6.61

Gross Heat of Combustion 20,471 kJ/kg

Microbiological Characteristics

Care should be exercised when handling biomedical waste primarily due to its infectious or hazardous nature. Testing was carried out by Barbeito et al. to evaluate whether sterilization, or a total pathogen kill, could be achieved by incineration (Barbeito and Shapiro 1977). His research indicates that destruction of micro-organisms within the incinerator depends on the temperature and time exposure. Barbeito indicates that any emission of micro-organisms from the incinerator could be attributed to insufficient retention time and temperature as a result of the following conditions:

- initial charging of the incinerator before operating temperatures are achieved;
- failure to preheat the refractory lining;
- temperature fluctuations caused by intermittent use;
- exceeding design linear velocities, thereby reducing the retention time;
- charging beyond incinerator capacity; and
- excessive moisture content of the waste.

Other factors such as the type of refractory lining, the positioning and number of burners, and the precision of temperature controlling devices, can also have a significant bearing on the effectiveness of sterilization.

Barbeito recommends that the following measures be taken to ensure the complete destruction of micro-organisms in the incinerator:

- the minimum temperatures in the primary and secondary chambers should be maintained at no less than 760° (1400°F) and 870°C (1600°F), respectively;
- a minimum of one-half hour should be used as a preheat period for the secondary chamber prior to feeding the waste into the incinerator;
- if an incinerator is not operated continuously, only non-infectious waste should be incinerated initially after the unit is fired up; infectious waste should only be fed into the incinerator after the secondary chamber has been on for one-half hour; and
- each incinerator should be tested with bacterial spores, the most resistant micro-organisms, to establish the minimum temperatures required to achieve complete sterilization.

The destruction of micro-organisms in the incinerator ash also depends on temperature and time exposure. It is therefore desirable to discharge the ash on a batch basis at the end of each incineration cycle (typically 4-6 hours) to provide a long solids retention time in the primary chamber in order to achieve complete destruction of the micro-organisms.

Technical Specification for Biomedical Waste Incinerator

General

The incinerator shall be a controlled-air, grateless type dual chamber thermal-destruction unit that is approved for hospital use for general and pathological waste by the Ministry of Environment, Air Management Branch, Ministry of Health, C.G.A. and Fuel Safety Branch, and other authorities having jurisdiction. The incinerator supplier shall make application and gain approval from the authorities having jurisdiction.

In addition to submitting a full description of the incinerator offered, the vendor must complete the incinerator data sheet (as appended), clearly indicating any deviation from published specification and including a reference list detailing past experience.

Operating Criteria

(i) Capacity

The unit shall be designed to burn a minimum of ----- lbs/hr. of waste with an average density of ------ lbs/cu.ft calorific value of 8,000 btu/lb and moisture content of 20%. The waste stream will be made up of approximately the following types of waste:

----- lbs/day of human/animal anatomical waste.
----- lbs/day of non-anatomical infectious waste.
----- lbs/day of sharps in hard shell containers, ------ containers.
----- lbs/day of non-infectious general hospital waste.

(ii) Design

(a) Secondary Chamber

The incinerator shall provide a minimum secondary chamber retention time of 1 sec. at maximum burning rate. The retention time shall be calculated at 1000°C (1832°F) and shall be accomodated within the confines of the incinerator unless specifically approved otherwise.

The incinerator secondary chamber shall be thermally designed for 1100°C (2012°F). The design shall promote maximum turbulence to ensure complete oxidation of all combustibles.

(b) Primary Chamber

Primary chamber shall be sized to ensure sufficient residence time for complete decomposition of the waste, total heat release should not exceed 25000 btu/cu.ft/hr, and hearth loading should not exceed 10 lbs/hr/ft^2 for type 4 waste, and 15 lbs/hr/ft^2 for general biomedical waste. Provision should be made in hearth design to prevent leakage of fluid from the chamber or into the primary airports. Hearth design to ensure even air distribution throughout the waste bed and in such a way as to prevent

'overfire air' conditions developing. Sidewall air energy will not be permitted.

Operating Mode

(i) The incinerator shall be the batch feed type and shall have a primary chamber capacity of ----- cubic feet. Primary chamber and loading door design shall be such as to allow for maximum possible utilization of primary chamber volume and ease of access for loading and de-ashing.

or

(ii) The incinerator shall be supplied with a hydraulically operated ram feeder assembly of ----- cu. yard capacity. The feeder assembly shall include hydraulically operated fire door, manually/hydraulically operated hopper door, hydraulic power pack and all associated controls.

Construction

(i) The incinerator shall be internally lined with 3 1/2 inches of block insulation plus 4 1/2 inches of high quality, low iron content refractory, rated for use at 2500°F, such that the cold face temperature of the incinerator will be approximately 160°F. The manufacturer shall show by calculation that his cold face temperature shall be at or about 160°F, based on prevailing site conditions. The refractory shall be secured to the shell with stainless steel anchors on no more than 12" centers.

(ii) The incinerator shell shall be constructed with mild steel plate of no less than 3/16" thickness. The shell shall be suitably reinforced using structural steel members.

(iii) The primary chamber shall have a charging/de-ashing door at least 48 inches high and 30 inches wide. This door shall be electrically interlocked to prevent the primary burners firing with the door open.

(iv) The secondary chamber shall have an access door for inspection and clean-out.

(v) The incinerator shall be painted with one primer coat and one finish coat of heat resistant enamel paint.

Components and Auxiliary Equipment

(i) To avoid infiltration of tramp air, the primary burners will be of the sealed type; package burners are not acceptable.

(ii) To ensure optimum fuel efficiency the secondary chamber temperature shall be controlled via a fully modulating split-range temperature indicating controller. One signal shall control the burner firing rate, the other signal shall control the secondary chamber combustion air flow.

(iii) Primary chamber temperature control will be effected by control of primary combustion air flow via a temperature-indicating control. Control function may be high-low or fully modulating.

(iv) A dual element thermocouple shall be provided in the primary and secondary chambers. The second element shall send a signal to 24-hour circular open-chart recorder. The recorder shall be supplied by the incinerator manufacturer/by others.

The control panel shall be pre-wired, tested and will house the following controls as a minimum:

(v) Sight glasses shall be provided in both the primary and secondary chambers permitting safe observation of the combustion process throughout the burn.

(vi) Incinerator Controls

- o fused disconnect switch
- o control transformer
- o power on switch
- o cycle start push button interlocked to purge timer
- o secondary chamber indicating temperature controller
- o primary chamber indicating temperature controller
  cycle timer
- o burndown and cooldown timers
- o emergency stop pushbutton
- o auto/manual switches for:

  . primary burner(s)
  . secondary burner
  . combustion air fans

- o indicating lights for:

  . power on
  . ready to feed
  . cycle in progress
  . cycle in complete
  . burner on (2)
  . flame failure
  . fans on

- o All necessary relays, limit switches, motor starters, transformers and fuses shall also be included.

See Table 7.4A-7.

TABLE 7.4A-7

Biomedical Waste Incinerator Form

MODEL: _____

SIZE: _____

Capacity lbs/hr. - Waste as specified: _____

Type 4 specified: _____

Auxiliary Fuel Usage _____ KW (_____) BTU/HR

Electrical Power Requirement:

Primary Chamber:

- Volume (ft.3): _____
- Heat Release BTU/cu. ft.: _____
- Hearth Area: _____
- Hearth Loading lbs/hr/ft 2: _____
- Refractory Thickness (in.): _____
- Insulation Thickness (in.): _____
- Refractory Temp. limitation (Deg. F): _____
- Projected Cold Face Temp: _____
- Shell Thickness: _____
- Charging/Deashing Door Size: _____
- Burner Capacity BTU/hr: _____
- Primary Air Fan Capacity (SCFM): _____

Secondary Chamber:

- Volume (ft.3): _____
- Gas Retention Time (secs @ 1832°F): _____
- Refractory Thickness (in.): _____
- Insulation Thickness (in.): _____
- Refractory Temp. Limitation (Deg. F): _____
- Projected Cold Face Temp: _____
- Shell Thickness: _____
- Cleanout Door Size: _____
- Burner Capacity BTU/hr: _____
- Secondary Air Fan Capacity (SCFM): _____

Breeching/Stack

- Inside Diameter: _____

Classifications

The Ministry will classify biomedical waste according to the categories presented in Table 7.4A-1. The Ministry recommends that biomedical waste be segregated and packaged in leakproof, color-coded plastic bags to facilitate identification, handling, storage, decontamination and transportation.

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7.5 Ocean Disposal

7.5.1 Introduction

The dumping of waste at sea is an example of a "dilute and disperse" method of disposal - the waste is dispersed into the ocean so that it is immediately diluted to a concentration at which it caused negligible local harm. The composition of the waste must be such that it pollutants are then degraded, neutralized or otherwise transformed by natural microbiological and chemical processes. The rate of addition must take into account the efficacy of these processes with respect to the chemical, biological and toxicological characteristics of the waste. Unassimilated substances such as certain metals or persistent toxic organics will accumulate in the ocean since nature is not capable of altering them. Degradable wastes, given sufficient time and dilution, can become incorporated in the natural oceanic background.

Ocean dumping is generally regarded as a short or medium-term option for wastes which, for economic or technical reasons, are difficult to treat on land. National authorities, when considering disposal at sea as an alternative for land-based disposal and treatment of wastes should carry out a comprehensive environmental impact assessment to identify a solution which poses least detriment to the environment.

In general, five sources of marine pollution can be identified (International Maritime Organization [IMO] 1985).

(1) Land-based Source - contaminants entering the marine environment through runoff from land (pipelines, outfalls, rivers, etc.).

(2) Vessel-generated Pollution - operational decharges from ships (e.g., deblasting or cleaning of tanks) or resulting from maritime accidents.

(3) Dumping at sea - the disposal of land-based industrial and municipal wastes at sea, from ships.

(4) Sea-bed activities - the releases of contaminants directly arising from activities such as mineral exploration.

(5) Pollution from or via the atmosphere - Fallout or coprecipitation of contaminants released into the atmosphere from land, sea or air-based activities.

This section concentrates on Item (3): Sea Dumping.

7.5.2 International Conventions

The ocean is an international resource. It is an important source of food, it establishes the climate and oxygen-carbon dioxide balance in the atmosphere and provides water for the Earth's hydrocycle. Improper use of the ocean as a receptacle for waste can jeopardize this resource and cause serious ecological damage.

A comprehensive international policy on ocean disposal is therefore needed, to end unregulated dumping, prohibit the disposal of materials harmful to the marine environment and lay down guidelines for the safe disposal of acceptable wastes. Table 7.5-1 lists some of the Conventions that have been promulgated through international cooperation, applying to various oceanic locations (IMO 1985).

Of these, the "International Convention on the Prevention of Marine Pollution by Dumping of Wastes and other Matter," commonly called the "London Convention," is applicable worldwide and has, at present, 61 countries, and their dependencies, as Contracting Parties. The International Maritime Organization (IMO) serves as its secretariat, and meetings are held annually at IMO Headquarters in London. Acceding governments are required to comply with the provisions of the Convention, and conduct sea disposal in a safe and responsible manner. Most Contracting Parties have, in addition, formulated national legislation enforcing the application of the Convention (for example, the Food and Environment Protection Act 1985, in the UK).

Global rules, standards and procedures for the prevention and control of marine pollution from land-based sources, from the atmosphere or from sea bed activities have not yet been developed, although the need to take measures for pollution prevention from these sources has been recognized for many years. The Geneva Convention on the High Seas, 1958, already requests States to draw up regulations to prevent pollution of the seas resulting from the exploitation and exploration of the sea-bed and its subsoil. On the other hand, the recently adopted Convention on the Law of the Sea provides a broad outline for action concerning the marine pollution from all sources at the global level, including land-based sources, the atmosphere and sea-bed activities.

A further initiative aimed at global control of marine pollution was taken by UNEP in 1983 with the convening of a Working Group on the Protection on the Marine Environment against Pollution from Land-based Sources resulting in the formulation of the "Montreal Guidelines (UNEP 1985).

Other global Conventions covering discharges into the sea from ships and the prevention of accidental pollution are MARPOL (International Convention for the Prevention of Pollution from Ships) and SOLAS (Safety of Life at Sea), both of which are administered by IMO.

7.5.3 Categorization of Wastes

(i) Limitation on Waste Type

Ocean disposal should be limited to those wastes which are rapidly rendered harmless by natural, physical, chemical or biological processes. The London Dumping Convention categorized substances according to their potential for causing damage to the marine environment. Dumping of substances on the "black list" (Annex 1 of the Convention) is prohibited because of their toxicity, persistence and bio-accumulation.

DIPLOMADO EN CONTROL DE LOS RESIDUOS
GENERADOS EN HOSPITALES
Y OTROS CENTROS DE SALUD

TÉCNICAS DE EVALUACIÓN DE IMPACTO AMBIENTAL

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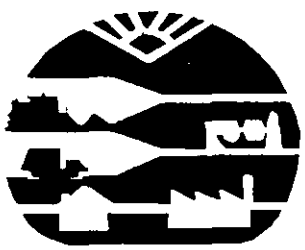

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Information for Environmental Impact Assessment

Robert Jeltes *

THE ROLE OF INFORMATION IN EIA

When making decisions about activities one should take in consideration significant impacts on the environment. EIA is meant to provide decisionmakers with the information necessary in this respect. So, EIA is a decisionmaking information tool.

To be able to perform EIA in such a way that decisionmakers can make optimal use of it, many kinds of relevant data and raw information have to be collected, refined and aggregated. In the execution of EIA in the Netherlands, several different participants are involved. They are the proponents of new plans or activities, the consultants engaged by the proponents, competent authorities, legal advisers, an independent review commission and public participants.

According to the Dutch legislation, EIA involves a process in which the following phases can be distinguished.

- Scoping of the subjects and predictions to be taken into consideration in the Environment Impact Statement (EIS), which results in the formulation of guidelines for the EIS,
- Preparation of the EIS;
- Review of the EIS;
- Decisionmaking;
- Realization of the plan or activity, and

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• Mon. ..ng and post-project analysis.

Broadly speaking, other countries performing EIA will have to do a similar kind of process. During the different phases of EIA, all participants need various kinds of information.

INFORMATION FOR EIA: THE DEMAND SIDE

In this section a broad inventory of the different kinds of information needed in EIA is provided. The items to be covered in EIA, according to Dutch legislation, will be mentioned. These place their own demands on the information supply. A more general picture of the information demand of EIA can be derived from a so-called environmental causality chain. In such a chain, the impact of any human activity on the environment is shown in a schematic form. Figure 1 shows such a chain which could be useful to check the types of information one might need in an EIA.

Dutch EIA legislation also includes the main requirements for the contents of an EIS (Table 1, left column). These requirements have the consequences for the information demand presented in the right column of the table.

As early as the scoping phase the same kind of information, albeit in a more global form, is required. The information demand will concentrate on (alternatives for) activities, the environmental quality of the locations(s) in consideration, the effects to be predicted and the prediction methods to be used.

Information about effects is derived by using prediction methods and information about the (existent and future environmental) baseline situation and the planned activity. With data about the planned activity, one can apply prediction methods to calculate the contributions of the new activity to the existent (and future) environmental baseline situation. Also the information can be used to make post-activity assessments, and so get information useful for assessment of the situation to be expected after realization of the planned activity (Figure 2).

To obtain information on emissions and ambient concentrations one needs prediction methods. For information about impacts on receptors one needs data on exposition-effect relations, environmental standards and policy goals. From this, one can understand that a variety of information is needed to execute EIA. The value of the assessments performed

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Figure 1: The contribution of information to EIA

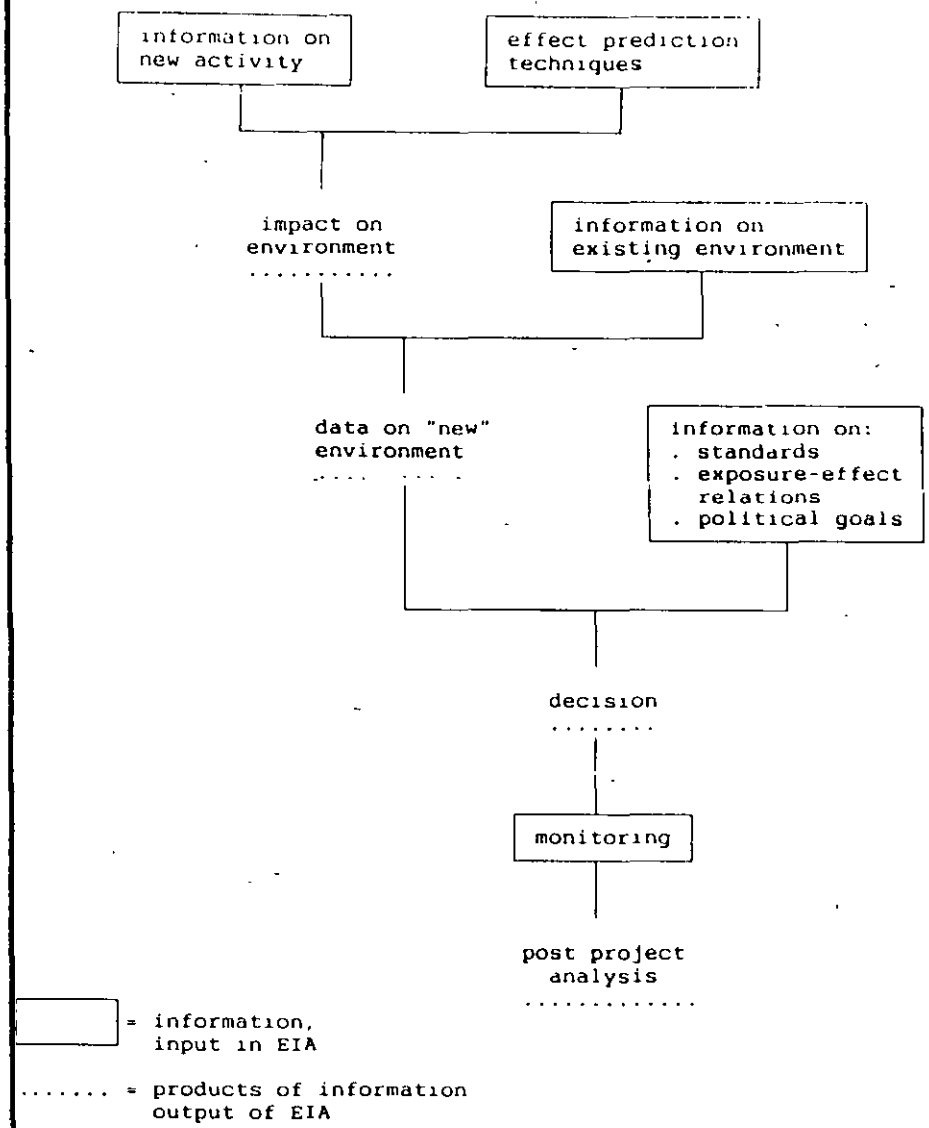

Figure 2: Example of an environmental causality chain

ACTIVITY → EMISSIONS → TRANSPORT, DISTRIBUTION → AMBIENT CONCENTRATIONS → IMPACT ON RECEPTORS

Table 1: Information demand based on content of Dutch EIS

EIS Content	Information Demand
- Description of activity/ alternatives	Processes, techniques Fuels, raw materials Products, emissions effluents, waste, risk mitigation techniques Clean technology
- decision processes in which use will be made of the EIS	Inventory of relevant previous decisions
- baseline situation around the location(s) in consideration for the activity/ alternatives	Data on the environmental quality Flora and fauna inventories Data on land use in the area in consideration
- impact on the environment	Effect prediction methods
- comparison of the impact of activity and alternatives	Political goals Environmental quality standards Exposure-effect relations Expert knowledge
- post project analysis	Possibilities for monitoring

depends on the existance, accessibility and quality of the information required.

INFORMATION SUPPLY

A brief analysis of the information sources available in the Netherlands is presented below based on the causality chain shown in Figure 2

Physical Planning and Economic Activities

Economic statistical data are published regularly by the Central Bureau of Statistics However, as far as these data are concerned, the collection was not started with an eye to the requirements of EIA In EIA one needs relevant information on raw materials, energy supply, processes, clean technology and products as well as information on emissions and waste.

Emissions and Waste Streams

The Physical Planning Agency provides a registration system for emissions. For waste streams, an information system has been developed by the National Institute of Public Health and Environmental Protection Information about intrusions in the environment (like canal diggings, etc) is available, but this "diffused" over a number of data bases in the Netherlands.

Transport and Distribution of Pollution

For this item one needs data and information on activities and their emissions. One also needs special data as input for models used in this field. Data and information about models are found in international literature. Intermediary reviews might be useful to improve accessibility

Monitoring of pollutants: flora and fauna inventories

Monitoring networks exist for ambient concentrations in the atmosphere, surface water and ground water. Also, some big monitoring stations track soil and biota. A great deal of information is available on the distribution of flora and fauna. However, large areas are not sufficiently covered and a number of species are not considered. There is also a constant need for new inventories, the state of flora and fauna changes. To this end, several projects have been started and others are being developed.

Effe dose-effect relations

I know of no information bases or systems established especially for the registration of environmental effects on biota and goods. In case of environmental accidents, effects on health and the environment are investigated on an ad hoc basis.

For information on dose-effect relations, one can make use of international literature. Dose-effect relations are included in the basic documents on toxic substances which are being drafted in the Netherlands.

In summary, one can say that much of the information necessary for EIA can be obtained in the Netherlands. However, the following shortcomings indicate that improvements should be considered:

- difficulties with respect to the accessibility;
- gaps in information on sources of pollution;
- shortcomings in the accessibility of information on intrusions in the environment;
- lack of information about the environmental quality of the soil;
- accessibility of data on exposition/dose-effect relations;
- availability and accessibility of data on effects on man, biota and goods; and,
- gaps in the knowledge about flora and fauna distribution.

IMPROVEMENTS IN INFORMATION SUPPLY

One of the findings of the evaluation of the experiments with EIA in the Netherlands in the seventies was that timely production of quality EIAs was hampered by insufficient accessibility of the widely dispersed information sources. This applied to all necessary information (Figure 1). In addition, lack of data led to an inadequate EIA information to the problem of accessibility, there is a lack of data, which leads to an inadequate information supply in EIA. In the following, a short review of a number of improvements in the fields of accessibility and supply of data are described.

Effect Prediction Methods

First, the accessibility and comprehensibility of one specific type of information, viz. effect prediction methods, has been improved by the preparation of a series of systematic review books on prediction methods in the Netherlands (Jeltes and Hermens). These handbooks are meant as aids for all parties involved in EIA. The series is composed of sections on environmental compartments, polluting agents and receptors. Each handbook contains an introduction to the theory and practice of prediction. Furthermore, a systematic review of the existing methods is presented. Relatively simple keys are helpful in retrieving methods specifically useful for one's concrete problem. The handbooks also contain information on policy instruments, sources of pollution, literature, monitoring networks etc.

In this way, this series can be helpful for predicting in the context of EIA. The introduction has appeared in English (VROM, 1984). One on health has been described during a conference (Aiking et al)

Improvement of accessibility of information

To make EIA information more accessible, the possibilities of a national referral center for environmental information were investigated (Adriaanse et al, 1988). Such a center has been established at the National Institute of Public Health and Environmental Protection in Bilthoven. Since then people involved in EIA and others have used it. The integrated and automated system is composed of referral subsystems for:

- (profiled) sources of information (organizations, institutes, departments, libraries) with their specialistic knowledge ("who, what, where")
- literature on the environment
- data bases with environmental information of locations

Cooperation with those who control information sources progressed smoothly because the independence of the sources included in the reference system is not affected. Furthermore, the center can help to stimulate the application of information generated in institutions and, thus, promote their activities. The establishment of this center has lead - in cooperation with others - to the development of a national environmental

thesaurus of the Multilingual Descriptor System of the European Community

Biotic Information

For a number of years cooperation and coordination have been established between national and provincial authorities for a number of basic environmental inventories regarded as importance. A number of subjects such as collection and storage of data, supply of information, standardization and research are included in this cooperative effort. Establishment of a cooperation structure with a central facility for storage and processing of the results of inventories is a goal. This cooperation will increase the accessibility of the information on biotics

Sources of Pollution

In the context of other developments on the improvement of the information supply in the field of sources of pollution is being developed. It is expected that EIA will profit from these activities. EIA also may have benefit from the so-called base documents which are being developed. These are meant to be used as aids for environmental management. Some base documents may include information on toxic substances, waste streams, products and branches of industry. Others concerning substances include information on physico-chemical properties, monitoring, sources, exposure, toxicity, mitigation possibilities etc.

CONCLUSIONS

In the Netherlands legal demands determine the information requirements of EIA. The minimum that is required is information on. the planned activity, the environment concerned, effect prediction and exposure-effect relations. About these items, information can be found in international literature and databases However, new intermediary facilities being established in the Netherlands can help to bridge the gap between information supply and demand.

Information on existing effect prediction methods is being collected in a series of handbooks for EIA. EIA studies may also profit from base documents on subjects such as toxic substances, waste streams, branches of industry etc., which are prepared in another context.

For information on environmental quality, the Netherlands has at its disposal monitoring networks for air, rain water, surface water and ground water.

Information on flora and fauna is collected on different government levels by many institutions. A cooperative facility is being established for coordination of the efforts in this field on the different government levels To improve the accessibility and the application of all environmental information collected in the Netherlands - now dispersed over many sources - a national referral center has been developed.

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DAÑOS AL AMBIENTE POR CONTAMINANTES, SU IDENTIFICACION Y EVALUACION EN LOS ECOSISTEMAS

Biol. Jaime J. Saavedra Solá

Los contaminantes que se generan como producto de las diversas actividades del hombre, provocan una serie de afectaciones en los organismos vivos (incluyendo a las propias poblaciones humanas), y son un factor más, que contribuyen conjuntamente con otras acciones como puede ser el cambio de uso del suelo y eliminación de ciertos tipos de vegetación, en el impacto total de degradación sobre los ecosistemas terrestres y acuáticos, que se pueden observar en amplias regiones a nivel mundial.

En muchos países incluyendo México, se han implementado una serie de herramientas de planeación ambiental como es el caso de las Evaluaciones de Impacto Ambiental (EIA) y los Estudios de Riesgo, cuyo objetivo principal (como es reconocido en las primeras), es el de maximizar los beneficios socioeconómicos de la población, y la reducción, mitigación y/o eliminación de los impactos negativos que un proyecto, programa o actividad de desarrollo puedan ejercer en el medio (natural y social).

En el desarrollo de las EIA, se dan una serie de actividades entre las que destaca la actividad de monitoreo. El monitoreo se puede definir como la colección sistemática de datos, a través de una serie de medidas repetitivas de verificación de la dinámica ambiental, que pudo o se está alterando cuanti-cualitativamente a raíz de la ejecución u operación de la obra, programa y/o actividad.

Entre las razones que destacan para promover el monitoreo de los impactos se tienen las siguientes:

1. Son un factor de advertencia temprana si los impactos son más severos que como se habían estimado originalmente.

2. Pueden ayudar a señalar el deficiente manejo de medidas de mitigación y proponer entonces las adecuadas.

3 Verificar que las condicionantes en el manejo de la materia y energía de los diversos procesos, incluyendo las descargas de aguas residuales, niveles de ruido, emisiones a la atmósfera, etc , se estén cumpliendo.

4. Ayudan a incrementar el conocimiento de las afectaciones que puede provocar una acción humana en los diversos medios

5. Mejorar la potencialidad predictiva de futuros estudios de impacto

El monitoreo ambiental de los diferentes contaminantes para poder verificar y predecir los efectos ecológicos que provoquen en el medio natural y, principalmente en la salud del hombre, tiene que tomar en cuenta la distribución y transporte de las substancias tóxicas en los ecosistemas, ésta dependerá de factores tales como:

a. características fisicoquímicas y transformaciones biológicas de los contaminantes en el ambiente.

b. uso y producción total de contaminantes y precursores.

c tasas, tipos de aplicación y condiciones de los ecosistemas

d respuestas ecotoxicológicas de los contaminantes

Los impactos de las substancias tóxicas (bien sea que sean naturales o sintéticos), especialmente de aquellos de bajo nivel de efectos crónicos, son difíciles de evaluar a diferencia de aquellos de gran magnitud que frecuentemente se asocian a eventos catastróficos (filtraciones de petróleo vs derrame de un buque tanque).

Moriarty, F. (1990), señala que la cantidad de compuestos químicos (muchos de ellos considerados como contaminantes) que se liberan al ambiente se puede estimar al conocer sus ventas-mercado, sus usos y métodos de disposición, e indica que la dinámica de los contaminantes en el medio físico para producir efectos en la vulnerabilidad de la biota es diferente, según el compartimento del medio físico seguido. água, aire y/o suelo (ver tabla anexa).

La dinámica que siguen los contaminantes en los diferentes compartimentos es de una gran complejidad, como lo señala Peterle.T (1991), al respecto se indican las relaciones siguientes:

* Interacción aire/agua.- entre los factores relacionados con el intercambio de materiales está la temperatura, grasas y aceites en superficie, particulas suspendidas, disturbios físicos en la superficie del agua (olas, rocío, rápidos y cascadas),contenido de humedad en el aire, etc.

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* Interacción sedimentos-suelo/agua - los suelos y sedimentos son reservorios (sumideros) importantes de contaminantes, entre los factores que favorecen o limitan el intercambio destacan el contenido de materia orgánica de los suelos, tamaño de partículas, fuerza de mezclaje, etc.

* Interacción aire/suelo - aun cuando no se cuente con gran número de estudios de las relaciones que en este sistema se presentan, las siguientes se consideran variables determinantes velocidad y humedad del aire, textura y contenido de materia orgánica de la superficie del suelo, presencia y tipos de vegetación, pendientes, etc.

* Interacción biota/agua.- esta relación es muy importante en el fenómeno de bioconcentración (toma de contaminantes a partir del paso de éstos desde el agua al organismo), entre los factores destacan la temperatura del agua, el contenido de solidos, características fisicoquímicas de los compuestos, características poblacionales y condiciones del hábitat.

* Interacción biota/sedimentos-suelo - los organismos del suelo son muy importantes en la remoción de contaminantes del suelo, así como también por ser de los primeros eslabones de fenómenos de biomagnificación.

* Muchos factores y procesos que tienen que ver con las interacciones intra e interespecíficas de las poblaciones, dan cuenta del intercambio de materia y energía entre los organismos; entre estas destacan: hábitos alimenticios, tasas metabólicas, situaciones fenológicas, etc.

En relación a lo señalado por Moriarty,F., algunos autores como Korte,F (1977) enfatizan que el riesgo de contaminación en el medio no depende solamente de la toxicidad de los compuestos, sino también de su producción, uso y dispersión por actividades antropogénicas. Por lo cual sugiere que en el caso del uso de nuevos productos sintéticos, a los cuales se les pretenda evaluar su riesgo contaminante, deben de tomarse en cuenta las preguntas siguientes:

- ¿ Que cantidad se piensa producir ?

- ¿ Cuales son los usos (domestico, industrial, agropecuario, etc.) destinados para los productos ?

- ¿ Cual es la tendencia de dispersión de los compuestos en el ambiente?

- ¿ Que persistencia y conversión tienen en el medio biotico y abiotico ?

- ¿ Cuales son las posibles consecuencias toxicólogos en los ecosistemas?.

También al respecto del monitoreo, se ha señalado que el esquema ideal depende de dos actividades fundamentales, la primera es reconocer las principales vías o rutas que siguen los contaminantes y los posibles blancos

(diversos niveles de organización biotica hacia donde se dan los efectos) que pueden indicar un evento contaminante A partir de conocimientos toxicológicos (generalmente bajo condiciones controladas de laboratorio), se establecen las dosis críticas que provocan una respuesta como son:

* DL-50 - Dosis que mata al 50% de los organismos de prueba.

* DE-50 - Dosis que produce cierta respuesta en el 50% de los organismos de prueba.

* TLm - Nivel medio de tolerancia a ciertos intervalos de tiempo (24, 96, etc. hr), y frecuentemente se utiliza parámetros fisicoquímicos tañes como oxígeno disuelto, temperatura, salinidad, etc

* NLi - Nivel letal incipiente, es la concentración a la que cesa la toxicidad aguda y se considera generalmente como la concentración para la cual sobreviven el 50% de los organismos de prueba.

* CS - Concentración segura, es la concentración máxima de una substancia tóxica, que no ejerce efectos apreciables sobre la especie bajo estudio, tras una larga exposición que incluya varias generaciones.

* CTMA - Concentración máxima admisible, es la concentración de substancias tóxicas en el medio - compartimientos- que no provoca daños

Sprague, J. (1969), da el siguiente conjunto de definiciones para los efectos de toxicidad:

a Agudo: provoca rápidamente la crisis.

b Crónico: continua durante mucho tiempo, es persistente.

c. Letal: provoca la muerte.

d Subletal: nivel inferior al que causa la muerte.

e. Acumulativo: Manifestado o intensificado por adiciones sucesivas

Una vez que las dosis de respuesta crítica se han determinado, es posibl establecer criterios para las relaciones cuantitativas entre la exposición c

contaminantes y los efectos en organismos, de lo cual se derivan ciertas condicionantes de manejo ambiental:

1 Estandares de protección primaria, como aquellas cantidades de contaminantes en los blancos que no deben ser excedidos.

2 Límites de calidad ambiental, relacionados con los niveles máximos de contaminantes en la vía o vías que llegan al blanco como receptor final.

3. Límites de descargas al medio, se reglamentan para las diversas emisiones de contaminantes desde sus fuentes, para proteger la calidad del medio ambiente

De entre varios problemas que se presentan al cuantificar los contaminantes como el fin último del monitoreo, sin tomar prácticamente en cuenta los efectos ecológico-ambientales, Price, D (1978) señala los siguientes (modificado por Saavedra, J).

a Es prácticamente imposible medir todos los contaminantes en el medio.

b Las técnicas analíticas de rutina pueden subestimar los valores reales.

c Los niveles de contaminantes encontrados, puede ser que no den pruebas de la complejidad de los procesos biológicos que se dan en el sistema.

d Los contaminantes pueden interactuar y dar respuestas diferentes a como se comportaban toxicológicamente de manera aislada.

e. Las determinaciones químicas regulares (principalmente en la atmósfera y agua), pueden en ocasiones dejar a un lado eventos contaminantes extraordinarios.

Por todo lo indicado anteriormente, se observa que la dinámica en el espacio y tiempo que siguen los contaminantes en el ambiente es muy compleja, pero al reconocer que la preocupación fundamental del hombre hacia las substancias tóxicas es la propia salud de la población humana, se han diseñado una serie de técnicas de aproximación de los fenómenos toxicológicos, que para fines prácticos agilizan el abordaje de ésta problemática, tal es el caso de las denominadas rutas críticas. Si la contaminación se logra controlar en estas rutas críticas (las de mayor importancia cuanti-cualitativa hacia el hombre), es muy probable poder obtener el control de la contaminación de las principales fuentes de exposición (ver ejemplo anexo de ruta crítica).

Las rutas críticas de tóxicos se pueden empezar a definir, a partir de modelos conceptuales (ver modelo conceptual anexo), en donde se indican las rutas y substancias tóxicas principales, deduciéndose posteriormente las capacidades límite del entorno, mediante comparaciones con las normas relativas de exposicion y

...ando de las dinámicas de concentraciones entre los diversos compartimento... ...egan a final de cuentas a influir en el metabolismo humano.

Como herramientas para intentar conocer mejor el como, cuando, cuanto y ...de de los contaminantes en el medio, se hace uso frecuentemente de cuatro tipos de estudios básicos.

1 Exámenes para averiguar que substancias tóxicas se encuentran en un conjunto de materiales vivos y no vivos, en un tiempo y lugar determinados. El propósito de estos estudios es determinar la exposición/distribución de contaminantes y posibles relaciones de causa - efecto

2 Monitoreo regular de contaminantes en ciertos compartimentos o sistemas de estudio (medio natural) El fin que persiguen este tipo de estudios, es el de determinar tendencias en acumulación y distribución de contaminantes, predecir futuros eventos de peligro-riesgo ambiental, y con esta información decidir al respecto de llevar a cabo otros estudios.

Muestreo de eventos extraordinarios de contaminación, muchas veces asociado a fuentes puntuales de derrames, explosiones, etc , siendo en este caso el propósito principal determinar el peligro inmediato hacia la población (morbi-mortalidad), según la dinámica en el tiempo y en el espacio del agente tóxico.

Investigaciones especificas del comportamiento de contaminantes, en este rubro se pueden señalar el uso de trazadores radioactivos de substancias tóxicas, para observar su dinámica en el ecosistema.

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VIEWPOINT

INDICES OF ENVIRONMENTAL QUALITY
THE SEARCH FOR CREDIBLE MEASURES

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Informed choices about environmental policy require increasing our capacity to monitor changes in the status of environmental quality. For example, monitoring concentrations of toxic substances in the atmosphere, water, soil, and food chain is crucial in order to prevent adverse health effects. Monitoring alterations in the productivity and biodiversity of various ecosystems is essential to the anticipation of problems before they reach critical proportions. Moreover, measuring changes in environmental quality over time gives policymakers a basis for assessing the effectiveness of environmental policies.

However, monitoring environmental change is much more difficult than most people think. Environmental changes are difficult to interpret without a clear understanding of how environmental systems work. There are sharp disagreements among scientists and policymakers concerning the best measures and methods for measuring changes in environmental quality. In this Viewpoint article, we argue that the measures and methods used to monitor the status of the environment play an important role in framing environmental problems and in shaping the way we think about possible solutions. We suggest that the success

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of environmental monitoring activities and their impact on policy-making depend above all on our ability to handle disagreement among experts.

The Need for Environmental Indicators

Attempts to monitor the status of environmental resources have increased the volume of environmental information available. However, they have failed to provide decision makers and the public with specific answers to critical questions concerning actual conditions, trends, and the causes of environmental damage. First, environmental monitoring systems are designed to meet specific regulatory purposes. They reflect the often fragmented approach of the regulations themselves. Secondly, monitoring data gathered by different agencies in different periods using different methods are not comparable over time. Moreover, raw data are often too complex to relate to poor or good conditions. Likewise, fluctuations in physical, biological, and chemical variables are very difficult to correlate to environmental trends.

To enhance their ability to monitor environmental change, national and international organizations have recently specified sets of indicators. At the 1989 economic summit in Paris the Group of Seven requested that the Organization for Economic Cooperation and Development (OECD), within the context of its work on integrating environment and economic decision making, examine how selected environmental indicators could be developed (OECD 1989).

Several OECD countries have allocated substantial economic resources to set up environmental monitoring systems and to produce national environmental statistics. Currently, the Office of Research and Development of the U.S. Environmental Protection Agency (EPA) is developing a monitoring system to assess and document the changing condition of national ecological resources (US EPA 1990a). The Canadian federal government is currently developing a computerized environmental information system for specifying national and large-scale regional environmental indicators. Several European countries, such as France, the Netherlands, the Federal Republic of Germany, Denmark, and the United Kingdom, who already produce regular reports on the state of the environment, have recently tried to upgrade existing environmental statistics. As part of Scandinavian environmental cooperation among Denmark, Finland, Iceland, Norway, and Sweden the Integrated Monitoring Programme was begun in Finland in 1985.

Currently, the OECD is developing environmental indicators in three specific areas: 1) indicators for reporting on environmental conditions and trends, 2) indicators for integrating environmental considerations into sectoral decision-making, and 3) indicators for incorporating natural resources into overall economic accounts. These indicators will be used to monitor the state of the environment and its evolution over time; evaluate the performance of projects, programs, and plans, and communicate with the public and among decision makers (OECD 1991a, 1991b).

Measuring Environmental Quality

The status of environmental resources can best be described through using physical, chemical, or biological variables. These variables in turn are used to construct indicators of environmental change of various kinds. Indicators of air quality, for example, are measures of the concentrations of air pollutants. Indicators of surface water quality consolidate changes in several variables such as pH, dissolved oxygen, suspended solids, etc. The process of designing indices of environmental quality implies simplification and the use of subjective judgment.

Detecting variations in these indicators at local, regional, and national levels is relatively simple. However, the choice of variables, the construction of indicators, and the selection of measurement methods are critical. While some environmental phenomena are relatively well understood, others are still unclear. Incomplete and inadequate choice concerning indicators and measurement methods can lead to wrong interpretations.

The definition of environmental "indicators" and "indices" was taken up in a exchange of views between Wayne Ott and Herbert Inhaber (Ott and Inhaber 1979) in the 1970s. Inhaber states, "Environmental indicators provide information about the state of the environment, not obtainable in other ways" (Inhaber 1976). In his view the development of an environmental index is aimed at reducing a large amount of unrelated data to a single measure. He defines an index as "the comparison of a quantity to a scientific or arbitrary standards" (Inhaber 1976). Ott prefers to define an indicator as a mathematical function based on one pollutant variable (for example, the sulfur dioxide concentration) and an index as a mathematical function based on two or more pollutant variables (Ott 1978).

The EPA Environmental Monitoring and Assessment Program (EMAP) (see US EPA 1990a) defines an environmental indicator as "a characteristic of the environment that, when measured, quantifies the magnitude of stress, habitat characteristics, degree of exposure to the stressor, or degree of ecological response to the exposure" (US EPA 1990b). The EPA defines an environmental index as a mathematical aggregation of indicators or metrics. One example is the Index of Biotic Integrity (IBI), which combines several metrics describing fish community structure, incidence of pathology, population sizes, and other characteristics" (US EPA 1990b), proposed by the EPA to assess the quality of streams.

Scientific Controversies

Environmental indicators and indices are essential to the development of environmental statistics. Yet, the task is not straightforward. Disagreement persists among experts concerning appropriate definitions. Controversies exist within and across different disciplines. Ecologists express the conditions of environmental

resources in terms of ecological integrity and assess them on the basis of observed changes in ecological attributes. Experts disagree on the definition of ecological integrity and on the characterization of critical conditions.

The basic controversy between advocates and opponents of environmental indices concerns the distortion that can occur in the simplification process implied by aggregating environmental variables into one single value. Advocates of environmental indices maintain that, while imperfect, measures of environmental quality are useful tools and that some distortion is acceptable. The opponents reject these possible distortions and warn about misleading the users of these measures.

The EPA Environmental Monitoring and Assessment Program

The environmental indicators used in the EMAP are being developed for six ecological resources categories: near-coastal waters, inland surface waters, wetlands, forests, arid lands and agroecosystems. The EMAP strategy identifies three main categories of indicators: 1) response indicators, 2) exposure or habitat indicators, and 3) stressor indicators (US EPA 1990a).

Response indicators are characteristics of the environment measured to provide evidence of the overall biological conditions of resources. They quantify the response of ecosystems to anthropogenic stress by measuring organisms, populations, communities, and ecosystems processes. For example, one response indicator for arid land is soil erosion, for inland surface water an important indicator is the Fish Index of Biotic Integrity.

Exposure or habitat indicators may be used to diagnose and measure ecosystem exposure to pollutants and habitat degradation. Exposure indicators are measures of the occurrence or magnitude of ecosystems exposure to physical, chemical, and biological stress (i.e., ambient pollutant concentration). Habitat indicators are physical attributes that characterize conditions necessary to support an organism, population, or community (i.e., abundance and density of key physical features).

Stressor indicators measure socioeconomic, demographic, and natural processes which cause changes in exposure and habitat conditions and are indicative of environmental stress. They include hazard indicators (e.g., emissions of air pollutants), management indicators (e.g., incidence of dredging and filling activities), and natural process indicators (e.g., natural climatic fluctuations).

EMAP indicators are designed to answer critical questions such as: 1) What is the current status, extent, and geographic distribution of our ecological resources? 2) What proportions of these resources are degrading or improving, where, and at what rate? 3) What are the likely causes of adverse effects? and 4) Are adversely affected ecosystems responding as expected to control and mitigation programs (US EPA 1990b)?

The EPA strategy of selecting indicators that will help to answer these specific questions does not address the problem of subjective judgment. The review process for selecting indicators includes several steps by which a large number of experts will evaluate expected and actual performance of proposed indicators and will specify those that match selected desirable criteria. How controversies will be solved is not clear.

The EPA's Office of Research and Development claims that EMAP scientists "will answer these questions by defining and implementing over the next five years integrated monitoring networks . . ." (US EPA 1990b). The EPA insists also that "EMAP networks will use a statistically based sampling design to provide unbiased estimates with quantifiable confidence limits over regional and national scales for periods of years and decades" (US EPA 1990b).

Although the EPA approach is extremely well structured and responds to accepted statistical principles, it does not address the critical question of how best to resolve the scientific and political controversies involved in the choice of indicators. We argue that there is no universal method for determining changes in environmental quality, likely causes of adverse effects, or satisfactory responses. Environmental quality is a mixture of both tangibles (such as the concentration levels of chemical substances in the atmosphere) and intangibles (such as an acceptable level of air quality for the exposed population and the environment). Conflicts will continue to exist.

The Search for Credible Measures

The intended purposes of measuring environmental changes is to inform policy making. Therefore, a measure of its success is the impact of monitoring activities on designing and adjusting environmental policies at the national, regional, and local levels to meet new environmental emergencies and priorities.

Compared with economic and social indicators, environmental indicators have little direct impact on environmental policy and even less impact on sectoral or economic policies. Economic statistics are well developed worldwide. While the development of economic indicators has been characterized by enormous controversies, several economic indices such as Gross National Product (GNP) and the price indices are recognized worldwide as measures of economic wealth. These two economic indices are generally used as the basis for economic policy-making.

Some important insights into the present debate on environmental indicators may be gained by examining the controversial history of social indicators. While social indicators now significantly influence social and economic policies, the development of these indices was characterized by great controversies concerning cause-and-effect relationships. A similar pattern of controversy can be observed in the attempts to define indicators of environmental quality, particularly quality-of-life indices (Carley 1981). Beesley and Russwurm contend that "social in-

dicators are embedded within a political and value judgment reality which may pose problems in their design and use" (Beesley and Russwurm 1990). Also, it is not always possible to establish relationships between the objective social indicators and the social concepts that they are supposed to measure. This has provoked considerable interest in searching for subjective social indicators which might be particularly useful in highlighting social concerns and problems (Beesley and Russwurm 1990). However, these attempts lack the "official" seal of approval that objective indicators carry (Carley 1981).

Similar concerns emerge regarding the attempts to incorporate subjective judgment in the development of aggregate environmental indices. Efforts have been made to weight individual (expert-selected) environmental indicators into composite environmental indices using expert opinions. These include the work of Inhaber for Canada (Inhaber 1976) and those applying the Delphi technique. Some current work uses public opinion polls to weight environmental indicators in forming aggregate indices such as Hope, Parker, and Peake have done for the United Kingdom (Hope and Parker 1990, Hope, Parker, and Peake 1990). These approaches underscore the important role of social considerations in developing such measures.

Conclusions

Indicators of environmental quality will not influence the policy-making process unless there is agreement on the choice and the design of such measures. As Judith Innes has suggested for social indicators, "the intended purpose of developing measurements to be used in the policy-making process has to play a role in the process of designing them" (Innes 1975). In her analysis of social indicators and public policy she maintains that the things we measure and the way we measure them contribute to the formation of norms and goals.

We suggest that measurement is an integral part of the process of identifying problems as well as of searching for solutions. Our increased capacity to collect, analyze, and manage information will not have an impact on policy-making unless we are more careful about the information we select. Scientific disputes and incomplete knowledge have serious implications for policy decisions. Furthermore, the serious social implications of irreversible environmental changes underscore the responsibility of the scientific community to take part in the policy-making process. Designing appropriate measures to monitor environmental problems requires the ability to balance scientific, social, and political considerations in the process of designing and applying these measures. This process will inevitably reflect tradeoffs between political and social actors. Effective and comprehensive policy making requires increased sophistication in assessing conflicts between scientific experts.

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TESIS PROFESIONAL.
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CAPITULO 1. EL IMPACTO AMBIENTAL.

1.1. Definiciones.

El "impacto ambiental", según lo define la Ley General del Equilibrio Ecológico y Protección del Ambiente (LGEEPA), es la "modificación del ambiente ocasionada por la acción del hombre o de la naturaleza".

Otra definición señala que "impacto ambiental" es cuando una acción o actividad produce una alteración en el medio o en alguno de sus componentes (Esteban, 1980).

Para Medina y Sanchez (1977), "impacto ambiental" es el efecto causado por las acciones del hombre sobre el ambiente, con la característica de que este efecto debe ser negativo, perjudicial, no previsto o no deseado y, en ocasiones, desconocido para el proyectista o el que realiza la acción.

Como puede notarse, no hay gran diferencia entre las definiciones anteriores ya que todas hablan de afectación del ambiente ocasionada por una acción o actividad. Sin embargo hay otra definición de carácter antropocéntrico, que define al impacto ambiental como las modificaciones al ambiente que conllevan a un cambio neto en el nivel de vida de la población (Bojórquez y Ortega, 1988).

Una vez determinada la definición del concepto, lo que sigue

es precisar esas afectaciones al medio natural o, hablando en forma más precisa, esos impactos. Esto se hace a través de una evaluación de impacto ambiental (EIA).

El Programa de las Naciones Unidas para el Medio Ambiente (PNUMA) define la EIA como el examen, análisis y evaluación de unas actividades planeadas con miras a lograr un desarrollo que desde el punto de vista del medio ambiente sea adecuado y sostenible (PNUMA, 1987).

Otra definición de EIA dice que es un análisis sistemático de las relaciones entre una acción y el ambiente, para determinar cómo se afectarán entre sí, y su objetivo es identificar, predecir, interpretar y comunicar los impactos que dicha acción inducirá al medio. Lo anterior se plasma en lo que se conoce como Manifestación de Impacto Ambiental (Bojorquez y Ortega, 1988).

La Manifestación de Impacto Ambiental (MIA), tal como la define la LGEEPA, es "el documento mediante el cual se dá a conocer, con base en estudios, el impacto ambiental, significativo y potencial que generaría una obra o actividad, así como la forma de evitarlo o atenuarlo en caso de que sea negativo".

El "procedimiento de impacto ambiental" es aquel que describe secuencialmente los pasos para la preparación y presentación de la MIA de proyectos de obra o actividad y para supervisar la instrumentación de las medidas de mitigación, compensación,

restauración o control que se establezcan en la autorización de la MIA El procedimiento consta de tres fases recepción de proyectos, evaluación y resolución y supervisión.

Dependiendo de las características del efecto causado por una obra o actividad se pueden presentar diversos tipos de impactos, los cuales se pueden definir de la siguiente manera (SARH, 1983):

- Impacto irreversible. Es aquel que por la naturaleza de la alteración no permitirá que las condiciones originales se restablezcan Como ejemplo, las modificaciones del relieve que resultan de la construcción de una gran presa de almacenamiento con frecuencia tienen un impacto irreversible.

- Impacto reversible. Es el impacto en que los efectos sobre el ambiente pueden ser anulados en cierta medida, de tal forma que puedan alcanzarse condiciones similares a las que caracterizaban al ambiente antes de implementar el proyecto Un ejemplo es la restitución de la calidad del agua en una presa o río si se interceptan y tratan las descargas contaminantes.

- Impacto inevitable. Es el que por el tipo de proyecto no puede dejarse de provocar. Por ejemplo, la construcción de una presa implicará la inundación de un área, con la consiguiente afectación inevitable de los usos actuales del suelo.

- Impacto residual Es el impacto que persiste en cierta medida, a pesar de la aplicacion de medidas de atenuacion. Como ejemplo, los contaminantes contenidos en la descarga de una planta de tratamiento de aguas residuales, por no poderse lograr una remoción total de los mismos.

- Impacto directo. Es la alteración que sufre un factor del ambiente en alguno de sus atributos por la acción directa del hombre. Como ejemplo está la disminución de la luz incidente de una ciudad debido a la emisión industrial de humos y polvos.

- Impacto indirecto. Es la consecuencia derivada de un impacto directo sobre algún atributo del mismo factor o de otro diferente. Un ejemplo es la incidencia de raquitismo a causa de la disminución de luz en ciudades industriales.

- Impacto a corto plazo. Es el impacto producido en las primeras estapas del proyecto, es decir, desde los estudios preliminares de campo hasta la construcción de la obra. Por ejemplo, los impactos ambientales que ocasionan los campamentos para los constructores.

- Impacto a largo plazo. Este impacto es el producido durante la etapa de operación del proyecto. Como ejemplo está el obstáculo que algunos caminos representan por el tránsito vehicular que soportan, para los movimientos migracionales de especies terrestres de fauna.

- Impacto acumulativo Es aquel en que sus efectos vienen a sumarse directa o sinergísticamente a condiciones ya presentes en el ambiente o a otros impactos. Un ejemplo de este impacto es que un cambio suave de salinidad en un estero puede tener repercusiones de poca importancia, a menos que se sumen a este los efectos de un cambio brusco de temperatura.

- Impacto positivo o benéfico. Es el efecto que redunda a favor de la naturaleza de un factor ambiental.

- Impacto negativo o adverso. Es aquel efecto que repercutirá de forma contraria a la naturaleza de algun factor ambiental.

Otros conceptos útiles en las evaluaciones de impacto ambiental son los siguientes:

- Magnitud del impacto. Describe la extensión o grado de severidad de cada impácto potencial y también se relaciona con la reversibilidad del efecto.

- Factores ambientales. Son los componentes fundamentales del ambiente, entre los que están: aire, agua, suelo, clima, geologia, flora, fauna, hombre, etc.

- Atributos ambientales. Son variables que representan características generales de los factores ambientales. En el caso del agua un atributo sería su calidad; del suelo son sus propiedades físicas.

- Parametros Son variables que representan características particulares de los atributos ambientales Siguiendo con el ejemplo del agua, algunos parámetros de su calidad son el oxígeno disuelto, la demanda bioquímica de oxígeno (DBO), la demanda química de oxígeno (DQO) y los sólidos disueltos. En el caso del suelo, algunos parámetros en relación a sus propiedades físicas son la estructura, la textura, porosidad, drenaje, etc.

- Medida de mitigación. Es cualquier política, estrategia, acción, equipo, sistema, etc tendientes a minimizar en lo posible los impactos adversos que se pueden presentar durante la construcción y operación de una obra. Una medida de mitigación es, por ejemplo, el tratamiento de las aguas residuales que se descargan a un río.

- Area del proyecto. Es la superficie que ocuparán físicamente las obras, instalaciones, servicios, infraestructura, terrenos, etc. de un proyecto.

- Area de influencia. Es el área donde se dejarán sentir los impactos adversos y benéficos de un proyecto. Un mismo proyecto puede tener diferentes áreas de influencia, dependiendo de los factores ambientales que vayan a ser afectados. Por ejemplo los efectos de la calidad del agua se manifestarán en los cuerpos de agua afectados y los efectos socioeconómicos se manifestarán en otras áreas que pueden ser distintas a las primeras.

Proponente, es el responsable de una obra o proyecto que elabora y presenta la manifestación de impacto ambiental

1.2. Aspectos Metodológicos.

Para identificar y evaluar los impactos ambientales se han creado una serie de técnicas o metodologías, herramientas que ayudan primeramente a la identificación, medición e interpretación de los impactos ambientales causados en las distintas fases de un proyecto, para que posteriormente se puedan establecer las medidas de mitigación que ayuden a remediar dichos impactos.

Existen mas de 70 metodologías que pueden utilizarse para identificar y evaluar el impacto ambiental, sin embargo solamente se han empleado alrededor de 15 (Novelo, 1988).

Idealmente, estas metodologías deben considerar cuatro aspectos (Saavedra Solá, 1991):

- Deben incluir todos los aspectos y procesos "clave" que pueden alterar el ambiente natural y socioeconómico por la obra o actividad.
- Servir como guías para la búsqueda y generación de información.
- Ayudar en la evaluación de alternativas sobre una base común.
- Ayudar en la selección de medidas de mitigación y de los posibles programas de monitoreo de impactos.

La elección de una u otra dependerá de la complejidad del problema, de los datos requeridos por las propias metodologías y sobre todo por la disponibilidad de información. Sin embargo lo ideal es que se utilicen varias técnicas en un estudio, ya que como se verá mas adelante algunas solamente identifican los impactos y no dan una valoración a los mismos. Lo importante será que las técnicas seleccionadas permitan identificar, predecir y evaluar los impactos que una obra ocasionará al medio ambiente en cada una de las etapas.

Dado que gran parte de estas técnicas son de carácter subjetivo ya que solamente hacen evaluaciones cualitativas y no cuantitativas, hay objeciones acerca de la sustentación teórica y experimental de las mismas (y en general de toda la metodología de evaluación de impacto ambiental), sin embargo son los métodos mas confiables para evaluar los efectos que causa una obra en el ambiente (Bojórquez y Ortega, 1989).

Entre las técnicas o metodologías más importantes están las listas de chequeo, matrices, redes de interacción, sobreposición de mapas, juicio de expertos, comparación de escenarios, modelos conceptuales y encuestas. Aunque solamente las tres primeras se utilizan con mas frecuencia.

A) Listas de chequeo.

También llamadas listas de verificación, son técnicas usadas para la identificación de impactos ambientales y con frecuencia se usan como insumo para la elaboración de las matrices de interacción o de causa-efecto. Hay varios tipos de

listados, los cuales varían por sus características y grado de complejidad:

- Listados simples. Son listados sencillos que contienen por un lado los factores ambientales y en seguida los impactos generados, pueden estar ordenados por tipo de impactos o por fase del proyecto. La información que proporcionan es mínima ya que no dan datos sobre medición y calificación de los impactos, por tanto su función es solamente una ayuda para recordar qué afectaciones se considerarán al aplicar otras metodologías.

- Listados descriptivos. Estos listados proporcionan información sobre recopilación de datos y los análisis correspondientes a cada factor ambiental. Un ejemplo de estos listados es el creado por el Laboratorio de Ingeniería y Construcción del ejército de EUA, consta de 9 áreas funcionales sobre 11 categorías ambientales.

Las áreas funcionales son: construcción, operación, mantenimiento y reparación; capacitación; cambio de funciones; estado actual; declaraciones; actividades industriales; investigación, desarrollo, prueba y evaluación; administración y apoyo. A su vez cada área funcional se subdivide en actividades básicas, lográndose obtener hasta 2,000 actividades básicas de todas las áreas funcionales.

Las categorías ambientales son: ecología, salud, calidad del aire, agua superficial, agua subterránea, sociología,

economía, ciencias de la tierra, usos del suelo, ruidos y transporte. Estas categorías se subdividen en factores ambientales, pudiendo obtenerse aproximadamente 1 000 factores. Con lo anterior se puede obtener un listado de impactos y el sistema computarizado se utiliza para identificar impactos potenciales generados por las actividades.

- Listados de escala. Adkins y Burke desarrollaron un método de este tipo para proyectos de transporte, ambientales y socioeconómicos. Consiste en la jerarquización cualitativa de impactos enlistando los agentes de impacto y los factores afectados enumerados en cierto orden dando valores entre -5 a +5 y el promedio de la totalidad de los impactos da el grado de impactos en el sitio, siempre se deben considerar dos alternativas. Un ejemplo de este tipo de listados se presenta en la lámina no. 1.

-Listados de escala y peso. Fueron desarrollados en los Laboratorios Batelle de EUA por Dee N. y colaboradores en 1972, para determinar el impacto ambiental de proyectos hidroeléctricos y es llamado Sistema de Evaluación Ambiental. Evalúa los efectos de una obra a partir de los aspectos no económicos, para lo cual utiliza la información recabada en las etapas de factibilidad y diseño de las obras. El sistema está ordenado en cuatro categorías ambientales que son: ecología, contaminación ambiental, estética e interés humano. Cada categoría a su vez está dividida en componentes ambientales que en total suman 18, los que a su vez agrupan 78

LAMINA 1 EJEMPLO DE LISTADO DE ESCALA SEGuN LA METODOLOGIA DE ADKINS Y BURKE PARA UN PROYECTO DE TRANSPORTE

FACTOR	V A L O R E S	
	ALTERNATIVA 1	ALTERNATIVA 2
A) Area local		
1. Contaminación con ruido		
a) Area dayacente a la carretera	-2	-1
b) Area general.	0	-1
2 Contaminación del aire		
a) Area adyacente a la carretera.	-3	-2
b) Area general.	-1	-1
3. Drenaje		
a) Area adyacente.	-1	-1
b) Area general.	0	0
4. Calidad del agua		
a) Contaminación del agua.	0	0
b) Cantidad de agua.	0	0
5. Disposición de desechos	0	0
6. Efectos sobre la flora	-2	-1
7. Efectos en la fauna	-5	-5
8. Parques	+5	+2
9. Campos de juego	+5	0
10.Sitios arqueológicos	0	0
11.Sitios históricos	+2	+1
12.Espacios abiertos	+3	+1
13.Aspectos visuales		
a) Area adyacente	+3	+1
b) Area general	+2	+1
14.Seguridad		
a) Tráfico	+3	+1
b) Peatón	+5	+1
B) Experiencia de automovilistas		
1. Vista de la carretera	+3	+1
2. Vista del área adyacente	0	+1
3. Vista panorámica	+1	+3
4. Areas de peligro	+3	-1
RESUMEN		
Número de parámetros positivos	11	8
Número de parámetros negativos	6	10

Fuente: Garza, Flora. Listas de chequeo. Mimeo. s/f.

parametros ambientales (Véase lamina no 2). La evaluación se hace utilizando una escala de calidad ambiental donde se asigna un valor especifico a cada parametro, lo cual permite realizar sumas algebraicas por categoria y globales, asimismo detecta sitios considerados como peligrosos o carentes de información Con el uso del sistema es posible tener datos de calidad globales, por categoria, por componente y por parámetro antes y después de la implementación del proyecto, tambien puede identificar necesidades de investigación y hacer recomendaciones en relación a la planeación y desarrollo de los proyectos.

En relación a los impactos causados por las obras de riego y drenaje, la International Commission on Irrigation and Drainage (ICID) ha desarrollado una lista de chequeo, la cual se muestra en la lámina no. 3.

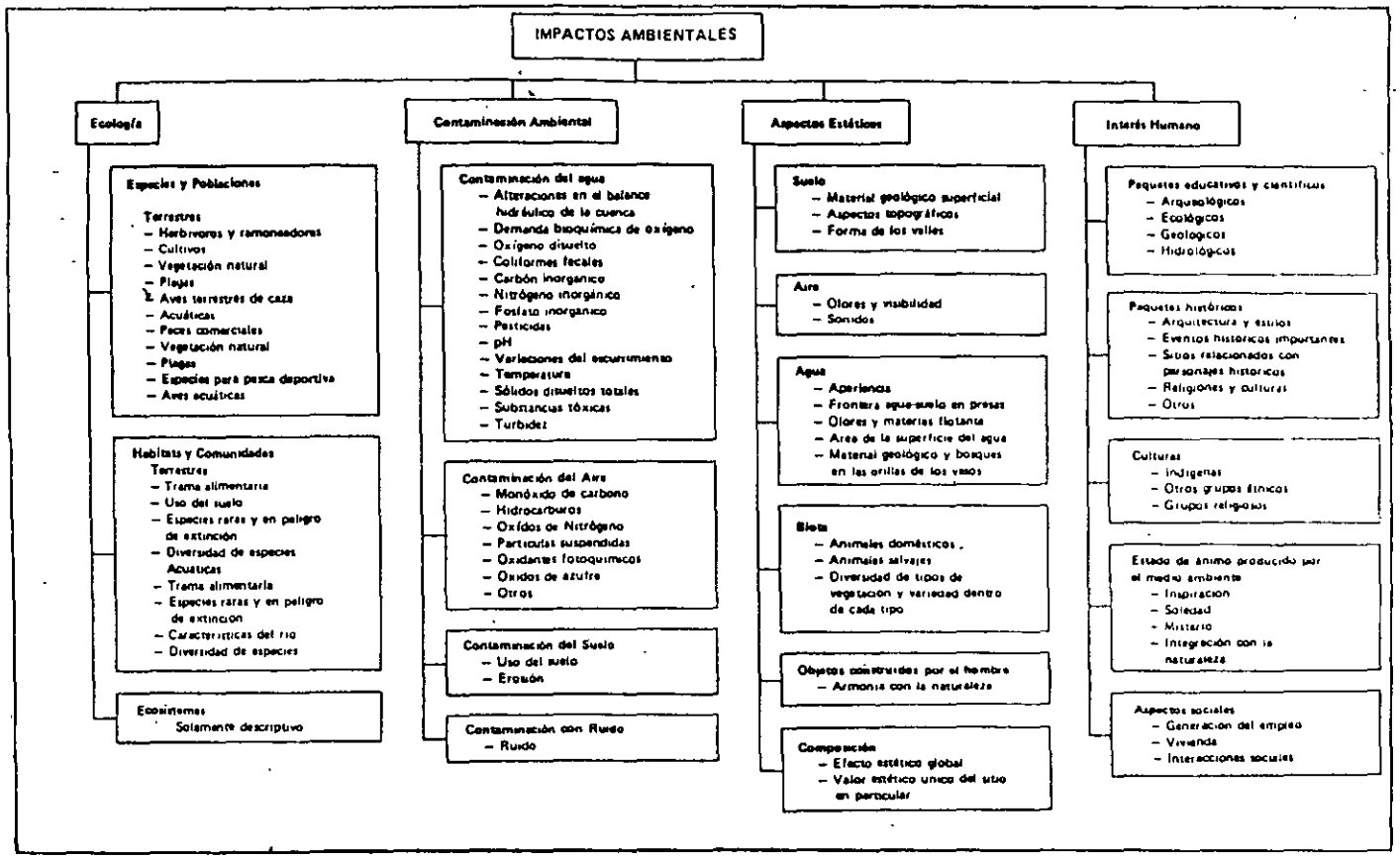
B) Matrices.

Las matrices, tambien llamadas de interacción o de causa-efecto, son tablas donde en el eje horizontal se colocan las actividades del proyecto, generalmente agrupadas por las fases de que consta, y en el eje horizontal los factores del medio natural y social que potencialmente pueden ser impactados por las actividades del proyecto.

Por medio de esta técnica es posible identificar y evaluar un impacto, aunque en forma cualitativa.

El impacto se señala en la interacción de ambos ejes

LAMINA 2 SISTEMA DE EVALUACION AMBIENTAL DE LOS APROVECHAMIENTOS HIDRAULICOS DESARROLLADO POR LOS LABORATORIOS BATELLE.



Fuente: Dee, N. et al Environmental Evaluation System for Water Resource Planning Batelle Columbus Laboratories. Columbus Ohio, 1972. (Citado por Medina y Sanchez, 1977).

LAMINA 3 LISTA DE CHEQUEO

ATRIBUTOS AMBIENTALES	PARAMETROS
HIDROLOGIA	Regimen de escurrimiento. Regimen de inundacion Direccion y capacidad del acuifero Nivel freatico Cambio en el regimen de escurrimiento por el proyecto.
CONTAMINACION	Principales descargas contaminantes y su caracterización (orgánicas e inorgánicas, metales pesados y residuos de agroquimicos) Cambio en la calidad del agua con el proyecto.
SUELOS	Propiedades de los suelos: - Erodabilidad - Riesgo de salinizacion - Drenaje horizontal y vertical. Cambio de las propiedades de los suelos con el proyecto.
EROSION	Niveles de erosion local. Morfologia del cauce. Erosión estuarina. Incremento de la erosión ocasionada por el proyecto.
ECOLOGIA	Cuerpos de agua y su caracterización. Caracterización de las áreas vecinas: - Sistema de valles y lomeríos. - Zonas humedas y planicies. - Especies raras o ecologicamente imprtantes. - Fauna predominante. Cambio en los sistemas naturales por el proyecto.
ASPECTOS SOCIOECONOMICOS	Tasas de crecimiento. Migración. Organización de la comunidad y/o niveles de participación de los usuarios. Sitios históricos, arqueológicos o paisajisticos. Programas de reubicación. Efectos locales o regionales con el proyecto.
SALUD	Agua potable y alcantarillado. Vivienda. Servicios de salud. Efectos esperados como consecuencia de los programas de reubicación. Riesgos de contaminación de los productos obtenidos. Cambio en los niveles de servicios con el proyecto.
DESEQUILIBRIOS ECOLOGICOS	Principales plagas o malezas esperadas. Malezas acuáticas potenciales a establecerse. Cambio en la composición faunística que implique la proliferación de plagas.

Fuente: ICID. Environmental effects of irrigation, drainage and flood control projects: Check-list, 1980. Traducción: Garza F.

describiendose en terminos de magnitud e importancia. Al ser un resumen de los impactos detectados, a las matrices se les pueden integrar categorias que califican dicho impacto y pueden ser: benéficos o adversos, reversibles o irreversibles; reparables o irreparables, de corto, mediano o largo plazo; temporales o permanentes; locales, regionales o globales; directos o indirectos; sumatorios, sinergísticos o antagónicos; etc.

Una de las matrices más conocida y utilizada es la Matriz de Leopold, creada en 1971, fué el primer método que se utilizó en las evaluaciones de impacto ambiental. Consta de 100 columnas donde se colocan las acciones del proyecto que pueden provocar un impacto y 88 renglones donde van los componentes ambientales abióticos, bióticos y socioeconómicos y sus características que pueden ser afectados, de tal manera que se obtienen 8 800 posibles interacciones, aunque muy pocas de éstas son realmente importantes. La matriz consta de dos fases, la primera es identificar los impactos y la segunda es su evaluación, para lo cual se deben utilizar dos formatos. Como criterios de evaluación están la magnitud e importancia de un impacto, en el caso de la magnitud se utilizan valores en una escala convencional del 1 al 10, siendo 10 la máxima alteración provocada en el factor ambiental considerado y el número 1 la mínima alteración; para la importancia del impacto el signo + define un impacto positivo y el signo - el impacto negativo, en la lámina no. 4 se presenta una parte de la matriz original de Leopold. La matriz tiene demasiados elementos y acciones por lo que generalmente la matriz se

LAMINA 4. MATRIZ PARCIAL DE LEOPOLD.

INSTRUCCIONES

1. Identificar todas las acciones (localizadas al otro lado de la cima de la matriz) que forman parte del proyecto propuesto
2. Debajo de cada una de las acciones propuestas coloque un "slash" en la intersección con cada ítem en el lado de la matriz si puede producirse un impacto.
3. Una vez completada la matriz en el rincón superior izquierdo de cada caja con un "slash" coloque un número de 1 a 10 que indica la MAGNITUD del posible impacto, 10 representa la mayor magnitud de impacto y 1 el menor (no ceros). Antes de cada número coloque el + (si el impacto fuera positivo). En el rincón bajo de la derecha de la caja coloque un número de 1 a 10 que indica la IMPORTANCIA del posible impacto (e.g. regional contra local). 10 representa la máxima importancia y 1 la menor (no nula).
4. El texto que acompaña la matriz debe suponer una discusión de los impactos significativos. Aquellas filas y columnas con gran número de cassilas marcadas y casillas individuales con los números más grandes.

			A - Introducción de flora o fauna exótica	B - Control biológico	C - Modificaciones de hábitat	D - Modificaciones de la cubierta del suelo	E - Modificaciones de hidrología de las aguas superficiales	F - Modificaciones del sistema de drenaje de las aguas	G - Control de los cursos de agua y descripción del caudal	H - Canalización	I - Irrigación	J - Modificación del tiempo	K - Quema	L - Agotamiento	M - Ruido y vibraciones	A - Urbanización	B - Áreas industriales y construcciones	C - Aeropuertos	D - Autopistas y puentes	E - Carreteras y senderos	F - Ferrocarriles	G - Cortaje y montacargas	H - Líneas de transmisión, oleoductos y pasadizos	I - Barreras incluyendo las cercas	J - Dragado y recuperación de canales	K - Revestimiento de canales	L - Canales	M - Presas y diques	N - Muelles, rompeolas, diques de recreo (deportivos) y terminales marítimas	O - Instalaciones en el mar	P - Obras de recreo	Q - Voladura y perforación	R - Terraplenado y desmonte	S - Túneles y construcciones subterráneas
			A - MODIFICACIONES DEL REGIMEN													B - TRANSFORMACIÓN DEL SUELO Y CONSTRUCCIÓN																		
CARACTERÍSTICAS FÍSICAS Y QUÍMICAS	1 - TIERRA	A - Recursos minerales																															
		B - Materiales de construcción																															
		C - Suelos																															
		D - Condición del suelo																															
		E - Campos de fuerza y radiaciones de fondo																															
		F - Rasgos físicos excepcionales																															
	2 - AGUA	A - Superficie																															
		B - Marina																															
		C - Subterránea																															
		D - Calidad																															
		E - Temperatura																															
		F - Reaprovisionamiento																															
		G - Nieve, hielo																															

EJEMPLO

	A	B	C	D
A	2/1			8/5
B	3/2	8/8	3/1	9/7
C	7/2			4/6

Fuente: Wathern, P (1988) Environmental impact assessment. p-12. Citado por Saavedra Solá, 1991.

reduce adaptandola a las necesidades propias de cada proyecto, tal como se muestra en la lámina no. 5. Esto último es una ventaja ya que la matriz puede reducirse o aumentarse, además se pueden identificar impactos positivos y negativos por fases del proyecto y la escala de valores de magnitud e importancia puede reducirse también, simplificando el proceso.

Las matrices de cribado son modificaciones de la matriz de Leopold y constan de dos niveles de análisis, no utiliza valores numéricos de magnitud e importancia, en este caso los impactos se identifican de acuerdo a un código.

C) Redes de interacción o de efectos.

Originalmente esta técnica fué elaborada por Sorensen en la Universidad de California y en forma conjunta con el Departamento de Agricultura de los Estados Unidos para determinar impactos ambientales causados por proyectos de tipo residencial y de transporte en zonas costeras del estado de California.

Como la técnica se basa en interacciones de causa-condición-efecto, permite además de identificar los impactos, clasificarlos en primarios, secundarios, terciarios, etc. De esta manera es posible detectar impactos acumulativos o indirectos, los cuales no es posible determinar con una matriz. Otra ventaja que tiene es que permite identificar interrrelaciones entre acciones causales y posibles efectos alterados.

LAMINA 5. MATRIZ DE EVALUACION DE IMPACTOS AMBIENTALES DE UNA PRESA REGULADORA.

ACTIVIDADES DEL PROYECTO

- = Sin efecto
- a = Efecto adveso no significativo
- A = Efecto adverso significativo
- b = Efecto benéfico no significativo
- B = Efecto benéfico significativo
- 1 = Efecto temporal
- 2 = Efecto permanente

FACTORES POTENCIALMENTE AFECTADOS

			ETAPA DE PREPARACION DEL SITIO								ETAPA DE CONSTRUCCION													ETAPA DE OPERACION Y MANTENIMIENTO						
			DESMONTES	TRAZO Y NIVELEACION	CONST. CAMINOS ACCESO	BANCOS DE MATERIALES	REVESTIMIENTO DE CAMINOS	INSTAL. DE CAMPAMENTOS	INSTAL. DE LINEA ENERGIA ELEC.	REUBICACION DE POBLADO	RECTIFICACION CAMINO ACTUAL	EXCAVACIONES Y RELLENOS	EXPLOTACION DE BANCOS DE MAT. DENTRO DEL EMBALSE	EXCAVACION PARA CIMENTACION	DRAGADO OBRA DE DESVIO	CONSTRUCCION DE ATAGUIAS	DESPLANTE DE LA CORTINA	CONSTRUCCION OBRA DE TOMA	CONST. DE LA CORTINA	ACARREO DE MATERIALES	USO DE LETRINAS	OPERACION DE MAQUINARIA	DISPOSICION DE DESECHOS	EXPLOTACION BANCOS DE MATERIAL FUERA DEL CAUCE	LLENADO DEL EMBALSE	AVENIDAS EXTRAORDINARIAS	CONTROL DE AVENIDAS	FUNCIONAMIENTO C H	COMEDERO	MATENIMIENTO DE QUIPOS	OSCILACION DE NIVEL DEL AGUA
FACTORES ABIOTICOS	AGUA SUPERFICIAL	PATRON DE DRENAJE		A1	A1	A1	a1			A1	A2				A2			A2												
		FLUJO (GASTO)									A2	A1	A1		A1												B2			
		DINAMICA DEL CAUCE									A2	A2	A2	A2	A2	A2	A2	A2	A2						A2	A2	B2	A2		
		CARAC. FISICO-QUIMICAS									A1	A1	A1							A1										
	CLIMA	TEMPERATURA	a1																					b2						
		HUMEDAD RELATIVA	a1																					b2						
		MICROCLIMA	a1																					b2						
	SUELO	CARAC. FISICO-QUIMICAS		A2	A1					A2	A2	A2	A2	A2							a1		a1	A2						A2
		USO ACTUAL	A2	A2	A1		A1			A2	A2													A1	A2	A2	B2			A2
		USO POTENCIAL	A2	A2	A1					a2	A2													A1	A2	A2	B2			A2
FACTORES BIOTICOS	FLORA	HERBACEA	a1		a1		a1	a1		a1	a2													a1	A2	a2	b2			a2
		ARBUSTIVA	A1		A1		A1	A2		a1	a2													a1	A2	a2	b2			A2
		ARBOREA	A2		A1		A1	A2		a1	A2													A1	A2	a2	b2			A2
		COBERTURA	a2					A2		a1	a2													a1	a2					a2
		DIVERSIDAD	a1							a1	a2													a1	a2					a2
	FAUNA	MAMIFEROS	A1		A1						a2											A1		a1	A2	A2	B2			
		AVES	a1					A2														a1		a1	B2					
		REPTILES	a1								a2											a1		a1						
		PECES									A2	A2	A2		A2	A2									a2					
ASPECTOS SOCIOECONOMICOS	MANO DE OBRA		B1	B1	B1	B1	b1	B1		b1	B1	B1	B1	B1	B1	B1	B1	B1	B1	B1		B1		B1				b1	b1	
	VIAS DE COMUNICACION				b1	B2				B2												a1			A2					
	INFRAESTRUCTURA				b1	B2		b1		B2															A2					
	CALIDAD DE VIDA					B2	B1			B2											B1	B1								
	AFECTACIONES E INDEMNIZACIONES							b2	b2																A2	A2				A2
	ACT. AGRICOLAS					B2				B2															A2	A1	B2			A1
	ACT PECUARIAS		a2			B2				B2															A2	A1	B2			
	ECONOMIA REGIONAL					B2				B2																a1	B2	B2			
ASPECTOS ESTETICOS	RELIEVE			A2	A1		A1			A2	A2			A2										A2						
	APARIENCIA VISUAL		A2	A1	A1		a1	A2		A2	A1	A1	A1	A1	a1	A1	A1	A1			a1	B1		A1	A2	a1				A2
	CALIDAD DEL AMBIENTE		A2		A1	a1	a1	a2		A2		A2								a1	B1	A1	B1	A1	b2					
	POLVOS Y HUMOS			A1	A1	A1				A1	A1									A1		A1		A1						
	RUIDOS			A1	A1	A1		A1		A1	A1	A1	A1	A1	A1	A1	A1			A1		A1		A1				a1		

ELABORO: IBARRA PEREZ H 1995

No es recomendable para grandes proyecto ya que el diagrama puede ser excesivamente grande lo que dificulta su análisis y por tanto su interpretación rápida. En la lámina 6 se muestra un ejemplo de esta técnica.

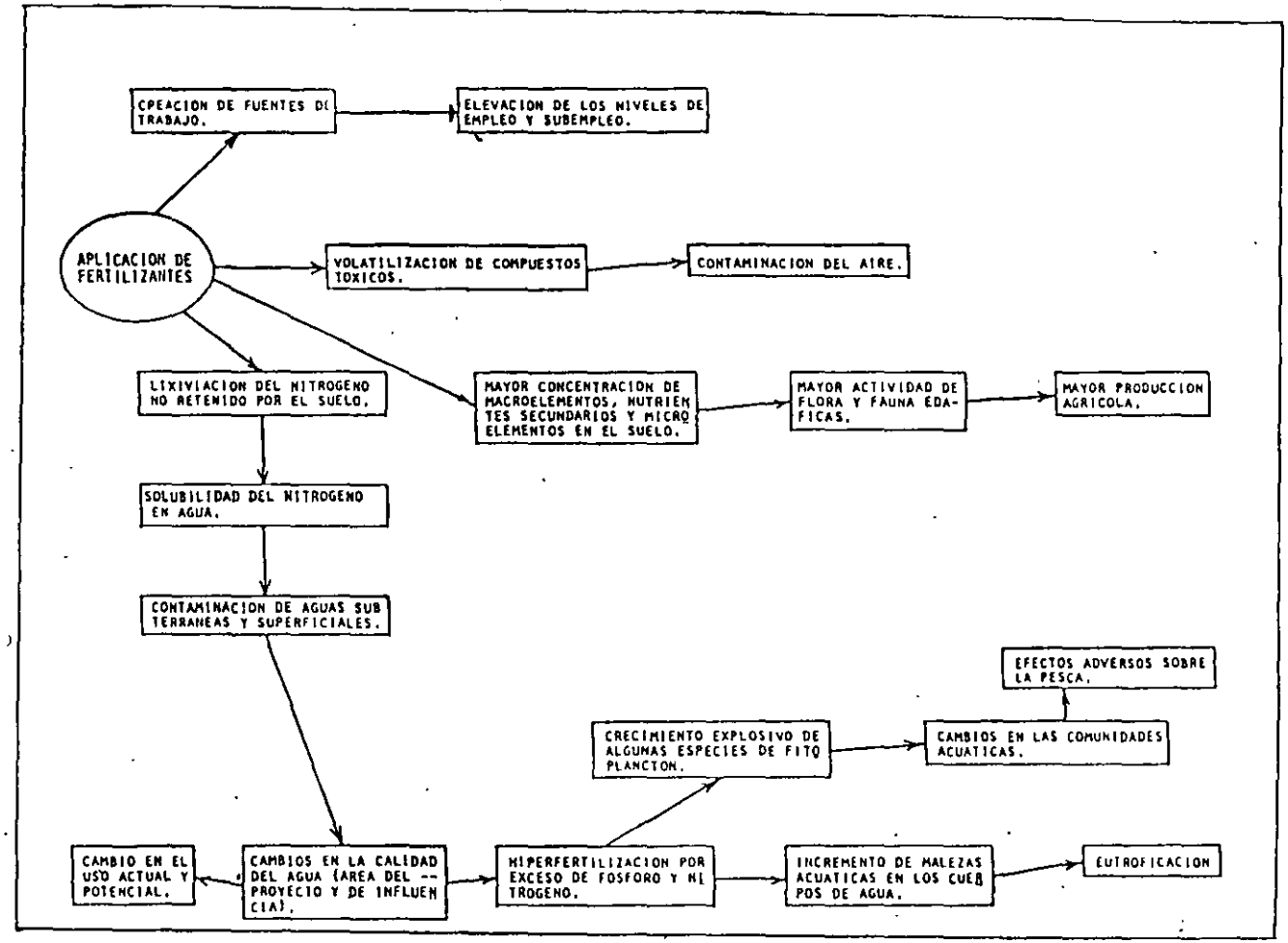
D) Sobreposición de mapas.

Esta técnica se basa en el uso de una serie de mapas temáticos plasmados en material transparente (acetatos), que se sobreponen para producir una caracterización compuesta del ambiente. Los mapas pueden contener datos sobre uso actual del suelo y vegetación, suelos, hidrología, geología, hábitats de especies determinadas, áreas suceptibles a la erosión y otras características ambientales. Esta técnica solamente selecciona alternativas e identifica cierto tipo de impactos localizando solamente los factores del medio ambiente mas sensibles de ser afectados. No cuantifica los impactos y no puede usarse para identificar interacciones secundarias o terciarias (Menéndez, 1991).

Es una técnica muy usada en proyectos lineales como carreteras, lineas de conducción de energia eléctrica, agua potable, etc. y el resultado que se obtiene son sombreados que de acuerdo a la intensidad o color, señala el grado de impacto.

Puede hacerse en forma manual o automática, esta última a través de sistemas de cómputo con los cuales la sobreposición se hace en forma más rápida, en áreas grandes y sobre todo que puede sobreponerse la cantidad de información que se desee.

LAMINA 6. RED DE INTERACCION PARA LA PRODUCCION AGRICOLA (APLICACION DE FERTILIZANTES).



FUENTE: CNA. DIAGNOSTICO AMBIENTAL DEL PROYECTO DE INFRAESTRUCTURA HIDROAGRICOLA ELOTA-PIAXTLA, SIN.

Este método es aplicable en análisis con enfoque geográfico en los que es muy útil, sin embargo debe usarse en forma conjunta con otras técnicas.

E) Juicio de expertos.

Consiste en la reunión y consulta de un grupo de expertos en el tema en cuestión para que a través de "lluvia de ideas" o por medio de técnicas sofisticadas como el método Delphi (cuestionario con procesamiento estadístico de las respuestas), se obtenga un consenso.

F) Comparación de escenarios.

Se refiere al estudio de las situaciones donde se ha realizado una experiencia similar a la que es objeto de estudio, extrapolándose los impactos generados. Es útil siempre y cuando se disponga de información suficiente para hacer las comparaciones.

G) Modelos conceptuales.

Son representaciones idealizadas de la realidad, en este caso del medio ambiente. Se plantean en forma de bloques unidos por redes de interacción. Para construir un modelo se deben identificar primeramente los límites del sistema, enseguida se determinan las entradas y salidas, posteriormente los componentes, seguidamente se establecen las relaciones entre cada uno de dichos componentes y finalmente se reafina el modelo, en algunos casos es posible cuantificar tanto los componentes como sus relaciones. Aunque existe una simbología estandarizada propuesta por H.T. Odum, se suelen utilizar

símbolos diversos de acuerdo al tipo de proyecto. Ejemplos típicos de modelos son el ciclo del agua o del nitrógeno. Pueden ser tipo esquema o tipo dibujo. En la lámina 7 se presenta un ejemplo del primer tipo.

H) Encuestas.

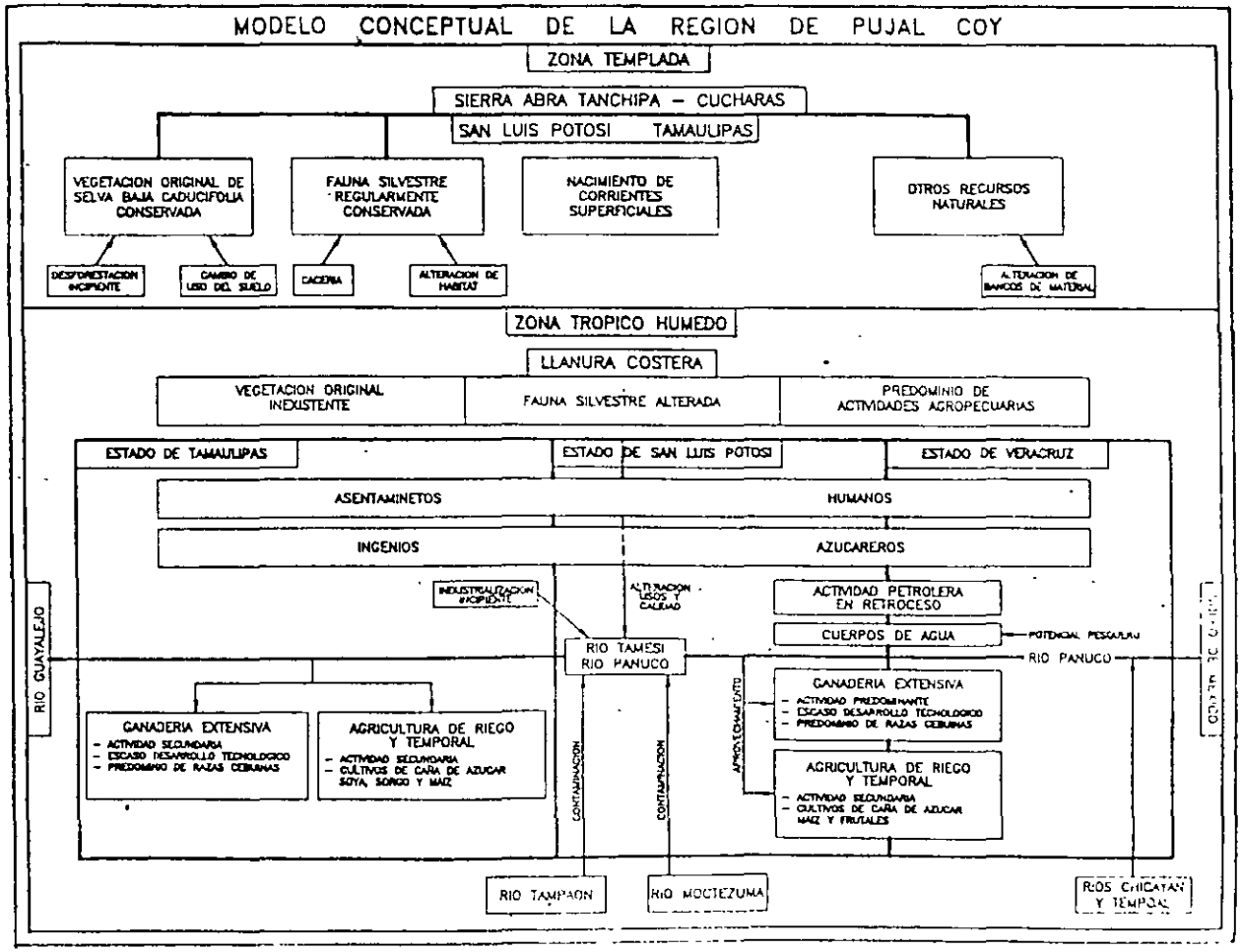
Consiste en la aplicación de una encuesta entre habitantes, grupos sociales, etc., seleccionados del lugar donde se construirá la obra o proyecto con el fin de detectar posibles impactos, sobre todo de carácter socioeconómico, que de otro modo difícilmente se identificarían como son:. problemas de tenencia de la tierra, cambio de patrones culturales etc.

Sin embargo no son adecuadas para obtener información sobre el medio o el proyecto, debido al desconocimiento del personal encuestado.

I) Modelos de simulación por computadora.

Pueden ser modelos de simulación numérica o modelos de simulación cualitativa. Los primeros requieren datos numéricos de los parámetros y sus variables, que es necesario recopilar en varios años por lo que su uso en las evaluaciones de impacto ambiental es restringido. En cambio los segundos por no requerir datos numéricos se pueden plantear en plazos cortos y ademas conociendo las características del ecosistema donde se implantará la obra o proyecto es posible predecir si una variable tenderá a aumentar, disminuir o permanecer constante. En México se han usado dos clases de simulaciones no numéricas: GSIM (SIMulación G) y KSIM (SIMulación K) (Bojórquez y Ortega, 1988).

LAMINA 7. MODELO CONCEPTUAL TIPO ESQUEMA DE LA REGION DE PUJAL COY.



FUENTE: SEDESOL PROYECTO DE ORDENAMIENTO ECOLOGICO Y [illegible] DE LA REGION DE PUJAL COY S.L.P. TAMPS. 1994

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Un modelo de simulacion por computadora es el SIRIA (Sistema de Información Rápida de Impacto Ambiental) que utilizaba la antigua SEDUE para la evaluación de impactos ambientales, maneja modelos cuantitativos de dispersión de contaminantes en aire y agua, el modelo cualitativo KSIM (SIMulación K) para simulación de escenarios, tablas para la toma de decisiones y sistemas expertos.

Otras técnicas usadas en las evaluaciones de impacto ambiental son los diagramas de flujo, mediciones directas, análisis de costo-beneficio, etc., aunque su empleo es mas restringido.

1.3. **Características del Procedimiento de Impacto Ambiental.**

De acuerdo a lo dispuesto en el Reglamento de la Ley General del Equilibrio Ecológico y la Protección del Ambiente en materia de impacto ambiental, al realizar una obra o actividad de las que requieran autorización previa, podrán presentarse dos casos:

a) Que el impacto ambiental de dicha obra o actividad no causará desequilibrio ecológico, no rebasará los límites y condiciones señaladas en los reglamentos y normas técnicas ecológicas (ahora Normas Oficiales Mexicanas) emitidas por la Federación para proteger el ambiente.

b) Que la obra o actividad proyectada esté en los casos descritos en el Artículo 5º del Reglamento.

Appraisal of Environmental Impacts and Mitigation Measures through Mathematical Matrices

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Abstract

Interaction matrices are widely used in environmental impact assessments (EAs) in Mexico. Most EIAs in Mexico are based upon these technique. However, interactions matrices are considered an illustrative, since their analytical power is deemed to be insufficient for effectively handling complex decision-making conditions. It can be argued that, in some instances, the misuse of interaction matrices has contributed to faulty EIAs, which have been deliberately misrepresentative and used for endorsement of projects. Consequently, an alternative for better EIAs in the short term is to enhance the matrix approach, so a more rigorous evaluation of impacts is achieved. The approach presented here is based upon mathematical matrices, which include minimum link matrices, interpretative structural models, and the use of exponential and linear equations to determine the significance of impacts. Our approach allows users to systematically consider all possible cause-effect interactions and pathways, and includes the consideration of primary and secondary impacts. Furthermore, the approach increases the effectiveness of matrices in handling data in a rigorous way.

Keywords: Environmental impact assessment, ecological impacts, highways, Mexico.

Heading: Mathematical matrices approach for impact assessment.

1. Introduction

Interaction matrices are widely used in environmental impact assessments (EIAs). A matrix consists of a grid diagram in which two distinct lists -environmental factors and project activities- are arranged along perpendicular axes. An interaction between components on opposing axes is marked and scored in the cell common to both. The original approach, the Leopold Matrix, was designed to assess the impacts generated by large infrastructure projects (Munn 1975, Holling 1978). Matrices are currently applied to EIAs for a variety of development projects (Munn 1975, Holling 1978, Wright and Greene 1987, Bojórquez-Tapia 1989, Shopley et al. 1990, Shopley and Fuggle 1984, Zeiss 1994).

However, matrices are considered as an illustrative rather than an analytical approach, because they are deemed to be ineffective for handling complex decision-making and appraisal of the efficiency of mitigation measures is difficult (Holling 1978). In Mexico, extensive application of matrices has resulted in deficient and vague impact assessments. One result of the subjectivity and lack of traceability of

interaction matrices is that EIAs are often deliberately misrepresentative. EIAs have been frequently used to endorse projects rather than as a tool for the resolution of environmental conflicts. Nonetheless, interaction matrices are widely used in Mexico. They are employed in a broad range of evaluation approaches (Wright and Groono 1987, Bojórquez-Tapia 1989, Shopley et al. 1990, Zoiss 1994) because of their several advantages: they are easy to use, promote interdisciplinary analysis, and simplify communication concerning impacts. Consequently, a crucial requirement for better EIAs is to improve the matrix approach so that impacts can be evaluated more rigorously.

The objective of this paper is to present a matrix procedure which facilitates a systematic and traceable evaluation of environmental impacts. This approach reduces the weaknesses of matrix analyses and allows users to assess the efficiency of any mitigation measure. The approach is presented by means of a case study: a highway project in Mexico City.

The approach is based upon a series of mathematical matrices, which are rectangular arrays of quantities upon which algebraic operations can be legitimately performed (Shopley and Fuggle 1984). Thus, mathematical matrices are used to derive interpretive structural models (Prakumar and Mohapatra 1989), generate qualitative simulations (Fleming 1978, Kane et al. 1972, Kane et al. 1973), and assess the significance of impacts. The significance of each impact is estimated through a set of significance criteria, as suggested by Duinker and Beanlands (1986), which are quantified on an ordinal scale, and merged into a significance index, which results from applying an exponential and a linear equations. Our results demonstrate that mathematical matrices allows users to assess both primary and higher order interactions (sensu Shopley et al. 1990) in a systematic and traceable way. Furthermore, the approach increases the effectiveness of analysis in handling a variety of conditions and kinds of data.

2. Evaluation Procedure

Environmental impact assessments should consist of a procedure designed for a comprehensive and systematic appraisal of foreseeable

environmental impacts of development projects. Following Bojórquez-Tapia (1989), an EIA comprises the following steps: (1) project description and environmental and characterization, (2) identification and prediction of impacts, and (3) evaluation of impact significance.

2.1 Project description and environmental characterization

This stage involves the use of a geographical information system (GIS) and an initial interaction matrix. The study area is divided into homogeneous land systems through a hierarchical process based upon geomorphic characteristics. The land systems are homogeneous areas or zones that facilitate the identification and inventory of environmental attributes (Matteucci et al. 1985, Cendrero and Diaz de Teran 1987, Blankson and Green 1991, Bos 1993). Similarly, project activities are defined and related to the land systems. All activities and components suitable for mapping are incorporated into the GIS.

Both the project activities and the environmental factors are incorporated into a binary matrix to depict the direct dependencies. Thus, interactions are marked in the corresponding cell as either 0 (absent) or 1 (present).

2.2 Identification and prediction of impacts

The next step is to develop a flow diagram from the matrix. This step simplifies the examination of both direct cause-and-effect relationships, and higher order interactions. Higher order interactions are those generated by interdependencies between system's components that are not directly connected, such as indirect feedback linkages and causal chains (Shopley et al. 1990). Likewise, the analysis of higher order dependencies is facilitated through the development of a minimum link matrix (Shopley et al. 1990, 1994), that renders the shortest connection between variables in an indirect causal chain.

Since the number of interactions in a matrix may be considerable, flow charts may become complex and hard to outline. Hence, it is convenient to use a systematic scheme to delineate causal chains, such as through an interpretative structural model (Vizayakumar and Mohapatra 1989, 1992) by which the variables involved are sorted hierarchically. Both the interpretative structural model and the minimum link matrix are generated by means of a similar process: the binary matrix is exponentially elevated to the nth power, where n is the highest order interaction.

A KSIM qualitative simulation (Holling 1978, Kane et al. 1972, Kane et al. 1973) is then carried out to reveal the dynamic behavior of the system components. Sets of scenarios are generated to detect the sensitivity of the variables to different circumstances.

2.3 Evaluation of impact significance

The importance of each interaction is evaluated by means of environmental indicators and significance criteria. An indicator is a measurable parameter of environmental change (Munn 1975). Thus, an indicator shows both the baseline condition and the effect of a project on an environmental component.

Should an interaction in the matrix exist, its significance is assessed by means of a set of basic, supplementary, and quality criteria (Bojórquez-Tapia 1989, Duinker and Beanlands 1986). Basic criteria include magnitude or intensity, spatial extent, and duration. Supplementary criteria entail synergism between variables, accumulative effects, and controversy surrounding the interaction. Quality criteria encompass information that supports the prediction of an impact, its probability of occurrence, confidence in the prediction, and existence of

environmental standards. Thus, basic criteria are those that are indispensable for defining an interaction, while the supplementary criteria are those that complement that description but which can be missing from the description of an interaction. Likewise, quality criteria serve to judge the rationality of the assessment.

The criteria are valued on an ordinal scale corresponding to oral expressions related to the effect of an activity on the indicator variable of the environmental component. While valuation of most of the criteria is rather straightforward, synergical and accumulative effects require the consideration of the dynamic simulation and the higher order dependencies. The oral expressions and their value in the ordinal scale are the following: null (0), null to low (1), very low (2), low (3), low to moderate (4), moderate (5), moderate to high (6), high (7), very high (8), extremely high (9). An exception, in terms of the quality criteria, is the existence of environmental standards, which are rated as present or absent. When uncertainty exists on determining the value of a criterion, it is assigned the highest figure. This rule is consistent with a precautionary rationale for environmental conflicts (Crowfoot and Wondolleck 1990); that is, lessening the chance of underestimating an

impact, minimizes the risk to the public (Shrader-Frechette and McCoy 1993).

Since the maximum value in the ordinal scale is 9, a basic index (MED_{ij}) and a supplementary index (SAC_{ij}) are obtained by the following equations:

$$MED_{ij} = \frac{1}{27}(M_{ij} + E_{ij} + D_{ij})$$

$$SAC_{ij} = \frac{1}{27}(S_{ij} + A_{ij} + C_{ij})$$

Where: M_{ij} = magnitude, E_{ij} = spatial extent, D_{ij} = duration, S_{ij} = synergy effects, A_{ij} = accumulative effects, and C_{ij} = controversy.

As stated above, basic criteria cannot be valued as null, so the ranges of those indexes fluctuate as follows:

$$\frac{3}{27} \leq MED_{ij} \geq 1$$

$$0 \leq SAC_{ij} \geq 1$$

The impact of an interaction (I_{ij}) and its significance (S_{ij}), which takes into consideration the mitigation measure (MI_{ij}), are obtained through the following equations:

$$I_{ij} = MED_{ij}^{1-SAC_{ij}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

$$S_{ij} = I_{ij} - \left(I_{ij} \cdot \frac{MI_{ij}}{9}\right) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Since basic criteria cannot be valued as null, then:

$$\frac{3}{27} \leq S_{ij} \geq 1$$

Mitigation measures are assessed on an ordinal scale similar to that for the basic and supplementary criteria. Costs have to be taken into account to discern their relative importance and chances of implementation before a mitigation measure is fully evaluated.

Finally, S_{ij} values are ranked in four impact significance classes: low (0 to 0.25), moderate (0.25 to 0.49), high (0.50 to 0.74) and very high (0.75 to 1.00). The efficiency of the mitigation measures is then evaluated. This is carried out by observing the magnitude in the reduction of an impact's significance, as well as the number of impacts that are ameliorated, directly or indirectly, by a single mitigation measure.

3. Case Study

3.1 Project Description and environmental characterization

The La Venta-Colegio Militar project consisted of the construction and operation of a 23.3 km, four-lane toll road. The project was located on the southwest section of Mexico City, and it was designed to complement the wester portion of a projected external transit loop (Figure 1). The project encompassed 233 ha, though about one half of the area was expected to be directly affected by the construction activities. The project included the construction of several bridges on the principal courses, numerous runoff underpasses, and one tunnel which is to cut through the highest portion of the route.

The study area was divided into geomorphic regions, following a hierarchical approach. Thus, two distinct units were identified based upon the main formations (Figure 1): Sierra de Las Cruces and Sierra Chichinautzin. At a larger scale, these contained a total of six distinct homogeneous ecological zones. Sierra de las Cruces included shallow soils of low permeability, and a diverse land cover. Sierra Chichinautzin presented permeable soils, a high potential for water recharge, and a rather homogeneous land cover. Along the route, natural land cover has been fragmented by urban development, and illegal human settlements were scattered throughout the region. The proposed route intersected 18 watersheds which were perceived as important for groundwater recharge.

Major concerns of both the public and the government related to the effects of the project on increasing urban development, loss of natural land-cover, increased risk of extinction of flora and fauna species, reduced groundwater recharge, and higher local air pollution. On the other hand, the principal benefit of the project, according to the developers, would be decrease in travel time during rush hours, and a reduction of automobile air emissions within Mexico City.

2.2 Identification and prediction of impacts

The analysis included three different scales to include the principal concerns and conflicts mentioned above: Mexico City, regional, and local. The first assessed the project's effects on the transit and air pollution levels within Mexico City. The second looked into the issues related to Sierra Las Cruces and Sierra Chichinautzin, and the third analyzed the impacts along a belt of 1 km from both sides of the geometric center of the highway, encompassing those which would occur in each of the six ecological zones.

An interaction matrix was prepared based upon the descriptions of the setting and the Pert diagram for the project's activities (Figure 2). The interaction matrix included 33 environmental factors , 25 project activities, and 274 interactions. Environmental factors were defined as those ecological, physical, and social attributes of the region prone to be affected by the project.

As a minimum, one indicator variable was used to analyze each interaction. Estimates of change for each indicator was derived from an assortment of sources. For example, land cover data were obtained

from satellite images and aerial photographs through the GIS; expected transit demand and air pollution figures were obtained by means of simulation models; and the presence of important habitats was derived from the literature and correlated with specific land systems and land covers by means of the GIS.

A structural model was prepared and used as a basis for a KSIM qualitative simulation (Figure 3). A set of scenarios were generated to explore the consequences of the project according to the foreseeable conditions. These were derived from expert knowledge and public opinion. Simulation results revealed the sensitivity of the system to reductions in transportation costs. Main repercussions were related to variables involved with development of rural areas around the project, increase in air pollution, and decrease of Mexico City's traffic. Thus, the KSIM simulation uncovered the most important interactions that could be studied in detail.

3.3 Assessment of impacts

Each interaction in the matrix was assessed by equations (1) and (2). The results (Table 1) showed that the majority of the interactions were

esteemed as having moderate values for the basic criteria and low values for the supplementary criteria. Likewise, about one third of the impacts were judged as very high and high, while the rest was appraised as moderate. The final significance values demonstrated that the relevance of the majority of those impacts was reduced to either low or moderate after the mitigation measures were considered in the analysis (Table 1).

Since those results included both positive and negative impacts, each project activity was examined to depict its specific negative effects, and to determine the efficiency of the mitigation measures. A total of 72 negative impacts with high and very high values were detected for 16 of the project activities (Table 2). When considering the significance values, that is, after the mitigation measures were included in the analysis, the resulting number of high and very high values was reduced to 14. Therefore, it was concluded that, while most of the negative effects could be avoided, some of them could not be lessened. Notwithstanding, careful examination of the data bases revealed the cause-effect relationships for each of those interactions. Thus, it was deducted that they were generated by the following

project activities: land acquisition, clearing of trees, excavation, slope protection, land cuts/embankments, tunnel and bridges, power lines, and construction and operation of junctions. The predicted effects involved changes in life style and land use patterns, habitat loss, landscape alteration, and increase local transit. Consequently, though those effects were unavoidable, they were considered as an acceptable environmental costs with respect to the expected benefits of the project.

4. Discussion and Conclusions

Environmental impact assessments are regarded as integrative analysis by which sound inferences can be derive in relation to the effects of development projects. Their objective is to enhance the rationality in decision-making and provide information for an environmental conflict resolution process. This implies a meticulous treatment on how to mitigate negative impacts; otherwise, an EIA becomes a futile endeavor. Consequently, EIAs are a tool for the public and the government to scrutinize the technical and environmental options of

development enterprises (Harashina 1995, OEA 1987, Wright and Greene 1987).

Experience in Mexico, however, confirms Ross (1994) statement on the effectiveness of EIAs: They are generally perceived as a bureaucratic requirement for project's approval. In contrast to their original purpose, most EIAs consist of lenghtly descriptions, based upon implicit values, and biased and subjective analyses, which fail to focus on the key issues (Bojórquez-Tapia and Ortega 1989). In some instances, conflicts have escalated because EIAs have been deliberately misrepresentative in order to endorse a project. Such faulty EIAs have been the antithesis of good environmental planning, and are not uncommon elsewhere (Dickman 1991, Ross 1994)

From the analytical point of view, those problems arise from the limitations of the matrix approach (Holling 1978, Lawrence 1993). First, matrices are not necessarily comprehensive or systematic. Second, their format is unrealistic since only binary interactions are considered and sequential impacts are difficult to identify. Third, interactions between project activities and environmental attributes

may rely on unsubstantiated judgements. Fourth, matrices tend to be subjective and biased since impacts' significance is not explicit. And fifth, they inhibit scrutiny and traceability, because the process by which interpretations and conclusions are reached cannot be reproduced. Interaction matrices, thus, are regarded as an illustrative rather than an analytic approach (Holling 1978).

Nonetheless, interaction matrices are applied in an assortment of impact evaluation approaches (Wright and Greene 1987, Bojórquez-Tapia 1989, Shopley et al. 1990, Zeiss 1994). Their usage has been justified on the following grounds (Munn 1975, Holling 1978): (1) they are easy to employ, (2) they constitute a comprehensive -although qualitative- summary of a large number of impacts, (3) they promote an interdisciplinary examination of a project, and (4) they simplify communication of what the impacts may be.

An alternative for better EIAs in Mexico in the short term is to enhance matrices to enable users to appraised impacts rigorously. Our results show that mathematical matrices can be a valid impact prediction tool because they facilitate the inclusion of multiple viewpoints and

perspectives of different members of an interdisciplinary team. These are in fact the prerequisites for a more reasoned evaluation of environmental impacts (Canter 1991).

A comprehensive examination of impacts implies addressing the environmental conflicts more likely to be generated by a project. This is justified by the need of EIAs to provide information for environmental dispute settlement processes. Accordingly, the interaction matrix for the La Venta-Colegio Militar highway project was prepared taking into account the issues, interests, and perceived conflicts of the different stakeholders.

It may be argued that subjectivity and biases are inherent to environmental disputes (Crowfoot and Wondolleck 1990). Hence, EIAs must credibly include dissimilar kinds of data, which may be either quantitative or qualitative, or perhaps derived from perceptions and assumptions. Also, EIAs must accede to variations in assumptions, inputs, and judgments.

The use of mathematical matrices increases the effectiveness of EIA in handling data. Explicit appraisal of impacts is achieved because mathematical matrices force users to be rigorous in the definition of interactions. The minimum link matrix and the structural models uncover the hierarchical order and connectivity patterns among variables, while qualitative simulations simplify the dynamic analysis of cause-and-effect relationships (Holling 1978, Shopley et al. 1990, Vizayakumar and Mohapatra 1989, 1992). Hence, the combination of these techniques facilitates the consideration of complex pathways between variables, and the segregation of the primary or direct impacts from the secondary effects, that is, those generated by the interdependencies between systems' components (Shopley et al. 1990).

Equations (1) and (2) yield impact significance values consistent with the precautory principle of minimizing the public risk (Shrader-Frechette and McCoy 1993). Besides, different project alternatives can be compared through the significance scores. In the case of La Venta-Colegio Militar impact assessment, data was derived from direct field measurements, quantitative simulation models, and expert knowledge.

Factual data, more easily obtained for the basic criteria, was kept separated from the more subjective value judgements for the supplementary criteria. The results (Tables 1, 2) allowed the interdisciplinary team to estimate the efficiency of the mitigation measures.

However, impact statements are often criticized for not considering the "right" alternatives. The EIA of La Venta-Colegio Militar highway project has been questioned by some local interest groups. Such criticism confirms that different people are going to consider different alternatives depending upon their preferences, their concerns, what they have at stake, and their perception of what constitutes a good outcome (Crowfoot and Wondolleck 1990).

As our results corroborate, no theory exists for making a value-neutral determination of when enough alternatives have been considered (Beacon 1980). Judgment on the significance of environmental impacts is not merely a scientific or technical matter to be decided by experts, but rather a socioeconomic, ethical, aesthetic, political, and cultural determination by the people (Shrader-Frechette and McCoy 1993).

Therefore, the public has the right to scrutinize the conclusions of an EIA as part of a conflict settlement process. The role of EIAs is to help information exchange among interest groups (Harashina 1995).

The advantage of the matrix procedure presented here is that information is organized in a simple format, while judgements on impacts are systematic and traceable. Settlement of environmental conflicts is facilitated because the rationale behind the assessment can be verified and, hence, the approach meets Loomis (1993) prerequisite for good environmental planning: "the analyst job is to let the analysis speak by itself."

Acknowledgment

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Figure 1. Study area.

Figure 2. Interaction matrix for the EIA of the La Venta-Colegio Militar highway project.

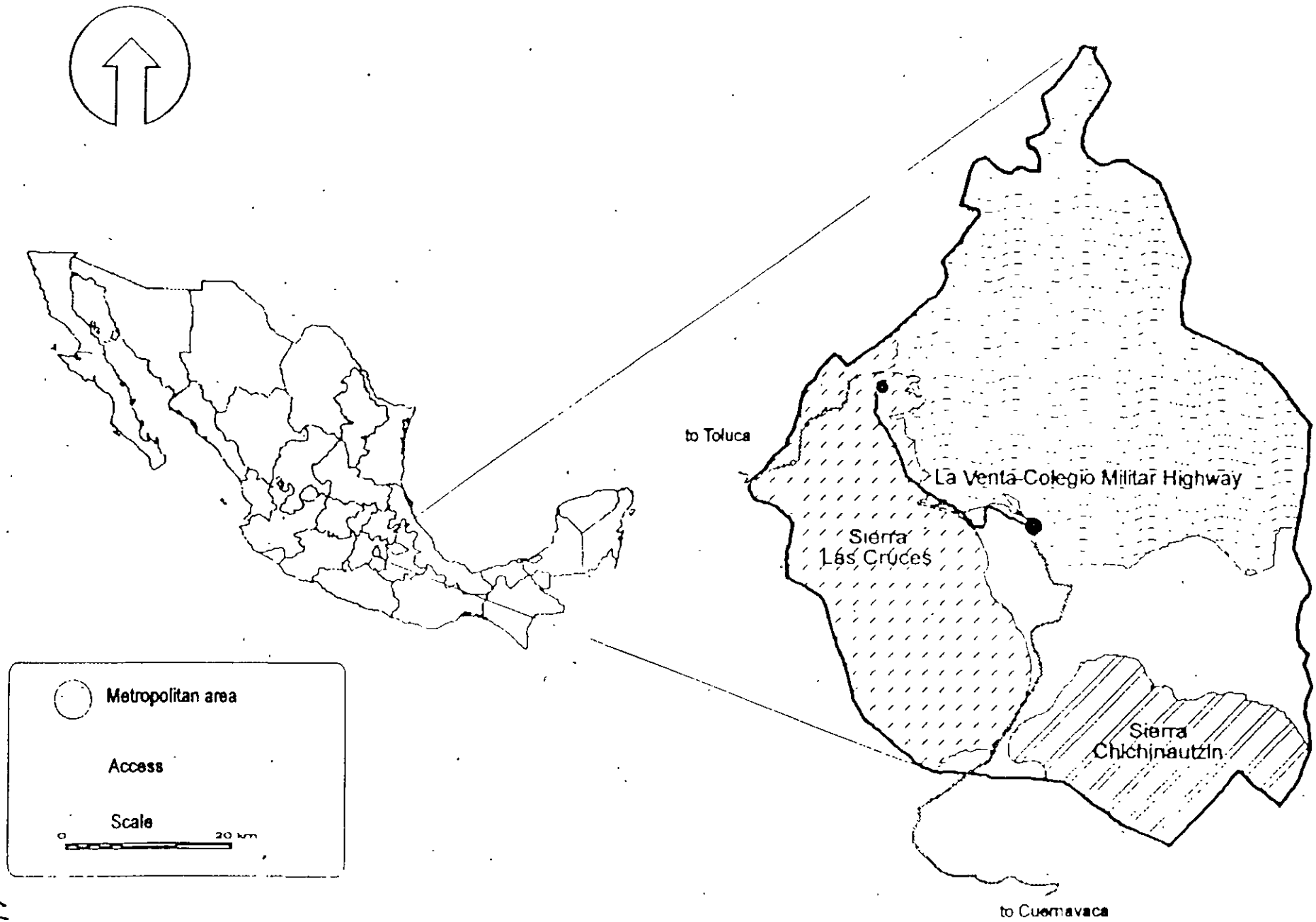
Figure 3. Structural model for the EIA of La Venta-Colegio Militar highway project.

Table 1. Percentage per value class of the total number of interactions considered in the EIA for La Venta Colegio-Militar highway project. Value classes are the following Low (L < 0.24), Moderate (0.25 < M > 0.49), High (0.50 < H > 0.74), and Very High (VH > 074).

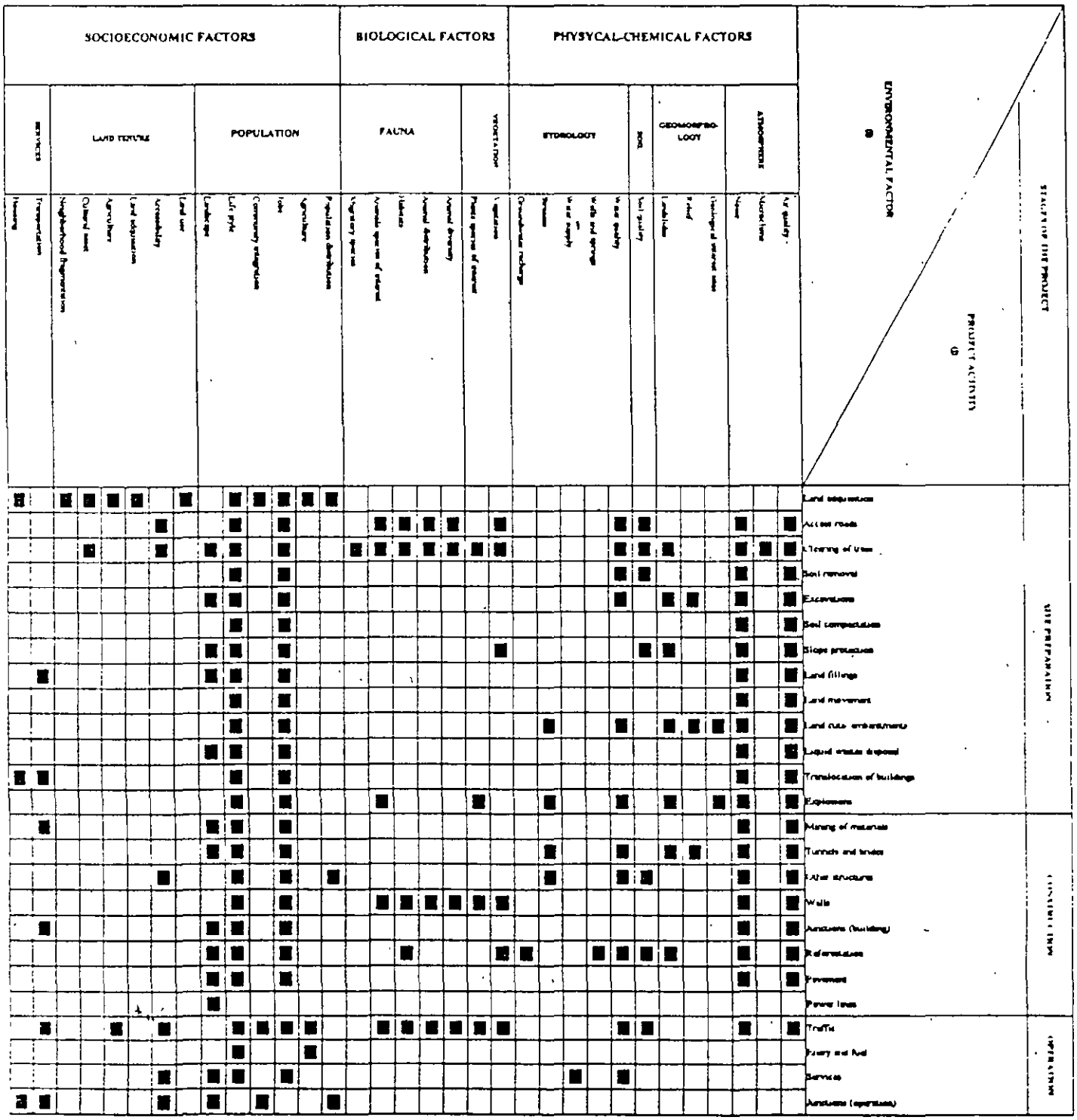
Criteria	Value Class			
	Low	Moderate	High	Very High
Basic	1	64	25	9
Supplementary	67	18	9	6
Impact	0	64	14	21
Significance	27	60	8	5

Table 2. Number of negative interactions by value class per project activity of the EIA for the La Venta-Colegio Militar highway project. Impact and significance correspond to equations (1) and (2) in the text, respectively. Value classes are the following Low (L < 0.24), Moderate (0.25 < M > 0.49), High (0.50 < H > 0.74), and Very High (VH > 0.74).

Project Activity	Impact				Significance			
	L	M	H	VH	L	M	H	VH
Land acquisition	0	0	5	6	7	2	1	1
Access roads	0	10	0	2	2	10	0	0
Clearing of trees	0	5	1	14	13	5	1	0
Soil removal	0	6	0	1	3	4	0	0
Excavations	0	5	0	4	3	4	1	1
Soil compactation	0	4	0	0	0	4	0	0
Slope protection	0	4	1	0	0	4	1	0
Land fillings	0	5	0	0	1	4	0	0
Land cuts/ embankments	0	8	0	5	3	8	2	0
Liquid wastes disposal	0	5	0	0	1	4	0	0
Explosions	0	9	1	0	8	2	0	0
Mining of materials	0	6	0	0	2	4	0	0
Tunnels and bridges	0	6	0	3	3	5	0	1
Walls	0	4	0	0	0	4	0	0
Junctions (construction)	0	4	2	0	1	4	1	0
Reforestation	0	4	0	0	0	4	0	0
Pavement (building)	0	4	1	0	0	5	0	0
Power lines	0	0	1	0	0	0	1	0
Traffic	0	5	8	4	9	7	1	0
Energy and fuel	0	0	3	0	3	0	0	0
Services	0	0	4	1	4	1	0	0
Junctions (operation)	0	0	3	2	2	1	2	0


to Toluca
La Venta-Colegio Militar Highway
Sierra
Las Cruces
Sierra
Chichinautzin
to Cuernavaca
Metropolitan area
Access
Scale
0
20 km

6/4/7

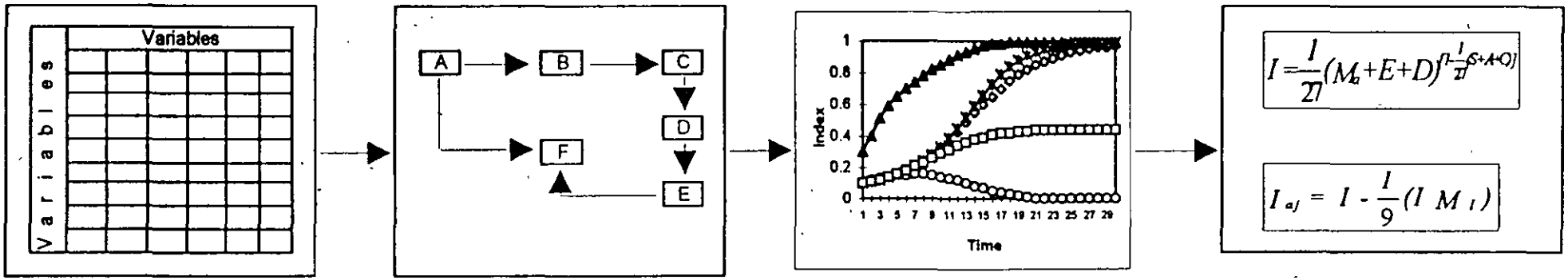

SOCIOECONOMIC FACTORS
BIOLOGICAL FACTORS
PHYSYCAL-CHEMICAL FACTORS
ENVIRONMENTAL FACTOR
PROJECT ACTIVITY
SEQUENCE OF THE PROJECT
SERVICES
LAND TENURE
POPULATION
FAUNA
VEGETATION
ETIOLOGY
SOIL
GEOMORPHOLOGY
ATMOSPHERE
Housing
Transportation
Neighborhood fragmentation
Cultural uses
Agriculture
Land adaptation
Accessibility
Land use
Landscape
Life style
Community composition
Jobs
Agriculture
Population distribution
Migratory species
Animals species of interest
Habitats
Animal diversity
Animal distribution
Plants species of interest
Vegetations
Groundwater recharge
Erosion
Water supply
Water quality
Soil quality
Landslides
Relief
Discharge of sediments
Noise
Odors
Air quality
Land adquisition
Access roads
Clearing of sites
Soil removal
Excavations
Soil compactation
Slope protections
Land fillings
Land movement
Land cuts embankments
Liquid wastes disposal
Translocation of buildings
Explosives
Mining of materials
Tunnels and levies
Other structures
Walls
Structures (building)
Reforestations
Pavement
Power lines
Traffic
Quarry and fuel
Services
Structures (operations)
SITE PREPARATION
CONSTRUCTION
OPERATION

Matrix

Structural model

Qualitative simulation

Assessment of significance



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A MANUAL TO PREPARE
ENVIRONMENTAL ASSESSMENTS

1.0. Introduction

Environmental issues are receiving a deeper attention all around the world. Multilateral development agencies and banks are more concerned than ever about the environment. Overwhelming evidences of some development projects failing to achieve their objectives and pressure form conservationist groups have undoubtedly played a major role in the development of this environmental awareness.

Today, top management of international development banks and agencies publicly recognize that sound environmental management and natural resources conservation can not be separated from economic development. Expressions such as "sound ecology is good economics" are now being stated by policy makers. The old environmentalists' saying "What is ecologically sound is economically viable in the long run", may be climbing its way up through the policy and decision makking ladder. An **environmental assessment (EA)** is now required before most development projects can be approved for implementation.

Recent policy statements indicate that **environmental analysis** is now regarded as an intrinsec component of the project identification and development process. Therefore, environmental considerations should be taken since the earliest stages, and mantained during the whole process. It is actually similar to engineering, social, and economic analysis.

However, main directives from top management take a long time to actually permeate the bureaucracy at all levels, and in every day life EAs are still regarded more as barriers to project development and implementation than valuable project design tools. For example, in most development agencies and international banks a full EA is not required for emergency release projects. The argument to provide an exception being that those projects need to be "processed rapidly."

In other words environmental considerations are still regarded as something that will delay project approval, final design, and implementation. This kind of approach indicates that we are still far away from achieving sound project identification and design process, which properly incorporates environmental considerations.

1.1. Environmental Assessment:

Environmental assessment is the most common name given to the process of addressing these environmental concerns. However, it is not a well defined term. Other names commonly used for the same activity include environmental impact assessment, environmental

impact statment, and environmental impact report. All those terms, unfortunately, have been identified with some kind of "evaluation" which is made at a certain moment on time, to check if the environment is likely to be "negatively affected".

If that is the case, the EA should provide mitigating measures. However, in the majority of cases, the timing for EAs is rather late during the project development process. As a consequence of poor timing, mitigating measures often imply major transformations within the general project implementation scheme, which was already developed before project managers even started to think about to think about environmental concerns.

Resistance from project managers is likely to occur as a natural response to what they consider an intrusion in their project. Furthermore, mitigating measures suggested by late EAs are likely to compete for financial resources already allocated for other activities. New bureaucratic positions envisted with great deal of power have been created, which can literally stop projects because they do not meet sastisfactory procedures for implementation of mitigating measures coming from EAs.

Obviously, the previously described scenario is not the best for sound project development and the health of ecosystems or the people involved. Therefore, the main pourpose of this document is to define what a sound environmental assessment should be. How and when should they be done, and why have they become more necessary.

2.0. Increasing Need for Environmental Assessments

Nobody can think of a development project without an economic analysis, since development activities are, by definition, immerse in the economic system. There was a time when banks, agencies and governments actually talked about "economic development" to mean a better life for people of third world countries. If the project is succesfull, there are going to be all kind of economical indicators which will demonstrate so. If it is a private project we will look at profit, market share, total revenue, contribution, etc. On the other hand if it is a public project we would look at its impact on GIP, foreign exchange generation, and net balance of payment results.

Social analysis on the other hand are more limited to public initiatives.

However, the same is not true for the natural system. Even all development projects and activities take place in the environment, environmental analysis in relation to project development is a relatively new concept.

The fact that economic and social analysis were there earlier than environmental analysis. must be a reason

Development activities inevitably generate conflicts; maximization of sector output, as in agriculture, often wreak havoc on the productivity of the fisheries sector downstream. Benefit to a target group, as through diversion of water to supply the needs of an urban population, may be offset by the hardship imposed upon farmers who can no longer count on that water for irrigation. Such intersectorial conflicts result in sub-optimum development. The ultimate goal of environmental management is the optimization of regional output through a balanced development of all sectors.

Conflict resolution. These Guidelines provide a framework for conflict resolution--the prevention or mitigation of the impacts on one activity upon development options in another sector. Conflict resolution leads logically toward the more ambitious goal of optimizing the contribution of all sectors to overall development. This involves the management of the interacting natural, agricultural and urban-industrial components of the human environment. The process requires a systematic, interdisciplinary effort incorporating the contribution of the biological, physical, applied and social sciences, planning and a structure for administration and control.

2.0. Concepts and Principles

If regional development is to be achieved it is important that the basic principles governing the structure and functioning of regional ecosystems be understood. These principles provide the ecological framework for integrating disciplinary contributions and for communicating development options to decision makers.

Environment and Ecosystem. Environment is synonymous with ecosystem. The latter term, when defined to include human activities on a regional scale, has operational validity underlain by widely applicable scientific principles. Implicit in the use of the term environment is the rigorously defined synonym. An ecosystem comprises a community of organisms including humans in interaction with the physical environment within an arbitrarily defined geographical area. Sunlight and solar driven climatic processes result in a locally characteristic food chain or trophic structure of plants and animals and material cycles determined by substrate conditions. By virtue of culture and technology humans can redirect energy flows (including fossil fuels) and material cycles to create alternative trophic structures, such as agriculture, planted forests and cities. Cities constitute complex consumer communities that are totally dependent on a surrounding solar

covered mosaic of communities for energy, materials and waste reception.[1]

Environmental Processes. Systems may vary greatly in scale as illustrated in Figure 1. However, they all require an energy flow to drive their processes. At the biosphere scale (Figure 1a) only solar energy enters across the system boundary. Solar energy drives the great patterns of atmospheric and oceanic circulation, photosynthesis, respiration, and material cycles. The solar energy degraded and transformed in this process is radiated to space again as dispersed heat.

Transformations are a natural and irreversible process. Energy flows naturally from an organized state to a dispersed one. In the process highly concentrated energy storage such as cities, forests, a windmill or an automobile are developed. Great quantities of energy must be degraded to build this structure. Highly concentrated energy flows such as electricity or information also demand the loss of a great deal of lower quality energy. For example, generating one kilocalorie of electrical energy from coal involves the degradation of some three kilocalories of coal to high entropy waste heat which must be dissipated into the air or surrounding waters and then radiated into space. Sulphur in the coal is not destroyed by burning, only transformed to a sulphur oxide contribution to acid rain. The environmental manager is concerned with mitigating such side effects as the energy sector generating heat and SO_2 which can affect the productivity of other sectors.

Development. Development is defined as both a process and a state. In a forest the process is called succession, an increase in the diversity of species and of biomass until a dynamic steady state or climax is reached. The state of development is limited ultimately by the resources available--solar energy, soils and rainfall and by stresses operating such as cold or high winds.

An analogous process of development occurs in regional ecosystems in which human activities play a prominent role. The process of development is reflected in many ways, bringing new resources into production, diversifying the skills of the population, expanding the physical and service infrastructure and increasing income and consumption. Just as with the forest this process in regional ecosystems proceeds toward a developed state. This state is ultimately limited by the local resource base and the outside resources, energy and capital, that the transformation of local agricultural, forest and mineral resources can attract.

[1]This definition is adapted from E.P. Odum, 1971, *Fundamentals of Ecology*, p. 8 (*Ecologia*).

Table 1 illustrates some of the analogous characteristics of human and natural system as they approach a developed state. The stress of strong, salt-ladened winds can limit the development of a coastal forest, similarly regional or national development can be limited by the stresses of exploitive social structures and flight of capital to Swiss bank accounts.

The concept that development is a definable goal or state allows the environmental manager to devise strategies to guide sectorial activities toward that goal.

Environmental Management. The environmental manager is most concerned with regional scale ecosystems which consists of a mosaic of interacting natural and managed terrestrial and aquatic ecosystems. The output of these ecosystems should be geared towards an improvement of the quality of life. For the purpose of analysis and management of sectorial activities we may divide the regional ecosystem into its generalized components. In increasing order of human intervention are the natural, managed and urban-industrial components (Figure 2). The management of the complex interchanges among components ultimately result in the sustained flow of goods and services upon which the human population depends for its well-being.

Looking at Figure 2 it is intuitively clear that all three components contribute to development. A modern society cannot live as hunters and gatherers in a totally natural environment. Neither systems regardless of the technological sophistication and command over petroleum resources it might enjoy. This relationship of component contributions to development is illustrated conceptually in Figure 3. The graph represents the changes in the component outputs of goods and services to society as the land base is converted from its natural state to managed or urban-industrial uses. Up to approximately 50 percent conversion, losses in natural system values are compensated for by the increasing benefits from use of the land resource for more intensive functions. Beyond the 50 percent level net benefits from all three components decline as does the overall system benefit to society. Reasons for this decline include:

1. Direct loss of natural system goods and services such as forest products, fisheries and recreation.

2. Overloading of the waste assimilative capacity of natural systems resulting in increasing investment requirements for waste treatment.

3. Loss of natural system watershed protective functions with resultant sedimentation of infrastructural works, decreased aquifer recharge and erratic surface water flows.

The component management recommendations for optimum development of a particular region depend in part on a thorough resource assessment. Scarcity and high cost of fossil fuels, technology, or other high energy quality subsides places a premium on natural systems contributions, such as extended useful life of hydroelectric projects and products from managed successional forests rather than from plantations.

3.0. A Structure and Method for Environmental Management

The concept of environmental management is underlain by scientific principles and logic. The utility of the concept, however, is measured by its application to practical problems of development. This section provides methodological guidelines to assist a team confronted with a variety of complex regional development problems.

Timing. Timely integration of the environmental sciences in development is critical. No methodology can be effective if it is implemented after crucial technical and political decisions have been irrevocably made. This problem has plagued many countries where the environmental impact assessment process has been patterned after the United States model. Too often the assessment team operates independently from project design and implementation and begins its work after a firm project has been presented to a funding institution. Inevitably an adversary relationship is created to the detriment of the project and the perceived value of the environmental science input. Experience indicates that the opportunity to significantly influence a project comes during the six-month period which approximates the time lapse between the emergence of a concrete idea and the completion of the feasibility study. As shown in Figure 4, flexibility to modify a project declines rapidly as the design stage progresses. The Guidelines offer a systematic methodology for minimizing errors in project location, design, and operation, as well as avoiding conflicts with other activities in the region. The feasibility study should clearly indicate the task of the environmental sciences during subsequent project design, implementation, and later evaluation stages.

Balance. Given appropriate timing, the success and credibility of the environmental management approach lies in its balanced [illegible]. The impact assessment process used by many agencies identifies the potential negative effects of an action. If a project is found to have no significant negative impacts, it is cleared, effectively eliminating further environmental science contribution. In contrast, the management approach includes the potential for a positive contribution, for example:

- Design of land use strategies to minimize sedimentation and eutrophication of a reservoir.

- Design of ecologically sound cropping systems and integrated pest management strategies.

The negative impact issue is treated as a development problem affecting the productivity of another sector of the regional economy. Emphasis is placed on enhancing long-term net productivity of a regional system, rather than maximizing single sector production.

The Mandate. The contribution of environmental management to development depends, on part, upon the character of the mandate given the regional development authority. Below are given two alternatives task scenarios:

1	2
Plan dams located in the piedmont for flood control and irrigation of annual crops downstream.	Present alternatives strategies for optimum land and water management with the objective of improving human well-being in the region.

In the first scenario the team must either accommodate a preconceived approach or fight an uphill battle to have alternatives considered. In the second case the team has the flexibility to weigh the costs and practicality of structural and/or non-structural water management strategies. Crop, fishery, and forestry options can be explored considering the aptitude and desires of the population.

The organizer of the management team must have clearly defined the scope and degree of flexibility in the mandate.

Team Formation. Composition of the team will be dictated by the nature of the problems and opportunities being addressed. Among the disciplines likely to be needed in a regional scale project are the following:

Engineering:	civil engineering hydraulic engineering sanitary engineering
Physical Sciences:	geomorphology geology hydrology

Biological Sciences:	plant ecology aquatic ecology limnology epidemiology
Social Sciences:	anthropology sociology
Applied Sciences:	agronomy animal husbandry soils economics architecture forestry wildlife ecology fisheries ecology
Integrative Sciences:	systems ecology geography regional planning

A core team of experienced individuals representing the technical, ecological, social, and economic aspects of regional development can be complemented by specialists as problems are identified. Often a core team member has the breadth to cover several disciplines at the initial stage of analysis. A goal of the development authority should be to have the core team as part of its permanent staff, with specialists available on loan from other agencies or from the international consulting community.

In a planning exercise integrating environmental management consideration, the engineer, economist, and ecologist still perform their disciplinary and sectorial functions. What is added is an interdisciplinary structure and a methodology for communications, evaluating recommendations and for making adjustments in the plant. All team members should use the system approach in the sense that regardless of specialty, each understands that important interactions and inter-relationships occur outside the traditional area of any particular discipline or sector. In this context, the function of the ecologist and other environmental scientists is to quantify and evaluate these interactions and inter-relationships and make management recommendations to the planning team.

Technical Short Course. An assessment short course addressing a specific problem will serve to bring all team members up to a common level of understanding of procedures in modeling, of concepts in the applied sciences, and of the inter-relationships among disciplines and sectors in development. An intensive one-week course with mandatory attendance by all team participants

should accomplish the leveling process. Giving the course in the project room designated by the sponsoring institution has the advantage of access to materials and continuity of the transition into the study itself. The alternative is a conference center or other facility totally isolated from professional or personal distractions.

Regional Assessment. During the training course, the team should have become familiar with the literature, maps, and aerial photographs relevant to the study area. Included at this point should be a land and aerial reconnaissance of the area including initial contact with local leaders and citizens. Analysis of a complex regional ecosystem is facilitated by the use of models. The individual with the greatest aptitude for conceptual model development as identified during the training course should lead the modeling process described below.

Models. The use of models forms the core of this methodology. Models are an abstraction and simplification of reality. A region may be represented using models of increasing abstraction by aerial photography, maps, diagrams of components and interactions, and a series of equations. Modeling requires a macroscopic perspective which is employed in the selective elimination of superfluous detail and allows us to concentrate on analysis of the processes to be managed (Figure 5). For example, the complexity of interactions within the human component is fascinating but for purposes of regional system management it may be reduced to a simple box with various exchanges with other components and the outside (Figure 2).

Steps in Modeling:

Step 1: Identification of systems limits. All ecosystems have arbitrary limits, however, the principles of integrative levels indicates that to understand a system such as a river and its floodplain, one should analyze the next higher encompassing system, in this case, the watershed (Odum, 1975). This tends to internalize natural system interactions though generally not all socioeconomic ones. Each discipline or sector represented should discuss how a given boundary would affect its analysis. A boundary cutting across a statistical enumeration district or ecosystem can complicate analysis. Political or other considerations may dictate other limits. Once lines are drawn, boundary conditions are established and internal interactions can be distinguished from exchanges with other systems.

Step 2. Definition of scale. The mandate of the planning exercise will determine the focus of the model. Location of a

highway requires a very different model than a mandate to optimize regional development. Scale, units of measure, qualitative considerations, and relative accuracy of data from different sources should be discussed by the team in the context of each discipline or sector involved. Compatible levels of detail in analysis must be agreed upon that take into account the common constraints of area size, time available; and planning objectives. Base maps should be prepared at a common scale for the use of each discipline in compiling data. Maps should display a minimum of landscape features for ease of reference.

Step 3. Identification of inputs and outputs. Once system limits have been established (Step 1), outside energies, materials, and information that affect the system can be listed. These may include sunlight, rainfall, tidal action, tectonic movement, fuels, goods, technology, immigrants, and policy decisions, all of which interact with the system components. Outputs include products, emigrants, water, pollutants, and heat.

Step 4. Identification of components or subsystems. It is useful to go into considerable detail in identifying components at this early stage of model elaboration. Later, components may be combined or eliminated if not critical to analysis. The basic divisions in any regional model are the natural component including both terrestrial and aquatic elements, the managed component including agriculture, ranching, aquaculture, and silviculture, and the man-created component including cities, industries, and water control structures. At a later stage, new components proposed as planning alternatives can be added as described in step 7. The first effort involves making lists of components on paper (Table 2). After Step 4, the components will be arranged in diagram form.

Step 5. Preparing the diagram. When lines connecting different components are drawn to represent flows of energy or materials and information, one has a conceptual model of the regional system. By quantifying the flows and storage, such a model can be expressed as a series of non-linear differential equations and computer simulated to test the effects of various management strategies.

Step 6. Refining and quantifying the model. Examine the first draft model tracing each input, interaction, and output. Are some subsystems expressed in far more detail than others? Review the official mandate or objectives of the planning exercise. Are the components and interactions of relevance to the objectives represented and adequately detailed? Can the model be simplified by combining or eliminating components or interactions of

secondary effects. Based on existing knowledge of the region, annotate areas or processes the represent either potential problems, opportunities, or conflicts, in terms of future development. For example, not on base maps areas subject to inundation, of highly erodible soils, with excessive population density, forest resources, swamps with waste buffering potential, and areas of high agricultural potential.[2] On the basis of available information on the region, quantify all the flows and storage possible. Storage values would be stocks, such as number of cattle, volume of standing timber, and population. Flows would be exports of cattle, lumber production, and migration. This effort will help identify data gaps, facilitate exchange of information, and further define the identification of critical problems and opportunities.

Step 7. Superimpose proposed development actions. On the basis of problems and resources identified, as well as the preconceived development proposals that are often part of the planning mandate, superimpose the possible alternative actions on the system model developed and refined in Steps 1-6. Each proposed actions loosens a whole chain of secondary effects on the system. A proposed dam causes something analogous to loose sparking wires carrying electrical current which must be plugged in as interactions to other components (Figure 9). For example, the fishery sector must determine from the infrastructure sector how water will be managed in order to assess effects on fishery resources. Table 3 illustrates various examples of intra-sector and inter-sector effects of development activities. The engineer will have to ask the forest sector specialist, the geomorphologist, and geographer what future sediment yields may be from the watershed. The interchange of questions and ideas occurring as the conceptual model evolves provides orientation to research on alternatives during the reconnaissance and prefeasibility phases of the project.

Summary. The seven steps outlined above carry the modeling process through the first cycle. In successive interactions, a

[2]The Process of land capability assessment is an integral part of the reconnaissance and prefeasibility phases of a regional development project. At the regional scale, an adaptation of the familiar Holdridge Life Zone system has provided a useful tool. Life Zones are subdivided into capability units which reflect local conditions of soil, slope, drainage, and climactic anomalies such as cloud forest conditions. Such a classification involves an ecologist, forester, geomorphologist, soil scientist, and agronomist. Composite capability maps overlain with maps of roads, settlement patterns, and actual land use can be combined with cultural and economic assessment to quantify the regional model.

better understanding is gained of the functioning of the regional system which has a direct bearing on the quality of the alternative recommendations stemming from Step 7. It is a continuing responsibility of the team leader to guide the data collection and assessment process toward the mandated development goals. Disciplinary experts can all too easily be lured away by interesting, but irrelevant, side issues.

Early in the quantification process, it becomes apparent that evaluation of the output of an interaction requires a prior sequence of data collection. For example, determination of the economic feasibility of producing soybeans for a lucrative export market depends in part on knowledge of farm population preferences, aptitude, and land access. Before discussing preference and aptitude of farmers, the capabilities and limitations of the land must be assessed. Based on continuing communication among team members, it is possible to advance the data base in all areas. But to reach a definite set of recommendations, the sequence of completion of disciplinary analyses will generally be as follows:

1. Ecological feasibility - The environmental sciences, such as ecology, forestry, and agronomy, evaluate options based upon the opportunities and limitations inherent in the climate, soils, and landforms of the study area.

2. Sociocultural feasibility - The rural sociologist or anthropologist evaluates the effect of a project based on the intended beneficiaries, as well as those prejudiced through physical or economic displacement. The probability of acceptance of change, capability to apply new technology, and appropriate mechanisms for extension are also determined.

3. Economic feasibility - Presented with an array of options in agriculture and forestry that have been screened for ecological and sociocultural appropriateness, the economist can efficiently perform cost/benefit and marketing analyses to determine economic feasibility.

4. Institutional feasibility - The team has an overall input to the assessment of the technical competence, organizational structure, and discipline of the public and private institutions that would provide support to a particular option.

The final step is integration, requiring a return to the regional system model to test the contribution of the various options to optimum sustained social and economic development. This, the goal of the environmental manager, involves both avoidin

intersectorial conflicts and using effectively all resources. Emphasis, for example, is upon farm and forest management systems rather than crop programs and lumbering operations in isolation

Definitive influence of the environmental management team over project design and implementation depends on effective communication with decision makers. Progress workshops should be scheduled regularly to apprise decision makers of findings, major problems, and tentative recommendations. Such communication between technical personnel and the decision makers is particularly important when recommendations will have political impacts.

Expected results of the process.

1. The entire process provides a technical framework in which group integration takes place. Working together to elaborate a system model forces specialists who have never functioned together professionally to see the complex interactions among their respective fields. All become more effective planning generalists, as well as sectorial experts.

2. The process results in a more broad and coherent interpretation of the planning objectives as each discipline defines its own perception of the goals stated by higher authority. The questions, "whether, how, and where," can be evaluated to determine the degree of flexibility existing in the environmental management process. Enhanced communication among sectors and disciplines permits definition of compatible scales and measures, levels of detail, and a calendar of activities within the time frame of the planning process.

3. The model provides a structure facilitating design research and data gathering activities. If the team is in accord that the model or sub-models derived from Step 7 represent the priority concerns in planning, the lines (flow) and components (storage) of the model represent the total of the data requirements. Disciplinary responsibilities may be assigned and a critical path program established for the data collection process.

Applications of Environmental Management. The procedures outlined in this section may be applied to several types of problems. Most broad in scope is regional development planning. Within the regional framework may arise a specific infrastructural study, similar in scope to the environmental impact assessments required by various institutions. Also within the regional framework serious environmental problems, such as

deforestation, may be identified for study. In any regional context exists the continuing issue of environmental administration. These four areas are discussed below:

1. Regional development. This generic framework for applying the environmental management approach has been discussed throughout the manual. Development assistance institutions have given high priority to funding integrated rural development projects, often with a rural, agricultural focus. The political mandate may range from a preconceived package of sectorial projects to the ideal situation in which specific alternatives for development are identified by the management study itself.

2. Infrastructural projects. Common among these are multipurpose and hydroelectric dams, inter-regional and penetration highways, ports, and tourist facilities. Generally the structure itself is a given and the evaluation is dedicated to questions of location, alignment, and settlement of people. Effective use of all resources, mitigation of negative impacts of the environment on the project (reservoir sedimentation), and mitigation of project impacts on other sectors (downstream fisheries) are common management considerations. In practice, the impact of a single project cannot be fully appreciated if viewed in isolation. Only in the context of anticipated actions by other sectors and their cumulative and synergistic effects can a specific project be evaluated. To be effective, an environmental management study for a project must begin and have input from the earliest stage of project conceptualization.

3. Environmental problem solving. Occasionally an environmental problem is recognized as being a regional or national disaster affecting social and economic development. Examples include deforestation, erosion, a disease outbreak, or decline in fishery production. Such problems are rooted in the functioning of a region. For example, deforestation by shifting agriculture is a widespread environmental problem. Development impacts affect various sectors including the peasants themselves, caught in a web of poverty, farming land unsuitable for sustained use in agriculture, the loss of valuable timber, decreased water supply to valley communities, shortened useful life of downstream reservoirs, and increased downstream flooding. The underlying causative factors--population growth, distorted land tenure patterns, inappropriate technology, and ineffective service infrastructure--indicate that only through analysis and management of the complex regional system can such a problem be solved.

4. Environmental administration. Though much less exciting than elaborating a development plan for a new settlement frontier or conducting an impact analysis of a proposed hydroelectric complex, environmental administration probably has the greatest potential role in long-term environmental management for development. Administration in this context is the execution of the array of laws, regulations, and permitting procedures governing controls on land use in critical watersheds, pesticide use, pollution, fishing, hunting, land clearing, and land use. The major reason these controls are rarely enforced effectively is that neither those who drafted the laws nor those responsible for their enforcement have a clear perception of the functioning of the system they seek to protect and enhance. Therefore, a team approach to understanding the regional systems being regulated and then evaluating the laws in light of a system perspective on their individual and collective effectiveness is essential. If environmental administration can be shown to significantly enhance regional productivity, then personnel and resource expenditures can be justified.

DIPLOMADO EN CONTROL DE LOS RESIDUOS GENERADOS EN HOSPITALES Y OTROS CENTROS DE SALUD

RIESGO AMBIENTAL

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UNAM

AMCRESPAC

ANTECEDENTES

En los últimos años se ha incrementado significativamente la importancia que representa el manejo del riesgo dentro del panorama industrial nacional, esto a raíz de las posibles consecuencias de un incidente en el cual se pudieran tener afectaciones hacia áreas que representen una vulnerabilidad significativa, tales como zonas urbanas o reservas ecológicas, entre otras. Esto a su vez adquiere mayor relevancia cuando se trata de sistemas o tecnologías de tratamiento de reciente creación, como lo son la mayoría de los equipos para tratamiento de residuos biológico-infecciosos.

El presente trabajo, tiene como objetivo el dar un breve panorama de la situación del Riesgo Ambiental enfocada a los residuos de tipo Biológico-Infecciosos en México; partiendo del marco jurídico y normatividad que los rige, hasta las acciones para su aplicación, así como las herramientas y criterios considerados para el análisis y evaluación de las empresas que tratan con este tipo de residuos, a través de los estudios que son presentados ante este Instituto, incluyendo algunos de los mecanismos y medidas de seguridad que son aplicadas a éstas.

Es de gran importancia hacer notar que la prevención de riesgos es más económica que restaurar posibles daños y es una responsabilidad que se debe asumir en forma consciente, desde el operador de una válvula hasta el ejecutivo que define la ubicación de la planta.

INTRODUCCIÓN

El manejo de todo tipo de residuos peligrosos industriales, municipales y hospitalarios ha tenido un desarrollo cada vez mayor en los últimos 10 años, debido a que en la sociedad civil se han incrementado las preocupaciones sobre posibles impactos adversos a la salud y el entorno ecológico.

Esta preocupación ha tenido como consecuencia el desarrollar evaluaciones de riesgo en múltiples actividades, que pudieran ocasionar afectaciones a la salud. Estas evaluaciones de riesgo han dado como resultado una serie de conocimientos relacionados con las estimaciones de afectación de impactos y riesgos a la salud por las actividades de este tipo.

La evaluación del impacto y riesgo es un instrumento eficaz, pero complejo y de continua evolución y actualización, que requiere de la participación de varias disciplinas, como la meteorología, toxicología,

biología, tecnología computarizada, así como la ingeniería ambiental, de procesos y la química entre otı con la finalidad de promover un desarrollo sustentable.

Es evidente que México se encuentra ante un desafío, ya que para avanzar en la solución de los problemas ambientales que enfrenta, es necesario considerar la implemetación de sistemas de tratamiento; es lógico pensar que estará en discusión la operación de dichos sistemas, por los impactos y riesgos resultantes.

OBJETIVO GENERAL

El objetivo del presente trabajo, es el de presentar un breve panorama de los residuos peligrosos de tipo biológico-infecciosos, partiendo desde la parte regulatoria de los residuos peligrosos en México, señalando de manera descriptiva las etapas de los sistemas generales de tratamiento de este tipo de residuos, así como de los riesgos intrínsecos de los procesos de tratamiento, finalizando con la descripción de algunas de las medidas de prevención y en su caso mitigación, consideradas por este Instituto para la utilización de estos sistemas.

LEGISLACIÓN Y NORMATIVIDAD EN MATERIA DE RIESGO

LEY GENERAL DEL EQUILIBRIO ECOLÓGICO Y LA PROTECCIÓN AL AMBIENTE

-Artículo 5., Fracción XIX.- Son asuntos de alcance general en la Nación o de interés de la Federación, la regulación de las actividades relacionadas con materiales o residuos peligrosos.

-Artículo 28.- La realización de obras o actividades públicas o privadas, que causan desequilibrios ecológicos o rebasan los límites y condiciones señalados en los Reglamentos y las Normas técnicas ecológicas emitidas por la Federación para proteger el ambiente, deberán sujetarse a la autorización previa del Gobierno Federal, por conducto de la Secretaría o de las entidades federativas o municipios, conforme a las competencias que señala esta Ley, así como al cumplimiento de los requisitos que se les impongan una vez evaluado el impacto ambiental que pudieren originar, sin perjuicio de otras autorizaciones que corresponda otorgar a las autoridades competentes.

-Artículo 29, Fracción VI.- Corresponde al Gobierno Federal por conducto de la Secretaría, evaluar el impacto ambiental a que se refiere el Artículo 28 de esta Ley, para instalaciones de tratamiento, confinamiento o eliminación de residuos peligrosos.

-Artículo 32.- Para la obtención de la Autorización a que se refiere el Artículo 28 del prese Ordenamiento, los interesados deberán presentar ante la Autoridad correspondiente, una manifestación de

impacto ambiental. En su caso, dicha manifestación deberá ir acompañada de un estudio de riesgo de la obra, de sus modificaciones o de las actividades previstas, consistente en las medidas técnicas preventivas y correctivas para mitigar los efectos adversos al equilibrio ecológico durante su ejecución, operación y en caso de accidente.

-Artículo 151.- La instalación y operación de sistemas para la recolección, almacenamiento, transporte, alojamiento, reuso, tratamiento, reciclaje, incineración y disposición final de residuos peligrosos, requerirá de la Autorización previa de la Secretaría.

-Artículo 152.- Los materiales y residuos que se definan como peligrosos para el equilibrio ecológico, deberán ser manejados con arreglo a las Normas Oficiales Mexicanas y procedimientos que establezca la Secretaría, con la participación de la Secretaría de Comercio y Fomento Industrial, de Salud, de Energía, Minas e Industria Paraestatal y de Agricultura y Recursos Hidráulicos.

RIESGO AMBIENTAL

Desde el punto de vista del análisis ambiental, riesgo es la posibilidad de sufrir un daño o perdida, y esta posibilidad ocurre durante casi cualquier actividad humana. El daño o perdida es una consecuencia adversa potencial de un evento peligroso. El riesgo de un evento define la probabilidad de este y la gravedad de sus consecuencias potenciales. Los riesgos no siempre pueden ser evitados, pero si pueden ser minimizados.

Para evaluar el riesgo de una actividad industrial, comercial o de servicio, el Instituto Nacional de Ecología, requiere a través del procedimiento de impacto ambiental o de la Procuraduría Federal de Protección al Ambiente, Protección Civil u Otros, la presentación de **un Estudio de Riesgo Ambiental,** siendo este un documento mediante el cual se da a conocer, a partir del análisis de las acciones proyectadas o instaladas para el desarrollo de una obra o actividad, los riesgos que dichas obras o actividades representen para el equilibrio ecológico o el ambiente, así como las medidas técnicas de seguridad, preventivas o correctivas tendientes a evitar, mitigar, minimizar o controlar los efectos adversos al equilibrio ecológico en caso de un posible accidente, durante la ejecución u operación normal de la obra o actividad de que se trate.

La dispersión de materiales peligrosos y contaminantes en la atmósfera ha creado un gran interés durante las últimas décadas. El cual ha dado como resultado, el desarrollo de diversos modelos de dispersión. Los primeros modelos se generaron para estudiar el comportamiento de contaminantes descargados desde respiraderos y chimeneas. Mas recientemente, el interés creciente en el análisis de riesgos se ha acompañado por una mayor preocupación en el comportamiento de nubes con densidades

significativamente diferentes a la del aire, siendo estas generalmente las de mayor importancia, debid su lenta dispersión.

El análisis y la identificación de los puntos de riesgo se realiza mediante la utilización de metodología especificas que apliquen a los sistemas utilizados para este tipo de actividades.

FLUJO GENERAL DE TRATAMIENTO DE RESIDUOS BIOLOGICO-INFECCIOSOS

1. ***Recolección***

2. ***Disponibilidad de tratamiento***, En caso de tener necesidad de almacenamiento temporal previo al tratamiento en algunos casos es necesario el almacenamiento para lo cual se requiere sistemas de refrigeración, conforme lo establece la NOM-087-ECOL-1995, referente a "Los requisitos para la separación, envasado, almacenamiento, recolección, transporte, tratamiento y disposición final de los residuos peligrosos biológico-infecciosos que se generan en establecimientos que presten atención médica".

3. ***Clasificación en planta***, En esta parte se clasifica el tipo de residuos (P.ej. residuos de fluidos corporales, orgánicos, inorgánicos, etc.), para la determinación del tipo de tratamiento más adecuado.

4. ***Tratamiento***, P.ej. Desinfección, Esterilización, Oxidación térmica, etc.

5. ***Generación de los residuos del tratamiento***, P.ej. Residuos estériles, cenizas, etc.

6. ***Disposición de los residuos generados***, P.ej. Relleno Sanitario, Reciclo de materiales, etc.

En el caso del tratamiento de los residuos biológico-infecciosos los riesgos se pueden dividir en tres:

- **Fugas o derrames de algunos residuos en estado gaseoso o líquido.**

  Este tipo de eventos puede presentarse debido a un mal manejo dentro de las áreas de almacenamiento de los residuos, durante el transporte interno de éstos o en caso de falla o ruptura de algún sistema o ducto de alimentación hacia el equipo principal de tratamiento de los residuos.

- **Fuga del combustible utilizado en el tratamiento de los residuos.**

  Las fugas de combustible se pueden presentar debido a fallas en los sistemas de regulación de la alimentación del combustible, en ductos de alimentación del mismo o en recipientes de almacenamiento. Los combustibles dentro de los tratamientos para residuos biológico-infecciosos, generalmente se utilizan para servicios auxiliares (Por ej. generación de vapor) o para equipos que requieren combustión interna (Por ej. oxidación térmica).

Los incendios pueden deberse a fugas de residuos con carácter inflamable o de combustibles, por los diferentes accesorios o ductos de alimentación de éstos. Es importante mencionar que se debe de presentar necesariamente una fuente de ignición (calor) para comenzar el incendio, por lo que se debe de minimizar o en su caso eliminar la presencia de las citadas fuentes.

- **Explosión en algunas secciones de las instalaciones de tratamiento.**

  Dentro de las instalaciones donde se maneja algún combustible para servicios auxiliares o inclusive para equipos de tratamiento de los residuos biológico-infecciosos, existe la posibilidad de explosión; por ejemplo, se pudiera presentar en el hogar de un sistema de combustión en un tratamiento por oxidación térmica.

MEDIDAS DE SEGURIDAD

Las medidas de prevención y mitigación de riesgos ha aplicarse en las diversas instalaciones industriales, se pueden clasificar en **medidas propiamente preventivas,** cuando su finalidad es reducir los niveles originados de riesgo o valores socialmente aceptables, **medidas de control,** cuando el objetivo es reducir los efectos en el ambiente de situaciones accidentales cuando se lleguen a presentar y **medidas de atención** cuando su objetivo es el de reducir los daños a la población y al equilibrio ecológico, cuando el accidente ha tenido lugar.

A continuación presentamos a manera de ejemplo una serie de medidas de seguridad consideradas en el rubro de preventivas, para las plantas que realizan el tratamiento de residuos peligrosos de tipo biológico-infecciosos:

1. LLevar a cabo auditorías de seguridad de las instalaciones y equipos de tratamiento.
2. Programas de mantenimientos preventivos.
3. Protocolos de prueba, para confirmar la eficiencia manejada en los equipos de tratamiento.
4. Pruebas analíticas a los residuos generados del tratamiento, para confirmar la eficiencia del tratamiento aplicado.
5. Plan de emergencias interno, estructura, medidas consideradas, capacitación a base de simulacros, etc.

Las medidas de seguridad particulares, varían dependiendo de las características de cada sistema de tratamiento, así como de la forma de operación y servicios auxiliares que requiera.

CONCLUSIONES

I. Prevenir riesgos es mas económico que restaurar daños y es una responsabilidad que se debe asumir en forma consiente, desde el operador de una válvula hasta el ejecutivo que define la ubicación de la planta.

II. Iniciar con estas bases es asegurar un medio saludable tanto para las generaciones actuales como para las futuras, así como el de garantizar el derecho a una calidad de vida cada vez mejor.

III. Es por eso, que con la oportuna aplicación de procedimientos de riesgo ambiental a proyectos con elevado potencial de riesgo, se esta dando un enorme paso a la resolución de la problemática de riesgo ambiental generadas por usos incompatibles del suelo.

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DIPLOMADO EN CONTROL DE LOS RESIDUOS
GENERADOS EN HOSPITALES
Y OTROS CENTROS DE SALUD

IDENTIFICACIÓN DE IMPACTO Y RIESGO

ESTUDIO DE CASO

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DIVISIÓN DE EDUCACIÓN CONTINUA
FACULTAD DE INGENIERIA
UNAM

AMCRESPAC

EVALUACION DEL IMPACTO AMBIENTAL EN LOS PROYECTOS INDUSTRIALES Y EL ANALISIS DE LA INFORMACION

CONTENIDO DEL TEMA
IMPACTO AMBIENTAL EN LOS PROYECTOS INDUSTRIALES

EVALUACION DEL IMPACTO AMBIENTAL EN LOS PROYECTOS INDUSTRIALES

PARAMO FIGUEROA, VICTOR HUGO

.- Introducción.

stóricamente y hasta nuestros días, se ha observado que muchas de s actividades que promueve el hombre ocasionan efectos o impactos en su medio ambiente circundante, siendo uno de estos los impactos producidos por la ejecución de proyectos industriales.

La disciplina denominada *Evaluación del Impacto Ambiental* es de muy reciente creación, si bien siempre han existido iniciativas por revenir y controlar los impactos ambientales, es hasta hace roximadamente 20 años que se iniciaron formalmente los estudios de mpacto ambiental.

a característica importante de esta disciplina científica es que volucra el uso del conocimiento, técnicas, procedimientos y herramientas pertenecientes a las más diversas ramas del conocimiento humano: ecología, geografía, biología, matemáticas, economía, ciología, química, física, etc.

1.- La relación MEDIO AMBIENTE-INDUSTRIA.

El hombre a través de su historia ha mostrado que el empleo que ha cho de los recursos de la naturaleza ha variado sensiblemente con el so del tiempo.

os seres humanos consumen energía para:

- Realizar sus procesos corporales (se denomina energía interna)
- Efectuar sus actividades diarias (se denomina energía externa)

Si bien el consumo de energía interna no ha variado substancialmente a través del tiempo, no sucede así con el consumo de energía externa, la cual en la actualidad es enormemente superior a la primera.

La evolución de hombre puede esquematizarse de la siguiente manera, ver figura I.1:

Hombre ---> Hombre ---> Hombre ---> Hombre ---> Hombre
Primitivo Cazador Agricultor Industrial Tecnológico

Figura I.1.- La evolución de hombre primitivo-tecnológico.

Desde el punto de vista energético, el empleo de los recursos comenzó a acelerarse a partir del invento de las máquinas (*era industrial*) produciendo entre otras cosas la contaminación y el desequilibrio ecológico.

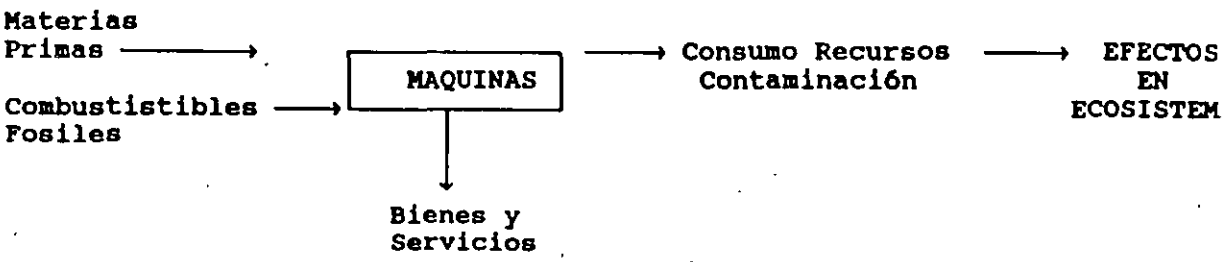
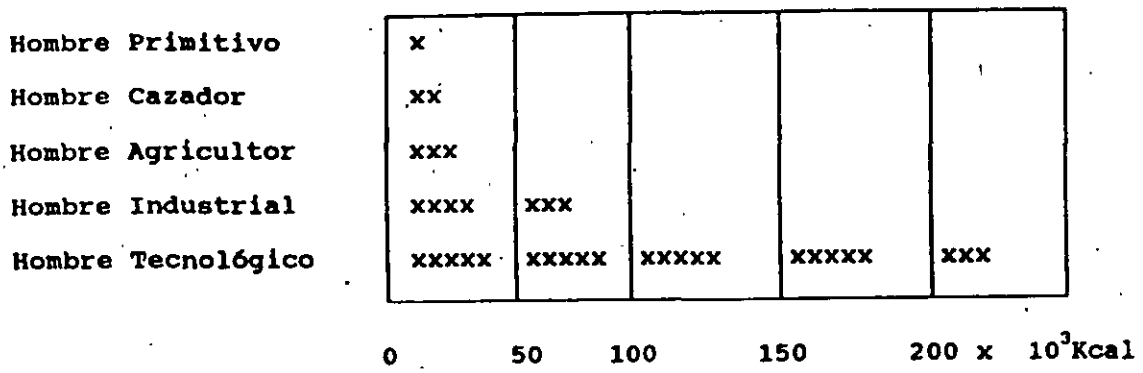


Figura I.2.- Esquema del consumo de energía del hombre a través del tiempo.



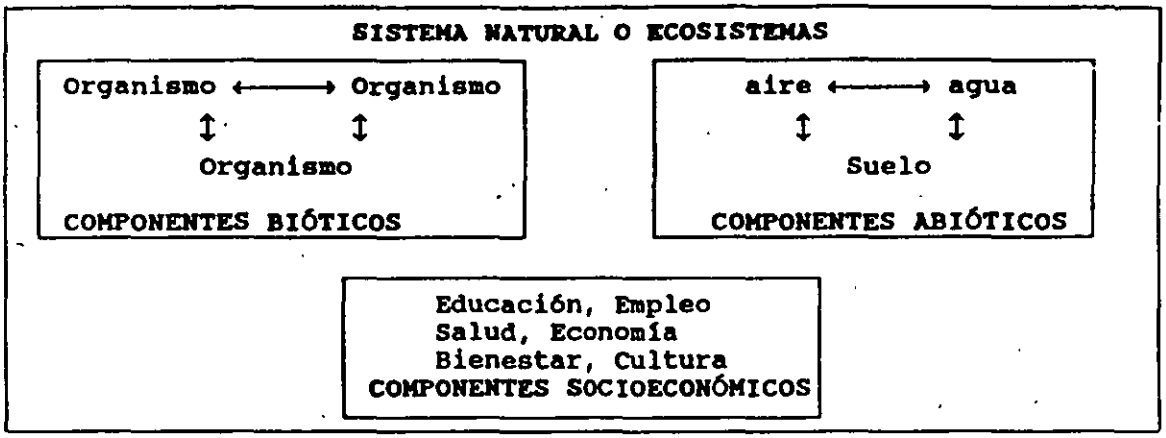
Cuadro I.1.- Consumo diario *per capita* de kilocalorías por el hombre en todos los tiempos.

El Sistema Natural (o Ecosistema) se define como un sistema formado por:

- a) Componentes bióticos
- a) Componentes abióticos
- a) Componentes socioeconómicos

El ecosistema tiene como características:

- a) sus componentes están interrelacionados:
- a) ser un sistema abierto (entra y sale materia y energía)
- a) poseer mecanismos de retroalimentación



Cuadro I.2.- Componentes de los ecosistemas

Lo anterior da como resultado que el ecosistema tienda hacia un equilibrio y a autorregularse, lo que implica que la modificación de algunos de sus componentes puede tener repercusiones en el sistema como un todo.

Desde el punto de vista humano los ecosistemas pueden ser clasificados en cuatro diferentes tipos:

1) Ecosistemas naturales maduros: aparecen más o menos en sus estados naturales, no son empleados ni habitados por el hombre (áreas silvestres, montañas, desiertos).

2) Ecosistemas naturales controlados: son aquellos que controla el hombre para uso recreativo o producción de recursos naturales (parques, bosques, zonas de caza, zonas costeras marítimas).

3) Ecosistemas productivos: los que emplea el hombre para la producción intensiva de alimentos o recursos naturales (granjas, ranchos para ganado, minas).

4) Ecosistemas urbanos: son los ecosistemas en donde el hombre vive y trabaja (áreas industriales, ciudades, pueblos).

En los ecosistemas urbanos se generan grandes cantidades de productos de desecho, que hasta cierto grado pueden ser asimilados por los ecosistemas naturales.

I.2.- Los efectos de la contaminación industrial.

Se define el término *CONTAMINACIÓN* como la presencia de uno o más contaminantes o cualquier combinación de ellos que perjudique o resulte nocivo a la vida, la salud y el bienestar humano, la flora y la fauna o degraden la calidad del aire, del agua, del suelo o de los bienes y recursos en general.

Un *CONTAMINANTE* es toda materia o sustancia, sus combinaciones o componentes, los derivados químicos o biológicos, así como toda forma de energía térmica, radiaciones ionizantes, vibraciones o ruído, que al incorporarse o actuar en el atmósfera, agua, suelo, flora, fauna o cualquier elemento ambiental, alteren o modifiquen su composición, o afecten a la salud humana.

Los contaminantes pueden ser de naturaleza diferente:

- a) Físicos
- a) Químicos
- a) Biológicos

y sus efectos se dejan sentir en formas diferentes en los ecosistemas terrestres.

El cuadro I.3, presenta una clasificación de los contaminantes de acuerdo a su naturaleza e indica los ecosistemas afectados:

Naturaleza del Contaminante	Ecosistemas			
	Atmósfera	Continentes	Lagos y Ríos	Mares
Físicos				
Radiaciones	x	x	x	x
Contaminación Térmica			x	x
Químicos				
Hidrocarburos y Residuos de combustión	x	x	x	x
Materias plásticas	x	x	x	x
Pesticidas		x	x	x
Detergentes			x	x
Compuestos orgánicos	x	x	x	x
Derivados del azufre	x	x	x	
Nitratos		x	x	x
Fosfatos		x	x	x
Residuos metálicos	x	x	x	x
Fluoruros	x	x		
Partículas minerales (aerosoles)	x	x		
Biológicos				
Materia orgánica muerta			x	x
Microorganismos patógenos	x	x	x	x

Cuadro I.3.- Clasificación de los contaminantes de acuerdo a su naturaleza e indica los ecosistemas afectados.

Los principales contaminantes atmosféricos son:

- El dióxido de azufre (SO_2) cuyas fuentes más importantes son la combustión del carbón, combustóleo y derivados del petróleo.

- Los óxidos de nitrógeno (NOx) que incluyen al óxido de nitrógeno (NO) y al dióxido de nitrógeno (NO_2). Los NOx son emitidos principalmente por los vehículos automotores y por la combustión de combustibles fósiles.

- El monóxido de carbono (CO) es producido en gran medida por los vehículos automotores y en general cuando la combustión es incompleta.

- Los hidrocarburos (HC) cuyo origen se encuentra en el almacenamiento,distribución y empleo de petróleo y sus derivados.

- Las partículas suspendidas (PS) cuyas fuentes son el polvo de industrias, construcción, hollín y residuos de la combustión.

- El plomo (Pb) proveniente principalmente de la combustión en vehículos automotores (se adiciona como aditivo a las gasolinas).

A *grosso modo* estos seis contaminantes constituyen aproximadamente el 90% de la contaminación atmosférica; sin embargo, algunos de ellos reaccionan en la atmósfera dando lugar a los contaminantes secundarios como son los oxidantes fotoquímicos, cuyo compuesto representativo es el ozono (O_3) y cuya formación se produce con la presencia de NOx e HC en presencia de la radiación solar. Igualmente el SO_2 y NOx pueden dar lugar a la formación de partículas (aerosoles) de sulfatos ($SO^{=}_4$) y nitratos (NO_3^{-}) que al ser incorporados en las precipitaciones producen la lluvia ácida.

Dentro de los contaminantes del agua se tiene :

- Residuos con requerimientos de oxígeno, provenientes de casas domésticas, fábricas y agricultura (aguas negras, aguas residuales, escurrimientos pluviales). Existen dos parámetros que sirven para evaluar el requerimiento de oxígeno.
  - La Demanda Bioquímica de Oxígeno (DBO) que representa la cantidad de oxígeno necesario para degradar la materia orgánica de un efluente.
  - La Demanda Química de Oxígeno (DQO) que representa la cantidad de oxígeno consumido para oxidar compuestos inorgánicos en un efluente.
- Detergentes y productos químicos inorgánicos presentes en los residuos líquidos de casas domésticas y fábricas.
- Fertilizantes y plaguicidas provenientes de fábricas y campos agrícolas.
- Metales pesados y calor originados en fábricas y por el tráfico terrestre y marítimo.
- Sedimientos acarreados por los escurrimiento pluviales de campos agrícolas.
- Petróleo y sustancias radioctivas producidas por las actividades energéticas.
- Pinturas, aceites y solventes de aguas residuales de fábricas.
- Microorganismos patógenos generados en casas domésticas y actividades agrícolas.

Entre los contaminantes del suelo se tienen:

- Detergentes,organismos patógenos, metales pesados, sustancias orgánicas tóxicas, solventes, grasas y aceites, generados por la irrigación con aguas negras y residuales.

- a) Fertilizantes y plaguicidas incorporados por su empleo intensivo en suelos agrícolas.
- a) Petróleo originado en derrames y fugas en las actividades de extracción y transporte.
- a) La erosión acelerada, si bien no es un contaminante químico, sí es una forma de degradación del suelo y en ella participan el hombre, las aguas, los vientos, la salinidad y sodicidad, las inundaciones, el drenaje insuficiente.

Los efectos de los contaminantes se dejan sentir tanto en los sistemas vivos como en los sistemas carentes de vida.

Algunos de los efectos en los sistemas vivos son:

- a) En la salud humana: mortalidad, morbilidad.
- a) En la productividad económica de sistemas ecológicos: agricultura, pesca comercial, silvicultura.
- a) En sistemas ecológicos que impactan las actividades humanas: pesca deportiva, caza, observación de fauna salvaje, actividades recreativas, educativas y científicas, paisaje.
- a) En sistemas ecológicos que no impactan las actividades humanas: diversidad de especies, estabilidad del ecosistema.

Algunos efectos en sistemas no vivientes son:

- a) Actividades de producción: daños a materiales, ensuciamientos, disminución en calidad de productos.
- a) Residencias familiares : daños a materiales, ensuciamientos.
- a) Cambios en el estado atmosférico y clima: calidad del aire, modificaciones del clima (isla de calor).
- a) Otros: visibilidad, tranquilidad y calidad de vida.

Cada uno de los contaminantes afecta de forma diferente los ecosistemas:

- Efectos de contaminantes del aire en el hombre:
  - CO : a concentraciones inferiores a 100 ppm produce la formación de carboxihemoglobina reduciendo la capacidad de oxigenación de la sangre y produciendo jaquecas y efectos sobre el sistema nervioso central. A concentraciones superiores a 100 ppm puede provocar la muerte por asfixia.
  - SO_2 : provoca irritación de nariz, garganta, pulmones y ojos.
  - HC y oxidantes fotoquímicos: algunos compuestos son irritantes y tóxicos.
  - NOx : el NO_2 es cuatro veces más tóxico que el NO, afectan las vías respiratorias irritándolas; a concentraciones muy elevadas pueden provocar edema pulmonar e incluso la muerte.
  - Partículas: afectan el aparato respiratorio.

- Efectos de los contaminantes del aire en las plantas:
  - SO_2 : Provoca lesiones caracterizadas por un amarillo gradual de las hojas; a concentraciones elevadas se forman necrosis que causan la caída de las mismas.
  - HC y oxidantes fotoquímicos: el O_3 provoca lesiones, necrosis y manchas blancas; el smog fotoquímico provoca manchas cafés bronceado en hojas adultas y un ataque general en las hojas jovenes.
  - NOx : a niveles encontrados en la ciudad causa lesiones, cambios de pigmentación en las hojas, necrosis y caída de las mismas.
  - Partículas: obstruyen los poros, alteran el proceso fotosintético al depositarse en las hojas; efectos variables dependiendo de la naturaleza química de las partículas.

ooo Efectos de los contaminantes del aire en los materiales:

- SO_2 : corrosión de metales, endurecimiento de pinturas, deterioro de materiales de construcción, ataque al cuero y papel.
- HC y oxidantes fotoquímicos: el ozono altera las fibras textiles naturales y sintéticas, procando roturas de las fibras y se forman grietas en el hule y caucho.
- NOx : los textiles pierden su color, los cables de cuproniquel son corroídos.
- Partículas: ensucian, provocan corrosión, crean falsos contactos efectivos.

oooo Efectos del ruído.

- Las fábricas, industrias y otros centros de trabajo, así como los vehículos y aeronaves son fuente importante de emisión de ruído.
- Los efectos del ruído en el hombre dependen de la duración e intensidad de las ondas sonoras; van desde la molestia y el stress hasta lesiones irreversibles en el oído.
- Las vibraciones en general provocan stress en las personas y daños en las construcciones.

___ Efectos de los contaminantes del agua:

- Residuos con requerimientos de oxígeno: las aguas residuales con altos valores de DBO provocan la desaparición de la flora y fauna acuáticas al consumir el oxígeno disuelto.
- Detergentes y fertilizantes: la presencia de polifosfatos provocan un estado de eutroficación (ver figura I.3):

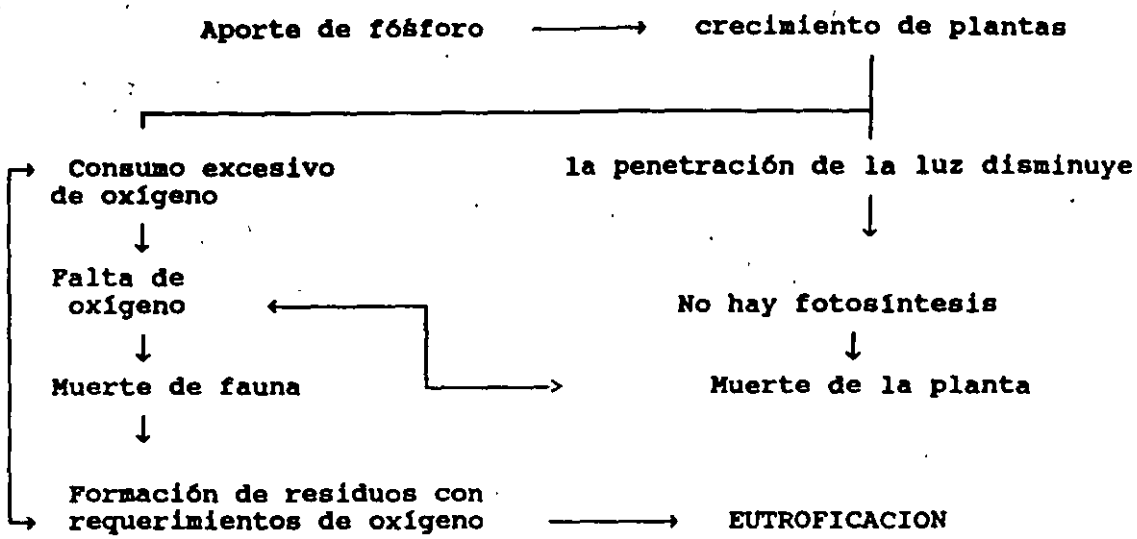


Figura I.3.- El fenómeno de eutroficación.

- Plaguicidas y organofosfatos: se acumulan en los organismos acuáticos (bioacumulación) hasta alcanzar concentraciones tóxicas; algunos no son biodegradables.
- Metales pesados: provocan enfermedades (acumulación de plomo, lesiones al cerebro) y algunos casos causan lesiones genéticas (Minamata, Japón 1953, lesiones en bebés debido al mercurio).
- Sedimentos: cubren los nidos y reservas de alimentos y destruyen la fauna acuática, se reduce la penetración de la luz, el agua se enturbia.
- Petróleo: tiene los mismos efectos que los residuos con requerimientos de oxígeno,reducción de la penetración de la luz, daño a aves acuáticas y otras especies, disminuye el intercambio de oxígeno atmósfera-agua.
- Calor: disminución de la cantidad de oxígeno disuelto, aumento de velocidad en reacciones químicas, daños a flora y fauna acuáticas

I.3.- Prevenir o controlar los IMPACTOS AMBIENTALES

En el párrafo anterior se discutieron algunos de los efectos causados por la contaminación del medio ambiente. Estos efectos se conocen como impactos ambientales, si bien, como se verá más adelante, existen otros tipos de impactos que no necesariamente se dan por la contaminación ambiental.

Existe un consenso general entre los estudiosos y practicantes de la ingeniería ambiental, en el sentido en que es preferible prevenir los impactos antes de que se produzcan. Sin embargo muchas veces la prevención no es suficiente y es necesario implementar controles de los mismos.

Los beneficios que se tienen al mejorar la calidad del agua son múltiples y esto implica ya sea una reducción de descargas contaminantes o un tratamiento de las mismas antes de su disposición en el cuerpo receptor.

Para evaluar este beneficio es necesario:

- Evaluar los cambios en los indicadores de la calidad del agua:

  Físicos y químicos:

  - oxígeno disuelto (OD)
  - temperatura
  - turbiedad
  - calor
  - pH
  - sustancias nutritivas
  - otras sustancias químicas

  Biológicos:

  - peces
  - algas
  - zooplancton
  - bacterias

∞ Evaluar los cambios en los usos humanos de cuerpos de agua:

Abastecimiento:

- o residencial
- o industrial
- o irrigación
- o Pesquerías
- o Recreación
- o Estética

∞∞ Evaluar el valor que dan los humanos el uso del agua: en particular la disponibilidad para pagar por la mejora de la calidad del agua.

En forma similar, los beneficios que se obtiene al mejorar la calidad del aire se estiman al contemplar la incorporación de equipos de control y evaluando los siguientes aspectos:

∘ Reducción de emisiones:

- o SO_2
- o PST
- o CO
- o HC
- o NOx
- o etc.

∞ Reducción de niveles ambientales:

- o SO2
- o PST
- o CO
- o HC
- o NOx
- o Oxidantes fotoquímicos
- o etc.

••• Efectos en los humanos y sus bienes:

- o morbilidad y mortalidad
- o productividad
- o suciedad y daños a materiales
- o amenidad visual

•••• Valor para los humanos de contar con un aire adecuado; disponibilidad para pagar por la mejora de la calidad del aire.

Estos dos aspectos mencionados corresponden a una estratégia de control de impactos ambientales, a continuación se analiza el aspecto. de prevención de los impactos que está intimamente con la planeación del territorio y de un proyecto industrial.

Planificar un sitio es el arte y ciencia de arreglar el uso de las porciones del territorio, considerando aspectos como:

- o análisis y selección de los sitios.
- o planes del uso del suelo.
- o formas visuales y del tiempo.
- o propiedades del drenado del terreno.
- o detalles necesarios para proyectos específicos.

Todo proyecto que contemple la prevención de problemas de contaminación y ambientales debe atender mínimamente dos principios:

a) La preservación de los recursos naturales no renovables
a) El manejo racional de los recursos naturales renovables.

Existen dos tipos de regiones que exigen enfoques de planeación completamente diferentes.

1: Areas deprimidas de caracter rural: es el caso de amplias zonas que a través de un proceso de emigración quedan prácticamente abandonadas.

2: Areas de rápido crecimiento : es el caso de grandes áreas metropolitanas y sus zonas de expansión industrial, y de los desarrollos turísticos e industriales en los litorales.

La planeación del territorio debe considerar los aspectos anteriores lo que redundará en general en la preservación del medio ambiente.

La planeación de un desarrollo industrial parte de la existencia de una Política de Desarrollo del País, la cual define las áreas de desarrollo industrial prioritarias.

Para desarrollar un proyecto industrial es necesario tomar decisiones importantes. Esta toma de decisiones está sujeta, en el caso del aspecto ambiental, a varias aspectos como:

- Limitaciones en los tipos y niveles de emisión de contaminantes.
- Situación geográfica y entorno de las fuentes de contaminación.
- Tecnología a emplearse o de reemplazo de las existentes.

Antes de tomar la decisión de desarrollar un proyecto es necesario conocer o estimar las posibles consecuencias sobre el medio ambiente. Para facilitar el proceso de toma de decisión es recomendable efectuar la comparación de varias alternativas. La comparación se puede hacer cualitativa o cuantitativamente; sin embargo es preferible emplear la segunda.

Una manera de comparar cuantitativamente varias alternativas de un proyecto consiste en la estimación monetaria de los beneficios o daños que producirán cada una de ellas.

El daño monetario que corresponde a tal o tal efecto es la suma de dinero necesario para dar una compesación a los que sufren un perjuicio tanto desde el punto ambiental como económico y de salud. La estimación de los daños en términos monetarios permite fundir en una sola cifra los diferentes tipos de daños, pérdidas financieras y pérdidas de amenidad. Las pérdidas financieras pueden ser definidas; por ejemplo, como las modificaciones hechas en la calidad del medio ambiente;en cuanto a las pérdidas de amenidad ellas constituyen una categoría residual que recubre el conjunto de las pérdidas diversas, algunas veces llamadas pérdidas intangibles, costo sicológico o costo social.

El empleo de la estimación monetaria de los daños debe hacerse con reserva ya que presenta algunas limitaciones:

- Existen daños para los cuales se conocen mal las incidencias y efectos de la contaminación sobre el medio ambiente.

- No es siempre fácil de transponer las estimaciones monetarias de una situación a otra.

- Algunas acciones tienen consecuencias irreversibles para las generaciones futuras, y esas consecuencias deberían en principio ser incorporadas en los cálculos de los daños en términos monetarios.

- Ciertos daños sicológicos son imposibles de evaluar en términos monetarios.

Las tablas siguientes presentan algunos ejemplos de tipos de daños al medio ambiente.

CATEGORIA DE DAÑO			
	SALUD HUMANA	FAUNA	FLORA
PERDIDAS FINANCIERAS	.PERDIDA DE CAPACIDAD DE PRODUCCIÓN	.PERDIDAD DE PRODUCCIÓN ANIMAL Y PISCICOLA	. REDUCCIÓN DE RENDIMIENTOS AGRÍCOLAS
	.COSTO DE ATENCIÓN MEDICA INCLUYENDO LOS COSTOS E INVESTIGACIÓN PARA EVITAR LA CONTAMINACIÓN		. REDUCCIÓN DE CRECIMIENTOS DE BOSQUES
	.COSTOS DE ENTIERRO PREMATURO		
PERDIDAS DE AMENIDAD	.AVERSIÓN POR EL RIESGO	. AVERSIÓN POR EL RIESGO	. AVERSIÓN POR EL RIESGO
	.COSTO DE LOS SUFRIMIENTOS	.REDUCCIÓN POR EL PLACER DE PESCAR Y CAZAR	.REDUCCIÓN DEL PLACER DEBIDO A PÉRDIDAS HORTICOLAS Y FORESTALES
	.COSTO DE LAS LIMITACIONES IMPUESTAS AL INDIVIDUO, A SU FAMILIA, A SU ENTORNO	.REDUCCIÓN DE LA POBLACIÓN DE ANIMALES SALVAJES	
	.COSTO DEL SUELO		

Cuadro I.4.- Ejemplos de tipo de daños.

CATEGORIA DE DAÑO			
	RECURSOS NATURALES	MATERIALES	CLIMA Y TIEMPO
PÉRIDAS FINANCIERAS	PÉRDIDA DE PRODUCCIÓN DEBIDO A LA CONTAMINACIÓN DEL AGUA Y DE SUELO	.REDUCCIÓN DE LA VIDA UTIL DE MATERIALES .REDUCCIÓN DE LA UTILIDAD DE UN MATERIAL .COSTO DE PRODUCCIÓN DE UN MATERIAL .COSTO SUPLEMENTARIO DE SUSTITUTO	.REDUCCIÓN DE RENDIMIENTOS AGRÍCOLAS DEBIDO A UNA DISMINUCIÓN DE LAS PRECIPITACIONES
PERDIDAS DE AMENIDAD	.AVERSIÓN POR EL RIESGO .PERDIDAS DE VENTAJAS DE RECREACIÓN	.AVERSIÓN POR EL RIESGO .RESISTENCIA A LOS MATERIALES ENSUCIADOS O DAÑADOS .DAÑO A LOS MONUMENTO Y OBJETOS DE VALOR ESTÉTICO	.AVERSIÓN POR EL RIESGO .REDUCCIÓN DE RECREACIÓN DEBIDO A LA REDUCCIÓN DE LA INSOLACIÓN O AL AUMENTO DE PRECIPITACIONES .PERDIDAS DE PLACER DEBIDO A LA REDUCCIÓN DE LA VISIBILIDAD

Cuadro I.5.- Ejemplos de tipo de daños al medio ambiente.

II.- La evaluación del IMPACTO AMBIENTAL en México.

II.1.- Antecedentes.

La fuerte presión ejercida por el crecimiento poblacional e industrial y la falta de una planeación integrada del uso del suelo y sus recursos, dío lugar a un desarrollo desequilibrado en diversas zonas del país.

En respuesta a la instrucción del Ejecutivo Federal en el Plan Nacional de Desarrollo 83-88, la SEDUE estableció el Procedimiento de Impacto Ambiental, como herramienta de planeación para proteger al medio ambiente de los impactos que conlleva un plan o programa de desarrollo, ya sea a través de la ejecución directa o por los servicios y actividades que de ellos se deriven. En ese entonces, la fundamentación legal del impacto ambiental se encontraba en los Artículos 7 y 38 de la Ley Federal de Protección al Ambiente, en el Artículo 13 de la Ley de Obras Públicas y en los Artículos 12 y 14 del Reglamento de ésta última.

Desde entonces la Ley define el *impacto ambiental* como "La alteración del ambiente ocasionada por el hombre o la naturaleza", derivándose los objetivos de las evaluaciones de Impacto Ambiental, que son:

- a) Ordenar las actividades productivas entre sí y éstas con el ambiente, de manera que se garantice su compatibilidad y se minimice el deterioro.
- a) Anticipar los impactos ambientales adversos de un plan o proyecto y diseñar los mecanismos técnicos para evitarlos o reducirlos.
- a) Generar los elementos para que el responsable y la autoridad competente elijan la alternativa de un plan o proyecto que representa el mínimo costo ambiental.

La siguiente figura, Fig I.4, muestra a en forma esquemática la mecánica seguida entre el proponente (ejecutor de un proyecto o actividad) y la autoridad, en el proceso de realización de un estudio de impacto ambiental y su aplicación:

ACCIONES A CARGO DE LA AUTORIDAD

ACCIONES A CARGO DEL RESPONSABLE

Identifica planes o proyectos que puedan causar cambios en el medio ambiente

DETECCIÓN Y SELECCIÓN

Realiza los estudios que se requieran para la manifestación de impacto con base en las instrucciones que proporcione la autoridad

MANIFESTACIÓN DE IMPACTO AMBIENTAL

Evalúa la manifestación de impacto ambiental y dictamina la aprobación condicionada o el rechazo del proyecto

EVALUACIÓN Y DICTAMEN

Lleva a cabo las acciones de prevención, mitigación restauración, compensación, o control de los impactos ambientales, de acuerdo con los términos del dictamen

INSTRUMENTACIÓN DEL DICTAMEN

Supervisa el cumpliento de los términos del dictámen.

SUPERVISIÓN

Figura I.4.- Funcionamiento de la mecánica seguida entre la Autoridad y el proponente de un proyecto, para la realización y ejecución de un estudio de impacto ambiental.

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II.2.- REGLAMENTO DE LA LEY GENERAL DEL EQUILIBRIO ECOLOGICO Y LA PROTECCION AL AMBIENTE EN MATERIA DE IMPACTO AMBIENTAL.

Con la promulgación de la Ley General del Equilibro Ecológico y la Protección al Ambiente (LGEEPA); del 28 de enero de 1988, el procedimiento de impacto ambiental, hasta entonces constituído como herramienta administrativa para la revisión y dictaminación de las evaluaciones de impacto ambiental, fue sustituído por el Reglamento de la LGEEPA en materia de impacto ambiental, en el cual se especifican las competencias y responsabilidades de las autoridades encargadas de su aplicación y los procedimientos y contenidos que deberán contener las manifestaciones de impacto ambiental.

Se definen una serie de obras y actividades, públicas o privadas, que pueden causar desequilibrios ecológicos o rebasar los límites y condiciones señalados en los reglamentos y las normas técnicas ecológicas; entre estas se encuentran:

- Obra pública federal
- Obras hidráulicas
- Vías generales de comunicación
- Oleoductos, gasoductos y carboductos
- Industria química, petroquímica, siderúrgica, papelera, azucarera, de bebidas, del cemento, automotriz y de generación y transmisión de electricidad
- Exploración, extracción, tratamiento y refinación de sustancias minerales y no minerales reservadas a la Federación
- Instalaciones de tratamiento, confinamiento o eliminación de residuos peligrosos
- Desarrollos turísticos federales
- Instalaciones de tratamiento, confinamiento o eliminación de de residuos radiactivos
- Aprovechamientos forestales de bosques y selvas tropicales y especies de difícil regeneración
- Obras o actividades que por su naturaleza y complejidad requieran de la participación de la Federación
- Actividades consideradas altamente riesgosas
- Cuando la obra o actividad que pretenda realizarse pueda afectar el equilibrio ecológico de dos o más entidades federativas o de otros países o zonas de jurisdicción internacional.

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Para llevar a cabo alguna de las actividades mencionadas, el interesado, en forma previa a la realización de la obra o actividad, debe de presentar una manifestación de impacto ambiental. En el caso de obras o actividades consideradas como altamente riesgosas, deberá presentarse adicionalmente un estudio de riesgo.

El reglamento establece 4 modalidades de informes de manifestación de impacto ambiental:

- Informe Preventivo
- Manifestación de Impacto Ambiental-Modalidad General
- Manifestación de Impacto Ambiental-Modalidad Intermedia
- Manifestación de Impacto Ambiental-Modalidad Específica.

En los casos arriba citados, se debe de presentar una manifestación en su modalidad general. Cuando las características de la obra o actividad, su magnitud o impacto factible sobre el ambiente, o las condiciones del sitio lo ameriten, será necesario presentar manifestaciones en su modalidad intermedia y hasta específica.

El grado de complejidad va en aumento y responde a la complejidad misma de un proyecto y la necesidad de contar con mayor información tanto del medio físico, socioeconómico y biológico, así como del proyecto mismo.

El Informe Preventivo debe contener, al menos, la siguiente información:

- Datos generales de quien pretenda realizar la obra o actividad, los estudios previos correspondientes
- Descripción de la obra o actividad proyectada
- Descripción de las materias primas y materiales que se emplearán, así como los productos y residuos que se generarán, incluyendo emisiones a la atmósfera, al agua, residuos y procedimientos para su disposición final.

La manifestación de impacto ambiental en su modalidad general deberá contener como mínimo la siguiente información:

- Nombre, denominación o razón social, nacionalidad, domicilio y dirección de quien pretenda llevar a cabo la obra o actividad objeto de la manifestación

- Descripción de la obra o actividad proyectada, desde la etapa de selección del sitio para la ejecución de la obra en el desarrollo de la actividad; la superficie de terreno requerido; el programa de construcción, montaje de instalaciones y operación correspondiente; el tipo de actividad, volúmenes de producción previstos e inversiones necesarias; la clase y cantidad de recursos naturales que habrán de aprovecharse, tanto en la etapa de construcción como en la operación de la obra o el desarrollo de la actividad; el programa para el manejo de residuos, tanto en la construcción y montaje como durante la operación o desarrollo de la actividad; y el programa para el abandono de las obras o el cese de las actividades

- Aspectos generales del medio natural y socioeconómico del área donde pretenda desarrollarse la obra o actividad

- Vinculación con las normas y regulaciones sobre uso del suelo en el área correspondiente

- Identificación y descripción de los impactos ambientales que ocasionaría la ejecución del proyecto o actividad, en sus distintas etapas

- Medidas de prevención y mitigación para los impactos ambientales identificados en cada una de las etapas.

La manifestación de impacto ambiental, en su modalidad intermedia, contempla los mismos puntos que la modalidad general, requiriéndose una ampliación de la información referente a la descripción de la obra o actividad, asi como la correspondiente a los aspectos del medio natural y socioeconómico. Además deberá contener la descripción del posible escenario ambiental modificado por la obra o actividad de que se trate, así como las adecuaciones que procedan a las medidas de prevención y mitigación propuestas en la manifestación general.

La manifestación de impacto ambiental, en su modalidad específica, deberá incluir como mínimo la siguiente información:

- Descripción detallada y justificación de la obra o actividad proyectada, desde la etapa de selección del sitio, hasta la terminación de las obras o el cese de la actividad, ampliando la información a que se refiere la descripción de la obra o actividad en la modalidad general de la manifestación

- Descripción del escenario ambiental, con anterioridad a la ejecución del proyecto

- Análisis y determinación de la calidad, actual y proyectada, de los factores ambientales en el entorno del sitio en que se pretende desarrollar la obra o actividad proyectada, en sus distintas etapas

- Identificación y evaluación de los impactos ambientales que ocasionaría la ejecución del proyecto, en sus distintas etapas

- Determinación del posible escenario ambiental resultante de la ejecución del proyecto, incluyendo las variaciones en la calidad de los factores ambientales

- Descripción de las medidas de prevención y mitigación para reducir los impactos ambientales adversos identificados en cada una de las etapas de la obra o actividad, y el programa de recuperación y restauración del área impactada, al concluir la vida útil de la obra o al término de la actividad correspondiente.

En anexo se presenta una recopilación de la normatividad vigente en materia de impacto ambiental.

En cuanto a los Estudios de Riesgo, estos se refieren a la elaboración de un documento mediante el cual se da a conocer, a partir del análisis de las acciones proyectadas para el desarrollo de una obra o actividad, los riesgos que dichas obras o actividades representen para el equilibrio ecológico o el ambiente, así como las medidas técnicas de seguridad, preventivas y correctivas, tendientes a evitar, mitigar, minimizar o controlar los efectos adversos al equilibrio ecológico en caso de un posible accidente durante la ejecución u operación normal de la obra o actividad de que se trate.

Los estudios de riesgo presentan tres niveles de profundidad que corresponden las modalidades de:

- Informe Preliminar de Riesgo
- Estudio de Riesgo
- Estudio Detallado de Riesgo.

Como en el caso de las manifestaciones de impacto ambiental, el detalle y profundidad de análisis se incrementa de uno a otro.

Algunos critérios generales para determinación de riesgos por localización son enfocados a:

- Atmósfera
- Agua
- Suelo
- Biota
- Socioeconomía

todos ellos pretenden minimizar incompatibilidades entre los usos del suelo existentes y las características del medio, con el proyecto a realizar.

Existen otros critérios para determinación de riesgo potencial por la tecnología aplicada en los procesos industriales. Una técnica de evaluación de este tipo de riesgo son los árboles de fallas. Una vez identificados los puntos de riesgo, se establecen los escenarios de accidentes para fugas y derrames de sustancias tóxicas, explosivas o inflamables y con ayuda de técnicas y procedimientos de modelación, se establecen las áreas de afectación del escenario bajo análisis. Posteriormente se determinan las acciones preventivas, correctivas y de atención necesarias.

Igualmente la operatividad de procesos industriales presentan riesgos por factores humanos: errores de diseño, condiciones de los procesos controlables y no controlables.

icionalmente se deben considerar criterios para la aplicación de [illegible], diseño, construcción, operación y seguridad industriales:

- Arreglo topológico que considere la separación física de actividades que puedan calificarse de alto riesgo.
- Diseños de instalaciones utilizando criterios técnicos y elementos materiales que garanticen su funcionamiento con un mínimo de riesgo.
- Diseños adecuados para la recepción y conducción de materias primas y productos.
- Etiquetado de sustancias peligrosas.
- Señalamientos preventivos y de orientación sobre la operatividad industrial.
- Diseño, instalación y mantenimiento de los sistemas de seguridad y control de incendio en apoyo a la normatividad vigente.
- Instrumentación de programas de mantenimiento preventivo y correctivo.

pesar de las medidas preventivas señaladas, un accidente puede [illegible]cirse, por lo que es conveniente contar con un plan de [illegible]ergencias, el cual permita dar respuesta inmediata.

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III.- IDENTIFICACION Y EVALUACION DE IMPACTOS AMBIENTALES.

Como se mencionó, un estudio de impacto ambiental consiste en ver de qué manera un proyecto afecta (adversa o benéficamente) al medio circundante. Para ello es necesario conocer por una parte las características del medio y, por otra, las del proyecto. Esta información debe permitir describir el proyecto en sus diversas etapas de desarrollo (planeación, construcción, operación, mantenimiento, término de vida útil) así como los elementos importantes existentes en el área física donde se implementará.

Para describir un proyecto es necesario considerar:

- Características generales
  - o Tipo de proyecto
  - o Justificación
  - o Ubicación
  - o Superficie de ocupación
  - o Uso del suelo y tenencia
  - o Compatibilidad con uso del suelo
  - o Relación con otros proyectos o actividades
  - o Programa de trabajo
  - o Programa de operación
- Estudios preliminares de campo
  - o Tipo de estudios e investigaciones
  - o Obras y servicios de apoyo
  - o Actividades de apoyo
  - o Equipo y maquinaria
  - o Tipo y cantidades de residuos
  - o Niveles de ruido
- Preparación del sitio y construcción
  - o Recursos aprovechables en la zona
  - o Obras provisionales y permanentes
  - o Preparación para construcción
  - o Procedimientos de construcción
  - o Equipo y maquinaria
  - o Aprovisionamiento de materiales
  - o Empleo de energéticos
  - o Estimaciones de desechos

- o Disposición de residuos sólidos
- o Descarga de desechos líquidos
- o Control y evacuación de emisiones
- o Medidas de seguridad de accidentes
- o Planes de emergencia

- Operación y mantenimiento

  - o Descripción de procesos
  - o Descripción de materiales
  - o Programa de operación
  - o Programa de mantenimiento
  - o Recursos humanos
  - o Estimación de desechos
  - o Disposición de residuos sólidos
  - o Descarga de desechos líquidos
  - o Manejo y control de emisiones
  - o Medidas de seguridad de accidentes
  - o Planes de contingencia

- Término de vida útil y abandono

  - o Estimación de la vida útil del proyecto
  - o Planes y acciones para el abandono del proyecto
  - o Acciones de restitución y aprovechamientos para bancos de material y de préstamo.

La caracterización del medio natural, incluyendo la descripción de:

- o El medio físico
- o El medio biológico
- o El medio socioecónomico

La información se refiere a

- Medio físico

  - o Localización y ubicación
  - o Geología
  - o Geomorfología
  - o Climatología

- o Hidrología
- o Oceanología
- o Edafología

- Medio biológico

  - o Flora
  - o Fauna
  - o Ecosistemas

- Medio socieconómico:

  - o Demografía
  - o Actividades económicas
  - o Educación
  - o Salud
  - o Vivienda
  - o Infraestructura y servicios
  - o Aspectos históricos, antopológicos, arqueológicos y técnicos
  - o Aspectos estéticos y paisajísticos

III.1- MATRICES DE IDENTIFICACIÓN DE IMPACTO AMBIENTAL.

En general una matriz de identificación consiste en elaborar una tabla en donde las columnas representan las actividades de un proyecto y las líneas corresponden a elementos del medio natural que pueden ser impactados por el proyecto.

En la figura I.5, se muestra la forma esquemática de las matrices de identificación de cualquier proyecto industrial.

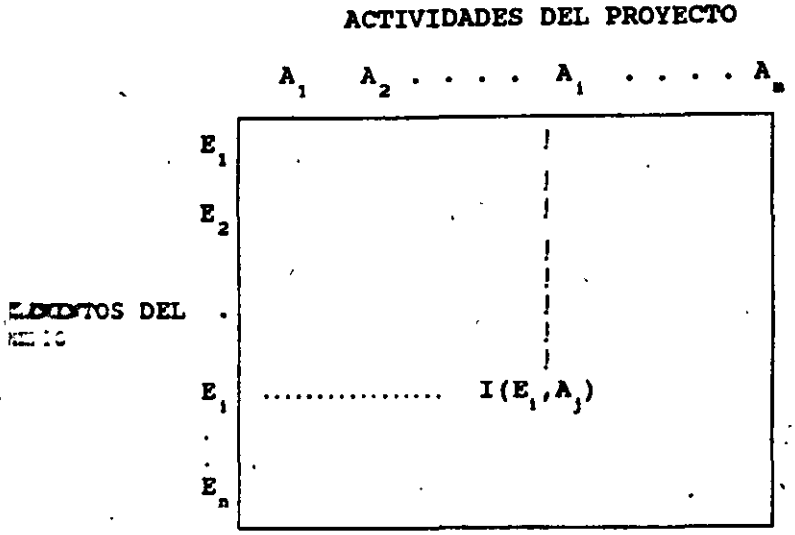

Figura I.5.- Matriz de la correspondencia de las actividades de un proyecto y los elementos del medio natural.

En cada interacción columna-línea se tendrán dos posibilidades:

- Existe un impacto (positivo o negativo) de la actividad A_j sobre el elemento E_i.
- No existe impacto.

La matriz de identificación se forma entonces al identificar todas las interacciones en donde se prevee se producirán impactos. El paso siguiente es hacer una discusión sobre las actividades del proyecto que impactan o los elementos del medio impactados.

Este tipo de matrices permiten:

- Tener una idea rápida de los impactos globales generados por un proyecto.
- Identificar requerimientos de áreas de estudio o de profundidad en la información.

El segundo tipo matriz de identificación es la llamada *Matriz de Leopold*. Esta matriz contempla cuatro fases de desarrollo del proyecto:

- Localización y preparación del sitio.
- Construcción
- Operación y mantenimiento
- Actividades futuras y relacionadas

y cuatro áreas del medio donde se pueden presentar efectos ambientales:

- Area físico-química
- Area ecológica
- Area estética
- Area socioeconómica

Para aplicar esta matriz es necesario:

- Asegurar que el proyecto cumpla con todos los requerimientos gubernamentales.
- Identificar todas las actividades que pueden ocurrir durante las cuatro etapas de desarrollo del proyecto.
- Identificar las áreas en las categorías físico-química, ecología, estética y socieconomía que pueden ser afectadas por las actividades identificadas.

- Preparar la matriz poniendo en columnas las actividades de cada etapa del proyecto y en líneas las áreas de cada categoría del medio natural.

- Analizar todas las posibles interacciones actividad-elemento del del medio, calificado cada uno de ellos de acuerdo a los siguientes criterios:

  ( ) no existen efectos adversos
  (?) no se sabe si los efectos son significativos
  (A) adverso significativo
  (a) adverso no-significativo
  (B) benéfico significativo
  (b) benéfico no-significativo.

- Tratar de eliminar al máximo los efectos significativos, buscando información adicional o recurriendo a expertos en las diferentes áreas.

- Identificar medidas de control y mitigación para las interacciones calificadas con (A) y (a):

  (A) adverso significativo, se ha detectado medida de mitigación.
  (a) adverso no-significativo, se ha detectado medida de mitigación.

- Discutir cada uno de los impactos identificados más importantes.

Para calificar las interacciones de la matriz se pueden tomar en cuenta los siguientes critérios generales: magnitud, durabilidad, plazo y frecuencia, riesgo, importancia y mitigación. A partir del empleo de este tipo de matriz de cribado se pueden tener varios tipos de dicisiones:

- no existen efectos adversos
- existen efectos potenciales no-significativos
- no se conocen efectos adversos potenciales
- existen efectos significativos

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III.2- Superposición de planos temáticos

Este método de evaluación de impactos ambientales se aplica principalmente para evaluar el impacto producido por la ocupación del suelo. Sin embargo, la metodología es también apropiada para establecer la amptitud territorial de una zona para soportar un desarrollo e implementar estrategias de manejo y conservación de recursos naturales.

La metodología parte de la cartografía temática sobre aspectos de:

- Topografía
- Climatología
- Hidrología
- Geología
- Uso del suelo y vegetación
- Edafología
- Uso potencial del suelo
- Socioeconomía

El plano topográfico presenta información sobre distancias horizontales y elevaciones del terreno (curvas de nivel).

El plano climatológico presenta gráficamente los climas de una zona o región (tipo de clima), temperaturas medias anuales, precipitación media anual, horas de sol, vientos, etc.).

La carta hidrológica muestra información sobre el drenaje superficial horizontal apoyándose en el plano topográfico, incluyendo arroyos ríos, estanques, lagos, presas, etc.

Existen dos tipos de planos geológicos: el superficial o litológico que muestra las características y distribución de los materiales superficiales (afloramientos, origen de los suelos, tipos de rocas y suelos, fracturas, fallas, inclinación de la distribución de los estratos en proyección vertical. Estos planos además permiten apreciar la importancia de los acuíferos subterráneos.

El plano de uso del suelo y vegetación presenta información sobre el uso actual del suelo, incluyendo cultivos, pastizales, matorrales, bosques, etc.

La carta edafológica se refiere a la distribución de diferentes tipos de suelo. Una clasificación muy empleada es la de la FAO/UNESCO la cual incluye:

- Unidades de suelo (génesis y morfología)
- Clase textura (arena,migajón,arcilla)
- Fases física (estratos duros, presencia de rocas)
- Fases químicas (salinidad, sodicidad)

El plano de uso potencial del suelo se refiere a la capacidad para desarrollar actividades agrícolas, pecuarias, forestales y desarrollo de vida silvestre. Los planos indican las deficiencias de agua, pendiente del terreno, profundidad del suelo, erosión, obstrucción para actividades agrícolas, inundación, deficiencia del drenaje del suelo, salinidad, sodicidad, acidez, fijación de fósforo, inestabilidad del suelo.

La carta socioeconómica contiene información sobre límites políticos, poblaciones, servicios, etc.

El procedimiento general para aplicar el método de superposición de planos temáticos es:

- Recopilación de información: cartas temáticas, estudios de fotointerpretación y de campo.

•• Inventario de información: la información del punto (•) se ordena y sistematiza.

••• Vaciado de la información en planos temáticos: un plano por cada tema, estos planos se realizan sobre micas transparentes.

•••• Evaluación de cada plano: se efectúa una jerarquización (o valoración) de sus elementos y la evaluación se representa con diferentes tonos de coloración en el plano.

___ Diagnóstico del área bajo análisis: se efectúa la superposición de los planos para formar un plano resúmen.

500

Si el diagnóstico se emplea para fines de un análisis de aptitud territorial, se debe dar mayor importancia a:

- Factores físicos que puedan condicionar el desarrollo de un proyecto
- Zonas de importancia ecológica
- Aspectos de costos de implantación.

El resultado final será la identificación de las áreas donde el desarrollo de un proyecto resulte lo menos costoso tanto desde el punto de vista económico como ecológico.

Cuando el diagnóstico se quiere emplear para establecer estratégias para la conservación de los recursos, es necesario identificar aquella áreas que presenten un gran interés, desde el punto de vista productivo como desde el ecológico, con el fin de establecer acciones tendientes a preservar, mejorar y conservar el estado que guardan.

Para emplear el diagnóstico con fines de identificación y evaluación de impactos producidos por un desarrollo, es necesario sobreponer al diagnóstico el área que ocupará el proyecto para identificar:

- los elementos que serán afectados por la ocupación del sitio
- los factores del medio que podrán verse impactados por la construcción u operación del proyecto.

Un aspecto importante de ésta metodología, es el concerniente a la valoración, que en algunos casos se puede cifrar pero en muchos la única manera de hacerlo es subjetivamente. Sin embargo, para éstos últimos se pueden seguir criterios como los siguientes; para el caso de ecosistemas:

Critérios de valoración

Aumento del valor

alejamiento del clímax	proximidad al clímax
degradación	integridad
monotonía	diversidad
sencillez	complejidad
inestabilidad	estabilidad
exotismo	naturalidad
común	rareza
escasez	abundancia relativa
resistencia	fragilidad
inexistencia de especies amenazada	frecuencia de especies amenazadas
condición de común	singularidad
reversibilidad	irreversibilidad
ausencia y escasez de endemismos	presencia y abundancia de endemismo
no representatividad	representatividad
alejamiento del límite del habitat	proximidad a límite de su habitat
no atractivo	atracción.

Disminución del valor

III.3: MODELOS DE SIMULACIÓN.

Las técnicas descritas anteriormente se aplican más que nada en la identificación de impactos ambientales, sin embargo, cuando se identifica un impacto importante es necesario efectuar una evaluación del mismo con el fin de verificar o estimar el posible alcance de sus efectos, a fin de poder proponer medidas adecuadas de atención.

La herramienta que permite efectuar estas evaluaciones son los modelos de simulación de sistemas ambientales, los cuales incluyen entre otros:

- Simulación de descargas contaminantes a la atmósfera
- Simulación de descargas contaminantes al agua
- Simulación de descargas contaminantes al suelo
- Simulación de propagación de ruidos
- Simulación de sistemas ecológicos
- Simulación de sistemas humanos

Es necesario tener presente que un modelo es una representación simplificada de la realidad por lo que al emplearlos es necesario interpretar los resultados con una perspectiva adecuada.

IV: MEDIDAS DE CONTROL Y MITIGACIÓN.

Con el fin de reducir o eliminar los impactos que genera un proyecto se pueden aplicar dispositivos y técnicas de control (sistemas de tratamiento, equipos de control de contaminantes) o medidas correctivas y compensatorias.

IV.1: Dispositivos y técnicas de control.

- Técnicas de control de contaminantes del aire.

o Gases:

- Adsorción: el contaminante es adsorbido; es decir, retenido selectivamente sobre un substrato sólido. No existe reacción química y en algunos casos se puede recuperar el contaminante.
- Absorción: el contaminante es absorbido en un solvente líquido. Por lo general, el contaminante reacciona con el solvente dando un producto secundario.
- Condensación: consiste en condensar gases o vapores contaminantes ya sea por efecto de presión o por disminución de la temperatura.
- Combustión: en general es una oxidación del material. Los productos finales principales de una combustión son CO_2 y H_2O. Se aplica principalmente para control de hidrocarburos.

o Partículas:

- Dispositivos mecánicos: son equipos que utilizan fuerzas mecánicas para separar las partículas del gas (cámaras de sedimentación, ciclones, impactores).
- Dispositivos de capas filtrantes: comprenden los filtros de fibras y fieltros (casas de bolsas) y los separadores granulares (lechos de filtración).

- Dispositivos hidráulicos: ponen en juego el lavado del gas por un líquido, el tratamiento del gas se hace como vapor saturado (torres de lavado, torres de platos, venturis).

- Dispositivos eléctricos: consisten en efectuar una ionización del gas y de las partículas, y la captación subsecuente de las partículas cargadas o ionizadas (electrofiltros).

La selección de un dispositivo en particular, requiere de un análisis del problema a tratar y del contaminante a controlar:

- Volúmen a tratar
- Propiedades físicas
- Propiedades químicas
- Características del efluente a tratar
- Porciento de remoción requerido
- Etc.

La tabla siguiente es un ejemplo de eficiencias que se pueden alcanzar con algunos equipos para el tratamiento de partículas:

Equipo	Diámetro de partículas (micrones)		
	0.01	1.0	5.0
Ciclón		27	73
Lavador		85	96
Venturi		97.5	99.6
Precipitador electrostático	40	85	95
Casa de bolsas	95	99.5	99.9

- Técnicas de tratamiento de agua:

El tratamiento de la contaminación del agua se hace a través de varias etapas que pueden ser diferentes de un caso a otro, dependiendo de las características del efluente a tratar. Sin embargo los sistemas de tratamiento pueden comprender algunos o varios de los siguientes métodos:

- **Pretratamiento:** consiste en eliminar materiales gruesos de las aguas a tratar (pedazos de papel, tela, envases de papel, grava, etc.), con rejillas, tamices o tanques de sedimentación.

- **Tratamiento primario:** puede consistir en una neutralización u homogenización del efluente, en una coagulación, en la flotación de partículas, en el lagunaje.

- **Tratamiento secundario:** se conoce como tratamiento biológico ya que consiste en poner el efluente a tratar, en contacto con una población de micro-organismos, los cuales van a consumir la materia biodegradable (lodos activados, filtros rociadores, discos biológicos, etc.).

- **Tratamiento terciario:** consiste en adecuar la calidad del agua tratada para que sea apta a un uso en particular: potable, irrigación, etc., (ozonización, cloración, intercambio iónico).

Las secuencias siguientes, muestran dos tipos de sistemas de tratamiento clásicos:

Pretratamiento ---> Decantación primaria ---> Tratamiento secundario ---> Clarificación

Pretratamiento ---> Floculación química ---> Decantación primaria ---> Tratamiento secundario ---> Tratamiento terciario

- Métodos de tratamiento de residuos sólidos:

  - Rellenos sanitarios: se depósitan los residuos en capas que se cubren con tierra; requiere extensa superficie.
  - Incineración: combustión de los residuos, minimiza el volúmen final de residuos.
  - Composteo: los residuos son transformados en abono por las bacterias de la descomposición.
  - Pirólisis: obtención de combustibles a través de una combustión de residuos en ausencia de oxígeno.

Por lo general, antes de tratar los residuos con las técnicas mencionadas se les hace un proceso de separación de subproductos (vidrio, papel, metal).

En el caso de residuos sólidos industriales, es necesario establecer sus características antes de tratarlos o eliminarlos. En particular se debe determinar su peligrosidad (corrosividad, toxicidad). En caso de que un residuo resulte riesgoso, se puede tratar; neutralizándolo y/o transformándolo químicamente, antes de eliminarlo. Cuando ésto no es posible, su eliminación se puede hacer por medio de: incineración, disposición en un cementerio industrial, en tierras profundas, disposición en el fondo del mar. En cualquier caso es necesario tomar medidas de seguridad para evitar que el producto sea liberado al medio ambiente en forma incontrolada.

- **Métodos de mitigación y control de ruidos:**

  - **Aislamiento de la fuente**
  - **Aislamiento del receptor**
  - **Instalación de barreras aislantes.**

IV.2: Medidas correctivas y compensatorias.

Se refieren a acciones a tomar en las diferentes etapas de un proyecto para reducir o mitigar los impactos generados o que se generarán. Por ejemplo, en la etapa de concepción, planeación y selección del sitio se pueden considerar medidas tales como:

- Modificación de la concepción del proyecto
- Modificación de procesos y equipos
- Inclusión de equipo de control
- Diseño de barreras y aislamientos, y
- Alternativas de localización.

En la etapa de construcción, los impactos que se dan son muchas veces irreversibles (cambio en el uso del suelo, eliminación de la cubierta vegetal, etc.), y se pueden aplicar medidas compensatorias tales como:

- Reubicación de poblaciones
- Creación de parques
- Creación de zonas de cultivo
- Indemnizaciones.

En otros casos, los impactos son temporales y se pueden implementar medidas como:

- Aislamiento de la zona
- Control de emisiones de polvo
- Disposición adecuada de residuos
- Creación de campamentos, y
- Mantenimiento de caminos.

En la operación y mantenimiento los problemas son principalmente por contaminación, por lo que las medidas a implementar son los equipos y técnicas de control ya descritos; además se consideran otras acciones como:

- Mejorar el aspecto visual
- Reforestar, e
- Indemnizar por daños ocasionados.

estas medidas deben ir a la par con un programa de monitoreo y vigilancia del medio natural.

Para la etapa de abandono del proyecto, las medidas de mitigación están encaminadas a:

- Aprovechar las instalaciones existentes
- Dejar el sitio en buena condición de seguridad e higiene
- Reacondicionar el sitio para otra actividad, y
- Restituir las condiciones del medio natural.

Hay otro tipo de medidas que se deben considerar y que son las de orden legal y administrativo, las cuales tienen como función:

- Normar el uso del suelo
- Regir el aprovechamiento y conservación de los recursos naturales
- Asegurar la protección de todos los bienes históricos y culturales, y
- Preservar la salud de la población.

V. SELECCIÓN DE ALTERNATIVAS DE UN PROYECTO.

El objetivo de éstas técnicas es suministrar herramientas de evaluación que permitan la selección de opciones de implantación o modalidades de proyectos considerando un conjunto de alternativas diferentes. Entre las técnicas de selección se tienen:

- Matrices ponderadas: consisten en formar una matriz de interacción y ponderar las características de un proyecto para analizar varias opciones.
- Método de Batelle-Columbus: consiste en dar valores a las características del medio natural y comparar diversas opciones del proyecto con un escenario "cero" del sitio a evaluar.
- Método de selección de alternativas bajo criterios múltiples: es parecido a las matrices ponderadas, sin embargo, permite manejar información cualitativa y cuantitativa al mismo tiempo. Una ventaja de ésta técnica es que se maneja por medio de computadoras, facilitando en gran medida la concepción y comparación de varias alternativas.

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DIPLOMADO EN CONTROL DE LOS RESIDUOS
GENERADOS EN HOSPITALES
Y OTROS CENTROS DE SALUD

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AMCRESPAC

FOREWORD

Introduction

The Federal Government has a long record of concern about hazardous materials and their potential impact on people and the environment. Over the years, several Federal agencies have provided training, technical assistance and guidance to State and local governments and industry in planning and response to emergencies involving hazardous materials. For example, the Federal Emergency Management Agency (FEMA) published the *Planning Guide and Checklist for Hazardous Materials Contingency Plans* (FEMA-10) in 1981 to assist communities developing emergency response plans. The Department of Transportation (DOT) has published several editions of the *Emergency Response Guidebook* to serve as guidance for initial action to be taken by fire fighters, police, and emergency services personnel at the scene of transportation incidents involving hazardous materials. In 1985, the Environmental Protection Agency (EPA) published *Chemical Emergency Preparedness Program* (CEPP) *Interim Guidance* to provide technical assistance for a voluntary program focusing on airborne toxic chemicals under EPA's National Strategy for Toxic Air Pollutants.

Government-wide guidance on emergency planning for hazardous material was introduced in 1987 after the passage of Title III of the Superfund Amendments and Reauthorization Act (SARA) with the publication of the National Response Team's *Hazardous Materials Emergency Planning Guide* (NRT-1). This effort to coordinate Federal planning processes concerning specific hazardous materials addressed by SARA was followed with the joint publication by EPA, FEMA and DOT of *Technical Guidance for Hazards Analysis*.

Handbook of Chemical Hazards Analysis Procedures

This *Handbook of Chemical Hazard Analysis Procedures* has several objectives one of which is to expand *NRT-1* and the *Technical Guidance on Hazards Analysis* document by including information for explosive, flammable, reactive and otherwise dangerous chemicals. Although *NRT-1* was aimed at addressing planning for all types of hazardous materials, SARA Title III required local planners to focus on a specific initial list of acutely toxic chemicals (referred to as Extremely Hazardous Substances) due to their high inhalation toxicity when airborne, and this was the primary focus of the supplemental guidance document. By introducing additional methodologies on how to plan for these and other dangerous chemicals, this handbook serves as a stepping stone from *NRT-1* and the *Technical Guidance on Hazards Analysis* to a more comprehensive approach for emergency planning. If deemed necessary and appropriate by the National Response Team after distribution and field use of this handbook by emergency planning personnel, a further enhanced hazard analysis guide may be prepared in the future.

Because this handbook provides methods to investigate local hazards in greater detail than permitted by earlier guidance, results of calculations using air dispersion models may differ. The Federal Government is continuing to evaluate these types of models and others to determine the degree of impact on calculations concerning the consequences of a chemical release. For these reasons and because this handbook requires use of the accompanying software for full utilization, users should carefully assess accident scenarios selected for evaluation to ensure that computational procedures are appropriate for the chemical being

studied. Difficulties encountered and suggestions or comments (both positive and negative) should be submitted to DOT, FEMA, and/or the EPA. Be advised that workshops are being planned by these Agencies during 1989 to address comments, gather input on the handbook and the related software, and explain their functions. Similarly, DOT, FEMA and EPA are interested in receiving information on problems and experiences associated with use of the *Technical Guidance on Hazards Analysis* document and NRT-1.

Beyond providing additional methodologies for assessing the potential impacts of hazardous material releases, this handbook also expands the three-step hazards analysis approach (hazard identification, vulnerability analysis, and risk analysis) presented in *NRT-1* and its supplement by introducing a four-step approach involving hazard identification, consequence analysis, probability analysis, and risk analysis. In addition, it provides a tutorial on hazardous chemicals, suggestions for applying hazard analysis results to writing and updating an emergency plan, and an expanded discussion of issues relating to sheltering-in-place (in-place protection) and evacuation. **Because additional projects are underway concerning these and other topics described in Chapter 14 and Appendix C of the handbook, sponsoring agencies are especially interested in comments on these sections. The workshops mentioned above will provide an opportunity for discussion and comment. General comments on the handbook, its associated computer program named ARCHIE, and earlier planning aids are highly encouraged and may also be submitted in writing to:**

Federal Emergency Management Agency
Technological Hazards Division
Federal Center Plaza
500 C Street, S.W.
Washington, DC 20472

U.S. Department of Transportation
Research and Special Programs Administration
Office of Hazardous Materials Transportation
DHM-50, 400 7th Street, S.W.
Washington, DC 20590

U.S. Environmental Protection Agency
Chemical Emergency Preparedness and Prevention Office
401 M Street, S.W., 0S-120
Washington, DC 20460

Alternatively, input to these agencies may be transmitted via use of the Hazardous Materials Information Exchange (HMIX) computerized bulletin board system operated and maintained by FEMA and the DOT. HMIX includes a Conference dedicated to ARCHIE where users may leave messages, questions or comments relating to the program or handbook, exchange viewpoints, and receive responses to inquiries. HMIX may be accessed by modem and commercial phone line at:

(312) 972-3275

An HMIX users manual and technical assistance can be obtained by calling:

1-800-PLAN-FOR Nationwide

or

1-800-367-9592 in Illinois

If you are unable to access HMIX to submit comments or questions relating specifically to the computer program, please send them in writing to:

ARCHIE Support (DHM-51/Room 8104)
Office of Hazardous Materials Transportation
Research and Special Programs Administration
U.S. Department of Transportation
400 7th Street, S.W.
Washington, D.C. 20590

Additional copies of this handbook maybe obtained by writing to:

Federal Emergency Management Agency
Publications Office
500 C Street, S.W.
Washington, D.C. 20472

1.0 INTRODUCTION

1.1 BACKGROUND

The fact that hazardous materials pose a threat to public safety and the environment is of vital concern to industry and all levels of government, particularly in the aftermath of the tragedy in Bhophal, India, that took over 2000 lives and injured tens of thousands of others in the course of a few hours. Although the safety record of the oil and gas and chemical manufacturing and transportation industries in the United States has been excellent in recent years, and there has not been a similar catastrophic accident or incident with major loss of life in the United States in several decades, there is nevertheless a clear need for constant vigilance on the part of government agencies and those responsible for the movement and handling of hazardous materials to minimize the possibility of significant discharges to the external environment. Similarly, there is a clear and possibly even more urgent need to ensure that both government and industry are prepared to respond quickly, efficiently, and effectively in the event of an accident to reduce or prevent adverse impacts on public safety and the environment. Time is critical in the first moments of an accident. A mismanaged response due to a lack of preplanning can contribute to the causation of fatalities and injuries as well as an increase in damage to property and the environment.

The primary purpose of this handbook and its associated computer program is to provide emergency planning personnel with the resources necessary to undertake comprehensive evaluations of potentially hazardous facilities and activities within their respective jurisdictions and thereby formulate a basis for their planning efforts. Chapters 2 through 8 of the handbook discuss fundamental definitions and concepts relating to hazardous material properties and associated threats to public safety. Chapter 9 provides an *overview* of the overall hazard analysis process required to identify, characterize, and evaluate the subject threats. Chapter 10 follows with specific guidance relating to hazard identification while Chapter 11 provides assistance in evaluating the likelihood that any given accident or incident will actually occur in the foreseeable future. Chapter 12 describes and discusses the ***Automated Resource for Chemical Hazard Incident Evaluation*** (ARCHIE) computer program and how it may be used to conduct consequence analysis for postulated accident scenarios. Chapter 13 next guides the user through a simplified risk analysis procedure designed to provide a planning basis, while Chapter 14 provides guidance on how results of the overall hazard analysis process may be utilized in development of a comprehensive emergency response plan.

Several appendices to the handbook provide additional guidance and details. Appendix A is a tutorial on fundamental mathematical skills. Appendix B presents an overview of the technical basis for consequence analysis procedures, while Appendix C provides an overview of "Shelter-in-Place" concepts. Appendix D follows with the presentation of a chemical

compatibility chart for potentially reactive materials. Appendix E is a guide to installation of the ARCHIE computer program, while Appendix F ends the handbook with the basis for accident/incident probability analysis procedures.

1.2 RELATED PLANNING GUIDES AND DOCUMENTS

Multi-Agency Publications of the Federal Government

The National Response Team (NRT) is comprised of representatives of 14 federal agencies having major responsibilities for issues involving the environment, transportation, and public health and safety. It is the primary body in the United States charged with responsibility for planning, preparedness, and response actions related to spills or discharges of oil and hazardous materials into the environment.

The NRT published the Hazardous Materials Emergency Planning Guide in March 1987 as document NRT-1. This guide provides a fairly detailed overview of the efforts required for:

- Selecting and organizing an emergency planning team
- Defining the tasks of the planning team
- Developing an emergency plan and individual plan elements
- Appraising, testing, and maintaining the plan

The guide focuses on the needs and requirements of public authorities in local and state governments but also contains useful information for industrial planning personnel in terms of the basic elements of the planning process. Additionally, it provides insights into those issues of concern to public authorities and the importance of cooperation and coordination of emergency planning activities between the public and private sectors. Copies of the guide are available by writing:

Hazardous Materials Emergency Planning Guide
OS-120
401 M Street, S.W.
Washington, D.C. 20460

Subsequent to completion and distribution of NRT-1, the U.S. Environmental Protection Agency (EPA), in conjunction with the Federal Emergency Management Agency (FEMA) and the U.S. Department of Transportation (DOT), published ***Technical Guidance for Hazards Analysis -- Emergency Planning for Extremely Hazardous Substances*** to fulfill obligations mandated by the Superfund Amendments and Reauthorization Act (SARA) of 1986. Focusing primarily on the hazards associated with a specific list of highly toxic substances deemed to pose acute inhalation hazards when discharged into the atmosphere,

the guide provides simplified guidance for hazard identification, vulnerability analysis, and risk analysis of facilities subject to reporting requirements under Title III of SARA. Additionally, the document contains a simplified screening procedure for ranking the threats due to designated Extremely Hazardous Substances (EHS) in a community. Copies may be obtained by writing the same address given above for NRT-1.

Publications of the Federal Emergency Management Agency

The Federal Emergency Management Agency (FEMA) publishes the ***Guide for Development of State and Local Emergency Operations Plans*** (CPG 1-8) and the ***Guide for Review of State and Local Emergency Operations Plans*** (CPG 1-8A), which provide information to emergency management personnel and state and local government officials about FEMA's concept of planning under the Integrated Emergency Management System (IEMS). This system emphasizes integration of planning for all types of hazards that pose a threat to a community and provides extensive guidance in the coordination, development, review, validation, and revision of emergency operations plans.

The concepts if not the specific details of FEMA's guidance are applicable to individual communities and chemical facilities in that many such sites may be subject to a variety of natural and technological hazards. Under a wide variety of circumstances, a single emergency plan that provides "umbrella coverage" for a locality can ensure increased efficiency and effectiveness of a planning effort by reducing duplication of common activities.

FEMA, in conjunction with DOT and the EPA, has also published a wide variety of emergency planning guidance documents relating to emergencies involving nuclear power plants, the transportation of radioactive materials, and natural disasters. A sample of planning aids that address hazardous materials include:

- ***Hazardous Materials Contingency Planning Course (student manuals)***
- ***Disaster Planning Guidelines for Fire Chiefs***
- ***Disaster Operations: A Handbook for Local Governments***
- ***Objectives for Local Emergency Management***

Publications of the Federal Emergency Management Agency relating to a wide variety of threats to public health and safety can be obtained by writing:

Federal Emergency Management Agency
Publications Office
500 C Street, S.W.
Washington, D.C. 20472

Publications of the U.S. Department of Transportation

The U.S. Department of Transportation (DOT) has sponsored a large number of research studies and demonstration projects related to planning for transportation emergencies involving hazardous materials over the years. Appendix E of NRT-1 contains a fairly comprehensive list of resulting reports. A representative sample of current and past available titles includes:

- ***Community Teamwork: Working Together to Promote Hazardous Materials Transportation Safety -- A Guide for Local Officials***
- ***A Community Model for Handling Hazardous Materials Transportation Emergencies***
- ***Risk Assessment Users Manual for Small Communities and Rural Areas***
- ***Manual for Small Towns and Rural Areas to Develop a Hazardous Materials Emergency Plan; with an Example Application of the Methodology in Developing a Generalized Emergency Plan for Riley County, Kansas***
- ***Community Model for Handling Hazardous Material Transportation Emergencies: Executive Summaries***
- ***Hazardous Materials Demonstration Project Report: Puget Sound Region***
- ***Hazardous Materials Hazard Analysis: Portland, Oregon***
- ***Hazardous Materials Management System: A Guide for Local Emergency Managers***
- ***Lessons Learned: A Report on the Lessons Learned from State and Local Experiences in Accident Prevention and Response Planning for Hazardous Materials Transportation***

The *Community Teamwork* document may be obtained by writing to:

Office of Hazardous Materials Transportation
Attention: DHM-50
Research and Special Programs Administration
Department of Transportation
400 7th Street, S.W.
Washington, D.C. 20590

Information on the availability of the Hazardous Materials Management System Guide and other documents developed for the Portland, Oregon area can be obtained by writing:

Multinomah County Emergency Management
12240 N.E. Glizan
Portland, Oregon 97230

Most of the other publications and documents of a similar nature are available from the National Technical Information Service, 5285 Port Royal Road, Springfield, Virginia 22161 (telephone: 703-487-4650).

Publications of the U.S. Environmental Protection Agency

The EPA has published a series of documents to assist emergency planning personnel. Available titles include:

- ***Introduction to Exercises in Chemical Emergency Preparedness Programs***
- ***A Guide to Planning and Conducting Table-Top Exercises***
- ***A Guide to Planning and Conducting Field Simulation Exercises***
- ***Report of a Conference on Risk Communication and Environmental Management***
- ***Identifying Environmental Computer Systems for Planning Purposes***
- ***Chemicals in Your Community***

These documents may be obtained by writing:

Environmental Protection Agency
OS-120
401 M Street, S.W.
Washington, DC 20460

Publications of the Chemical Manufacturers Association

Even before SARA required the assignment of individual facility emergency coordinators to Local Emergency Planning Committees (LEPC's), the Chemical Manufacturers Association (CMA) established a Community Awareness and Emergency Response (CAER) program to encourage local chemical plant managers to take the initiative in cooperating with local communities in the development of integrated emergency plans for response to hazardous material incidents. The NRT guidance document cited above notes that knowledgeable chemical industry representatives can be especially helpful during the planning process and advises community planners to seek out local CMA/CAER program participants. More specifically, the document points out that many chemical plant officials are both willing and able to share equipment and personnel during emergency response operations.

The CMA publishes three documents that could prove considerably useful during the overall planning process, including:

- ***Community Awareness and Emergency Response Program Handbook***
- ***Site Emergency Response Planning***
- ***Community Emergency Response Exercise Program***

These publications are available at nominal cost from the CMA. Information on specific items can be obtained by calling (202) 887-1100 or writing:

Publications Fulfillment
Chemical Manufacturers Association
2501 M Street, N.W.
Washington, D.C. 20037

Publications of the AIChE Center for Chemical Process Safety

Established under the auspices of the American Institute of Chemical Engineers (AIChE), this being the primary professional society of chemical engineers in the United States, the Center for Chemical Process Safety has undertaken an ambitious program to promote and ensure safety at chemical plants. Initial efforts have involved the development and publication of a series of safety guideline documents. The first four titles below are complete and currently available to the public. The latter titles are expected to be published during 1989 or shortly thereafter.

- ***Guidelines for Hazard Evaluation Procedures***
- ***Guidelines for Safe Storage and Handling of High Toxic Hazard Materials***
- ***Guidelines for Use of Vapor Cloud Dispersion Models***
- ***Guidelines for Vapor Release Mitigation***
- ***Guidelines for Chemical Process Quantitative Risk Assessment***
- ***Guidelines for Technical Management of Chemical Process Safety***
- ***Guidelines for Obtaining Process Equipment Reliability Data***
- ***Guidelines for Human Reliability in Process Safety***
- ***Guidelines for Process Control Safety***
- ***Guidelines for Processing and Handling Reactive Chemicals***

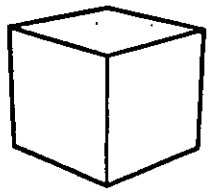
Information on these and other AIChE publications is available from:

AIChE Publication Sales Department
345 East 47 Street
New York, NY 10017

Other Pertinent Publications

Besides the above fairly recent and generalized planning guides published by the federal government or industry trade associations, there are several other sources of general information and data available that may be helpful during the overall emergency planning process. Selected publications are listed and described in Chapter 14. Publications devoted to specific topics of possible interest to readers are referenced at appropriate locations throughout the chapters and appendices that follow.

2.0 KEY PROPERTIES OF CHEMICAL SUBSTANCES



SOLID

LIQUID

GAS

2.1 STATES OF MATTER

Most materials can exist in more than one physical state, a common example being ordinary water. It is well known that liquid water will freeze and become a solid at 32 degrees Fahrenheit (°F) at normal atmospheric pressure. The temperature of 32°F is known as the freezing point for this substance. Alternatively, this temperature can be referred to as its melting point. For water, both the freezing point and melting point are exactly the same and well-defined. This is true for most other substances, but there are exceptions to this general rule.

At 212°F, liquid water begins to boil at normal atmospheric pressure as it begins a transition or ***phase*** change from a liquid state to a vapor or gas. The specific temperature at which a liquid boils under a given set of environmental conditions is known as its boiling point temperature or ***boiling point*** for short. If the boiling takes place at normal atmospheric pressure, the more appropriate and accurate phrase to use is ***normal boiling point*** or boiling point at one atmosphere. The importance of qualifying the term boiling point with the words "normal" and "one atmosphere" will be discussed a bit later. For now, it is simply adequate to note that a great many materials in the environment have their own unique freezing/melting and normal boiling points which can be radically different than those of water. For example, the petroleum product known as butane, the flammable substance in most disposable lighters, has a normal boiling point of 31°F and will boil and rapidly vaporize if spilled as a liquid on a block of ice having a temperature of 32°F. A temperature of -216°F

would be required to solidify or freeze the butane to a solid, yet even this very low temperature would be insufficient to prevent boiling of such substances as liquid hydrogen, helium, nitrogen, and several others.

Not all substances, incidentally, can exist in all three states of matter in the natural environment. Some solids undergo a process called ***sublimation*** upon heating whereby the solid state directly transforms to a gaseous state without first becoming a liquid. A good example is solid carbon dioxide, also known as *"dry ice."* Carbon dioxide can only become a liquid in confinement under special conditions of storage.

2.2 DEFINITIONS OF TEMPERATURE AND HEAT

The discussion so far has demonstrated that the temperature of a substance can influence its form and properties. There is a great deal more to be said on the subject, however, so there is value in formal definition of important terms before proceeding. We start with the concept of ***temperature*** and the flow of heat and energy from one body to another.

The dictionary defines the temperature of a substance as its *"degree of hotness or coldness measured on a definite scale."* The key word here is ***scale***. In the United States, the scale with which we are most familiar is the Fahrenheit scale, and most of us are aware that most of the world uses the Celsius or Centigrade scale, this being a part of the metric system. Both of these temperature measurement systems are considered ***relative*** scales because key numbers are essentially the freezing point and boiling point of water at normal atmospheric pressure. These numbers are 32°F and 212°F respectively on the Fahrenheit scale and 0°C and 100°C on the Celsius scale. In order to convert from one scale to another, one of two common equations is used, these being:

$$\text{degrees F} = (1.8 \times \text{degrees C}) + 32$$

$$\text{degrees C} = (\text{degrees F} - 32)/1.8$$

It is also useful to know that a one degree *change* on the Celsius scale is equal to a 1.8° *change* on the Fahrenheit scale. Thus, a temperature rise of 18° on the Fahrenheit scale is equivalent to a rise of 10° on the Celsius scale.

Besides these two scales, there are two others that are commonly used in the scientific community and which are defined as ***absolute*** scales in the sense that zero degrees refers to an absolute lack of heat in the object being measured. Absolute zero is about 460° below zero on the Fahrenheit scale and about 273° below zero on the Celsius scale.

One of these absolute scales is known as the Rankine scale and is related to the Fahrenheit scale such that a temperature in degrees Rankine equals the temperature in degrees F plus 460. Thus, 100°F equals 560°R, where the R denotes use of the Rankine scale.

The second absolute scale is the Kelvin scale and is in very common use by today's engineers and scientists on a worldwide basis. It is related to the Celsius scale such that a temperature in degrees Kelvin equals the temperature expressed in degrees Celsius plus 273.15. Thus, 100°C equals 373.15°K, where the K denotes use of the Kelvin scale.

As noted before, all temperature scales are used to measure and represent the degree of hotness or coldness of a substance. In actuality, however, this is a somewhat misleading statement, because heat can be technically defined as "*energy whose interchange between a system and its surroundings takes place only by virtue of a temperature difference.*" Thus, heat is a form of energy that increases the temperature of substances and which can flow from a warm body to one which is cooler. Whenever a cold body is placed in a warm environment, there will be a temperature difference, and heat will flow from the warmer environment to the colder body. Alternatively, if the body is warmer than its surroundings, it will lose heat. Thus, when a cold liquid is spilled into a warm environment, it will experience a heat gain. Depending on the temperatures involved, this temperature may be sufficient to cause the liquid to boil (remember the boiling butane on the block of ice?). Alternatively, if the liquid was hot to begin with, it may lose sufficient heat to solidify or freeze. The importance of these concepts will become apparent as the discussion turns to the topic of how a chemical may behave when released into varying environmental conditions.

2.3 DEFINITION OF PRESSURE

The next concept to be discussed is that of pressure, which can be defined as the amount of force brought to bear on some unit area of an object. When we press our thumb down on a table, we are applying force on the table. The harder we press, the greater the force, and the greater the pressure we apply to the table surface.

As we sit here, the air in the sky above us presses down on our bodies and all objects around us with the pressure of approximately 14.7 pounds per square inch of surface area, commonly abbreviated as 14.7 psi. This pressure, essentially the average air pressure at sea level, is also known as one standard atmosphere. When one speaks of a pressure of two atmospheres as might be found in a tank, pipeline, or other container of a hazardous material, it *generally* means that 29.4 psi is present, or two times 14.7 psi.

The word *generally* is emphasized because pressure also has absolute and relative scales of measurement. The 14.7 psi of atmospheric pressure at sea level is an absolute measurement and is more properly presented in units of pounds per square inch - absolute, or ***psia*** for short. Zero psia in this case refers to a complete absence of pressure such as one might find in the perfect vacuum of outer space. The most common relative scale of measurement, this being one only used in the United States for the most part, presents numerical values in terms of ***gauge*** pressure, where a reading of zero matches an absolute pressure of one standard atmosphere. In this system, an absolute pressure of 15.7 psia would be expressed as 1.0 pound per square inch - gauge, or 1.0 ***psig*** for short. Two atmospheres of absolute pressure would be equivalent to one atmosphere gauge pressure.

There are several other systems of pressure measurement that are of an absolute nature. The most common include:

- Millimeters of mercury (mm Hg) - in which 760 mm Hg are equivalent to one standard atmosphere.
- Newtons per square meter (N/m^2) - in which 101,325 N/m^2 are equal to one standard atmosphere.
- Pascals (Pa) - which are another name for N/m^2, such that 101,325 Pa are equal to one standard atmosphere.
- Bars - in which 1.01325 bars are equal to one standard atmosphere.
- Inches of water (in H_2O) - in which 407.6 in H_2O are equal to one standard atmosphere.
- Inches of mercury (in Hg) - in which 29.9 in Hg are equal to one standard atmosphere.

The latter two sets of units are not in as common use in the scientific community as the first four but it is well to know of their existence. Those of you who pay attention to weather forecasts will recognize that meteorologists have traditionally reported current atmospheric pressures in units of inches of mercury.

2.4 VAPOR PRESSURES OF LIQUIDS AND SOLIDS

Liquids have a tendency to evaporate even at temperatures well below their boiling points. The reason for this stems from the observation that molecules of a liquid (these being the smallest parts of the liquid which retain the identity of the substance at the atomic level) have a tendency to break away from the surface of a liquid and enter the vapor state. The

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speed of this process, in the absence of wind effects, is a function of temperature such that a warm liquid will evaporate more quickly than the same liquid at a cooler temperature. Note, however, that different liquids at the same temperature will evaporate at different rates depending on their particular properties.

One primary measure of a liquid's tendency to vaporize is known as its ***vapor pressure***, this being the pressure exerted by its vapors on the walls of a container which is partially full of the liquid and free of any other vapor or gas. Higher temperatures cause increases in the vapor pressure. Lower temperatures cause a decrease, and there is a direct relationship between the temperature of any given substance and its vapor pressure. Table 2.1 provides a list of vapor pressures for variety of common substances showing how they differ with respect to temperature. Note that the pressures are expressed in units of millimeters of mercury (mm Hg), this being the most common set of units used for this purpose in the United States, particularly for substances at temperatures below their normal boiling points. Note also that there are wide variations in the temperatures associated with specific vapor pressures and that even iron will have a measurable vapor pressures if heated to very high temperatures.

The substances listed in Table 2.1, and all others, exert their specific vapor pressures whether or not they are enclosed in a sealed container. When in a container, they reach a state of ***equilibrium*** such that some molecules go from the liquid state to the vapor state while others pass back from the vapor to the liquid at the same rate, and no material is lost to the outside environment. When in the open, molecules entering the vapor state mix with air and move further and further away from the liquid surface with time. As they are replaced above the surface with new molecules evaporating from the liquid, the volume of liquid is depleted. Eventually, all the liquid evaporates (be it in minutes, hours, days, or years) and the surface becomes dry.

Figure 2.1 illustrates these various phenomena. In the top diagram, we observe molecules evaporating from a pool of liquid and entering the atmosphere. Note that any type of wind or breeze blowing across the surface of the liquid would help the individual molecules in escaping and moving away from the liquid and thereby increase the overall rate of evaporation. This rate is indeed a partial function of air velocity over the surface such that higher velocities usually produce higher evaporation rates.

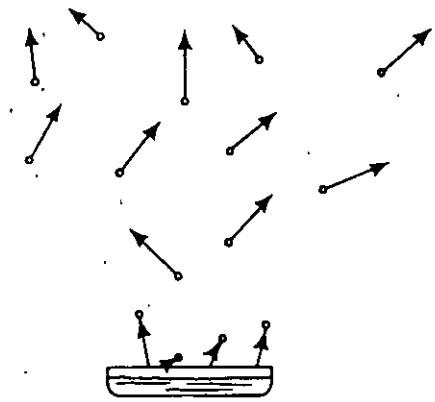
In the middle diagram of Figure 2.1, the liquid is confined within a container and the escaping vapor molecules are trapped. Eventually, as illustrated in the bottom diagram, a state of equilibrium is attained.

TABLE 2.1
VAPOR PRESSURES AS A FUNCTION OF TEMPERATURE

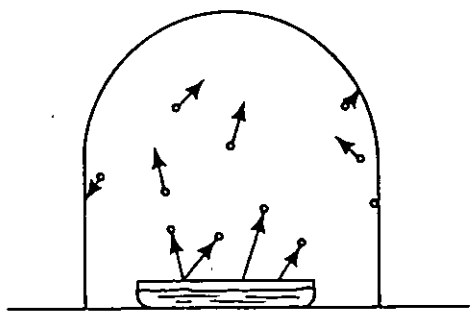
	Vapor Pressure (mm Hg)					
	1	**10**	**40**	**100**	**400**	**760**
Chemical	**Temperature (°F)**					
Benzene	-38.2	11.3	45.7	79.0	141.1	176.2
Butane	-150.7	-108.0	-74.4	-47.6	2.7	31.1
Ethyl alcohol	-24.3	27.9	66.2	94.8	146.3	173.1
Ethylene glycol	127.4	197.8	248.0	287.2	353.3	387.1
Iron	3249	3702	4035	4280	4721	4955
Methyl alcohol	-47.2	2.8	41.0	70.2	121.8	148.5
Propane	-200.0	-163.3	-134.3	-111.3	-68.1	-43.8
Water	-18*	52.3	93.3	122.3	176.5	212.0

*Approximate

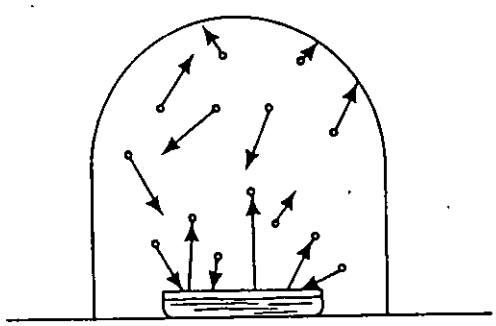
FIGURE 2.1
EVAPORATION AND VAPOR-LIQUID EQUILIBRIUM PHENOMENA



EVAPORATION: MOLECULES ESCAPING FROM THE LIQUID TO BECOME VAPOR



EVAPORATION: MOLECULES CONFINED



VAPOR–LIQUID EQUILIBRIUM: MOLECULES ESCAPE FROM AND RETURN TO THE LIQUID

It should be realized that there is a direct relationship between the vapor pressure of an evaporating substance and the maximum concentration that its vapor or gas may achieve when mixed with air in the open environment. This is true because higher vapor pressures above the surface of a substance require that more molecules of the substance be physically present. Thus, if the vapor pressure of the substance is known, one can compute the approximate maximum airborne contaminant (i.e., chemical) concentration it may attain. Such concentrations are most commonly expressed in units of percent in air by volume, parts per million parts of air (ppm) by volume, parts per billion parts of air (ppb) by volume, or milligrams of chemical per cubic meter (mg/m^3) of air. The equations needed for these computations are:

$$\%\ \text{concentration} = \frac{\text{vapor pressure (mm Hg)}}{760} \times 100$$

$$\text{ppm concentration} = \frac{\text{vapor pressure (mm Hg)}}{760} \times 1{,}000{,}000$$

$$\text{ppb concentration} = \text{concentration in ppm} \times 1000$$

$$\frac{mg}{m^3}\text{concentration} = \frac{(\text{ppm concentration}) \times (\text{molecular weight})}{0.08205 \times (273.15 + {}^{\circ}C)}$$

A restriction to remember in using these equations is that the concentration of a gas or vapor cannot under any circumstances exceed 100% by volume or its equivalent of 1,000,000 ppm regardless of the answer obtained. An example should help the understanding of these relationships.

From Table 2.1, we find that benzene has a vapor pressure of 100 mm Hg at a temperature of 79.0°F. From earlier discussion, we also know that 79.0°F is equal to 26.1°C. Therefore:

$$\%\ \text{concentration} = \frac{100 \times 100}{760} = 13.16\%\ \text{by volume}$$

$$\text{ppm concentration} = \frac{100 \times 1{,}000{,}000}{760} = 131{,}600\ \text{ppm by volume}$$

Computation of the equivalent concentration in mg/m^3 requires not only knowledge of the temperature in degrees Celsius but of the ***molecular weight*** (m.w.) of the material, this being an atomic measure of the weight of the substance. This weight is often (but not always) listed in material safety data sheets (MSDS) and product bulletins that present data

on the physical and chemical properties of chemicals. Section 2.8 of this chapter demonstrates how to compute the molecular weight of a substance given knowledge of its chemical formula. The molecular weight of benzene is 78.1, so:

$$\frac{mg}{m^3}\text{concentration} = \frac{(131{,}600)(78.1)}{(0.08205)(273.15+26.1)} = 418{,}600 mg/m^3$$

2.5 BOILING POINTS AS A FUNCTION OF PRESSURE

It was reported earlier that a pressure of 760 mm Hg is equal to 14.7 psia or one standard atmosphere. From Table 2.1 we see that water has a vapor pressure of 760 mm Hg at a temperature of 212°F, a temperature we recognize as its normal boiling point. What is significant about this observation is that it holds true for all liquids. Any liquid will begin to boil at the temperature at which its vapor pressure equals the pressure being exerted by the environment onto the surface of the liquid. In practical terms, this means that:

- Boiling points of materials are a function of pressure.
- Liquids in sealed containers (with an exception discussed below) will remain as liquids when heated above their normal boiling points although their vapor pressures may far exceed one standard atmosphere pressure within the container.
- If heating continues and the pressure is not adequately relieved by a safety device (such as a pressure relief valve), the pressure and temperature within the tank may eventually rise to the point that some part or all of the container may burst or rupture, possibly in a violent fashion. This may also occur if the capacity of the safety device is inadequate to prevent an excessive buildup of pressure.
- Materials exposed to environmental pressures below one standard atmosphere will boil at temperatures below their normal boiling points. Thus, water will boil at a temperature below 212°F when heated on top of a high mountain. Water released into a vacuum at any temperature will almost instantly vaporize.

It is well to realize that many substances with normal boiling points far below normal ambient temperatures are shipped or stored in commerce as liquids. This is most often achieved by placing the liquid within a strong tank and permitting it to remain in the liquid state under its own vapor pressure at equilibrium conditions. Examples of the most common of these materials considered hazardous include liquid anhydrous ammonia, ethylene, chlorine, ethylene oxide, vinyl chloride, and liquefied petroleum gas (LPG) or propane. Such

substances, frequently referred to as ***compressed liquefied gases***, are particularly hazardous because: 1) leaks may result in rapid venting of gas to the atmosphere; 2) leaks may result in discharge of liquids that rapidly ***flash*** vaporize and/or boil upon exiting their containers; and 3) the flammable, toxic, or otherwise hazardous gases and vapors evolved may travel considerable distances downwind before becoming diluted with air below hazardous concentrations.

Less frequent in transportation but more common at storage and processing sites are bulk quantities of substances such as chlorine, anhydrous ammonia, or liquefied natural gas (LNG) which have been liquefied by cooling to low temperatures via the use of refrigeration systems. Although the vapor pressure of gases liquefied by refrigeration may be close to ambient pressures within storage vessels, spills into the warmer external environment will again result in boiling and the evolution of large quantities of potentially hazardous gases and vapors.

The exception to the *"rule"* that liquids in sealed containers will remain as liquids when heated above their normal boiling points involves the fact that this is true only so long as the temperature of the liquid is below what is referred to as its ***critical temperature***. The critical temperature of a substance is the temperature above which it cannot remain in the liquid state regardless of any increase in pressure. Thus, substances heated above their critical temperatures are neither liquid nor gaseous, but rather, in a state somewhere in between. Picture them as very *thick* vapors.

2.6 DEFINITIONS OF SPECIFIC GRAVITY AND DENSITY

Boiling points, vapor pressures, and melting or freezing points can tell us much about how a material will initially behave when released into the environment, but more information is needed to better define actions and behavior. This section discusses relative and absolute measures of the weights of materials, while the next discusses the degree to which one substance can mix with another.

Every solid or liquid in the environment occupies a specific volume of space and has a certain weight. Thus, we may express the weight density of a substance as its weight divided by its volume. It is well known, for example, that pure water weighs about 62.4 pounds per cubic foot (lb/ft^3) of volume, which is equivalent to 1.0 gram per cubic centimeter (g/cm^3) or 1,000 kilograms per cubic meter (kg/m^3) in the metric system. We also have observed that different substances have different weights for the same volume. One cubic foot of oil weighs about 50 pounds. A cubic foot of steel weighs about 487 pounds.

An alternative method of expressing the weight density of a solid or liquid involves use of a quantity known as the liquid or solid ***specific gravity***. Quite simply, this quantity is determined by dividing the density of a substance by the density of water. Since 62.4 divided by 62.4 has a value of 1.0, water has a specific gravity of 1.0 and serves as the reference point for all materials. The liquid specific gravity of a typical oil is 50 divided by 62.4, giving a value of 0.80. The solid specific gravity of steel is 487 divided by 62.4 and equals 7.80.

As is the case with vapor pressures, both the density and specific gravity of solids and liquids vary with temperature. Heat causes most (but not all) materials to expand in volume while cold causes them to shrink. Since the volume changes while the weight remains the same, the density of a substance generally decreases with heating and increases with cooling. This explains why most sources of information on the density of chemicals will provide the temperature at which the value was measured. In the case of specific gravities, they may list both the temperatures of the water and chemical substance used to determine the specific gravity.

Knowledge of liquid or solid specific gravities is most important when it is desired to determine how a substance will behave in the presence of water. For example, the fact that the specific gravity of a typical oil is 0.80 supports the observation that most oils are lighter than water and have an initial tendency to float. The fact that steel's specific gravity is about 7.80 explains why a block of steel will immediately sink in water.

Discussion of vapor or gas specific gravities and densities is more complicated because these properties are affected by changes in pressure as well as temperature. However, since we are primarily interested in chemical substances that escape into the natural environment, since the natural environment has a nominal atmospheric pressure of one atmosphere, and since any gas or vapor entering the atmosphere will quickly adjust its volume to achieve a total pressure of one atmosphere, it is sufficient for the purposes of this text to only consider specific gravities and densities of gases or vapors at atmospheric pressure.

The discussion begins with the observation that air has a density of 0.0763 lb/ft^3 (about 1.22 kg/m^3) at a temperature of 60°F and a pressure of one atmosphere. As in the case of other substances, higher temperatures cause a decrease in density and lower temperatures cause an increase. Similarly, there is a quantity known as the ***vapor specific gravity*** or ***vapor density*** which is a ratio of the density of a pure gas or vapor to the density of air. Found in many data sources, this specific gravity or density (the former term being used rather interchangeably with the latter) is based on the assumption that air has a value of 1.0. Thus, vapors or gases with vapor specific gravities less that 1.0 are *presumably* lighter than air in the natural environment while those with values greater than 1.0 are *presumably* heavier.

The word *presumably* is emphasized because the values for vapor specific gravities found in all too many data sources are frequently misinterpreted by their users, particularly and specifically in the case of substances below a temperature that permits them to exist as a pure vapor or gas at a pressure of one atmosphere. This can lead to incorrect conclusions about the actions of a vapor or gas upon its release to the environment.

The problem has arisen because many sources compute the vapor density of *any* substance by a shortcut method involving division of the molecular weight of the substance by the molecular weight of air, the latter being approximately 28.9 (as the weighted average for the mixture of gases that comprise air). Thus, since benzene has a molecular weight of 78.1, these sources will report a vapor specific gravity or density value of approximately 2.70, which to many people suggests that the vapors of benzene *in the natural environment* are always 2.70 times heavier than air, which is an absolutely untrue assumption. The misinterpretation results in the belief that benzene vapors will always hug the ground over considerable distances as they spread from the site of a release and may somehow accumulate and persist in pits, hollows, basements, or other low lying areas.

It was earlier explained that benzene has a vapor pressure of 100 mm Hg at a temperature of 79.0°F and that this vapor pressure translates into a maximum vapor concentration directly over the liquid surface of approximately 13.16% by volume. It follows that benzene cannot exist as a pure vapor at this temperature in the natural environment and that it is incorrect to assume that it is a pure vapor when estimating its vapor density relative to air (which is what is being done when a molecular weight ratio is computed). Rather, it is necessary to compare the benzene-air *mixture* density with the density of pure air to determine whether the vapors generated by the release will be heavier or lighter than air. This is accomplished in an approximate fashion via the following procedure:

Step 1: Compute the approximate density ρv of pure chemical vapor in lb/ft³ at temperature T (in °F).

$$\rho v = \frac{1.3691 \times \text{molecular weight}}{(T + 460)}$$

Step 2: Compute the approximate density ρa of air in lb/ft³ at ambient temperature T (in °F).

$$\rho a = \frac{39.566}{(T + 460)}$$

Step 3: Compute the relative vapor density of the chemical-air mixture.

$$\text{Relative vapor density} = \frac{\{C \times \rho v\} + \{(100 - C) \times \rho a\}}{100 \times \rho a}$$

Where C = saturated concentration of the chemical vapor in air in percent by volume.

Benzene has a molecular weight of 78.1 and a maximum vapor concentration (more precisely referred to as its ***saturated*** vapor concentration) of 13.16% in air at 79°F. Use of these values in the above equation, together with the assumption of an air temperature of 79°F, provides a true relative vapor density value of 1.22. What this means is that the benzene-air mixture **directly** above a pool of benzene at the specified temperature is only 1.22 times heavier than air and not the 2.7 times suggested by the vapor density frequently reported in the literature for this substance. Since this mixture will very quickly mix with additional air as it drifts away from the pool, it will rapidly approach the density of pure air and behave as if there were little or no difference in its density. In scientific terms, it will behave as a ***neutrally buoyant*** vapor-air mixture.

If the relative vapor density of a substance under prevailing discharge conditions exceeds 1.5 (as a general rule of thumb), then vapors or gases may indeed behave as heavier-than-air (or ***negatively buoyant***) mixtures for some distance from the source of discharge. Conversely, a relative vapor density significantly less than one suggests that a vapor-air mixture may be lighter than air (or ***positively buoyant***).

In determining or deciding whether any particular gas or vapor will be negatively, neutrally, or positively buoyant in air, it is also often necessary to consider the circumstances under which the substance may be released to the atmosphere. For example, in situations in which a compressed liquefied gas is discharged from a container, particularly when in the liquid state, the resulting vapor cloud or plume may include a considerable amount of fine liquid droplets. Although the gas or vapor mixture with air may normally be positively or neutrally buoyant, the presence of these relatively heavy droplets (also referred to as ***aerosols***) may cause the cloud or plume to behave initially in a negatively buoyant fashion.

2.7 SOLUBILITY IN WATER

All of us have observed that sugar and salt dissolve in water and seem to disappear, that our favorite alcoholic beverage can be mixed freely with water-based mixers, and that the *"fizz"* in containers of soda pop, tonic, or beer is due to carbon dioxide gas that has been dissolved in the liquid. In each case, the solid, liquid, or gas that has dissolved in water is said to be ***soluble*** in water.

An important concept to understand is that different materials have different degrees of solubility. At one extreme, there are liquids which are ***soluble in all proportions*** with water and which are also said to be ***miscible***. This means that any amount of the substance can be added to water and at no point in the process will the substance form a separate layer or phase. At the other extreme, there are substances which do not dissolve in water whatsoever and which are considered to be ***insoluble*** or ***immiscible***. A somewhat extreme example of the latter case involves stone pebbles in a glass of water. No matter how hard the pebbles are shaken or stirred, they will not dissolve or form a ***solution*** with water, this being the term used for a mixture of two liquid substances which are mutually soluble.

In between the above extremes are substances which are ***partially soluble*** in water. For example, there is only a certain amount of ordinary table salt that can be dissolved in water before any new salt added to the solution simply sinks to the bottom and is unable to dissolve. In the case of table salt, 35.7 grams of salt will dissolve in 100 grams of water at a temperature of 32°F and this will rise to about 39.8 grams (there are about 454 grams in a pound) at a temperature near 212°F. And yes, that means that solubility is also a function of temperature. Generally speaking, hot liquids can dissolve more of a partially soluble liquid or solid than cold liquids. Alternatively, because of effects involving vapor pressures and their increase with temperature, cold liquids can generally dissolve more gases and vapors than hot liquids. Increases in pressure may also increase the solubility of gases in liquids.

2.8 MOLECULAR WEIGHTS OF CHEMICAL SUBSTANCES

There are approximately 89 natural ***elements*** in the world that in various combinations make up all matter that surrounds us. In addition, a number of man-made elements have been produced under laboratory conditions involving nuclear reactions and many more have been theorized but never observed. The atoms of all elements have been assigned individual ***atomic weights*** relative to oxygen by scientists. These are listed in Table 2.2 for most common elements likely to be encountered in normal commerce and use.

Combinations of various atoms called ***molecules*** make up the smallest part of any chemical compound that retains the specific properties of the substance and have specific ***molecular weights*** that can be computed from the number of atoms of each element present in the compound, as determined by examination of the ***chemical formula*** of the substance. Such formulae are always found in material safety data sheets for pure substances and many other sources of chemical data. Examples include:

- H_2O for water
- CO_2 for carbon dioxide
- NaCl for sodium chloride

TABLE 2.2
ATOMIC WEIGHTS OF SOME COMMON ELEMENTS

Table gives chemical symbol, name, and atomic weight of each element.

Ag	Silver	107.87	Cu	Copper	63.54	P	Phosphorus	30.97
Al	Aluminum	26.98	F	Fluorine	19.00	Pb	Lead	207.19
As	Arsenic	74.92	Fe	Iron	55.85	Rb	Rubidium	85.47
B	Boron	10.81	Ga	Gallium	69.72	S	Sulfur	32.06
Ba	Barium	137.34	H	Hydrogen	1.00	Sb	Antimony	121.75
Be	Beryllium	9.01	Hg	Mercury	200.59	Se	Selenium	78.96
Bi	Bismuch	208.98	I	Iodine	126.90	Si	Silicon	28.09
Br	Bromine	79.91	Li	Lithium	6.94	Sn	Tin	118.69
C	Carbon	12.01	K	Potassium	39.10	Sr	Strontium	87.62
Ca	Calcium	40.08	Mg	Magnesium	24.31	Ta	Tantalum	180.95
Cd	Cadmium	112.40	Mn	Manganese	54.94	Ti	Titanium	47.90
Ce	Cerium	140.12	Mo	Molybdenum	95.94	U	Uranium	238.03
Cl	Chlorine	35.45	N	Nitrogen	14.01	V	Vanadium	50.94
Co	Cobalt	58.93	Na	Sodium	22.99	W	Tungsten	183.85
Cr	Chromium	52.00	Ni	Nickel	58.71	Zn	Zinc	65.37
Cs	Cesium	132.91	O	Oxygen	16.00	Zr	Zirconium	91.22

- KOH for potassium hydroxide
- CH_3NHNH_2 for methyl hydrazine
- C_6H_6 for benzene

As noted earlier, knowledge of molecular weights is required for computation of vapor concentrations in air in some cases, and indeed, knowledge of this weight is mandatory for a wide variety of calculations involving hazardous materials. Since molecular weights are not always found on materials safety data sheets, however, it is worthwhile to understand how they may be computed using the information provided in Table 2.2. This is best accomplished by an example.

From the list above we see that methyl hydrazine has a chemical formula of CH_3NHNH_2 (which may also be shown as CH_6N_2 in some references). What this means is that each molecule of this chemical consists of:

- One (1) atom of carbon represented by the symbol "C"
- Two (2) atoms of nitrogen represented by the symbol "N", and
- Six (6) atoms of hydrogen represented by the symbol "H".

From Table 2.2 we find that the atomic weights of carbon, nitrogen, and hydrogen are respectively 12.01, 14.01, and 1.00. Thus, we can compute the molecular weight of this substance by multiplying the atomic weight of each of the three elements by the number of its atoms in the molecule, and then summing the results. For methyl hydrazine, the result is:

$$\text{Molecular weight} = (1 \times 12.01) + (2 \times 14.01) + (6 \times 1.00) = 46.03$$

3.0 ACTIONS UPON RELEASE TO THE ENVIRONMENT

3.1 PHYSICAL STATE PRIOR TO RELEASE

The first step in determining how a substance will behave upon release to the environment requires knowledge of the physical state of the material within its storage or transportation container. This in turn requires knowledge of the relationship between the temperature of the material, its boiling point, and its melting point. The possibilities are:

- The temperature of the material in its container is less than its melting point, in which case the material is a solid in its container. A good example would be dry table salt in a large drum.

- The temperature is greater than the melting point of the material but less than its normal boiling point, in which case the material is a liquid and the container contents are approximately at normal atmospheric pressure. An example is water in a tank at temperatures above freezing. Such liquids, however, could also consist of substances which are normally solids but which have been melted and maintained at relatively high temperatures to keep them liquid. They could also be substances which are normally gases in the natural environment but which have been liquefied via refrigeration.

- The temperature is greater than the boiling point of the material, in which case the material is a compressed gas (gas under high pressure in a cylinder or other container) or a liquefied compressed gas (a substance that is normally a gas at normal ambient conditions but which has been turned into a liquid by subjecting it to and maintaining it at high pressures, thus raising its actual boiling point).

Table 3.1 summarizes the various possibilities in greater detail. The table requires a bit of study for complete understanding, but the effort is extremely worthwhile.

3.2 MATERIAL STATES DURING AND INITIALLY AFTER RELEASE

Once there is an understanding of the state of a hazardous material within a storage or transportation container, it is next necessary to consider how the substance will behave *initially* when discharged into an environment of normal ambient temperatures and pressures. There are 10 scenarios to consider based on the last column of Table 3.1, all of which assume that the spill or discharge does not take place during a fire or other abnormal event which would change internal and/or external temperatures.

TABLE 3-1
TYPICAL STATES OF MATERIALS IN STORAGE OR TRANSPORTATION CONTAINERS

Normal Melting or Boiling Points	Container Conditions	State of Material (Scenario #)
Melting point less than ambient T	T less than melting point and less than ambient T	Cold solid (1)
Melting point greater than ambient T	T near ambient T	Solid near ambient T (2)
Boiling point greater than ambient T	T greater than melting point, greater than ambient T, but less than boiling point	Warm or hot liquid (molten solid) (3)
Melting point less than ambient T	T greater than melting point but less than ambient T and boiling point	Cold liquid (4,5)
Boiling point greater than ambient T	T near ambient T	Liquid at ambient T (6)
	T greater than ambient T but less than boiling point	Hot liquid (7)
	T greater than boiling point and greater than ambient T	Hot or warm compressed gas or vapor over hot liquid (8)
Boiling point less than ambient T	T near ambient T	Compressed gas or compressed liquefied gas under pressure at ambient T (9, 10)
	T greater than boiling point and greater than ambient T	Hot or warm compressed gas or compressed liquefied gas under pressure at T greater than ambient (9, 10)

Notes: T = temperature within container; ambient T = temperature outdoors

Scenario #1: Cold or Refrigerated Solids

Some materials that are normally liquids or gases at ordinary temperatures or pressures are handled as solids at temperatures below their melting points and below ambient temperatures to make them easier or safer to transport or use. When exposed to a warmer environment, they will melt to become liquids, or if they are substances that pass directly from a solid to gaseous phase (i.e., substances that "sublime") they will vaporize. For example, ice spilled on the ground in summer will melt to become liquid water. Solid carbon dioxide (dry ice) will "sublime" as it warms to become carbon dioxide gas.

Scenario #2: Normally Solid Materials

Materials that are solids at ordinary ambient temperatures and which are transported or otherwise handled at such temperatures will remain as solids upon release from their containers. Dry table salt and sugar are good examples.

Scenario #3: Molten Solids

Some substances which are normally solids are melted to become liquids, since liquids are sometimes easier to handle. Indeed, for transportation, a solid may be melted and poured into a tank vehicle of some kind where it will slowly cool with time, and even possibly resolidify. When it reaches its destination, it will be pumped out if still a liquid, or first remelted (possibly using heating coils inside the tank) and then pumped out. Such substances will either be discharged as solids or as liquids that may solidify if exposed to cooler ambient temperatures during an accidental spill or discharge situation.

Scenarios #4 and #5: Cold or Refrigerated Liquids

Liquids that are handled at cold temperatures and/or which are refrigerated may have normal boiling points that are either below or above ambient temperatures. The latter substances will simply warm up when released to the environment (Scenario #4), much as cold water will heat in the sun. Those with below ambient boiling points (Scenario #5), which are typically cooled to reduce their vapor pressures in equipment or for use in air-conditioning or refrigeration systems, will warm to their normal boiling point temperatures upon release and begin to boil. Due to thermodynamic cooling effects associated with liquid evaporation or boiling, these liquids will remain at their normal boiling points. If spilled onto a surface that is a good heat insulator, the boiling may eventually slow down or stop, but the quiescent pool that remains will continue to rapidly evaporate. This evaporation process will maintain the remaining liquid near its boiling point as it picks up heat from its surroundings.

Scenario #6: Normally Liquid Materials

Materials that are normally liquids at ordinary temperatures and pressures and which are transported or otherwise handled at such temperatures will remain as liquids upon release to the environment. Good examples would be gasoline or fuel oils pouring from a hole in a storage or transportation container.

Scenarios #7 and #8: Hot Liquids

There are many cases where a substance that is a liquid at normal ambient temperatures and pressure might be heated for one purpose or another. Such liquids, if below their boiling point (Scenario #7), will cool upon release to the environment and remain as liquids. However, if they were heated above their boiling points (Scenario #8), then any space above the liquid in a container will contain gas or vapor at a pressure in excess of one atmosphere. What happens in the event of an accident or incident in this latter case will depend on what part of the container is damaged.

- If the container is punctured or otherwise damaged in the space above the liquid, vapors of the liquid will blow out (i.e., vent) from the resulting hole into the atmosphere and will continue to do so until the liquid cools below its boiling point. For example, picture steam blowing out the stack of an old-time steam locomotive.

- If the container is punctured below its liquid surface, the liquid will pour out of the hole while some amount of its "flashes" to vapor upon release. The part that remains as liquid will boil briefly and then slowly cool to ambient temperature while evaporating. As an example, picture a leak on the face of an automobile radiator with steam, a hot water mist, and hot water exiting the leak area.

Scenario #9: Compressed Liquefied Gases

Regardless of whether these liquids are at ambient or higher temperatures, they will typically be in pressure vessels designed to maintain and withstand substantial pressures. As in the prior case, what happens during an accident or incident will depend on what part of the container is damaged.

- If the container is punctured or otherwise damaged in the space above the liquid, the gas will typically vent at high velocity from the resulting hole into the atmosphere, possibly creating some amount of liquid droplets during the process. The velocity is likely to drop with time as boiling within the tank cools the mass of liquid (the tank surface may actually

become quite cold and even frost over due to thermodynamic cooling effects), but such venting of gas may continue for considerable periods of time (possibly until no more liquid is left in the tank).

- If the container is punctured below its liquid surface, the liquid may literally jet from the hole (remember the very high pressure apt to be in the vapor space over the liquid) and potentially large amounts may flash into gas or vapor. Indeed, depending on the material and the temperatures and pressures involved, the tank may blow out a large mass of vapor mixed with small liquid droplets (an ***aerosol***) to the extent that no liquid reaches the surface beneath the tank. If liquid does reach the surface, it will have a tendency to form a boiling or rapidly evaporating pool.

Scenario #10: Compressed Gases

Gases which are compressed to high pressures in a container or gas cylinder but which have not been liquefied will vent from any opening in the container at high velocity. As the gas vents, the pressure in the container will drop and the container and its contents will cool. At some point, when the pressure within the tank drops to standard atmospheric pressure, venting will cease or drop to a low rate consistent with the amount of heat that enters the container from its surroundings.

3.3 DISCHARGES ONTO LAND

Up to this point, the discussion has essentially focussed on how the boiling point and melting point of a substance may affect its actions upon release to the environment. It is now time to consider how the density and solubility of the substance impacts on where it will go once outside and how there are differences to be considered between discharges on land or water or into the air. The discussion begins with discharges onto land and again considers the physical states in which spilled substances may reach a land surface.

Cold or refrigerated solids with melting points below ambient temperature will either melt to form a liquid or sublime when spilled onto a land surface. Substances that are normally solid will remain in the solid state, while molten solids may flow for a time as liquids and eventually solidify as they cool.

Liquids with boiling points above ambient temperatures will remain as liquids and will generally cool down or heat up as necessary to approach the temperature of the ambient environment. Those with boiling points below ambient temperatures may boil on a land surface until most of the liquid has volatilized (i.e., vaporized). Alternatively, as the ground

surface cools beneath a boiling pool that has been confined by natural or man-made barriers, the boiling may cease and the remaining quiescent pool may simply evaporate at a fairly steady rate.

Gases or vapors may contaminate a land surface if they are soluble in water and either: 1) it is raining; or 2) water sprays are applied by spill response personnel to absorb, "knockdown" or otherwise accelerate the dispersion of the gas or vapor in air. The contamination occurs because the water droplets pick up some amounts of the gas or vapor and then fall to the ground.

Solids of any kind can contaminate the land surface, and are particularly of concern if they are soluble in water. In such cases, rain or other sources of water will dissolve the solids and permit them to soak deeper into the ground in a process called ***percolation***. Eventually, the dissolved chemicals may reach the water table (if any) below the land's surface and contaminate groundwater supplies serving public, private, or industrial water wells. Such contamination may pose a toxic hazard to the people, animals, and plant life that may be exposed to the soil or which use the contaminated groundwater for drinking, cooking, or crop irrigation. Similarly, the dissolved chemicals may cause undesired reactions, contamination, or corrosion of equipment upon entry to industrial processing equipment relying on well water. The situation for spilled liquids is about the same except that it must be realized that a liquid need not be soluble in water to percolate into soil or to contaminate groundwater supplies. Additionally, it must be noted that liquids are more mobile than spilled solids and do not necessarily require rain or other sources of water to assist in the spreading of contamination. The rate at which a liquid substance percolates or otherwise penetrates the ground is, of course, influenced by many factors. Penetration can be rapid in areas of extremely high permeability including limesinks, caverns, highly fractured rocks, or fractures widened by solution.

Other concerns associated with discharges of hazardous materials onto land surfaces are:

- Combustible substances may be ignited and pose a fire or explosion hazard (see Chapters 4 and 5).
- Hazardous vapors or gases may be liberated into the atmosphere from substances with significant vapor pressures at prevailing chemical or ambient temperatures (see Section 3.5 and Chapters 4 and 6).
- Solids, solids dissolved in or carried by land surface water runoff, or liquids may flow into drains or sewers leading to bodies of water or may directly contaminate such bodies (see Section 3.4).

3.4 DISCHARGES INTO WATER

Discharges of a chemical substance into a body of water may occur directly from damaged ships, barges, underwater pipelines, or railroad cars or trucks that have fallen into the water, or indirectly, as outflows from sewer or drain outfalls, runoff from spills on land, runoff of water used to control fires, or entry of contaminated groundwater into the water body. Virtually all key physical and chemical properties of hazardous materials discussed in this document play important roles in determining how a material will behave when spilled into water.

- The boiling point and vapor pressure of the material will determine whether some part of the material will boil off or otherwise vaporize upon contacting the water.

- The liquid or solid specific gravity or density of the material will determine whether it has an initial tendency to float or sink in water.

- The solubility of the material will determine whether it will dissolve in the water and the rate at which this will occur.

Table 3.2 describes the expected behavior of spills into water of materials with varying combinations of boiling point, vapor pressure, specific gravity, and solubility attributes. To be stressed is that the table describes spill behavior only in the minutes and hours directly after a release and that longer periods of time may result in different effects. For example, although it is well appreciated that oil will float on water, forming a surface slick that may foul shorelines, it is not as well known that waves, water, turbulence, and time may eventually cause a floating petroleum oil slick to emulsify (i.e., to become tiny droplets) that distribute themselves through the water column (i.e., throughout the depth of the water body), to dissolve in water to some extent, and to eventually settle on the bottom of the water body as a sludge. This sludge, in the case of petroleum oils, may mix with sand or dirt and form the "tar balls" often observed on shorelines after an offshore spill.

One special point to be made about substances often described as *insoluble* is that many of these may actually dissolve at such a slow rate in water that they are considered insoluble "*for all practical purposes*." Given enough time or agitation, a sufficient amount may actually dissolve to cause a toxic hazard to anybody or anything exposed to the contaminated water. ***Always be wary of claims of complete insolubility when a highly toxic substance has spilled into water.***

TABLE 3.2
EXPECTED BEHAVIOR OF SPILLS INTO WATER

Boiling Point	Vapor Pressure	Specific Gravity	Solubility	Expected Behavior in Water
Below ambient	Very high	Any	Insoluble	All of the liquid will rapidly boil from the surface of the water. Underwater spills will most often result in the liquid boiling and bubbles rising to the surface.
Below ambient	Very high	Less than Water	Low or Partial	Most of the liquid will rapidly boil off but some portion will dissolve in the water. Some of the dissolved material will evaporate with time from the water. Underwater spills will result in more dissolution in water than surface spills.
Below ambient	Very high	Any	High	As much as 50% or more of the liquid may rapidly boil off the water while the rest dissolves in water. Some of the dissolved material will evaporate with time from the water. Underwater spills will result in more dissolution in water than surface spills. Indeed, little vapors may escape the surface if the discharge is sufficiently deep.
Above ambient	Any	Less than Water	Insoluble	The liquid or solid will float on water. Liquids will form surface slicks. Substances with significant vapor pressures will evaporate with time.
Above ambient	Any	Less than Water	Low or Partial	The liquid or solid will float on water as above but will dissolve over a period of time. Substances with significant vapor pressures may simultaneously evaporate with time.
Above ambient	Any	Less than Water	High	These materials will rapidly dissolve in water up to the limit (if any) of their solubility. Some evaporation of the chemical may take place from the water surface with time if its vapor pressure is significant.

TABLE 3.2 (Continued)
EXPECTED BEHAVIOR OF SPILLS INTO WATER

Boiling Point	Vapor Pressure	Specific Gravity	Solubility	Expected Behavior in Water
Above ambient	Any	Near Water	Insoluble	Difficult to assess. Since they will not dissolve, and since specific gravities are close to water, they may float on or beneath the surface of the water or disperse as blobs of liquid or solid particles throughout the water column. Some evaporation of the chemical may take place from the water surface with time if its vapor pressure is significant.
Above ambient	Any	Near Water	Low or Partial	Although a material with these properties will behave at first like materials described directly above, it will eventually dissolve in the water. Some evaporation of the chemical may take place from the water surface with time if its vapor pressure is significant.
Above ambient	Any	Any	High	These materials will rapidly dissolve in water up to the limit (if any) of their solubility. Some evaporation of the chemical may take place from the water surface with time if its vapor pressure is significant.
Above ambient	Any	Greater than Water	Insoluble	Heavier-than-water insoluble substances will sink to the bottom and stay there. Liquids may collect in deep water pockets.
Above ambient	Any	Greater than Water	Low or Partial	These materials will sink to the bottom and then dissolve over a period of time.
Above ambient	Any	Greater than Water	High	These materials will rapidly dissolve in water up to the limit (if any) of their solubility. Some evaporation of the chemical may take place from the water surface with time if its vapor pressure is significant.

A second point to be made is that concentrations of water soluble contaminants in water are typically measured or expressed in units of parts (of contaminant) per million parts (ppm) of water on a weight basis or in units of milligrams (of contaminant) per liter (mg/l) of water. These units are essentially equivalent such that one ppm equals one mg/l. When a material is dissolved in water, the mixture is often referred to as an ***aqueous*** solution of the material. Conversely, materials that do not contain water are considered to be ***anhydrous***.

Of interest with respect to the evaporation of chemicals from water is that such evaporation can take place not only from floating pools or slicks of chemicals but from the surface of solutions. It is important to realize, however, that the vapor pressure of a chemical will drop when the chemical is added to water or water is added to the chemical, and the less chemical there is in the solution, the lower its vapor pressure will be at a specific temperature. Thus, evaporation from a concentrated solution (i.e., one containing considerable chemical) near a spill site might create a downwind vapor hazard, but the hazard might be negligible some time later after the chemical has had a chance to mix with more water. Similarly, a water-soluble chemical or solution that has a flammable vapor concentration above its surface at a given temperature may often be rendered nonflammable by the addition of a sufficient quantity of water.

Besides generating flammable or toxic vapors, chemicals spilled into water or sewers can pose a variety of hazards to the public and the environment.

- Flammable chemicals or solutions can pose a fire or explosion hazard in sewers, water treatment facilities, or any other spaces they may enter when extracted from a body of contaminated water.

- Insoluble materials, particularly oils, may cause drowning of waterfowl because of loss of buoyancy, exposure due to loss of the insulating capacity of feathers, and starvation and vulnerability to predators due to lack of mobility. Coating of the gills of fish may cause death due to lack of oxygen. Coating of any life forms on the bottom of a water body can kill by smothering.

- Any insoluble or soluble toxic substance that contaminates water may poison animals (including humans) or plant life (aquatic plants or irrigated crops) exposed to the water.

- Organic substances can potentially kill fish and other aquatic life forms by lowering the oxygen content of the water via biological as well as chemical processes.

- Contaminated water drawn into industrial processes may corrode or otherwise damage or destroy equipment, and possibly cause fire or explosion hazards.

3.5 FUNDAMENTAL CONCEPTS PERTAINING TO DISCHARGES INTO AIR

Hazardous vapors or gases, i.e., those that are flammable or toxic to man or his environment, may enter the atmosphere from several sources.

- They may be vented directly into the air from a pressure relief valve, "smokestack", ruptured reaction vessel, broken pipe, or other item of equipment at a chemical plant or other fixed site facility.

- They may be vented directly from a pressure relief valve, broken valve, loose fitting, or puncture in a transportation vehicle, container, or cylinder.

- They may evolve from volatile liquids or solids discharged onto the ground or into water.

Evaluation of vapor or gas discharge hazards first requires that the duration over which the discharge takes place be characterized. It then requires assessment of how the liberated vapors or gases will mix with air over time in a process referred to as ***vapor dispersion***, and finally, requires knowledge of the specific hazards posed by exposure of people to resulting concentrations of airborne contaminants at downwind locations.

Instantaneous vs. Continuous vs. Finite Duration Discharges

The most common methods available for assessment of vapor dispersion hazards require that discharges of vapor or gases into the atmosphere be classified as either being ***instantaneous*** or ***continuous*** in duration. Instantaneous discharges are those that take place over the course of a few seconds or a minute or so and then stop for all intents and purposes. The result of such a discharge is typically a ***puff*** of vapor or gas or a distinct ***cloud***. Continuous discharges take place over longer periods of time and produce long stretched-out ***plumes*** of gas or vapor such as those typically seen from continuously operating smokestacks. These cases represent the two extremes by which contaminant emissions may be characterized. In the real world, many discharges may be of too long a duration to be characterized as truly instantaneous, yet too short in duration to establish a continuous plume. These latter discharges are commonly said to be of ***finite duration***.

In the following, we concentrate upon describing the behavior of gases or vapors liberated from instantaneous or continuous discharges to the atmosphere, thus providing the reader an understanding of the two possible extreme cases. Realize, however, that the actual

behavior of a volume of contaminated air dispersing in the atmosphere, particularly if generated from a finite duration discharge, will behave in a manner somewhat between these two extremes.

Dispersion of Vapor Puffs or Clouds

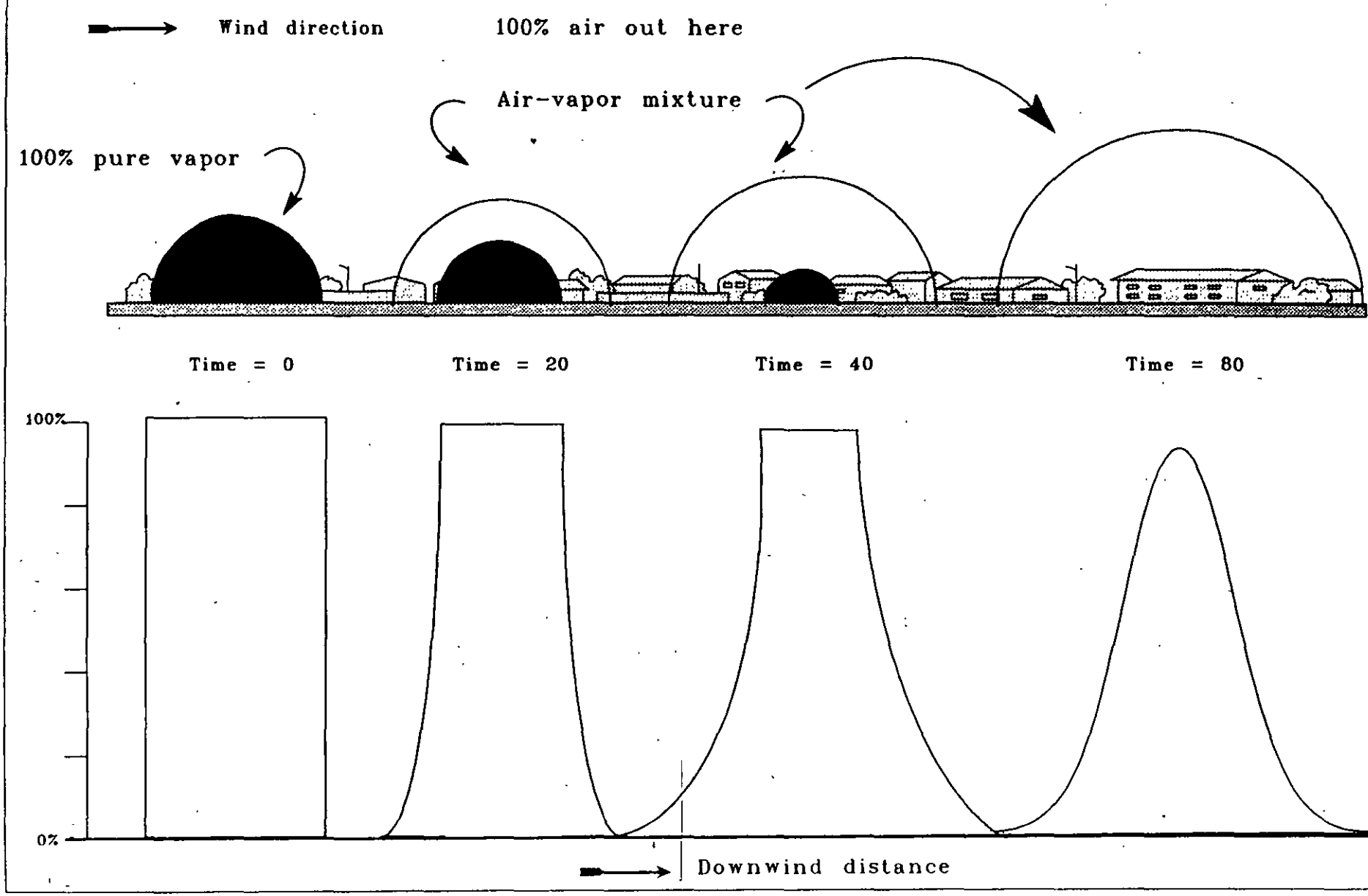
Picture if you will a large semi-spherical puff or cloud of a pure chemical vapor or gas on the ground that has somehow entered the atmosphere over the period of a few seconds and has a vapor specific gravity and vapor density similar to that of air. As the wind pushes on the puff, the puff will begin to move in the direction of the wind at a similar velocity. Simultaneously, air will begin to mix with the surface of the puff, thus diluting surface vapors. As more and more air mixes with the puff, the volume of the contaminated airspace will become larger and larger. Dilution with air, however, will cause vapor concentrations to drop with time at any point in the puff, although the central core of the puff may remain pure for a while.

What happens over time and distance as a puff disperses in air is somewhat hard to visualize with words alone, so it is worthwhile to use various illustrations and graphs in this endeavor. Figure 3.1 shows four initial stages as a puff moves downwind, each accompanied below by a graph of vapor concentration in air on the ground along a cross-section of the puff. At time equals zero, the instant the puff is formed, the concentration within the puff is close to 100% pure vapor and the air surrounding the puff is uncontaminated. At time equals 20, the puff has grown in size by mixing with air, and that portion which is still 100% pure vapor has become smaller. The vapor concentration in the remainder of the cloud ranges from 100% at the edge of the pure core of vapor to 0% at the edge of the cloud. By time equals 40, the core of 100% vapor has become even smaller, and by time equals 80, it has just disappeared. From this point onward, the peak or maximum groundlevel concentration will drop below 100% and continue to drop steadily.

Figure 3.2 continues the above sequence for a variety of later times on a single graph. What is happening is that the cloud grows larger and larger but its peak concentration, the point at its center along the ground, becomes lower and lower. At some point, this peak level will drop below whatever concentration level of the gas or vapor in air is considered hazardous. If one were to plot the groundlevel peak concentration at the center of the cloud with time or distance, it would resemble the graph in Figure 3.3.

Yet another useful way to look at cloud or puff dispersion is to look at the ground area covered by a particular preselected concentration (which could be a flammability or toxicity limit of some kind). Figure 3.4 demonstrates how this ground area changes from the point at which the puff is generated to the downwind location that every point in the puff is below the selected concentration. The view is looking down at the puff from a point up above, with

FIGURE 3.1
INITIAL STAGES OF VAPOR CLOUD OR PUFF DISPERSION



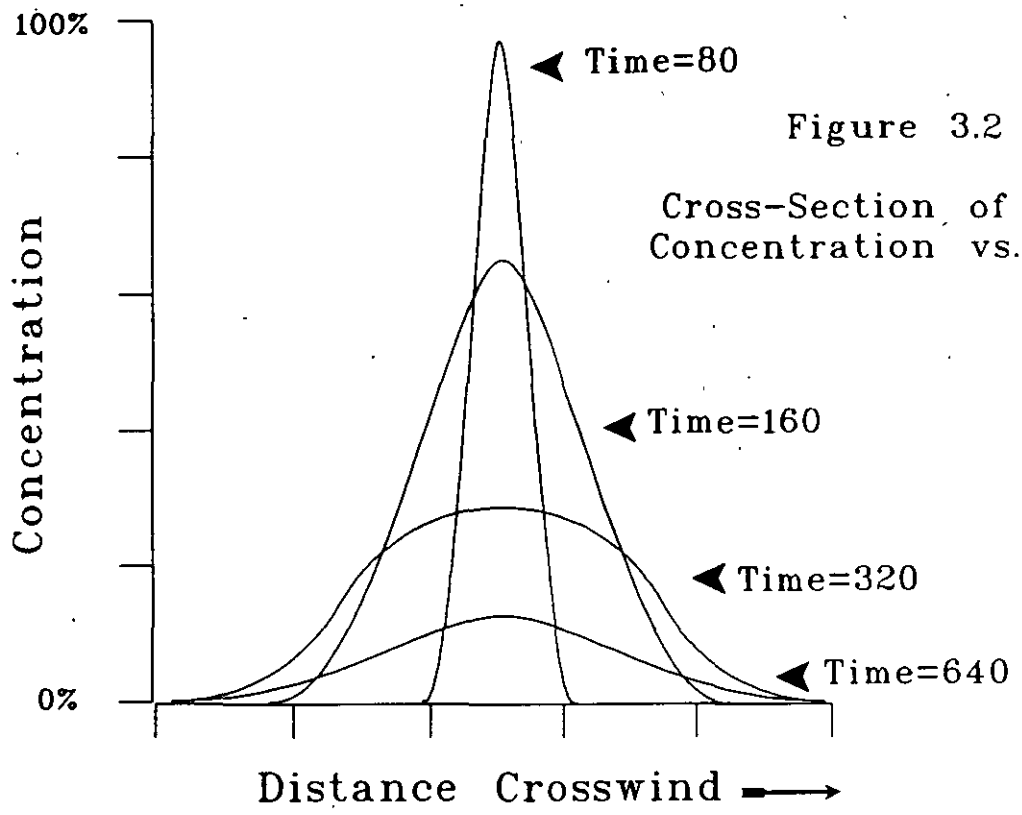


Figure 3.2

Cross-Section of Puff Concentration vs. Time

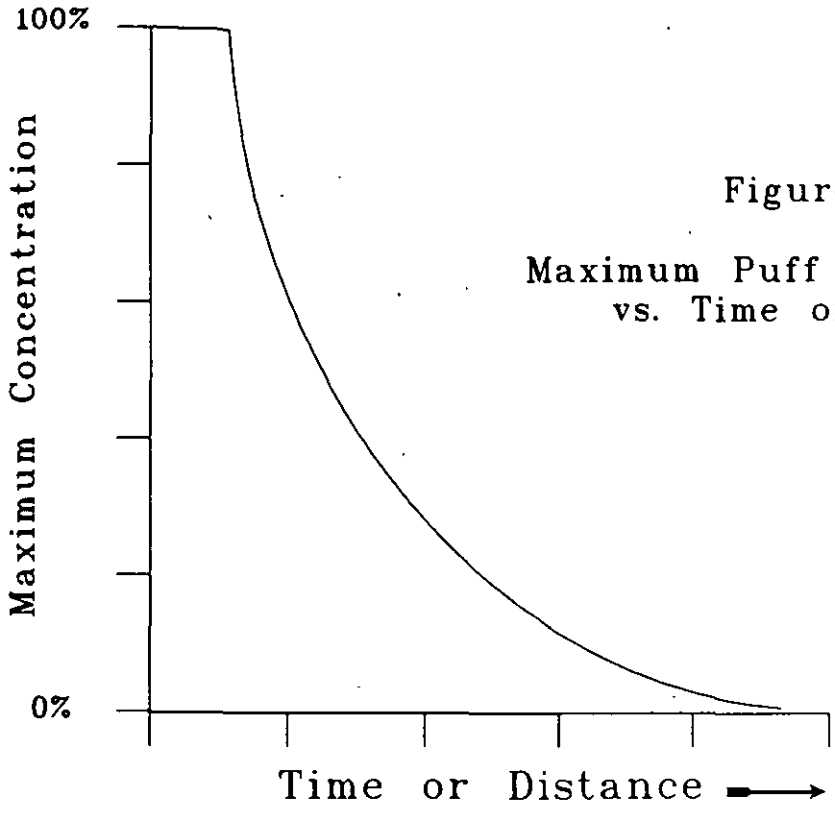


Figure 3.3

Maximum Puff Concentration vs. Time or Distance

FIGURE 3.4
PUFF OR CLOUD ISOPLETHS AT INCREASING TIMES

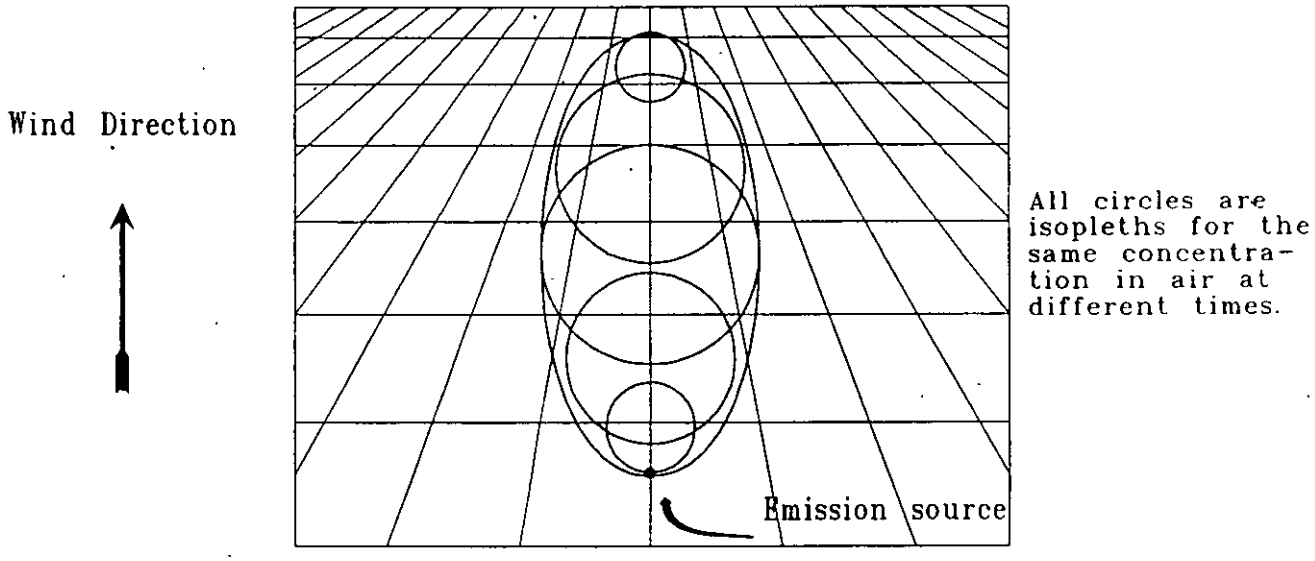
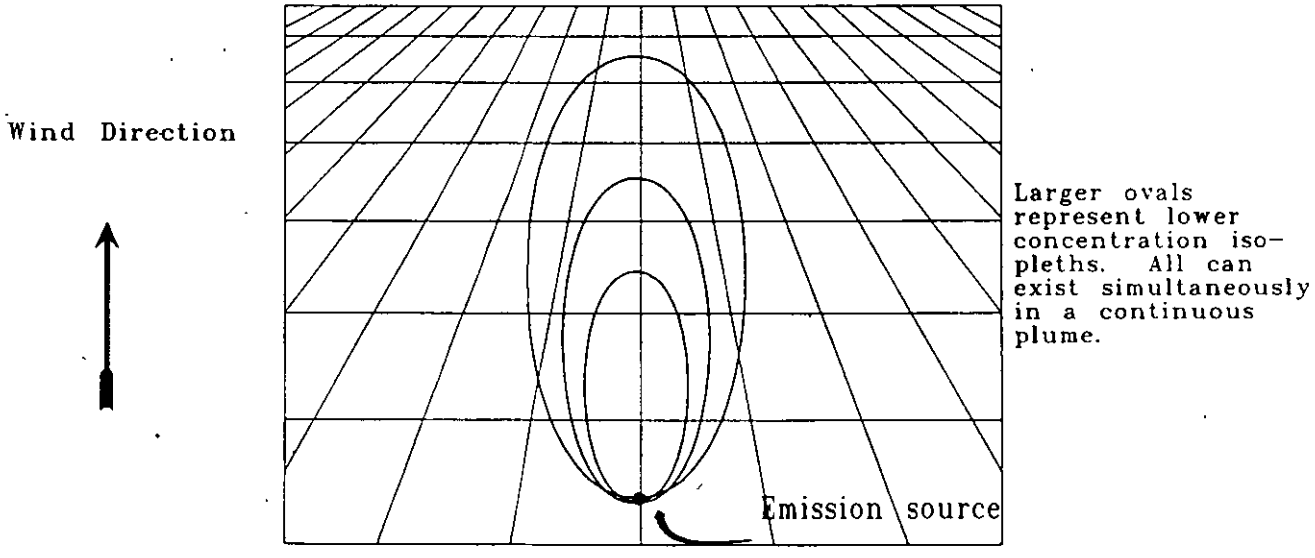


FIGURE 3.5
ISOPLETHS IN A CONTINUOUS PLUME



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each circle representing a different point in time. The line around the set of circles encloses the ground area that will be subjected at some time to airborne contaminant concentrations *at or above* the preselected concentration. In somewhat technical terms, the individual circles, these being lines of constant concentration, are referred to as ***isopleths***, as is the line enclosing the entire set of circles. The latter is also sometimes referred to as the cloud's ***footprint*** on the ground for a particular hazardous concentration.

The downwind distance that any point in puff, cloud, or plume will travel within any elapsed period of time is related to the velocity of the wind *in its direct vicinity* by the relationship:

Distance = Wind Velocity x Time

Although this expression seems rather simple and straightforward, there is a "catch" to its general use. As observed above, the distance traveled is proportional to the wind velocity in the direct vicinity of the puff. Meterologists and weather stations typically report the velocity or speed of the wind as it has been measured at a point 10 meters (about 33 feet) above the ground, where the velocity is usually greater than that very close to a ground surface. Indeed, volumes of contaminated air released at groundlevel may travel as little as 50 percent of the distance given by the above relationship when the wind velocity used in the equation is measured at a 10 meter height. Clouds, puffs, or plumes liberated to the atmosphere above this height may travel faster than the reported wind velocity.

Dispersion of Continuous Plumes

As noted previously, the emission of gases or vapors to the atmosphere over an extended period of time results in establishment of a vapor or gas plume. Points downwind of the source of emissions will be exposed to a relatively constant airborne contaminant concentration for a period of time approximately equal to the duration of the emission so long as the wind direction holds steady. Note however, as is also the case in instantaneous discharges, that some amount of time will be necessary for the front edge of a cloud or plume to reach downwind locations after the initiation of a discharge and for contaminant concentrations to rise to relatively constant levels at these locations. A similar amount of time will be necessary for the trailing edge to pass downwind points after cessation of vapor or gas liberation and for contaminant concentrations to drop below levels deemed to be safe. Thus, there are different arrival and departure times associated with different downwind locations for both clouds and plumes.

Figure 3.5 shows an example of what various concentration isopleths look like through a horizontal cross-section of an established plume. The innermost isopleth encloses the area

subjected to the highest concentrations. Moving out from the innermost isopleth, each isopleth in the outer direction represents a lower concentration than the previous isopleth. As in the previous case, the view is looking down from above.

3.6 VARIABLES THAT INFLUENCE ATMOSPHERIC VAPOR DISPERSION

There are numerous factors that influence the size and shape of downwind hazard zones resulting from vapor or gas discharges into the atmosphere. The most important of these variables are discussed individually and sometimes in combination below. Since several of them interact with each other, it may be a good idea to read this section more than once to better understand various interrelationships. A solid understanding of vapor cloud and plume behavior under various conditions is an important prerequisite to proper emergency response as well as emergency planning.

Effect of Toxic or Flammable Limit Selection on Hazard Zone Size

As explained in prior discussions, the concentration of an airborne contaminant decreases with increasing distance along the downwind centerline direction of the cloud or plume path as well as in the crosswind direction. What this means in practical terms is that the choice of a higher toxic or flammable limit for definition of hazard zone boundaries during accident consequence analysis efforts will result in a smaller overall hazard zone than if a lower limit had been chosen. Conversely, lower limits will lead to larger hazard zones than higher limits.

The choice of an appropriate toxic limit, also referred to as a "level of concern" in earlier guidance documents published by the federal government, is discussed in Chapter 6. Flammable limits are discussed in Chapter 4.

Effects of Discharge Rates and Amounts on Vapor Dispersion

In the case of instantaneous discharges and others of relatively short duration, the total amount (i.e., weight) of vapor or gas released to the atmosphere has an impact on the size and shape of downwind hazard zones. All other factors being equal, larger discharge amounts will result in longer and larger downwind hazard zones. Smaller amounts will result in shorter and smaller zones.

The case with continuous releases is similar. All other factors being equal, higher discharge rates will produce longer and larger hazard zones. Lower discharge rates will produce shorter and smaller zones.

The area from which a vapor evolves is particularly important when the vapor originates from a boiling or evaporating pool of liquid. A smaller pool will usually evolve a lesser amount of vapor per unit of time than a larger pool and therefore pose less of a downwind hazard. A larger pool, having a greater surface area, will produce vapors at a higher rate and pose a greater downwind hazard. Thus, control of exposed pool surfaces can provide some degree of control over adverse downwind impacts.

Effects of Atmospheric Stability Conditions on Vapor Dispersion

The time of day, the strength of sunlight (if any) in the area, the extent of cloud cover, and the wind velocity all play major roles in determining the level of turbulence in the atmosphere and thereby the distances downwind over which airborne contaminants will remain hazardous. Meteorologists typically categorize atmospheric conditions into six ***atmospheric stability classes*** that range generally from "A" to "F". Class A represents unstable conditions under which there are strong sunlight, clear skies, and high levels of turbulence in the atmosphere, conditions which promote rapid mixing and dispersal of airborne contaminants. At the other extreme, atmospheric stability Class F represents light steady winds, nighttime skies, and low levels of turbulence. Airborne contaminants mix and disperse far less slowly with air under these conditions, which also include atmospheric ***inversions*** (when temperatures increase with altitude rather than decrease as usual), and may travel much farther downwind at hazardous concentrations than in other cases. Table 3.3 denotes the various criteria used for determination of these stability classes. Information on the percentage of time that any particular locale experiences the conditions associated with each class can be generally obtained from the nearest office of the National Weather Service, which is listed under the heading of U.S. Department of Commerce in telephone directories of major cities. Meteorologists associated with local radio and television stations or airports will also be knowledgeable of these statistics.

During an actual emergency, it will be necessary to understand that atmospheric conditions may change with time and that these changes will influence the behavior of the dispersing cloud or plume. As inspection of Table 3.3 reveals, atmospheric stability varies strongly with time of day, wind speed, extent of cloud cover, and strength of sunlight. As we are aware, these are all highly variable factors, possibly changing on an hour by hour basis in some locations during certain seasons.

Gas or Vapor Buoyancy Effects on Vapor Dispersion

The descriptions of vapor cloud and plume behavior given earlier started with the assumption that the vapor specific gravity or density of the gas or vapor being released is approximately equal to that of air. However, as also discussed earlier, certain gases or vapors and their initial mixtures with air may actually be heavier or lighter than air.

TABLE 3.3
ATMOSPHERIC STABILITY CLASS SELECTION TABLE

A -- Extremely Unstable Conditions
B -- Moderately Unstable Conditions
C -- Slightly Unstable Conditions
D -- Neutral Conditions*
E -- Slightly Stable Conditions
F -- Moderately Stable Conditions

	Daytime Conditions			Nighttime Conditions	
	Strength of sunlight				
Surface Wind Speed, mph	**Strong**	**Moderate**	**Slight**	**Thin Overcast greater than or = 4/8 Cloudiness****	**less than or = 3/8 Cloudness**
Less than 4.5	A	A - B	B	-	-
4.5 - 6.7	A - B	B	C	E	F
6.7 - 11.2	B	B - C	C	D	E
11.2 - 13.4	C	C - D	D	D	D
Greater than 13.4	C	D	D	D	D

*Applicable to heavy overcast conditions day or night
**Degree of Cloudiness = Fraction of sky above horizon covered by clouds.

In general, lighter-than-air gases, vapors, or mixtures will mix with air in the same fashion as those that are closer to the vapor specific gravity of air. Groundlevel contaminant concentrations are likely to be lower, however, because maximum concentrations along the centerline of the cloud or plume will tend to be elevated. The rate at which a cloud or plume will rise as it moves downwind will primarily be a function of the difference in vapor specific gravity between it and air and the prevailing wind speed. Lighter gases or vapors will rise faster. Strong winds will tend to keep the cloud or plume closer to the ground for longer periods of time. Figure 3.6 for distinct clouds or puffs demonstrates these concepts and the principles that also apply to plumes. In both cases, it is necessary to remember that the velocity of the wind will influence downwind travel distances within any given period of time.

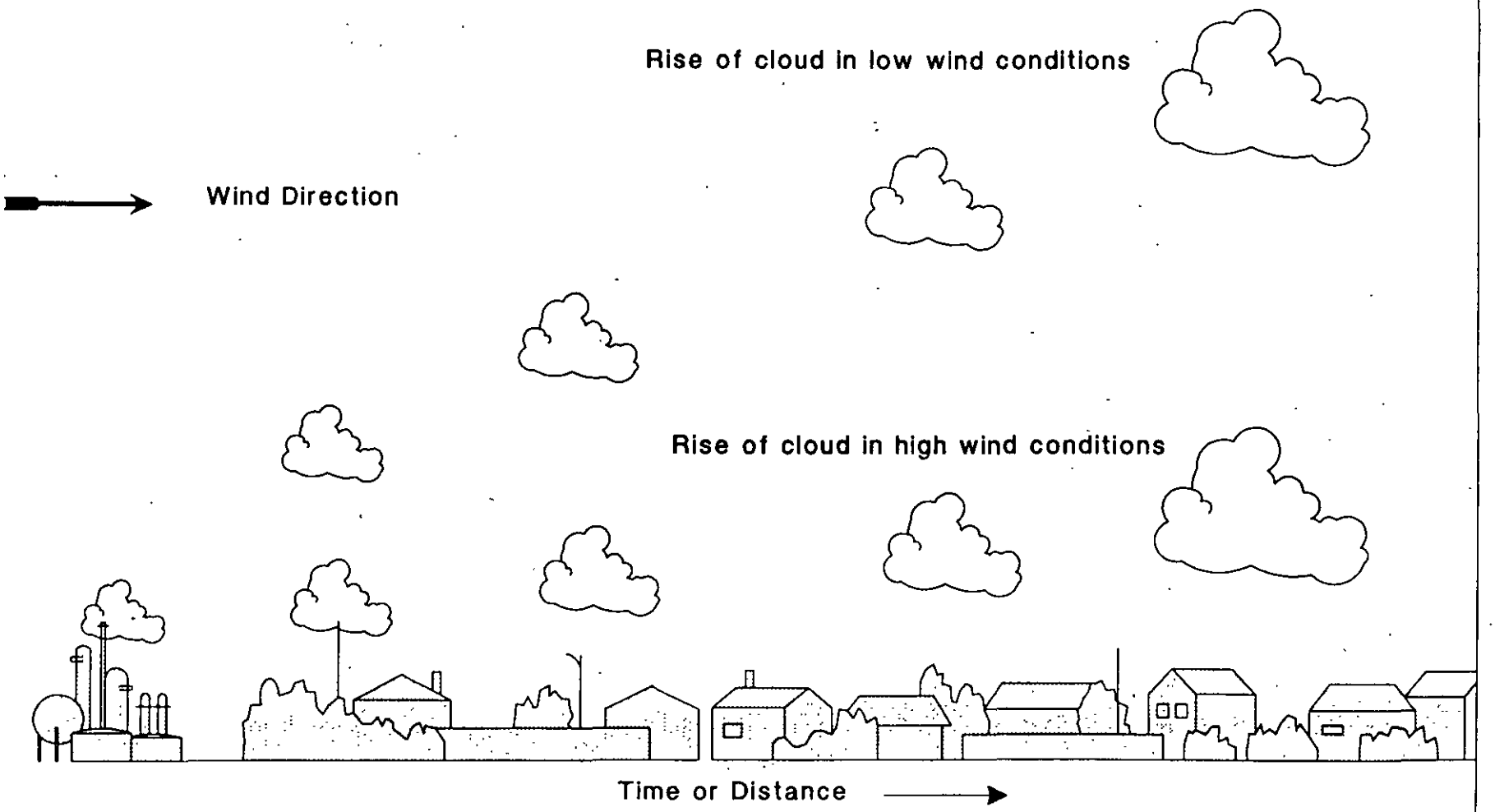
Heavier-than-air gases, vapors, or mixtures tend to hug the ground for a time when first released and may even follow terrain in directions across or against wind directions on certain boundaries. However, as these vapors and gases become more diluted with air, they will at some point begin behaving like mixtures with vapor specific gravities close to that of air. Thus, consideration of heavy gas or vapor dispersion phenomenon is more important for higher concentrations near the source (such as those associated with lower flammable limits) than for the lower concentrations typically associated with toxic limits.

The overall behavior of a heavy (negatively buoyant) cloud or plume can be very different than that of a neutrally or positively buoyant cloud or plume and the shape and dimensions of the cloud or plume can be strongly influenced by the duration of the discharge, prevailing atmospheric stability conditions, and prevailing wind velocities. For example, an instantaneous discharge of a flammable liquefied gas can result in a flammable or potentially explosive cloud that is 25 percent greater in maximum width than its length under neutral atmospheric conditions (see Table 3.3) when winds are of moderate velocity. Under more stable atmospheric conditions with lower wind speeds, the maximum width of the cloud could drop to approximately 80 percent of its length. Under specific combinations of conditions, particularly for large releases, cloud widths could be as much as 150 percent of length dimensions.

Continuous or otherwise prolonged discharges of heavy gases or vapors can behave yet differently from short-term releases. Under neutral atmospheric stability conditions, maximum plume widths typically range from 30 to 60 percent of lengths when winds are of moderate velocity. Under stable conditions, these widths can vary from 75 to 90 percent of lengths. In contrast, the maximum widths of neutrally or positively buoyant clouds or plumes are typically in the range of 40 to 50 percent of lengths.

Figure 3.6

Behavior of Lighter than Air Puffs or Clouds



Effects of Source Elevation on Vapor Dispersion

Although many discharges of gases or vapors are likely to take place at or near groundlevel, some may occur from the top of an elevated item of equipment or from a tall smokestack, pressure relief valve, or similar venting device. The principles set forth earlier with respect to post-discharge behavior of gases and vapors remain applicable in such cases, but it must be noted that groundlevel concentrations due to elevated sources may vary significantly from groundlevel concentrations due to groundlevel sources. Figure 3.7 illustrates some of the reasons for such differences.

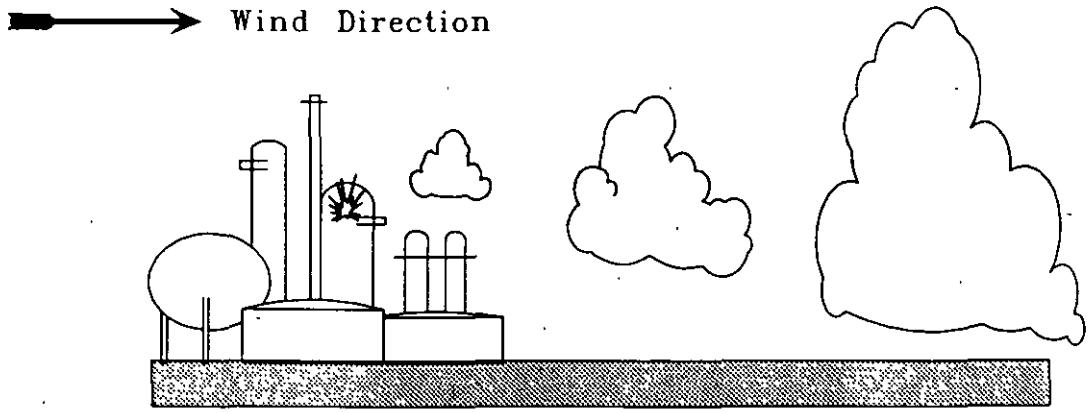
The most important concept to understand about elevated discharges is that maximum concentrations will be along the centerline path of cloud or plume travel in the downwind direction. In the case of neutrally buoyant clouds or plumes, groundlevel contaminant concentrations may be essentially zero until the bottom of the cloud or plume first touches ground. These concentrations will then rise with increasing downwind distance, reach a peak, and then drop with further distance. As demonstrated by the graph in Figure 3.3 presented earlier, this differs markedly from the variation of concentration with distance seen along the centerline path of such a cloud or plume.

When vapors or gases are lighter than air and therefore positively buoyant, the presence of harmful contaminant concentrations near groundlevel will strongly depend upon the wind velocity. As illustrated in Figure 3.6, the cloud or plume may rise quickly, slowly, and possibly not all depending on the wind speed (and the velocity with which the vapors or gases are discharged upwards into the air). Groundlevel concentrations will vary accordingly.

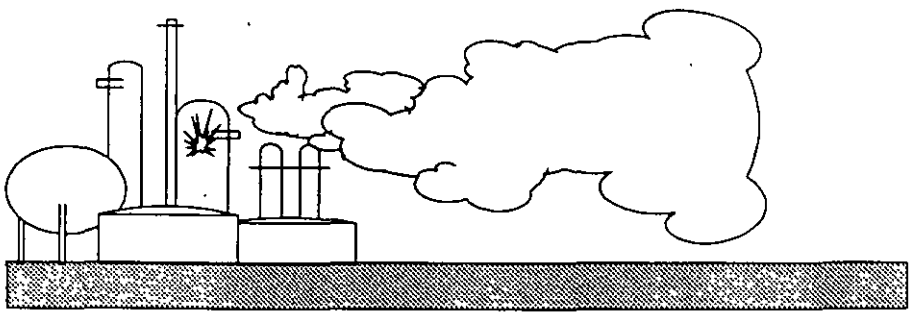
Effects on Dispersion Relating to Physical States of Contaminants

Although the discussion to this point has focused on the dispersion of gases and vapors in air, it is also important to understand that fine mists, fumes, or aerosols of liquids as well as fine dusts or powders may also be transported by the wind to downwind locations. Some discharges could involve mixtures of chemical vapors and aerosols and dusts.

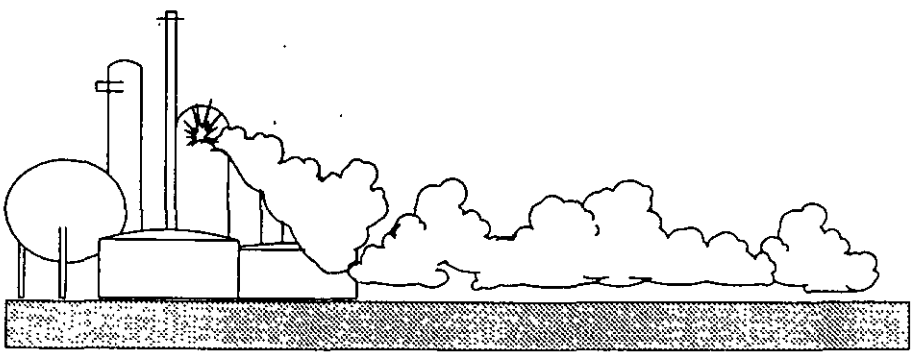
Larger and heavier droplets of liquid or particles of solids may "settle out" of the cloud or plume and drop to ground surfaces fairly close to their point of origin. Somewhat smaller particles may settle out a bit further downwind, while the smallest of all may travel as far as vapors and gases at equivalent concentrations in air. Droplets of volatile liquids may vaporize as they are carried by the wind or after they settle out of the main cloud or plume. They may also cause part or all of a cloud or plume to behave as if it is heavier than air even if the same substance in a purely gaseous state might be lighter than air or neutrally buoyant at prevailing temperatures. All of these phenomena can have an impact on groundlevel or close to groundlevel contaminant concentrations, generally resulting in levels above those



1. Puff dispersion of neutrally buoyant vapors. Groundlevel concentrations may be zero for some time until the puff first "hits" the ground. Same puff shown at different times above.



2. Continuous plume dispersion of neutrally buoyant vapors in air. Note again that some distance may be required before any contamination occurs near the ground.



3. Plume dispersion of heavy vapor. Puffs may follow a similar path during dilution with air.

Figure 3.7
Some Effects of Elevated Emissions

that would be expected in the absence of mists, fumes, aerosols, or dusts. Accurate prediction of cloud or plume behavior under these conditions is extremely complex and prone to substantial errors.

Effects of Discharge Velocities on Dispersion

Vapors or gases may be released to the atmosphere at relatively low velocities or may be vented under high pressure as a jet. There are various "jet" momentum effects that alter puff or plume behavior, particularly near the source of a discharge. A strong jet of vapor or gas will tend to entrain and mix with air rapidly at first, thus tending to reduce contaminant concentrations. These effects become less important, however, as the puff or plume moves downwind.

In the event that a high velocity high rate discharge of a heavier than air mixture of gas and liquid aerosols takes place in the downwind direction, there is a distinct possibility that downwind hazard zone lengths will be greater than those predicted by most vapor dispersion models in general use. The behavior of such highly pressurized discharges of compressed liquefied gases is a subject receiving considerable attention in scientific cicles at present, but accurate prediction of contaminant behavior under these conditions remains prone to substantial errors.

Effects of Local Terrain on Vapor Dispersion

In virtually all that has been said about atmospheric vapor dispersion phenomena up to this point, it has been tacitly assumed that the vapors or gases being discussed are dispersing over flat terrain without obstacles of any kind. In the real world, however, large portions of the country are by no means flat or devoid of hills, mountains, trees, or buildings. All of these topographical features and others influence the manner in which airborne contaminants disperse.

In most cases, a certain degree of "roughness" in the terrain is beneficial in the sense that it tends to speed up the rate at which contaminants mix with air and are thereby diluted. This is understandable if one thinks about how the wind behaves as it swirls around and over trees, hills, buildings, and other objects. There are two situations, however, in which terrain effects may cause increased hazards at or near groundlevel locations.

The first case involves situations in which contaminants are trapped within some sort of canyon, valley, or bowl-like depression in the land surface. Under these conditions, the walls or sides of these topographical features can prevent spreading of clouds or plumes and restrict dilution with air. The net result is that hazard zones might be of different size and

shape than otherwise expected. If an atmospheric inversion were to occur such that there was essentially a "cap" placed over a bowl-like depression or valley, airborne contaminants could be literally trapped for extended periods of time.

The second case involves the dispersion of gases or vapors from an elevated source when there are buildings or similar shaped features on the land in the downwind direction. As the wind passes over a building, some part of it may be drawn down into a swirling eddy pattern in a space behind the structure commonly referred to as its "wake cavity". The practical significance of this phenomenon is that contaminants liberated from elevated sources could potentially be drawn down towards groundlevel much sooner and at much shorter downwind distances than might otherwise be expected.

Readers should be advised that many of these phenomena are extremely difficult if not impossible to address in any sort of *generalized* vapor dispersion hazard prediction model or methodology regardless of its claimed level of sophistication or cost. Those who may be tempted to purchase any expensive software package to evaluate downwind vapor dispersion resulting from chemical accidents *for planning purposes* should first compare the results of the package with the results obtained from the computer program provided with this guide for several scenarios.

Effects of Wind Meandering on Evacuation or Protective Action Zones

The main reason that one would wish to determine or predict the concentration isopleths or footprints of gas or vapor clouds or plumes is to determine those downwind areas that may require public evacuation or other protective action in the event of a toxic and/or flammable vapor or gas release. It is important to realize, however, that the direction of the wind is rarely steady over any significant period of time and that the wind direction tends to shift back and forth between various directions. This shifting over time is often referred to as ***meandering***. The practical significance of wind meandering is that an area larger than that predicted by strict application of dispersion estimation methods may require evacuation or other means of public protection during an actual emergency.

The probability and extent of wind meandering in any locale is a complex function of several factors, but one of the most important involves the atmospheric stability class prevalent in the area at the time. The wind tends to meander less *on average* under stable conditions than in unstable weather.

Based on data presented on page 28 of the ***Handbook of Atmospheric Diffusion*** (U.S. Department of Energy, DOE/TIC-11223) by Hanna, Briggs, and Hosker, it has been determined that there is a 90 percent probability on average that a cloud or plume will remain within a downwind arc of 120 degrees from its point of origin under atmospheric stability class conditions A, B, and C. For more stable stability classes, the arc narrows to a 40 degree

angle. Figure 3.8 illustrates these observations, the practical significance of which is the finding that the area requiring evacuation or other protective action (such as sheltering populations in place) in the first hour of a hazardous vapor or gas release should usually be based on the above arcs and not the actual width of selected concentration isopleths. Where an evacuation is to be attempted, it is often best to start from a point nearest the emission source and work outwards towards downwind areas subject to lower concentrations. Be advised, however, that there is an exception to the above findings. When the velocity of the wind is very low under special circumstances, the direction of the wind can become very erratic. It is best to be prepared under low wind conditions for one or more sudden shifts in wind direction and the possibility that a cloud or plume may literally "hop" from one position or direction to another.

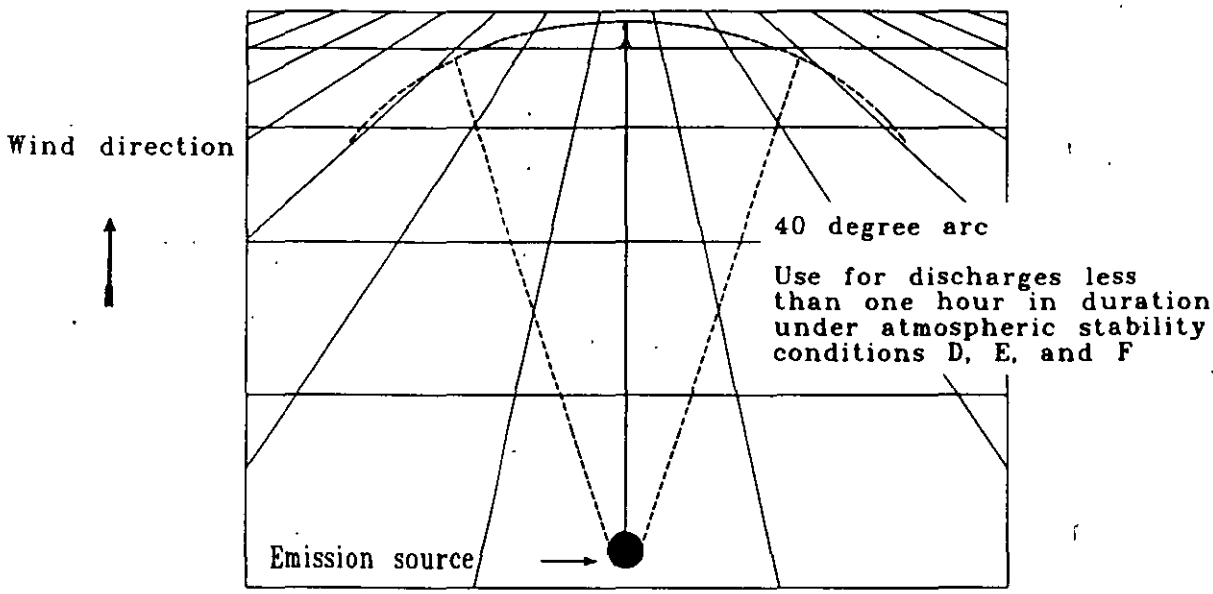
Indications of the specific areas that may require protective action in the event of specific spill or discharge situations can be obtained by drawing hazard zone boundaries on a map of the region in accordance with the "scale" shown on the map. These boundaries can be drawn for various wind directions and atmospheric stability classes to illustrate potential hazard zones under various conditions. Local census data may then be used to estimate the maximum number of people that may require protection. Note that the drawings will be most easily drawn using a ruler and protractor, keeping in mind that a full circle has 360 degrees.

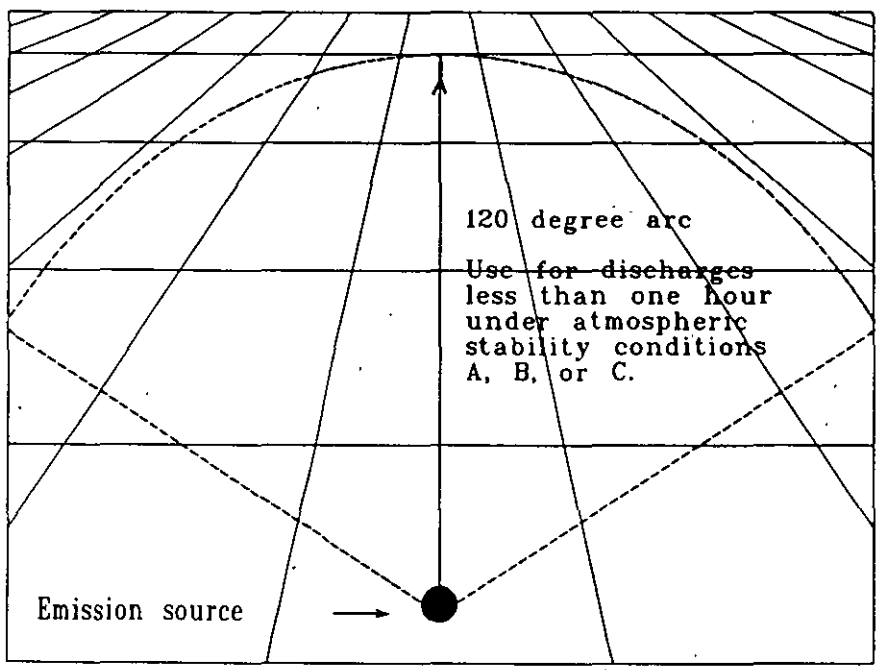
If the discharge or release may be prolonged, the probability will increase that there will be a major shift in wind direction. When and where possible, it is best to consult a meteorologist with detailed knowledge of current local conditions immediately for advice on how to expand the evacuation area as time progresses. For truly prolonged situations involving hazardous emissions, it may eventually become necessary to evacuate a full circle around the accident site out to the radial limits of the estimated hazard zone.

It is precisely because the direction of the wind during an accident cannot be predicted in advance and that the direction may shift during a hazardous event that the zone considered ***vulnerable*** around a potential accident or incident site encompasses a full circle around the site (or a "corridor" of overlapping circles if the site is along a railroad, pipeline, barge, or truck route). Although there may be many cases in which only a portion of the ***vulnerable zone*** will require protective action, public and industry officials must realize that the entire zone is at risk and will require attention during the emergency planning process, particularly with respect to populations at special risk or requiring special assistance.

The average probability of the wind being in any particular direction may be useful knowledge, particularly in locations where the wind is prone to flow in certain directions on a regular basis during various seasons. As in the case of atmospheric stability classes, the planning process can therefore benefit from consultation with a meteorologist at the nearest office of the National Weather Service or associated with a local radio or television station or

FIGURE 3.8
VAPOR DISPERSION HAZARD ZONE BOUNDARIES



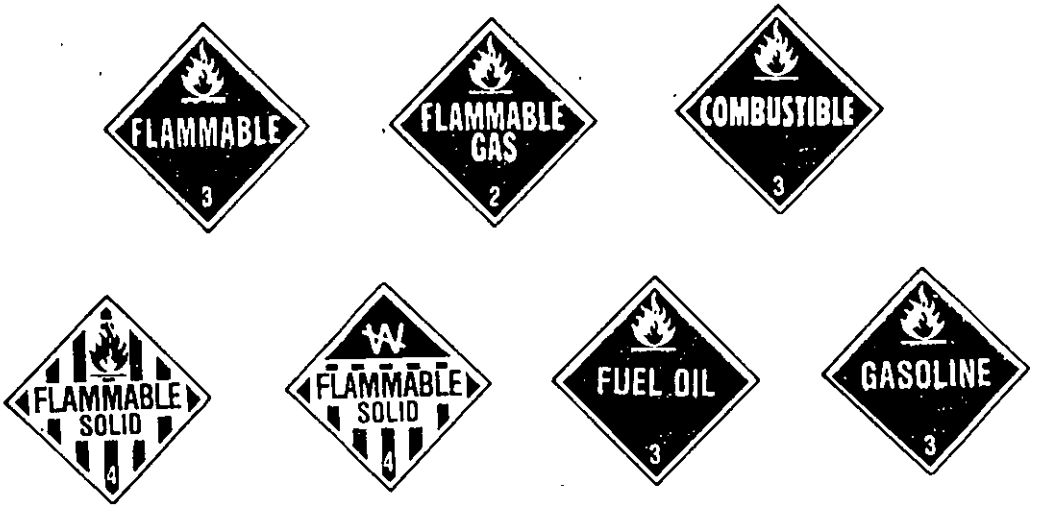


Arrows within boundaries of estimated hazard zones indicate length of downwind hazard distance in downwind centerline direction of wind.

Longer duration discharges may require up to 360 degree evacuations or protective measures if the wind direction may shift during the discharge. Consult a qualified meteorologist in actual emergencies for advice.

airport. It is common practice for these professionals to maintain or have access to detailed historical data pertaining to the frequency of various wind directions in the locale of their concern.

4.0 FIRE HAZARDS OF CHEMICAL SUBSTANCES



4.1 INTRODUCTION

When most of us think of an unwanted fire, we typically picture a burning building, a burning transport vehicle of some kind, or a burning forest with flames and smoke rising into the sky. These are clearly the most common types of fires and typically involve ordinary combustible materials such as paper, wood, cloth, plastics, and rubber. Fire departments across the nation face such fires on a daily basis and are well-equipped and trained to deal with them. Hazardous materials, however, may pose additional types of fire hazards with unusual characteristics. In the following, we first discuss measures of flammability potential, continue with a discussion of how the effects of fires may be evaluated, and finally, describe a number of "special" types of fires associated with hazardous materials.

4.2 MEASURES OF FLAMMABILITY POTENTIAL

It hardly needs saying, but most of us realize that some materials are much more easily ignited than others. Some require only a spark, such as the propane or LP-gas fuel in a gas barbecue, while others, such as a piece of granite, will not ignite even if placed under a welding torch. The most common measures of flammability potential for materials which are flammable or combustible are: 1) flash points; 2) lower flammable or lower explosive limits; 3) upper flammable or upper explosive limits; and 4) autoignition temperatures. These data are readily available in various handbooks and hazardous material data bases when known, and are commonly listed in chemical company material safety data sheets (MSDS). Fire

safety and combustion experts may also consider ignition energy requirements, fire points, flame spread rates, and heat and smoke generation rates of materials in evaluating their flammability characteristics, but knowledge of these latter attributes is not truly needed for the purposes of this document and sources of appropriate data are not readily available to the general public for a large number of subtances.

Flash Points

The ***flash point*** of a combustible substance, in simple terms, is the lowest temperature of a material at which the vapors over its liquid or solid surface will ignite and burn when exposed to a specified ignition source without necessarily causing self-sustaining combustion of the liquid or solid. Flash points vary from temperatures far *below* zero degrees Fahrenheit for flammable gases (such as natural gas, LP-gas, propane or butane), and volatile flammable liquids (such as gasoline), to hundreds of degrees *above* zero for heavy fuel oils. (Note: The temperature at which the vapors over a liquid or solid will ignite and continue to burn due to self-sustaining combustion of a liquid or solid is called its ***fire point***. These temperatures are available in the professional literature for only a relatively few materials.)

Materials with low flash points relative to temperatures in the ambient (i.e., natural) environment are usually ignited easily by a spark (be it from metal scraping metal or stone or from static electricity) or by a flame from any source. Most frequently, they are substances that are normally gaseous at ambient temperatures or liquids that readily evaporate or boil upon release. These vapors or gases can sometimes be carried by the wind to a source of ignition somewhat distant from the discharge site of the material and ***flashback*** to the spill source causing one or more of the fire hazards described later.

Substances with flash point temperatures close to ambient temperatures are also easily ignited by sparks or flames. The main difference between such materials and those described in the previous paragraph is that the ignition source must be closer to the fuel in order for ignition to take place. This follows from the observation that such materials are generally liquids of lower volatility than materials with substantially lower flash points.

The higher the flash point temperature is above ambient temperature, the more difficult it becomes to ignite a substance. Under normal circumstances, a fuel with a high flash point cannot be ignited by a spark or even a nearby flame unless: 1) the fuel is a liquid sprayed into the air as a fine mist; 2) the fuel is a finely divided solid; 3) a portion of the fuel is heated to its flash point by a nearby source of heat and then exposed to an ignition source; or 4) the fuel is heated to a temperature at or above its flash point prior to release and encounters an ignition source before cooling.

The flash point temperatures of combustible materials are determined using testing methods and equipment standardized by various organizations, with the American Society of Testing and Materials (ASTM) being the primary standard-setting body in the United States. There are two main classes of testing methods which respectively provide "open cup" or "closed cup" flash points, and each class represents more than one specific testing method. Because of differences in equipment design and testing procedure, the numerical value of closed-cup flash points is typically some 5-10° Fahrenheit lower than that of the open-cup flash point for the same substance, but the difference may be greater or less in individual cases. Due to other factors, most importantly the purity of the sample tested, it is not surprising to find a number of different closed cup or open cup flash points for any given substance, all of which differ to some extent. It is well, therefore, to consider flash point values reported in the literature as approximate rather than exact values.

Flammability and Explosivity Limits

It is rather well known that combustion cannot take place in the absence of a certain minimum amount of oxygen, be it available in air mixed with gases or vapors evolved from a combustible substance or from an internal component of the fuel. Conversely, there must be sufficient fuel vapors or gases available in a fuel-air mixture to support and sustain combustion. Thus, there are both lower and upper limits associated with fuel concentrations in air that will ignite and permit flames to spread away from the source of ignition (i.e, permit flames to ***propagate***). Fuel concentrations below the lower limit will contain insufficient fuel to ignite and propagate flame and are commonly referred to as being too ***lean*** to burn. Those above the upper limit are considered too ***rich*** to ignite; that is, they contain too much fuel and/or too little oxygen, as in the case of a "flooded" automobile engine.

The minimum concentration of a vapor or gas in air that will ignite and propagate flame is known as its ***lower flammable limit*** (LFL) concentration or its ***lower explosive limit*** (LEL) concentration and is usually expressed as a percentage by volume of fuel vapors in air. The words *flammable* and *explosive* are used interchangeably such that LFL values typically equal LEL values in the literature. The reasoning behind this is that the concentration of a fuel that will burn in air can also be expected to explode under the appropriate conditions. This supposition is only approximately true for some fuels (where precise LEL values might be slightly higher than LFL values), but it has become widely accepted over decades of use.

Similar to the above, the maximum concentration of a gas or vapor in air that will ignite and propagate flame is known as the ***upper flammable limit*** (UFL) or ***upper explosive limit*** (UEL) of the fuel. Again, the words *flammable* and *explosive* are often used in an interchangeable fashion.

LFL or LEL values are related to flash points of combustible substances in that the flash point is *theoretically* the temperature at atmospheric pressure to which a substance must be raised to produce a vapor or gas concentration over its surface equivalent to its LFL or LEL concentration. The relationship is not always observed in practice, however, because flash point measurement equipment and procedures, as discussed above, do not always produce precise values.

Flammable and explosive limits found in the literature are usually measurements made at normal atmospheric temperatures and pressures unless indicated otherwise. Be advised that there can be considerable variation in these limits at pressures or temperatures above or below normal. The general effect of an increase in temperature or pressure is to reduce the lower limit and increase the upper limit. Decreases in temperature or pressure have the opposite effect.

As a final note, it is also important to appreciate that certain solids, when dispersed in air as fine powders, may also be capable of burning or exploding upon encountering a suitable source of ignition. Some examples include coal dust produced in mining operations, grain dust produced in silos during storage or transfer operations, and flour produced in milling operations. Flammable or explosive limits for solid materials are usually expressed in units of weight of solid present in a specified volume of air.

Autoignition Temperatures

The ***ignition*** or ***autoignition temperature*** (AIT) of a substance, whether solid, liquid, or gaseous, is the minimum temperature necessary to initiate or cause self-sustaining combustion in the absence of a flame or spark. Even more so than flash points or flammable limits, these temperatures should be viewed as approximations due to the many factors that can affect testing results. Indeed, it must be noted that most values currently found in the literature were determined by testing methods that are now considered obsolete. Newer testing methods adopted by the ASTM frequently demonstrate substantially lower temperatures for the onset of combustion than older methods.

Table 4.1 provides examples of various hazardous materials and their associated flammability data. Those at or near the top of the list are extremely flammable and volatile and more likely to produce large quantities of flammable vapors or gases upon release; vapors or gases that may travel a considerable distance from the spill site and still be within flammable or explosive limit concentrations in air. Those at or near the bottom of the list are difficult to ignite without prior preheating and tend to have much lower vapor pressures (i.e., are generally of low volatility).

TABLE 4.1
EXAMPLE FLAMMABILITY CHARACTERISTICS

Substance	Closed-cup Flash Point (°F)	LFL (%)	UFL (%)	AIT (°F)
Propane	Very low	2.1	9.5	842
Gasoline	-45 to -36	1.4-1.5	7.4-7.6	536-853
Acetone	-4	2.5	13	869
Isopropyl alcohol	53	2.0	12.7 at 200°F	750
Turpentine	95	0.8	*	488
Fuel oil no. 2	126-204	*	*	494
Motor oil	275-600	*	*	325-625
Peanut oil	540	*	*	833

*Note: Flash points are often not recorded for substances that are gases at ambient temperatures because of the very low temperatures required to determine them. Similarly, flammable limits are not always available for substances with high flash points due to the high temperatures needed for ignition. Substances that are complex mixtures of a number of materials, (e.g., fuel oils) may have a range of flash points.

Sources: ***Fire Protection Guide on Hazardous Materials***, 8th ed., National Fire Protection Association, Quincy, MA, 1984.

CHRIS Hazardous Chemical Data, U.S. Coast Guard, U.S. Department of Transportation, Washington, D.C., 1978.

4.3 MEASURES OF FLAMMABILITY EFFECTS

Direct contact with a flame of any sort is obviously not a good idea for any prolonged period of time since the extreme heat may ignite combustible materials or severely burn and destroy living tissue. What may not be fully realized is that fires can also cause damage or injury from a distance via transmission of thermal radiation, not unlike the manner in which the sun warms the earth. Such radiation, which is completely different from nuclear radiation, will be strongest at the surface of a flame and will become rapidly weaker as one moves away in any direction. Consequently, during a major hazardous material release involving fire, property damage and human injuries may occur not only in burning areas, but also in a zone surrounding the fire.

Thermal radiation levels (also referred to as thermal radiation ***fluxes***) are measured and expressed in units of power per unit area of the item receiving the energy. However, since the damage or injury sustained by a receiving object is a function of the duration of exposure as well as the level, thermal radiation ***dosages*** are also of concern. These dosages are determined by combining radiation levels with exposure times and are expressed in units of energy per unit time per unit area of receiving surface. Table 4.2 lists some of the known effects of thermal radiation on bare skin as a function of exposure level and time.

4.4 TYPES OF FIRES

There are essentially six types of fires associated with hazardous material discharges, with the type of fire a function not only of the characteristics and properties of the spilled substance but the circumstances surrounding its release and/or ignition. The six types are:

- Flame jets
- Fireballs resulting from Boiling Liquid Expanding Vapor Explosions (BLEVEs)
- Vapor or dust cloud fires
- Liquid pool fires
- Fires involving flammable solids (as defined by the U.S. Department of Transportation), and
- Fires involving ordinary combustibles

TABLE 4.2
THERMAL RADIATION BURN INJURY CRITERIA

Radiation Intensity

kW/m^2	$Btu/hr\text{-}ft^2$	Time for Severe Pain (sec)	Time for 2nd Degree Burn (sec)
1	300	115	663
2	600	45	187
3	1000	27	92
4	1300	18	57
5	1600	13	40
6	1900	11	30
8	2500	7	20
10	3200	5	14
12	3800	4	11

Data sources: Buettner, K., "Effects of Extreme Heat and Cold on Human Skin, II. Surface Temperature, Pain and Heat Conductivity in Experiments with Radiant Heat," J. Ap. Phys., Vol. 3, p. 703, 1951.

Mehta, A.K., et al., "Measurement of Flammability and Burn Potential of Fabrics," Summary report to the NSF under Grant #GI-31881, Fuels Research Laboratory, Mass. Inst. of Tech., Cambridge, Mass., 1973.

Flame Jets

Transportation or storage tanks or pipelines containing gases under pressure (i.e., compressed gases) or normally gaseous substances that have been pressurized to the point they become liquids (i.e., compressed liquefied gases) may discharge gases at a high speed if somehow punctured or broken during an accident. The gas discharging or venting from the hole will form a gas jet that "blows" into the atmosphere in the direction the hole is facing, all the while entraining and mixing with air. If the gas is flammable and encounters an ignition source, a flame jet of considerable length may form (possibly hundreds of feet in length) from a hole less than a foot in diameter. Such jets pose a thermal radiation hazard to nearby people and property, and are particularly hazardous if they impinge upon the exterior of a nearby intact tank containing a flammable, volatile, and/or self-reactive hazardous material. Such events sometimes occur during multi-car train derailments or in incidents at crowded chemical plants or oil/gas processing or storage facilities. In these cases, the heat of the flame increases pressure in the intact tank while simultaneously weakening its outer wall. This may eventually cause the tank to rupture violently or explode in an event referred to as a BLEVE (see below), particularly if the flame impinges on the wall in the vapor space of the container where there is no adjacent liquid to draw heat away from the wall surface. If the contents of the intact tank are flammable, a large rising fireball may result. If the contents are nonflammable but toxic, a large amount of toxic vapors or gases may be suddenly released to the atmosphere.

Fireballs Resulting from BLEVES

Boiling Liquid Expanding Vapor Explosions (BLEVEs) are among the most feared events when sealed tanks of liquid or gaseous hazardous materials are exposed to fire. Although they are called explosions, they are not associated with strong blast waves *in many cases*. Rather, they involve the violent rupture of a container of flammable material and the rapid vaporization of the material. If the substance is flammable, a large rising fireball may form, the size of which will vary with the amount of hazardous material present, and which may be as much as 1,000 feet in diameter when involving a railroad tank car containing a flammable liquefied compressed gas like liquid propane or LPG. Although the fireball is generally of short duration, the intense thermal radiation generated can cause severe and possibly fatal burns to exposed people over relatively considerable distances in a matter of seconds. In addition, if the tank is relatively long and cylindrical in shape, part of the tank may literally "rocket" into the air, all the while spewing forth burning gases and liquids. Pieces of such tanks have been known to travel up to 5,000 feet in BLEVEs involving railroad tank cars. Fires and various impact damages have occurred at the landing points of larger pieces. (Note: Be advised that there is potential for the tank to rocket upon rupturing violently or exploding regardless of whether its contents are flammable or nonflammable.)

The phenomena leading to a BLEVE can occur with most liquids excessively heated in a closed or inadequately vented container, whether they are flammable or not, or are pure materials or mixtures, unless other circumstantial factors are considered. Two important factors are the duration of the external exposure fire and the flow capacity of any pressure relief valve if one is present. If the exposure fire is not of sufficiently long duration, or if the relief valve can vent vapor as fast as it is generated, a BLEVE will not occur. An additional factor is the availability of external cooling via fixed water spray systems, fire monitors, hose streams, etc. These can contribute to the prevention of a BLEVE either by suppressing the external fire or by cooling the heated vessel. Finally, note that the possibility of a BLEVE increases with the volatility of the hazardous material. Substances with higher vapor pressure at any given temperature are more at risk than those with lower vapor pressures.

Vapor or Dust Cloud Fires

Vapors evolved from a pool of volatile liquid or gases venting from a punctured or otherwise damaged container, if not ignited immediately, will form a plume or cloud of gas or vapor that moves in the downwind direction. If this cloud or plume contacts an ignition source at a point at which its concentration is within the range of its upper and lower flammable limits, a wall of flame may flash back towards the source of the gas or vapor, engulfing anything and everything in its path. Similarly, fires may flash through airborne clouds of finely divided combustible dusts whether or not they are formally classified as hazardous materials. People or property caught within the cloud as the flame passes may be severely injured or damaged if not protected.

Liquid Pool Fires

A liquid pool fire is defined as a fire involving a quantity of liquid fuel such as gasoline spilled on the surface of the land or water. As in prior cases, primary hazards to people and property include exposure to thermal radiation and/or toxic or corrosive products of combustion. An added complication is that the liquid fuel, depending on terrain, may flow downslope from the accident site and into sewers, drains, surface waters, and other catchments. There have been cases where such fires have ignited other combustible materials in the area or have caused BLEVEs of containers subjected to the flames. On occasion, pools of burning liquids floating on water have entered water intakes of industrial facilities and caused internal fires or explosions. Burning fuels entering sewers and drains not completely full of fluid have caused underground fires and/or threatened industrial or municipal treatment facilities at the receiving end of the sewer or drain.

Flammable Solid Fires

A ***flammable solid*** is defined by the U.S. Department of Transportation as any solid material, other than one classed as an explosive, which under conditions normally incident to transportation is liable to cause fires through friction, retained heat from manufacturing or processing, or which can be ignited readily and when ignited burns so vigorously and persistently as to create a serious transportation hazard. Included in this class are spontaneously combustible and water-reactive materials.

As the above definitions suggests, the term flammable solid encompasses materials with a wide range of hazardous properties.

- Some of these solids are considered hazardous because they can be ignited by friction, much like the head of a match.
- Some are organic materials such as charcoal, powdered coal, wet paper, and even fish scrap or fish meal which may at times internally generate heat to the point of self-ignition when improperly stored or transported.
- Some are metals in the form of powders or other small pieces which can self-ignite in prolonged contact with moisture, burn at very high temperatures, and/or be difficult if not impossible to extinguish without special techniques or materials, with aluminum and magnesium being good examples.
- Some of these materials (i.e., pyrophoric substances) may ignite if exposed to air or burn vigorously in the fashion of highway flares. Phosphorus has both of these properties and also generates large quantities of toxic and irritating smoke.
- Some have several of these properties.

Fires Involving Ordinary Combustibles

Some hazardous materials, including some of the flammable solids described above, burn with no special hazards beyond those associated with paper, wood, and other common materials of everyday life. Wet paper waste, for example, is only considered hazardous because it may ignite spontaneously (i.e., self-heat and self-ignite). Once burning, it poses no special or unusual threat. This is not meant to imply that such a fire would not be significant or important to consider in planning for emergencies, only that the nature of the threat is one encountered frequently by fire service personnel and well known to them.

4.5 PRODUCTS OF COMBUSTION

Besides evolving heat and thermal radiation, fires involving certain hazardous materials may generate smoke and gases that are more toxic than those evolved from ordinary substances. In most cases, the heat of a fire will cause these products of combustion to rise into the sky where they will become diluted with air below harmful levels before reapproaching the ground surface. On occasion, however, their toxicity level may be so high as to necessitate public evacuations until the fire has been extinguished. Indeed, a 1986 incident in Ohio involving the burning of phosphorus in a railroad car required the evacuation of at least 40,000 people due to the toxic and irritating smoke generated. This was the largest evacuation associated with a train wreck in the history of the United States.

Material safety data sheets (MSDS) and other data bases and handbooks describing individual substances will typically provide a general indication of expected products of combustion or thermal decomposition. The term "general" is used because far more often than not the discussion will be rather imprecise and unlikely to highlight more than a few rather common products of combustion or decomposition.

In the case of organic materials comprised solely of carbon, hydrogen, and oxygen, products of combustion virtually always include carbon dioxide and highly toxic carbon monoxide together with water vapor and some amounts of unburned vapors of the hazardous material. Substances of low molecular weight (i.e., simple hydrocarbons and alcohols), may indeed only generate these products of combustion when burning freely in the natural environment. More complex and heavier substances, however, may generate a complicated mixture of substances, some of which may be extremely toxic. A general rule of thumb to follow is that most strictly organic materials usually pose no more hazard when burning (although the hazard may indeed be very significant) than a burning wooden home or other building. The key exception involves fires involving organic materials of high toxicity in the unburned state, with pesticides being primary examples. Fires involving such materials may be particularly hazardous not only due to toxic combustion products but due to the potential dispersion of unburned pesticides.

One can obtain a general idea of unusual products of combustion or decomposition by looking at the chemical formula for any particular hazardous material of concern, this being an item almost always given in MSDS and other safety related publications for pure materials. Some of the more common symbols used for various individual components (i.e., elements) of chemical molecules include:

Element	Chemical Symbol
Bromine	Br
Carbon	C
Chlorine	Cl
Fluorine	F
Hydrogen	H
Lead	Pb
Mercury	Hg
Nitrogen	N
Oxygen	O
Phosphorus	P
Sulfur	S

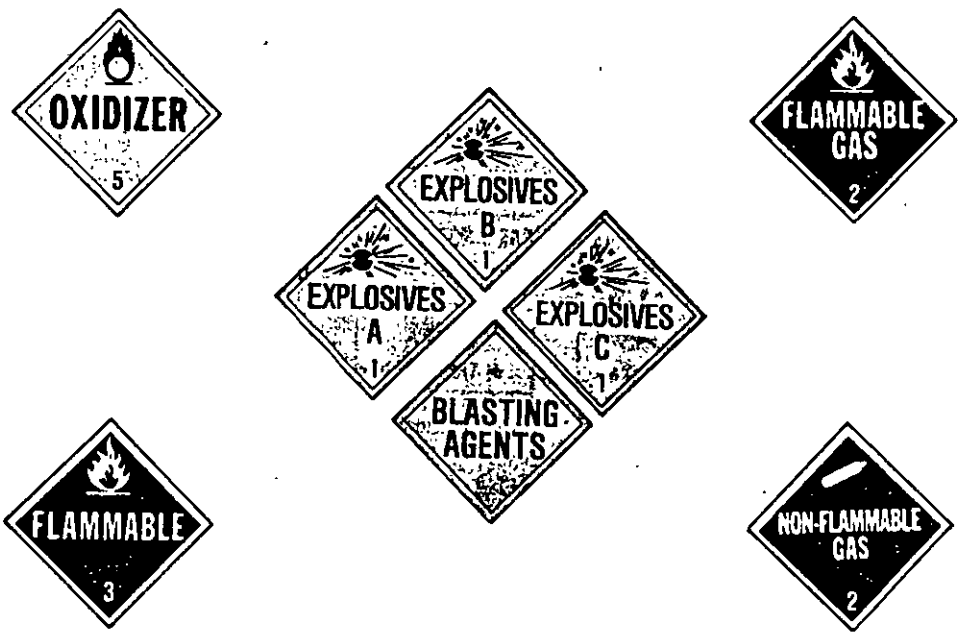
Hazardous materials containing bromine, chlorine, or fluorine, if subject to combustion or decomposition in a fire environment, may generate irritating and corrosive substances such as hydrogen bromide or hydrobromic acid, hydrogen chloride or hydrochloric acid, or hydrogen fluoride or hydrofluoric acid, and possibly gaseous bromine, chlorine or fluorine themselves. The extremely toxic substance known as phosgene may be formed in some cases when chlorine is present, particularly in combination with oxygen in the chemical molecule, so it is important to check for this possibility in MSDS and other information sources.

Both lead and mercury are well-known toxic metals that can be found as components of numerous chemical substances. Smoke or fumes from fires involving these toxic heavy metals and others (such as arsenic), must always be of concern.

Although pure nitrogen gas is non-toxic and a major component of air, chemical molecules containing nitrogen atoms may evolve toxic nitrogen oxides under fire conditions. The combination of carbon with nitrogen in a -CN group within a chemical molecule suggests that highly toxic cyanides may be generated in fires.

Dry phosphorus may ignite upon contact with air and generate thick white smoke containing phosphoric acid and phosphorus pentoxide. As noted earlier, this smoke is both highly irritating and highly toxic.

5.0 EXPLOSION HAZARDS OF CHEMICAL SUBSTANCES



5.1 DEFINITIONS

The dictionary contains two definitions of the word ***explode*** relevant to hazardous materials, these being:

- To burn suddenly so that there is violent expansion of hot gases with great disruptive force and a loud noise (in what is called a ***thermal explosion***).
- To burst violently as a result of pressure from within (in what is called a ***non-thermal explosion***).

The first definition clearly involves ignition and release of thermal energy from an explosive material or mixture while the second does not. In the following, we first discuss the conditions and factors that define the potential for both thermal and non-thermal explosions, follow with a discussion of how the effects of explosions can be measured, and then discuss the various types of explosions which meet the above criteria and which may be encountered in accidents involving hazardous materials.

5.2 FACTORS THAT INFLUENCE EXPLOSION POTENTIAL

Thermal Explosions

The definitions of lower and upper flammability limits presented earlier explained that these terms are used interchangeably with the terms lower and upper explosive limits in air. The reason for this is that a flammable mixture of a gaseous fuel in air, i.e., a mixture within the range of lower and upper flammable limit concentrations, may explode if ignited under appropriate conditions. Similarly, a cloud of combustible dust may explode if airborne concentrations are within these limits and the cloud is confined.

The set of conditions under which explosions of gases or vapors are most common involves ignition within the confined space of a building, sewer pipe, tunnel, partially empty liquid storage tank (on land or on a marine vessel), or other container. Dust explosions have frequently occurred in grain handling facilities and storage silos as well as other locations where fine combustible dusts are handled or generated.

It follows from the above that virtually all substances that are handled under conditions in which fuel-air mixtures are within explosive or flammable limits and fill a significant fraction of an enclosed space have a high probability of exploding rather than simply burning upon ignition. However, it must also be realized that gaseous mixtures may also explode at times when only partially confined or even if completely unconfined in an open environment. These latter explosions, referred to as ***unconfined vapor cloud explosions,*** often have far less power than explosions in confinement, and it has been observed that some substances have a far greater probability of exploding when unconfined than others. Nevertheless, past events have proven that unconfined explosions can occasionally cause devastating damage and widespread injuries, especially when the weight of airborne gas or vapor exceeds 1000 lbs. Below this weight, unconfined vapor cloud explosions are quite rare and typically involve a relatively few specific materials.

There also are many solids and liquids which may explode or detonate if ignited, shocked, or subjected to heat or friction, depending on their individual properties and characteristics. Some of the best known examples are TNT, dynamite, gunpowder, and nitroglycerine which may be referred to at times as ***condensed-phase*** explosives or ***high*** explosives. Determination of whether any particular liquid or solid may be explosive, and the conditions under which it may explode, requires investigation on a case-by-case basis, since there is no specific property or characteristic that sets explosives apart from other materials. Fortunately, manufacturers of these materials and hazardous material data bases and guidebooks will usually highlight the explosive properties of such materials.

The power or strength of a thermal explosion, however one wishes to express it, is a function of three primary factors:

- The amount of fuel present that is capable of exploding
- The amount of energy available in this portion of the fuel
- The fraction of the available energy (known as the ***yield***) expected to be released in the explosion process.

In simpler terms, it is understandable that two sticks of dynamite produce a larger blast than one stick, that fuel-air mixtures above or below explosive limit concentrations in air may not give additional strength to an explosion, and that some substances contain more energy per unit weight than others.

Non-thermal Explosions

The most simple type of non-thermal explosion to understand is that due to overpressurization of a sealed or inadequately vented container of some sort. Much as a balloon will burst if too much air is blown in, the walls of a sealed tank or other container may rupture violently if too much gas or liquid is forced in, if an internal chemical reaction produces excessive gases or vapors, or if a reaction or other source of heat increases the internal vapor pressure of the contents to the point that the walls are "stretched" beyond their breaking point. Since ignition and fire are not involved in the actual explosion process, these events are considered non-thermal explosions, although the contents of the container may ignite subsequent to its release if a suitable ignition source is present and the substance is flammable or combustible.

The strength of a non-thermal tank overpressurization explosion is a function of the pressure at which the walls of the container burst and the nature of the walls (i.e., whether they are ***brittle*** and will break suddenly with a "snap" or are ***ductile*** and more likely to stretch and then split or tear along some line on the surface). If the tank contains gas under pressure, the volume of the gas in the tank will also be important.

A final note is that non-thermal explosions involving compressed gases or vapors are far more likely to cause damage to distant objects than those involving liquids. This follows from the definition of shock and blast waves presented below and the relatively incompressible nature of liquids.

5.3 MEASURES OF EXPLOSION EFFECTS

When a firecracker or a stick of dynamite explodes, the violence and speed of the reactions taking place produce what is either referred to as a shock wave or a blast wave. Technically speaking, there is a difference between these two terms, but we will treat them rather interchangeably here. Either type of wave can be thought of as a thin shell of highly

compressed air and/or hot gases that rapidly expands in all directions from the point at which the explosion is initiated. Such waves can move at velocities exceeding the speed of sound in air, and, therefore, are capable of producing sonic "booms," much like those associated with supersonic aircraft. This is why significant explosions produce a loud "bang."

The damage caused by a shock or blast wave striking an object or a person is a complex function of many factors, and it is well beyond the scope of this document to attempt to describe all the complex interactions involved. Instead, we will simply refer to the wave as a rapidly expanding shell of compressed gases. The strength of the wave can then be measured in units of pressure (psi, e.g.), and the effects of ***peak overpressures*** within the wave (i.e., the maximum pressure in the wave in excess of normal atmospheric pressure) can be related to the level of property damage or personal injury likely to result.

Table 5.1 presents a list of peak overpressures and their expected effects on people and property. It is important to note that peak overpressures in a shock or blast wave are highest near the source of the explosion and decrease very rapidly with distance from the explosion site. Additionally, it must be noted that the location of the blast relative to nearby "reflecting surfaces" will influence the extent of damage incurred. For example, picture an explosion that takes place well above the surface of the ground. In this type of elevated or "free-air" event, the spherical shock wave has the opportunity to travel and dissipate in all directions simultaneously. Conversely, if the same explosion were to take place directly on the ground surface, the major portion of the energy released would only dissipate upwards and outwards. The ground surface would reflect most energy directed downward, and the net result would be a blast or shock wave with approximately twice the strength expanding from a hemi-spherical shaped volume of space situated on the ground. Hazard analysis procedures discussed in Chapter 12 and Appendix B of this guide and incorporated into the ARCHIE Computer Program therefore consider the location of an explosion relative to the ground surface. Not considered, however, are potential reflections from building walls and other surfaces that may cause actual damage patterns to be somewhat more erratic than those predicted by generalized hazard assessment methodologies for explosion events.

Beside personal injuries and property damage caused by direct exposure to peak overpressures, the blast or shock wave also has the potential to cause indirect impacts. These secondary effects of explosions include:

- Fatalities or injuries due to missiles, fragments, and environmental debris set in motion by the explosion or by the heat generated.

- Fatalities or injuries due to forcible movement of exposed people and their subsequent impact with ground surfaces, walls, or other stationary objects.

TABLE 5.1
EXPLOSION OVERPRESSURE DAMAGE ESTIMATES

Overpressure* (psig)	Expected Damage
0.03	Occasional breaking of large windows already under stress.
0.04	Loud noise (143 dB); sonic boom glass failure.
0.10	Breakage of small windows under strain.
0.15	Typical pressure for glass failure.
0.30	Some damage to house ceilings; 10% window glass breakage.
0.40	Limited minor structural damage.
0.50-1.0	Windows usually shattered; some window frame damage.
0.7	Minor damage to house structures.
1.0	Partial demolition of houses; made uninihabitable.
1.0-2.0	Corrugated metal panels fail and buckle. Housing wood panels blown in.
1.0-8.0	Range for slight to serious injuries due to skin lacerations from flying glass and other missiles.
1.3	Steel frame of clad building slightly distorted.
2.0	Partial collapse of walls and roofs of houses.
2.0-3.0	Non-reinforced concrete or cinder block walls shattered.
2.3	Lower limit of serious structural damage.
2.4-12.2	Range for 1-90% eardrum rupture among exposed populations.
2.5	50% destruction of home brickwork.
3.0	Steel frame building distorted and pulled away from foundation.
3.0-4.0	Frameless steel panel building ruined.
4.0	Cladding of light industrial buildings ruptured.
5.0	Wooded utility poles snapped.
5.0-7.0	Nearly complete destruction of houses.
7.0	Loaded train cars overturned.
7.0-8.0	8-12 in. thick non-reinforced brick fail by shearing of flexure.
9.0	Loaded train box cars demolished.
10.0	Probable total building destruction.
14.5-29.0	Range for 1-99% fatalities among exposed populations due to direct blast effects.

*These are the peak pressures formed in excess of normal atmospheric pressure by blast and shock waves.

Source:Lees,F.P, Loss Prevention in the Process Industries, Vol. 1, Butterworths, London and Boston, 1980.

The most common injuries due to missiles and the like are attributable to violent glass breakage and impact of airborne shards of glass with people. Fragments may include portions of any container that explodes and pieces of structures or equipment that are torn loose by the explosion and become airborne. Environmental debris essentially covers all else that may be forced out of place. The entire category can also be considered to encompass situations in which people are buried in the rubble of collapsed buildings or other structures.

It is very important to realize that a tank that BLEVEs or otherwise ruptures violently may break up into various fragments, one or more of which may be projected for considerable distances. Portions of cylindrical tanks have been known to literally "rocket" into the air while spewing forth burning liquids and have caused fires and impact damages upon falling back to the ground.

Where railroad tankcars or highway tank vehicles are at risk, hazardous material response guides have typically suggested that a radius of one-half mile be evacuated to prevent injuries from both fragment and thermal radiation hazards. Recent incidents have indicated, however, that individual fragments may occasionally travel as far as 4000-5000 feet from a tankcar BLEVE, and it is therefore prudent to evacuate to a radius of one mile in such cases, if this is practical. Since railroad tankcars carry 2-4 times as much cargo as typical highway tank vehicles, the one-half mile radius is ***probably*** sufficient for major truck accidents, but this is ***not*** absolutely certain for all cases.

The evacuation distances required for smaller or larger tanks than typically 3,000-12,000 gallon highway vehicles or 20,000-30,000 gallon capacity railroad tankcars will vary somewhat with the quantity of hazardous material present, but not as much as one might think. At the lower end of the scale, one major authority suggests a 1500 ft evacuation radius for situations in which an ordinary gas cylinder is involved in fire. Limited data for explosions or BLEVEs involving major stationary storage tanks do not indicate fragment hazards beyond one mile in the majority of ***known*** cases.

Where a tank or container ruptures violently due to internal overpressurization, fragment hazards are to some degree a function of whether the wall materials are brittle or ductile. Brittle materials (such as glass) may shatter into many smaller pieces. Tanks or containers made of ductile materials (such as most metals at or above relatively normal temperatures) are more likely to split or tear into a few large pieces.

Fatalities or injuries due to forcible movement of exposed people and their subsequent impact with objects quite literally involves situations in which the shock or blast wave pushes or picks up and throws bodies against obstacles.

5.4 TYPES OF EXPLOSIONS

Many of the basic types of explosions have already been described, but there are benefits in listing them again and providing more formal definitions of terms.

Container or Tank Overpressurization Explosions

As noted earlier, these events are a result of excessive pressure within a sealed tank or other container and are deemed to be non-thermal explosions. They occur when excessive pressure causes the walls of a tank or container to rupture violently, much as a balloon "pops" when too much air is blown in.

Dust Explosions

A cloud of combustible dust that is airborne and has concentrations within its upper and lower explosive limits may explode when ignited. Explosions usually occur when the dust fills most of an enclosed space of some kind.

An earlier discussion of fire hazards described how non-exploding clouds of dust in air may simply burn in a dust cloud fire that can also be referred to as a ***deflagration***. It is important to realize that there is no fine line between a deflagration and an explosion, since deflagrations are also capable of producing shock waves with measurable peak overpressures. It is usually when these overpressures become significant to the point of causing damage or injury that the event is called an explosion. It is when the shock or blast wave moves at a velocity greater than the speed of sound under the conditions present, thus being capable of causing maximum damage, that the event may be called a ***detonation***.

Gas or Vapor Explosions

As in the case of airborne dusts, a gas or vapor within flammable or explosive limit concentrations may cause a deflagration, explosion, or detonation upon ignition. These events can occur when the fuel-air mixture is confined, partially confined, or completely unconfined, but confinement of the mixture most definitely increases the probability of significant personal injury or property damage. Note that the gas or vapor may be directly released to the vulnerable environment or may evolve from evaporating or boiling liquids that have entered the area.

Condensed-Phase Explosions or Detonations

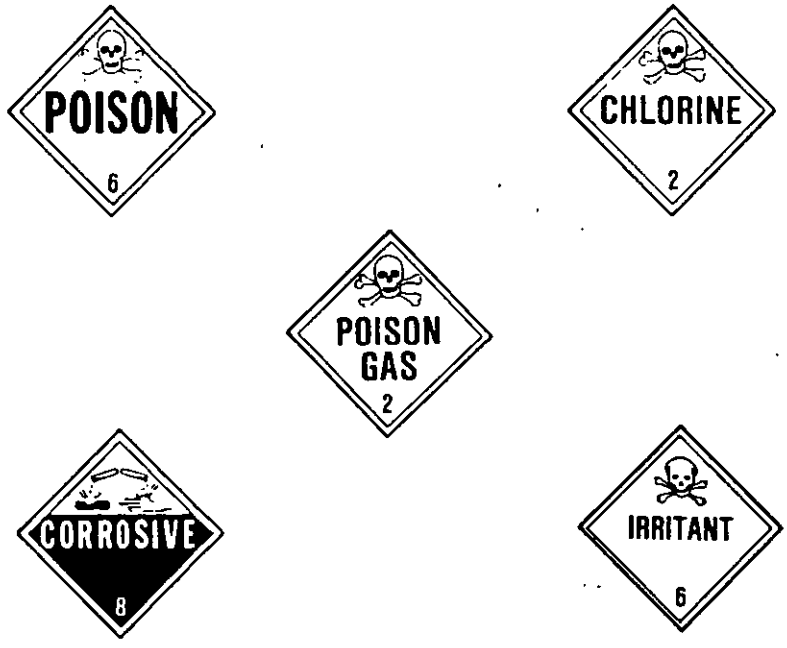
As noted above, when the substance that explodes or detonates is a liquid or a solid, the event is often called a condensed-phase explosion or detonation. Those who use this term may be prone to call events involving gases or vapors in air as ***diffuse-phase*** or ***gas-phase*** explosions or detonations.

Boiling Liquid Expanding Vapor Explosions (BLEVEs)

BLEVEs were described in some detail in the prior section discussing fire hazards of concern, where it was stated that they are not associated with strong shock or blast waves *in many cases*. Obviously, this also means that shock or blast waves with sufficient power to cause injury or damage may indeed occur at times.

Although some experts may disagree with the fine points of what is being said, BLEVEs can also be described as a combination of other types of fires and explosions. Indeed, bursting of a tank of liquid or compressed liquefied gas due to overheating is related to tank or container overpressurization explosions. Subsequent ignition of expanding gases, which may result in a large fireball, can be thought of as resulting in one type of gas or vapor cloud deflagration.

6.0 TOXICITY HAZARDS OF CHEMICAL SUBSTANCES



6.1 INTRODUCTION

Although hazardous materials can pose both short-term and possibly long-term toxicological threats to terrestrial and aquatic wildlife and plants, the immediate concern during significant discharges is protection of human life and health. Consequently, this section addresses the toxicity and toxic hazards posed to the public by chemical substances. It must be noted, however, that much of what will be presented can also be applied to understanding toxicological hazards to plants and animals.

6.2 ROUTES OF ENTRY

Toxic materials, be they solids, liquids, or gases/vapors, can affect living creatures via three primary ***routes of entry***.

- Inhalation -- the process by which irritants or toxins enter the body via the lungs as a result of the respiratory process

- Ingestion -- the process of consuming contaminated food or water or otherwise permitting oral intake of irritants or toxins

- Direct contact with skin or eyes -- the process by which hazardous materials cause injury to bodily tissues via direct contact or cause poisoning via absorption through the skin or other external tissues. Also included in this category is the passage of toxic materials into the body via puncture wounds or other breaks in the skin.

Inhalation exposures may result from breathing gases vented from containers, vapors generated from evaporating liquids (on land or in water), liquid aerosols generated during venting of pressurized liquids, fumes generated from spilled acids, gases or fumes generated by chemical reactions, dusts that become airborne due to an explosion or due to wind forces, the products of combustion of a burning hazardous material, or a variety of other mechanisms.

Ingestion (i.e., oral) exposures may follow from poor hygiene practices after handling of contaminated materials or from ingestion of contaminated food or water. Ingestion may also occur following inhalation of insoluble particles that become trapped in mucous membranes and swallowed after being cleared from the respiratory tract.

Direct contact may result from exposures to hazardous gases, liquids or solids in the environment, either on land, in the air, or in water. Effects may be local and involve irritation or burns of the skin or eyes or involve poisoning via absorption through external bodily tissues.

The fact that a toxic chemical can cause harm by inhalation, ingestion, or irritation or burning of the skin or eyes is probably well appreciated by most people. Poisoning due to absorption through external bodily tissues, however, is not as well known a hazard and benefits from further explanation.

In simple terms, there are various specific gases, liquids, and even solid materials which have the capability of passing through the skin or tissues of the eyes at various rates upon contact. Those that are highly toxic and which penetrate the body rapidly are the most hazardous. Those that penetrate slowly or which are of relatively low toxicity may require long term contact with large parts of the body to cause significant effects. Although some materials may give some warning that contact has occurred by causing some sort of burning sensation, others may give little or no warning to the victim.

While on this topic, it is also worthwhile to consider the commonly accepted meaning of phrases like ***high toxicity*** and ***low toxicity***. When one speaks of a material that is of high toxicity, it generally means that relatively small quantities may cause significant health effects upon inhalation, ingestion, and/or direct contact. Conversely, a low toxicity substance generally requires larger amounts to be inhaled, ingested, or contacted for an equally significant adverse health effect. It is therefore well to always remember that a large quantity

of a low toxicity material may present the same or greater ***toxic hazard*** to a community or individual than a much smaller quantity of a highly toxic material. It is also necessary to understand that the toxicity of a material is only one of several factors to be considered in determining the toxic hazard posed by the material. These concepts are reiterated and discussed in further detail in a later section.

6.3 TYPES OF TOXIC EFFECTS

Most toxic substances can be classified as irritants, asphyxiants, anesthetics and narcotics, systemic poisons, sensitizers, carcinogens, mutagens, and/or teratogenic substances. Systemic poisons may be further disaggregated into the categories of hepatotoxic agents, nephrotoxic agents, neurotoxic agents, agents which act on the blood or hematopoietic system, and agents which damage the lung.

Many of these terms may be unfamiliar because they are mostly used in the medical/public health community and among toxicologists. Fortunately, they need not all be memorized because most hazardous material data bases and guides, material safety data sheets, and manufacturers' product bulletins generally "translate" the effects of toxic materials upon the body into more common language. There are, however, certain terms and expressions that appear frequently and which can be helpful in understanding the most common effects of toxic materials upon the body.

Irritants

Irritants are substances with the ability to cause inflammation or chemical burns of the eyes, skin, nose, throat, lungs, and other tissues of the body in which they may come in contact. Some substances such as strong acids (e.g., sulfuric acid, oleum, chlorosulfonic acid, hydrochloric acid, hydrofluoric acid, or nitric acid) may be irritating to the point of being corrosive when concentrated, and may quickly cause second or third degree chemical burns upon contact with the skin or eyes. If inhaled as a gas, vapor, fume, mist, or dust, they may cause severe lung injury, and if ingested, can seriously damage the mouth, throat, stomach, and/or intestinal tract. Yet other irritants may have milder effects and may only cause reddening of the skin or eyes after contact.

Some of the most common irritants are organic solvents or hydrocarbon fuels which can dissolve natural oils in the skin and cause ***dermatitis***. After repeated or prolonged contact, these will dry the skin to the point that it may become cracked, inflamed and possibly infected. These same materials often cause irritation of the eyes and possibly loss upon contact of the corneal epithelium, a clear thin membrane that covers the surface of the cornea. Although the effect is temporary, since the epithelium will usually regrow in a few days, some data sources may refer to the effect as a "corneal burn."

Entry into the lungs of many liquid hydrocarbons and some organic liquids that are irritants may cause chemical ***pneumonia*** or ***pneumonitis*** together with ***pulmonary edema*** (filling of the lungs with fluid), hemorrhage, and tissue ***necrosis*** (i.e., death of living tissue). Since entry of liquids into the lungs usually involves ***aspiration*** when a victim who has accidentally ingested the substance vomits, the first aid instructions for such substances typically recommend against intentional inducement of vomiting. They also are likely to mention that the effects of aspiration into the lungs may not appear for several hours or even days after the exposure has taken place.

Asphyxiants

Simple asphyxiants are typically non-toxic gases that may cause injury by inhalation only if they are present in air in such high concentrations that they displace and exclude the oxygen needed to maintain consciousness and life. A good example is nitrogen, a gas that makes up about 78% of the air we breathe and which is perfectly harmless at this level as a component of air. If additional nitrogen or another such simple asphyxiant were added to the air to the point that the normal oxygen concentration of approximately 21 percent by volume was significantly reduced, however, the situation could become life-threatening. Tables 6.1 and 6.2 illustrate the effects of oxygen depletion on the body and the four stages of asphyxiation.

Chemical asphyxiants are substances that in one way or another prevent the body from using the oxygen it takes in and are often highly toxic substances. One classic example is carbon monoxide which combines with and "ties up" the component of blood (hemoglobin) that transports oxygen from our lungs to other organs. If too much of the hemoglobin becomes unavailable for carrying oxygen, a person may pass out and eventually die. Other examples are among the family of cyanides (i.e., substances which have a -CN, carbon-nitrogen, combination in their molecule and which somewhere in their names have the word "cyanide" or the letter combinations "cyan" or "nitrile"). These act by interfering with the action of the enzymes necessary for living tissues to use available oxygen, thus resulting in a condition referred to as ***cyanosis***.

Anesthetics and Narcotics

Numerous hydrocarbon and organic compounds classified as hazardous materials, including some alcohols, act on the body by ***depressing*** the ***central nervous system*** (CNS). Early symptoms of exposure to these substances include dizziness, drowsiness, weakness, fatigue, and incoordination. Severe exposures may lead to unconsciousness, paralysis of the respiratory system, and possibly death.

TABLE 6.1 EFFECTS OF OXYGEN DEPLETION	
Percent of Oxygen In Air	**Symptoms**
20	Normal
17	Respiration volume increases, muscular coordination diminishes, attention and clear-thinking requires more effort.
12 to 15	Shortness of breath, headache, dizziness, quickened pulse, efforts fatigue quickly, muscular coordination for skilled movements lost.
10 to 12	Nausea and vomiting, exertion impossible, paralysis of motion.
6 to 8	Collapse and unconsciousness occurs.
6 or below	Death in 6 to 8 minutes.

Source: Kimmerle, George, "Aspects and Methodology for the Evalution of Toxicological Parameters During Fire Exposure," ***JFF/Combustion Toxicology***, Vol. 1, February, 1974.

TABLE 6.2 FOUR STAGES OF ASPHYXIATION	
1st Stage:	21-14% oxygen by volume, increased pulse and breathing rate with disturbed muscular coordination.
2nd Stage:	14-10% oxygen by volume, faulty judgment, rapid fatigue, and insensitivity to pain.
3rd Stage:	10-6% oxygen by volume,nausea and vomiting, collapse,and permanent brain damage.
4th Stage:	Less than 6% by volume, convulsion, breathing stopped, and death.

Source: Cryogenics Safety Manual, British Cryogenics Council, London, 1970

Sensitizers

A few hazardous materials are ***sensitizers*** and cause ***sensitization***. What this means is that some people who are exposed to one of these materials may not be abnormally affected the first time, but may experience significant and possibly dangerous effects even in the presence of very low levels of the contaminant if ever exposed again. In simple terms, victims become extremely allergic to the material and possibly others of a similar nature.

Other Types of Toxic Agents

- ***Hepatotoxic agents*** are materials that cause liver damage.
- ***Nephrotoxic agents*** are materials that cause kidney damage.
- ***Neurotoxic agents*** are substances that in one way or another impact the nervous system and possibly cause neurological damage.
- ***Carcinogens*** are substances that may incite or produce cancer within some part of the body.
- ***Mutagens*** can produce changes in the genetic material of cells.
- ***Teratogenic materials*** may have adverse effects on sperm, ova, and/or fetal tissue.

Note: Besides the chemical asphyxiants described above, there are other substances that in one way or another act on the blood or the hematopoietic system (i.e., bone marrow). Inhalation of free silica or asbestos over a period of time can cause changes in lung tissue with serious health consequences. Yet other toxic substances also have unusual or unique effects on human health.

6.4 ACUTE VS. CHRONIC HAZARDS

The majority of industries and many common daily activities of life utilize equipment, processes, and materials that continuously or intermittently discharge toxic materials into the occupational and/or natural environment. Some workers may be exposed to such materials 8 hours per day, 5 days per week or so, over a large part of their careers. Similarly, the general public may be exposed to various contaminants continuously or intermittently. Such exposures are said to be of a ***chronic*** nature and usually but not always involve low concentrations of contaminants in air, food, water, and/or soil.

When a major accident or other rare event causes a significant spill or discharge of a toxic material into the environment, the general public or nearby workers may be exposed to relatively high levels of one or more toxic contaminants until such time as they escape or are rescued from contaminated locations or the contaminant becomes diluted below hazardous levels. These short-term, rare exposures (in the sense there will be long periods of time between repeated exposures if they reoccur at all) are referred to as ***acute*** exposures. Not all acute exposures, of course, need involve high concentrations of toxic materials. A small spill or discharge may produce low levels of contamination yet still be of an acute nature.

To be noted is that many chemicals will not persist for long periods of time in the environment, or at least in those parts of the environment of concern, while others may remain present for weeks, months, or even years. The former materials include substances that may be digested by bacteria (i.e., which are ***biodegradable***), substances that will undergo various reactions with materials in the environment that render them harmless, or those that become so diluted in air or water that they no longer present a hazard. Examples are simple alcohols that may be digested by bacteria in soil or water much as humans drink and digest alcoholic beverages, as well as volatile materials which evaporate and are swept away into the vast ocean of air above us. Such materials are unlikely to pose long-term chronic hazards in the event of a major spill or discharge in most cases. Alternatively, toxic substances which are relatively inert and which do not degrade, react, vaporize, or dissolve freely may pose health hazards for extended periods of time within a localized environment and may require additional planning to address long-term ***chronic*** exposure hazards to the public. Examples include heavy metals and various chlorinated hydrocarbons such as DDT, trichloroethylene, and PCBs.

6.5 IMPORTANCE OF EXPOSURE LEVEL AND DURATION

In considering the effects of toxic exposures, it is necessary to understand that the duration of an exposure can be as important as the level of exposure in determining the outcome. This follows from the observations that:

- The body has a capacity to cope with the intake of many contaminants at a certain rate. Below a certain *threshold* rate of intake or absorption which can be counterbalanced by the body's ability to excrete or somehow convert the contaminant to a harmless substance, toxic effects may be minimal or non-existent. For example, note that arsenic is commonly found in all human bodies at low levels. It is only when the level exceeds the safe threshold due to excessive intake that symptoms of toxicity become apparent.

- The rate at which a contaminant enters the body by inhalation is a function of the concentration of the contaminant in the air being breathed, the rate of breathing, the length of time the body remains within a volume of contaminated air, and the specific properties of the contaminant. Higher concentrations in air obviously lead to higher rates of intake or absorption into bodily tissues.

- The potential for toxic effects via skin absorption is a function of the amount of toxic material that contacts the body, the properties of the material, and the length of time it is permitted to remain in contact.

- Toxic effects via ingestion can also be a function of the amount or rate of intake over a period of time. Small doses of certain poisons ingested hours or days apart may not be harmful, but taking the total amount all at once may be deadly. Other poisons may accumulate in the body such that small doses taken over time may buildup to a fatal dose.

The reason that chronic exposure to low levels of toxic materials commonly found in the environment does not often cause widespread health problems is that the rate of intake is below the *threshold* at which health effects become apparent. Conversely, major spills or discharges of toxic materials may pose a significant threat to public health because the resulting contaminant concentrations in the local area may be so high that only a moment or two of exposure is sufficient to produce severe health problems due to an excessive ***body burden*** of contamination. This is particularly true where large amounts of toxic gases or vapors are released into the air. Relatively few members of the general public are ever harmed by direct contact with toxic materials, since most individuals have the common sense not to touch or go walking through spilled chemicals and will cleanse themselves promptly if such contact is made. Similarly, few people are likely to drink potentially contaminated water or eat contaminated food once warned of the possibility of contamination. Most at risk in such situations are emergency response personnel who enter contaminated areas without adequate personnel protective clothing and respiratory devices in attempts to contain or otherwise mitigate the impacts of the spill.

6.6 TOXICITY VS. TOXIC HAZARD

The observations above naturally lead to a further discussion of the difference between the ***toxicity*** of a substance and the ***toxic hazard*** it poses to the public. This is an extremely important concept because materials of high toxicity are often assumed to pose a severe toxic hazard regardless of the other properties of the material and the circumstances surrounding its spillage.

Imagine a one ton discharge of two different materials. The first is an extremely toxic, non-volatile solid material that has spilled in the middle of a street in a densely populated metropolis. The material is so extremely toxic that only 10 pounds would be sufficient to kill 100,000 people by ingestion if somehow introduced into their food in equal portions. The second discharge involves an overturned tank truck on the same street that has just released a very common compressed liquefied gas that is considered to be of moderate toxicity. As it boils and vaporizes upon release, the ton of liquid may become as much as 30,000 cubic feet or more of pure gas. If it were to mix uniformly with air and happened to be deadly in very short-term exposures at a concentration of 5,000 ppm in air, the potentially lethal cloud spreading over the city would conceivably have a total volume of 6 million cubic feet.

On a strictly weight basis, the solid material may be many thousands of times more toxic than the gas, but is unlikely to poison members of the public just a short distance away because it lacks mobility. Thus, the solid must be carefully handled and removed from the scene, but actually poses a relatively low toxic hazard to the public. Authorities may wish to evacuate the immediate spill area and cover the solid with plastic sheeting to prevent any dust from becoming airborne until its careful recovery, but the risk of fatalities among the general public will be low in most cases.

The situation with the lower toxicity liquefied gas poses a greater toxic hazard because the gas will quickly spread over downwind areas. The gas may prove rapidly fatal to people near the spill site and cause toxic effects among many hundreds or thousands of others in the downwind direction.

The *moral* of this story is that the toxic hazard posed by a material is not a sole function of its toxicity. One must always consider the amount of material present or spilled, the properties of the substance, and the opportunity it has to affect the population in its vicinity.

6.7 RECOGNIZED EXPOSURE LIMITS FOR AIRBORNE CONTAMINANTS

It should be fairly clear by this point that discharges of gases and vapors into the atmosphere generally pose greater toxic hazards to people than discharges of non-volatile materials. As is widely appreciated, one of the key tasks in planning for hazardous materials emergencies involves preparations for identifying, notifying, evacuating, sheltering, or otherwise protecting populations that may be exposed to such gases and vapors.

Achievement of the above goal requires planning personnel to select the airborne concentration in air that can be tolerated by exposed populations while toxic vapors or gases remain in the immediate area, since it is this concentration that will determine the boundaries of the hazard zone. This, in turn, requires knowledge of the source and nature of commonly

available and accepted exposure limits for airborne contaminants as well as their various advantages and disadvantages for the intended use. Primary data sources to be considered include:

- ACGIH Threshold Limit Values (TLVs)
- OSHA Permissible Exposure Limits (PELs)
- AIHA Workplace Environmental Exposure Limits (WEELs)
- NIOSH Immediately Dangerous to Life or Health Levels (IDLHs)
- AIHA Emergency Response Planning Guidelines (ERPGs)
- NAS/NRC Emergency Exposure Guidance Levels (EEGLs) and Short-term Public Emergency Guidance Levels (SPEGLs)

ACGIH TLVs

The American Conference of Governmental Industrial Hygienists (ACGIH) formed a committee in 1941 to review available data on toxic compounds and to establish exposure limits for employees working in the presence of airborne toxic agents. The committee continues to this day to publish an annual list of several hundred compounds and recommended exposure limits in a booklet titled ***Threshold Limit Values and Biological Exposure Indices***. Copies of the latest edition were available for $5 in late 1988 from the ACGIH at 6500 Glenway Ave., Bldg D-7, Cincinnati, Ohio 45211 or (513) 661-7881.

The primary purpose of the exposure limits adopted by the ACGIH is to protect healthy male workers in ***chronic*** exposure situations and the ACGIH specifically notes that "*These limits are **not** fine lines between safe and dangerous concentrations nor are they a relative index of toxicity, and **should not** be used by anyone untrained in the discipline of industrial hygiene.*" Nevertheless, the information provides valuable guideposts for identifying exposure limits that will usually be decidedly safe for short-term acute exposures.

Exposure limits established and published by the ACGIH are of several different types and include:

- ***Threshold Limit Value - Time Weighted Average*** (TLV-TWA): The time weighted average concentration for a normal 8-hour workday and a 40-hour workweek, to which nearly all workers may be repeatedly exposed, day after day, without adverse effect.

- ***Threshold Limit Value-Short Term Exposure Limit*** (TLV-STEL): A time-weighted average concentration to which workers *should not* be exposed for longer than 15 minutes and which should not be repeated more than four times per day, with at least 60 minutes between successive exposures. This limit supplements the TLV-TWA where there are recognized acute effects from a substance whose toxic effects are primarily of a chronic nature. STELs are recommended only where toxic effects have been reported from high short-term exposures in either humans or animals.

- ***Threshold Limit Value-Ceiling*** (TLV-C): The concentration in air that should not be exceeded during any part of the working exposure. Ceiling limits may supplement other limits or stand alone.

In addition to the above limits, the ACGIH occasionally enters the notation "skin" after listed substances. This notation indicates the potential for absorption of the substance through the skin, eyes, or other membranes and the possibility that such absorption may contribute to the overall exposure. An excessive amount of absorption may invalidate any TLV limit; a high potential for direct contact with the substance may suggest the need for special protective measures.

For many of the materials with an assigned TLV-TWA, the ACGIH could not find sufficient toxicological data to establish a TLV-STEL. For these substances, it recommends "*Short-term exposures should exceed three times the TLV-TWA for no more than a total of 30 minutes during a work day and under no circumstances should they exceed five times the TLV-TWA, provided that the TLV-TWA is not exceeded*" for the 8-hour workday. The airborne concentrations derived from this recommendation are referred to as ***excursion limits***.

OSHA PELs

The Occupational Safety and Health Administration (OSHA) within the U.S. Department of Labor is responsible for the adoption and enforcement of standards for safe and healthful working conditions for men and women employed in any business engaged in commerce in the United States. When first established in the early 1970's, OSHA essentially adopted the then current ACGIH TLV-TWAs and TLV-Cs as occupational exposure limits and made them official federal standards. Instead of calling the limits Threshold Limit Values, however, it referred to them as ***Permissible Exposure Limits*** (PELs). As in the case of TLVs, there are both time-weighted average (TWA) and ceiling (C) values for various materials as well as occasional peak values for shorter time periods. While the ACGIH reviews and frequently revises its TLVs on an annual basis, OSHA did not similarly update

its PELs except for a relatively small number of individual substances until early 1989 when it lowered the PELs for 212 widely used chemicals, adopted new PELs for 164 substances not previously regulated, and reaffirmed the PELs for 52 materials.

PELs are formally listed in Title 29 of the Code of Federal Regulations (CFR), Part 1910, Subpart Z, General Industry Standards for Toxic and Hazardous Substances. An inexpensive and valuable source of current PELs and much other information on chemical hazards is the ***NIOSH Pocket Guide to Chemical Hazards*** published by the National Institute for Occupational Safety and Health, a part of the U.S. Department of Health and Human Services. When in stock, single copies may be available at no cost from NIOSH Publications, 4676 Columbia Parkway, Cincinnati, Ohio 45226 (Telephone: 513-533-8287). Copies are otherwise available at nominal cost as DHHS (NIOSH) Publication No. 85-114 from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402 or one of the many regional branches of the GPO. Be advised, however, that it may take some time for NIOSH to update the currently available guide with the new PELs.

Besides PELs and a wide variety of other valuable information, the pocket guide includes the IDLH values described below.

AIHA WEELs

The American Industrial Hygiene Association (AIHA) has established a committee to develop ***Workplace Environmental Exposure Levels*** (WEELs) for toxic agents which have no current exposure guidelines established by other organizations. Essentially, the committee is attempting to establish occupational exposure limits for materials not addressed by the ACGIH or OSHA but of interest to various segments of industry. A separate guide providing documentation is being prepared for each substance.

There are two WEEL limits for most materials. The first is an 8-hour TWA value similar in concept to ACGIH TLV-TWA values. The second, which is only available in a limited number of cases, is a short-term TWA for exposures of either 1- or 15-minute duration. As of October of 1988, WEELs were available for 33 materials. Non-members prices were $5 for each individual guide and $125 for the entire set (plus shipping and handling).

The WEEL guides are available from AIHA Publications, 475 Wolf Ledges Parkway, Akron, Ohio, 44311-1087 (Telephone: 216-762-7294). A price list and order form are available at no charge.

NIOSH IDLHs

NIOSH defines ***Immediately Dangerous to Life or Health*** (IDLH) levels as the maximum airborne contaminant concentrations *"from which one could escape within 30 minutes without any escape-impairing symptoms or any irreversible health effects."* Not surprisingly, given that these limits are for 30-minute exposures under what are essentially emergency conditions, IDLH values generally far exceed corresponding TLVs or PELs. They are available in the pocket guide referenced above for most substances currently regulated by OSHA.

NAS/NRC EEGLs and SPEGLs

The Committee on Toxicology of the National Research Council (NRC), an operating arm of the National Academy of Sciences (NAS), has published a list of ***Emergency Exposure Guidance Limits*** (EEGLs) and ***Short-term Public Emergency Guidance Levels*** (SPEGLs) as guidance in advance planning for the management of emergencies. Although the Committee has been adding toxic substances to the list on a periodic basis, the careful attention to detail and thoroughness of its work has resulted in EEGLs being established for relatively few materials to date. Table 6.3 lists those available as of late 1988.

SPEGLs are concentrations whose occurrence is expected to be rare in the lifetime of any one individual. These values, of which there are only four in the table, *"reflect an acceptance of the statistical likelihood of a nonincapacitating reversible effect in an exposed population while avoiding significant decrements in performance"*. They are concentrations considered acceptable for public exposures during emergencies.

EEGLs differ from SPEGLs in that they are intended to apply to defined occupational groups such as military or space personnel rather than the general public. Because these groups are typically younger and healthier, the EEGL for any particular substance may differ substantially from the SPEGL.

Further information on these exposure limits and levels may be obtained by writing the National Academy of Sciences, Committee on Toxicology, 2101 Constitution Avenue, Washington, D.C., 20418 to the attention of Dr. Bakshi. Note that the Committee plans to have completed work on trichloroethylene and lithium chromate by early 1989 if not sooner.

AIHA ERPGs

Several major chemical companies formed a task force in 1986 to develop ***Emergency Response Planning Guidelines*** (ERPG) values for selected toxic materials. The results of their joint efforts are being published by the AIHA and are available from the publication office cited earlier. As of late 1988, guidelines had been completed for 10 substances

TABLE 6.3
SUMMARY OF EMERGENCY EXPOSURE GUIDANCE LEVELS FROM THE NATIONAL RESEARCH COUNCIL

Chemical	60-Minute EEGL (ppm)	Chemical	60-Minute EEGL (ppm)
Acetone	8,500	Dichlorofluoromethane (Freon-21)	100
Acrolein	0.05	Dichlorotetrafluoromethane (Freon-114)	10,000
Aluminum oxide	15 mg/m³	1,1-Dimethylhydrazine	0.24*
Ammonia	100	Ethanolamine	50
Arsine	1.0	Ethylene oxide	20 (proposed)
Benzene	1000 (proposed)	Ethylene glycol	40
Bromotrifluoromethane	25,000	Fluorine	7.5
Carbon disulfide	50	Hydrazine	0.12
Carbon monoxide	400	Hydrogen chloride	20
Chlorine	3	Hydrogen chloride	1*
Chlorine trifluoride	1	Hydrogen sulfide	10 (24 hr)
Chloroform	100	Isopropyl alcohol	400
Dichlorodifluoromethane (Freon-12)	10,000	Lithium bromide	15 mg/m³

Note: Units in parts per million by volume in air unless otherwise stated.
*SPEGL (Short-term Public Emergency Guidance Levels)

TABLE 6.3 (Continued)
SUMMARY OF EMERGENCY EXPOSURE GUIDANCE LEVELS
FROM THE NATIONAL RESEARCH COUNCIL

Chemical	60-Minute EEGL (ppm)	Chemical	60-Minute EEGL (ppm)
Mercury vapor	0.2 mg/m³ (24 hr)	Sodium Hydroxide	2 mg/m³
Methane	5,000 (24 hr)	Sulfur dioxide	10
Methanol	200	Sulfuric acid	1 mg/m³
Monomethyl hydrazine	0.24*	Toluene	200
Nitrogen dioxide	1*	Trichlorofluoromethane (Freon-11)	1,500
Nitrous oxide	10,000	Trichlorotrifluoroethane (Freon-113)	1,500
Ozone	1	Vinylidene chloride	10 (24 hr)
Phosgene	0.2	Xylene	200

Note: Units in parts per million by volume in air unless otherwise stated.
*SPEGL (Short-term Public Emergency Guidance Levels)

including ammonia, chlorine, chloroacetyl chloride, chloropicrin, crotonaldehyde, diketene, formaldelhyde, hydrogen fluoride, perfluoroisobutylene, and phosphorous pentoxide. Published in two sets of five, the first set costs $7 while the second is priced at $11.

As in the case of NAS/NRC efforts, the task force is attempting to define toxic exposure limits suitable for use in advance planning for emergencies. It ultimately wishes, however, to address a much greater number of chemicals than those considered to date by the NAS/NRC.

The task force intends to establish three limits for each material, these being:

- **ERPG-3**: The maximum airborne concentration below which, it is believed, nearly all individuals could be exposed for up to one hour without experiencing or developing life threatening health effects.

- **ERPG-2**: The maximum airborne concentration below which, it is believed, nearly all individuals could be exposed for up to one hour with out experiencing or developing irreversible adverse or other serious health effects or symptoms which could impair an individual's ability to take protective action. This particular limit is being developed using criteria similiar to those applied by the NAS/NRC.

- **ERPG-1**: The maximum airborne concentration to which nearly all individuals could be exposed for up to one hour without experiencing or developing health effects more severe than sensory perception or mild irritation, if relevant.

6.8 ADVANTAGES AND DISADVANTAGES OF VARIOUS LIMITS

A key problem of using TLV, PEL, or WEEL values in the course of evacuation planning or hazard assessment is that they are intended for use in the occupational environment where presumably healthy workers are exposed to concentrations near these limits day after day throughout their careers. This, and the desire to prevent health effects associated with both acute and chronic exposures, means that these values are often (but not always) much lower than what they need be to protect the public from exposures associated with rare or infrequent spills of brief duration. Consequently, use of a TLV, PEL, or WEEL value, although decidedly safe in the vast majority of cases, could conceivably result in major overprediction of downwind evacuation or hazard zones in many situations. Key exceptions involve materials such as chlorine, acids, caustics, and other generally corrosive materials for which limits are based on irritant rather than toxic effects and for which applied safety factors may be minimal.

NIOSH IDLH limits are considerably higher, are defined for an exposure duration closer to what would be expected in many actual short-term spill emergencies, and are closer to the borderline between levels that are barely tolerable and those that may cause significant injury. The problem is that "barely tolerable" contaminant concentrations may have the potential to cause considerable irritation or other distress, possibly to the point of prompting large numbers of people to seek medical assistance. Also, since NIOSH is again assuming that healthy workers are being exposed, IDLH concentrations may have the potential to cause significant injury to young children, the elderly, or individuals with preexisting health problems. Consequently, it is apparent that a safety factor must be applied if the IDLH is used in any way for protection of the general public, especially if exposures exceed 30 minutes in duration.

The NAS/NRC SPEGLSs and AIHA ERPG-2 values are possibly the best choice among currently available guidelines for protection of the public during relatively short-term events given the objectives of their respective developers. Unfortunately, only a small number of hazardous materials have been addressed to date.

Overall, the above discussion might seem to suggest there is no widely accepted method available for selection of an appropriate exposure limit for general populations subjected to toxic vapors or gases, particularly where the exposure limit is to be used for public emergency planning purposes. That is indeed (and unfortunately) an accurate appraisal of the current situation. So what should you do? Some *options*, in order of decreasing preference, and by no means mandatory for use, are as follows:

- Use the NAS/NRC SPEGL or the AIHA ERPG-2 value for the material if one has been established.

- Consult a toxicologist or similarly qualified individual for advice based on a formal review of the toxicity of the material of concern.

- Use the highest value among the following:

  - IDLH value divided by 10 (with "10" being a safety factor)
  - TLV-STEL
  - TLV-TWA multiplied by 3 (if a TLV-STEL does not exist)
  - TLV-C

- If the evacuation of additional areas is not a problem, or the exposure may be prolonged beyond one hour, use the TLV-TWA or the TLV-C value or apply an additional safety factor to other selections.

The above suggestions should not be considered more than rough guidelines that will generally lead to an adequately "safe" answer for most members of a community. There is, however, one more problem to consider.

The chronic exposure limits for substances known or suspected to be carcinogens are usually set at very low levels to protect workers from developing cancer during their lifetimes. Such values are generally many times (possibly several hundred times) lower than the limits enforced for the same materials prior to the discovery of a potential cancer threat. For example, the TLV-TWA for vinyl chloride is now 5 ppm whereas it was 200 ppm for many years, yet even 200 ppm is well below any concentration causing observable health effects in short-term *acute* exposures. Obviously, the size of the evacuation or hazard zone for a 5 ppm limit would be many times larger than a zone with boundaries of 200 ppm. The difference in the numbers of people that may require evacuation or other protective action may differ by thousands if not tens of thousands in urban areas.

There is no hard evidence that a single exposure to a substance such as vinyl chloride will cause excess cancers in a population of exposed humans. However, some scientists are of the opinion that *any* exposure might lead to at least a minor increased risk of such cancers, and this belief poses a dilemma during planning for evacuations, especially given the public fears that may naturally accompany the announcement that a cancer-causing agent has been released into the atmosphere. It is therefore necessary for government and industry to consider cases involving carcinogens carefully and on a case-by-case basis, giving full attention to the safety issues involving large-scale evacuations as well as the potential long-term health, political, and legal implications of their decisions.

6.9 RELATIONSHIP OF RECOMMENDATIONS TO EPA LOCs

Under the Superfund Amendments and Reauthorization (SARA) Act of 1986, the U.S. Environmental Protection Agency (EPA) established a list of several hundred Extremely Hazardous Substances (EHS) subject to emergency planning, community right-to-know, hazardous emissions reporting, and emergency notification requirements. In providing guidance to planning personnel for screening and prioritizing threats posed by EHS, the EPA made a first attempt at specifying what it termed Levels of Concern (LOCs) for these substances, essentially adopting portions of the approach recommended above.

For the 390 or so substances for which NIOSH has established IDLH levels, the EPA set LOCs to one-tenth of available IDLHs until such time as industry and government develop more appropriate exposure limits for protection of the public during episodic short-term emergencies. For substances for which IDLHs had not been established, the EPA developed a highly approximate procedure to estimate LOCs comparable to IDLHs. Essentially, IDLHs were estimated for new substances via use of data obtained from

laboratory experiments involving acute exposures of animals to toxic substances. Inhalation data were used in preference to data for other routes of exposure when available, but data for other routes of exposure were indeed used when necessary. The following equations were then applied to convert available data to airborne concentrations presumably comparable to IDLHs.

1) Estimated IDLH = LC_{50} x 0.1
2) Estimated IDLH = LCLo
3) Estimated IDLH = LD_{50} x 0.01
4) Estimated IDLH = LDLo x 0.1

The abbreviations used above for lethal concentrations and dosages are defined and described in Section 6.12 of this chapter. Please note that the above discussion only provides a general overview of the EPA's general approach and should not be applied in an indiscriminate fashion.

6.10 CONSIDERATION OF MIXTURES OF HARMFUL GASES AND VAPORS

Preceding discussions have focused on relatively pure substances. As is well appreciated, however, many materials handled by industry are multi-component mixtures. It is well therefore to discuss how to determine appropriate toxic limits for mixtures via a review of *traditional* guidance found in the literature.

The ACGIH, in an appendix to its TLV booklet, reports that one of the first tasks in looking at mixtures is a determination of whether mixture components have ***additive*** or ***independent*** effects on the human body. In other words, when two or more toxic agents in a mixture act upon the same organ system, it is their combined or additive effect rather than their individual effects that should be given primary consideration, and indeed, this is the preferred approach in the absence of specific information to the contrary. Where toxicological data firmly support a finding that the chief effects of the different substances are not in fact additive (in the sense that they produce purely local effects or affect different organs of the body), it is only then acceptable to assume that adverse effects are independent.

Where effects are evaluated as being additive, the ACGIH suggests that the sum of the following fraction be computed:

$$\text{Sum} = \frac{C_1}{T_1} + \frac{C_2}{T_2} \cdots \frac{C_n}{T_n}$$

where: C_n indicates the measured or predicted atmospheric concentration, T_n indicates the corresponding toxic limit in the same units as C_n, and there are "n" number of toxic substances in the mixture.

When the **Sum** of the fractions equals 1.0 or less, then the vapor mixture is considered to be at or below the toxic limit. In those cases where all components of a mixture are deemed to produce independent effects, the toxic limit is considered to be exceeded only when one or more of the individual C_n / T_n fractions has a value greater than one.

To be noted is that ***synergistic*** action or ***potentiation*** may occur with some combinations of toxic agents: these being cases in which the combined effect of the mixture actually exceeds the impact indicated by assumption of additive effects. Such cases, which are fortunately rather rare, must be considered on a case-by-case basis.

When the source of airborne contamination is a liquid mixture, the ACGIH suggests (to its typical audience of industrial hygienists and other occupational health personnel) that the composition of the airborne mixture be assumed similar to the composition of the original liquid mixture. In effect, this results in the further assumption that all components of the mixture will evaporate at a constant rate in direct proportion to their concentration in the liquid mixture. The assumption has merit when one in interested in evaluation of a relatively long-term time-weighted average exposure resulting from a mixture that will eventually evaporate in its entirety, but has severe limitations when applied to the assessment of acute exposures resulting from accidental and episodic events. It is well, nevertheless, to present the ACGIH's general methodology for estimating the toxic limit of a liquid mixture of this type, this being:

$$\text{Toxic Limit (mixture)} = \frac{1.0}{\frac{F_1}{C_1} + \frac{F_2}{C_2} \cdots \frac{F_n}{C_n}}$$

where: F_n indicates the weight fractions of individual components in the liquid mixture, and C_n indicates the corresponding toxic limits in units of mg/m^3.

A more formal approach to determining the airborne mixture toxic limit for evaporating or boiling pools of liquid requires consideration of vapor-equilibrium factors beyond the scope of this text. Nevertheless, where needs for a more precise limit are critical, it is desirable to apply more sophisticated analytical procedures to evaluate vapor compositions above liquid mixtures or to make direct measurements of representative samples. The procedures for such efforts are well within the state of the art of engineering practice and entail fundamental principles of thermodynamics.

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6.11 EXPOSURE LIMITS FOR CONTAMINATED WATER

The U.S. Environmental Protection Agency (EPA) has established or recommended water quality criteria for a variety of water uses and a relatively large number of chemicals. Advice from their personnel as to what concentrations of any particular chemical are tolerable in any given situation may be available with only a telephone call to one of the EPA's 10 regional offices.

Among the various standards and guidelines developed by the EPA for protection of water quality are:

- National Drinking Water Standards: The maximum contaminant levels (MCLs) for selected heavy metals, pesticides, radioactive substances, and other water quality characteristics permitted by law in water destined for human consumption. Listed in Parts 141 and 143 of Title 40 of the Code of Federal Regulations (CFR).

- Drinking Water Health Advisories (HAs) -- previously called Suggested No Adverse Response Levels (SNARLS): Human health effects advisories for unregulated drinking water contaminants commonly found in potable water supplies. HAs are somewhat unique in that they provide guidance for short-term exposure as well as the long-term chronic exposures typically of interest to the EPA.

- Maximum Contaminant Level Goals (MCLGs) -- formerly known as Recommended Maximum Contaminant Levels (RMCLs): Published in the Federal Register of June 12, 1984, the EPA proposed zero contamination limits for six halogenated hydrocarbons and benzene. Low levels of contamination were permitted for two other halogenated hydrocarbons (i.e., 1,1,1-trichloroethane and 1,4-dichlorobenzene). MCLGs were recently proposed for several additional contaminants.

- Federal Water Quality Criteria: Criteria for acute and chronic exposure of freshwater and saltwater aquatic life and human health based on long-term consumption of drinking water and contaminated fish or shellfish. Available for a relatively long list of substances.

Spills of toxic materials into a body of surface water differ from discharges of toxic vapors or gases into the air in that a large number of people are unlikely to suffer toxic effects before authorities have a chance to restrict water use. Indeed, response planning for the spill of any hazardous material into water more typically involves preparations to:

- Alert proper state and federal authorities.
- Warn public, industrial, agricultural, and recreational users of the water on as prompt a basis as possible of the contamination.
- Attempt to limit the degree of contamination or the amount of water affected.
- Attempt to remove as much of the contaminating substance as possible from the water (possibly employing a contractor with specialized expertise and equipment).
- Analyze the water to determine the extent of contamination.
- Consult with proper authorities as to whether the water is fit for use or whether other remedial actions are first necessary; and
- Prepare for the eventuality that a particular water supply may become unavailable for use for a time.

6.12 UNDERSTANDING TOXICOLOGICAL DATA IN THE LITERATURE

Toxicologists have a number of "short-hand" methods of expressing the toxicity of hazardous materials by various routes of entry. An understanding of some of the more common abbreviations used can lead to a greater understanding of how the toxicities of various materials can be assessed, particularly when these abbreviations are encountered in hazardous material data bases or the safety related literature of chemical manufacturers that address the effects of acute exposures.

The easiest way to learn the abbreviations is to look at a few examples and then discuss their meaning:

- The orl rat LD_{50} for Chemical A is 200 mg/kg.
- The ihl LC_{50} for the mus or gpg is 800 ppm/4 hrs. The TCLo is 100 ppm/4 hrs.
- The rbt skn LD_{67} is 50 mg/kg.

LD in the above examples is an abbreviation for ***lethal dose*** while LC stands for ***lethal concentration***. TC is short for ***toxic concentration*** while TD means ***toxic dose***. There are other similar abbreviations but these are by far the most common.

Each of the LD or LC notations are followed by a number that is usually a subscript. A "50" means that 50% of the test population of animals were killed under stated test conditions, a "67" means 67% were killed and so forth. The letters "Lo" instead of a number mean this is the lowest *reported* level having the stated effect.

In order for one of the above notations to have meaning, both the species of animal tested and the route of entry must be specified. Typical abbreviations are:

Species of Animal	Route of Entry
Rat = rat	Oral = orl
Mouse = mus	Skin application = skn
Guinea pig = gpg	Inhalation = ihl
Rabbit = rbt	
Human = hmn	
Mammal = mam	
Monkey = mky	

Both oral and skin application dosages are typically expressed in units of milligrams of chemical applied per kilogram of the animal's body weight, or ***mg/kg*** for short. The actual total amount of a toxic material necessary to cause the stated effect is determined by multiplying the dose in units of mg/kg by the weight of the animal species expressed in units of kilograms (1 kg = approximately 2.2 lb).

Inhalation data must include the concentration in air to which the animal species was subjected as well as the duration of exposure. Concentrations in air are typically expressed in units of ppm (by volume) or mg/m^3. Times are typically given in minutes or hours. ***Be advised that any airborne concentration not accompanied by an indication of the duration of exposure should be considered a useless and thoroughly meaningless item of information.***

One of the most comprehensive compilations of toxicological data is a multi-volume set of documents titled ***Registry of Toxic Effects of Chemical Substances***. The 1985-1986 edition, published in April 1987, is available for a cost close to $100 from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C., 20402, or one of the

many regional offices of the GPO, as Stock No. 17-33-00431-5. Developed jointly by the U.S. Public Health Service, Centers for Disease Control and NIOSH, the set is also listed as DHHS (NIOSH) Publication No. 87-114.

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7.0 REACTIVITY HAZARDS OF CHEMICAL SUBSTANCES

7.1 INTRODUCTION

It has up to this point been assumed that the hazardous materials being discharged or spilled do not in any way react with or chemically transform due to contact with water, air, other common materials in the environment, or other chemicals that may be present in the vicinity. It has also assumed that these materials are not ***self-reactive*** under conditions that may be encountered. Although the overall topic of chemical reactivity hazards is extremely complex, it is necessary to at least briefly outline some of the more common and/or dangerous types of reactions and how they may pose a threat to nearby populations. With due apologies to chemists, chemical engineers, and others with a knowledge of these topics, it is acknowledged that some liberties are taken in this process to ensure that various concepts are more easily understood by non-technical audiences.

7.2 EXOTHERMIC REACTIONS

When one substance is brought together or mixed with another and the resulting interaction evolves or generates heat, the process is referred to as an ***exothermic reaction***. Alternatively, if no reaction will take place unless heat is continuously added to the combination of ***reactants***, the interaction resulting from the provision of heat is called an ***endothermic reaction***. However, it is important to understand that some exothermic reactions may require heating just to get started, and will then proceed on their own.

Exothermic reactions pose special hazards whether occurring in the open environment or within a closed container. In the open, the heat evolved will raise the temperature of the reactants, of any products of the reaction, and of surrounding materials. Since several properties of all substances are a function of temperature, the resulting higher temperatures may affect how the materials involved may behave in the environment. Of key importance is the realization that heat will increase the vapor pressures of hazardous materials and the rate at which they vaporize. If very high temperatures are achieved, nearby combustible materials may ignite. Explosive materials, be they the reactants or products of the reaction, may explode upon ignition or excessive heating.

Similar hazards are associated with exothermic reactions taking place in closed containers. In this case, however, increasing internal temperatures as well as the evolution of gases from the reaction may increase internal pressures to the point that the tank or container ruptures violently in an overpressurization explosion, thus suddenly releasing large amounts of possibly flammable and/or toxic gases or vapors into the atmosphere. Such gases or vapors may also be released through ruptured pipes, opened pressure relief devices, or any other paths to the external environment.

Reactions with Water or Air

Some of the most basic types of exothermic reactions (which are barely "reactions" in the true sense of the term) occur when certain materials are dissolved in water. Such substances have what is called a positive ***heat of solution***. They do not transform to a different material, but simply generate heat while mixing. Some examples are sodium hydroxide (also called caustic soda) and sulfuric acid, which generates considerable heat to the point of causing some degree of "violence" when concentrated or pure materials are spilled into water. Yet other materials may ignite, evolve flammable gases, or otherwise react violently when in contact with water. Knowledge of the reactivity of any substance with water is especially important when water is present in the spill area or a fire takes place and firefighters do not wish to make the situation worse by applying water to the flames or chemicals.

While discussing such substances, it is well to add that several of the strong acids and related substances in this category of materials may evolve *large* amounts of ***fumes*** when in contact with water or moisture in the air. These fumes, which may consist of a mixture of fine droplets of acid in air and acid vapors, are usually highly irritating, corrosive, and heavier than air.

Many substances referred to as being ***pyrophoric*** will react violently or exothermically with air and are likely to ignite in a spontaneous fashion. Such substances (such as phosphorus) are commonly transported or stored in a manner that prevents exposure to air,

often submerged in water or some type of compatible oil. Note that the fact that a substance can be safely stored under water in no way suggests that it may also be safely submerged in oil. Nor may submersion in water be safe for a substance usually maintained under some type of oil.

Reactions with Combustible Organic Materials

Certain chemicals are known as strong ***oxidizing agents*** or ***oxidizers***. They have the common characteristic of being able to decompose or oxidize organic materials and react with a variety of inorganic materials while generating heat, oxygen, flammable gases, and possibly toxic gases. If the heat generated is sufficient to ignite a combustible or flammable material, a fire or explosion may occur.

Another group of chemicals are referred to as strong ***reducing agents***. These substances may evolve hydrogen upon reaction with many other chemicals, may evolve other flammable or toxic gases, and like oxidizing agents, may generate heat. As above, a fire or explosion may result if sufficient heat is generated to ignite a combustible or flammable substance. Strong reducing agents and oxidizing agents should never be allowed to make contact without appropriate safeguards since they represent opposite extremes of chemical reactivity.

Exothermic Polymerization Reactions

A few of the more common plastics in use on a widespread basis are polyethylene, polypropylene, polystyrene, and polyvinyl chloride (PVC). Although all are manufactured from liquids or gases, they are typically solids in their final form.

The above plastics are respectively manufactured from ethylene, propylene, styrene, and vinyl chloride by means of a ***polymerization*** reaction in which molecules of these materials are linked together into long chains of molecules. As the chains become longer and begin connecting to each other, thus greatly increasing the molecular weight of individual molecules, a solid plastic is formed.

Some chemicals capable of being polymerized have a strong tendency to do so even under normal ambient conditions and are especially prone to polymerize if heated above a certain temperature or if contaminated by a ***catalyst*** or ***polymerization initiator***, which in some cases might be a rather common substance such as water or rust. Once polymerization starts, an exothermic chain reaction may occur that develops high temperatures and pressures within containers and which can lead to possible explosion or violent rupture of the container and/or discharge of flammable and/or toxic gases if safety and control systems malfunction or are lacking. The incident in Bhopal, India partially involved this type of reaction when a container of methyl isocyanate contaminated with water and chloroform began polymerizing.

The heat of the runaway (i.e., out of control) reaction caused a large portion of the highly toxic isocyanate to vaporize into the air through a pressure relief system before it had a chance to polymerize.

Quite often, substances with the above tendency to ***self-polymerize*** or to undergo ***autocatalytic*** polymerization are transported or stored only while containing an amount of a substance called an ***inhibitor***. As their name implies, inhibitors act to inhibit, slow, or interfere with the chemical processes that can lead to a runaway uncontrolled polymerization reaction under *normal* conditions of transportation or storage. Inadvertent contamination or excessive heat, however, may overpower the inhibitor and allow the reaction to proceed. Thus, an inhibited cargo should not be considered safe if there is a possibility of it being overheated or contaminated with those substances that may initiate polymerization. The very fact that a substance needs an inhibitor for safe storage is in many cases (but by no means all) a sign of potential hazardous instability.

Exothermic Decomposition Reactions

Much as some chemical molecules can join together to form larger molecules via exothermic polymerization, others are unstable and can break apart in a runaway exothermic reaction once the process is initiated. Again, inhibitors may be used to slow the process down or to prevent its occurrence and various contaminants or heat may overcome the inhibitors or otherwise start a reaction. Containers may explode, rupture, and/or vent various flammable and/or toxic gases to the atmosphere.

Incidentally, the above decomposition and polymerization reactions are hazardous only if they somehow become uncontrolled and start a chain reaction that cannot be stopped with available equipment, materials, or safety systems. They are widely and safely conducted in chemical and other manufacturing plants across the nation on a daily basis without incident. It is only when control or safety systems break down or people make mistakes that problems begin.

7.3 NEUTRALIZATION REACTIONS

Spill response guides often suggest consideration of ***neutralization*** as a way in which a hazardous substance can be converted via a chemical reaction to one or more substances that pose lesser threats to the public health or the environment. It is therefore worthwhile to say a few words on the topic.

In the traditional sense of the word, neutralization typically refers to the combination of an acid and a base or alkaline material to form some sort of salt. A good example involves the careful combination of sodium hydroxide (caustic soda -- NaOH) with hydrochloric acid (muriatic acid -- HCl in water). This reaction, which may proceed violently for a time,

generate heat and gases, and cause boiling and spattering of acid if not properly controlled, results in the combination of sodium (Na) atoms with chlorine (Cl) atoms to form sodium chloride (NaCl), which is ordinary table salt. The remaining hydrogen (H) atoms and hydroxide (OH) molecules combine to form ordinary water (H_2O). Thus, one strongly corrosive and hazardous substance is used to convert another to a solution of ordinary salt and water.

When used in the spill response community, neutralization refers to the general use of one or more chemicals or other substances to render another less harmful. The term need not solely apply to acid-base reactions.

7.4 CORROSIVITY HAZARDS

The process by which a chemical gradually erodes or dissolves another material is often referred to as ***corrosion***. The process represents yet another type of chemical reactivity that must be considered in assessing the hazards of any given material, and is particularly important when: 1) choosing materials of construction for container walls or linings, piping, pumps, valves, seals, gaskets, and so forth; and 2) assuring that equipment and materials used during response to emergencies will not be damaged or destroyed by contact with the spilled material during their period of use. The word ***corrosive*** is also used descriptively to indicate that a substance may cause chemical burns of the skin, eyes, or other bodily tissues upon contact.

In evaluating whether one material is corrosive to another via reference to material safety data sheets, chemical company product bulletins, hazardous material data bases, or other reference sources, it is often important to place the time frame and rate of corrosion into the proper context. For example, certain reference sources may state that one substance is unacceptably corrosive to a particular material of construction because long term (i.e., 10 to 20 years) exposure will result in failure of the material prior to the desired lifetime of the equipment. Yet other reference sources may discuss the issue in terms of short term resistance of equipment or clothing construction materials to chemical attack, particularly if addressing use under emergency conditions. This distinction is not always clear in the literature.

Finally, note that some of the most corrosive substances to common metals include strong acids of one type or another. Not only may the "wrong" acid in contact with the "wrong" metal cause rapid corrosion of the metal, but the process may generate flammable and potentially explosive hydrogen gas.

7.5 OTHER HAZARDOUS RESULTS OR PRODUCTS OF REACTIONS

The above discussions have really only scratched the surface of the overall topic of hazardous chemical reactions. It is also necessary to point out that:

- The combination of various chemicals may produce new chemicals with hazards quite different and possibly more severe than those associated with the original materials.
- Some combinations may result in spontaneous fires; spontaneous explosions; formation of substances which will ignite or explode if shocked, heated or subjected to friction; generation of toxic gases, liquids or solids; or generation of flammable gases, liquids, or solids.
- It is necessary to look at hazardous materials on a fairly specific case-by-case basis to determine their reactivity hazards.

7.6 SOURCES OF CHEMICAL REACTIVITY DATA

There are numerous sources of chemical reactivity data that address the topic somewhat superficially and several that are highly technical and somewhat beyond the perceived "needs" of the audience to which this document is directed. The following three sources provide an excellent balance between completeness, precision, specificity, and common availability.

- ***Fire Protection Guide on Hazardous Materials***, containing "Manual of Hazardous Chemical Reactions," NFPA 491M-1986, National Fire Protection Association, Batterymarch Park, Quincy, MA 02269 (Telephone 1-800-344-3555 for orders).
- Bretherick, L., ***Handbook of Reactive Chemical Hazards***, 3rd edition, Butterworths, London and Boston, 1985. Available through libraries and bookstores serving the scientific community.
- Hatayama, H.K., et al., ***A Method for Determining the Compatibility of Hazardous Wastes***, EPA Report No. EPA-600/2-80-076, Municipal Environmental Research Laboratory, U.S. Environmental Protection Agency, Cincinnati, Ohio, April 1980. Available as publication PB80-221005 from the National Technical Information Service, Springfield, Virginia 22161.

The NFPA Fire Protection Guide on Hazardous Materials contains the described manual of chemical reactions as well as considerable additional information and data on hazardous materials. Found in the libraries of numerous fire departments, it was available in 1988 at a cost of approximately $49 to non-members. Although the section on hazardous chemical reactions has not truly been updated since 1975, and is not nearly as extensive as the work by Bretherick, the guide remains an excellent source for a broad range of specific information. Major sections of the guide can also be found in the NFPA National Fire Codes as Sections 325M, 49, 491M, and 704.

The handbook by Bretherick covers approximately 9000 compounds versus the 1600-1700 found in the NFPA guide. It is a major and somewhat unique work in the field which retails for $110.

The report prepared by Hatayama and his co-workers under the sponsorship of the EPA is an excellent supplement to either of the above sources of information. Those above mostly list and describe the specific hazardous consequences of combining various sets of chemicals, *as reported in the general literature*. Since there are many tens of thousands of known chemicals, and since only a small fraction of the possible combinations have been reported upon, neither of these sources can even begin to claim that combinations not listed are safe. The work by Hatayama et al. attempts to fill the gaps by providing a *general* indication of the *typical* effects of mixing a substance from one chemical *family* with a substance from another *family* via a single chemical compatibility chart. The title of the work suggests it only considers hazardous waste materials, but that in no way affects the validity of the information for hazardous materials in general. Appendix D to this guide contains a copy of the chart as well as additional explanatory information.

It is also necessary to note that many of the product bulletins and safety-related documents available free from most chemical manufacturers can be excellent sources of information when one is concerned with the reactivity hazards of a relatively small number of materials. The problem is that collection of such publications for a large number of materials can be a burdensome and lengthy process.

Chemical company literature, however, can be a great source of information on the compatibility of common materials of equipment construction with specific chemicals. Alternatives include some of the better hazardous materials data bases, books devoted to this topic, and more widely available handbooks in the fields of chemical and mechanical engineering. Many of these same sources address the compatibility of materials used for chemical protective clothing, and substantial information is available from the manufacturers of such clothing. One excellent source of information on protective clothing that deserves special notice is:

- Schwope, A.D., et al., ***Guidelines for the Selection of Chemical Protective Clothing***, 3rd edition, 1987; sponsored by the EPA and USCG and available for approximately $35 from the ACGIH Publications Section, 6500 Glenway Ave, Bldg D-7, Cincinnati, Ohio 45211 (Telephone 513-661-7881).

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8.0 HAZARDOUS MATERIAL CLASSIFICATION SYSTEMS

8.1 INTRODUCTION

Various organizations in the United States have established or defined classes or lists of hazardous materials for regulatory purposes or for the purpose of providing rapid indication of the hazards associated with individual substances. An awareness and knowledge of these classification systems can assist emergency preparedness personnel in identifying those materials that may pose a potential threat to their respective jurisdictions.

8.2 U.S. DEPARTMENT OF TRANSPORTATION CLASSIFICATIONS

As the primary regulatory agency concerned with the safe transportation of hazardous materials in interstate commerce, the U.S Department of Transportation (DOT) has established definitions of various classes of hazardous materials, established placarding and marking requirements for containers and packages, and adopted an international cargo commodity numbering system. Each of these topics is individually discussed in the following. Further details are available in 49 CFR 171-179.

Material Classification Definitions

The DOT classifies hazardous materials in transportation into one or more of the following categories.

An ***explosive*** is defined as "*any chemical compound, mixture, or device, the primary or common purpose of which is to function by explosion, i.e., with substantially instantaneous release of gas and heat...*" within certain limitations noted in DOT regulations. The overall category of explosives is further broken down into Class A, Class B, and Class C explosives. ***Class A*** materials are among the most powerful and include bombs, mines, torpedoes, and ammunition used by the military; various high explosives like nitroglycerin and dynamite; blasting caps, detonating fuzes, and powerful rocket propellants. ***Class B*** substances and devices are generally less powerful and typically (not always) function by rapid combustion rather than detonation. The class includes special fireworks, flash powders, some pyrotechnic signal devices, liquid or solid propellants, some smokeless powders, and certain types of ammunition. ***Class C*** explosives are manufactured articles which contain Class A or B materials, or both, as components in strictly restricted quantities. The class also includes certain types of fireworks.

A ***blasting agent*** is a material designed for blasting which has been tested in accordance with DOT regulations and "*found to be so insensitive that there is very little probability of accidental initiation to explosion or of transition from deflagration to detonation.*" In other words, the material is capable of exploding under very special conditions, but these conditions are unlikely to occur in transportation, even in the event of an accident involving fire or impact.

Flammable liquid refers to any liquid, within certain limitations and exceptions, that has a "closed-cup" flash point below 100°F (37.8°C). Similarly, ***combustible liquid*** refers to any liquid that has a flash point of 100°F or more but no higher than 200°F. A ***pyrophoric liquid*** is any liquid that ignites spontaneously in dry or moist air at or below 130°F (54.5°C).

Flammable solids are "*any solid material, other than one classed as an explosive, which, under conditions normally incident to transportation is liable to cause fires through friction, retained heat from manufacturing or processing, or which can be ignited readily and when ignited burn so vigorously and persistently as to create a serious transportation hazard. Included in this class are spontaneously combustible and water-reactive materials.*"

An ***oxidizer***, according to DOT regulations, "*is a substance such as a chlorate, permanganate, inorganic peroxide, or a nitrate, that yields oxygen readily to stimulate the combustion of organic matter.*" The key hazard associated with oxidizing agents or materials is that contact with a combustible substance, particularly organic materials, may cause the substance to ignite and possibly even explode.

An ***organic peroxide*** is essentially a derivative of hydrogen peroxide (H_2O_2) where one or more of the hydrogen atoms have been replaced by molecular chains containing carbon

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and hydrogen atoms. The substances in this category do not meet the definitions of Class A or B explosives but may be capable of exploding under certain conditions. They may also have the hazards associated with oxidizers.

DOT defines a ***corrosive*** material as "*a liquid or solid that causes visible destruction or irreversible alterations in human skin tissue at the site of contact, or in the case of leakage from its packaging, a liquid that has a severe corrosion rate on steel.*" A liquid is considered to have a severe corrosion rate if it "eats away" more than 0.25 inch of a certain type of steel at 130°F over the course of one year.

A ***compressed gas*** is defined as any material or mixture with an absolute pressure in a container of:

- More than 40 psia at 70°F
- More than 104 psia at 130°F
- If the substance is flammable and in the liquid state, more than 40 psia at 100°F.

A ***flammable compressed gas*** is a compressed gas that has a lower flammable limit (LFL) concentration of 13% or less by volume in air, or which has a flammable range (i.e., the difference between the LFL and UFL) of greater than 12%, or which behaves in a prespecified manner in a flammability testing apparatus. A ***liquefied compressed gas*** is a gas which is partially a liquid under the pressure in the container at 70°F. A ***non-liquefied compressed gas*** is a substance which is entirely gaseous at a temperature of 70°F.

Poisonous materials are divided into three groups in DOT regulations according to their degree of hazard in transportation. ***Poison A*** substances are "*poisonous gases or liquids of such a nature that a very small amount of the gas, or vapor of the liquid, mixed with air is dangerous to life.*" ***Poison B*** materials are liquids or solids, other than Class A poisons or irritating materials, "which are known to be so toxic to man as to afford a hazard to health during transportation; or which, in the absence of adequate data on human toxicity, are presumed to be toxic to man" because they meet certain criteria for inhalation, ingestion, or skin exposures when tested on laboratory animals. ***Irritating materials*** are liquid or solid substances "*which upon contact with fire or when exposed to air give off dangerous or intensely irritating fumes.*"

In the aftermath of the Bhopal incident, DOT rules were modified to require special marking of packages or containers of volatile toxic liquids which had previously escaped classification as poisons. After adopting a new set of special criteria for inhalation toxicity hazards, the DOT required that packages containing more than one liter and no more than

110 gallons of these materials be marked ***Inhalation Hazard.*** Poison placards were required in addition to other required placards for trucks, rail cars or containers carrying any amount of these materials. Shipping papers for containers holding more than one liter were required to include the statement ***Poison - Inhalation Hazard.***

An ***etiologic agent*** is "*a viable microorganism, or its toxin, which causes or may cause human disease,*" For the most part, such agents include potentially infected living tissue and bacteriological materials.

Radioactive materials are substances that give off potentially harmful nuclear radiation, and are classed in three groups according to the controls needed to provide "nuclear criticality safety" during transportation. ***Fissile Class I*** materials are among the safest of these substances, do not require nuclear criticality safety controls during transportation, and may be shipped together in an unlimited number of packages. ***Fissile Class II*** substances are somewhat more dangerous and can only be shipped in limited amounts when packages are shipped together. ***Fissile Class III*** do not meet the requirements of the other classes and must be controlled to provide nuclear criticality safety in transportation by special arrangement between the shipper and the carrier.

Finally the DOT has a category called ***Other Regulated Material*** (ORM) for a wide variety of hazardous materials shipped in limited quantities and in certain kinds of packaging. There are five classes of such cargos with the designations ORM-A, ORM-B, ORM-C, ORM-D, and ORM-E.

Identification Numbers

The DOT has assigned a four-digit identification to each of the hazardous materials regulated in transportation. When appearing in documentation, these numbers are preceded by the letters "UN" or "NA". The UN numbers, such as UN1203 for gasoline, were assigned in cooperation with the United Nations and are used on an international basis. The NA numbers are not recognized in international transportation except to and from Canada.

Most of the numbers and the material shipping names to which they are assigned represent very specific materials. It is well to recognize, however, that the DOT also permits some cargos to be identified in a rather generic fashion. For example, the identification number UN1993 applies to *flammable liquid, n.o.s.*. The last three letters are an abbreviation for *not otherwise specified,* so the number does not permit identification of the specific material in the container.

Placards and Labels

The DOT has numerous regulations dealing with the placards and labels that must appear respectively on bulk containers and packages of hazardous materials. Figure 8.1 illustrates the required placards, these being the fairly large signs that must appear on railroad tankcars, highway tank trucks, and other large transport vehicles. Labels are fairly similar and any differences are rather self-explanatory.

Special Notes

Before continuing, it is necessary to make two important observations about DOT classification systems and placarding and labeling requirements. The first is that these systems and requirements are modified on a frequent basis and there has been considerable activity to improve them in the aftermath of the Bhopal incident. Although the material presented herein is of a fairly general nature, some items may become outdated with time. Indeed, even as this document was being prepared, the DOT was in the process of finalizing new regulations in this area.

Secondly, and most importantly, be intensely aware that the **current** DOT material classification system has weaknesses that prompted the above activities. Furthermore, the current system is primarily designed to denote the perceived primary hazard of a material as determined by application of rigorous classification criteria. ***Do not under any circumstances assume that the hazard indicated by a warning label or placard attached to a container is the only hazard associated with the material found therein.***

8.3 U.S. ENVIRONMENTAL PROTECTION AGENCY CLASSIFICATIONS

The EPA has developed several lists of chemicals and chemical wastes that may be broadly categorized as"hazardous substances." Besides the water pollutants discussed earlier in Chapter 6, they include:

- A list of specific ***hazardous wastes*** and criteria for designating other materials as wastes under the Resource Conservation and Recovery Act (RCRA) of 1976 and subsequent amendments. See Title 40, Part 261 of the Code of Federal Regulations (40 CFR 261) for details.

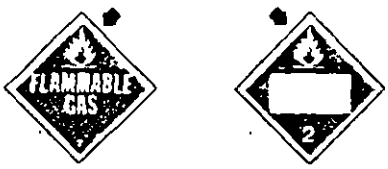
- A list of ***hazardous substances*** developed under Section 311 (b) (2) (A) of the Clean Water Act of 1977. See 40 CFR 112-114 for details.

- Chemicals listed as ***toxic pollutants*** under Sections 307(a) and 307(c) of the Clean Water Act. See 40 CFR 116-117 for details.

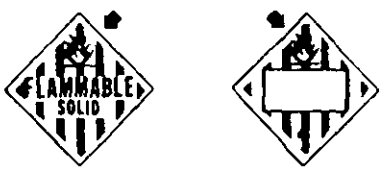
FIGURE 8.1
U.S. D.O.T. PLACARDS

The alternate display incorporating the UN/NA 4-digit number appears to the right of the placard.

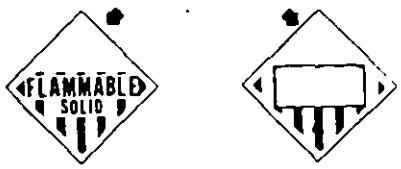
FLAMMABLE GAS



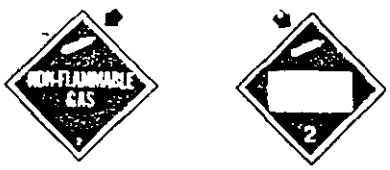
FLAMMABLE SOLID



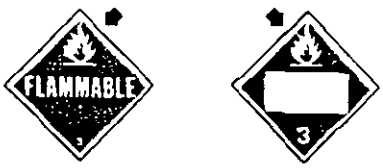
FLAMMABLE SOLID



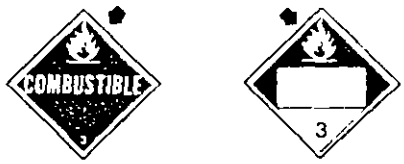
NON-FLAMMABLE GAS



FLAMMABLE

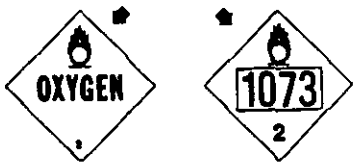


COMBUSTIBLE

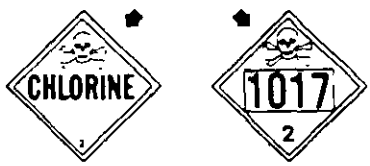


CORROSIVE

OXYGEN

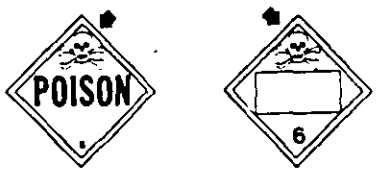


CHLORINE



EXPLOSIVES

POISON



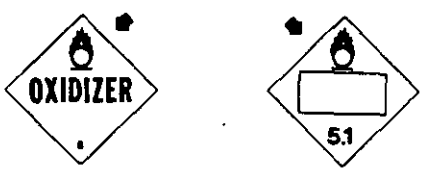
RADIOACTIVE

EXPLOSIVES

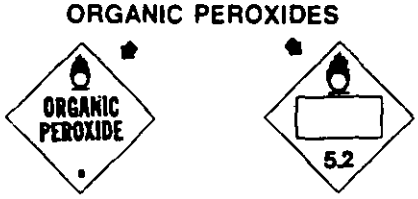
POISON GAS

NOTE: No alternate display is permitted for EXPLOSIVES A, POISON GAS, and RADIOACTIVE materials

OXIDIZERS



ORGANIC PEROXIDES



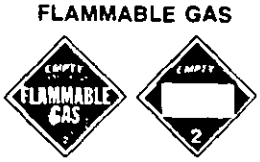
NOTE

Hazard Class Numbers

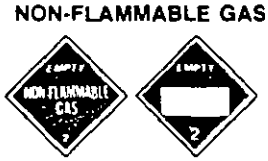
1 Explosives
2 Compressed gases
3 Flammable/Combustible Liquids
4 Flammable solids
5.1 Oxidizers
5.2 Organic peroxides
6 Poisons
7 Radioactive materials
8 Corrosives

PLACARDED EMPTY TANK CARS

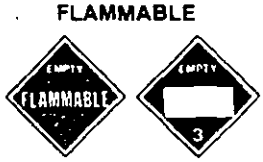
FLAMMABLE GAS



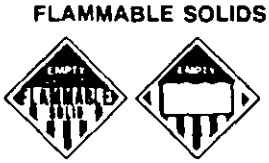
NON-FLAMMABLE GAS



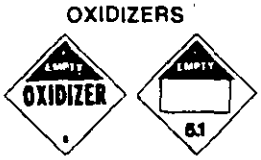
FLAMMABLE



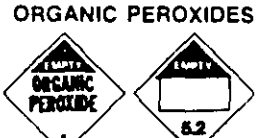
FLAMMABLE SOLIDS



OXIDIZERS



ORGANIC PEROXIDES



POISON

CORROSIVE

When required on tank cars, portable tanks or cargo tanks, identification numbers, as specified in §172.101 or §172.102, shall be displayed on an orange panel or placard. §172.332
An identification number may not be displayed on a Poison Gas, Radioactive or Explosives placard §172.334(a); but if a tank car, portable tank or cargo tank carrying such a commodity requires an identification number, it must be displayed on an orange panel. §172.332

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- A list of materials deemed to be ***Extremely Hazardous Substances*** (EHS) by virtue of their acute inhalation toxicity in air. Established under Title III, section 302(a) of the Superfund Amendments and Reuthorization Act of 1986, this list has been subject to frequent changes. It may be expanded in the future to include materials with other hazardous characteristics.

- A list of hazardous substances established under the 1980 Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), also known as Superfund. The list is comprised of chemicals listed under RCRA, the Clean Air Act, and/or the Clean Water Act. See 40 CFR 302 for details. Extremely Hazardous Substances are also to be included in this list.

- A list of toxic chemicals established under section 313 of SARA Title III for emissions reporting. See 40 CFR 372 for details.

The hazardous substances listed under CERCLA have been assigned ***reportable quantities*** by the EPA. These are the amounts that must be spilled within a specified period of time before the party responsible for the spill or discharge is ***required*** to report the spill to federal, state, and local governments. They range from one pound for materials considered to be extremely harmful to the environment (plus some chemicals which are under review and have not yet been assigned more appropriate reportable quantities) to 5000 lbs for those substances considered to pose significant but comparatively moderate environmental hazards. It is well to recognize that:

- The current EPA CERCLA hazardous substance list mostly includes substances that were identified as a result of their long-term environmental and public health hazards. There are many significant hazardous materials which do not appear in the list.

- Reportable quantities (RQs) were generally derived from an evaluation of the long-term health and environmental hazards of the listed chemicals. RQ values represent a relative ranking of the chemicals vis-a-vis each other and are not absolute indicators of risk. Due to the criteria by which they were derived, RQs should not be used to rank substances for planning or emergency response activities involving episodic spills or discharges of hazardous materials posing acute threats to the public.

Each Extremely Hazardous Substance designated by the EPA has been assigned a ***Threshold Planning Quantity*** (TPQ) which triggers various reporting, community right-to-know, and emergency planning requirements. Please note that:

- The list of Extremely Hazardous Substances was prepared quickly after the Bhopal incident as an attempt to denote those materials which pose a high acute toxicity hazard to the public when discharged into the environment. The list contains several substances that are highly toxic but lack mobility under ordinary spill conditions.

- Although Threshold Planning Quantities have an important role in defining regulatory requirements, there is no guarantee that lesser quantities of a designated EHS will not pose threats to public health and safety under all accident conditions.

8.4 NATIONAL FIRE PROTECTION ASSOCIATION HAZARD RANKINGS

In an attempt to provide fire service personnel a rapid means of assessing the dangers of hazardous materials, the National Fire Protection Association (NFPA) has developed a ranking system that assigns separate values in the range of zero to four to the health, flammability, and reactivity hazards of individual materials. A fourth category for "special" hazards uses the following symbols among occasional others:

- "**W**" to denote unusual reactivity with water

- "**OX**" to denote that the material has oxidizing properties

- "**COR**" to denote that the material is corrosive to living tissue

- The standard radioactivity symbol to denote radioactivity hazards

Table 8.1 defines the rankings specified by the NFPA for health, flammability, and reactivity. Although the individual rankings are often simply listed by category in NFPA documents and many chemical company material safety data sheets, they may also be seen within a diamond-shaped sign with blue, red, yellow, and white squares containing the respective rankings for health (blue), fire (red), reactivity (yellow) and other (white).

8.5 INTERNATIONAL MARITIME ORGANIZATION CLASSIFICATION

Under the auspices of the United Nations, the International Maritime Organization (IMO) has developed and continues to refine its International Maritime Dangerous Goods Code (IMDG) to facilitate and ensure the safety of international shipments of hazardous materials. The DOT has adopted and/or permits use of IMDG requirements under numerous circumstances, and it is very common to see references to these requirements in MSDS and

TABLE 8.1
NFPA HAZARD RANKINGS

Identification of Health Hazard Color Code: BLUE		Identification of Flammability Color Code: RED		Identification of Reactivity (Stability) Color Code: YELLOW	
	Type of Possible Injury		Susceptibility of Materials to Burning		Susceptibility to Release of Energy
Signal		Signal		Signal	
4	Materials which on very short exposure could cause death or major residual injury even though prompt medical treatment were given.	4	Materials which will rapidly or completely vaporize at atmospheric pressure and normal ambient temperature, or which are readily dispersed in air and which will burn readily.	4	Materials which in themselves are readily capable of detonation or of explosive decomposition or reaction at normal temperatures and pressures.
3	Materials which on short exposure could cause serious temporary or residual injury even though prompt medical treatment were given.	3	Liquids and solids that can be ignited under almost all ambient temperature conditions.	3	Materials which in themselves are capable of detonation or explosive reaction but require a strong initiating source or which must be heated under confinement before initiation or which react explosively with water.
2	Materials which on intense or continued exposure could cause temporary incapacitation or possible residual injury unless prompt medical treatment is given.	2	Materials that must be moderately heated or exposed to relatively high ambient temperatures before ignition can occur.	2	Materials which in themselves are normally unstable and readily undergo violent chemical change but do not detonate. Also materials which may react violently with water or which may form potentially explosive mixtures with water.
1	Materials which on exposure would cause irritation but only minor residual injury even if no treatment is given.	1	Materials that must be preheated before ignition can occur.	1	Materials which in themselves are normally stable, but which can become unstable at elevated temperatures and pressures or which may react with water with some release of energy but not violently.
0	Materials which on exposure under fire conditions would offer no hazard beyond that of ordinary combustible material.	0	Materials that will not burn.	0	Materials which in themselves are normally stable, even under fire exposure conditions, and which are not reactive with water.

other hazardous material publications. Indeed, the DOT has proposed to adopt IMDG performance oriented packaging requirements in their entirety for implementation in the United States.

The IMO has categorized its overall list of hazardous materials into nine major classes, many of which are further broken down into two or more divisions. Table 8.2 lists and describes the basic definitions of IMO classes and divisions. Detailed definitions, including more specific breakdowns for explosives, are provided in the text of the IMDG code.

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TABLE 8.2
BASIC IMO MATERIAL CLASSES AND DIVISIONS

Class 1 -- Explosives

Division 1.1	Substances and articles which have a mass explosion hazard. *Explosive A*
Division 1.2	Substances and articles which have a projection hazard but not a mass explosion hazard. *Explosive A or B*
Division 1.3	Substances and articles which have a fire hazard and either a minor blast hazard or a minor projection hazard or both, but not a mass explosion hazard. *Explosive B*
Division 1.4	Substances and articles which present no significant hazard. *Explosive C*
Division 1.5	Very insensitive substances. *Blasting Agent*

Class 2 -- Gases (compressed, liquelified or dissolved under pressure)

Division 2.1	Flammable gases. *Flammable gas*
Division 2.2	Nonflammable gases. *Nonflammable gas*
Division 2.3	Poison gases. *Poison A* and other poison gas

Class 3 -- Flammable liquids

Division 3.1	Low flash point group (liquids with flash points below 0°F). *Flammable liquid*
Division 3.2	Intermediate flash point group (liquids with flash points of 0°F or above but less than 73°F). *Flammable liquid*
Division 3.2	High flash point group (liquids with flash points of 73°F or above up to and including 141°F). *Flammable liquid or Combustible liquid*

Class 4 -- Flammable solids or substances

Division 4.1	Flammable solids. *Flammable solid*
Division 4.2	Substances liable to spontaneous combustion. *Flammable solid* or, for pyrophoric liquids, *Flammable liquid*
Division 4.3	Substances emitting flammable gases when wet. *Flammable solid*

Class 5 -- Oxidizing substances

Division 5.1	Oxidizing substances or agents. *Oxidizer*
Division 5.2	Organic peroxides. *Organic peroxide*

Class 6 -- Poisonous substances and infectious substances

Division 6.1	Poisonous substances. *Poison B*
Division 6.2	Infectious substances. *Etiologic agent*

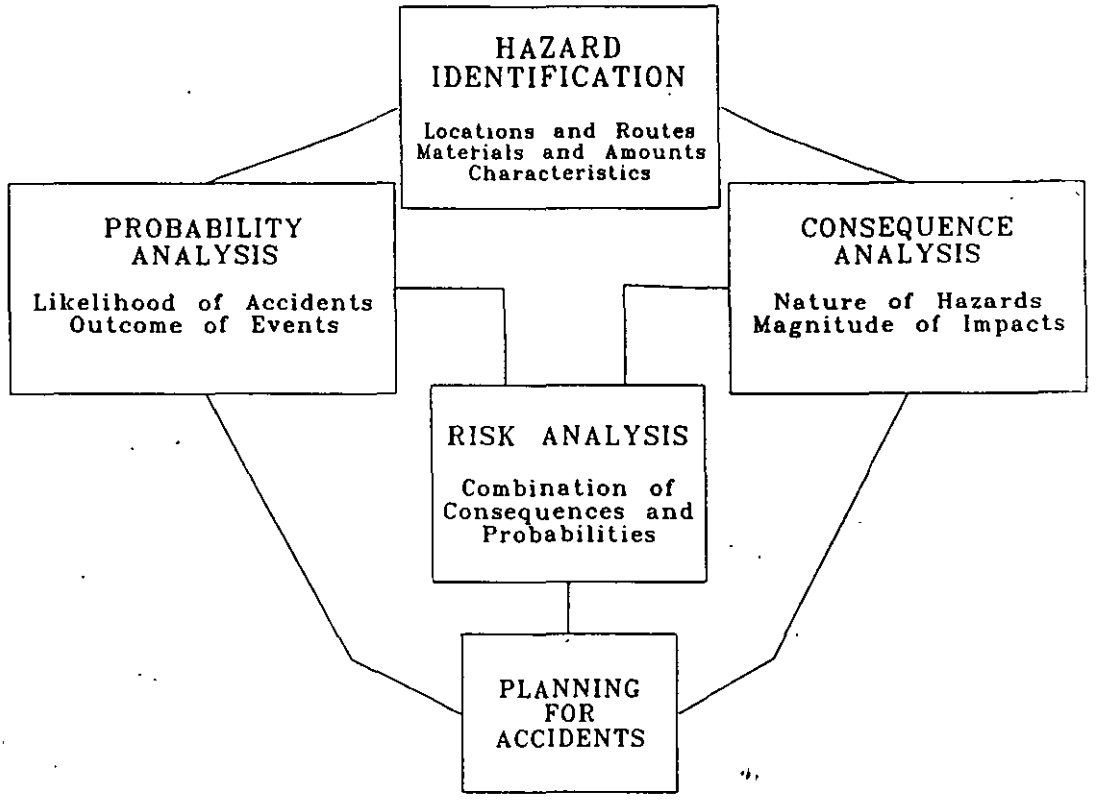
Class 7 -- Radioactive substances. *Radioactive material*

Class 8 -- Corrosives. *Corrosive material*

Class 9 -- Miscellaneous dangerous substances. *Other regulated material*

Note: Corresponding DOT classes are shown in italics following IMO classes and divisions.

9.0 OVERVIEW OF THE HAZARD ANALYSIS PROCESS



9.1 INTRODUCTION

Chapter 1 to this document reported that recent guidance manuals published by the federal government have used the term *hazard analysis* to describe the overall procedure for evaluating the hazards, consequences, vulnerabilities, probabilities, and risks associated with the presence of hazardous materials within any given locality or jurisdiction. This term will also be used herein for the sake of consistency with earlier publications, although it is recognized that *hazard analysis* is often applied in a somewhat different context within government and industry.

There are four basic steps presented in this guide for the conduct of a hazard analysis, and a related fifth step that takes advantage of the knowledge gained during the effort to develop a comprehensive emergency plan for hazardous materials that focuses attention on the known threats to a community or facility while maintaining sufficient flexibility to deal effectively and efficiently with unforeseen events. These steps include:

- Location, identification, and characterization of potential spill sources and accident sites in the jurisdiction or locality of concern in a process referred to as ***hazard identification.*** This step essentially concludes with the identification

and/or postulation of fundamental accident scenarios requiring further consideration and analysis. Results from the probability analysis step which follows can often help in further refining these scenarios.

- Evaluation of the likelihood of individual accident scenarios in a process called ***probability analysis.*** This step permits examination and/or prioritization of potential accident scenarios in terms of their probability of occurrence.

- Evaluation of the consequences and impacts associated with the occurrence of postulated accident scenarios in a process that is referred to as ***consequence analysis.*** This step provides an understanding of the nature and outcome of an accident and permits examination and/or prioritization of scenarios in terms of their potential impact on people and property.

- Combination of results from the accident probability and consequence analysis efforts to provide a measure of overall risk associated with the specific activity or activities being studied in a process referred to as ***risk analysis***. The effort permits examination and/or prioritization of scenarios in terms of *overall* "risk".

- Use of the results of the above activities (which in aggregate provide a ***planning basis*** for emergency preparedness personnel) during actual development and preparation of an emergency plan.

It is the express purpose of this chapter to introduce and describe these various steps further and to set the stage for accomplishment of necessary efforts via use of the data, information, analysis procedures and computational methods presented in subsequent chapters of this guide.

Note that the various steps of the overall hazard analysis need not be performed in precisely the order shown for all postulated accident scenarios. Indeed, as descriptions of the various steps are read, keep in mind that:

- Some users of this guide may wish to employ all steps outlined to one postulated accident sceneario at a time, starting with the scenario they *perceive* as posing the greatest threat to their jurisdiction and then working down their "list".

- Some users may wish to perform one step at a time for all postulated accident scenarios.

- Some users may wish to ignore the probability analysis step for one or more postulated accident scenarios if they perceive or determine that the consequences of an accident would be major or catastrophic and wish to plan for them

regardless of their likelihood of occurrence. Such decisions are specifically supported by guidance provided below and in Chapter 13. Although the most severe yet credible accidents that can be foreseen in any jurisdiction or locality are most likely to have low probabilities of occurrence, the very fact that consequences may be catastrophic or major is usually sufficient justification for consideration of the scenario during the emergency planning process.

- Some users may wish to skip the assessment of accident impacts and consequences for scenarios that are determined to be highly unlikely and are also known to pose comparatively low threats to the public due to the quantity and/or characteristics of the materials involved.

- Some users may wish to perform a "quick and dirty" assessment of potential accident probabilities and/or consequences using readily available information and assuming "worst case" conditions for unknown data or parameters. The answers obtained could then be used to prioritize more formal analyses of important accident scenarios.

9.2 STEP 1: HAZARD IDENTIFICATION

Hazard identification involves delineation and specification of those facilities and transportation modes that handle hazardous materials within the locality or jurisdiction of concern. In other words, it requires that planning personnel determine where and how hazardous materials are stored, handled, or processed in their locality; how and by what routes they are transported to and from these facilities; and where and how hazardous materials may pass through the area on their way to other destinations via rail, highway, marine, or pipeline transportation routes.

A directly related and important activity involves characterization of each potential spill or accident site in sufficient detail to formulate potential accident scenarios and to permit subsequent evaluation of accident probability, likely spill amount, and nature and magnitude of resulting impacts. In other words, once detective work has discovered where hazardous materials are located, this step involves gathering the data and information necessary to eventually postulate the circumstances under which accidents may occur and to evaluate the approximate hazards and risks that these accidents may pose to surrounding populations.

Specific guidance and advice pertaining to the conduct of a hazard identification effort follow in Chapter 10 of this guide.

9.3 STEP 2: PROBABILITY ANALYSIS

With all the media attention given to the topic on a national as well as international basis in recent times, one might easily come to believe that a major disaster involving hazardous materials is bound to occur within the foreseeable future wherever such materials are handled, stored, processed, or transported. Indeed, a survey of public authorities a few years ago placed such events at the top of a list of concerns for conceivable emergencies in their respective jurisdictions. Fortunately, however, catastrophic spills or discharges, i.e., those that actually kill or significantly injure more than a few people at a time, are actually rare events in our large and heavily industrialized nation, although accidents in general involving hazardous materials are very common. The vastly increased attention given to chemical safety in recent times by industry and government alike should serve to further improve overall safety performance in the future. Better preparedness to respond to accidents should serve to reduce overall risks to society by helping to reduce or limit adverse impacts once an accident has occurred.

The probability analysis step may be considered optional where community leaders or facility owners wish to prepare for every conceivable accident regardless of its probability of occurrence and have the time, manpower, and resources to achieve their goals. More often than not, however, emergency planners will find that time and resources are limited, that other threats to the community or public needs compete for attention, and that there is value in conducting a probability analysis. Prioritization of chemical related threats in terms of probability permits attention to these threats in an orderly fashion and reduces the chance that time and resources will be expended on scenarios of exceedingly low credibility or significance.

The task of evaluating the potential for a hazardous material emergency in any locality or jurisdiction involves use of historical accident data in conjunction with local factors (to the extent possible) to predict the frequency of future accidents, and to some extent, the general consequences of these events. Prediction of the future, of course, is an inexact science, but probabilistic accident assessment methods can provide approximate indications of the number and nature of accidents expected *on average* in a given locale within a specified period of time, and can therefore provide valuable guideposts for decision-making purposes.

There are many localities where the total traffic and use of hazardous materials pose a clear threat to public health and safety and which are generally aware of the need for comprehensive emergency planning. These localities could benefit from a probabilistic assessment of accident potential which permits the various threats to be ranked and prioritized, thus ensuring that the most important and serious threats receive the full attention they deserve and that available resources are wisely allocated. (Note: At least one instance is known where a city purchased a set of expensive chemical protective clothing -- fully encapsulating suits

resembling space suits -- and stored them away after allowing its hazmat response team members to try them on once. The suits eventually mildewed and rotted from lack of need and attention.)

At the opposite end of the spectrum are localities which face relatively few hazardous material threats and which may be unsure whether the risk of an accident warrants extensive expenditures of time and resources for emergency preparedness. A probabilistic assessment of accident potential, coupled with the results of a consequence analysis, can assist these localities in deciding upon the appropriate level of planning and preparedness. Together with assessments of other natural and man-made threats to the locality, priorities can be set for allocating time and resources to threats with the highest potential for harming the public. Efforts can be initiated for sharing response capabilities and resources among neighboring jurisdictions where the chances of a significant accident in a region encompassing several jurisdictions are considerable, but the chance that the accident will occur in any specific locale within the region is comparatively low.

Guidelines and methods for probabilistic assessment of hazardous materials emergencies are presented in Chapter 11 of this guide.

9.4 STEP 3: CONSEQUENCE ANALYSIS

Probabilistic assessment of accident potential can provide a good idea of the likelihood that a potential accident will actually take place. It must be realized, however, that the most frequent types of spills or discharges have relatively minor consequences, and that more serious accidents will generally have lower probabilities of occurrence. Thus, a full understanding of the *risks* faced by any specific locale requires knowledge not only of the probabilities associated with different types of accidents, but also the expected impacts and consequences of these events.

Estimation of potential accident impacts and consequences can be accomplished via a variety of consequence, vulnerability, and hazard assessment methodologies described in Chapter 12 of this guide and incorporated within the computer program named ARCHIE that is an integral part of this document.

9.5 STEP 4: RISK ANALYSIS

The risk analysis step is also somewhat optional in the sense that it relies upon the results of the accident probability analysis for completion. It entails combination of the probability or likelihood of an accident occurring with a measure of the predicted consequences of the accident to provide an overall measure of *risk* that can be used for threat prioritization and planning purposes.

Readers should be aware that the term *risk* is often misused by society. Being usually defined as a *combined* measure of the probability and severity of potential threats, it is possible for a threat with low probability of occurrence and relatively high potential severity to pose a comparable level of risk to a community (from a planning perspective) as a threat with a higher probability of occurrence but lower severity. Thus, the performance of a risk analysis permits all threats to be viewed from a perspective that is not biased by consideration of either probabilities or consequences alone.

Chapter 13 provides guidance on how the accident scenarios evaluated in Steps 2 and 3 may be evaluated in terms of risk. It also contains a discussion of how the risks associated with hazardous materials compare with more common threats to life and property. The latter topic is considered important because the hazardous materials accident problem has several emotional and political aspects that sometimes tend to distort the truth.

9.6 STEP 5: USE OF HAZARD ANALYSIS RESULTS IN EMERGENCY PLANNING

The scenarios resulting from the overall hazard analysis process will hopefully represent the full range of *significant* hazardous material emergencies that have a reasonable likelihood of occurring in the foreseeable future within any given locality. It remains to consider how these scenarios and related analysis results may be used to focus an emergency response plan on credible threats to the locality of concern and to ensure that the emergency plan provides for efficient, rapid, and comprehensive mitigation of adverse impacts.

Chapter 14 of the guide discusses the planning ramifications associated with individual accident scenarios in some detail and serves as a guide for the use of these scenarios during emergency planning. Note that each scenario deemed credible and worthy of consideration gives planning personnel the opportunity to sit back under non-emergency conditions, identify steps that must be taken to protect the public, and ensure that response personnel will have the necessary organization, communications systems, equipment, materials, manpower, sources of assistance, and training to cope with the situation and minimize casualties, property damage, and environmental pollution.

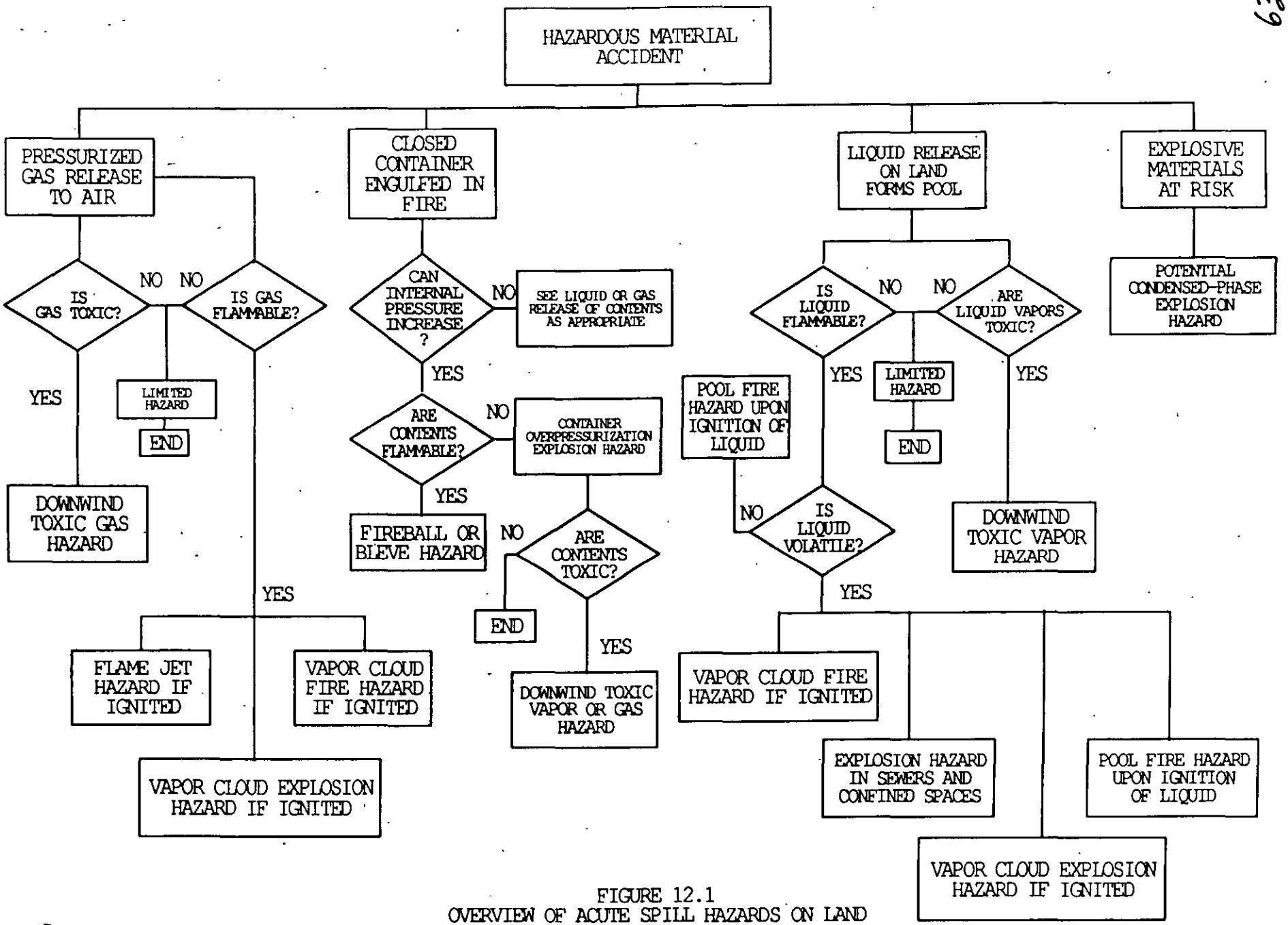


FIGURE 12.1
OVERVIEW OF ACUTE SPILL HAZARDS ON LAND

DIPLOMADO EN CONTROL DE LOS RESIDUOS GENERADOS EN HOSPITALES Y OTROS CENTROS DE SALUD

MARCO REGULATORIO EN MÉXICO

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INTRODUCCION

Los aspectos legales y normativos en México, relacionados con los residuos biológico-infecciosos (**RPBI**), se inscriben dentro de los ordenamientos establecidos para los residuos peligrosos (**RP**) en general. Dado que los **RPBI** caen dentro de la categoría de peligrosos, como se verá más adelante, en el presente documento se analiza primeramente el marco normativo de los **RP**, y, posteriormente, se particulariza sobre los ordenamientos que tratan directamente a los **RPBI**. En cualquier caso, en el desarrollo del marco normativo general se hará referencia a aquellos ordenamientos que tengan una relación directa con los **RPBI**.

Cabe señalar que, si bien son varias las dependencias del ejecutivo federal involucradas en la elaboración y publicación de ordenamientos relacionados con los **RP** y los **RPBI**, en este documento se presta especial atención a los ordenamientos generados por la Secretaría del Medio Ambiente, Recursos Naturales y Pesca (SEMARNAP) y dependencias que la precedieron (SEDUE; SEDESOL). Se incluyen también, aunque de manera menos detallada los ordenamientos relacionados emitidos por otras dependencias.

1. Marco jurídico general

El elemento normativo básico del cual emanan todos los ordenamientos jurídicos en México se encuentra constituido por la **Constitución Política de los Estados Unidos Mexicanos**. Por regla general, los ordenamientos jurídicos emanados de la Constitución son, en orden jerárquico, las leyes, los reglamentos, y las normas (normas oficiales mexicanas). Así, una ley sobre un concepto específico requiere de reglamentos y normas para que pueda ser aplicada. El siguiente esquema muestra la estructura jerárquica del sistema normativo general en México.

Constitución Política de los Estados Unidos Mexicanos
Leyes
Reglamentos
Normas Oficiales Mexicanas (NOM)

De esta manera, la estructura anterior adapta la siguiente forma para el caso particular de los residuos peligrosos:

Constitución Política de los Estados Unidos Mexicanos
Ley General del Equilibrio Ecológico y
la Protección al Ambiente (LGEEPA)
Reglamento de la LGEEPA en materia
de Residuos Peligrosos
Normas Oficiales Mexicanas en materia
de Residuos Peligrosos

En forma adicional, existen acuerdos, decretos, etc., mediante los cuales se publican ordenamientc obligaciones en relación a los **RP**. Existen, como se mencionó con anterioridad, otras dependencias del Ejecutivo que han emitido ordenamientos en relación a los **RP**, como son la Secretaría de Comunicaciones y Transportes (SCT), la Secretaría de Salud (SSA), etc. Ambos casos se tratan más adelante.

1.1 Constitución Política de los Estados Unidos Mexicanos

Este ordenamiento, promulgado el 5 de febrero de 1917, no menciona de manera explícita y directa aspectos relacionados con los **RP**. Sin embargo, establece claramente en varios de sus artículos los conceptos básicos que dan fundamento y origen a los ordenamientos de nivel jerárquico inferior.

De esta manera, en el artículo 4° se menciona el derecho de toda persona a la protección de su salud, señalando que el desequilibrio del ecosistema no afecte a la población y en especial al individuo. El artículo 24 se refiere al uso de los recursos productivos, cuidando su conservación y el medio ambiente, mientras que el artículo 27 incorpora el concepto de conservación de los recursos naturales, así como el de prestar atención a los centros de población para preservar y restaurar el equilibrio ecológico. Por su parte, el artículo 73 menciona el aspecto de expedición de leyes en materia de protección al ambiente y de preservación restauración del equilibrio ecológico.

1.2 Ley General del Equilibrio Ecológico y la Protección al Ambiente

Esta Ley fue publicada en el Diario Oficial de la Federación (DOF) el 28 de enero de 1988, estructurada en seis títulos y compuesta por un total de 194 artículos. En el Título Primero, Capítulo I (artículo 3°) define, entre otros conceptos, a los residuos peligrosos: "*todos aquellos residuos, en cualquier estado físico, que por sus características corrosivas, tóxicas, venenosas, reactivas, explosivas, inflamables,* ***biológicas, infecciosas*** *o irritantes representen un peligro para el equilibrio ecológico o el ambiente*".

El artículo 5° establece que la regulación de las actividades relacionadas con materiales o residuos peligrosos son asuntos de alcance general en la nación o de interés de la Federación. Los artículos 8° y 9° establecen las atribuciones de la Secretaría (actual **SEMARNAP**) en el ámbito de los **RP** frente a los otros niveles de gobierno.

Asimismo, el Capítulo V del Título Cuarto, está dedicado exclusivamente a los **RP**, si bien cuenta únicamente con cuatro artículos. El artículo 150 establece el compromiso de la Secretaría que determinará y publicará

el DOF los listados de materiales y residuos peligrosos. Cabe mencionar que a la fecha, aún no se han publicado los listados de *materiales* peligrosos. Por su parte, el artículo 151 determina la obligatoriedad de requerir la autorización previa de la Secretaría para instalar y operar sistemas de cualquier tipo de manejo de **RP**, y el artículo 152 determina que los **RP** deberán ser manejados con arreglo a las (entonces) normas técnicas ecológicas. Finalmente, el artículo 153 menciona las condiciones que deben observarse en la eventual importación y exportación de **RP**.

Como se puede desprender de lo anterior, los artículos de la LGEEPA estrechamente vinculados con los **RPBI** resultan ser el 3°,150, 151 y 152. Los dos primeros desde el punto de vista de la definición y clasificación de los **RPBI** como **RP**. El artículo 151 afecta directamente a todos aquellos interesados en prestar servicios de recolección, transporte, tratamiento o disposición final de **RPBI**, y el artículo 152 tiene injerencia tanto en los centros de generación de **RPBI** como en todos los sistemas de manejo y disposición final.

1.3 Reglamento de la Ley General del Equilibrio Ecológico y la Protección al Ambiente en Materia de Residuos Peligrosos

Posterior a la publicación de la LGEEPA, el 25 de noviembre de 1988 se publicó en el DOF el Reglamento de la Ley General del Equilibrio Ecológico y la Protección al Ambiente en Materia de Residuos Peligrosos, con objeto de proveer de un instrumento para el desarrollo y aplicación de los conceptos establecidos en la LGEEPA.

Este reglamento está estructurado en cinco capítulos ordenados de la siguiente manera:

Capítulo I. Disposiciones generales.

Capítulo II. De la generación de residuos peligrosos.

Capítulo III. Del manejo de residuos peligrosos

Capítulo IV. De la importación y exportación de residuos peligrosos.

Capítulo V. De las medidas de seguridad y control y sanciones.

Puesto que los **RPBI** caen dentro de la categoría de **RP**, todos los ordenamientos contemplados en este reglamento son aplicables a aquéllos. Sin embargo, es posible establecer que el Capítulo II tiene una mayor injerencia en relación a las fuentes generadoras, es decir, a las instituciones de atención médica, laboratorios, veterinarias, centros de investigación, etc. Por su parte, los conceptos del Capítulo III tendrán

una mayor aplicación en los prestadores de servicios de recolección, transporte, tratamiento y disposi final de **RPBI**, cuando estos servicios sean prestados por terceros.

Por otra parte, es de suponer que dada la propia naturaleza de los **RPBI**, no será común la importación/exportación de este tipo de residuos, por lo que los conceptos contemplados en el Capitulo IV no tendrán una aplicabilidad significativa en éste caso.

1.4. Normas Oficiales Mexicanas

En el último nivel de la estructura jerárquica del marco normativo, se encuentran las normas oficiales mexicanas (NOM) en materia de residuos peligrosos. A partir de 1988, la entonces Secretaría de Desarrollo Urbano y Ecología (SEDUE) publicó siete normas en materia de residuos peligrosos, denominadas en ese momento Normas Técnicas Ecológicas (NTE). Con la publicación de la Ley Federal de Metrología y Normalización, publicada el 16 de julio de 1992, se modificaron ciertas condiciones entre las cuales se planteaba la homogeneización de la nomenclatura de las normas mexicanas. De esta manera, mediante Decreto publicado el 29 de noviembre de 1994, las siete normas técnicas ecológicas en materia de **RP** actualmente presentan la siguiente nomenclatura (se anota entre paréntesis la anterior):

- **NOM-052-ECOL-1993**, que establece las características de los residuos peligrosos, el listado los mismos y los límites que hacen a un residuo peligroso por su toxicidad al ambiente (antes NOM-C**RP**-001-ECOL/93).
- **NOM-053-ECOL-1993**, que establece el procedimiento para llevar a cabo la prueba de extracción para determinar los constituyentes que hacen a un residuo peligroso por su toxicidad al ambiente (antes NOM-C**RP**-002-ECOL/93).
- **NOM-054-ECOL-1993**, que establece el procedimiento para determinar la incompatibilidad entre dos o más residuos considerados como peligrosos por la norma oficial mexicana NOM-052-ECOL-1993 (antes NOM-C**RP**-003-ECOL/93).
- **NOM-055-ECOL-1993**, que establece los requisitos que deben reunir los sitios destinados al confinamiento controlado de residuos peligrosos, excepto los radiactivos (antes NOM-C**RP**-004-ECOL/93).
- **NOM-056-ECOL-1993**, que establece los requisitos para el diseño y construcción de las obras complementarias de un confinamiento controlado de residuos peligrosos (ANTES NOM-C**RP**-005-ECOL/93).

- **NOM-057-ECOL-1993,** que establece los requisitos que deben observarse en el diseño, construcción y operación de celdas de un confinamiento controlado para residuos peligrosos (antes NOM-CRP-006-ECOL/93).
- **NOM-058-ECOL-1993,** que establece los requisitos para la operación de un confinamiento controlado de residuos peligrosos (antes NOM-CRP-007-ECOL/93).

Estas normas se convierten así en los instrumentos que permiten la aplicación última de los conceptos legales de la Ley y su Reglamento, y permiten a la autoridad competente la vigilancia y aplicación de sanciones en caso de infringir lo establecido en los mencionados ordenamientos.

Básicamente, la norma 052 se relaciona directamente con los **RPBI**, ya que en ella se catalogan como peligrosos bajo la clasificación **RPNE1.2/01** a **RPNE1.2/06**, en su Anexo 3, Tabla 2 (Clasificación de residuos por fuente no específica) de esta norma. Por su parte, las normas relativas a la disposición final de **RP** en confinamientos controlados se encuentran también relacionadas con los **RPBI**, ya que, como se verá más adelante, este destino es permitido para los **RPBI** por la actual normatividad bajo ciertas condiciones. Por lo tanto, para la disposición final de **RPBI** en celdas, se consideran como referencia los criterios de selección del sitio, construcción, operación, monitoreo y control de la celda, estipulados en las normas 055 y 057 principalmente.

Además de las siete normas anteriores, en 1995 se publicó una adicional con lo que actualmente se cuenta en México con ocho normas oficiales en materia de **RP**. Esta última norma trata directa y exclusivamente a los **RPBI**, por lo que se discute posteriormente de manera particular.

Por otro lado, es importante mencionar que actualmente existe un proyecto de **NOM** que "regula el control interno y el tratamiento térmico de residuos sólidos municipales, residuos peligrosos e industriales no peligrosos, estableciendo los límites máximos permisibles de emisión a la atmósfera en establecimientos que realicen esta actividad o que presten este servicio". La publicación de esta norma, como proyecto, se prevé para el segundo semestre de 1996, y tendrá aplicación para los operadores de incineradores de **RPBI** cuando entre en vigor, como norma definitiva. Resulta de suma importancia entonces, que aquellos promoventes interesados en ofrecer este servicio, consideren los parámetros de descarga a la atmósfera que deberán cumplir los equipos de incineración, a fin de evitar posibles problemas en su cumplimiento.

Finalmente, es importante señalar que existen otras **NOM** publicadas por la **SEMARNAP**, que si bien no están en relación directa con los **RPBI**, sí afectan a algunos prestadores de servicios en este ámbito. Tal es el caso de los propietarios de vehículos que transportan **RPBI**, los cuales deberán cumplir las **NOM** vigentes en materia de emisiones vehiculares a la atmósfera. Los límites permisibles y los parámetros requeridos

dependerán del combustible que se consuma y en ocasiones del peso vehicular de las unidades transporte. Asimismo, los establecimientos de tratamiento de **RPBI** que cuenten con calderas deberán cumplir con la normatividad vigente en materia de emisiones a la atmósfera por fuentes fijas. En este caso también la norma a observar dependerá de la capacidad del equipo y el combustible a utilizar.

No debe olvidarse tampoco la necesidad de cumplir con las concentraciones máximas permisibles en las descargas de aguas residuales de los centros de tratamiento de **RPBI**, las cuales pueden variar dependiendo del cuerpo receptor de la descarga, entre otros.

1.5 Otros ordenamientos

Además de los cuatro elementos de la estructura jerárquica descritos con anterioridad, existen otros ordenamientos publicados por la autoridad en materia ambiental en relación directa con los **RP**. Estos consisten básicamente en manifiestos que deben ser presentados y elaborados por los generadores de **RP** o bien por aquellas entidades dedicadas al manejo de los mismos. Estos documentos son:

- Manifiesto para empresas generadoras de **RP** (DOF 3 de mayo de 1989)
- Manifiesto de entrega, recepción y transporte de **RP** (DOF 3 de mayo de 1989)
- Manifiesto para casos de derrame de **RP** por accidente (DOF 3 de mayo de 1989)
- Reporte semestral de **RP** recibidos para reciclaje o tratamiento (DOF 3 de mayo de 1989)
- Reporte mensual de **RP** confinados en sitios de disposición final (DOF 3 de mayo de 1989)
- Reporte semestral de **RP** enviados para su reciclo, tratamiento, incineración o confinamiento (DOF 3 de mayo de 1989)
- Manifiesto para empresas generadoras eventuales de bifenilos policlorados (Gaceta Ecológica N° 11, noviembre 1990)

Con excepción del último manifiesto, la observancia en la elaboración y presentación de estos documentos aplica para los generadores de residuos biológico-infecciosos, así como para las empresas que ofrecen los servicios de recolección, transporte, tratamiento y disposición final (cuando aplique esta última opción).

Por otra parte, la **Dirección de Materiales, Residuos y Actividades Riesgosas** del Instituto Nacional de Ecología ha elaborado una Guía para realizar el protocolo de pruebas de los equipos destinado

tratamiento de **RPBI**. Si bien este documento no constituye un ordenamiento similar a los anteriores (Ley, Reglamento, normas, manifiestos), que han sido publicados en el DOF, es importante mencionarlo aquí, ya que es requisito darle cumplimiento para obtener el correspondiente permiso de operación para cualquier sistema de tratamiento de **RPBI**. Esta guía resulta sumamente útil, ya que describe de manera compendiada, los requisitos necesarios para otorgar el permiso para operar sistemas de tratamiento o de transporte de **RPBI**. Destacan los siguientes: Estudio de Impacto Ambiental, Estudio de Riesgo, Manifiesto de Manejo de Residuos Peligrosos, Protocolo de Pruebas, Licencia de Funcionamiento.

2. Marco jurídico particular

En la actualidad, el único ordenamiento emitido por la autoridad en materia ambiental, que se refiere de manera particular a los residuos biológico-infecciosos, se encuentra constituido por la norma oficial mexicana *NOM-087-ECOL-1995*, que establece los requisitos para la separación, envasado, almacenamiento, recolección, transporte, tratamiento y disposición final de los residuos peligrosos biológico-infecciosos que se generan en establecimientos que presten atención médica (publicada en el DOF el 11 de noviembre de 1995).

Esta norma define de manera particular a un residuo peligroso biológico infeccioso, como aquél "que contiene bacterias, virus u otros microorganismos con capacidad de causar infección o que contiene o puede contener toxinas producidas por microorganismos que causan efectos nocivos a seres vivos y al ambiente, que se generan en hospitales y establecimientos de atención médica".

Por su importancia, se incluye al término del presente documento, copia íntegra de la Norma 087. Cabe destacar aquí la importancia de su publicación y de su entrada en vigor, ya que en ella se encuentrá implícito un cambio radical en la manera en que se venían manejando los **RPBI** en México.

3. Ordenamientos de otras dependencias

Además de la autoridad en materia ambiental, existen otras dependencias del ejecutivo federal que han elaborado y publicado ordenamientos que se relacionan directa o indirectamente con el manejo de los **RPBI**. A continuación se mencionan los más importantes.

3.1. Secretaría de Salud

La Secretaría de Salud es la dependencia del Ejecutivo Federal responsable de la elaboración y publicación de ordenamientos con un enfoque de la protección de la salud de los mexicanos.

La Ley General de Salud , signada el 26 de diciembre de 1983, contempla algunos conceptos relaciona con los **RPBI**, específicamente referidos a los tejidos y órganos, entre otros. En su artículo 334, establece que "cualquier órgano o tejido que haya sido desprendido o seccionado... deberá ser manejado en condiciones higiénicas y su destino final será la incineración, salvo que se requiera para fines terapéuticos, de docencia o de investigación...". Este requerimiento ha sido considerado, como se ha visto, en la norma 087 descrita en el Capítulo 2.

Por su parte, de la mencionada Ley se deriva el Reglamento de la Ley General de Salud en materia de control sanitario de la disposición de órganos, tejidos y cadáveres de seres humanos, el cual complementa a la Ley en lo que se refiere a lo dispuesto en su Art. 334 citado.

3.2. Secretaría de Comunicaciones y Transportes

Esta dependencia es la responsable de elaborar y publicar los ordenamientos necesarios en materia de transporte de **RP** en vías generales de comunicación terrestre. En consecuencia, aquellos interesados en prestar el servicio de transporte de **RPBI**, sean los propios generadores o un tercero, deberán apegarse a lo establecido en la normatividad emitida por la SCT, cuando los vehículos que en su interior transporten **RPBI** transiten por las mencionadas vías de comunicación.

3.2.1 Reglamento para el Transporte Terrestre de Materiales y Residuos Peligrosos

Este Reglamento, publicado en el DOF el 7 de abril de 1993, está estructurado en nueve títulos que comprenden 136 artículos, ordenados de la siguiente manera:

- *Título* Primero — Disposiciones Generales
- *Título Segundo* — Del envase y el embalaje
- *Título Tercero* — De las características, especificaciones y equipamiento de los vehículos motrices y unidades de arrastre a utilizar
- *Título Cuarto* — De las condiciones de seguridad
- *Título Quinto* — Del transporte en vías de jurisdicción federal
- *Título Sexto* — De las disposiciones especiales del transporte de residuos peligrosos
- *Título Séptimo* — De la responsabilidad
- *Título Octavo* — De las obligaciones específicas

Conviene señalar aquí que la SCT no se apega a la clasificación de **RP** establecido en la **NOM-052-ECOL-1993**, sino que utiliza en este Reglamento una clasificación de las substancias peligrosas, aun cuando el título del mismo menciona a los **RP**. Esto se deriva del hecho que existen sustancias peligrosas que no son residuos, frecuentemente mucho más peligrosas que estos últimos, por lo que se tiene que establecer una forma de clasificación más amplia. Existe por otra parte el hecho de que, como se ha mencionado con anterioridad, la **SEMARNAP** no ha elaborado aún el listado de materiales peligrosos, como lo establece la LGEEPA de 1988. La clasificación establecida por la SCT para las substancias peligrosas es como sigue:

Clase 1	Explosivos
Clase 2	Gases comprimidos, refrigerados, licuados o disueltos a presión
Clase 3	Líquidos inflamables
Clase 4	Sólidos inflamables
Clase 5	Oxidantes y peróxidos orgánicos
Clase 6	Tóxicos agudos (venenos) y agentes infecciosos
Clase 7	Radiactivos
Clase 8	Corrosivos
Clase 9	Varios.

Para la SCT, los **RPBI** caerían dentro de la Clase 6, la cual contempla dos divisiones:

- ***División 6.1*** *Tóxicos agudos* (venenos): son aquellas substancias que pueden causar la muerte, lesiones graves o ser nocivas para la salud humana si se ingieren, inhalan o entran en contacto con la piel. Los gases tóxicos (venenos) comprimidos pueden incluirse en la clase "Gases".
- ***División 6.2*** *Agentes Infecciosos*: son los que contienen microorganismos viables incluyendo bacterias, virus, parásitos, hongos, o una combinación híbrida o mutante; que son conocidos o se cree que pueden provocar enfermedades en el hombre o en los animales.

Cabe mencionar que estas definiciones son anteriores a la definición de **RPBI** que se incluye en la norma 087 ya discutida.

3.2.2 Normas Oficiales Mexicanas

Con objeto de dotar a la autoridad competente, con instrumentos específicos para la aplicación del Reglamento descrito en el apartado anterior, la SCT ha publicado una serie de normas oficiales mexicanas relacionadas con el transporte terrestre de materiales y residuos peligrosos. A continuación se mencionan aquellas normas que pueden tener relación con el transporte de **RPBI**.

- **NOM-003-SCT2-1993**. Características de las etiquetas de envases y embalajes destinadas al transporte de materiales y residuos peligrosos.
- **NOM-004-SCT2-1994**. Sistema de identificación de unidades destinadas al transporte terrestre de materiales y residuos peligrosos.
- **NOM-005-SCT2-1994**. Información de emergencia para el transporte terrestre de substancias, materiales y residuos peligrosos.
- **NOM-006-SCT2-1994**. Aspectos básicos para la revisión ocular diaria de la unidad destinada al autotransporte de materiales y residuos peligrosos.
- **NOM-007-SCT2-1994**. Marcado de envases y embalajes destinados al transporte de sustancias y residuos peligrosos.
- **NOM-010-SCT2-1994**. Disposiciones de compatibilidad y segregación para el almacenamiento , transporte de substancias, materiales y residuos peligrosos.
- **NOM-012-SCT2-1994**, sobre el peso y dimensiones máximas que deben cumplir los vehículos de autotransporte que transitan en los caminos y puentes de jurisdicción federal.
- **NOM-019-SCT2-1994**. Disposiciones generales para la limpieza y control de remanentes de substancias y residuos peligrosos en las unidades que transportan materiales y residuos peligrosos.
- **NOM-021-SCT2-1994**. Disposiciones generales para transportar otro tipo de bienes diferentes a las substancias, materiales y residuos peligrosos en unidades destinadas al traslado de materiales y residuos peligrosos.
- **NOM-043-SCT2-1995**. Documento de embarque de substancias, materiales y residuos peligrosos.
- **NOM-051-SCT2-1994**. Especificaciones especiales y adicionales para el envase y embalaje de los materiales peligrosos de la División 6.2 Substancias Infecciosas.

PODER EJECUTIVO

SECRETARIA DE MEDIO AMBIENTE, RECURSOS NATURALES Y PESCA

NORMA Oficial Mexicana NOM-087-ECOL-1995, Que establece los requisitos para la separación, envasado, almacenamiento, recolección, transporte, tratamiento y disposición final de los residuos peligrosos biológico-infecciosos que se generan en establecimientos que presten atención médica.

Al margen un sello con el Escudo Nacional, que dice. Estados Unidos Mexicanos - Secretaría de Medio Ambiente, Recursos Naturales y Pesca

NORMA OFICIAL MEXICANA NOM-087-ECOL-1995, QUE ESTABLECE LOS REQUISITOS PARA LA SEPARACION, ENVASADO, ALMACENAMIENTO, RECOLECCION, TRANSPORTE, TRATAMIENTO Y DISPOSICION FINAL DE LOS RESIDUOS PELIGROSOS BIOLOGICO-INFECCIOSOS QUE SE GENERAN EN ESTABLECIMIENTOS QUE PRESTEN ATENCION MEDICA

JULIA CARABIAS LILLO, Secretaria de Medio Ambiente, Recursos Naturales y Pesca, con fundamento en lo dispuesto por los artículos 32 bis fracciones I, II, IV y V de la Ley Orgánica de la Administración Pública Federal, 5o fracciones I, VIII y XIX, 8o fracciones I, II y VII, 36, 37, 151, 152, 160 primer párrafo, 162 y 171 de la Ley General del Equilibrio Ecológico y la Protección al Ambiente, 1o 2o y 4o fracciones II, III y IV, 5o , 6o y 58 de su Reglamento en Materia de Residuos Peligrosos, 38 fracción II, 40 fracciones I y III, 41, 43, 44, 45, 46 y 47 de la Ley Federal sobre Metrología y Normalización, y

CONSIDERANDO

Que en cumplimiento a lo dispuesto en la fracción I del artículo 47 de la Ley Federal sobre Metrología y Normalización, el 19 de agosto de 1994 se publicó en el **Diario Oficial de la Federación**, con carácter de Proyecto, la presente Norma, bajo una denominación ampliada, a fin de que los interesados, en un plazo de 90 días naturales, presentaran sus comentarios al Comité Consultivo Nacional de Normalización para la Protección Ambiental, sito en Río Elba número 20, 1er. piso, colonia Cuauhtémoc, código postal 06500, México, D F.

Que durante el plazo a que se refiere el considerando anterior, de conformidad con lo dispuesto en el artículo 45 del Ordenamiento Legal citado en el párrafo anterior, estuvieron a disposición del público los documentos a que se refiere dicho precepto

Que en el plazo a que hace referencia el considerando primero, los interesados presentaron sus comentarios al Proyecto de Norma, los cuales fueron analizados por el citado Comité Consultivo Nacional de Normalización, realizándose las modificaciones procedentes La Secretaría de Medio Ambiente, Recursos Naturales y Pesca publicó las respuestas a los comentarios recibidos en el **Diario Oficial de la Federación**, de fecha 20 de septiembre de 1995

Que habiéndose cumplido el procedimiento establecido en la Ley Federal sobre Metrología y Normalización para la elaboración de Normas Oficiales Mexicanas, el Comité Consultivo Nacional de Normalización para la Protección Ambiental, en sesión de fecha 12 de junio de 1995, aprobó la Norma Oficial Mexicana NOM-087-ECOL-1995, bajo una denominación ampliada que establece los requisitos para la separación, envasado, almacenamiento, recolección, transporte, tratamiento y disposición final de los residuos peligrosos biológico-infecciosos que se generan en establecimientos que presten atención médica, por lo que he tenido a bien expedir la siguiente

NORMA OFICIAL MEXICANA NOM-087-ECOL-1995, QUE ESTABLECE LOS REQUISITOS PARA LA SEPARACION, ENVASADO, ALMACENAMIENTO, RECOLECCION, TRANSPORTE, TRATAMIENTO Y DISPOSICION FINAL DE LOS RESIDUOS PELIGROSOS BIOLOGICO-INFECCIOSOS QUE SE GENERAN EN ESTABLECIMIENTOS QUE PRESTEN ATENCION MEDICA

INDICE

0. Introducción

El manejo de los residuos peligrosos biológico-infecciosos en los establecimientos que prestan atención médica constituyen un gran problema a nivel nacional, por lo que es necesario el establecimiento de requisitos para su control.

1. Objetivo y campo de aplicación

Esta Norma Oficial Mexicana establece los requisitos para la separación, envasado, almacenamiento, recolección, transporte, tratamiento y disposición final de los residuos biológico-infecciosos que se generen en establecimientos que presten atención médica, tales como clínicas y hospitales, así como laboratorios clínicos, laboratorios de producción de agentes biológicos, de enseñanza y de investigación, tanto humanos como veterinarios en pequeñas especies y centros antirrábicos, y es de observancia obligatoria en dichos establecimientos, cuando éstos generen más de 25 kg (veinticinco kilogramos) al mes o 1 kg (un kilogramo) al día de los residuos peligrosos contemplados en esta Norma

2. Referencias

** NOM-052-ECOL-1993 Que establece las características de los residuos peligrosos, el listado de los mismos y los límites que hacen a un residuo peligroso por su toxicidad al ambiente, publicada en el **Diario Oficial de la Federación** el 22 de octubre de 1993

** NOM-029-ECOL-1993 Que establece los límites máximos permisibles de contaminantes en las descargas de aguas residuales a cuerpos receptores provenientes de hospitales, publicada en el **Diario Oficial de la Federación** el 18 de octubre de 1993

** NOM-031-ECOL-1993 Que establece los límites máximos permisibles de contaminantes en las descargas de aguas residuales provenientes de la industria, actividades agroindustriales, de servicios y el tratamiento de aguas residuales a los sistemas de drenaje y alcantarillado urbano o municipal, publicada en el **Diario Oficial de la Federación** el 18 de octubre de 1993.

* NMX-DGN Z-21 Magnitudes y unidades de base del sistema internacional (SI)

* Norma Mexicana

** Norma Oficial Mexicana

3. Definiciones

3.1 Agente biológico

Preparación de microorganismos, sus metabolitos o derivados que se utilizan con fines terapéuticos o de investigación.

3.2 Atención médica

El conjunto de servicios que se proporcionan con el fin de proteger, promover y restaurar la salud humana y animal

3 3 Cepa

Cultivo puro de microorganismos procedente de un aislamiento

3 4 Combustión

Método de tratamiento que consiste en la oxidación de los residuos mediante procesos controlados a altas temperaturas

3.5 Cremación

Proceso para la destrucción de partes orgánicas y residuos patológicos mediante la combustión.

3.6 Desinfección.

Destrucción de los microorganismos patógenos en todos los ambientes, materias o partes en que pueden ser nocivos, por los distintos medios mecánicos, físicos o químicos contrarios a su vida o desarrollo, con el fin de reducir el riesgo de transmisión de enfermedades.

3.7 Ductos neumáticos o de gravedad.

Sistemas de conductos que son utilizados para el transporte de residuos, usando como fuerza motriz, aire a presión, vacío o gravedad.

3.8 Establecimiento de atención médica

El lugar público o privado, fijo o móvil cualquiera que sea su denominación, que preste servicios de atención médica, ya sea ambulatorio o para internamiento de seres humanos y animales.

3.9 Muestra biológica

Fracción de tejido o fluido corporal que se extrae de organismos vivos para su análisis, durante su diagnóstico o tratamiento

3.10 Organo

La entidad morfológica compuesta por la agrupación de tejidos diferentes que concurren al desempeño del mismo trabajo fisiológico.

3.11 Residuo peligroso biológico-infeccioso.

El que contiene bacterias, virus u otros microorganismos con capacidad de causar infección o que contiene o puede contener toxinas producidas por microorganismos que causan efectos nocivos a seres vivos y al ambiente, que se generan en establecimientos de atención médica.

3.12 Sangre.

El tejido hemático con todos sus elementos.

3.13 Tejido

La entidad morfológica compuesta por la agrupación de células de la misma naturaleza, ordenadas con regularidad y que desempeñan una misma función.

3.14 Tratamiento de residuos peligrosos biológico-infecciosos.

El método que elimina las características infecciosas de los residuos peligrosos biológico-infecciosos

4. Clasificación de los residuos peligrosos biológico-infecciosos

Para efectos de esta Norma Oficial Mexicana y de acuerdo con lo establecido en la NOM-052-ECOL-1993, que establece las características de los residuos peligrosos, el listado de los mismos y los límites que hacen a un residuo peligroso por su toxicidad al ambiente, publicada en el **Diario Oficial de la Federación** el 22 de octubre de 1993, se consideran residuos peligrosos biológico-infecciosos los siguientes:

4.1 La sangre

4.1.1 Los productos derivados de la sangre incluyendo, plasma, suero y paquete globular.

4.1.2 Los materiales con sangre o sus derivados, aun cuando se hayan secado, así como los recipientes que los contienen o contuvieron

4.2 Los cultivos y cepas almacenadas de agentes infecciosos

4.2.1 Los cultivos generados en los procedimientos de diagnóstico e investigación, así como los generados en la producción de agentes biológicos

4.2.2 Los instrumentos y aparatos para transferir, inocular y mezclar cultivos.

4.3 Los patológicos

4.3.1 Los tejidos, órganos, partes y fluidos corporales que se remueven durante las necropsias la cirugía o algún otro tipo de intervención quirúrgica

4.3.2 Las [illegible]as biológicas para análisis químico, microbiológico citológico o histológico

4.3.3 Los cadáveres de pequeñas especies animales provenientes de clínicas veterinarias, centros antirrábicos o los utilizados en los centros de investigación

4.4 Los residuos no anatómicos derivados de la atención a pacientes y de los laboratorios

4.4.1 El equipo, material y objetos utilizados durante la atención a humanos o animales

4.4.2 Los equipos y dispositivos desechables utilizados para la exploración y toma de muestras biológicas

4.5 Los objetos punzocortantes usados o sin usar.

4.5.1 Los que han estado en contacto con humanos o animales o sus muestras biológicas durante el diagnóstico y tratamiento, incluyendo navajas, lancetas, jeringas, pipetas Pasteur, agujas hipodérmicas, de acupuntura y para tatuaje, bisturíes, cajas de Petri, cristalería entera o rota, porta y cubre objetos, tubos de ensayo y similares.

5. Clasificación de los establecimientos generadores de residuos peligrosos biológico-infecciosos

5.1 Para efectos de esta Norma Oficial Mexicana, los establecimientos de atención médica se clasifican como se establece en la Tabla 1

Tabla 1

NIVEL I	NIVEL II	NIVEL III
* Clínicas de consulta externa y veterinarias en pequeñas especies	* Hospitales que tengan de 1 a 50 camas	* Hospitales con más de 50 camas
* Laboratorios clínicos que realicen de 1 a 20 análisis al día	* Laboratorios clínicos que realicen de 21 a 100 análisis al día.	* Laboratorios clínicos que realicen más de 100 análisis clínicos al día * Laboratorios para la producción de biológicos. * Centros de enseñanza e investigación. * Centros antirrábicos.

5.2 Las unidades médicas independientes que se encuentren ubicadas en un mismo inmueble y que generen en su conjunto residuos peligrosos en los términos y cantidades señalados en esta Norma, deberán designar un representante común quien será el responsable del manejo de estos residuos.

Las obligaciones a que queden sujetas las unidades médicas señaladas en el párrafo anterior, serán determinadas por la Secretaría de Medio Ambiente, Recursos Naturales y Pesca, a través del Instituto Nacional de Ecología

6. Manejo

6.1 Los establecimientos referidos en la Tabla 1 de esta Norma Oficial Mexicana, además de cumplir con lo establecido en el Reglamento de la Ley General del Equilibrio Ecológico y la Protección al Ambiente en Materia de Residuos Peligrosos, deberán cumplir con las siguientes fases de manejo de sus residuos

6.1.1 Identificación de los residuos y de las actividades que los generan

6.1.2 Envasado de los residuos generados

6.1.3 Recolección y transporte interno

6.1.4 Almacenamiento temporal

6.1.5 Recolección y transporte externo

6.1.6 Tratamiento

6.1.7 Disposición final

6.2 Identificación y envasado

6.2.1 Se deberán separar y envasar todos los residuos peligrosos biológico infecciosos generados en establecimientos de atención médica, de acuerdo con sus características físicas y biológico infecciosas conforme a la Tabla 2 de esta Norma Oficial Mexicana

Tabla 2

TIPO DE RESIDUOS	ESTADO FISICO	ENVASADO	COLOR
4.1 Sangre 4.2 Cultivos y cepas almacenadas de agentes infecciosos	Sólidos	Bolsa de plástico	Rojo
4.4 Residuos no anatómicos derivados de la atención a pacientes y los laboratorios	Líquidos	Recipientes herméticos	Rojo
4.3 Patológicos	Sólidos	Bolsa de plástico	Amarillo
	Líquidos	Recipientes herméticos	Amarillo
4.5 Objetos punzocortantes usados y sin usar	Sólidos	Recipientes rígidos	Rojo

6.2.2 Los recipientes de los residuos peligrosos punzocortantes deben ser rígidos, de polipropileno, resistentes a fracturas y pérdida del contenido al caerse, destruibles por métodos fisicoquímicos, esterilizables, con una resistencia mínima de penetración de 12 5 N (doce punto cinco Newtons) en todas sus partes y tener tapa con o sin separador de agujas y abertura para depósito con dispositivos para cierre seguro. Deben ser de color rojo y libres de metales pesados y cloro, debiendo estar etiquetados con la leyenda que indique "PELIGRO, RESIDUOS PUNZOCORTANTES BIOLOGICO-INFECCIOSOS" y marcados con el símbolo universal de riesgo biológico (Anexo 1) de esta Norma Oficial Mexicana

6.2.2.1 La resistencia mínima de penetración será determinada por la medición de la fuerza requerida para penetrar los lados y la base con una aguja hipodérmica calibre 21, mediante dispositivos como el Instrón, Calibrador de Fuerza Chatillón o tensiómetro

6.2.2.2 Una vez llenos, los recipientes no deben ser abiertos o vaciados

6.2.3 Los recipientes de los residuos peligrosos líquidos deben ser rígidos, con tapa hermética, etiquetados con una leyenda que indique "PELIGRO, RESIDUOS PELIGROSOS LIQUIDOS BIOLOGICO-INFECCIOSOS" y marcados con el símbolo universal de riesgo biológico (Anexo 1)

6.3 Recolección y transporte interno.

6.3.1 Se destinarán carritos manuales de recolección exclusivamente para la recolección y depósito en el área de almacenamiento

6.3.1.1 Los carritos manuales de recolección se desinfectarán diariamente con vapor o con algún producto químico que garantice sus condiciones higiénicas

6.3.1.2 Los carritos manuales de recolección deberán tener la leyenda, "USO EXCLUSIVO PARA RESIDUOS PELIGROSOS BIOLOGICO-INFECCIOSOS" y marcado con el símbolo universal de riesgo biológico (Anexo 1) de esta Norma Oficial Mexicana.

6.3.1.3 El diseño del carrito manual de recolección deberá prever la seguridad en la sujeción de las bolsas y los contenedores, así como el fácil tránsito dentro de la instalación

6.3.1.4 Los carritos manuales de recolección no deberán rebasar su capacidad de carga durante su uso

6.3.2 No podrán utilizarse ductos neumáticos o de gravedad como medio de transporte interno de los residuos peligrosos biológico-infecciosos, tratados o no tratados

6.3.3 Se deberán establecer rutas de recolección para su fácil movimiento hacia el área de almacenamiento

6.3.4 El equipo mínimo de protección del personal que efectúe la recolección consistirá en uniforme completo, guantes y mascarilla o cubreboca Si se manejan residuos líquidos se deberán usar anteojos de protección

6 3.5 Los establecimientos de atención médica pertenecientes al nivel I quedarán exentos del cumplimiento de los puntos 6 3 1 y 6 3 3

6.4 Almacenamiento.

6.4.1 Se deberá destinar un área para el almacenamiento de los residuos peligrosos biológico infecciosos.

6.4.1.1 Los establecimientos que correspondan al nivel I quedarán exentos del cumplimiento del punto 6.4.4, pudiendo ubicar los contenedores del punto 6.4 2 en el lugar más apropiado dentro de sus instalaciones de manera tal que no obstruyan las vías de acceso y sean movidos sólo durante las operaciones de recolección.

6.4.2 Los residuos peligrosos biológico-infecciosos envasados deberán almacenarse en contenedores con tapa y rotulados con el símbolo universal de riesgo biológico, con la leyenda "PELIGRO, RESIDUOS PELIGROSOS BIOLOGICO-INFECCIOSOS".

6.4.3 El periodo de almacenamiento temporal a temperatura ambiente estará sujeto al tipo de establecimiento, como sigue:

6.4.3.1 Nivel I, hasta 7 días.

6.4.3.2 Nivel II: hasta 96 horas.

6.4.3.3 Nivel III: hasta 48 horas.

6.4.3.4 Los residuos patológicos, humanos o de animales deberán conservarse a una temperatura no mayor de 4 °C. (cuatro grados centígrados)

6.4.4 El área referida en el punto 6.4 1 debe

6.4.4.1 Estar separada de las siguientes áreas: de pacientes, visitas, cocina, comedor, instalaciones sanitarias, sitios de reunión, áreas de esparcimiento, oficinas, talleres y lavandería.

6.4.4.2 Estar techada y ubicada donde no haya riesgo de inundación y que sea de fácil acceso

6.4.4.3 Contar con extinguidores de acuerdo al riesgo asociado

6.4.4.4 Contar con muros de contención lateral y posterior con una altura mínima de 20 cm (20 centímetros) para detener derrames

6.4.4.5 Contar con señalamientos y letreros alusivos a la peligrosidad de los mismos, en lugares y formas visibles

6.4.4.6 Contar con una pendiente del 2% (dos por ciento) en sentido contrario a la entrada.

6.4.4.7 No deben existir conexiones con drenaje en el piso, válvulas de drenaje, juntas de expansión, albañales o cualquier otro tipo de comunicación que pudiera permitir que los líquidos fluyan fuera del área protegida.

6.4.4.8 Tener una capacidad mínima, de tres veces el volumen promedio de residuos peligrosos biológico-infecciosos generados diariamente

6.4.4.9 El acceso a esta área sólo se permitirá al personal responsable de estas actividades y se deberán realizar las adecuaciones en las instalaciones para los señalamientos de acceso respectivos

6.4.4.10 El diseño, la construcción y la ubicación de las áreas de almacenamiento temporal destinadas al manejo de residuos peligrosos biológico-infecciosos deberán contar con la autorización correspondiente por parte de la Secretaría de Medio Ambiente, Recursos Naturales y Pesca, a través del Instituto Nacional de Ecología.

6.5 Recolección y transporte externo

6.5.1 La recolección y el transporte de los residuos peligrosos referidos en el punto 1 de esta Norma Oficial Mexicana, deberá realizarse conforme a lo dispuesto en el Reglamento de la Ley General del Equilibrio Ecológico y la Protección al Ambiente en Materia de Residuos Peligrosos, en el Reglamento para el Transporte Terrestre de Materiales y Residuos Peligrosos y en las normas oficiales mexicanas aplicables y deberá cumplir lo siguiente

6 5.2 Sólo podrán recolectarse los residuos que cumplan con el envasado, embalado y etiquetado o rotulado como se establece en el punto 6 2 de esta Norma Oficial Mexicana

6.5 3 Los residuos peligrosos biológico-infecciosos no deberán ser compactados durante su recolección y transporte

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6.5.4 Los contenedores referidos en el punto 6 4 2 deberán ser lavados y desinfectados despues de cada ciclo de recolección

6.5 5 Los vehículos recolectores deberán ser de caja cerrada, hermética y contar con sistemas de captación de escurrimientos, además de sistemas mecanizados de carga y descarga

6.5.5.1 Las unidades para el transporte de residuos peligrosos biológico infecciosos deberan contar con sistemas de enfriamiento para mantener los residuos a una temperatura de 4 °C (cuatro grados centigrados) cuando la Secretaría de Medio Ambiente, Recursos Naturales y Pesca lo considere necesario

6.5.6 Los residuos peligrosos biológico-infecciosos sin tratamiento, no deberán mezclarse con ningun otro tipo de residuos municipales o de origen industrial durante su transporte

6.6 Tratamiento.

6.6.1 Los residuos peligrosos biológico-infecciosos deberán ser tratados por métodos físicos o químicos.

6.6.2 Los métodos de tratamiento serán autorizados por la Secretaría de Medio Ambiente, Recursos Naturales y Pesca, a través del Instituto Nacional de Ecología y deberán cumplir los siguientes criterios generales.

6.6.2.1 Deberá garantizar la eliminación de microorganismos patógenos, y

6.6.2.2 Deberán volver irreconocibles a los residuos peligrosos biológico-infecciosos.

6.6.3 Los residuos patológicos deben ser cremados, excepto aquéllos que estén destinados a fines terapéuticos, de investigación y docencia

6.6.4 Los métodos de tratamiento deberán cumplir previo, a su autorización, un protocolo de pruebas que al efecto determine la Secretaría de Medio Ambiente, Recursos Naturales y Pesca, a través del Instituto Nacional de Ecología.

6.6.5 El tratamiento podrá realizarse dentro del establecimiento generador o en instalaciones específicas fuera del mismo En ambos casos se requerirá la autorización de la Secretaría de Medio Ambiente, Recursos Naturales y Pesca, a través del Instituto Nacional de Ecología

6 7 Los establecimientos que presten atención médica deberán presentar su programa de contingencias en caso de derrames, fugas o accidentes relacionados con el manejo de estos residuos

7. Disposición final

7.1 Una vez tratados e irreconocibles, los residuos peligrosos biológico-infecciosos se eliminarán como residuos no peligrosos.

7.2 En localidades con una población hasta de 100,000 habitantes se podrán disponer los residuos peligrosos biológico-infecciosos sin tratamiento, en celdas especiales, conforme a lo establecido en el Anexo 2 de esta Norma Oficial Mexicana

7.2.1 El diseño, la construcción y la operacion de las celdas especiales serán autorizados por la Secretaría de Medio Ambiente, Recursos Naturales y Pesca, a través del Instituto Nacional de Ecología

8. Grado de concordancia con normas y recomendaciones internacionales

8.1 Los elementos y preceptos de orden técnico y jurídico en esta Norma Oficial Mexicana se basan en los fundamentos técnicos y científicos reconocidos internacionalmente.

9. Bibliografía

9.1 ASTM-D-882-83 Métodos de prueba para propiedades de tensión de hojas plásticas delgadas.

9.2 ASTM-D-1004-66 Metodos de prueba para resistencia a desgarre inicial de peliculas y hojas de plástico

9.3 British Standard Institution BS 7320 1990 Specification for Sharp Containers (Especificaciones para contenedores de punzantes)

9 4 CDC Guidelines for Isolation Precautions in Hospitals (Lineamientos de la CDC sobre Precauciones de Aislamiento en Hospitales) Infection Control 4 145 325 1983

9 5 [illegible] Biosafety in Microbiological and Biomedical Laboratories (Bioseguridad en Laboratorios Biomédicos y Microbiológicos) Atlanta U.S.A. 1984

9.6 Code of Federal Regulations Parts 53 to 60 (Código Federal de Regulaciones, partes 53 a 60) 1991

9.7 Commission of the European Communities Survey of the Collection, Recycling and Safe Disposal of Hospital Wastes in the Member States of the European Communities (Investigación sobre la Recolección Reciclaje y Disposición Segura de Residuos Hospitalarios en los Estados Miembros de las Comunidades Europeas) 1982

9.8 Gordon J., Zank N , Brooks K , Cofone L , R Howard, Canellos G , Goldgraben R , Cioffi J. Disposal of Hospital Wastes Containing Pathogenic Organisms Final Report (Reporte Final sobre la Disposición de Residuos Hospitalarios que Contienen Organismos Patógenos) 1979

9.9 Hospital Solid Waste Disposal in Community Facilities (Disposición de Residuos Sólidos Hospitalarios en Instalaciones Comunitarias), NTS Report PB-222 018/4 1973

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9.11 Monreal J , Zepeda F. Consideraciones sobre el Manejo de Residuos de Hospitales en América Latina. OPS/OMS, 1991

9.12 Review of Federal/State Medical Waste Management (Revisión del Manejo de Residuos Médicos Federales y Estatales). Report No EPA/600/d-91/038. 17 pp 1991.

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9.15 Rutala, W A. Odette R. L , SAMSA, Management of infectious Waste by U S. Hospitals (Manejo de Residuos Infecciosos de Hospitales en Estados Unidos) JAMA 262(12), 1635-1640, 1989.

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9.17 USEPA. EPA Guide for Infectious Waste Management (Guía de la EPA para el Manejo de Residuos Infecciosos). Office of Solid Waste and Emergency Response EPA-530SW-86-014, 1986.

10. Observancia de esta Norma

10.1 La vigilancia del cumplimiento de la presente Norma Oficial Mexicana corresponde a la Secretaría de Medio Ambiente, Recursos Naturales y Pesca, a través de la Procuraduría Federal de Protección al Ambiente con la intervención procedente de la Secretaría de Salud, en el ámbito de sus respectivas competencias Las violaciones a la misma se sancionarán en los términos de la Ley General del Equilibrio Ecológico y la Protección al Ambiente, su Reglamento en Materia de Resíduos Peligrosos y demás ordenamientos jurídicos aplicables

10.2 Los Gobiernos del Distrito Federal, de los Estados y de los Municipios, podrán realizar actos de inspección y vigilancia para la verificación del cumplimiento de esta Norma Oficial Mexicana, previa la publicación en el Diario Oficial de la Federación de los acuerdos de coordinación que se celebren con la Secretaría de Medio Ambiente, Recursos Naturales y Pesca

TRANSITORIOS

PRIMERO. La presente Norma Oficial Mexicana entrará en vigor 180 días después de su publicacion en el Diario Oficial de la Federación

SEGUNDO. Los establecimientos generadores de residuos peligrosos biológico infecciosos deberán cumplir con la fase de manejo señalada en el punto 6 6, 90 días despues de la entrada en vigor de la presente Norma

Dada en la Ciudad de México, Distrito Federal, a los veinticinco días del mes de septiembre de mil novecientos noventa y cinco - La Secretaria de Medio Ambiente, Recursos Naturales y Pesca Julia Carabias Lillo - Rubrica

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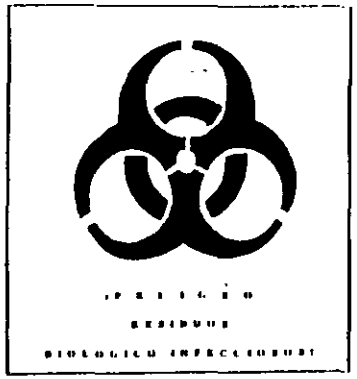
ANEXO 1

SIMBOLO UNIVERSAL DE RIESGO BIOLOGICO



ANEXO 2

CELDAS ESPECIALES PARA LA DISPOSICION DE RESIDUOS PELIGROSOS BIOLOGICO-INFECCIOSOS

1. Selección del sitio

El sitio destinado para la construcción de las celdas especiales cumplirá los siguientes requisitos

1.1 Generales.

1.1.1 Restricción por afectación a obras civiles o zonas protegidas.

1.1.1.1 Las distancias mínimas a aeropuertos serán de 3,000 m (tres mil metros), cuando maniobren aviones con motor de turbina 1,500 m (mil quinientos metros), cuando maniobren aviones con motor de pistón

1.1.1.2 Respetar las áreas de protección, derecho de vías de autopistas, caminos principales y caminos secundarios.

1.1.1.3 No ubicarse dentro de áreas protegidas

1.1.1.4 Respetar los derechos de vía de obras civiles tales como oleoductos, gasoductos, poliductos, torres de energía eléctrica, acueductos, etc

1.2 Hidrológicos

1.2.1 Ubicarse fuera de zonas de inundación con periodos de retorno de 100 años En caso de no cumplir lo anterior, deberá demostrar que no existe obstrucción del flujo en el área de inundación o la posibilidad de deslaves o erosión que provoquen arrastre de los residuos sólidos que pongan en peligro la salud y el ambiente.

1.2.2 No ubicarse en zonas de pantanos, marismas y similares

1.2.3 La distancia de ubicación con respecto a cuerpos de aguas superficiales, será de 300 m (trescientos metros) como mínimo y garantizar que no exista afectación a la salud y al ambiente

1.3 Geológicos

1.3.1 Ubicarse a una distancia no menor de 60 m (sesenta metros) de una falla activa con desplazamiento en un periodo de un millón de años

1.3.2 Ubicarse fuera de zonas donde los taludes sean inestables, es decir, que puedan producir movimiento de suelo o roca por procesos estáticos y dinámicos

1.3.3 Evitar zonas donde existan o se puedan generar asentamientos diferenciales que lleven al fracturamiento o fallamiento del terreno que incrementen el riesgo de contaminación al acuífero

1.4 Hidrogeológicos

1.4.1 En caso de que el sitio para la disposición final de los residuos peligrosos biológico infecciosos no tratados esté sobre materiales fracturados, garantizar que de forma natural no exista conexión con los acuíferos y que el factor de tránsito de la infiltración (f) sea menor o igual a 3×10^{10} os-1 (tres por diez a la menos diez segundos a la menos uno), de acuerdo con lo establecido en la Nor icial Mexicana NOM-083-ECOL-1995, que establece las condiciones que deben reunir los sitios destinados a la disposición final de los residuos sólidos municipales

1.4.2 En caso de que el sitio para la disposición final de los residuos peligrosos biológico-infecciosos no tratados esté sobre materiales granulares, garantizar que el factor de tránsito de la infiltración (f) sea menor o igual de 3×10^{-10} segundos^{-1} (tres por diez a la menos diez segundos a la menos uno), de acuerdo con lo establecido en la Norma Oficial Mexicana que establece las condiciones que deben reunir los sitios destinados a la disposición final de los residuos sólidos municipales.

1.4.3 La distancia mínima a pozos de agua potable, tanto en operación como abandonados, será mayor a 360 m (trescientos metros).

1.5 Consideraciones de selección

1.5.1 En caso de que exista potencial de contaminación a cuerpos de agua superficial y subterránea, se recurrirá a soluciones mediante obras de ingeniería El sitio seleccionado para la construcción de las celdas especiales garantizará que el tiempo de arribo de contaminantes no reactivos al acuífero, sea mayor a 300 años

2. Construcción de la celda

2.1 Ser impermeabilizada la celda artificialmente en la base y los taludes, con el objeto de evitar el flujo de lixiviados

2.2 Se utilizarán membranas de polietileno de alta densidad, con un espesor mínimo de 1.5 ml (uno punto cinco milímetros).

2.3 La celda contará con los sistemas de captación y de monitoreo de lixiviados, así como de biogas

2.4. Contar como mínimo con las siguientes obras complementarias caminos de acceso, báscula, cerca perimetral, caseta de vigilancia, drenaje pluvial y señalamientos

3. Operación

3.1 En la zona de descarga se cumplirán los siguientes requisitos

3.1.1 Antes de depositar los residuos, aplicar una solución de cal en proporción 3:1 a razón de 10 l/m^2 (10 litros por metro cuadrado)

3.1.2 La descarga de los residuos se realizará mediante sistemas mecanizados

3.1.3 Una vez depositados los residuos, se les aplicará un baño con la solución de cal indicada en el punto 3 1.1

3.1.4 En caso de presencia de insectos, se aplicará una sustancia insecticida para su eliminación

3.2 Los residuos se compactarán, con objeto de reducir el volumen y prolongar la vida útil de la celda Para esto se utilizará maquinaria pesada.

3.3 Al final de la jornada los residuos se cubrirán en su totalidad con una capa de arcilla compactada con un espesor mínimo de 30 cm (treinta centímetros).

3.4 Los vehículos se desinfectarán antes de abandonar las celdas especiales Asimismo la maquinaria será desinfectada al final de cada jornada

3.5 Llevar un registro diario de la cantidad, procedencia y ubicación de los residuos depositados

4 Monitoreo y control

4 1 Realizarse el monitoreo de las aguas subterráneas cada seis meses para verificar la presencia de lixiviados

4.2 Cuando, como consecuencia del monitoreo se dete la existencia de lixiviados éstos se extraerán de los pozos correspondientes para su análisis, tratamiento y posterior confinamiento, conforme a las normas oficiales mexicanas correspondientes

4.3 Los operarios de las celdas especiales contarán con el equipo de protección personal que establezcan las disposiciones aplicables y las normas oficiales mexicanas de seguridad correspondientes

4 4 Contará con un programa de atención a contingencias y desastres que pudieran ocurrir en las instalaciones y al realizar cualquiera de las actividades propias de la operación