TOXIC SUBSTANCE STORAGE TANK CONTAINMENT ASSURANCE AND SAFETY PROGRAM

TRAINING MANUAL

MARYLAND DEPARTMENT OF

HEALTH AND MENTAL HYGIENE

STATE OF MARYLAND

DEPARTMENT OF HEALTH AND MENTAL HYGIENE

OFFICE OF ENVIRONMENTAL PROGRAMS

SCIENCE AND HEALTH ADVISORY GROUP

MD-489-D502

TOXIC SUBSTANCE STORAGE TANK CONTAINMENT ASSURANCE AND SAFETY PROGRAM: TRAINING MANUAL

PREPARED UNDER
U.S. ENVIRONMENTAL PROTECTION AGENCY
GRANT NUMBER CS807904010
AUTHORIZED BY SECTION 28 OF THE
TOXIC SUBSTANCES CONTROL ACT

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FOR:

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SEPTEMBER 1983

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This report has been reviewed by the State of Maryland Department of Health and Mental Hygiene, Office of Environmental Programs, and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the Department of Health and Mental Hygiene, or the United States Environmental Protection Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

Because hazardous materials vary widely in their characteristics and in the manner in which they should be stored, the material contained within this Manual can serve only as a guide. It is the responsibility of the storage facility owner to seek the assistance of appropriately qualified professionals with the necessary skills to design a storage system which can be used safely, and which provides the necessary measures for public and environmental protection.

ACKNOWLEDGEMENTS

Development of this document was accomplished with the assistance of an advisory committee representing the following State of Maryland agencies:

- Department of Health and Mental Hygiene

  Office of Environmental Programs

  - Air Management Administration
  - Waste Management Administration
  - Science and Health Advisory Group

- Department of Public Safety and Correctional Services

  State Fire Marshall's Office

- Department of Natural Resources

  Water Resources Administration

- Department of Licensing and Regulation

  Maryland Occupational Safety and Health Administration

also,

- Maryland Casualty Company, Baltimore

We also wish to express our appreciation for the guidance and direction provided throughout this project by Mr. K.K. Wu, Toxics Integration Coordinator, U.S. Environmental Protection Agency, Region III, Philadelphia, Pennsylvania.

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SECTION 1

INTRODUCTION

Accidental spills or releases of hazardous materials can have effects such as contamination of groundwater and surface water, exposure of populations to hazardous materials, destruction of property, severe financial liabilities, and adverse corporate publicity.

It is estimated that 40% of all spill incidents are caused by equipment failures, and 18% by human error. Many of these spills could be prevented by appropriate application of design, maintenance, testing, and inspection procedures.

In order to reduce the occurrence of spills or releases from storage facilities, the design of the facilities and maintenance and operating procedures should be evaluated. If they do not meet current standards, appropriate corrective measures should be implemented. These measures constitute a Containment Assurance and Safety Program. Objectives of such a program include:

- Utilization of the most recent chemical, technical, and structural standards for storage system design and maintenance;

- Standardization of preventive maintenance and inspection practices;

- Education of management, maintenance, and inspection personnel in proper hazardous materials control practices; and

- Provision of guidelines for developing a spill prevention program.

The Toxic Substance Storage Tank Containment Assurance and Safety Program: Guide and Procedures Manual was developed to provide basic guidelines upon which a containment assurance and safety program should be based. It provides guidelines for various design, maintenance, inspection, and emergency procedures, and refers to the appropriate standards and codes with which storage tanks should be in compliance.

This Training Manual is intended to be a companion to the Guide and Procedures Manual by providing an introduction to and summary of its contents. Subjects highlighted include:

- Chemical compatibility issues;
- Storage system design elements;

- Maintenance and inspection procedures;
- Health and safety issues; and
- Spill prevention and countermeasures.

The Training Manual is not intended to be a substitute for the Guide and Procedures Manual. Rather, it is meant to identify areas of key importance, and may serve as the basis for an in-plant training program. Users of The Training Manual are advised to consult the Guide and Procedures Manual and the appropriate bibliographies therein for detailed information on a given topic.

SECTION 2

CHEMICAL COMPATIBILITY

Care must be taken to avoid inadvertent mixture of incompatible chemicals and materials. Combining two or more incompatible chemicals may result in such consequences as:

- Heat generation;
- Fire;
- Explosion; or
- Gas generation.

Exposure of construction materials to incompatible chemicals may result in:

- Corrosion;
- Loss of structural integrity; or
- Total destruction of tank and pipe system.

Therefore, an inspector must be able to identify potentially incompatible chemical/chemical or chemical/material combinations.

Table 2-1 lists the major chemical classes. An extensive listing of chemicals within these classes is found in Appendix A. By identifying the classes to which two chemicals belong, the Chemical Compatiblity Matrix in Appendix B may be used to determine the likely reactions resulting from their combination. (The matrix assumes chemicals of 100% concentration at 25°C and 760 mm Hg).

The procedure for using the Chemical Compatibility Matrix (Appendix B) is as follows:

1. Determine the chemical classes to which two chemicals belong, as listed in Table 2-1 and Appendix A.

2. Locate the chemical class with the higher number on the left side of the Appendix B chart.

3. Follow that row to the right until it intercepts the column with the lower number.

4. The abbreviation at the point of intersection (explained in the matrix legend) indicates the likely reaction.

5. If the point of intersection is blank, the classes are considered generally compatible. Two or more abbreviations

Table 2-1

LIST OF CHEMICAL CLASSES

Chemical Class Number	Class Name
1	Acids, mineral, non-oxidizing
2	Acids, mineral, oxidizing
3	Acids, organic
4	Alcohols and glycols
5	Aldehydes
6	Amides
7	Amines, aliphatic and aromatic
8	Azo compounds, diazo compounds, and hydrazines
9	Carbamates
10	Caustics
11	Cyanides
12	Dithiocarbamates
13	Esters
14	Ethers
15	Fluorides, inorganic
16	Hydrocarbons, aromatic
17	Halogenated organics
18	Isocyanates
19	Ketones
20	Mercaptans and other organic sulfides
21	Metal compounds, inorganic
22	Nitrides
23	Nitrites
24	Nitro compounds
25	Hydrocarbons, aliphatic, unsaturated
26	Hydrocarbons, aliphatic, saturated
27	Peroxides and hydroperoxides, organic
28	Phenols and cresols
29	Organophosphates, phosphothioates, and phosphodithioates
30	Sulfides, inorganic
31	Epoxides
32	Combustible and flammable materials
33	Explosives
34	Polymerizable compounds
35	Oxidizing agents, strong
36	Reducing agents, strong
37	Water and mixtures containing water
38	Water reactive substances

Source: Hatayama, et al., 1980.

indicate a series of expected reactions in the order in which they would be expected.

As an example, consider determining the compatibility of toluene diisocyanate and nitric acid. From Table 2-1 and Appendix A it is determined that these compounds are in Class 18 (Isocyanates) and Class 2 (Oxidizing Mineral Acids), respectively. Since 18 is the higher number, locate Class 18 on the left side of the matrix and follow that row to the right until it intersects the column for Class 2. The abbreviations "H," "F," and "GT" appear at the point of intersection. Consulting the legend, it is determined that the primary consequences of mixing these two classes of chemicals would be heat generation (H). Secondary consequences resulting from the generation of heat would be fire (F) and generation of toxic gases (GT).

Resistance of tank construction materials to corrosion by given chemicals is of primary importance for avoiding tank failure. Appendix C provides a matrix of general compatibility between specific chemicals and a variety of commonly used storage tank, liner, and appurtenance construction materials.

To use the Appendix C Chemical/Material Compatibility Matrix, find the chemical of interest in the vertical axis. Then follow the row to the right until it intersects the column for the material of interest. The symbol at the point of intersection should be interpreted as follows:

+ = The chemical/material combination is generally suitable under most conditions.

c = The chemical/material combination is conditionally suitable, depending upon such factors as temperature, concentration, presence of trace contaminants, degree of agitation, method of material fabrication, etc. More specific data should be obtained from the reference sources cited, to determine suitability under specific conditions.

-- = The chemical/material combination is generally unsuitable under most conditions.

N = Data are insufficient to determine suitability in general. Refer to appropriate references for more specific data.

Corrosion rates are dependent on a variety of factors such as chemical concentration, temperature, and humidity. Furthermore, in choosing the appropriate material for use with a specific type of chemical, it is necessary to consider such factors as:

- Rate of corrosion that may occur;
- Pressure resistance;
- Inherent strength; and
- Degree of material permeability.

Because of variances caused by factors such as the above, use of the Chemical/Material Compatibility Matrix should be limited to a preliminary screening of appropriate materials for a given chemical application. Professional and technical sources should be consulted for the final chemical/material selection.

SUGGESTED EXERCISES

1. Name possible consequences of combining two or more incompatible chemicals.

2. Name possible consequences of exposing chemicals to incompatible construction materials.

3. Identify the chemical classes to which the following compounds belong:

   - Chloroform,
   - Parathion,
   - Hydrogen sulfide,
   - Hydrogen peroxide,
   - Mercuric oxide,
   - Hydrochloric acid,
   - Sulfuric acid,
   - Vinyl chloride,
   - Benzoyl peroxide, and
   - Styrene.

4. Identify the likely chemical reactions resulting from the following chemical class combinations:

   - Aromatic Hydrocarbons and Oxidizing Mineral Acids,
   - Ketones and Aldehydes;
   - Caustics and Isocyanates;
   - Water-reactive Substances and Aromatic Hydrocarbons; and
   - Peroxides and Nitriles.

5. Identify the likely reactions resulting from the following chemical combinations:

   - Baygon and Sulfuric Acid,
   - Potassium Nitrate and Zinc sulfate,
   - Vinyl chloride and Potassium hydroxide,
   - Diazinon and Ammonium sulfide, and
   - Formaldehyde and Hydrogen peroxide.

6. Identify the degree of suitability of the following chemical and material combinations:

   - Epoxy resins and Acetone,
   - Pentachlorophenol and Stainless steel,
   - Glass and Ammonium flouride,

- Oleum and Mild Steel, and
- Nickel and Cresote.

7. In addition to chemical compatibility, what other factors must be considered in determining suitability of chemical and material combinations?

SECTION 3

STORAGE SYSTEM DESIGN ELEMENTS

3.1 TYPES OF STORAGE TANKS

Tanks may be classified simply in terms of the internal vapor pressures they are designed to sustain. This yields three types:

- Atmospheric, for operating pressures close to atmospheric;
- Low-pressure, for operating pressures from 0.5 to 15 pounds per square inch gage (psig);
- High-pressure, for operating pressures above 15 psig.

By determining the vapor pressure of a chemical at a given temperature, it is possible to specify the appropriate tank type. Table 3-1 illustrates appropriate tank types for a number of specific chemicals, assuming operation at 25°C (77°F). Other factors which must be considered in storage system selection include, but are not limited to:

- Vapor control measures;
- Applications to which the system will be subjected;
- Strength, resistance, and suitability of materials to use in system construction;
- Static load induced by the tank contents;
- External loads, such as wind, on the tank;
- Desired tank capacity; and
- Specific gravity of the tank contents.

Table 3-2 lists the major technical design standards applicable to atmospheric, low-pressure, and high-pressure tanks.

Tank foundations should provide uniform, adequate support and avoid creating local corrosion sites. Foundations should be underlain by sufficient pervious material to provide flexible, continuous support, and to prevent accumulation of moisture under the tank. The bearing capacity (Table 3-3) of the supporting soils should be sufficient to support the tank load. For large tanks with high shells, a foundation ringwall may be required to distribute the tank load more evenly. Figures 3-1 and 3-2 illustrate two types of tank foundations.

Table 3-1

STORAGE TANK TYPE FOR
LIQUID CHEMICALS, 25°C (77°F)

Chemical	Tank Type	Chemical	Tank Type
Acetaldehyde	H	Ethylene diamine	A
Acetamide	A	Ethylene dichloride	L
Acetic acid	A	Ethylene glycol	A
Acetone	L	Ethylene glycol monoethyl ether	A
Acetonitrile	L	Formic acid	L
Acetophenone	A	Freons	H
Acrolein	L	Furfural	A
Acrylonitrile	L	Gasoline	A
Allyl alcohol	L	Glycerine	A
Ammonia	H	Hydrocyanic acid	L
Benzene	L	Ispoprene	L
Benzoic acid	A	Methyl acrylate	L
Butane	H	Methyl amine	H
Carbon disulfide	L	Methylchloride	H
Carbon tetrachloride	L	Methyl ethyl ketone	L
Chlorobenzene	L	Methyl formate	L
Chloroethanol	A	Naphtha	A
Chloroform	L	Nitrobenzene	A
Chloropicrin	L	Nitrophenol	A
Chlorosulfonic acid	A	Nitrotoluene	A
Cumeme	A	Pentane	L
Cyclohexane	L	Petroleum oil	A
Cyclohexanane	A	Propane	H
Dichloromethane	L	Pyridine	A
Diesel oil	A	Styrene	A
Diethyl ether	L	Sulfuric acid	A
Dimethylformamide	A	Sulfur trioxide	L
Dimethyl pthalate	A	Tetrachloroethane	A
Dioxane	L	Tetrathydrofuran	L
Epichlorohydrin	A	Toluene	A
Ethanol	L	Trichloroethylene	L
Ethyl acetate	L	Xylene	A
Ethyl benzene	A		

Key: A = Atmospheric, less than 0.5 psig
L = Low Pressure, less than 15 psig but greater than 0.5 psig
H = High Pressure, greater than 15 psig

Source: Ecology and Environment, 1982.

Table 3-2

EXISTING STRUCTURAL GUIDELINES

Tank Type	Existing Guidelines	Promulgating Organization	Comment
High Pressure	Boiler and Pressure Vessel Code Section VIII, Divisions 1 and 2 Section X, fiberglass reinforced plastic pressure vessels	American Society of Mechanical Engineers 345 E. 47th Street New York, NY 10017 212/705-7722	
Low Pressure	Standard 620, recommended rules for design of large, welded, low-pressure storage tanks	American Petroleum Institute 201 L Street, NW Washington, DC 20057 202/457-7000	Applicable to non-petroleum as well as petroleum storage tanks Sections VIII and X of the ASME Boiler and Pressure Vessel Code also apply
Atmospheric	Standard 650, welded steel for oil storage	API	Applicable to non-petroleum as well as petroleum storage tanks
	Standard 12A, oil storage tanks with riveted shells	API	
	Standard 12B, bolted production tanks	API	
	Standard 12D, large welded production tanks	API	
	Standard 12E, wooden production tanks	API	
	Standard 12F, small welded production tanks	API	

Table 3-2 (Cont.)

Tank Type	Existing Guidelines	Promulgating Organization	Comment
Atmospheric (Cont.)	Standard for welded aluminum-alloy storage tanks, ANSI B96.1 - 1981	American National Standards Institute, Inc. 1430 Broadway New York, NY 10018	
	Standard steel tanks, D100-67	American Water Works Association 6666 W. Quincy Ave. Denver, CO 80234 303/794-7711	Adaptable to storage tanks of chemicals as well as water
	Steel underground tanks for flammable and combustible liquids, UL 58	Underwriters Laboratory 333 Pfingsten Rd. Northbrook, IL 60062 312/272-8800	
	Steel above-ground tanks for flammable and combustible liquids	Same as above	

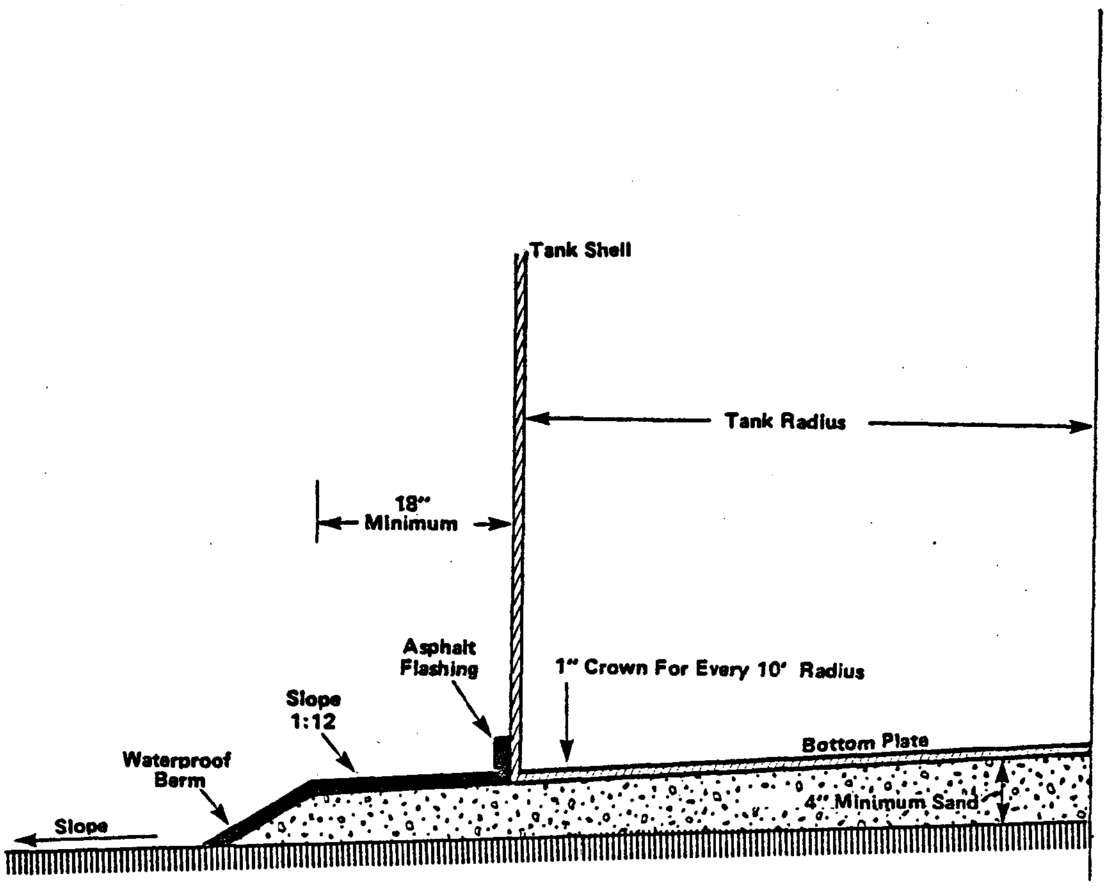
Source: Ecology and Environment, Inc., 1982.

Table 3-3

APPROXIMATE BEARING CAPACITIES

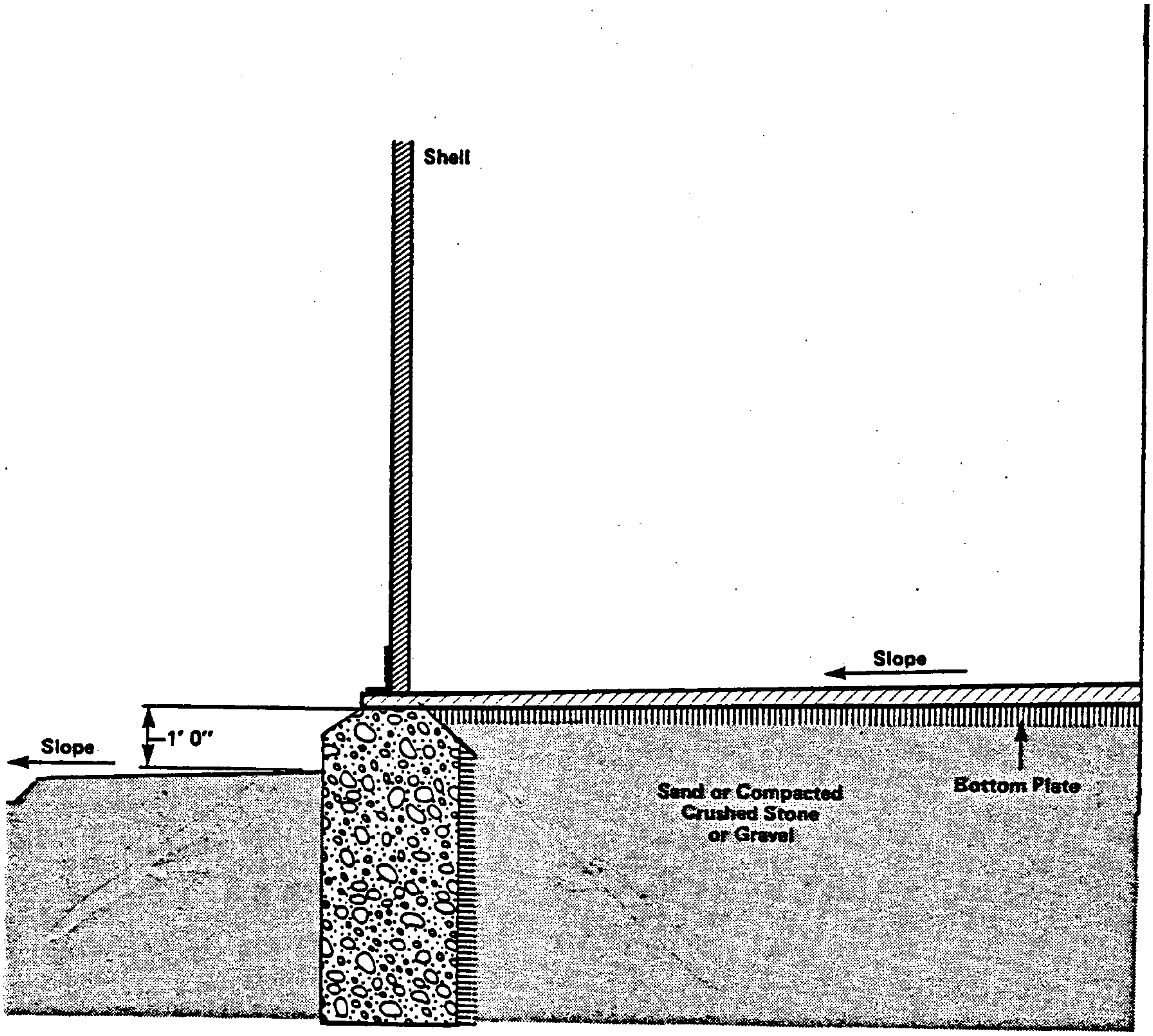
Soil Type	Tons/Square Foot
Soft clay	1
Dry fine sand	2
Dry fine sand with clay	3
Coarse sand	3
Dry hard clay	3.5
Gravel	4
Rock	10 to 40

Source: Perry and Chilton, 1973.



SOURCE: Staniar, 1959.

Figure 3–1 FOUNDATION SCHEMATIC FOR OUTDOOR TANKS



SOURCE: Staniar, 1959.

Figure 3–2 ILLUSTRATIVE RING WALL FOUNDATION

Smaller tanks resting on supports require saddles that contact at least 120° of the tank circumference. The saddles should be channelized to drain precipitation and spillage, and they should be continuously sealed along all points of contact. Wear plates should be installed between the tank and saddle, but should not be of decomposable materials which may encourage corrosion. Figure 3-3 illustrates types of vertical and horizontal support.

3.2 VALVES

Selection of the appropriate valve type and materials is based on such factors as:

- Liquid viscosity and corrosivity;
- Pressure; and
- Type of service.

The major valve types are as follows:

- Gate - for flow isolation;
- Globe - for throttling or flow-regulating;
- Diaphragm - for regulating service under pressure of 0 to 50 pounds per square inch (psi);
- Butterfly - for regulating and isolating service;
- Ball - for regulating service;
- Pressure relief - for emergency venting of excessive vapors and liquids; and
- Check - to prevent reversal of flow through a pipe.

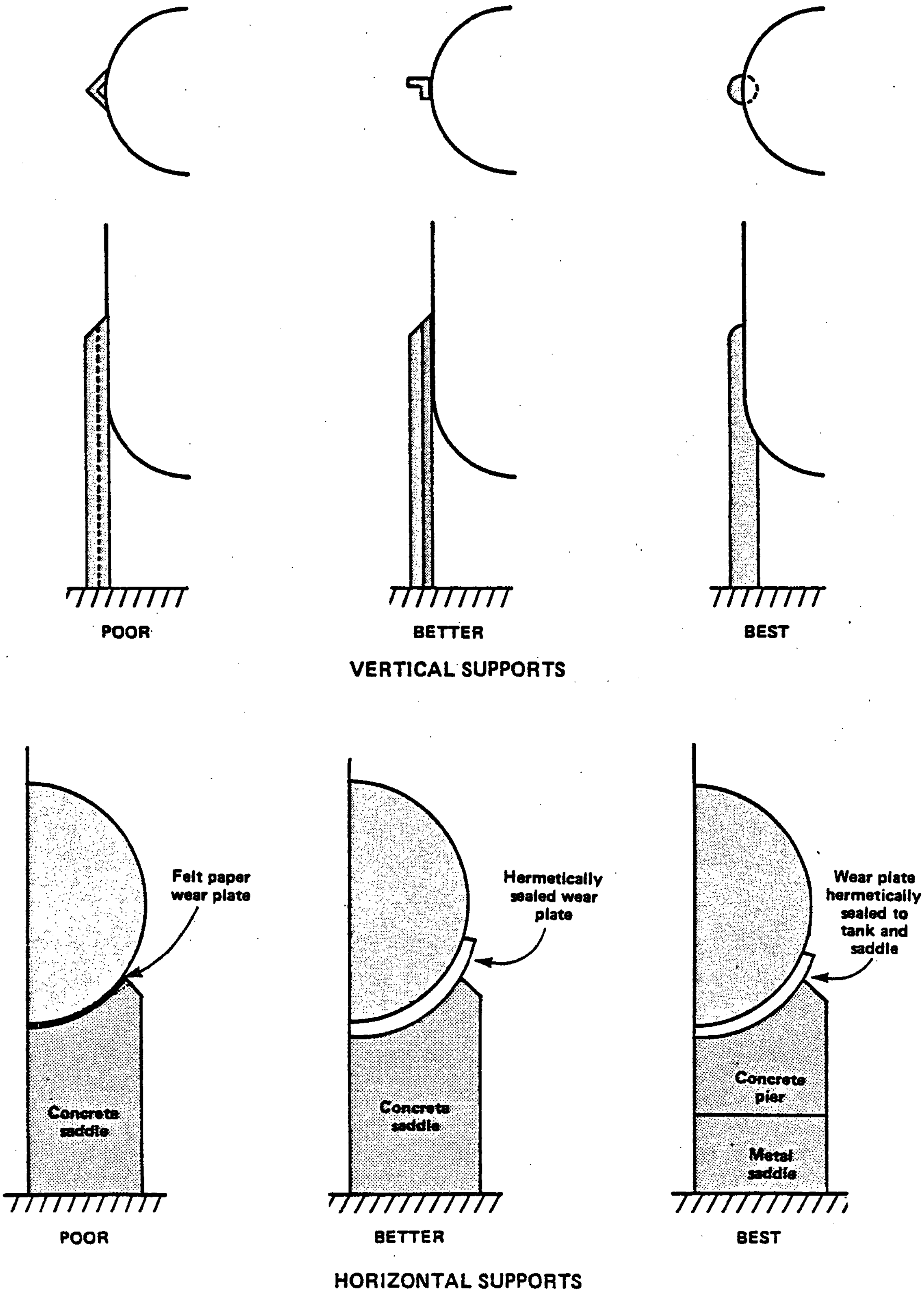
3.3 TANK VENTING

Tank vents and vapor emission controls are required to compensate for the following conditions:

- Air intake during tank emptying;
- Vapor exhaust during tank filling;
- Tank "breathing" because of temperature fluctuations;
- Evaporation of tank contents; and
- Emergencies, such as fires.

Venting under normal operating conditions can be achieved with open vents, pressure vacuum valves, pressure relief valves, and pilot-operated relief valves. Further specifications may be obtained from API Standard 2000, <u>Venting Atmospheric and Low-Pressure Storage Tanks</u>.

High pressure tanks require the use of emergency venting only. Such methods may include pressure relief valves, rupture discs, or gages or manholes designed to open at excessive pressures.



SOURCE: Staniar, 1959

Figure 3–3 ASSMENT OF VERTICAL AND HORIZONTAL TANK SUPPORTS

Emissions may be controlled in several manners. Safety relief valves are often connected to piping systems which reroute the discharge to a remote discharge point or to a control device. Other control methods for atmospheric and low-pressure tanks are floating roofs, flexible diaphragms, and lifter roofs. Devices for control of discharged vapors include carbon adsorption, thermal and catalytic incinerators, and refrigerated condensors.

3.4 FACILITY SITING

Prediction of safe facility locations is dependent on a variety of physical, chemical, statistical, meteorological, and demographic factors specific to the existing or proposed facility. These factors should be incorporated into a hazard and risk analysis consisting of the following steps:

- Identification of types and causes of potentially hazardous accidents;

- Determination of chance of such accidents occurring at the facility; and

- Prediction of the consequences of an accident.

This analysis requires the use of such tools and methods as a fault tree analysis, analysis of relevant historical data, and mathematical models such as the Gaussian Point Source Model, Pasquill-Gifford dispersion coefficients, or the United States Coast Guard Vulnerability Model. Further guidelines, based on flammability, are provided by NFPA 30 Flammable and Combustible Liquids Code, and by the United States Department of Housing and Urban Development's "Safety Considerations in Siting Housing Projects" (see Figure 3-4).

3.5 SPILL CONTAINMENT AND CONTROL

Facilities should incorporate physical controls to contain the spread of spilled product. Factors which should be incorporated into facility design and operation include:

- Drainage lines from areas of expected light spillage to oil-water separation or sump;

- Development of a positive contingency control plan;

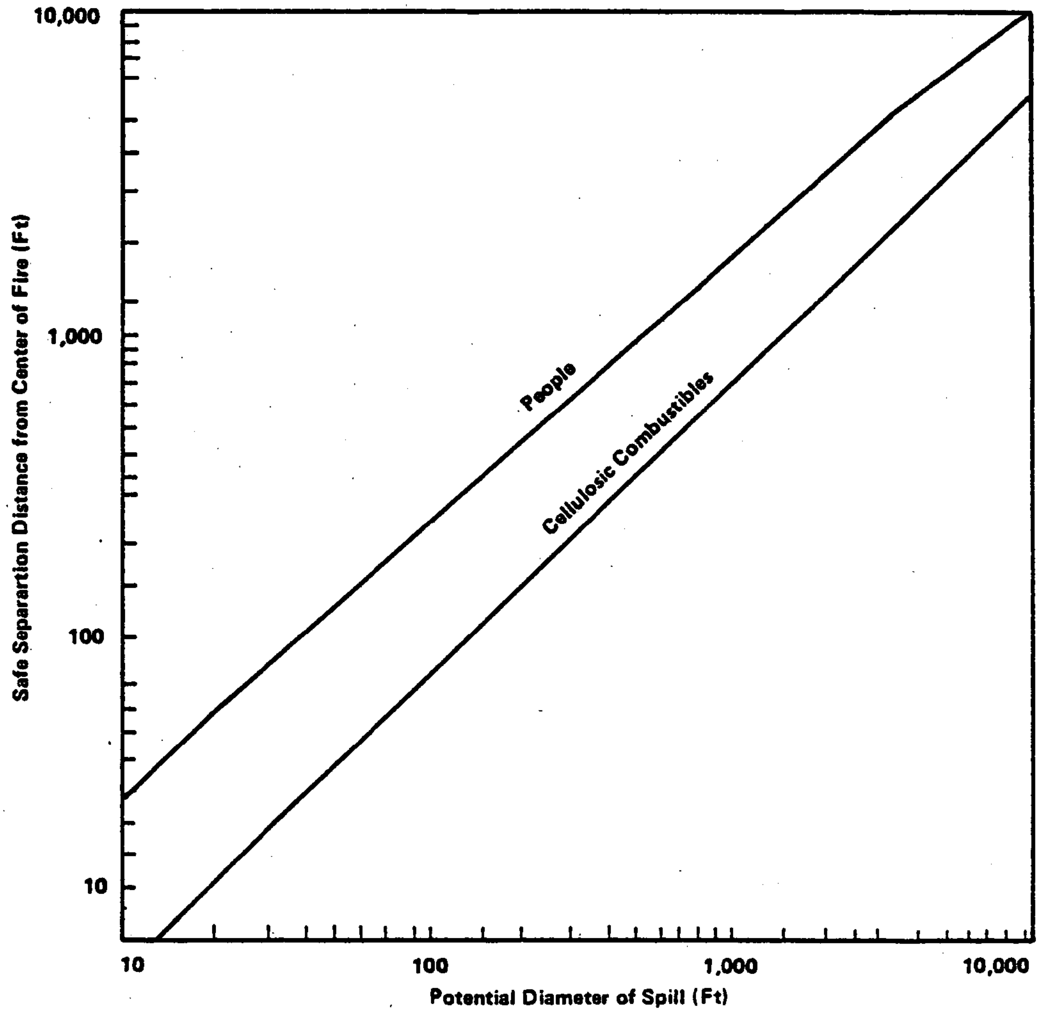
- Control of storm runoff via sewers, ditches, etc.;

- Retention or diversion structures; and

- Impervious surfaces (natural or synthetic).

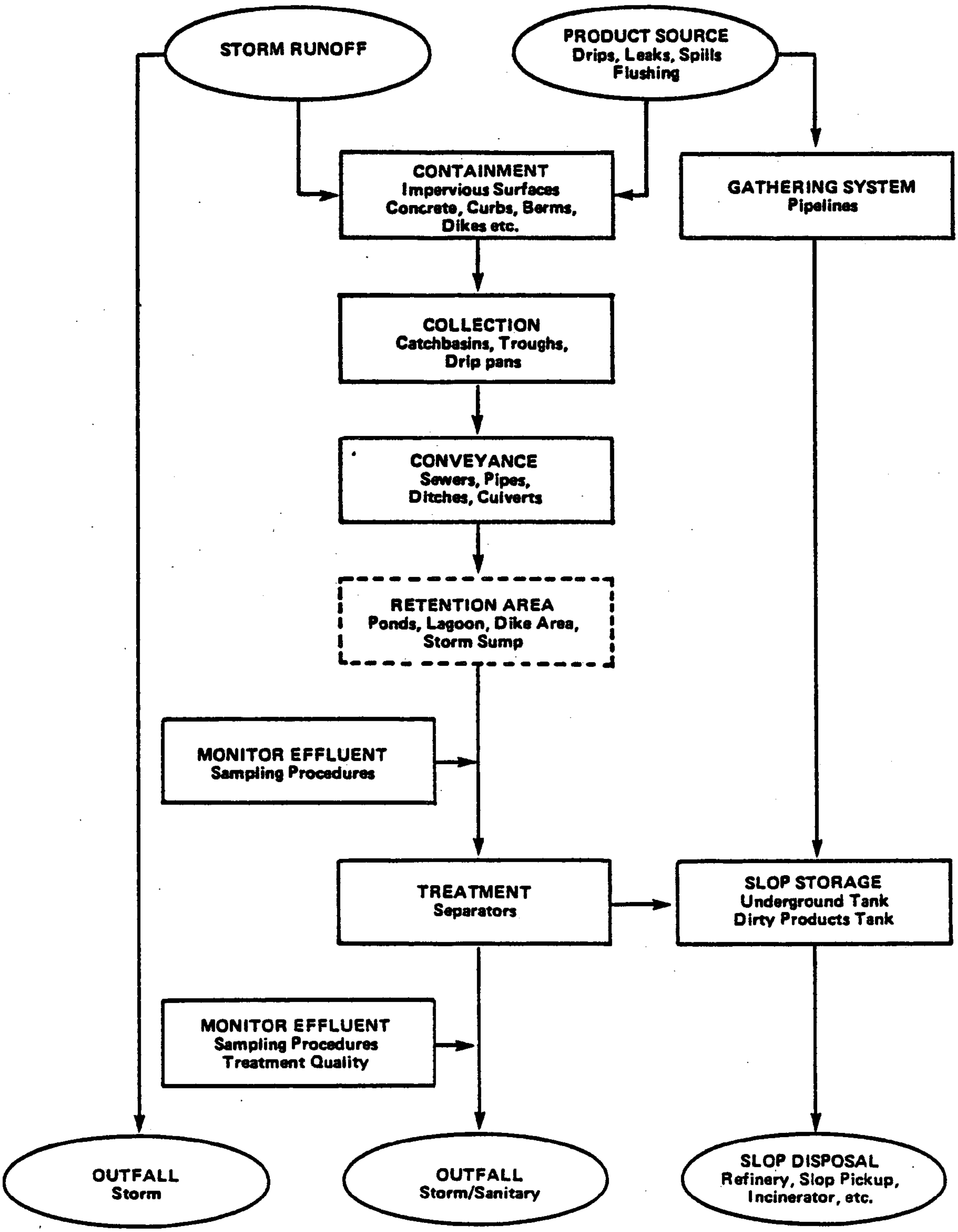
Figure 3-5 outlines the necessary elements in a spill containment and control system.

Selection of materials used for containment or collection is dependent upon:



SOURCE: United States Department of Housing and Urban Development, 1975.

Figure 3—4 SAFE SEPARATION DISTANCES FROM SPILLS OF COMMON LIQUID INDUSTRIAL FUELS-FIRE THREAT



SOURCE: PACE, 1980.

Figure 3–5 SPILL CONTAINMENT AND CONTROL FLOW

- Degree of impermeability required;
- Longevity or weather resistance required; and
- Compatibility with the stored material.

Some commonly used containment materials include:

- Natural clays;
- Treated bentonite clays;
- Synthetic membrane liners;
- Asphalt; and
- Concrete

Each of these materials must be evaluated individually to determine its appropriate application at a given facility.

Secondary containment structures should be able to contain at least the entire volume of the largest tank within the containment area, plus an additional 10% allowance to accommodate accumulated precipitation or other materials. These areas should be equipped with manually operated release valves (normally kept closed and locked) so that accumulated rainwater may be removed from the area periodically.

3.6 IGNITION SAFEGUARD

Hazardous materials storage facilities should be evaluated to determine the presence of or need for fire protection safeguards. The evaluation should determine at least the following:

- The type, quantity, and location of equipment necessary for the detection and control of fires, leaks, and spills;

- The methods necessary for protection of equipment and structures from the effects of fire exposure;

- Fire protection water systems;

- Fire extinguishing and control equipment;

- The equipment and processes to be incorporated within an Emergency Shutdown System (ESD) including an analysis of subsystems, if any, and the need for depressuring specific vessels or equipment during a fire;

- The type and location of sensors necessary to initiate automatic operation of the ESD or its subsystems;

- The availability and duties of individual plant personnel and the availability of external response personnel during an emergency; and

- The protective equipment and special training needed by the individual plant personnel for their respective emergency duties.

Table 3-4 provides illustrative guidelines for fire prevention during storage of hazardous materials.

Electrical ignition sources can be eliminated through adherence to NFPA 70, the National Electric Code. To prevent static ignition, the following safeguards may be used:

- "Avoid splash-filling" of tanks or other strenuous agitation of contents. The discharge from a fill hose into a tank should be close to the bottom of the tank.
- Limit the velocity of the incoming stream to 1 m/sec to minimize the agitation of tank contents and subsequent build-up of charge.
- Eliminate ungrounded objects..
- Eliminate spark promoters within a tank such as protruding metal surfaces or floating objects.
- Bond and ground all metallic objects on RP tanks.
- Electrically ground tank fill nozzles to the tank during tank loading.

Additional preventive measures include:

- Performing "hot work," such as welding, only after the area is determined to be cleared of flammable gases and vapors;
- Limiting smoking to designated safe areas;
- Using only intrinsically safe devices within flammable areas; and
- Compliance with other regulatory or administrative controls.

Flammable gas detectors, fire detectors, and smoke or temperature sensors should be installed to sound alarms at continuously attended locations, or to activate emergency shutdown systems. Fire extinguishing methods must be readily available in accordance with NFPA Standard Number 10, as well as NFPA Standards 11, 11-A, 11-B, 12, 12-A, 12-B, 16, and 17. Methods for controlling some specific chemical fires are shown in Table 3-5.

3.7 FAIL-SAFE AND WARNING DEVICES

Various sensing and warning devices can be used to prevent spills by activating shut-off or diversion mechanisms, or by providing alarms of adverse circumstances. Devices are available for level detection, leak monitoring, and gas detection.

Level detectors are used to monitor tank contents and alert the operator of potential overfill situations. They may be linked to alarm or control mechanisms. Types of level detectors include:

Table 3-4

FIRE PROTECTION TECHNIQUES FOR STORAGE OF SELECTED HAZARDOUS MATERIALS

Chemical	Fire Prevention
Cyanides	Avoid physical damage; insulate from acids
Chromic acid	Separate from oxidizable materials; avoid storage on wooden surfaces; remove spills
Hydrofluoric acid	Corrodes many materials except lead, wax, polyethylene, and platinum; store in vented area
Hydrochloric acid	Separate from oxidizable materials; store in cool, vented area; avoid contact with common metals
Nitric acid	Separate from metallic powders, carbides, hydrogen sulfide, turpentine, organic acids, and oxidizable materials; avoid direct sunlight
Sulfuric acid	Avoid nitrates, powdered metals, chlorates, and other oxidizable materials
Acetic acid	Avoid oxidizable and combustible materials; keep above freezing point
Ferric chloride	Protect against physical damage; store in cool, vented area
Ammonium persulfate	Keep away from strong oxidizers like chlorates, nitrates, and nitrites
Caustics	Store in dry place; avoid moisture; separate from ignitable materials
Ammonia	Store in cool, vented area; avoid combustible materials; avoid chlorine, bromine, iodine, acids
Alkaline wastes	Store in cool, vented area; avoid flammable materials
Mercury	Store in cool, vented area away from combustibles
Tetraethyl lead and lead oxide mixed	Store in cool, vented area; avoid strong oxidizing agents; store in sprinklered area
Lead compounds and oxides	Store in cool, dry place; avoid storage on wood floors; avoid combustibles
Zinc compounds	Store in cool, dry, vented area; avoid strong acids and alkalies
Sodium compounds	Store away from combustibles; avoid high temperatures
Aluminum, phosphorus compounds, and sulphur compounds	Keep dry; insulate from acids, caustics, and chlorinated hydrocarbons; avoid combustible materials

Source: Ecology and Environment, Inc., 1982.

Table 3-5

SELECTED METHODS OF EXTINGUISHING CHEMICAL FIRES

Chemical	Extinguishing Methods
Cyanides	Use water; do not use CO_2 extinguishers; avoid toxic fumes
Chromic acid	Use water; caution should be exercised against possibility of stream explosion
Hydrofluoric acid	Use water; neutralize with soda ash or lime; if water is ineffective, use "alcohol foam"
Hydrochloric acid	Use water; neutralize with soda ash or slaked lime
Nitric acid	Use a water spray; neutralize with soda ash or lime
Sulfuric acid	Use large amounts of water; reaction may occur; neutralize with ash or lime; sand or gravel also will help
Acetic acid	Use water spray, dry chemical, "alcohol foam," or carbon dioxide
Ferric chloride	Use water
Ammonium persulfate	Use water spray or water flooding; avoid toxic fumes
Caustics	Flood with water; avoid spattering or splashing
Ammonia	Stop flow of material; use water to keep container cool; avoid fumes
Alkaline wastes	Use water; neutralize with dilute acid (acetic) if necessary
Mercury	Use water; avoid toxic mercury vapor
Tetraethyl lead and lead oxide mixed	Fight fires from explosion-restraint location; use water, dry chemical, foam, or carbon dioxide
Lead compounds and oxides	Use flooding amounts of water
Zinc compounds	Smother with suitable dry powder
Sodium compounds	Use water, dry powder; neutralize with appropriate chemical, if necessary
Aluminum, phosphorus compounds, and sulphur compounds	Do not use water; smother with suitable dry powder

Source: Ecology and Environment, Inc., 1982.

- Float-activated devices - characterized by a buoyant member on the liquid surface, coupled to an indicating gauge.

- Electrical capacitance sensors - typically consisting of a rod electrode positioned vertically within a tank, and a second electrode which is usually the tank wall. The electrical capacitance measured between the electrodes indicates the height of the interface along the rod electrode.

- Optical sensors - which operate on the principle of light beam refraction in fluids. An electronic control device generates a signal which is converted to a light pulse by sensors mounted in the tank. The light pulse is transmitted through the tank via fiber optics, through a prism, and then out again through fiber optics. The light pulse is then reconverted to an electronic signal which indicates the liquid level.

- Ultrasonic sensors - which utilize principles of sound wave generation to monitor liquid level. They may use piezoelectric transmitters and receivers to indicate presence of liquid within a specific area, or sonar transmitters to measure distance between the liquid/vapor interface and a sonar receiving element.

- Thermal conductivity sensors - which consist of two temperature-sensitive probes connected in a Wheatstone bridge. When the probes are in air or gas, the probes are at the maximum temperature differential and highest voltage. As they become submerged, the probe temperatures equalize and the voltage across the bridge drops.

These devices may be limited to either mechanical, electronic, or pneumatic devices which can be used to operate alarms, valves, or pumps, shut down filling operations, or divert flow to emergency overflow tanks.

Leak detectors are used to detect liquid leaks onto the ground surface, or into the surrounding groundwater. Leak detection devices can be placed within a diked area to quickly reveal the first occurrence of a spill. For underground tanks, sensors can be placed within slotted groundwater monitoring wells situated close to the storage area in a downgradient direction. Spilled material that has saturated the soil and entered the groundwater table will be readily detected. However, the variety of chemicals that can be detected in this manner may be limited by specific physical or chemical properties. Specific equipment manufacturers should be contacted for information on specific applications.

Types of leak detectors include:

- Electrical resistivity sensors - consisting of one or more sensors which deteriorate in the presence of the stored product. Once a spill or leak is detected in this manner, the sensors must be replaced.

- Interstitial sensors - which monitor either the pressure, vacuum, or presence of fluid between walls of a double-walled tank.

- Thermal conductivity sensors - which, when connected to an electronic control device, can detect any changes in the thermal conductivity of their surrounding environment to determine if a leak or spill has occurred. These detectors can determine if the monitored area is dry, wet with water, or wet with leaking product.

Gas detectors are another form of leak detector used to monitor a variety of flammable, non-flammable, or toxic gases and vapors in the ambient air or in dry, permeable soil. They can be portable or permanently installed, and may be used near valves and fittings, in the backfill, or in specifically installed vapor wells. Types of gas detectors include:

- Combustible gas detectors;
- Oxygen detectors;
- Gas-specific detectors (e.g., CO, H_2S, etc.);
- Infrared analyzers;
- Photoionization detectors; and
- Flame-ionization detectors.

Combustible gas detectors can be used to detect conditions which present an explosive hazard as a result of the release of any flammable or combustible gases, or vapors from flammable or combustible liquids. Other detectors are a·ailable for specific gases, such as carbon monoxide or hydrogen sultide. Infrared analyzers are particularly useful in identifying single compounds that are infrared-active. These would include carbon dioxide, halogenated hydrocarbons, and most other hydrocarbons.

At unattended hazardous materials storage facilities, the appropriate sensing and warning devices should be connected to an alarm circuit. This circuit should transmit the alarm to a continuously attended facility to indicate any symptoms of trouble such as abnormal temperatures, pressure increases, level changes, etc. The sensing devices may also be used to activate ventilation equipment or process interruption equipment.

Use of the above liquid and gas leak detection devices may be supplemented by such methods as inventory control, periodic soil and surface water sampling, and groundwater monitoring well sampling for long-term monitoring and documentation of surrounding environmental conditions.

SUGGESTED EXERCISES

1. Name several factors which must be considered in selecting the appropriate type of storage system.

2. Name and distinguish characteristics of three types of storage tanks, based on internal operating pressures.

3. Identify two objectives of tank foundation design.

4. Identify two technical standards applicable to low-pressure storage tanks.

5. Name six types of valves and the types of service for which they are appropriate.

6. Identify five conditions which require tank ventilation.

7. Name three types of vapor emission control devices.

8. Describe the three steps of a hazard and risk analysis of a proposed storage facility site.

9. Identify several factors which should be incorporated into facility design to contain and control spilled materials.

10. How is the volume of a secondary containment structure determined?

11. Identify four methods to control ignition resulting from static electrical charges.

12. Discuss five areas which must be evaluated in a determination of fire protection safeguards for a hazardous materials storage facility.

13. Identify three types of fail-safe devices and provide at least two examples of each.

SECTION 4

CORROSION CONTROL

Corrosion results in more tank failures than any other cause. Factors influencing corrosion include:

- Velocity and pressure of chemical material streams;
- Compatibility of tank materials with tank contents;
- Environmental factors, such as moisture; and
- Inappropriate corrosion control methods.

Types of corrosion include:

- Uniform surface degradation (such as oxidation);
- Intergranular;
- Pitting;
- Stress cracking;
- Fatigue;
- Galvanic;
- Thermogalvanic;
- Crevice;
- Oxygen concentration cell;
- Erosion;
- Cavitation;
- Impingement attack;
- Mechanical;
- Fretting;
- Hydrogen embrittlement;
- Stray current; and
- Differential environment cell.

Frequencies of metal failure attributed to various types of corrosion are listed in Table 4-1. Illustrations of various corrosion types appear in Figures 4-1 through 4-6.

A variety of methods are available to control the types of corrosion. These include:

- Corrosion inhibitors;
- Cathodic or anodic protection;
- Protective liners; and
- Protective coatings.

Control methods for various types of corrosion are summarized in Table 4-2. Applications of Corrosion Inhibitors are listed in Table 4-3, and comparative resistances of protective coatings are summarized in

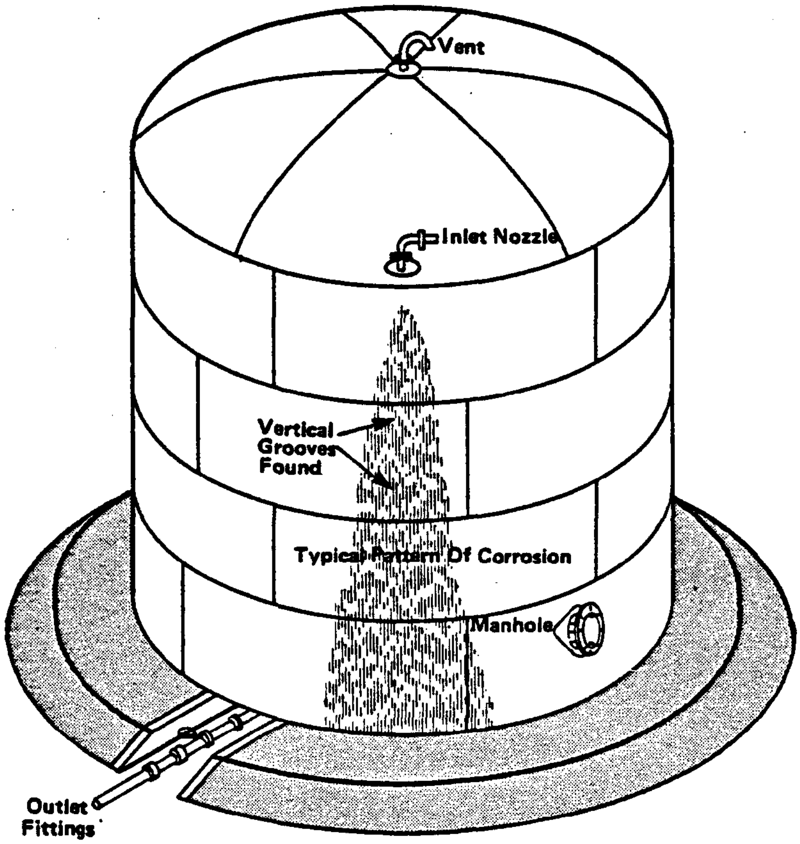
Table 4-1

METAL FAILURE FREQUENCY OVER A TWO-YEAR PERIOD
(56.9% Corrosion and 43.1% Mechanical)*

Corrosion Failures†	Percent (%)
Uniform corrosion	31.5
Stress corrosion cracking, Corrosion fatigue	23.4
Pitting corrosion	15.7
Intergranular corrosion	10.2
Corrosion-erosion, Cavitation damage, Fretting corrosion	9.0
High temperature corrosion	2.3
Weld corrosion	2.3
Thermogalvanic corrosion	2.3
Crevice corrosion	1.8
Selective attack	1.1
Hydrogen damage	0.5
Galvanic corrosion	0.0

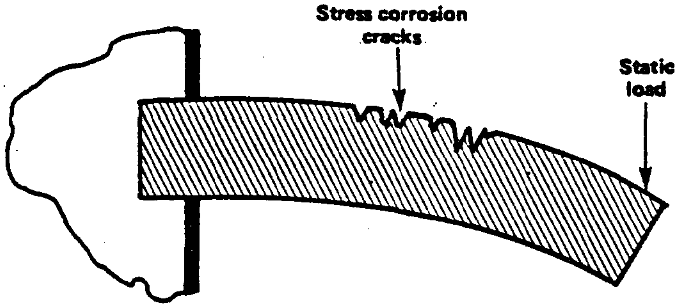
*The percentages can vary considerably in other industrial locations or environments.

Source: Pludek, 1977.



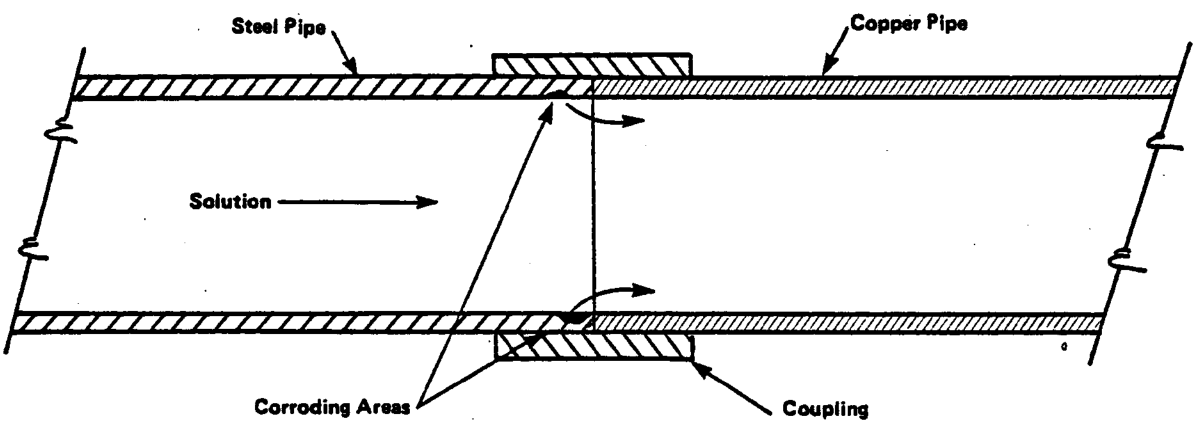
SOURCE: Shields and Dessert, 1981.

Figure 4–1 CORROSION DUE TO IMPROPER INLET NOZZLE PLACEMENT



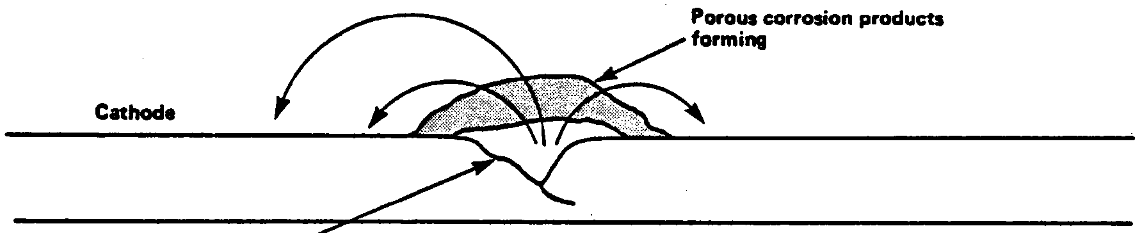
SOURCE: Pludek, 1977.

Figure 4–2 STRESS CORROSION CRACKING



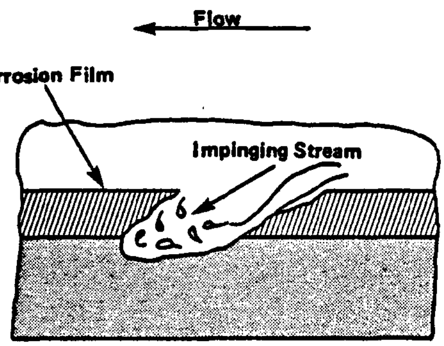
SOURCE: Department of the Navy, 1964.

Figure 4—3 INTERIOR GALVANIC CORROSION DUE TO COUPLING COPPER AND STEEL PIPE



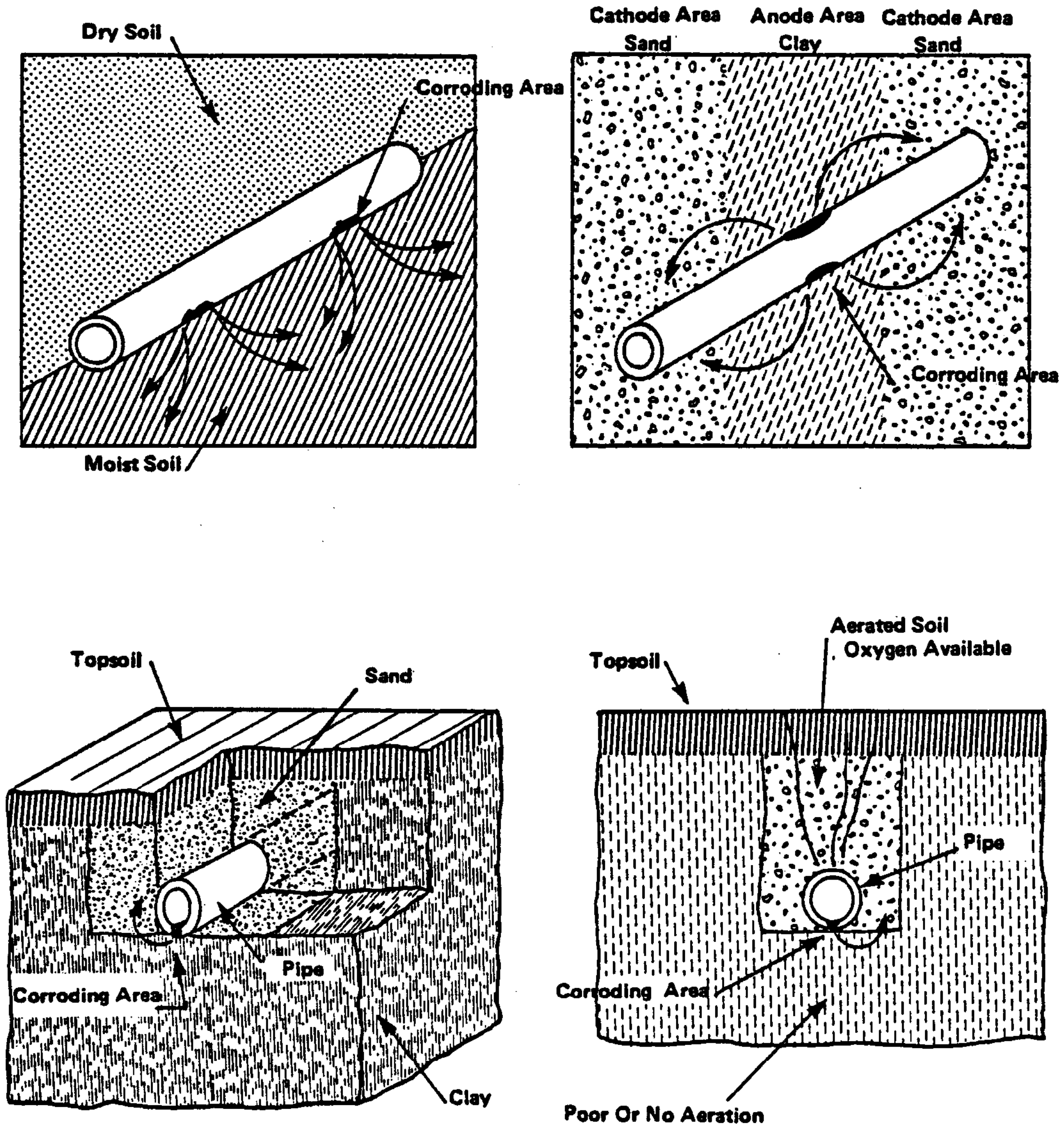
SOURCE: Department of the Navy, 1964.

Figure 4—4 OXYGEN CONCENTRATION CELL WITH RUST ON TANK WALL



SOURCE: Pludek, 1977.

Figure 4–5 IMPINGEMENT ATTACK



SOURCE: Department of the Navy, 1964.

Figure 4–6 DIFFERENTIAL ENVIRONMENT UNDERGROUND

Table 4-2

CORROSION CONTROL METHODS

Type of Corrosion	Control Methods
Uniform Corrosion	• Inhibitors • Protective coating • Anodic protection
Intergranular Corrosion	• Avoiding temperatures that can cause contaminant precipitation during heat treatment or welding
Pitting Corrosion	• Protective coating • Allowing for corrosion in wall thickness
Stress-Corrosion Cracking	• Reducing residual or applied stresses • Redistributing stresses • Avoiding misalignment of sections joined by bolts, rivets, or welds • Materials of similar expansion coefficients in one structure • Protective coating • Cathodic protection
Corrosion Fatigue	• Minimizing cyclic stresses and vibrations • Reinforcing critical areas • Redistributing stresses • Avoiding rapid changes in load, temperature, or pressure • Inducing compressive stresses through peening, swagging, rolling, vapor blasting, chain tumbling, etc.
Galvanic Corrosion	• Avoiding galvanic couples • Completely insulating dissimilar metals (Paint alone is insufficient) • Using filler rods of same chemical composition as metal surface during welding • Avoiding unfavorable area relationships • Using replaceable parts of the anodic (attacked) metal • Cathodic protection • Inhibitors

Table 4-2 (Cont.)

Type of Corrosion	Control Methods
Thermogalvanic Corrosion	• Avoiding non-uniform heating and cooling • Maintaining uniform coating or insulation thickness
Crevice Corrosion; Concentration Cells	• Minimizing sharp corners and other stagnant areas • Minimizing crevices to a minimum, especially in heat transfer areas and in aqueous environments containing inorganic solutions or dissolved oxygen • Enveloping or sealing crevices • Protective coating • Removing dirt and mill-scale during cleaning and surface preparation • Welded butt joints with continuous welds instead of bolts or rivets • Inhibitors
Erosion; Impingement Attack	• Decreasing fluid stream velocity to approach laminar flow • Minimizing abrupt changes in flow direction • Streamlining flow where possible • Installing replaceable impingement plates at critical points in flowlines • Filters and steam traps to remove suspended solids and water vapor • Protective coating • Cathodic protection
Cavitation Damage	• Maintaining pressure above liquid vapor pressure • Minimizing hydrodynamic pressure differences • Protective coating • Cathodic protection • Injecting or generating larger bubbles
Fretting Corrosion	• Installing barriers which allow for slip between metals • Increasing load to stop motion, but not above load capacity • Porous protective coating • Lubricant

Table 4-2 (Cont.)

Type of Corrosion	Control Methods
Hydrogen Embrittlement	• Low-hydrogen welding electrodes • Avoiding incorrect pickling, surface preparation, and treatment methods • Inducing compressive stresses • Baking metal at 200-300°F to remove hydrogen • Impervious coating such as rubber or plastic
Stray-current Corrosion	• Providing good insulation on electrical cables and components • Grounding exposed components of electrical equipment • Draining off stray currents with another conducting material • Electrically bonding metallic structures • Cathodic protection
Differential-environment Cells	• Underlaying and backfill underground pipelines and tanks with the same material • Avoiding partially buried structures • Protective coating • Cathodic protection

Source: Adapted from Pludek, 1977.

Table 4-3

TYPICAL INHIBITORS AND THE CORROSION ENVIRONMENT IN WHICH THEY ARE EFFECTIVE

Inhibitor	Inhibitor Concentration (percent by weight)	Environment	Metals to be Protected
Benzanilide	0.2	Lubricants	Cd-Ni: Co-Pbb bearings
Borax	2-3	Alcohol anti-freeze	Car cooling systems
Calgon	small	Water	Steel
Dioctyl ester of sulpho-succinic acid	0.05	Refined petroleum	Pipelines
Disodium hydrogen phosphate	0.5	Citric acid	Steel
Erythritol	small	K_2SO_4	Mild steel
Ethylaniline	0.5	HC solutions	Ferrous metals
Formaldehyde	small	Oil wells	Oil-well equipment
Mercaptobenzthiazole	1	HC solutions	Iron and steel
Morpholine	0.2	Water	Heat exchangers
Oleic acid	small	Polyhydric alcohol	Iron
Phenyl acridine	0.5	H_2SO_4 solutions	Iron
Potassium dichromate	0.05-0.2	Tap water	Iron-brass
Potassium dihydrogen Phosphate + sodium nitrate	small + 5 percent	Seawater	Steel
Potassium permanganate	0.1	NaOH solutions	Aluminum
Pyridine + phenylhydrazine	0.5 + 0.5	HC solutions	Ferrous metals
Quinoline ethiodide	0.1	H_2SO_4	Steel
Rosin amine-ethylene oxide	0.2	HC solutions	Mild steel
Sodium benzoate	0.5	NaCl solutions	Mild steel
Sodium carbonate	small	Condensate	Iron
Sodium chromate	0.07	$CaCl_2$ brine cooling water	Copper-brass rectifiers
Sodium dichromate	0.025	Water	Air conditioning
Sodium dichromate + sodium nitrate	0.1 + 0.05	Water	Heat exchangers

Table 4-3 (Cont.)

Inhibitor	Inhibitor Concentration (percent by weight)	Environment	Metals to be Protected
Sodium hexametaphosphate	0.002	Water (about pH 6)	Lead
Sodium metaphosphate	Small	Ammonia	Mild steel
Sodium nitrite	0.005	Water	Mild steel
Sodium orthophosphate	1	Water (pH 7.25)	Iron
Sodium silicate	Small	Seawater	Zn; Zn-Al alloys
Tetramethylammonium oxide	0.5	Aqueous solutions of organic solvents	Iron and steel
Thiourea	1	Acids	Iron and steel

Source: Uhlig, 1971.

Table 4-4. Cathodic protection is illustrated in Figures 4-7 and 4-8. Suitability of many protective liner materials can be found in Appendix C.

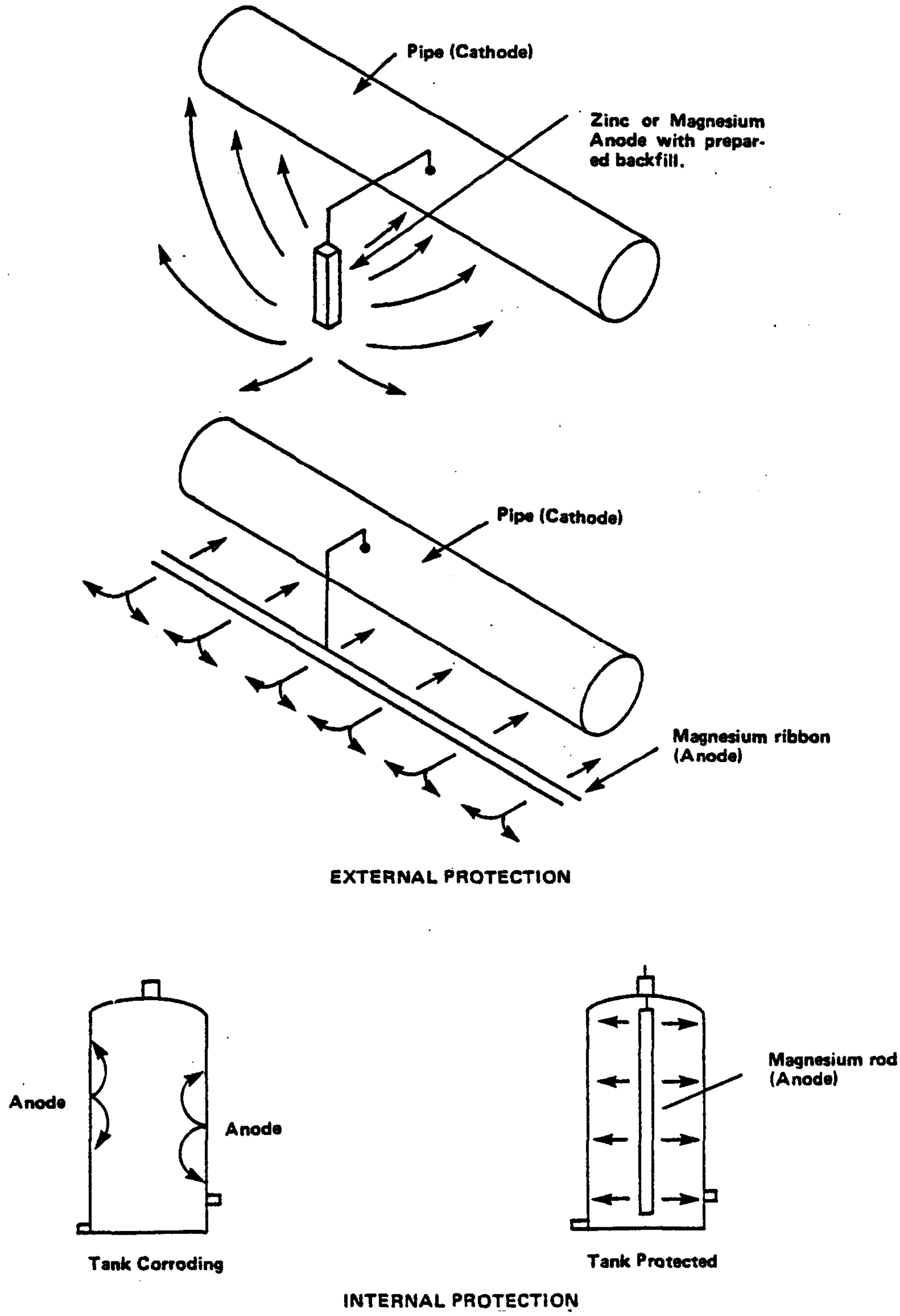
Table 4-4

COMPARATIVE RESISTANCES OF TYPICAL COATINGS

Coating Type	Acid	Alkali	Salts	Solvents	Water	Oxidation	Sunlight and Water	Stress	Abrasion	Heat
Acrylic	8	8	9	5	8	9	10	?	10	8
Alkyd	6	6	8	4	8	3	10	5	6	8
Asphalt	10	7	10	2	10	2	7	5	3	4
Chlorinated Rubber	10	10	10	3	10	9	7	7	7	5
Epoxy	10	9	10	8	10	6	9	3	6	9
Furan	10	10	10	10	10	2	8	1	5	9
Inorganic (metallic)	1	1	5	10	5	10	10	?	10	10
Latex	2	1	6	1	2	1	10	?	6	5
Neoprene	10	10	10	4	10	6	8	10	10	10
Oil Base	1	1	6	2	7	1	10	4	4	7
Phenolic	10	2	10	10	10	7	9	2	5	10
Saran	10	8	10	5	10	10	7	7	7	7
Urethanes	9	10	10	9	10	9	8	?	10	8
Vinyl	10	10	10	5	10	10	10	8	7	7

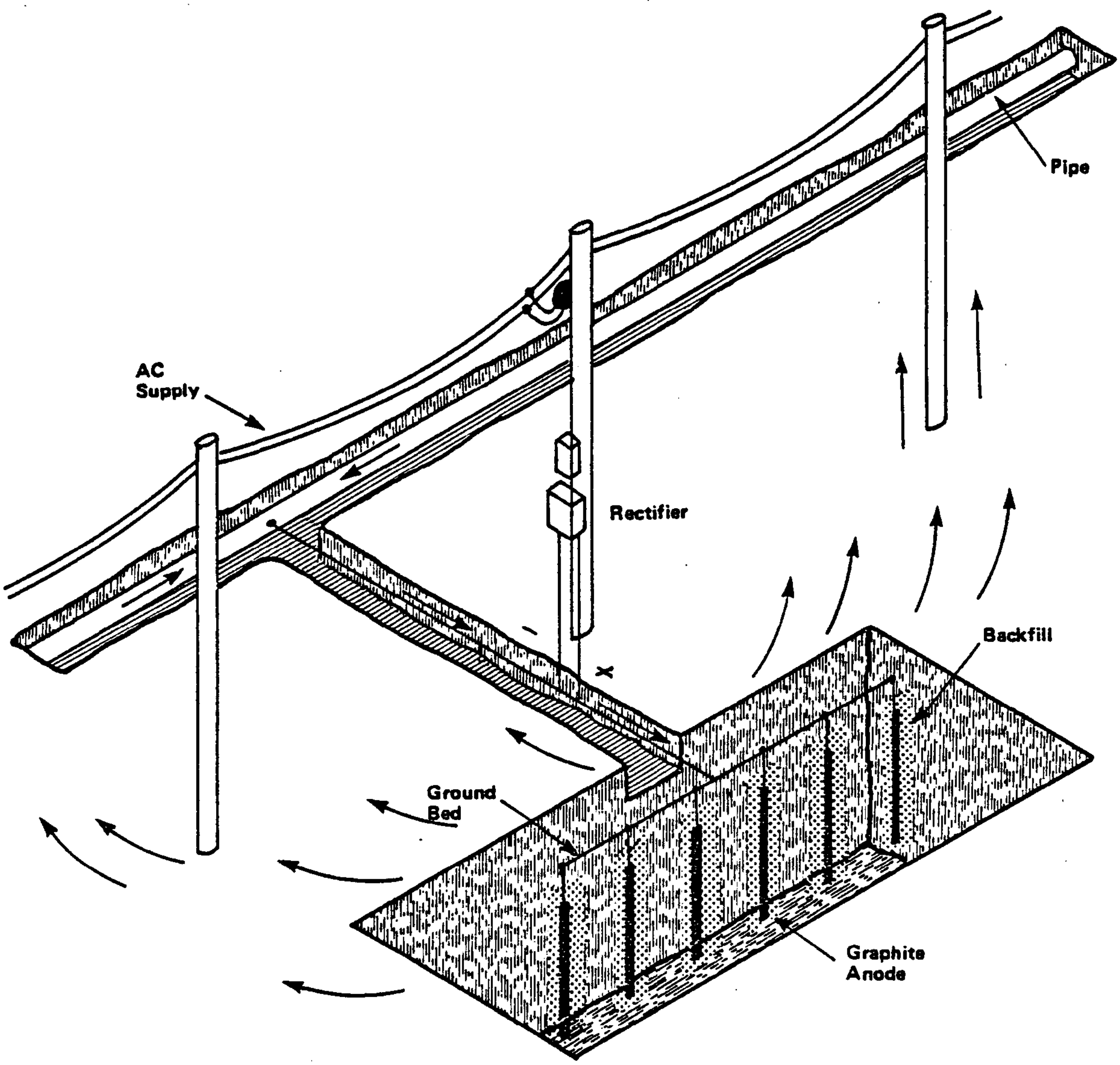
Scale: 1 = Nonresistant
10 = Extremely resistant
? = Insufficient data

Sources: NACE, Process Industries Corrosion, 1975.
Staniar, W., ed. Plant Engineering Handbook, 1959.



SOURCE: Department of the Navy, 1964.

Figure 4–7 CATHODIC PROTECTION BY THE SACRIFICIAL ANODE METHOD



SOURCE: Department of the Navy, 1964.

Figure 4—8 CATHODIC PROTECTION BY THE IMPRESSED CURRENT METHOD

SUGGESTED EXERCISES

1. Name three factors which influence presence and rate of corrosion.

2. Identify and distinguish at least six types of corrosion.

3. Which four types of corrosion account for 80% of all corrosion-related metal failure?

4. Identify appropriate corrosion control methods for the types of corrosion identified in question 3.

5. Identify inhibitors which may be used to protect the following combination of metals in corrosive environments:

    - Steel and water,
    - Mild steel and ammonia,
    - Aluminum and sodium hydroxide solutions,
    - Zinc and seawater,
    - Iron and steel and hydrocarbon solutions.

6. Rank the following coatings in order of resistance to solvents, alkalis, and abrasion, respectively:

    - Acrylic
    - Epoxy
    - Latex
    - Asphalt
    - Oil base

7. Describe the differences between cathodic and anodic protection.

SECTION 5

INSPECTION AND MAINTENANCE

A successful maintenance and inspection program will:

- Minimize probability of accidental spills or releases,
- Reduce risks of fire or exposure,
- Maintain safe working conditions,
- Detect potential trouble spots and begin corrective action before serious damage occurs, and
- Reduce monetary losses.

Therefore, an inspection program must be able to identify such problem areas as:

- Excessive corrosion or erosion,
- Structural fatigue or metal cracking,
- Deterioration of liners and appurtenances,
- Weakening or cracking of welds and joints, and
- Leakage of valves, pipes, and tanks.

5.1 TEST METHODS

There are several methods for nondestructive testing of the structural integrity of aboveground tanks, or of underground tanks before installation. These methods include:

- Radiographic,
- Ultrasonic,
- Wet magnetic particle,
- Dry magnetic particle,
- Liquid (dye) penetrant,
- Hydrostatic,
- Eddy current, and
- High-voltage spark.

The appropriate test type for detecting specific defects are summarized in Table 5-1. An extensive listing of applications and limitations of various test types is found in Table 5-2.

5.2 AREAS OF INSPECTION

Figures 5-1 and 5-2 illustrate specific areas of aboveground tanks which should be inspected. Table 5-3 denotes the references

Table 5-1

APPLICATION OF NON-DESTRUCTIVE TEST METHODS

Type of Imperfection Detected	Test Type: Visual	Random Radiographic	100% Radiography	Ultrasonic	Wet Magnetic Particle	Dry Magnetic Particle	Liquid Penetrant	Hydrostatic	Eddy Current	Spark Testing
VALVE										
Cracks	X				X					
Strength								X		
TANK										
Cracks or surface discontinuties	X				X	X	X		X	X
Subsurface dis- continuties		X		X					X	X
Thinning				X					X	
Strength								X		
WELDS										
Crack	X				X	X	X			
Incomplete penetration	X	X	X							
Porosity			X							
Slag inclusions			X							

SOURCE: Ecology and Environment, Inc., 1982.

Table 5-2

NON-DESTRUCTIVE TEST METHODS

Method	Measures or Detects:	Applications	Advantages	Limitations
Acoustic emission	Crack initiation and growth rate Internal cracking in welds during cooling Boiling or cavitation Friction or wear Plastic deformation	Pressure vessels Stressed structures	Remote and continuous surveillance Permanent record Dynamic (rather than static) detection of cracks Portable Triangulation techniques to locate flaws	Transducers must be placed in contact with surface of part to be tested Highly ductile materials yield low amplitude emissions Part must be stressed or operating Test system noise needs to be filtered out
Acoustic-impact (tapping)	Debonded areas or delaminations in metal or non-metal composites or laminates Loose rivets or fasteners Crushed core	Brazed or adhesive-bonded structures Bolted or riveted assemblies Composite structures Honeycomb assemblies	Portable Easy to operate May be automated Permanent record or positive meter readout No couplant required	Part geometry and mass influences test results Impactor and probe must be repositioned to fit geometry of part Reference standards required Pulser impact rate is critical for repeatability

Table 5-2 (Cont.)

Method	Measures or Detects:	Applications	Advantages	Limitations
Eddy current (200 Hz to 6 MHz)	Surface and subsurface cracks and seams Alloy content Heat treatment variations Wall thickness, coating thickness Crack depth Conductivity Permeability	Tubing "Spot checks" on all types of surfaces Proximity gage Metal detector Metal sorting Measure conductivity	No special operator skills required High speed, low cost Automation possible for symmetrical parts Permanent record capability for symmetrical parts No couplant or probe contact required	Conductive materials Shallow depth of penetration (thin walls only) Masked or false indications caused by sensitivity to variations such as part geometry, lift-off Reference standards required Permeability variations
Electric current	Cracks Crack depth Resistivity Wall thickness Corrosion-induced wall thinning	Metallic materials Electrically conductive materials	Access to only one surface required Battery or DC source Portable	Edge effect Surface contamination Good surface contact required Difficult to automate Electrode spacing Reference standards required

Table 5-2 (Cont.)

Method	Measures or Detects:	Applications	Advantages	Limitations
Fluoroscopy (Cino-fluorography) (Kine-fluorography)	Level of fill in containers Foreign objects Internal components Density variations Voids, thickness Spacing or position	Particles in liquid flow Presence of cavitation Operation of valves and switches	High-brightness images Real-time viewing image magnification Permanent record Moving subject can be observed	Costly equipment Lack of geometric sharpness Thick specimens Speed of event to be studied Viewing area
Holiday detector High voltage (spark)	Inegrity of coatings or linings	Detects holidays in coatings of thickness >15 mils	Portable Easy to operate	Possible damage if dielectric strength exceeded
Holiday detector Low voltage	Integrity of coatings	Detects holidays in coatings of thickness <20 mils	Portable Easy to operate	Requires contact with substrate
Leak testing	Leaks Helium, Ammonia, Smoke, Water, Air Bubbles, Radioactive gas, Halogens	Joints Welded, Brazed, Adhesive-bonded Sealed assemblies Pressure or vacuum chambers Fuel or gas tanks	High sensitivity to extremely small, tight separations not detectable by other NDT methods Sensitivity related to method selected	Accessibility to both surfaces of part required Smeared metal or contaminants may prevent detection Cost related to sensitivity

Table 5-2 (Cont.)

Method	Measures or Detects:	Applications	Advantages	Limitations
Magnetic particle	Surface and slightly subsurface defects; cracks, seams, porosity, inclusions Permeability variations Extremely sensitive for locating small tight cracks	Ferromagnetic materials; bar, forgings, weldments, extrusions, etc.	Advantage over penetrant is that it indicates subsurface defects, particularly inclusions Relatively fast and low cost May be portable	Alignment of magnetic field is critical Demagnetization of parts required after tests Parts must be cleaned before and after inspection Masking by surface coatings
Magnetic field	Cracks Wall thickness Nonmagnetic coating thickness on steel	Ferromagnetic materials Inspection of coatings on steel Wall thickness of nonmagnetic materials	Measurement of magnetic material properties May be automated Easily detects magnetic objects in nonmagnetic material Portable	Permeability Reference standards required Edge-effect Probe lift-off Loss of accuracy on curved surfaces

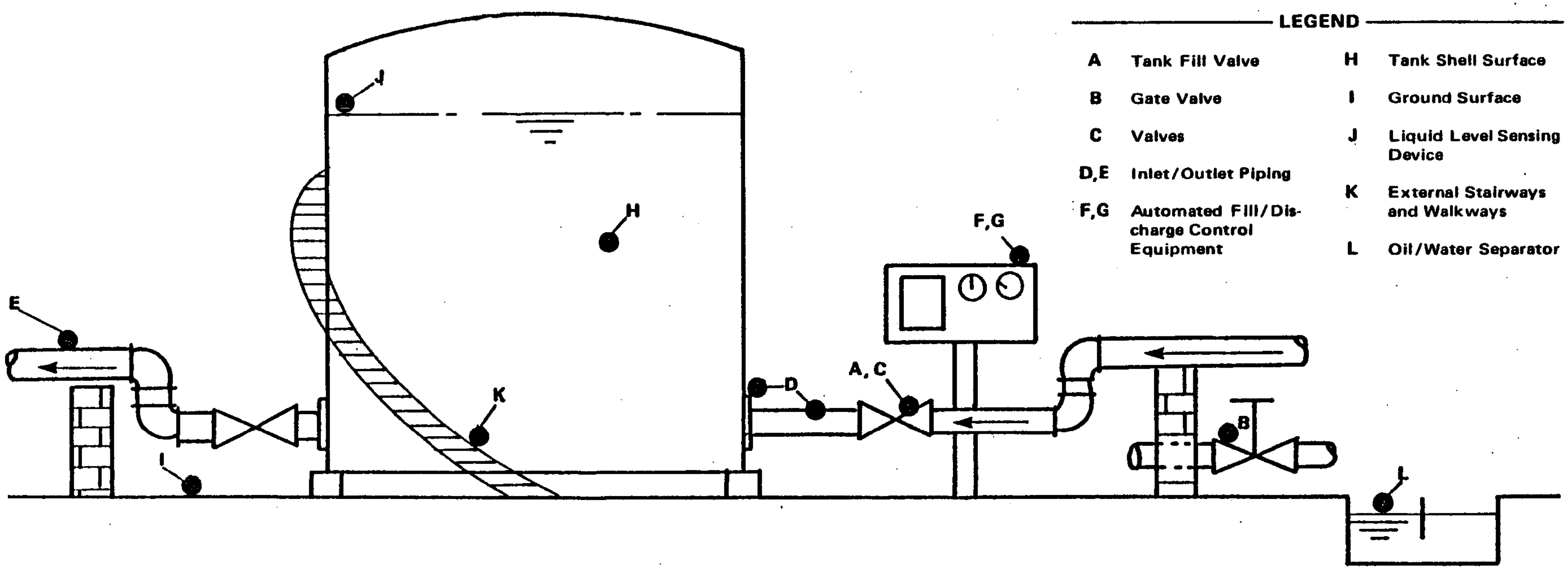
Table 5-2 (Cont.)

Method	Measures or Detects:	Applications	Advantages	Limitations
Microwave (300 Mhz-300-Ghz)	Cracks, holes, deboned areas, etc., in non-metallic parts Changes in composition degree of cure, moisture content Thickness measurement	Reinforced plastics	Between radio waves and and infrared in the electromagnetic spectrum Portable Contact with part surface not normally required Can be automated	Will not penetrate metals Reference standards required Horn to part spacing critical Part geometry Wave interference Vibration
Penetrants (Dye or fluorescent)	Defects open to surface of parts; (cracks, porosity, seams, laps, etc.) Through-wall leaks	All parts with nonabsorbing surfaces forgings, weldments, castings, etc.)	Low cost Portable Indications may be further examined visually Results easily interpreted	Surface films, such as coatings, scale, and smeared metal may prevent detection of defects Parts must be cleaned before and after inspection Defect must be open to surface Bleed-out from porous surfaces can mask indications of defects

Table 5-2 (Cont.)

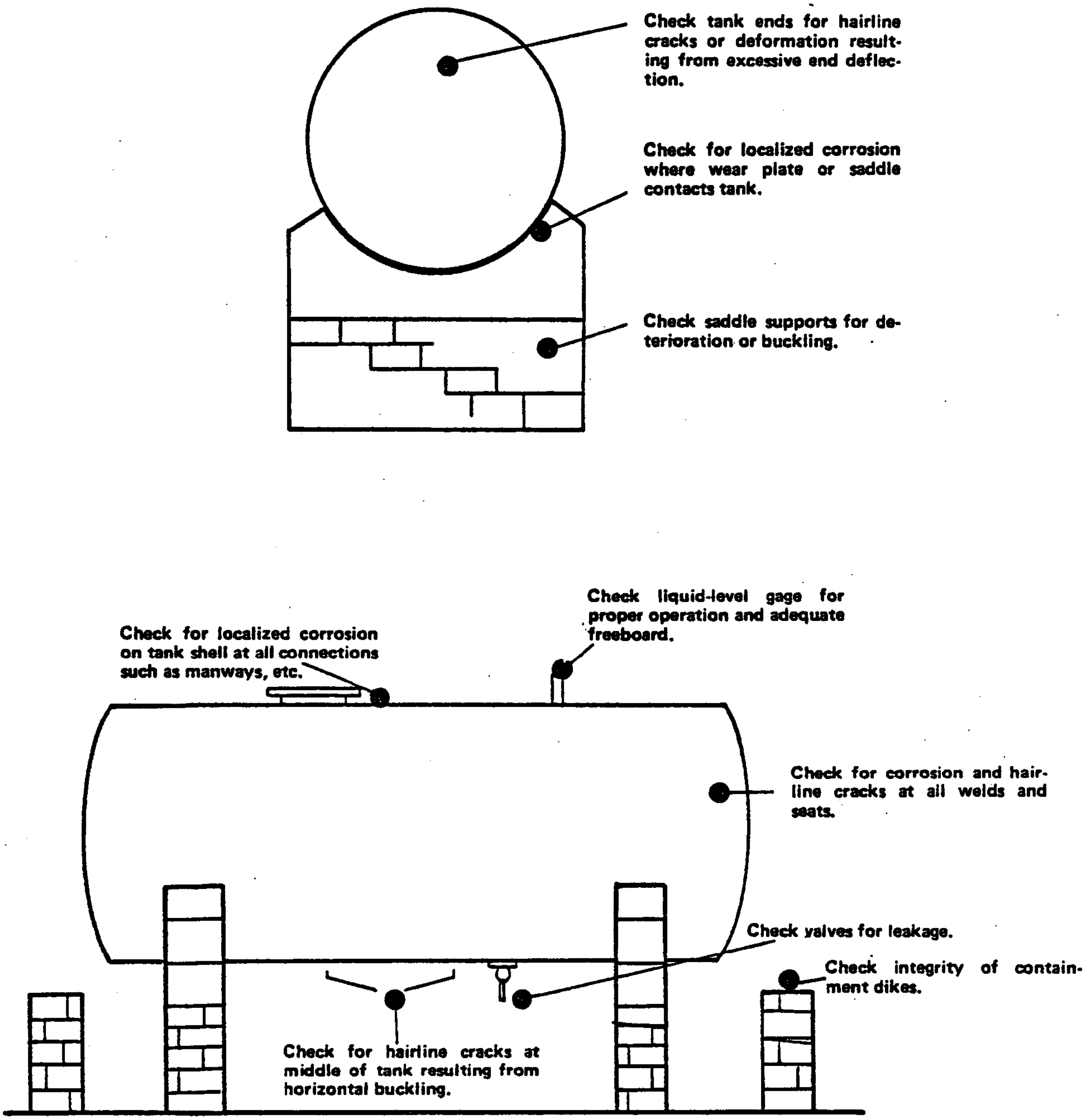
Method	Measures or Detects:	Applications	Advantages	Limitations
Radiography (X-rays-film)	Internal defects and variations; porosity; inclusions; cracks; lack of fusion; geometry variations; corrosion thinning Density variations Thickness, gap and position Misassembly Misalignment	Castings Electrical assemblies Weldments Small, thin, complex wrought products Nonmetallics Composites	Permanent records; film Adjustable energy levels (5 kv-25 mev) High sensitivity to density changes No couplant required Geometry variations do not affect direction of X-ray beam	High initial costs Orientation of linear defects in part may not be favorable Radiation hazard Depth of defect not indicated Sensitivity decreases with increase in scattered radiation
Ultrasonic (0.1-25MHz)	Internal defects and variations; cracks, lack of fusion, porosity, inclusions, delaminations, lack of bond, texturing Thickness	Wrought metals Welds Brazed joints Adhesive-bonded joints Nonmetallics In-service parts	Most sensitive to cracks Test results known immediately Automating and permanent record capability Portable High penetration capability	Couplant required Small, thin, complex parts may be difficult to check Reference standards required Trained operators for manual inspection Special probes

Source: NACE, 1980.



SOURCE: Ecology and Environment, Inc., 1983.

Figure 5–1 AREAS OF CONCERN IN TYPICAL ABOVEGROUND VERTICAL TANK SYSTEM (See Table 5–3 for requirements)



SOURCE: Ecology and Environment, Inc., 1983.

Figure 5–2 AREAS OF CONCERN IN TYPICAL HORIZONTAL TANK SYSTEM

Table 5-3

TYPICAL ABOVEGROUND TANK SYSTEM - AREAS OF CONCERN

Item	Requirement
A	Tank fill valve should be in the closed position and locked when not in use.
B	The gate valve used for emptying the diked containment area should be of the hand-operated variety only and should be closed and locked at all times.
C	All valves should be inspected for signs of leakage or deterioration.
D, E	Inlet and outlet piping, as well as tank flanges should be checked for leakage and to insure that adequate support is provided
F, G	Automated fill control and discharge control equipment should be checked to see that it is operating properly.
H	The tank shell surface should be visually inspected for areas of rust, or other deterioration. Particular attention should be paid to peeling area, welds and seams.
I	The ground surface inside the diked area should be checked for obvious signs of leakage or spillage.
J	The liquid level sensing device should be checked to insure that there is adequate freeboard.
K	External stairways and walkways should be checked to insure that they are unobstructed and sound.
L	The oil/water separator should be checked for adequate feeeboard and to insure that it is operating properly.

Source: Ecology and Environment, Inc., 1983 designated in Figure 5-1. Leaks in underground tanks can be detected by a number of hydrostatic, liquid-level, sonic, or indirect measurements. These tests include:

- Kent-Moore (Heath Petro-tite) test;
- J-tube manometer test;
- Arco HTC Leak Test
- Laser beam leak detection;
- Sunmark Leak Lokator;
- Sonic measurement test;
- Inventory control records; and
- Monitoring wells.

Usually only two or three of these tests are authorized for use in any one jurisdiction. Consequently, it is the responsibility of the tank owner to be sure the procedure to be used is authorized in that jurisdiction. Records of leak test results should be kept in a log. A suggested format is illustrated in Figure 5-3. Although the specific information to be recorded will vary with the type of test used, the format illustrates the type of data that should be recorded.

Tank liners of magnetic materials may be tested by the magnetic particle method. Other metal liners may be tested by the dye penetrant method. Non-conductive liner materials may be tested by the high voltage spark test.

Valves require frequent visual inspection for leaks and imperfections. When tanks are out of service, valves should be dismantled for inspection of internal conditions. Caliper measurements of body thickness should be taken, especially if corrosion is visible. After reassembly, the valves should be pneumatically or hydrostatically tested. Specific critical inspection areas of common valve types are illustrated in Figures 5-4 through 5-10.

Other storage facility areas requiring routine inspection are:

- Stairways and walkways;
- Flame arrestors;
- Dikes and berms;
- Grounding and electrical connections;
- Pressure and vacuum vents;
- Liquid level gaging and detection equipment;
- Water drains;
- Pipe supports and connections; and
- Foundations.

Figure 5-11 illustrates areas of a typical tank foundation which should be inspected.

5.3 INSPECTION FREQUENCIES

The intervals for performing various inspection tasks should be determined on a case-by-case basis. Factors which should be considered in determining those frequencies include:

- The chemical nature of the material stored;
- Known or expected corrosion rates;

LEAK TESTING LOG

FACILITY OWNER: ____________________

ADDRESS: ____________________

TANK: ____________________

CONTENTS: ____________________

CAPACITY: ____________________

VOLUME IN TANK: ____________________

PRODUCT ADDED TO FILL TESTER: ____________________

TOTAL QUANTITY IN TANK: ____________________

Time	Description of Procedures	Volume or Level	Change in Volume or Level	Temperature Change	Net Volume Change	
					This Reading	Cumulative

Test Results/Certification: ____________________

____

____

____
Signature of Tester

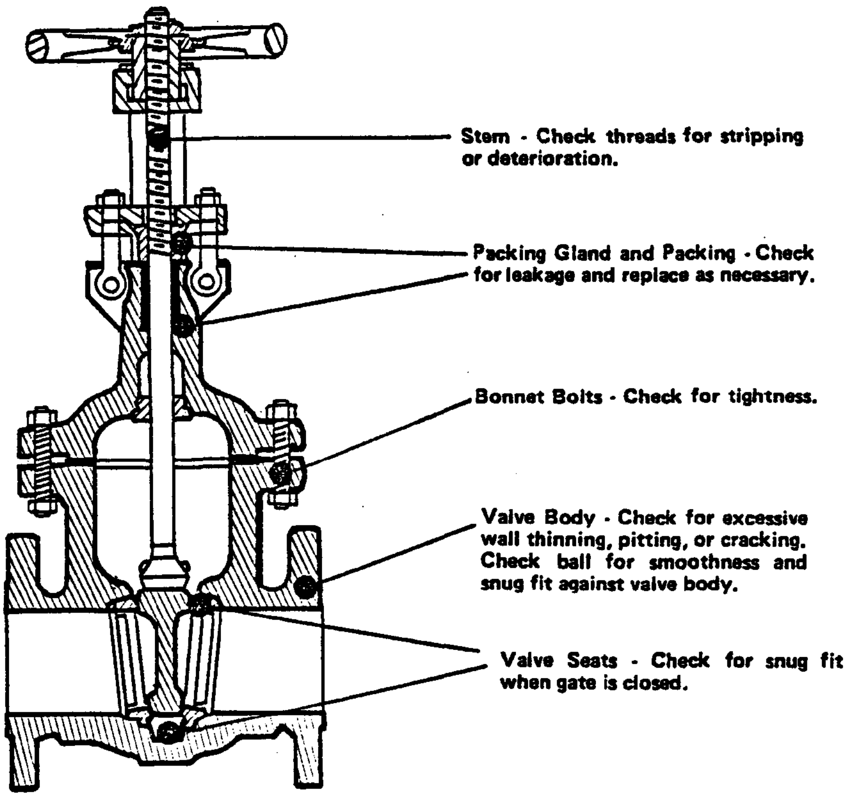
Organization: ____________________

Address: ____________________

____

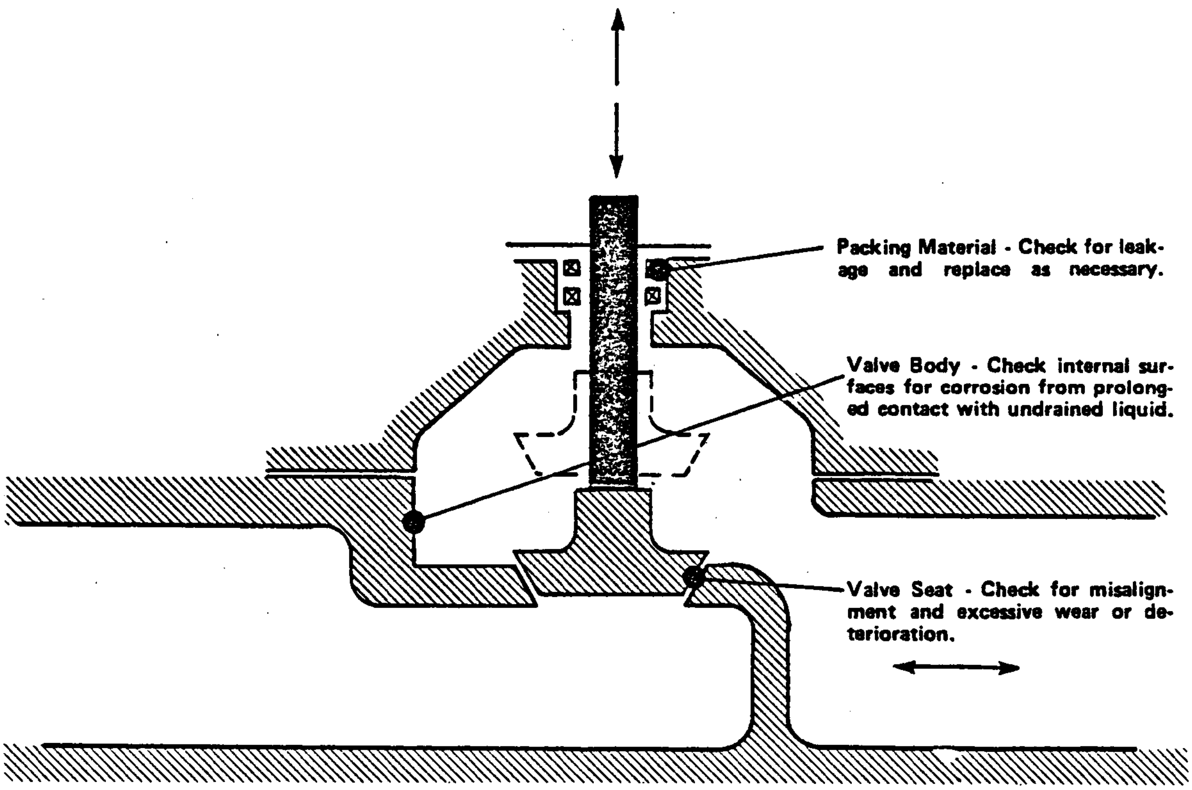
SOURCE: Ecology and Environment, Inc., 1983.

Figure 5–3 LEAK TESTING LOG



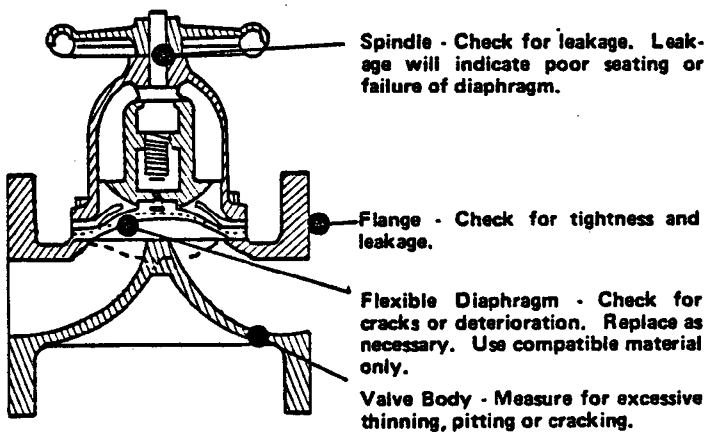
SOURCE: British Valve Manufacturers Association, 1966.

Figure 5–4 CRITICAL AREAS OF GATE VALVE



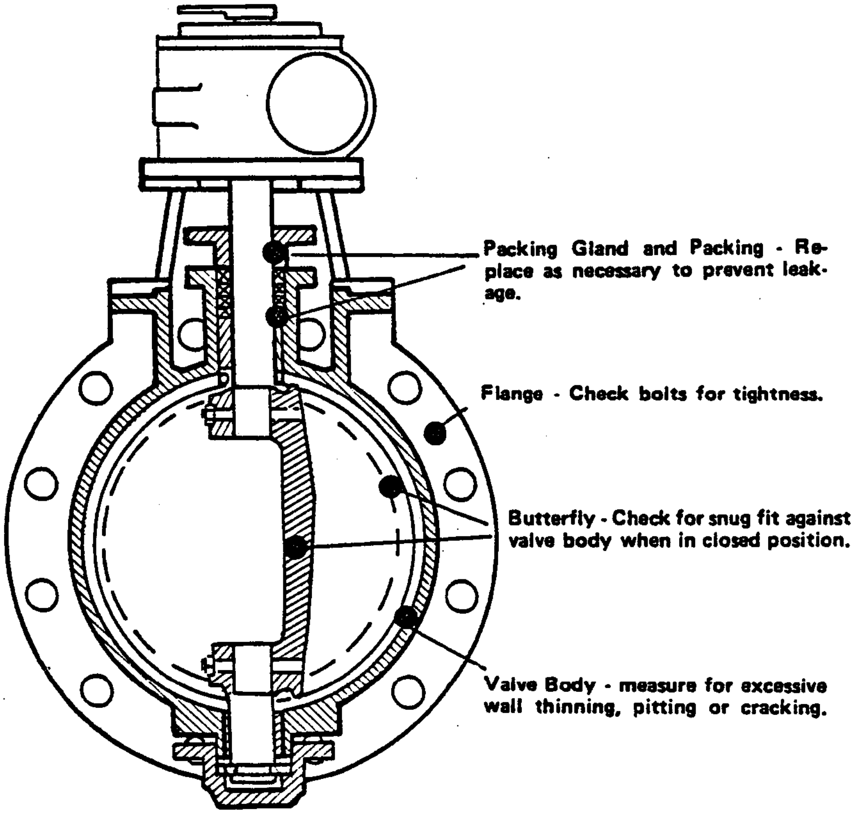
SOURCE: Perry and Chilton, 1973.

Figure 5–5 CRITICAL AREAS OF GLOBE VALVE



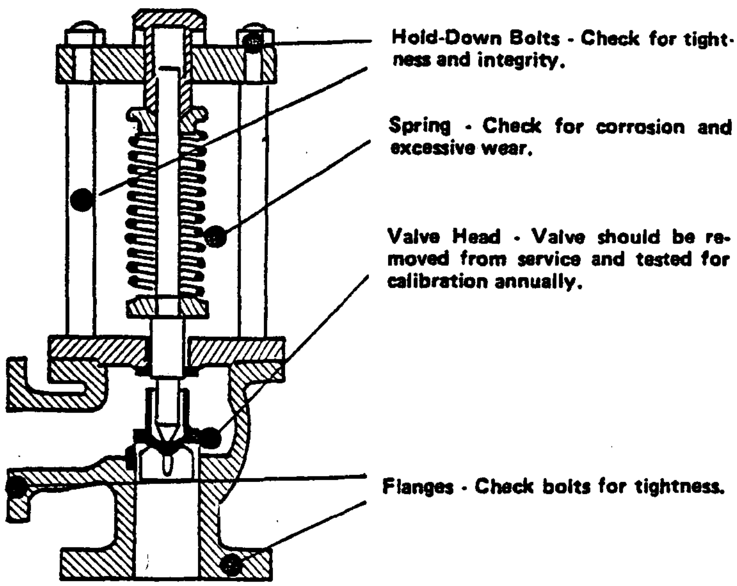
SOURCE: British Valve Manufacturers Association, 1966.

Figure 5–6 CRITICAL AREAS OF DIAPHRAGM VALVE



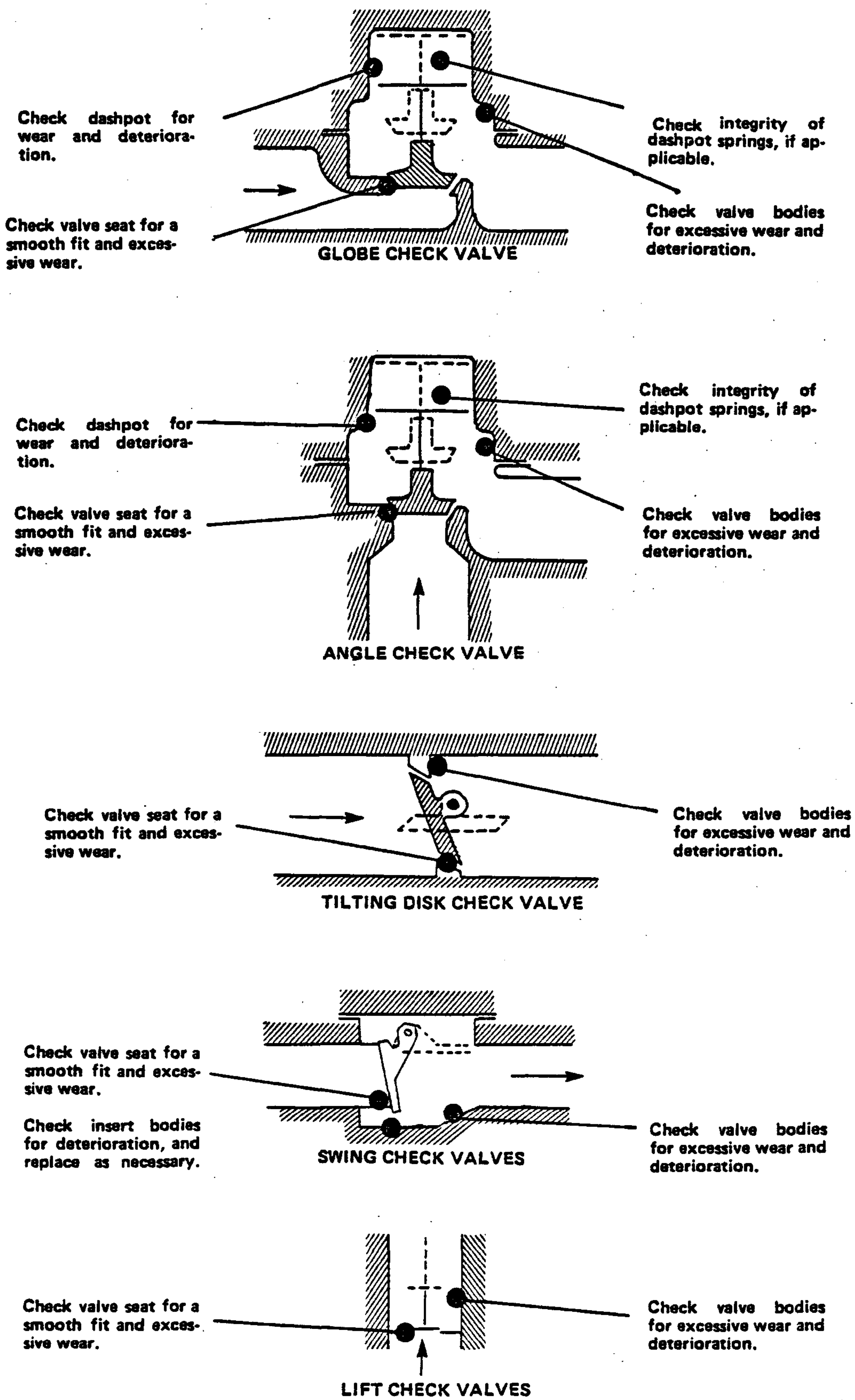
SOURCE: British Valve Manufacturers Association, 1966.

Figure 5—7 CRITICAL AREAS OF BUTTERFLY VALVE



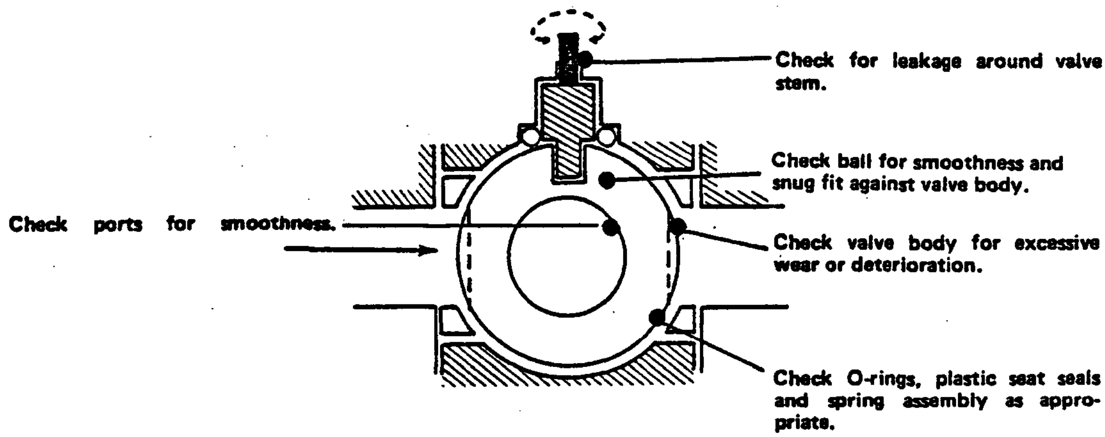
SOURCE: British Valve Manufacturers Association, 1966.

Figure 5–8 CRITICAL AREAS OF SAFETY (PRESSURE RELIEF) VALVE



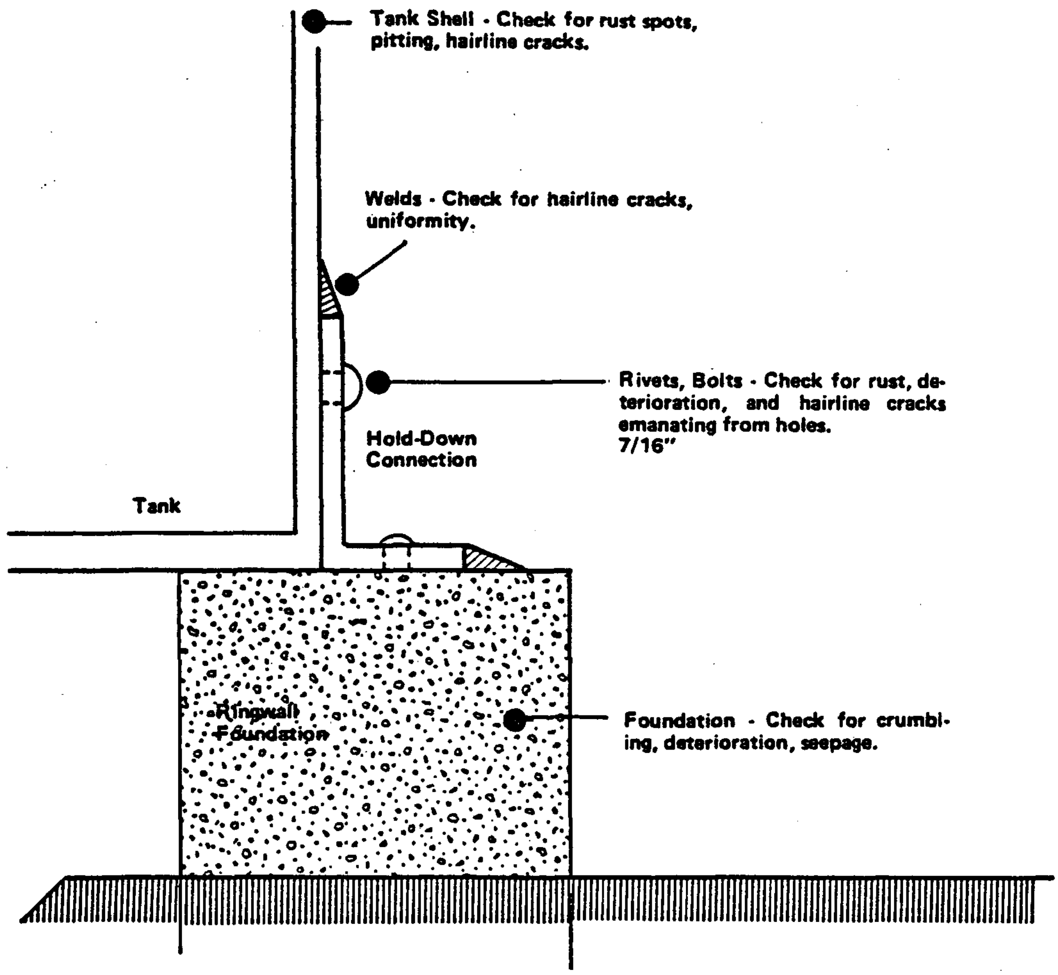
SOURCE: Perry and Chilton, 1973.

Figure 5–9 TYPES AND CRITICAL AREAS OF CHECK VALVES



SOURCE: Perry and Chilton, 1973.

Figure 5–10 CRITICAL AREAS OF BALL VALVE



SOURCE: Ecology and Environment, Inc., 1983.

Figure 5—11 AREAS OF CONCERN IN A TYPICAL TANK FOUNDATION

- Acceptable corrosion allowances;
- Historical or previously observed conditions; and
- Facility location.

Table 5-4 outlines suggested frequencies for a variety of inspection tasks. In order to standardize inspection procedures, suggested inspection records are illustrated in Figures 5-12 through 5-15.

5.4 PRIORITIES FOR CORRECTIVE ACTION

Priorities for correcting adverse conditions are based largely on the potential consequences of failure to correct the conditions, and the probability that those consequences will occur. When time or resources are factors, priority must be given to correcting those defects with the highest probability of causing the worst consequences. Among the factors to be considered in determining maintenance and repair priorities are:

- Age of the facility;
- Construction materials;
- Physical/chemical/toxicological properties of the stored materials;
- Ouantities stored;
- Operation of warning or control devices;
- Geologic/hydrologic/topographic properties of the facility;
- Design specifications and tolerances;
- Size and proximity of adjacent population;
- Monetary value of the stored materials, facility, and off-site property; and
- Likely consequences of storage system failure.

In any situation, it is best to take corrective action at the earliest detection of problems.

5.5 TANK CLEANING

Tank cleaning procedures must be performed carefully to prevent inadvertent spills, releases, reactions, or personnel exposure. Proper equipment to be used includes:

- Air monitoring equipment;
- Protective clothing;
- Appropriate ventilation or air supplies;

Table 5-4

MINIMUM INSPECTION TASKS AND FREQUENCIES

Frequency	Task
Daily	Visually check valve stems and flanges for leakage
	Visually check piping for misalignment, bending, or leakage with particular attention to tees, couplings, elbows, and connections
	Inspect ground surface around vertical and horizontal tanks for signs of leakage
	Check discharge and fill control equipment before product is transferred to insure that it is functioning properly
	Check liquid level in the tank before product is added to insure adequate capacity
	Check gate valve from diked area to insure that it is closed and locked
	Check walkways and stairways for obstructions
	Check and record inventory of tank contents
Weekly	Check liquid level gaging equipment to insure that it is functioning properly
	Check roof drains for obstructions
	Check vents and pressure-relief devices for obstructions
	Check grounding lines and connections for integrity
	Check stairways for damaged rungs or handrails
	Check containment dike or berm for integrity
	Does oil/water separator or equivalent require pumping
	Check separator discharge for clarity
	Does diked area require drainage
	Check fire extinguishing equipment
Monthly	Inspect all exterior tank surfaces, welds, rivets/bolts, foundation
	Check impressed current rectifiers
	Inventory all spill control and other emergency response equipment
Quarterly	Non-destructive thickness testing of piping and valves

Table 5-4 (Cont.)

Frequency	Task
Semi-Annually (at scheduled down-time)	Thickness testing for shell walls
	Inspection of liners
	Leak testing of foundation
	Leak testing of underground tanks assembly
Annually (at scheduled down-time)	Test structural stability of support structures for elevated tanks and test pressure relief valves for calibration
	Measure tank-to-soil potential

Source: Ecology and Environment, Inc., 1983.

Daily Inspection Checklist

TANK # ______________________ PAGE ______ OF ______

LOCATION ______________________ INSPECTED BY ______________

FILL LEVEL ______________________ DATE ______________

CONTENTS ______________________

Inspection Tank	Accept-able	Unaccept-able (Specify)	Recommended Corrective Action	Referred To
Is fill valve locked and closed?				
Is dike gate valve locked and closed?				
Condition of valve # ___ # ___ # ___				
Condition of inlet piping				
Condition of outlet piping				
Fill control equipment functioning?				
Discharge control equipment functioning?				
Visual check of tank shell integrity				
Evidence of leakage on ground?				
Is there adequate freeboard in tank				
Are stairways and walkways unobstructed				

SOURCE: Ecology and Environment, Inc., 1983.

Figure 5—12 DAILY INSPECTION CHECKLIST

WEEKLY INSPECTION CHECKLIST

TANK # ____________________ PAGE ______ OF ______

LOCATION ____________________ INSPECTED BY ____________________

FILL LEVEL ____________________ DATE ____________________

CONTENTS ____________________

Item	Acceptable	Unacceptable (specify)	Recommended Corrective Action	Referred To
Is liquid level gaging equipment operating properly?				
Is emergency shut-down system functioning properly?				
Are roof vents clear?				
Are roof drains clear?				
Are pressure relief devices free of obstruction?				
Are stairways and handrails in good condition?				
Is containment dike/berm intact?				
Does diked area require damage?				
Is there adequate freeboard in oil-water separator				
Is fire extinguishing equipment in place and functioning properly?				
Leak detection equipment functioning properly?				

SOURCE: Ecology and Environment, Inc., 1983.

Figure 5—13 WEEKLY INSPECTION CHECKLIST

Item	Accept-able	Unaccept-able (specify)	Recommended Corrective Action	Referred To
Check ignition safeguards: Isolated metal objects and fill nozzels grounded?				
Absence of spark promoters from tank interior?				
Inlet flow rate sufficiently limited?				
Ground connections secure?				
Metallic shunts intact?				

SOURCE: Ecology and Environment, Inc., 1983.

Figure 5—13 WEEKLY INSPECTION CHECKLIST (Cont.)

MONTHLY TANK INSPECTION LOG

TANK # ______ LOCATION: ______ FILL LEVEL: ______

CONTENTS: ______ INSPECTED BY: ______ DATE: ______ PAGE ___ OF ___

Item	Observations	Recommendations for Corrective Action
Tank shell and roof -Discoloration or flaking of coating -Localized corrosion -Structural damage -Development of hairline cracks -Bulging or cavitation -Deterioration at joints and connections		
Welds -Localized corrosion -Separatin or distortion of welded components -Development of hairline cracks		
Rivets/bolts -Localized corrosion -Loosened components -Missing		
Foundations/supports -Cracking or deterioration of concrete ringwall or support -Uneven settlement -Slippage of tank from foundation or support -Buckling of saddle or vertical supports -Loosened anchor bolts		

SOURCE: Ecology and Environment, Inc., 1983.

Figure 5–14 MONTHLY TANK INSPECTION LOG

THICKNESS TESTING LOG

TANK # ____________ LOCATION: ____________ CONTENTS: ____________

Date of Inspection	Fill Level	Thickness, Inches																	Tank Certified for Continued Service at Liquid Height h =	Tank Certified for Continued Service at Liquid Gravity G =
		h_1	h_2	h_3	h_4	h_5	h_6	h_7	h_8	$Roof_1$	$Roof_2$	$Bottom_1$	$Bottom_2$	$Valve_1$	$Valve_2$	$Valve_3$	Inlet Piping	Outlet Piping		

SOURCE: Ecology and Environment, Inc., 1983.

Figure 5—15 THICKNESS TESTING LOG

- Appropriate cleaning equipment, such as steam nozzles, agitators, sandblasters, etc.;

- Safety belts and lines; and

- First aid kits.

Procedures for cleaning tanks will vary with the specific job to be performed. However, they may be generalized as follows:

- Purge tanks and lines of contents;

- Purge all residual vapors;

- Monitor tank interiors for gases, vapors, and oxygen content;

- Provide adequate ventilation of vapors, and fresh air supply for personnel;

- Use hot or cold cleaning solutions compatible with the residual tank contents; and

- Take precautions to prevent spills of cleaning materials.

5.6 TANK CLOSURE

Tank closure may be temporary, pending future usage, or permanent, at the end of the useful life of the tank. Temporary closure is performed by:

- Removing tank contents;
- Filling with water and corrosion inhibitors;
- Capping all fill and draw-off lines; and
- Opening all vent lines.

Permanent closure may be achieved by removal or by abandonment in place. For permanent closure, the tank should be:

- Emptied of all liquids, solids, sludges, and vapors;
- Thoroughly cleaned;
- Filled with an inert solid, such as sand, gravel, or concrete;
- Capped at all fill, vent, draw-off, and access points;
- Securely anchored if aboveground; and
- If it is to be disposed of, rendered unusable or dismantled.

SUGGESTED EXERCISES

1. Name three objectives of a maintenance and inspection program.

2. Identify areas of concern on which an inspection program should focus.

3. Identify the applications and limitations of the following non-destructive test methods:

   - Wet magnetic particle,
   - Eddy current,
   - Ultrasonic,
   - Radiographic, and
   - Spark testing.

4. Identify six tests for detecting leakage in underground tanks. Which are approved or use in this facility's regulatory jurisdiction?

5. Identify eight areas which should be inspected in a typical aboveground tank system.

6. Identify critical inspection areas for the following valve types:

   - Globe,
   - Diaphragm,
   - Ball, and
   - Butterfly.

7. Which factors must be considered in determining inspection frequencies?

8. Identify three inspection tasks which must be performed at daily, weekly, and semi-annual intervals, respectively.

9. Name six factors to be considered in determining maintenance and repair priorities.

10. Describe procedures to be employed during tank cleaning.

11. Describe procedures to be employed during temporary tank closure.

SECTION 6

PERSONNEL HEALTH AND SAFETY

Health and safety hazards can be controlled by:

- Hazard elimination or substitution;
- Engineering controls;
- Administrative controls; and
- Personal protective equipment.

Control of health and safety hazards are regulated by OSHA or by appropriate state regulations. These standards should be supplemented by ANSI, NIOSH, and ACGIH recommendations, which are more extensive, more up-to-date, and often referenced by the state or OSHA regulations.

6.1 PERSONAL PROTECTIVE EQUIPMENT

Hazardous materials facility personnel should be provided with and use appropriate equipment to protect against skin or respiratory exposures. Materials for hand and body protection include:

- Leather, asbestos, wool, and aluminized materials for heat protection;

- Padded material for protection against cuts, blows, and bruises; and

- Impervious materials, such as natural and synthetic rubber, neoprene, vinyl, and polypropylene. Resistance of some of these impervious materials to selected chemicals is shown in Table 6-1.

Standards for respiratory protection programs specify a number of requirements, including:

- Written standard operating procedures on respirator selection and use;

- Instruction and training in use and limitations of respirator; and

- Routine cleaning, inspection, and maintenance.

Respirators should be selected on the basis of:

- Nature of the hazard;

Table 6-1

CHEMICAL RESISTANCE OF PROTECTIVE CLOTHING MATERIALS

	Neoprene	Polyvinyl Chloride (PVC)	Paracril/ PVC	Polyurethane	Chlorinated Polyethylene	Butyl Rubber	Natural Rubber	Nitrile	Vitron	Polyvinyl Acetate (PVA)
Acetaldehyde	C	C	A	C	I	A	A	C	U	U
Acetic Acid	A	C	A	C	A	C	A	A	U	U
Acetone	A	C	U	C	A	C	A	C	U	U
Acrylonitrile	A	C	A	A	A	C	C	C	I	I
Ammonium Hydroxide	A	A	A	A	A	A	A	A	A	U
Amyl Acetate	C	C	A	C	C	C	C	C	U	A
Aniline	C	C	A	A	A	C	C	C	C	C
Benzaldehyde	C	C	A	C	C	A	C	C	U	A
Benzene	C	U	C	A	C	U	U	C	C	A
Benzyl Alcohol	A	C	A	C	A	A	A	A	I	I
Benzyl Chloride	C	C	A	C	U	C	C	C	C	I
Butyl Acetate	C	C	A	C	A	C	C	C	U	A
Butyl Alcohol	A	A	A	C	A	A	A	A	I	C
Carbolic Acid	C	C	A	A	A	C	A	C	A	C
Carbon Disulfide	C	C	A	C	C	U	C	C	I	A
Carbon Tetrachloride	C	C	A	C	C	U	C	A	A	A
Chloroacetone	C	U	C	C	U	C	C	C	I	I
Chloroform	C	C	A	C	U	U	C	C	A	A

A=Acceptable
U=Unacceptable
C=Conditionally Acceptable
I=Insufficient Data

Note: This table is provided as a guide only. The user is advised to contact the protective clothing manufacturer regarding the specific applicability and limitations of a material under proposed conditions of use.

Table 6-1 (Cont.)

	Neo-prene	Poly-vinyl Chloride (PVC)	Paracril/ PVC	Polyur-ethane	Chlorinated Polyethy-lene	Butyl Rubber	Natural Rubber	Nitrile	Vitron	Poly-vinyl Acetate (PVA)
Coal Tar Products	C	C	A	A	C	C	C	C	I	I
Cyclohexane	C	C	U	A	A	U	C	A	A	I
Diacetone Alcohol	A	A	A	C	A	A	A	A	I	I
Dibutyl Phthalate	C	C	A	C	C	A	C	A	A	A
Ethanol	A	A	A	C	I	A	A	A	A	U
Ethyl Ether	C	C	A	C	A	C	C	A	U	A
Ethylene Glycol	A	A	A	C	A	A	A	A	A	C
Formaldehyde	C	A	A	C	A	C	A	A	A	U
Formic Acid	A	A	A	A	A	A	A	C	U	U
Furfural	A	C	A	C	A	A	A	C	U	C
Gasoline	A	C	A	A	A	U	C	A	A	A
Glycerine	A	A	A	C	A	A	A	A	A	A
Hydrobromic Acid	A	A	A	C	A	A	I	I	I	I
Hydrochloric Acid	A	A	A	U	A	A	A	A	A	U
Hydrofluoric Acid	C	C	C	U	A	A	A	A	A	U
Hydrogen Peroxide	A	A	A	A	A	C	A	A	C	U
Hydrogen Sulfide	A	A	A	U	A	A	I	I	A	I
Isopropyl Alcohol	A	A	A	C	A	A	A	A	A	U
Kerosene	A	C	A	A	A	U	C	A	A	A
Lactic Acid	A	A	A	A	A	A	A	A	A	C
Linseed Oil	A	A	A	C	A	C	C	A	A	A

A=Acceptable
U=Unacceptable
C=Conditionally Acceptable
I=Insufficient Data

Note: This table is provided as a guide only. The user is advised to contact the protective clothing manufacturer regarding the specific applicability and limitations of a material under proposed conditions of use.

Table 6-1 (Cont.)

	Neoprene	Polyvinyl Chloride (PVC)	Paracril/ PVC	Polyurethane	Chlorinated Polyethylene	Butyl Rubber	Natural Rubber	Nitrile	Vitron	Polyvinyl Acetate (PVA)
Malic Acid	A	A	A	C	I	U	I	I	I	I
Methyl Acetate	A	C	C	C	A	A	C	C	I	I
Methanol	A	A	A	C	A	A	A	A	C	U
Methyl Ethyl Ketone	C	U	C	C	C	A	A	U	U	C
Nitric Acid	C	C	A	U	C	C	C	C	A	U
Nitrobenzene	C	C	A	C	C	U	C	C	A	I
Oleic Acid	A	A	A	C	A	A	C	A	A	A
Perchloroethylene	C	U	A	C	C	U	U	A	A	A
Phosphoric Acid	A	A	A	C	A	A	A	A	A	U
Pine Oil	A	A	A	C	A	U	C	A	I	I
Potassium Hydroxide	A	A	A	C	A	A	A	A	C	U
Sodium Hydroxide	A	C	A	C	A	C	A	A	C	U
Sulfuric Acid	C	C	A	U	C	C	C	C	C	U
Tannic Acid	A	A	A	A	A	A	A	A	A	U
Toluene	C	U	A	A	C	U	C	C	A	A
Trichloroethylene	C	C	A	C	C	U	C	C	A	A
Triethanolamine	A	A	A	C	A	A	A	A	U	A
Turpentine	C	C	A	C	A	U	C	A	A	A

A=Acceptable
U=Unacceptable
C=Conditionally Acceptable
I=Insufficient Data

Source: Ecology and Environment, Inc., 1982, from manufacturers' data.

Note: This table is provided as a guide only. The user is advised to contact the protective clothing manufacturer regarding the specific applicability and limitations of a material under proposed conditions of use.

- Characteristics of the work to be performed;
- Location of the hazardous area with respect to safe breathing zones;
- Time period for which respiratory protection will be needed;
- Extent of worker's activity in the hazardous area;
- Physical characteristics, capabilities, and limitations of various respirator types; and
- Respirator fit and protection factors.

Respirators may be classified as either air-supplied or air-purifying. Air supplied respirators are required when oxygen levels are less than 19.5%, and may also be used when toxic gases, vapors, or particles exceed permissible concentrations. These include self-contained breathing apparatus (SCBA) or air-line respirators. If the atmosphere is determined to be immediately dangerous to life and health, the air-supplied respirator must be of the continuous flow type with escape provisions, or it may be a pressure-demand or positive-pressure closed-circuit SCBA. Air purifying respirators are used to remove gaseous or particulate contaminants, and can only be used when oxygen levels exceed 19.5%. These include simple filter, chemical cartridge and cannister respirators. Table 6-2 provides guidelines for respirator selection, and Table 6-3 lists protection factors which can be achieved under optimum conditions.

6.2 ACTIVITIES IN HAZARDOUS AREAS

In areas of possibly ignitable vapors, no work with ignition sources can be performed unless the vapor concentrations are monitored. All metal equipment should be properly grounded and bonded, and use of non-sparking tools and intrinsically safe equipment is advised. Smoking should be prohibited in these areas.

Work in confined spaces requires:

- Oxygen and vapor monitoring;
- Adequate fresh air supplies;
- Constant audible and visible communication;
- Adequate rescue resources; and
- Appropriate training in first aid and cardio-pulmonary resuscitation (CPR).

6.3 FIRST AID AND MEDICAL SURVEILLANCE

A facility should have a medical surveillance program which ensures that workers are fit to perform their duties, and provides continual follow-up to monitor effects of potential exposures.

Table 6-2

SELECTION OF RESPIRATORS

Hazard	Respirator (see note)
Oxygen deficiency, immediately dangerous to life and health.	Air-line, continuous-flow, pressure-demand type with escape provisions. Air-line, continuous-flow helmet, hood, or suit, with escape provisions. Self-contained breathing apparatus (pressure-demand type, or positive-pressure, closed-circuit type).
Oxygen deficiency, not immediately dangerous to life and health.	Self-contained breathing apparatus. Hose mask with blower. Combination air-line respirator with auxiliary self-contained air supply.
Gas and vapor contaminants immediately dangerous to life and health.	Self-contained breathing apparatus (pressure-demand-type, open-circuit, or positive-pressure closed circuit). Powered air-purifying, full facepiece respirator with chemical cannister (if escape provisions are provided). Self-rescue mouthpiece respirator (for escape only). Combination air-line respirator with auxiliary self-contained air supply.
Gas and vapor contaminants not immediately dangerous to life and health.	Air-line respirator. Hose mask with or without blower. Air-purifying respirator with chemical cartridge.
Particulate contaminants immediately dangerous to life and health.	Self-contained breathing apparatus (pressure-demand-type open-circuit, or positive-pressure, closed-circuit). Air-purifying, full facepiece respirator with appropriate filter (if escape provisions are provided). Combination air-line respirator with auxiliary self-contained air supply.
Particulate contaminants not immediately dangerous to life and health.	Air-purifying, respirator with particulate filter pad or cartridge. Air-line respirator. Air-line, continuous flow helmet, hood or suit. Hose mask with or without blower.
Combination gas, vapor, and particulate contaminants immediately dangerous to life and health.	Self-contained breathing apparatus (pressure-demand-type open-circuit, or positive-pressure, closed-circuit). Air-purifying, full-facepiece respirator with chemical cannister and appropriate filter (if escape provisions are provided). Combination air-line respirator with auxiliary self-contained air supply.
Combination gas, vapor, and particulate contaminants not immediately dangerous to life and health.	Air-line respirator. Hose mask with or without blower. Air-purifying respirator with chemical cartridge and appropriate filter.

Note: For the purpose of this table, "immediately dangerous to life and health" is defined as any atmosphere that poses an immediate hazard to life, or produces immediate, irreversible debilitating effects on health. Consult ANSI Z88.2-1980 for further definition and clarification of respirator selection criteria.

Source: 29 CFR 1926.103 and ANSI Z88.2 - 1980.

Table 6-3

OPTIMAL RESPIRATORY PROTECTION FACTORS

Type Respirator	Protection Factor
I. Air purifying:	
A. Particulate removing	
Single-use, dust	5
Quarter mask, dust	5
Half mask, dust	10
Half or quarter mask, high efficiency	10
Half or quarter mask, fume	10
Full facepiece, high efficiency	50
Powered, high efficiency, all enclosures	1,000
Powered, dust or fume, all enclosures	
B. Gas and vapor removing	10
Half mask	50
Full facepiece	
II. Atmosphere supplying:	
A. Supplied air	
Demand, half mask	10
Demand, full facepiece	50
Hose mask without blower, full facepiece	50
Pressure demand, half mask	1,000
Pressure demand, full facepiece	2,000
Hose mask with blower, full facepiece	50
Continuous flow, half mask	1,000
Continuous flow, full facepiece	2,000
Continuous flow, hood, helmet, or suit	2,000
B. Self contained breathing apparatus (SCBA)	
Open circuit, demand, full facepiece	50
Open circuit, pressure demand full facepiece	10,000
Closed circuit, oxygen tank-type, full facepiece	50

Source: Clayton and Clayton, 1978.

Although the program should be directed by a physician, it should be administered on a daily basis by the Facility Safety Coordinator. This person should:

- Maintain on-going first aid and safety training;
- Provide technical expertise in health and safety matters;
- Oversee compliance with health and safety standards; and
- Prepare and review all job-related safety plans.

Facility safety plans should be developed for major and routine maintenance procedures. The plans should include:

- First aid procedures for the expected hazards;
- Addresses and directions to emergency facilities;
- Medical limitations of personnel performing the work; and
- Identification of personnel duties and responsibilities, especially in an emergency.

SUGGESTED EXERCISES

1. Identify three methods to control health and safety hazards.

2. Name four organizations which promote standards for occupational health and safety.

3. Hazardous materials facility workers require protection primarily against what two types of exposures?

4. Identify protective clothing materials which may be effective against exposure to:

   - Acetone,
   - Sulfuric acid,
   - Methyl ethyl ketone,
   - Kerosene, and
   - Benzene.

5. Name seven factors which must be considered in selecting respiratory protection.

6. What types of respiratory protection are suitable for the following atmospheres:

   - Oxygen-deficient, immediately dangerous to life and health; or

   - Combination gas, vapor, and particulate contaminants, <u>not</u> immediately dangerous to life and health.

7. Rank the following types of respirators in order of respiratory protection provided (most to least):

   - Powered air-purifying device,
   - Quarter-face dust mask,
   - Full facepiece air-purifying mask,
   - Open-circuit, pressure-demand, full facepiece SCBA, and
   - Continuous-flow helmet respirator.

8. Identify five precautions which must be taken for work in hazardous areas.

9. Discuss the necessary elements of facility safety plans.

SECTION 7

SPILL CONTROL AND PREVENTION

To maximize a response team's effectiveness, and to minimize spill consequences, contingency plans for emergencies should be developed and available prior to occurrence of an emergency. Plans should be developed to address spills on land, water, or releases into the air. In conjunction with contingency planning, the team should be thoroughly trained in response procedures applicable to the specific facility. Ideally, a training manual such as this should be developed for the facility, and it should be read and understood by each team member as part of the emergency response training program.

7.1 LAND SPILLS

Land spills require prompt action to prevent migration of product to surface or groundwater. Containment measures may include:

- Sorbent materials;
- Anti-wetting agents;
- Gelling agents;
- Imbiber beads;
- Containment dikes; or
- Interceptor trenches.

Figures 7-1 and 7-2 illustrate methods for removing contaminants from groundwater.

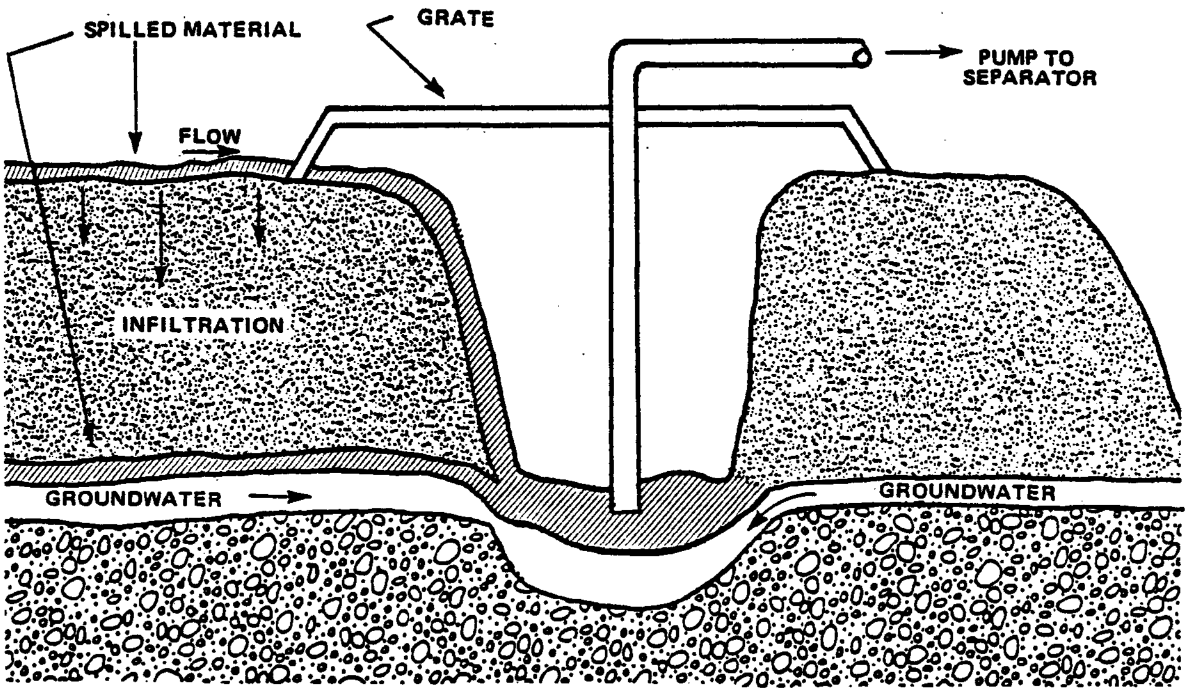
Removal techniques will vary with the types material spilled and the type of surface. These techniques include:

- Vacuum collection;
- Excavation;
- In-situ neutralization;
- Microbiological agents; or
- On-site treatment.

Materials from hazardous materials spills must be disposed of in accordance with applicable hazardous waste regulations.

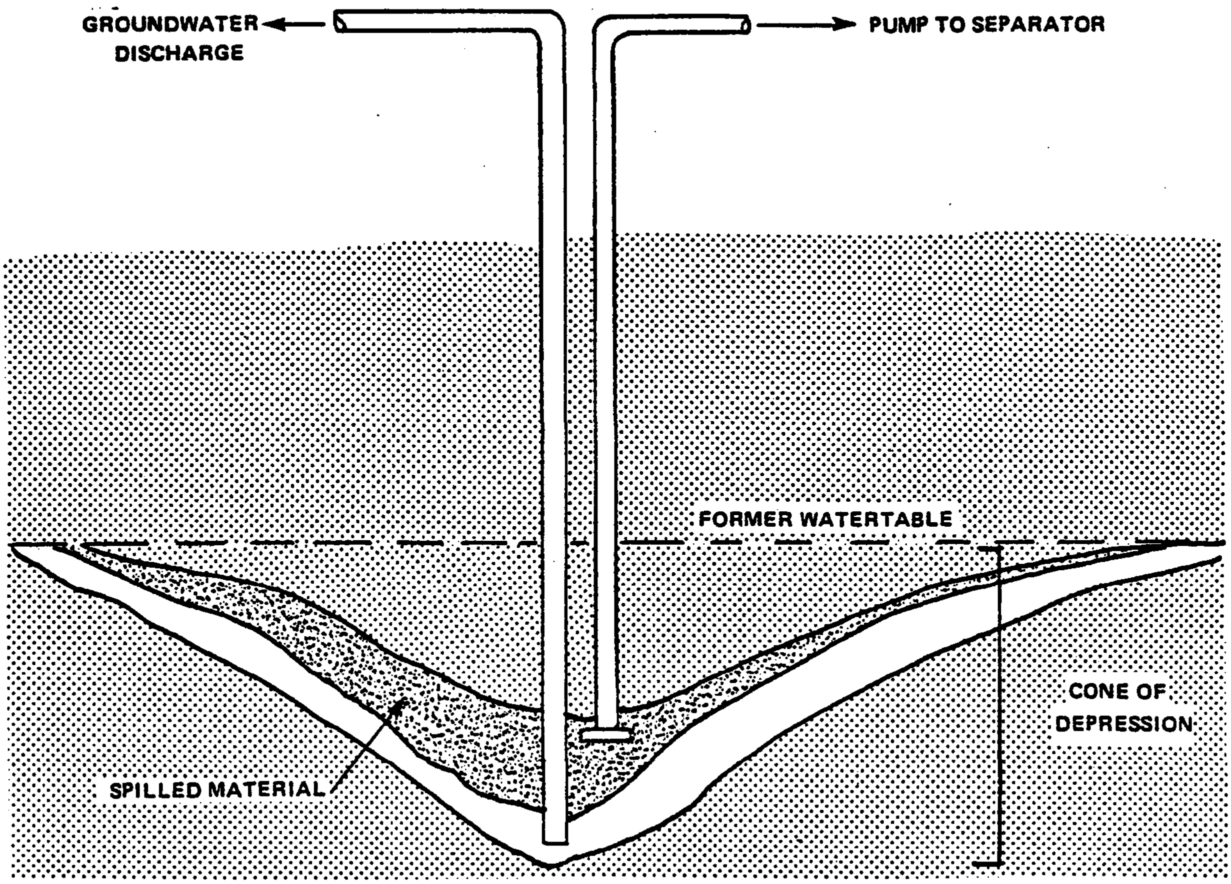
7.2 SURFACE WATER SPILLS

Containment of surface water spills can be achieved through proper selection and deployment of the following types of containment equipment:



SOURCE: Texas A&M, 1978

Figure 7–1 CROSS-SECTION OF INTERCEPTOR TRENCH CONTAINMENT AND COLLECTION SYSTEM FOR FLOATING CONTAMINANTS



SOURCE: Texas A&M, 1978

Figure 7–2 SCHEMATIC OF DEEP GROUNDWATER RECOVERY WELL FOR FLOATING CONTAMINANTS

- Dams;
- Natural debris;
- Filter fences;
- Sorbent materials;
- Skirted booms;
- Sorbent booms; or
- Aeration techniques.

Figures 7-3 through 7-5 illustrate methods of spill containment. Removal of spilled product should be begun as quickly as possible. Removal techniques include:

- Gravity skimmers;
- Suction skimmers;
- Vacuum collection;
- Adhesion equipment;
- Advancing weirs;
- Sorbents;
- Dredges; and
- Filter fences.

Figures 7-6 through 7-11 illustrate various spill removal techniques. Properties of various sorbent materials are summarized in Table 7-1.

Chemical and biological agents (burning agents, sinking agents, dispersants, collecting agents, and biological cultures) are available for spill control, although physical removal methods are usually preferable. Authorization for use of chemical and biological agents must be obtained from the appropriate regulatory agency prior to application. Appropriate countermeasures for spills of more than 200 chemicals on land or water are summarized in Appendix D.

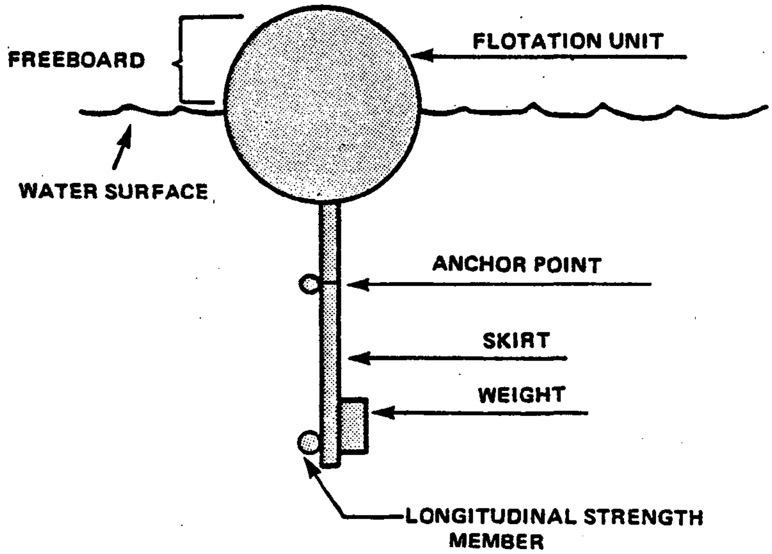
7.3 ATMOSPHERIC RELEASES

Initial response to a gas or vapor discharge should be directed toward eliminating the source of the discharge. Personnel should wear appropriate protective equipment, and should have available a variety of plugs and patches of various sizes to stop the leaks. Depending upon wind conditions, atmospheric stability, and the nature of the chemical released, the area may have to be evacuated until the discharge is under control.

If the source cannot be stopped, measures must be taken to control the release. These include:

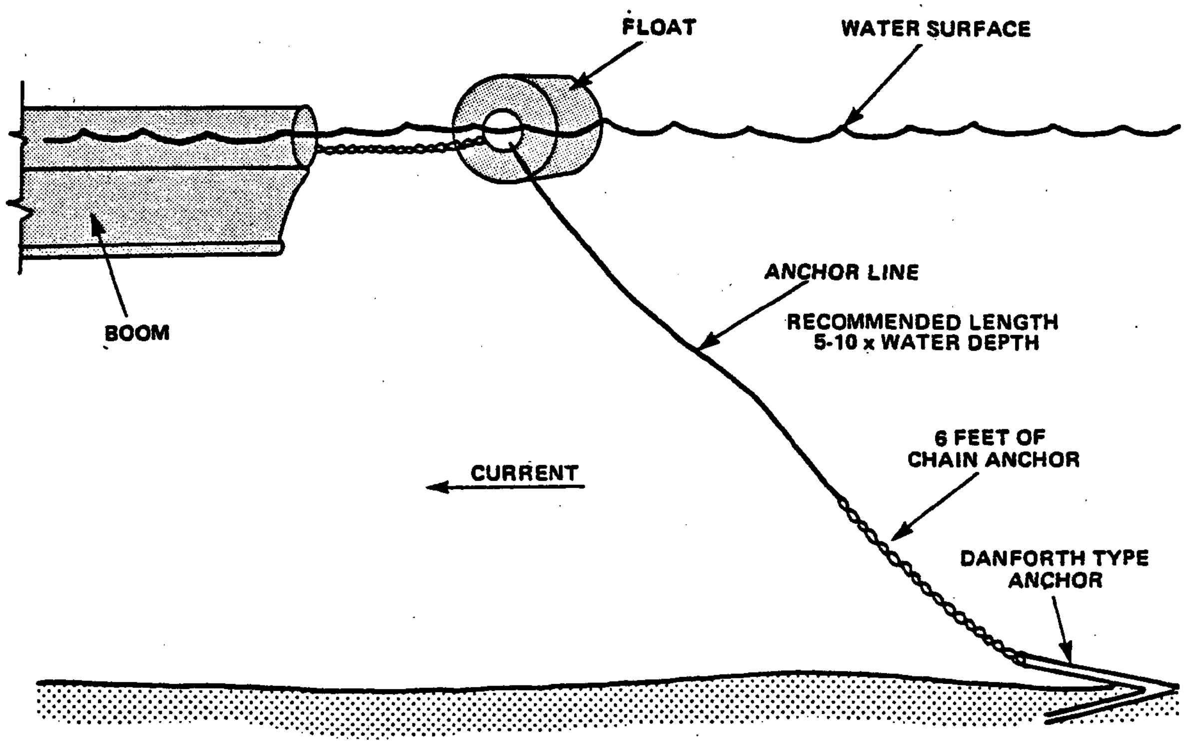
- Water sprays;
- Firefighting foams;
- Diversion vents;
- Trench vents; or
- Emergency encapsulation (containment structures).

Normal atmospheric dispersion must be relied upon for returning air to safe levels. Blower fans may be used to assist dispersion. Where possible, vapors can be routed to treatment systems of such types as carbon adsorbtion or thermal oxidation.



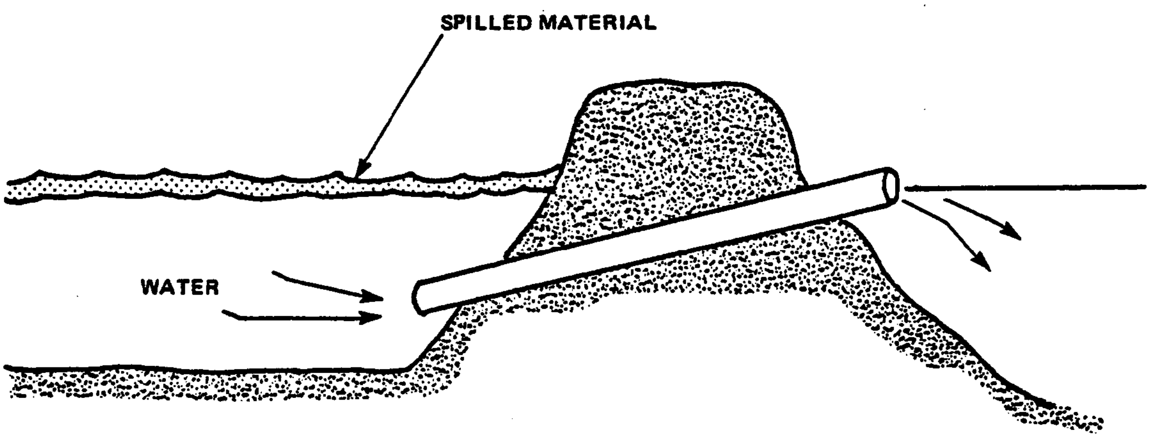
SOURCE: Texas A&M, 1978

Figure 7–3 CROSS-SECTION OF A TYPICAL BOOM, SHOWING MAJOR PARTS



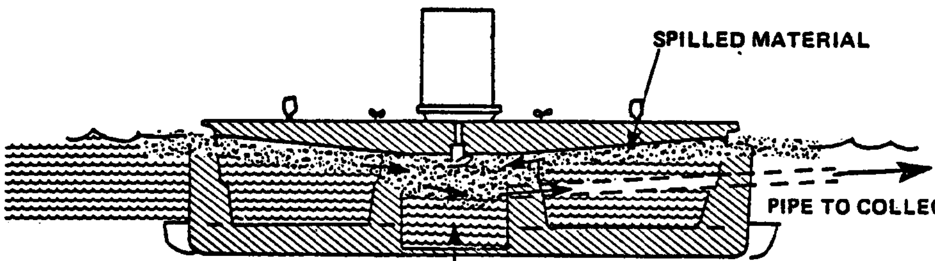
SOURCE: Texas A&M, 1978

Figure 7–4 SCHEMATIC OF TYPICAL BOOM ANCHORING SYSTEM



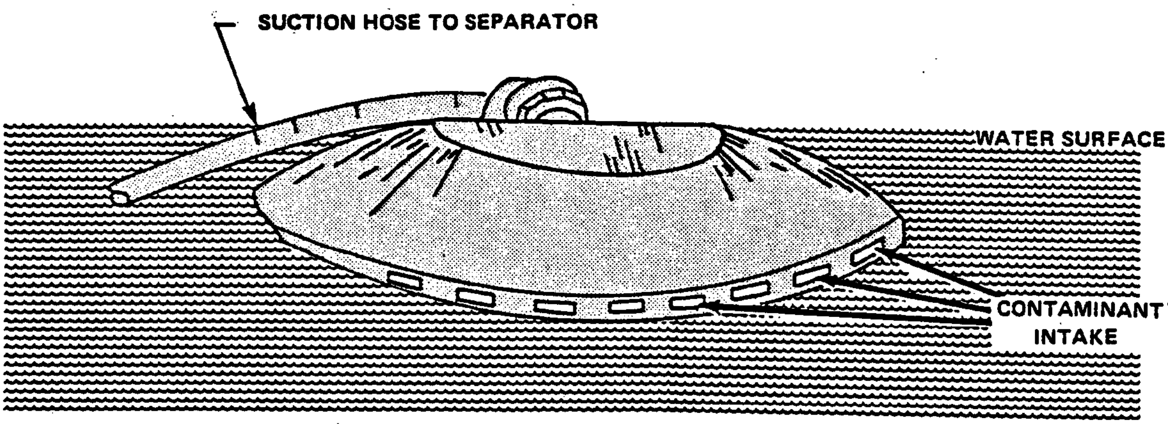
SOURCE: Texas A&M, 1978

Figure 7–5 SCHEMATIC OF TYPICAL UNDERFLOW DAM



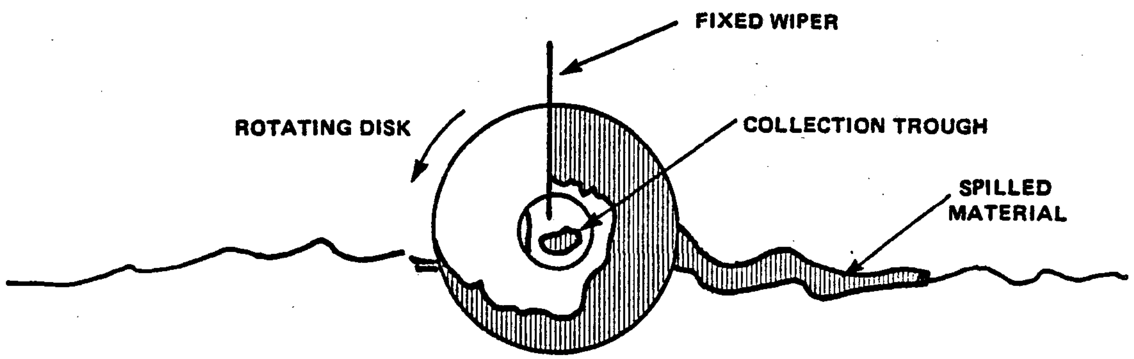
SOURCE: Texas A&M, 1978

Figure 7–6 CROSS-SECTION OF TYPICAL FLOATING WEIR SKIMMING UNIT.



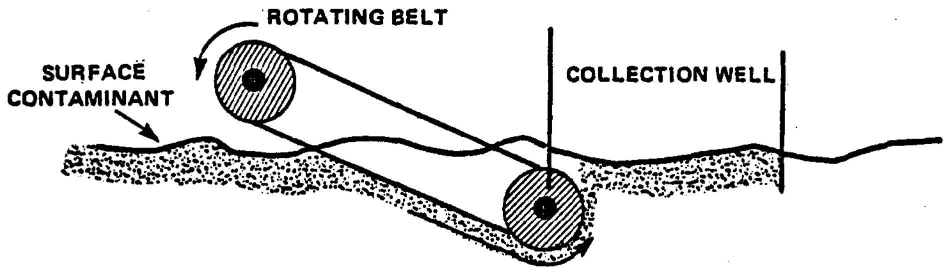
SOURCE: Texas A&M, 1978

Figure 7–7 ILLUSTRATION OF FLOATING SUCTION SKIMMING UNIT



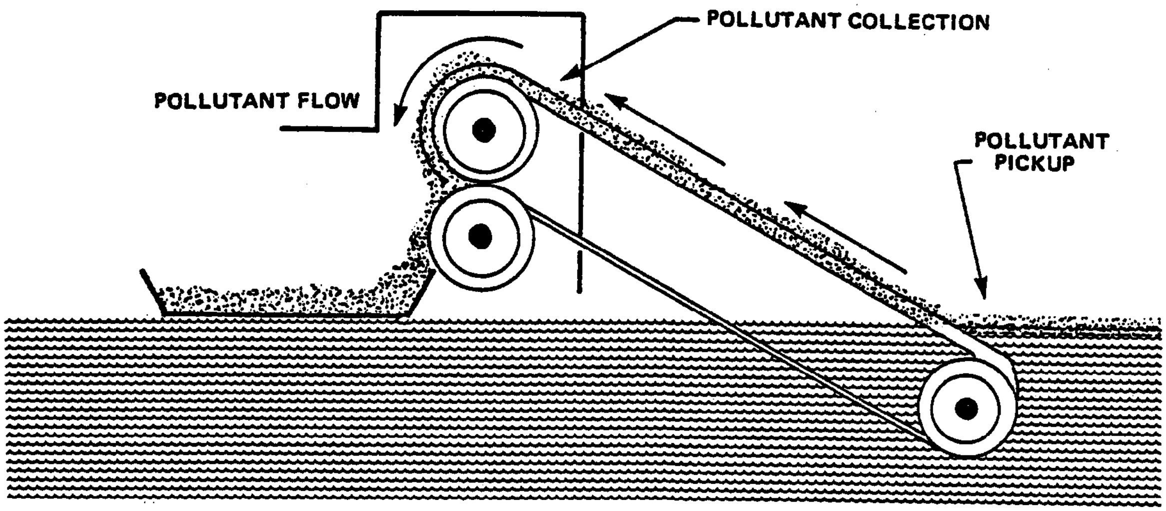
SOURCE: Texas A&M, 1978

Figure 7–8 CROSS-SECTION OF TYPICAL OLEOPHILIC DRUM SKIMMER



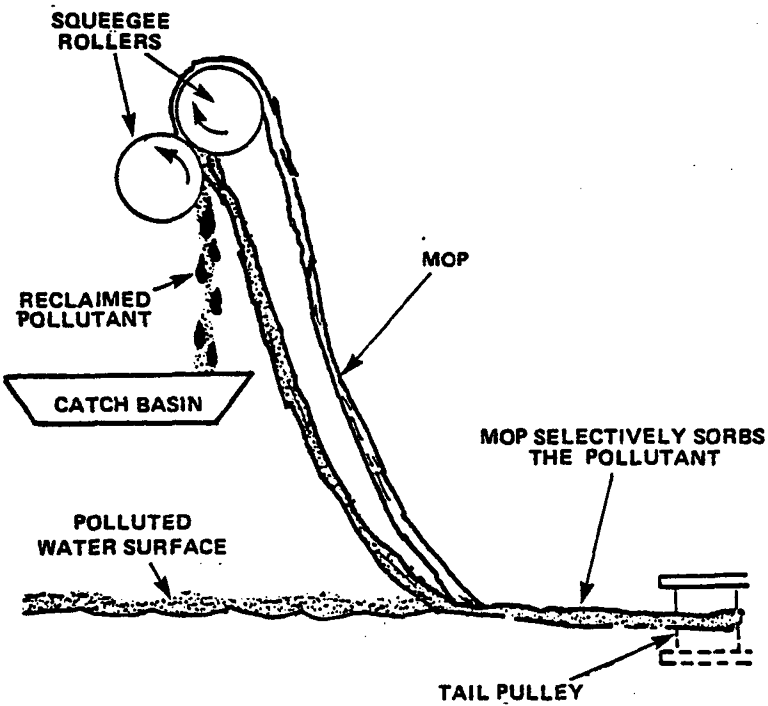
SOURCE: Texas A&M, 1978

Figure 7–9 SCHEMATIC OF INCLINED PLANE BELT SKIMMER



SOURCE: Texas A&M, 1978

Figure 7—10 SCHEMATIC OF OLEOPHILIC BELT SKIMMER.



SOURCE: Texas A&M, 1978

Figure 7–11 SCHEMATIC OF OLEOPHILIC ROPE SKIMMER

Table 7-1

PROPERTIES OF SORBENT MATERIAL

Type	Advantages	Disadvantages	Example	Capacity
Natural Sorbents	Non-toxic, biodegradeable	Soak up both organics and water; will sink when saturated Recovery of large amounts of sorbent is a labor-intensive operation Trapped product may drain off sorbent material	Peat moss Straw Milled corn cobs Wood cellulose fiber Milled cottonseed fiber	In general, absorb 3 to 6 times their weight
Inorganic or Mineral-Based Sorbents	Relatively inexpensive	Very light materials; difficult to distribute when windy Non-biodegradable Dust may cause respiratory irritations Can be abrasive to recovery equipment	Perlite Vermiculite Volcanic ash	In general, absorb 4 to 8 times their weight
Synthetic Sorbents	Exceptionally high recovery efficiences Some materials can be re-used after oil removal Easily spread	Expensive Non-biodegradeable	Polyurethane Urea formaldehyde Polyethylene Polypropylene	Variable, but higher than non-synthetic solvents, typically about 20 to 25 times their own weight

Table 7-1 (Cont.)

Type	Advantages	Disadvantages	Example	Capacity
	Easily recovered			
	Available in many forms (e.g., rolls, sheets, booms)			
Synthetic Foam Sorbents	Most efficient sorbents available	Saturated slabs may tear during recovery	Polyurethane foam	Variable, but higher than non-synthetic solvents, typically about 20 to 25 times their own weight
	Efficiency independent of viscosity			
	Can be produced on-site by mixing two liquids			

Source: <u>Handbook for Oil Spill Protection Cleanup Priorities</u>, 1981, Versor, Inc.

7.4 SPILL PREVENTION AND CONTINGENCY PLANNING

All facilities should develop a Spill Prevention Control and Countermeasure (SPCC) Plan. These plans should include description of secondary containment, drainage, storage tanks, transfer operations, maintenance and inspection procedures, security, and personnel training. The plan should be reviewed and updated at least every three years.

In conjunction with the SPCC, the facility should also develop an Emergency Contingency Plan delineating procedures to be taken and outlining resources and responsibilities in the event of an uncontrolled spill or emeregency. The plan should contain a written inventory of emergency equipment, sources of assistance, and descriptions of emergency procedures, and should be regularly reviewed and amended. General emergency procedures which should be outlined and followed include:

1. Activate alarms or other communication system to alert facility personnel;

2. Organize the in-house response team or notify the local spill contractor;

3. Notify appropriate state and local agencies, (which should already have copies of the contingency plan);

4. Characterize the emergency with respect to the source, the amount of released material, and the hazards created;

5. If evacuation is warranted, initiate evacuation procedures. (outside authorities may be needed to assist in evacuation if it involves surrounding areas);

6. If areas outside the facility are affected, the appropriate response or enforcement agencies must be notified. These may include the National Response Center or the local On-Scene Coordinator;

7. Take all reasonable measures to keep the spill or fire from spreading;

8. Provide for treating, storing, or disposing of contaminated soil, water, or other material;

9. As the cleanup nears completion, the appropriate state and local officials should be notified (if they are not already on-scene), so that they may determine when normal facility operation may be resumed.

Formats for emergency plan data are found in Figures 7-12 and 7-13.

EMERGENCY PHONE NUMBERS

1. In-house Emergency Response Coordinator and Alternates

   A. Name: ______________________ Telephone: __________
      Address: ______________________________________
   B. Name: ______________________ Telephone: __________
      Address: ______________________________________
   C. Name: ______________________ Telephone: __________
      Address: ______________________________________

2. U.S. Coast Guard:
   Local Phone: ______________________________________

3. National Response Center: (800) 424-8802

4. EPA On-scene Coordinator: ______________________________

5. State Emergency Government: ____________________________

6. Local Emergency Government: ____________________________

7. Hospital/Health Treatment: A. ______________________
   B. ______________________
   C. ______________________

8. Police: A. ______________________________
   B. ______________________________
   C. ______________________________

9. Sheriff: ______________________________________

10. Fire Department: ______________________________

11. Spill Clean-up Contractors:
    A. ______________________________________
    B. ______________________________________

12. Other:
    ____
    ____

SOURCE: Ecology and Environment, Inc., 1983.

Figure 7–12 EMERGENCY PHONE NUMBERS FORM

EMERGENCY DATA SHEET

Facility ______________________ Telephone __________

Address ____

____

1. Tank Identification

   A. Tank Number ______________________

   B. Location ______________________

2. Chemical Identification

   A. Name ______________________

      Synonyms ______________________

   B. Molecular Formula ______________________

   C. Molecular Weight ______________________

   D. Boiling Point ______________________

   E. Density ______________________

   F. US DOT Classification ______________________

   G. US DOT I.D. Number ______________________

      CAS I.D. Number ______________________

References:

NIOSH Registry of Toxic Effects p. ___

CRC Handbook of Chemistry p. ____

49 CFR 100-199

Hazardous Materials Emergency Response Guidebook, US DOT

3. Health Effects

   A. Acute ______________________

   ____

   B. Chronic ______________________

   ____

SOURCE: Ecology and Environment, Inc., 1983.

Figure 7–13 EMERGENCY DATA SHEET FORM

C. Toxicity ______________________________

D. Route of Exposure

Eye Ingestion
Lung Skin

E. First Aid ______________________________

____

____

F. Medical Monitoring ______________________________

____

____

References:

Pocket Guide to Chemical Hazards, NIOSH/OSHA

ACGIH TLV Handbook, Dangerous Properties of Industrial Materials, Sax.

4. Fire Protection

A. Prevention Technique ______________________________

B. Extinguishing Agents ______________________________

C. Combustion Products ______________________________

References:

Fire Protection Guide on Hazardous Materials, NFPA

Hazardous Materials, US DOT

5. Hazardous Properties

A. Major Chemical Incompatibilities ______________________________

References:

CHRIS, Condensed Guide to Chemical Hazards, USCG

Merck Index

SOURCE: Ecology and Environment, Inc., 1983.

Figure 7–13 EMERGENCY DATA SHEET FORM (Cont.)

6. Methods of Storage

   A. Primary ______________________________

   B. Second Containment ______________________________

   C. Storage Hazards ______________________________

References:

Fire Protection Guide on Hazardous Materials, NFPA

7. Environmental Protection

   A. For Material in Fire:

____
____
____
____
____
____

   B. For Material not in Fire:

____
____
____
____
____
____

References:

CHRIS, Condensed Guide to Chemical Hazards, USCG

Hazardous Materials, Emergency Response Guidebook

Fire Protection Guide on Hazardous Materials, NFPA

Chemtrec, (800) 424-9300

8. Personal Protection

____
____
____
____

SOURCE: Ecology and Environment, Inc., 1983.

Figure 7–13 EMERGENCY DATA SHEET FORM (Cont.)

References:

Fire Protection Guide on Hazardous Materials, NFPA

CHRIS, Condensed Guide to Chemical Hazards, USCG

Hazardous Materials Emergency Response Guidebook, US DOT

Bests' Safety Directory

9. Other Information

SOURCE: Ecology and Environment, Inc., 1983.

Figure 7—13 EMERGENCY DATA SHEET FORM (Cont.)

SUGGESTED EXERCISES

1. Identify four methods to contain releases of spilled materials on land, surface water, and air, respectively.

2. How must materials used in spill cleanup be disposed?

3. Identify appropriate spill countermeasures for the following chemicals:

   - Arsenic trioxide,
   - Pentachlorophenol,
   - Vinyl acetate,
   - Parathion,
   - Calcium hydroxide, and
   - Hydrochloric acid.

4. What factor may influence evacuation due to an atmospheric release?

5. Describe the elements of an SPCC plan.

6. Describe emergency procedures which should be incorporated into a facility Emergency Contingency Plan.

7. Complete Figure 7-12 (emergency phone numbers) for this facility.

8. Complete Figure 7-13 (emergency data sheet) for each of three materials stored at this facility.

APPENDIX A

LIST OF CHEMICAL REPRESENTATIVES BY CLASS

Class 1 Acids, Mineral, Non-Oxidizing

Boric acid*
Chlorosulfonic acid*
Difluorophosphoric acid
Disulfuric acid
Fluoroboric acid
Fluorosulfonic acid
Fluosilicic acid
Hexafluorophosphoric acid
Hydriodic acid*
Hydrobromic acid*
Hydrochloric acid*
Hydrocyanic acid*
Hydrofluoric acid*
Monofluorophosphoric acid
Permonosulfuric acid
Phosphoric acid*
Selenous acid

Class 2 Acids, Mineral, Oxidizing

Bromic acid
Chloric acid*
Chromic acid*
Hypochlorous acid
Nitric acid*
Nitrohydrochloric acid
Oleum*
Perbromic acid
Perchloric acid*
Perchlorous acid
Periodic acid
Sulfuric acid*
Sulfur trioxide*

Class 3 Acids, Organic (All Isomers)

Acetic acid*
Acrylic acid
Adipic acid
Benzoic acid*
Butyric acid
Capric acid
Caproic acid
Caprylic acid
Chloromethylphenoxyacetic acid
Cyanoacetic acid
Dichlorophenoxyacetic acid
Endothal
Fluoracetic acid
Formic acid*
Fumaric acid
Glycolic acid
Hydroxydibromobenzoic acid
Lactic acid*
Maleic acid*
Monochloroacetic acid
Oleic acid*
Oxalic acid
Peracetic acid
Phenoxyacetic acid*
Phthalic acid*
Propionic acid
Salycilic acid*
Succinic acid
Trichlorophenoxyacetic acid
Trinitrobenzoic acid
Toluic acid
Valeric acid

Class 4 Alcohols and Glycols (All Isomers)

Acetone cyanohydrin
Allyl alcohol*
Aminoethanol
Amyl alcohol
Benzyl alcohol
Butanediol
Butyl alcohol
Butyl cellosolve*
Chloroethanol*
Crotyl alcohol
Cyclohexanol*
Cyclopentanol
Decanol
Diacetone alcohol
Dichloropropanol
Diethanol amine
Diisopropanolamine
Ethanol*
Ethoxyethanol
Ethylene chlorohydrin*
Ethylene cyanohydrin
Ethylene glycol*
Ethylene glycol monomethyl ether*
Glycerin*
Heptanol
Hexanol
Isobutanol
Isopropanol
Mercaptoethanol
Methanol*
Monoethanol amine*
Monoisopropanol amine
Nonanol
Octanol
Propanol
Propylene glycol

*Representative chemical found in compatibility matrices.

Propylene glycol monomethyl ether
Triethanolamine

Class 5 Aldehydes (All Isomers)

Acetaldehyde*
Acrolein*
Benzaldehyde
Butyraldehyde
Chloral hydrate
Chloracetaldehyde
Crotonaldehyde
Formaldehyde*
Furfural*
Glutaraldehyde
Heptanal
Hexanal
Nonanal
Octanal
Propionaldehyde
Tolualdehyde
Urea formaldehyde
Valeraldehyde

Class 6 Amides (All Isomers)

Acetamide*
Benzadox
Bromobenzoyl acetanilide
Butyramide
Carbetamide
Diethylamide*
Diethyltoluamide
Dimethylformamide*
Dimefox
Diphenamide
Fluroacetanilide
Formamide
Propionamide
Schradan
Tris-(1-aziridinyl) phosphine oxide
Wepsyn* 155
Valeramide

Class 7 Amines, Aliphatic and Aromatic (All Isomers)

Aminodiphenyl
Aminoethanol*
Aminoethanolamine
Aminophenol
Aminopropionitrile
Amylamine
Aminothiazole
Aniline*
Benzidine
Benzylamine
Butylamine
Chlorotoluidine
Crimidine
Cupriethylenediamine
Cyclohexylamine
Diamine*
Dichlorobenzidine
Diethanolamine
Diethylamine*
Diethylenetriamine
Diisopropanolamine
Dimethylamine
Dimethylaminoazobenzene
Diphenylamine
Diphenylamine chloroarsine
Dipicrylamine
Dipropylamine
Ethylamine
Ethylenendiamine*
Ehtyleneimine
Hexamethylenediamine
Hexamethylenetetraamine
Hexylamine
Isopropylamine
Methylamine*
N-Methyl aniline
4,4-Methylene bis(2-chloroaniline)
Methyl ethyl pyridine
Monoethanolamine*
Monoisopropanolamine
Morpholine
Naphthylamine
Nitroaniline*
Nitrogen mustard
Nitrosodimethylamine
Pentylamine
Phenylene diamine
Picramide
Picridine
Piperidine
Propylamine
Propyleneimine
Pyridine*
Tetramethylenediamine
Toluidine
Triethanolamine
Triethylamine
Triethylenetetraamine
Trimethylamine
Tripropylamine

Class 8 Azo Compounds, Diazo Compounds, and Hydrazines (All Isomers)

Aluminum tetraazidoborate
Aminothiazole
Azidocarbonyl guanidine
Azido-s-triazole
a.á-Azodiisobutyronitrile
Benzene diazonium chloride
Benzotriazole
t-Butyl azidoformate
Chloroazodin
Chlorobenzotriazole
Diazodinitrophenol
Diazidoethane
Dimethylamino azobenzene
Dimethyl hydrazine*
Dinitrophenyl hydrazine
Guanyl nitrosoaminoguanylidine hydrazine
Hydrazine*
Hydrazine azide
Methyl hydrazine
Mercaptobenzothiazole
Phenyl hydrazine hydrochloride
Tetrazene

Class 9 Carbamates

Aldicarb
Bassa*
Baygon*
Butacarb
Bux*
Carbaryl
Carbanolate
Dioxacarb
Dowco* 139
Formetanate hydrochloride
Furadan*
Hopcide*
N-Isopropylmethylcarbamate
Landrin*
Matacil*
Meobal
Mesurol*
Methomyl
Mipcin*
Mobam*
Oxamyl
Pirimicarb
Promecarb
Tranid*
Tsumacide*

Class 10 Caustics

Ammonia*
Ammonium hydroxide*
Barium hydroxide
Barium oxide
Beryllium hydroxide
Cadmium amide
Calcium hydroxide*
Calcium oxide*
Lithium amide
Lithium hydroxide
Potassium aluminate
Potassium butoxide
Potassium hydroxide
Sodium aluminate
Sodium amide
Sodium carbonate*
Sodium hydroxide*
Sodium hypochlorite
Sodium methylate
Sodium oxide

Class 11 Cyanides

Cadmium cyanide
Copper cyanide
Cyanogen bromide
Hydrocyanic acid*
Lead cyanide
Mercuric cyanide
Mercuric oxycyanide
Nickel cyanide
Potassium cyanide*
Silver cyanide
Sodium cyanide*
Zinc cyanide

Class 12 Dithiocarbamates

CDEC
Dithane* M-45
Ferbam
Maneb
Metham
Nabam
Niacide*
Polyram-cobi*
Selenium diethyl dithiocarbamate
Thiram
Zinc salts of dimethyl dithiocarbamic acid
Zineb
Ziram

Group 13 Esters (All Isomers)

Allyl chlorocarbonate
Amyl acetate
Butyl acetate*
Butyl acrylate

Butyl benzyl phthalate
Butyl formate
Dibutyl phthalate
Diethylene glycol monobutyl ether acetate
Ethyl acetate*
Ethyl butyrate
Ethyl chloroformate
Ethyl formate
2-Ethyl hexylacrylate
Ethyl propionate
Glycol diacetate
Isobutyl acetate
Isobutyl acrylate
Isodecyl acrylate
Isopropyl acetate
Medinoterb acetate
Methyl acetate
Methyl acrylate
Methyl amyl acetate
Methyl butyrate
Methyl chloroformate
Methyl formate*
Methyl methacrylate
Methyl proprionate
Methyl valerate
Propiolactone*
Propyl acetate
Propyl formate
Vinyl acetate
Dimethyl phthalate*

Class 14 Ethers (All Isomers)

Anisole
Butyl cellosolve*
Bromodimethoxyaniline
Dibutyl ether
Dichloroethyl ether*
Diethyl ether*
Dimethyl ether
Dimethyl formal
Dioxane*
Diphenyl oxide
Ethoxyethanol
Ethylene glycol monomethyl ether*
Furan*
Glycol ether
Isopropyl ether
Methyl butyl ether
Methyl chloromethyl ether
Methyl ethyl ether
Polyglycol ether
Propyl ether
Propylene glycol monomethyl ether
TCDD
Tetrachloropropyl ether
Tetrahydrofuran*
Trinitroanisole
Vinyl ethyl ether
Vinyl isopropyl ether

Class 15 Fluorides, Inorganic

Aluminum fluoride*
Ammonium bifluoride
Ammonium fluoride*
Barium fluoride
Beryllium fluoride
Cadmium fluoride
Calcium fluoride
Cesium fluoride
Chromic fluoride
Fluoroboric acid
Fluosilicic acid*
Fluorosilicic acid*
Hexafluorophosphoric acid
Hydrofluoric acid*
Hydrofluorosilicic acid*
Magnesium fluoride
Potassium fluoride
Selenium fluoride
Silicon tetrafluoride
Sodium fluoride
Sulfur pentafluoride
Tellurium hexafluoride
Zinc fluoroborate

Class 16 Hydrocarbons, Aromatic (All Isomers)

Acenaphthene
Anthracene
Benz-a-pyrene
Benzene*
n-Butyl benzene
Chrysene
Cumene*
Cymene
Decyl benzene
Diethyl benzene
Diphenyl
Diphenyl acetylene
Diphenyl ethane

Diphenyl ethylene
Diphenyl methane
Dodecyl benzene
Dowtherm
Durene
Ethyl benzene*
Fluoranthrene
Fluorene
Hemimellitene
Hexamethyl benzene
Indene
Isodurene
Mesitylene
Methyl naphthalene
Naphthalene*
Pentamethyl benzene
Phenanthrene
Phenyl acetylene
Propyl benzene
Pseudocumene
Styrene*
Tetraphenyl ethylene
Toluene*
Stilbene
Triphenylethylene
Triphenylmethane
Xylene*

Class 17 Halogenated Organics (All Isomers)

Acetyl bromide
Acetyl chloride
Aldrin*
Allyl bromide
Allyl chloride
Allyl chlorocarbonate
Amyl chloride
Benzal bromide
Benzal chloride
Benzotribromide
Benzotrichloride
Benzyl bromide
Benzyl chloride*
Benzyl chlorocarbonate
Bromoacetylene
Bromobenzyl trifluoride
Bromoform
Bromophenol
Bromopropyne
Bromotrichloromethane
Bromotrifluoromethane
Bromoxynil
Butyl fluoride
Carbon tetrachloride*
Carbon tetrafluoride
Carbon tetraiodide
Chloral hydrate
Chlordane
Chloracetaldehyde
Chloroacetic acid
Chloroacetone*
Chloroacetophenone
Chloroacrylonitrile
Chloranil (tetrachloroquinone)
Chloroazodin
Chlorobenzene*
Chlorobenzotriazole
Chlorobenzoyl peroxide
Chlorobenzylidene malononitrile
Chlorobutyronitrile
Chlorocresol*
Chlorodinitrotoluene
Chloroethanol*
Chloroethylenimime
Chloroform*
Chlorohydrin
Chloromethyl methyl ether
Chloromethyl phenoxyacetic acid
Chloronitroaniline
Chlorophenol
Chlorophenyl isocyanate
Chloropicrin*
Chlorothion
Chlorotoluidine
CMME
Crotyl bromide
Crotyl chloride (1-chloro-2-butene)
DDD
DDT
DDVP
Dibromochloropropane
Dichloroacetone*
Dichlorobenzene
Dichlorobenzidine
Dichloroethane
Dichloroethylene
Dichloroethyl ether*
Dichloromethane (methylene dichloride)*
Dichlorophenol
Dichlorophenoxy acetic acid
Dichloropropane
Dichloropropanol
Dichloropropylene
Dieldrin
Diethyl chloro vinyl phosphate
Dichlorophene
Dinitrochlorobenzene

Endosulfan
Endrin
Epichlorohydrin*
Ethyl chloroformate
Ethylene chlorohydrin*
Ethylene dibromide
Ethylene dichloride*
Fluoroacetanilide
Freons*
Heptachlor
Hexachlorobenzene
Hydroxydibromobenzoic acid
Isopropyl chloride
α-Isopropyl methyl phosphoryl fluoride
Lindane
Methyl bromide
Methylchloride*
Methyl chloroform
Methyl chloroformate
Methyl ethyl chloride
Methyl iodide
Monochloroacetone
Nitrochlorobenzene
Nitrogen mustard
Pentachlorophenol*
Perchloroethylene
Perchloromethylmercaptan
Picryl chloride
Polybrominated biphenyls
Polychlorinated biphenyls
Polychlorinated triphenyls
Propargyl bromide
Propargyl chloride
TCDD
Tetrachloroethane*
Tetrachlorophenol
Tetrachloropropyl ether
Trichloroethane
Trichloroethylene*
Trichlorophenoxyacetic acid
Trichloropropane
Trifluoroethane
Vinyl chloride
Vinylidene chloride (1,1-dichloroethylene)

Class 18 Isocyanates (All Isomers)

Chlorophenyl isocyanate
Diphenylmethane diisocyanate
Methyl isocyanate
Methylene diisocyanate
Polyphenyl polymethylisocyanate
Toluene diisocyanate*

Class 19 Ketones (All Isomers)

Acetone*
Acetophenone*
Acetyl acetone*
Benzophenone
Bromobenzoyl acetanilide
Chloroacetophenone
Coumafuryl
Coumatetralyl
Cyclohexanone*
Diacetone alcohol
Diacetyl
Dichloroacetone*
Diethyl ketone
Dimethyl ketone*
Diisobutyl ketone
Heptanone
Hydroxyacetophenone
Isophorone
Mesityl oxide
Methyl t-butyl ketone
Methyl ethyl ketone*
Methyl isobutyl ketone*
Methyl isopropenyl ketone
Methyl n-propyl ketone
Methyl vinyl ketone
Monochloroacetone
Nonanone
Octanone
Pentanone
Quinone (Benzoquinone)*

Class 20 Mercaptans and Other Organic Sulfides (All Isomers)

Aldicarb
Amyl mercaptan
Butyl mercaptan
Carbon disulfide*
Dimethyl sulfide
Endosulfan
Ethyl mercaptan*
Mercaptobenzothiazole
Mercaptoethanol
Methomyl
Methyl mercaptan

Naphthyl mercaptan
Perchloromethyl mercaptan
Phospholan
Polysulfide polymer
Propyl mercaptan
Sulfur mustard
Tetrasul
Thionazin

Class 21 Metal Compounds, Inorganic

Aluminum fluoride*
Aluminum sulfate*
Ammonium arsenate
Ammonium dichromate
Ammonium hexanitrocobaltate
Ammonium molybdate
Ammonium nitridoosmate
Ammonium permanganate
Ammonium tetrachromate
Ammonium tetraperoxychromate
Ammonium trichromate
Antimony
Antimony nitride
Antimony oxychloride
Antimony pentachloride
Antimony pentafluoride
Antimony pentasulfide
Antimony perchlorate
Antimony potassium tartrate
Antimony sulfate
Antimony tribromide
Antimony trichloride
Antimony triiodide
Antimony trifluoride
Antimony trioxide
Antimony trisulfide
Antimony trivinyl
Arsenic
Arsenic pentaselenide
Arsenic pentoxide
Arsenic pentasulfide
Arsenic sulfide
Arsenic tribromide
Arsenic trichloride
Arsenic trifluoride
Arsenic triiodide
Arsenic trisulfide
Arsines
Barium
Barium azide
Barium carbide
Barium chlorate
Barium chloride
Barium chromate
Barium fluoride
Barium fluosilicate
Barium hydride
Barium hydroxide
Barium hypophosphide
Barium iodate
Barium iodide
Barium nitrate
Barium oxide
Barium perchlorate
Barium permanganate
Barium peroxide
Barium phosphate
Barium stearate
Barium sulfide
Barium sulfite
Beryllium
Beryllium-copper alloy
Beryllium fluoride
Beryllium hydride
Beryllium hydroxide
Beryllium oxide
Beryllium tetradhydroborate
Bismuth
Bismuth chromate
Bismuthic acid
Bismuth nitride
Bismuth pentafluoride
Bismuth pentoxide
Bismuth sulfide
Bismuth tribromide
Bismuth trichloride
Bismuth triiodide
Bismuth trioxide
Borane
Bordeaux arsenites
Boron arsenotribromide
Boron bromodiodide
Boron dibromoiodide
Boron nitride
Boron phosphide
Boron triazide
Boron tribromide
Boron triiodide
Born trisulfide
Boron trichloride
Boron trifluoride
Cacodylic acid
Cadmium
Cadmium acetylide

Cadmium amide
Cadmium azide
Cadmium bromide
Cadmium chlorate
Cadmium chloride
Cadmium cyanide
Cadmium fluoride
Cadmium hexamine chlorate
Cadmium hexamine perchlorate
Cadmium iodide
Cadmium nitrate
Cadmium nitride
Cadmium oxide
Cadmium phosphate
Cadmium sulfide
Cadmium trihydrazine chlorate
Cadmium trihydrazine perchlorate
Calcium arsenate
Calcium arsenite
Chromic acid*
Chromic chloride
Chromic fluoride
Chromic oxide
Chromic sulfate
Chromium
Chromium sulfide
Chromium trioxide
Chromyl chloride
Cobalt
Cobaltous bromide
Cobaltous chloride
Cobaltous nitrate
Cobaltous sulfate
Cobaltous resinate
Copper
Copper acetoarsenite
Copper acetylide
Copper arsenate
Copper arsenite
Copper chloride
Copper chlorotetrazole
Copper cyanide
Copper nitrate
Copper nitride
Copper sulfate
Copper sulfide
Cupriethylene diamine
Cyanochloropentane
Diethyl zinc
Diisopropyl beryllium
Diphenylamine chloroarsine
Ethyl dichloroarsine
Ethylene chromic oxide
Ferric arsenate
Ferrous arsenate
Hydrogen selenide
Indium
Lead
Lead acetate
Lead arsenate
Lead arsenite
Lead azide
Lead carbonate
Lead chlorite
Lead cyanide
Lead dinitroresordinate
Lead monoinitroresorcinate
Lead nitrate
Lead oxide
Lead styphnate
Lead sulfide
Lewisite
London purple
Magnesium arsenate
Magnesium arsenite
Manganese
Manganese acetate
Manganese arsenate
Manganese bromide
Manganese chloride
Manganese methylcyclopentadienyl tricarbonyl
Manganese nitrate
Manganese sulfide
Mercuric acetate
Mercuric ammonium chloride
Mercuric benzoate
Mercuric bromide
Mercuric chloride
Mercuric cyanide
Mercuric iodide
Mercuric nitrate
Mercuric oleate
Mercuric oxide
Mercuric oxycyanide
Mercuric potassium iodide
Mercuric salicylate
Mercuric subsulfate
Mercuric sulfate
Mercuric sulfide
Mercuric thiocyanide
Mercurol
Mercurous bromide
Mercurous gluconate
Mercurous iodide

Mercurous nitrate
Mercurous oxide
Mercurous sulfate
Mercury
Mercury fulminate
Methoxyethylmercuric chloride
Methyl dichloroarsine
Molybdenum
Molybdenum sulfide
Molybdenum trioxide
Molybdic acid
Nickel
Nickel acetate
Nickel antimonide
Nickel arsenate
Nickel arsenite
Nickel carbonyl
Nickel chloride
Nickel cyanide
Nickel nitrate
Nickel selenide
Nickel subsulfide
Nickel sulfate
Osmium
Osmium amine nitrate
Osmium amine perchlorate
Phenyl dichloroarsine
Potassium arsenate
Potassium arsenite
Potassium dichromate
Potassium permanganate
Selenium
Selenium fluoride
Selenium diethyl dithiocarbamate
Selenous acid
Silver acetylide
Silver azide
Silver cyanide
Silver nitrate*
Silver nitride
Silver styphnate
Silver sulfide
Silver tetrazene
Sodium arsenate
Sodium arsenite
Sodium cacodylate
Sodium chromate
Sodium dichromate
Sodium molybdate
Sodium permanganate
Sodium selenate
Stannic chloride
Stannic sulfide
Strontium arsenate
Strontium monosulfide
Strontium nitrate
Strontium peroxide
Strontium tetrasulfide
Tellurium hexafluoride
Tetraethyl lead*
Tetramethyl lead
Tetraselenium tetranitride
Thallium
Thallium nitride
Thallium sulfide
Thallous sulfate
Thorium
Titanium
Titanium sulfate
Titanium sesquisulfide
Titanium tetrachloride
Titanium sulfide
Tricadmium dinitride
Tricesium nitride
Triethyl arsine
Triethyl bismuthine
Triethyl stibine
Trilead dinitride
Trimercury dinitride
Trimethyl arsine
Trimethyl bismuthine
Trimethyl stibine
Tripropyl stibine
Trisilyl arsine
Trithorium tetranitride
Trivinyl stibine
Tungstic acid
Uranium sulfide
Uranyl nitrate
Vanadic acid anhydride
Vanadium oxytrichloride
Vanadium tetroxide
Vanadium trichloride
Vanadyl sulfate
Zinc
Zinc acetylide
Zinc ammonium nitrate
Zinc arsenate
Zinc arsenite
Zinc chloride*
Zinc cyanide
Zinc fluoborate

Zinc nitrate
Zinc permanganate
Zinc peroxide
Zinc phosphide
Zinc salts of dimethyldithio carbamic acid
Zinc sulfate
Zinc sulfide
Zirconium
Zirconium chloride
Zirconium picramate

Class 22 Nitrides

Antimony nitride
Bismuth nitride
Boron nitride
Copper nitride
Disulfur dinitride
Lithium nitride
Potassium nitride
Silver nitride
Sodium nitride
Tetraselenium tetranitride
Tetrasulfur tetranitride
Thallium nitride
Tricadmium dinitride
Tricalcium dinitride
Tricesium nitride
Trilead dinitride
Trimercury dinitride
Trithorium tetranitride

Class 23 Nitriles (All Isomers)

Acetone cyanohydrin
Acetonitrile*
Acrylonitrile*
Adiponitrile
Aminopropionitrile
Amyl cyanide
a,á-Azodiisobutyronitrile
Benzonitrile
Bromoxynil
Butyronitrile
Chloroacrylonitrile
Chlorobenzylidene malononitrile
Chlorobutyronitrile
Cyanoacetic acid
Cyanochloropentane
Cyanogen
Ethylene cyanohydrin
Glycolonitrile
Phenyl acetonitrile
Phenyl valerylnitrile
Propionitrile
Surecide*
Tetramethyl succinonitrile
Tranid*
Vinyl cyanide

Class 24 Nitro Compounds (All Isomers)

Acetyl nitrate
Chlorodinitroluene
Chloronitroaniline
Chloropicrin
Collodion
Diazodinitrophenol
Diethylene glycol dinitrate
Dinitrobenzene
Dinitrochlorobenzene
Dinitrocresol
Dinitrophenol
Dinitrophenyl hydrazine
Dinitrotoluene
Dinoseb
Dipentaerythritol hexanitrate
Dipicryl amine
Ethyl nitrate
Ethyl nitrite
Glycol dinitrate
Glycol monolactate trinitrate
Guanidine nitrate
Lead dinitroresorcinate
Lead mononitroresorcinate
Lead styphnate
Mannitol hexanitrate
Medinoterb acetate
Nitroaniline*
Nitrobenzene*
Nitrobiphenyl
Nitrocellulose
Nitrochlorobenzene
Nitroglycerin
Nitrophenol*
Nitropropane*
N-Nitrosodimethylamine
Nitrosoguanidine
Nitrostarch
Nitrotoluene*
Nitroxylene
Pentaerythritol tetranitrate
Picramide
Picric acid*
Picryl chloride

Polyvinyl nitrate
Potassium dinitrobenzfuroxan
RDX
Silver styphnate
Sodium picramate
Tetranitromethane
Trinitroanisole
Trinitrobenzene
Trinitrobenzoic acid
Trinitronaphthalene
Trinitroresorcinol
Trinitrotoluene
Urea nitrate

Class 25 Hydrocarbons, Aliphatic, Unsaturated (All Isomers)

Acetylene
Allene
Amylene
Butadiene*
Butene
Cyclopentene
Decene
Dicyclopentadiene
Diisobutylene
Dimethyl acetylene
Dimethyl butyne
Dipentene
Dodecene
Ethyl acetylene
Ethylene
Heptene
Hexene
Hexyne
Isobutylene
Isooctene
Isoprene*
Isopropyl acetylene
Methyl acetylene
Methyl butene
Methyl butyne
Methyl styrene
Nonene
Octadecyne
Octene
Pentene
Pentyne
Polybutene
Polypropylene
Propylene
Styrene*
Tetradecene
Tridecene
Undecene
Vinyl toluene

Class 26 Hydrocarbons, Aliphatic, Saturated

Butane*
Cycloheptane
Cyclohexane*
Cyclopentane
Cyclopropane
Decalin
Decane
Ethane
Heptane
Hexane
Isobutane
Isohexane
Isooctane
Isopentane
Methane
Methyl cyclohexane
Neohexane
Nonane
Octane
Pentane
Propane

Class 27 Peroxides and Hydroperoxides, Organic (All Isomers)

Acetyl benzoyl peroxide
Acetyl peroxide
Benzoyl peroxide*
Butyl hydroperoxide
Butyl peroxide
Butyl peroxyacetate
Butyl peroxybenzoate
Butyl peroxypivalate
Caprylyl peroxide
Chlorobenzoyl peroxide
Cumene hydroperoxide
Cyclohexanone peroxide
Dicumyl peroxide
Diisopropylbenzene hydroperoxide
Diisopropyl peroxydicarbonate
Dimethylhexane dihydroperoxide
Hydrogen peroxide*
Isopropyl percarbonate
Lauroyl peroxide
Methyl ethyl ketone peroxide
Peracetic acid
Succinic acid peroxide

Class 28 Phenols, Cresols (All Isomers)

Amino phenol
Bromophenol
Bromoxynil
Carbacrol
Carbolic oil
Catecol
Chlorocresol*
Chlorophenol
Coal tar*
Cresol*
Creosote*
Cyclohexyl phenol
Dichlorophenol
Dinitrocresol
Dinitrophenol
Dinoseb
Eugenol
Guaiacol
Hydroquinone*
Hydroxyacetophenone
Hydroxydiphenol
Hydroxyhydroquinone
Isoeugenol
Naphthol
Nitrophenol*
Nonyl phenol
Pentachlorophenol
Phenol*
o-Phenyl phenol
Phloroglucinol
Picric acid*
Pyrogallol
Resorcinol*
Saligenin
Sodium pentachlorophenate
Sodium phenolsulfonate
Tetrachlorophenol
Thymol*
Trichlorophenol
Trinitroresorcinol

Class 29 Organophosphates, Phosphothioates, and Phosphodithioates

Abate*
Azinphos ethyl
Azodrin*
Bidrin*
Bomyl*
Chlorfenvinphos
Chlorothion*
Coroxon*
DDVP
Demeton
Demeton-s-methyl sulfoxid
Diazinon*
Diethyl chlorovinyl phosphate
Dimethyldithiophosphoric acid
Dimefox
Dioxathion
Disulfoton
Dyfonate*
Endothion
EPN
Ethion*
Fensulfothion
Guthion*
Hexaethyl tetraphosphate
Malathion*
Mecarbam
Methyl parathion
Mevinphos
Mocap*
α-Isopropyl methylphosphoryl fluoride
Paraoxon
Parathion*
Phorate
Phosphamidon
Phospholan
Potasan
Prothoate
Shradan
Sulfotepp
Supracide*
Shradan
Sulfotepp
Supracide*
Surecide*
Tetraethyl dithionopyrophosphate
Tetraethyl pyrophosphate
Thionazin
Tris-(1-aziridinyl) phosphine oxide
VX
Wepsyn* 155

Class 30 Sulfides, Inorganic

Ammonium sulfide
Antimony pentasulfide
Antimony trisulfide
Arsenic pentasulfide
Arsenic sulfide
Arsenic trisulfide
Barium sulfide
Beryllium sulfide
Bismuth sulfide

Bismuth trisulfide
Boron trisulfide
Cadmium sulfide
Calcium sulfide
Cerium trisulfide
Cesium sulfide
Chromium sulfide
Copper sulfide
Ferric sulfide
Ferrous sulfide
Germanium sulfide
Gold sulfide
Hydrogen sulfide
Lead sulfide
Lithium sulfide
Magnesium sulfide
Manganese sulfide
Mercuric sulfide
Molybdenum sulfide
Nickel subsulfide
Phosphorous heptasulfide
Phosphorous pentasulfide
Phosphorous sesquisulfide
Phosphorous trisulfide
Potassium sulfide
Silver sulfide
Sodium sulfide
Stannic sulfide
Strontium monosulfide
Strontium tetrasulfide
Thallium sulfide
Titanium sesquisulfide
Titanium sulfide
Uranium sulfide
Zinc sulfide

Class 31 Epoxides

Butyl glycidyl ether
t-Butyl-3-phenyl oxazirane
Cresol glycidyl ether
Diglycidyl ether
Epichlorohydrin*
Epoxybutane
Epoxybutene
Epoxyethylbenzene
Ethylene oxide
Glycidol
Phenyl glycidyl ether
Propylene oxide

Class 32 Combustible and Flammable Materials, Miscellaneous

Alkyl resins
Asphalt
Bakelite*
Buna-N*
Bunker fule oil
Camphor oil
Carbon, activated, spent
Cellulose
Coal oil
Diesel oil*
Dynes thinner
Gas oil, cracked
Gasoline*
Grease
Isotactic propylene
J-100
Jet oil
Kerosene*
Lacquer thinner
Methyl acetone
Mineral spirits
Naphtha*
Oil of bergamot
Orris root
Paper
Petroleum naphtha
Petroleum oil*
Polyamide resin
Polyester resin
Polyethylene
Polymeric oil
Polypropylene
Polystyrene
Polysulfide polymer
Polyurethane
Polyvinyl acetate
Polyvinyl chloride
Refuse
Resins
Sodium polysulfide
Stoddard solvent
Sulfur (elemental)
Synthetic rubber
Tall oil
Tallow
Tar
Turpentine*
Unisolve
Waxes
Wood

Class 33 Explosives

Acetyl azide
Acetyl nitrate
Ammonium azide
Ammonium chlorate
Ammonium hexanitrocobaltate
Ammonium nitrate
Ammonium nitrite
Ammonium periodate
Ammonium permanganate
Ammonium picrate
Ammonium tetraperoxychromate
Azidocarbonyl guanidine
Barium azide
Benzene diazonium chloride
Benzotriazole
Benzoyl peroxide*
Bismuth nitride
Boron triazide
Bromine azide
Butanetriol trinitrate
t-Butyl hypochlorite
Cadmium azide
Cadmium haxamine chlorate
Cadmium hexamine perchlorate
Cadmium nitrate
Cadmium nitride
Cadmium trihydrazine chlorate
Calcium nitrate
Cesium azide
Chlorine azide
Chlorine dioxide
Chlorine fluoroxide
Chlorine trioxide
Chloroacetylene
Chloropicrin
Copper acetylide
Cyanuric triazide
Diazidoethane
Diazodinitrophenol
Diethylene glycol dinitrate
Dipentaerithritol hexanitrate
Dipicryl amine
Disulfur dinitride
Ethyl nitrate
Ethyl nitrite
Fluorine azide
Glycol dinitrate
Glycol monolactate trinitrate
Gold fulminate
Guanyl nitrosaminoguanylidene hydrazine
HMX
Hydrazine azide
Hydrazoic acid
Lead azide
Lead dinitroresorcinate
Lead mononitroresorcinate
Lead styphnate
Mannitol hexanitrate
Mercuric oxycyanide
Mercury fulminate
Nitrocarbonitrate
Nitrocellulose
Nitroglycerin
Nitrosoguanidine
Nitrostarch
Pentaerythritol tetranitrate
Picramide
Picric acid*
Picryl chloride
Polyvinyl nitrate
Potassium dinitrobenzfuroxan
Potassium nitrate
RDX
Silver acetylide
Silver azide
Silver nitride
Silver styphnate
Silver tetrazene
Smokeless powder
Sodium azide
Sodium picramate
Tetranitromethane
Tetraselenium tetranitride
Tetrasulfur tetranitride
Tetrazene
Thallium nitride
Trilead dinitride
Trimercury dinitride
Trinitrobenzene
Trinitrobenzoic acid
Trinitronaphthalene
Trinitroresorcinol
Trinitrotoluene
Urea nitrate
Vinyl azide
Zinc peroxide

Class 34 Polymerizable Compounds

Acrolein
Acrylic acid
Acrylonitrile*
Butadiene*
n-Butyl acrylate
Ethyl acrylate
Ethylene oxide
Ethylenimine
2-Ethylhexyl acrylate
Isobutyl acrylate
Isoprene

Methyl acrylate*
Methyl methacrylate
2-Methyl styrene
Propylene oxide
Styrene*
Vinyl acetate
Vinyl chloride
Viyl cyanide
Vinylidene chloride
Vinyl toluene

Class 35 Oxidizing Agents, Strong

Ammonium chlorate
Ammonium dichromate
Ammonium nitridoosmate
Ammonium perchlorate
Ammonium periodate
Ammonium permanganate
Ammonium persulfate
Ammonium tetrachromate
Ammonium tetraperoxychromate
Ammonium trichromate
Antimony perchlorate
Barium bromate
Barium chlorate
Barium iodate
Barium nitrate
Barium perchlorate
Barium permanganate
Barium peroxide
Bromic acid
Bromine
Bromine monofluoride
Bromine pentafluoride
Bromine trifluoride
t-Butyl hypochlorite
Cadmium chlorate
Cadmium nitrate
Calcium bromate
Calcium chlorate
Calcium chlorite
Calcium hypochlorite
Calcium iodate
Calcium nitrate
Calcium perchromate
Calcium permanganate
Calcium peroxide
Chloric acid*
Chlorine
Chlorine dioxide
Chlorine fluoroxide
Chlorine monofluoride
Chlorine monoxide
Chlorine pentafluoride
Chlorine trifluoride
Chlorine trioxide
Chromic acid*
Chromyl chloride
Cobaltous nitrate
Copper nitrate
Dichloroamine
Dichloroisocyanuric acid
Ethylene chromic oxide
Fluorine
Fluorine monoxide
Guanidine nitrate
Hydrogen peroxide
Iodine pentoxide
Lead chlorite
Lead nitrate
Lithium hypochlorite
Lithium peroxide
Magnesium chlorate
Magnesium nitrate
Magnesium perchlorate
Magnesium peroxide
Manganese nitrate
Mercuric nitrate
Mercurous nitrate
Nickel nitrate
Nitrogen dioxide
Osmium amine nitrate
Osmium amine perchlorate
Oxygen difluoride
Perchloryl fluoride
Phosphorus oxybromide
Phosphorus oxychloride
Potassium bromate
Potassium dichloroisocyanurate
Potassium dichromate
Potassium nitrate
Potassium perchlorate
Potassium permanganate
Potassium peroxide
Silver nitrate*
Sodium bromate
Sodium carbonate peroxide
Sodium chlorate
Sodium chlorite
Sodium dichloroisocyanurate
Sodium dichromate
Sodium hypochlorite*
Sodium nitrate
Sodium nitrite
Sodium perchlorate
Sodium permanganate
Sodium peroxide
Strontium nitrate
Strontium peroxide
Sulfur trioxide*

Trichloroisocyanuric acid
Uranyl nitrate
Urea nitrate
Zinc ammonium nitrate
Zinc nitrate
Zinc permanganate
Zinc peroxide
Zirconium picramate

Class 36 Reducing Agents, Strong

Aluminum borohydride
Aluminum carbide
Aluminum hydride
Aluminum hypophosphide
Ammonium hypophosphide
Ammonium sulfide
Antimony pentasulfide
Antimony trisulfide
Arsenic sulfide
Arsenic trisulfide
Arsine
Barium carbide
Barium hydride
Barium hypophosphide
Barium sulfide
Benzyl silane
Benzyl sodium
Beryllium hydride
Beryllium sulfide
Beryllium tetrahydroborate
Bismuth sulfide
Boron arsenotribromide
Boron trisulfide
Bromodiborane
Bromosilane
Butyl dichloroborane
n-Butyl lithium
Cadmium acetylide
Cadmium sulfide
Calcium
Calcium carbide
Calcium hexammoniate
Calcium hydride
Calcium hypophosphide
Calcium sulfide
Cerium hydride
Cerium trisulfide
Cerous phosphide
Cesium carbide
Cesium hexahydroaluminate
Cesium hydride
Cesium sulfide
Chlorodiborane
Chlorodiisobutyl aluminum
Chlorodimethylamie diborane
Chlorodipropyl borane
Chlorosilane
Chromium sulfide
Copper acetylide
Copper sulfide
Diamine*
Diborane
Diethyl aluminum chloride
Diethyl zinc
Diisopropyl beryllium
Dimethyl magnesium
Ferrous sulfide
Germanium sulfide
Gold acetylide
Gold sulfide
Hexaborane
Hydrazine*
Hydrogen selenide
Hydrogen sulfide
Hydroxyl amine
Lead sulfide
Lithium aluminum hydride
Lithium hydride
Lithium sulfide
Magnesium sulfide
Manganese sulfide
Mercuric sulfide
Methyl aluminum sesquibromide
Methyl aluminum sesquichloride
Methyl magnesium bromide
Methyl magnesium chloride
Methyl magnesium iodide
Molybdenum sulfide
Nickel subsulfide
Pentaborane
Phosphine
Phosphonium iodide
Phosphorus (red amorphous)
Phosphorus (white or yellow)
Phosphorus heptasulfide
Phosphorus pentasulfide
Phosphorus sesquisulfide
Phosphorus trisulfide
Potassium hydride
Potassium sulfide
Silver acetylide
Silver sulfide
Sodium
Sodium aluminate
Sodium aluminum hydride
Sodium hydride
Sodium hyposulfite
Sodium sulfide
Stannic sulfide
Strontium monosulfide
Strontium tetrasulfide

Tetraborane
Thallium sulfide
Titanium sesquisulfide
Titanium sulfide
Triethyl aluminum
Triethyl stibine
Triisobutyl aluminum
Trimethyl aluminum
Trimethyl stibine
Tri-n-butyl borane
Trioctyl aluminum
Uranium sulfide
Zinc acetylide
Zinc sulfide

Class 37 Water and Mixtures Containing Water

Aqueous solutions and mixtures
Water

Class 38 Water Reactive Substances

Acetic anhydride*
Acetyl bromide
Acetyl chloride
Alkyl aluminum chloride
Allyl tirchlorosilane
Aluminum aminoborohydride
Aluminum borohydride
Aluminum bromide
Aluminum chloride
Aluminum fluoride
Aluminum hydophosphide
Aluminum phosphide
Aluminum tetrahydroborate
Amyl trichlorosilane
Anisoyl chloride
Antimony tribromide
Antimony trichloride
Antimony trifluoride
Antimony triiodide
Antimony trivinyl
Arsenic tribromide
Arsenic trichloride
Arsenic triiodide
Barium
Barium carbide
Barium oxide
Barium sulfide
Benzene phosphorus dichloride
Benzoyl chloride
Benzyl silane
Benzyl sodium
Beryllium hydride
Beryllium tetrahydroborate
Bismuth pentafluoride
Borane
Boron bromodiiodide
Boron dibromoiodide
Boron phosphide
Boron tribromide
Boron trichloride
Boron trifluoride
Boron triiodide
Bromine monofluoride
Bromine pentafluoride
Bromine trifluoride
Bromo diethylaluminum
n-Butyl lithium
n-Butyl trichlorosilane
Cadmium acetylide
Cadmium amide
Calcium
Calcium carbide
Caldium hydride
Calcium oxide
Calcium phosphide
Cesium amide
Cesium hydride
Cesium phosphide
Chlorine dioxide
Chlorine monofluoride
Chlorine pentafluoride
Chlorine trifluoride
Chloroacetyl chloride
Chlorodiisobutyl aluminum
Chlorophenyl isocyanate
Chromyl chloride
Copper acetylide
Cyclohexenyl trichlorosilane
Cyclohexyl trichlorosilane
Decaborane
Diborane
Diethyl aluminum chloride
Diethyl dichlorosilane
Diethyl zinc
Diisopropyl beryllium
Dimethyl dichlorosilane
Dimethyl magnesium
Diphenyl dichlorosilane
Diphenylmethane diisocyanate
Disulfuryl chloride
Dodecyl trichlorosilane
Ethyl dichloroarsine
Ethyl dichlorosilane
Ethyl trichlorosilane
Fluorine
Fluorine monoxide

Fluorosulfonic acid
Gold acetylide
Hexadecyl trichlorosilane
Hexyl trichlorosilane
Hydrobromic acid*
Iodine monochloride
Lithium
Lithium aluminum hydride
Lithium amide
Lithium ferrosilicon
Lithium hydride
Lithium peroxide
Lithium silicon
Methyl aluminum sesquibromide
Methyl aluminum sesquichloride
Methyl dichlorosilane
Methylene diisocyanate
Methyl isocyanate
Methyl trichlorosilane
Methyl magnesium bromide
Methyl magnesium chloride
Methyl magnesium iodide
Nickel antimonide
Nonyl tirchlorosilane
Octadecyl trichlorosilane
Octyl trichlorosilane
Phenyl trichlorosilane
Phosphonium iodide
Phosphoric anhydride
Phosphorus oxychloride
Phosphorus pentasulfide
Phosphorus trisulfide
Phosphorus (amorphous red)
Phosphorus oxybromide
Phosphorus oxychloride
Phosphorus pentachloride
Phosphorus sesquisulfide
Phosphorus tribromide
Phosphorus trichloride
Polyphenyl polymethyl isocyanate
Potassium
Potassium hydride
Potassium oxide
Potassium peroxide
Propyl trichlorosilane
Pyrosulfuryl chloride
Silicon tetrachloride
Silver acetylide
Sodium
Sodium aluminum hydride
Sodium amide
Sodium hydride
Sodium methylate
Sodium oxide
Sodium peroxide
Sodium-potassium alloy
Stannic chloride
Sulfonyl fluoride
Sulfuric acid (70%)*
Sulfur chloride
Sulfur pentafluoride
Sulfur trioxide*
Sulfuryl chloride
Thiocarbonyl chloride
Thionyl chloride
Thiophosphoryl chloride
Titanium tetrachloride
Toluene diisocyanate
Trichlorosilane
Triethyl aluminum
Triisobutyl aluminum
Trimethyl aluminum
Tri-n-butyl aluminum
Tri-n-butyl borane
Trioctyl aluminum
Trichloroborane
Triethyl arsine
Triethyl stibine
Trimethyl arsine
Trimethyl stibine
Tripropyl stibine
Trisilyl arsine
Trivinyl stibine
Vanadium trichloride
Vinyl trichlorosilane
Zinc acetylide
Zinc phosphide
Zinc peroxide

APPENDIX B

CHEMICAL CLASS COMPATIBILITY MATRIX

APPENDIX 8

CHEMICAL CLASS COMPATIBILITY MATRIX

Class Number	Chemical Class																																						
1	Acids, Mineral, Non-oxidizing	1																																					
2	Acids, Mineral, Oxidizing		2																																				
3	Acids, Organic		G_H	3																																			
4	Alcohols and Glycols	H	H_F	H_P	4																																		
5	Aldehydes	H_P	H_F	H_P		5																																	
6	Amides	H	H_{GT}				6																																
7	Amines, Aliphatic and Aromatic	H	H_{GT}	H		H		7																															
8	Azo Compounds, Diazo Compounds, and Hydrazines	H_G	H_{GT}	H_G	H_G	H			8																														
9	Carbamates	H_G	H_{GT}						G_H	9																													
10	Caustics	H	H	H		H				H_G	10																												
11	Cyanides	GT_{GF}	GT_{GF}	GT_{GF}					G			11																											
12	Dithiocarbamates	H_{GF_F}	H_{GF_F}	$H_{GF_{GT}}$		GF_{GT}		U	H_G				12																										
13	Ester	H	H_F						H_G		H			13																									
14	Ethers	H	H_F												14																								
15	Fluorides, Inorganic	GT	GT	GT												15																							
16	Hydrocarbons, Aromatic		H_F														16																						
17	Halogenated Organics	H_{GT}	$H_{F_{GT}}$				H_{GT}	H_G		H_{GF}	H							17																					
18	Isocyanates	H_G	$H_{F_{GT}}$	H_G	H_P			H_P	H_G		H_{P_G}	H_G	U						18																				
19	Ketones	H	H_F						H_G		H	H								19																			
20	Mercaptans and Other Organic Sulfies	GT_{GF}	$H_{F_{GT}}$						H_G									H	H	H	20																		
21	Metal Compounds, Inorganic	S	S	S			S	S			S											21																	
22	Nitrides	GF_{HF}	H_{F_E}	H_{GF}	GF_{H_F}	GF_H			U	H_G	U	GF_H	GF_H	GF_H				GF_H	U	GF_H	GF_H		22																
23	Nitriles	$H_{GT_{GF}}$	$H_{F_{GT}}$	H							U											S	GF_H	23															
24	Nitro Compounds, Organic		$H_{F_{GT}}$			H					H_E												H_{GF_E}		24														
25	Hydrocarbons, Aliphatic, Unsaturated	H	H_F			H																				25													
26	Hydrocarbons, Aliphatic, Saturated		H_F																								26												
27	Peroxides and Hydroperoxides, Organic	H_G	H_E		H_F	H_G		H_{GT}	H_{F_E}	$H_{F_{GT}}$		$H_{E_{GT}}$	$H_{F_{GT}}$					H_E	H	E	$H_{F_{GT}}$	H_G	H_{GF_E}	$H_{P_{GT}}$		H_P		27											
28	Phenols and Cresols	H	H_F						H_G										H_P				GF_H					H	28										
29	Organophosphates, Phosphothioates, Phosphodithioates	H_{GT}	H_{GT}						U		H_E																	U		29									
30	Sulfides, Inorganic	GT_{GF}	$H_{F_{GT}}$	GT		H			E										H									H_{GT}			30								
31	Epoxides	H_P	H_P	H_P	H_P	U		H_P	H_P		H_P	H_P	U								H_P	H_P	H_P					H_P	H_P	U	H_P	31							
32	Combustible and Flammable Materials, Miscellaneous	H_G	$H_{F_{GT}}$																				H_{GF_F}					$H_{F_{GT}}$					32						
33	Explosives	H_E	H_E	H_E					H_E		H_E			H_E								E	E					H_E	H_E		H_E	H_E	H_E	33					
34	Polymerizable Compounds	P_H	P_H	P_H					P_H		P_H	P_H	U									P_H	P_H					P_H	P_H		P_H			H_E	34				
35	Oxidizing Agents, Strong	H_{GT}		H_{GT}	H_F	H_F	$H_{F_{GT}}$	$H_{F_{GT}}$	H_E	$H_{F_{GT}}$		$H_{E_{GT}}$	$H_{F_{GT}}$	H_F	H_F		H_F	H_{GT}	$H_{F_{GT}}$	H_F	$H_{F_{GT}}$		H_{F_E}	$H_{F_{GT}}$	H_E	H_F	H_F	H_G	H_F	$H_{F_{GT}}$	$H_{F_{GT}}$	H_{F_G}	H_{F_G}	H_E	$H_{F_{GT}}$	35			
36	Reducing Agents, Strong	H_{GF}	$H_{F_{GT}}$	H_{GF}	H_{GF_F}	GF_{H_F}	GF_H	H_{GF}	H_G				H_{GT}	H_F				H_E	GF_H	GF_H	GF_H			H_{GF}	H_E			H_E	GF_H	GT_{GF}		H	GF_H	H_E	$H_{P_{GF}}$	H_{F_E}	36		
37	Water and Mixtures Containing Water	H	H						G										H_G			S	GF_H								GT_{GF}						GF_{GT}	37	
38	Water Reactive Substances	← EXTREMELY REACTIVE! DO NOT MIX WITH ANY CHEMICAL OR WASTE MATERIAL! EXTREMELY REACTIVE! →																																					38
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38

LEGEND

Reactivity Code	Consequences
H	Heat generation
F	Fire
G	Innocuous and non-flammable gas generation
GT	Toxic gas generation
GF	Flammable gas generation
E	Explosion
P	Violent polymerization
S	Solubilization of toxic substances
U	May be hazardous but unknown

Source: Hatayama, et al., A Method for Determining the Compatibility of Hazardous Waste, U.S EPA, 1980.

APPENDIX C

CHEMICAL/MATERIALS COMPATIBILITY MATRIX

Sources:

Mellan, I., Corrosion Resistant Materials Handbook, Noyes Data Corporation, 1976.

Perry, R. and C. Chilton, Chemical Engineer's Handbook, McGraw-Hill, 1973.

Rabald, E., Corrosion Guide, Elsevier Scientific Publishing Company, 1968.

Shreir, L., Corrosion, Volumes 1 and 2, Newnes Publishing Company, 1976.

Staniar, W., Plant Engineering Handbook, McGraw-Hill, 1959.

APPENDIX C

CHEMICAL/MATERIAL COMPATIBILITY MATRIX

Chemical Name	Chemical Class	Material: Mild Steel	Type 304 Stainless	Type 316 Stainless	Stainless 20 Alloys	Cast Iron	Silicon Cast Iron	Aluminum and Alloys	Nickel	Monel (65 Ni; 30 Cu)	Inconel (80 Ni; 14 Cr; 7 Fe)	Hastelloy B	Hastelloy C	Hastelloy D	Epoxy Resins	Furnace Resins	Glass	Phenolic Resins	PVC	Butyl Rubber	Neoprene	Ceramic	Saran	Polyethylene	Cement	Wood
Acetaldehyde	5	+	+	+	+	+	+	+	+	+	+	N	N	N	+	+	+	+	--	+	--	+	N	--	--	--
Acetamide	6	N	N	--	N	--	N	N	N	N	N	N	N	N	+	N	N	--	N	N	+	N	N	+	N	N
Acetic acid 10%	3	--	+	+	+	--	+	C	--	--	+	+	+	+	+	C	+	--	C	+	+	+	+	+	--	+
Acetic acid 100%	3	--	--	+	+	--	+	C	--	--	--	+	+	+	+	+	+	+	+	N	--	+	--	--	--	+
Acetic anhydride	38	--	+	+	+	+	+	C	+	+	+	+	+	+	+	--	+	+	--	--	--	+	--	--	--	--
Acetone	19	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	--	+	--	+	--	--	N	N
Acetophenone	19	+	+	+	+	+	N	+	+	+	+	N	N	N	N	N	+	N	--	+	--	+	N	--	N	N
Acrylonitrile	23, 34	N	N	N	N	N	N	N	N	N	N	N	N	N	--	N	N	--	N	--	--	N	N	N	N	N
Aldrin	17	N	+	+	N	N	N	N	N	N	N	N	N	N	+	+	N	N	N	N	N	N	N	N	N	N
Ally alcohol	4	N	N	N	N	N	N	+	N	N	N	N	N	N	N	N	N	+	C	N	N	N	N	--	N	N

LEGEND

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Chemical Name	Chemical Class	Mild Steel	Type 304 Stainless	Type 316 Stainless	Stainless 20 Alloys	Cast Iron	Silicon Cast Iron	Aluminum and Alloys	Nickel	Monel (65 Ni; 30 Cu)	Inconel (80 Ni; 14 Cr; 7 Fe)	Hastelloy B	Hastelloy C	Hastelloy D	Epoxy Resins	Furnace Resins	Glass	Phenolic Resins	PVC	Butyl Rubber	Neoprene	Ceramic	Saran	Polyethylene	Cement	Wood
		Material																								
Aluminum fluoride	21	C	N	N	N	C	N	+	+	N	N	N	N	N	+	+	N	+	+	+	+	+	+	+	+	+
Aluminum sulfate	21	--	--	C	+	--	+	--	C	C	C	+	+	+	+	+	+	+	+	+	+	+	+	+	--	+
Amino ethanol	4, 7	+	+	+	N	N	N	+	N	N	N	N	N	N	+	+	+	N	N	+	+	N	N	N	+	N
Ammonia, aq.	10	+	+	+	+	+	+	+	--	--	--	+	+	+	+	+	+	+	--	--	+	+	--	+	N	N
Ammonium fluoride	15	--	--	N	+	--	--	--	N	N	--	N	N	N	+	+	--	N	+	+	+	--	+	--	--	N
Ammonium hydroxide	10	+	+	+	+	N	N	--	--	--	+	N	N	N	+	+	C	+	+	+	+	+	--	+	N	N
Aniline	7	C	+	+	+	+	+	+	+	+	+	+	+	+	+	C	+	--	--	--	--	+	N	+	N	N
Beer		--	N	+	+	+	N	+	N	+	N	N	N	N	--	--	+	+	+	+	+	N	N	+	N	N
Benzene	16	+	+	+	+	+	+	+	+	+	+	+	+	+	--	C	+	+	--	--	--	+	--	--	--	N
Benzoic acid	3	--	+	+	+	--	+	+	+	+	+	+	+	+	+	+	+	--	+	+	+	+	+	+	--	N
Benzoly peroxide	27, 33	N	N	+	N	--	N	N	N	N	N	N	N	N	--	--	+	--	N	N	+	+	N	N	N	N
Benzyl chloride	17	--	N	+	--	--	+	--	+	+	N	+	+	N	--	C	+	C	--	--	--	+	N	N	--	--
Boric acid	1	--	+	+	+	--	+	+	C	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	--	N

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Chemical Name	Chemical Class	Mild Steel	Type 304 Stainless	Type 316 Stainless	Stainless 20 Alloys	Cast Iron	Silicon Cast Iron	Aluminum and Alloys	Nickel	Monel (65 Ni; 30 Cu)	Inconel (80 Ni; 14 Cr; 7 Fe)	Hastelloy B	Hastelloy C	Hastelloy D	Epoxy Resins	Furnace Resins	Glass	Phenolic Resins	PVC	Butyl Rubber	Neoprene	Ceramic	Saran	Polyethylene	Cement	Wood
		Material																								
Butadiene	25, 34	+	+	+	N	N	N	+	N	N	N	N	N	N	N	N	N	N	N	N	--	N	N	--	N	N
Butane	26	+	+	+	N	N	N	+	N	N	N	N	N	N	N	N	N	--	N	--	--	N	N	+	N	N
Butyl acetate	13	+	+	+	+	+	+	+	+	+	+	+	+	+	C	--	+	--	--	--	--	+	--	--	--	N
Calcium hydroxide	10	+	+	+	+	+	--	C	+	+	+	+	+	+	+	+	C	--	+	+	+	+	+	+	N	N
Carbamide		N	N	+	N	N	N	+	N	N	N	N	N	N	+	+	+	N	N	+	+	N	N	N	N	N
Carbon disulfide	20	+	N	C	+	+	+	+	+	+	N	N	+	N	--	+	C	+	--	--	--	+	--	--	N	N
Carbon tetrachloride	17	--	--	C	+	+	+	C	+	+	+	+	+	+	+	+	+	+	+	--	--	+	+	--	N	N
Carbonic acid		N	+	+	+	N	+	C	--	N	+	+	+	N	+	+	+	+	+	+	+	+	+	+	--	N
Chloric acid	2, 35	--	--	--	+	N	N	--	--	--	N	N	N	N	N	N	+	N	N	N	N	N	N	+	N	N
Chloroacetone	17, 19	--	N	N	N	N	N	--	N	N	N	N	N	N	N	N	+	--	--	--	--	N	N	N	--	N

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Chemical Name	Chemical Class	Mild Steel	Type 304 Stainless	Type 316 Stainless	Stainless 20 Alloys	Cast Iron	Silicon Cast Iron	Aluminum and Alloys	Nickel	Monel (65 Ni; 30 Cu)	Inconel (80 Ni; 14 Cr; 7 Fe)	Hastelloy B	Hastelloy C	Hastelloy D	Epoxy Resins	Furnace Resins	Glass	Phenolic Resins	PVC	Butyl Rubber	Neoprene	Ceramic	Saran	Polyethylene	Cement	Wood
Chlorobenzene	17	+	+	+	+	+	+	+	+	+	+	N	N	N	C	+	+	--	--	--	--	+	--	--	--	N
Chlorocresol	17, 28	C	+	+	+	C	+	+	+	+	+	N	N	N	--	--	+	--	+	--	--	+	--	--	--	+
Chloroethanol	4, 17	+	+	+	N	N	N	+	N	N	N	N	N	N	+	+	+	N	--	+	--	N	N	N	N	N
Chloroform (dry)	17	+	+	+	+	+	+	+	+	+	+	+	+	+	+	C	+	+	--	--	--	+	--	--	N	N
Chlorosulfonic acid	1	--	N	C	+	--	+	C	+	+	+	+	+	+	--	--	+	--	+	--	--	N	N	N	N	N
Chromic acid 25%	2, 21, 35	--	--	--	C	--	+	--	--	--	N	N	+	N	--	--	+	--	+	+	--	+	+	C	--	N
Chromic acid 80%	2, 21, 35	+	--	--	+	--	+	--	--	--	N	N	+	N	--	--	+	--	+	--	--	+	+	C	--	N
Creosote	28	+	+	+	C	N	N	C	N	C	N	N	N	N	N	N	+	--	N	--	--	N	N	N	--	N
Cresol	28	+	+	+	+	+	+	+	+	+	N	N	N	N	N	+	+	--	--	--	--	N	N	--	--	N
Cumene	16	N	N	+	N	N	+	+	N	N	N	N	N	N	N	N	N	N	N	N	--	N	N	N	N	N
Cyclohexane	26	C	N	N	+	+	N	+	N	+	N	N	N	N	N	N	+	--	+	--	--	N	N	--	N	N
Cyclohexanone	19	--	N	N	N	N	N	N	N	N	N	N	N	N	N	N	+	N	--	--	--	N	N	--	N	N

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Chemical Name	Chemical Class	Mild Steel	Type 304 Stainless	Type 316 Stainless	Stainless 20 Alloys	Cast Iron	Silicon Cast Iron	Aluminum and Alloys	Nickel	Monel (65 Ni; 30 Cu)	Inconel (80 Ni; 14 Cr; 7 Fe)	Hastelloy B	Hastelloy C	Hastelloy D	Epoxy Resins	Furnace Resins	Glass	Phenolic Resins	PVC	Butyl Rubber	Neoprene	Ceramic	Saran	Polyethylene	Cement	Wood
		Material																								
Cyclohexanol	4	N	N	+	N	N	N	--	N	N	N	N	N	N	+	N	+	N	--	--	--	N	N	+	N	N
Diamine	8, 36	--	+	N	N	N	N	+	N	N	N	N	N	N	N	N	+	N	N	+	--	N	N	N	N	N
Dichloroacetone	17, 19	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Dichloroethyl ether	14, 17	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Dichloromethane	17	+	N	C	N	N	N	+	N	N	N	N	N	N	N	N	+	N	--	--	--	N	N	N	N	N
Diesel oil	32	+	+	+	+	+	+	+	N	N	N	N	N	N	N	N	N	N	N	--	N	N	N	N	N	N
Diethylamide	6	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Diethylamine	7	C	+	+	+	N	+	C	+	+	+	N	N	N	N	N	+	N	--	+	+	+	N	N	N	N
Dimethylformamide	6	N	N	N	N	N	N	+	N	N	N	N	N	N	--	--	N	N	--	+	--	N	N	N	N	N
Dimethyl hydrazine	8	N	N	N	N	N	N	+	N	N	N	N	N	N	N	N	N	N	--	N	N	N	N	N	N	N
Dimethyl ketone	19	+	+	+	N	N	N	+	N	N	N	N	N	N	+	+	+	N	--	+	--	N	N	N	N	N
Dimethyl phthalate	13	N	N	N	N	N	N	+	N	N	N	N	N	N	N	N	N	N	N	+	--	N	N	--	N	N
Dioxane	14	+	+	N	N	N	N	C	N	N	N	N	N	N	N	N	+	N	--	--	--	N	N	N	--	--
Epichlorohydrin	17, 31	+	+	+	N	N	N	+	N	N	N	N	N	N	+	+	+	N	--	--	--	N	N	N	N	N
Ethanol (water free)	4	+	+	+	+	+	+	+	+	+	+	+	+	N	+	N	+	+	+	+	+	+	+	N	N	N

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Chemical Name	Chemical Class	Mild Steel	Type 304 Stainless	Type 316 Stainless	Stainless 20 Alloys	Cast Iron	Silicon Cast Iron	Aluminum and Alloys	Nickel	Monel (65 Ni; 30 Cu)	Inconel (80 Ni; 14 Cr; 7 Fe)	Hastelloy B	Hastelloy C	Hastelloy D	Epoxy Resins	Furnace Resins	Glass	Phenolic Resins	PVC	Butyl Rubber	Neoprene	Ceramic	Saran	Polyethylene	Cement	Wood
		Material																								
Ethyl acetate	13	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	--	C	--	+	--	--	--	+
Ethyl benzene	16	N	N	+	N	N	N	+	N	N	N	N	N	N	+	+	+	N	--	--	--	N	N	--	N	N
Ethylene chlorohydrin	4, 17	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	N	--	+	--	+	--	--	N	+
Ethylene diamine	7	N	N	+	N	N	N	C	N	N	N	N	N	N	N	N	+	N	N	+	+	N	N	N	N	N
Ethylene dichloride	17	+	+	+	+	N	+	C	+	+	C	+	N	N	+	C	+	+	--	--	--	+	--	--	N	N
Ethylene glycol	4	C	+	+	+	C	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	C	N	+
Ethylene glycol monobutyl ether	4, 14, 17	N	+	+	N	N	+	+	N	N	N	N	N	N	+	+	+	N	+	+	--	N	N	N	N	N
Ethyl ether	14	C	N	C	N	N	N	C	N	N	N	N	N	N	--	--	+	N	--	--	--	N	N	--	N	N
Ethyl mercaptan	20	--	N	+	N	N	N	+	N	N	N	N	N	N	--	--	+	N	N	--	--	N	N	N	N	N
Fatty acids		--	+	+	+	--	+	+	+	+	+	+	+	+	+	+	+	C	+	+	--	+	+	C	--	+
Fluosilicic acid	1, 15	--	--	--	+	--	--	--	N	C	N	N	N	N	+	+	--	N	C	+	+	N	N	C	N	N

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		Material																								
Formaldehyde	5	--	N	C	+	C	+	C	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	N	N
Formic acid	3	--	+	+	+	--	+	C	+	+	--	+	+	+	+	+	+	C	+	+	+	+	+	+	N	N
Freons	17	N	N	+	N	N	N	C	N	N	N	N	N	N	N	N	N	N	--	--	--	N	N	N	N	N
Furan	14	+	+	+	N	N	N	+	N	N	N	N	N	N	N	N	N	+	N	--	--	N	N	N	N	N
Furfural	5	+	+	+	+	+	+	+	+	+	N	N	N	N	--	C	+	--	--	+	--	N	N	--	N	N
Gasoline	32	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	C	--	--	+	+	--	N	N
Glycerine	4	+	+	+	+	+	+	+	+	+	+	C	+	+	N	N	+	+	+	+	C	+	+	+	--	N
Hydrazine	8, 36	--	+	+	+	--	N	+	--	--	--	--	--	--	+	+	--	+	+	C	--	N	N	N	N	--
Hydriodic acid	1	N	N	N	N	N	N	--	N	N	N	N	N	N	N	--	N	--	N	N	N	N	N	N	N	N
Hydrobromic acid	1, 38	--	--	--	--	--	+	--	N	--	N	+	N	N	+	C	+	C	+	+	--	+	+	+	--	N
Hydrochloric acid 15%	1	--	--	--	--	--	+	--	--	--	N	+	N	N	+	C	+	+	+	C	C	+	+	+	N	N
Hydrochloric acid 38%	1	--	--	--	--	--	+	--	--	--	N	+	N	N	+	C	+	--	+	--	--	+	+	+	N	N
Hydrocyanic acid (concentrated)	1, 11	C	+	+	+	C	+	+	+	+	+	+	+	+	+	+	+	C	+	+	--	+	+	+	N	N
Hydrofluoric acid 20%	1, 15	--	--	--	+	--	--	--	--	+	N	+	+	+	+	+	--	+	+	+	--	--	--	+	--	N
Hydrofluoric acid 75%	1, 15	--	--	--	+	--	--	--	--	+	N	+	+	+	--	--	--	--	C	+	--	--	--	+	--	N
Hydrofluorosilicic acid	15	--	N	C	+	N	N	--	N	N	N	N	N	N	+	+	--	N	+	+	+	N	N	N	N	N

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Chemical Name	Chemical Class	Mild Steel	Type 304 Stainless	Type 316 Stainless	Stainless 20 Alloys	Cast Iron	Silicon Cast Iron	Aluminum and Alloys	Nickel	Monel (65 Ni; 30 Cu)	Inconel (80 Ni; 14 Cr; 7 Fe)	Hastelloy B	Hastelloy C	Hastelloy D	Epoxy Resins	Furnace Resins	Glass	Phenolic Resins	PVC	Butyl Rubber	Neoprene	Ceramic	Saran	Polyethylene	Cement	Wood
Hydrogen peroxide	27	--	C	C	C	--	C	+	C	C	+	N	+	N	N	--	C	C	+	+	+	+	N	+	C	--
Hydroquinone	28	C	+	C	N	--	N	C	+	+	+	N	N	N	+	+	+	+	+	C	C	+	N	+	N	N
Kerosene	32	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	--	--	+	+	--	N	N
Lactic acid	3	--	C	C	+	--	+	C	C	C	+	+	+	+	+	+	+	C	+	+	+	+	+	+	+	N
Malathion	29	--	N	+	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Maleic acid	3	--	+	+	+	--	+	C	N	N	N	+	N	N	+	+	+	N	+	--	--	+	N	+	N	N
Methanol	4	+	+	+	+	+	+	+	+	+	+	+	+	N	+	+	+	+	+	+	+	+	+	+	+	+
Methyl acrylate	13, 34	+	+	+	N	N	N	+	N	N	N	N	N	N	N	N	+	N	C	C	C	N	N	N	N	N
Methyl amine	7	+	+	+	N	+	N	C	C	C	+	N	N	N	N	+	+	+	--	+	+	+	N	+	+	N
Methyl chloride	17	C	C	C	+	+	+	--	+	+	+	N	N	N	N	N	+	+	--	C	--	N	--	--	N	N
Methyl ethyl ketone	19	+	+	+	N	N	N	+	N	N	N	N	N	N	--	--	+	+	--	+	--	N	N	--	+	N
Methyl formate	13	+	+	+	N	N	N	+	N	N	N	N	N	N	N	N	N	N	C	+	+	N	N	N	N	N
Methyl isobutyl ketone	19	+	+	+	N	N	N	+	N	N	N	N	N	N	C	C	+	+	--	+	--	N	N	--	N	N

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Chemical Name	Chemical Class	Material: Mild Steel	Type 304 Stainless	Type 316 Stainless	Stainless 20 Alloys	Cast Iron	Silicon Cast Iron	Aluminum and Alloys	Nickel	Monel (65 Ni; 30 Cu)	Inconel (80 Ni; 14 Cr; 7 Fe)	Hastelloy B	Hastelloy C	Hastelloy D	Epoxy Resins	Furnace Resins	Glass	Phenolic Resins	PVC	Butyl Rubber	Neoprene	Ceramic	Saran	Polyethylene	Cement	Wood
Monoethanolamine	4, 7	+	+	+	N	N	N	N	N	N	N	N	N	N	+	+	+	N	N	+	+	N	N	N	N	N
Naphtha (coal tar)	32	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	C	--	--	+	N	+	N	N
Naphthalene	16	N	N	N	+	+	N	+	N	N	N	N	N	N	N	N	N	+	--	--	--	N	+	--	N	N
Nitric acid 10%	2	--	+	+	+	--	+	--	--	--	--	--	+	--	--	N	+	C	+	+	--	+	+	+	--	--
Nitric acid 100%	2	--	C	C	+	--	+	C	--	--	--	--	C	--	--	--	+	--	--	--	--	+	--	--	--	--
Nitrobenzene	24	+	+	+	+	+	+	+	+	+	+	+	+	+	C	C	+	C	--	+	--	+	--	--	N	N
Nitrophenol	24, 28	C	+	+	N	C	N	+	+	+	+	N	N	N	+	+	+	+	--	N	N	N	N	N	C	+
Nitropropane	24	+	N	+	N	N	N	+	N	N	N	N	N	N	N	N	N	N	+	+	--	N	N	N	N	N
Nitrotoluene	24	+	+	+	+	+	+	+	+	+	+	N	N	N	N	N	+	N	N	--	--	+	N	N	+	+
Oleic acid	3	C	+	+	+	C	+	+	+	+	+	+	+	+	+	+	+	+	+	--	--	+	+	--	--	+
Oleum	2	C	C	C	+	C	N	+	--	--	N	N	+	N	--	--	+	N	--	--	+	N	N	--	--	--
Oxalic acid	3	--	C	C	+	--	+	C	+	+	+	+	+	+	+	+	+		+	+	+	+	+	+	+	N
Parathion	29	N	+	+	N	N	N	+	N	N	N	N	N	N	+	+	N	N	N	N	N	N	N	N	N	N
Pentachlorophenol	17, 28	+	+	+	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N

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Chemical Name	Chemical Class	Material																								
		Mild Steel	Type 304 Stainless	Type 316 Stainless	Stainless 20 Alloys	Cast Iron	Silicon Cast Iron	Aluminum and Alloys	Nickel	Monel (65 Ni; 30 Cu)	Inconel (80 Ni; 14 Cr; 7 Fe)	Hastelloy B	Hastelloy C	Hastelloy D	Epoxy Resins	Furnace Resins	Glass	Phenolic Resins	PVC	Butyl Rubber	Neoprene	Ceramic	Saran	Polyethylene	Cement	Wood
Perchloric acid	2	--	--	--	--	--	+	--	--	--	--	N	N	N	+	+	C	N	C	N	--	N	N	C	--	--
Phenol	28	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	--	--	+	--	+	--	--	+	+
Phosphoric acid 50%	1	--	+	+	+	--	+	--	C	+	C	N	+	N	+	+	+	C	+	+	+	--	+	+	--	N
Phosphoric acid 100%	1	--	C	+	+	--	+	--	C	--	N	N	+	N	+	+	+	--	+	+	N	--	N	N	--	N
Phthalic acid	3	C	+	+	+	C	+	+	+	+	+	+	+	N	+	N	+	N	N	+	N	+	+	N	N	N
Phthalic anhydride		C	+	+	+	C	+	+	+	+	+	+	+	N	+	N	+	N	N	+	N	+	+	N	N	+
Picric acid	24, 28, 33	--	+	+	+	--	+	--	--	--	--	+	+	+	N	N	+	--	--	N	--	+	--	+	N	N
Potassium cyanide	11	+	+	+	+	C	+	--	+	+	+	+	+	+	+	+	C	--	+	+	+	+	+	+	+	N
Propiolactone	13	N	+	+	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Pyridine	7	+	+	+	+	+	+	+	N	N	N	N	N	N	N	N	+	+	--	--	--	+	N	+	+	+
Quinone	19	+	+	+	+	+	+	+	+	+	+	N	N	N	N	N	+	N	N	N	N	+	N	+	+	+
Resorcinol	28	N	N	N	N	N	N	+	N	N	N	N	N	--	N	N	N	N	N	N	N	N	N	N	N	N

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Salycilic acid	3	C	+	+	+	C	+	C	+	+	+	N	N	N	+	+	+	+	--	+	C	+	+	+	N	+
Silver nitrate	21, 35	--	+	+	+	+	+	--	--	--	+	+	+	+	+	+	+	+	+	+	+	+	+	+	N	N
Soap solutions		C	C	C	+	C	+	C	+	C	+	+	+	+	+	+	+	+	+	+	+	+	N	+	N	N
Sodium carbonate	10	+	+	+	+	+	+	--	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	C	N
Sodium chloride		+	C	C	+	C	+	C	+	+	C	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Sodium cyanide	11	+	+	+	+	+	+	--	--	--	--	N	N	N	+	+	C	+	+	+	+	+	--	+	+	+
Sodium hydroxide	10	+	+	+	+	+	--	--	+	+	+	+	N	+	+	+	C	--	+	+	+	--	--	+	+	N
Sodium hypochlorite	10, 35	--	--	--	C	--	+	--	C	C	C	--	+	--	C	--	+	--	+	+	--	+	+	+	N	N
Styrene	16, 25, 34	N	N	C	N	N	N	+	N	N	N	N	N	N	N	N	+	--	--	--	--	N	N	--	N	N
Sulfuric acid (0 to 30%)	2, 38	--	--	C	+	--	C	--	--	+	--	+	+	+	+	+	+	--	+	+	+	+	+	+	N	N
Sulfuric acid (50%)	2, 38	--	--	--	+	--	+	--	--	+	--	+	+	+	+	+	+	--	+	+	+	+	--	+	N	N
Sulfuric acid (95%)	2, 38	C	--	C	+	+	+	--	--	C	--	+	+	+	--	--	+	--	--	--	--	+	--	--	N	N
Sulfur trioxide (dry)	35, 38	+	+	+	+	+	--	+	--	--	--	N	N	N	+	N	+	N	+	+	--	+	+	+	N	N
Tetrachloroethane	17	N	N	+	N	N	N	--	N	N	N	N	N	N	+	+	+	N	--	--	--	N	N	N	N	N
Tetraethyl lead	21	N	N	+	N	N	N	N	N	N	N	N	N	N	N	N	N	N	+	--	N	N	N	+	N	N

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		Mild Steel	Type 304 Stainless	Type 316 Stainless	Stainless 20 Alloys	Cast Iron	Silicon Cast Iron	Aluminum and Alloys	Nickel	Monel (65 Ni; 30 Cu)	Inconel (80 Ni; 14 Cr; 7 Fe)	Hastelloy B	Hastelloy C	Hastelloy D	Epoxy Resins	Furnace Resins	Glass	Phenolic Resins	PVC	Butyl Rubber	Neoprene	Ceramic	Saran	Polyethylene	Cement	Wood
Tetrahydrofuran	14	N	N	+	+	N	N	N	N	N	N	N	+	N	--	N	N	N	--	N	--	+	N	--	N	N
Toluene	16	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	--	--	--	+	+	--	C	C
Transformer oil		N	N	+	N	N	N	+	N	N	N	N	N	N	+	+	+	+	--	--	+	N	N	N	N	N
Trichloroethylene	17	--	--	+	+	+	+	+	+	+	+	+	+	+	+	N	+	+	--	C	--	+	--	--	N	N
Turpentine	32	N	N	+	N	N	N	+	N	N	N	N	N	N	+	+	+	N	N	--	--	N	N	+	N	N
Urea		N	N	+	N	N	N	+	N	N	N	N	N	N	+	+	+	N	+	+	+	N	N	+	N	N
Xylene	16	+	+	N	N	N	N	+	N	N	N	N	N	N	--	--	+	+	N	--	--	N	N	--	--	N
Zinc chloride	21	--	C	C	+	--	+	C	+	+	+	+	+	N	+	+	+	+	+	+	+	+	+	+	N	C

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APPENDIX D

COUNTERMEASURES FOR HAZARDOUS SUBSTANCE SPILLS ON LAND AND WATER

Source: Pilie, R.J., R.E. Baier, R.C. Zeigler, R.P. Leonard, J.C. Michalovic, S.L. Pek, and D.H. Bock; 1975. Methods to Treat, Control and Monitor Spilled Hazardous Materials, EPA-670/2-75-042, National Environmental Research Center, Office of Research and Development, United States Environmental Protection Agency, Cincinnati, Ohio.

Appendix D consists of matrix of countermeasures recommended for treating hazardous substance spills. Chemicals are listed in alphabetical order in the first column. The second column identifies each compound's EPA Toxicity Classification, based on LC_{50} toxic concentrations, as follows:

Category	Toxicity Range
A	$LC_{50} \leq 1$ ppm
B	1 ppm $< LC_{50} \leq 10$ ppm
C	10 ppm $< LC_{50} \leq 100$ ppm
D	100 ppm $< LC_{50} \leq 500$ ppm

The third and fourth columns list, respectively, the density and physical form (solid or liquid) of the pure hazardous substance. The physical/chemical properties of a chemical discharge (solubility, density, volatility, and ability to disperse in water) must be considered in estimating its potential to harm the environment. Column five identifies the P/C/D category, which takes into account physical/chemical properties. The P/C/D categories are as follows:

IVF - Insoluble Volatile Floater
INF - Insoluble Non-volatile Floater
IS - Insoluble Sinker
SM - Soluble Mixer
P - Precipitator
SF - Soluble Floater
M - Miscible
SS - Soluble Sinker

The remaining columns of the matrix indicate which categories of countermeasures are effective for controlling hazardous substances discharged on the ground or into water.

MATERIAL	EPA CATE-GORY	DENSITY	PHYSICAL FORM	P/C/D CATE-GORY	MASS TRANSFER MEDIA			NEUTRALIZING AGENT		PRECIPI-TATING AGENT	BIOLOGICAL TREATMENT AGENT	GELLING AGENT	ABSORBING AGENT	OXIDIZING AGENT	DISPERSING AGENT
					ACTIVA-TED CARBON	CATIONIC RESIN	ANIONIC RESIN	ACID	BASE						
ACETALDEHYDE	C	0.783	L	M	●				●			●	●		
ACETIC ACID	C	1.049	L	M	●				●		●	●	●		
ACETIC ANHYDRIDE	C	1.083	L	SF	●				●		●	●	●		●
ACETONE CYANOHYDRIN	C	0.90	L	SF	●							●	●		●
ACETYL BROMIDE	D	1.52	L	SS	●		●					●	●		
ACETYL CHLORIDE	D	1.11	L	SS	●				●			●	●		
ACROLEIN	A	0.839	L	SF	●						●	●	●		●
ACRYLONITRILE	C	0.807	L	SF	●							●	●		●
ADIPONITRILE	D	0.95	L	SF	●							●	●		●
ALDRIN	A	1.65	S	IS	●										
ALLYL ALCOHOL	B	0.854	L	M	●						●	●	●		
ALLYL CHLORIDE	C	0.9	L	IVF	●						●	●	●		●
ALUMINUM FLUORIDE	D	2.88	S	P	●	●	●			●					
ALUMINUM SULFATE	D	1.69	S	P	●					●					
AMMONIA	C	0.60	L	SF	●	●		●				●			●
AMMONIUM ACETATE	D	1.073	S	SM	●	●									
AMMONIUM BENZOATE	D	1.26	S	SS	●	●	●								
AMMONIUM BICARBONATE	D	1.58	S	SS	●	●									
AMMONIUM BICHROMATE	D	2.15	S	SS	●	●	●			●					
AMMONIUM BIFLUORIDE	D	1.21	S	SS	●	●	●			●					
AMMONIUM BISULFITE	D	–	S	SS	●	●								●	
AMMONIUM BROMIDE	D	2.43	S	SS	●	●	●								
AMMONIUM CARBAMATE	D	–	S	SS	●	●	●								
AMMONIUM CARBONATE	S	–	S	SM	●	●									
AMMONIUM CHLORIDE	D	1.53	S	SS	●	●									
AMMONIUM CHROMATE	D	1.91	S	SS	●	●	●								
AMMONIUM CITRATE	D	–	S	SS	●	●									
AMMONIUM FLUOBORATE	D	1.85	S	SS	●	●	●								
AMMONIUM FLUORIDE	D	1.31	S	SM	●	●	●			●					
AMMONIUM HYDROXIDE	C	0.9	S/L	M	●	●		●				●			
AMMONIUM HYPOPHOSPHITE	D	–	S	SS	●	●									
AMMONIUM IODIDE	D	2.56	S	SM	●	●	●								
AMMONIUM NITRATE	D	1.66	S	SM	●	●	●								
AMMONIUM OXALATE	D	1.50	S	SS	●	●	●								
AMMONIUM PENTABORATE	D	–	S	SS	●	●	●								
AMMONIUM PERSULFATE	D	1.98	S	SS	●	●									
AMMONIUM SILICOFLUORIDE	C	2.01	S	SS	●	●	●								

APPENDIX D: HAZARDOUS SUBSTANCE/COUNTERMEASURE MATRIX

MATERIAL	EPA CATEGORY	DENSITY	PHYSICAL FORM	P/C/D CATEGORY	MASS TRANSFER MEDIA: ACTIVATED CARBON	MASS TRANSFER MEDIA: CATIONIC RESIN	MASS TRANSFER MEDIA: ANIONIC RESIN	NEUTRALIZING AGENT: ACID	NEUTRALIZING AGENT: BASE	PRECIPITATING AGENT	BIOLOGICAL TREATMENT AGENT	GELLING AGENT	ABSORBING AGENT	OXIDIZING AGENT	DISPERSING AGENT
AMMONIUM SULFAMATE	D	–	S	SM	●	●	●								
AMMONIUM SULFIDE	D	1.02	S	SS	●	●	●							●	
AMMONIUM SULFITE	D	1.41	S	SS	●	●	●							●	
AMMONIUM TARTRATE	D	1.61	S	SS	●	●	●								
AMMONIUM THIOCYANATE	D	1.31	S	SM	●	●	●								
AMMONIUM THIOSULFATE	D	–	S	SM	●	●	●								
AMYL ACETATE	C	0.88	L	INF	●						●	●	●		●
ANILINE	C	1.022	L	SS	●						●	●	●		●
ANTIMONY PENTACHLORIDE	C	2.34	S	P	●	●				●					
ANTIMONY PENTAFLUORIDE	C	2.99	S	P	●	●	●			●					
ANTIMONY POTASSIUM TARTRATE	C	2.6	S	P	●	●	●			●					
ANTIMONY TRIBROMIDE	C	4.14	S	P	●	●	●			●					
ANTIMONY TRICHLORIDE	C	3.14	S	P	●	●				●					
ANTIMONY TRIFLUORIDE	C	4.38	S	P	●	●	●			●					
ANTIMONY TRIOXIDE	C	6.2	S	P	●	●				●					
ARSENIC ACID	C	2 - 2.6	S	P	●		●		●	●		●	●		
ARSENIC DISULFIDE	C	3.4	S	IS	●	●	●			●		●	●		
ARSENIC PENTOXIDE	B	4.09	S	P	●	●				●					
ARSENIC TRICHLORIDE	C	2.16	S	P	●	●				●					
ARSENIC TRIOXIDE	B	3.89	S	P	●	●	●			●					
ARSENIC TRISULFIDE	B	3.43	S	IS	●	●	●			●					
BARIUM CYANIDE	A	–	S	SS	●	●	●			●				●	
BENZENE	C	0.879	L	INF	●							●	●		●
BENZOIC ACID	D	1.266	S	SS	●				●			●	●		
BENZONTRILE	C	1.01	L	SS	●							●	●		
BENZOYL CHLORIDE	D	1.20	L	SS	●							●	●		
BENZYL CHLORIDE	D	1.09	L	IS	●							●	●		
BERYLLIUM CHLORIDE	D	1.90	S	P	●	●				●					
BERYLLIUM FLUORIDE	C	1.99	S	P	●	●	●			●					
BERYLLIUM NITRATE	C	1.56	S	P	●	●				●					
BUTYL ACETATE	C	0.89	L	SF	●						●	●	●		●
BUTYLAMINE	C	0.74	L	M	●							●	●		
BUTYRIC ACID	D	1.00	L	M	●		●		●		●	●	●		●
CADMIUM ACETATE	A	2.01	S	SS	●	●				●					
CADMIUM BROMIDE	A	5.19	S	P	●	●	●			●					
CADMIUM CHLORIDE	A	4.05	S	P	●	●				●					
CALCIUM ARSENATE	C	3.0	S	IS	●		●			●					

APPENDIX D: HAZARDOUS SUBSTANCE/COUNTERMEASURE MATRIX (Cont.)

MATERIAL	EPA CATEGORY	DENSITY	PHYSICAL FORM	P/C/D CATEGORY	MASS TRANSFER MEDIA: ACTIVATED CARBON	MASS TRANSFER MEDIA: CATIONIC RESIN	MASS TRANSFER MEDIA: ANIONIC RESIN	NEUTRALIZING AGENT: ACID	NEUTRALIZING AGENT: BASE	PRECIPITATING AGENT	BIOLOGICAL TREATMENT AGENT	GELLING AGENT	ABSORBING AGENT	OXIDIZING AGENT	DISPERSING AGENT
CALCIUM ARSENITE	C	–	S	SS	●		●								
CALCIUM CARBIDE	D	2.2	S	P	●										
CALCIUM CHROMATE	D	2.89	S	SS	●		●								
CALCIUM CYANIDE	A	–	S	SS	●		●							●	
CALCIUM DODECYLBENZENE-SULFONATE	B	–	S	SS	●		●								
CALCIUM HYDROXIDE	D	2.504	S	SS				●							
CALCIUM HYPOCHLORITE	A	2.35	S	SM	●				●						
CALCIUM OXIDE	D	3.40	S	SM	●										
CAPTAN	A	1.6	S	SS	●								●		
CARBARYL	B	–	S	SS	●								●		
CARBON DISULFIDE	C	1.26	L	SS	●							●	●		
CHLORDANE	A	1.59	L	IS	●							●	●		
CHLORINE	A	3.2	L	SF	●								●		
CHLOROBENZENE	B	1.1	L	IS	●							●	●		
CHLOROFORM	B	1.5	L/G	IS	●							●	●		
CHLOROSULFONIC ACID	C	1.8	L	SS	●		●		●			●	●		
CHROMIC ACETATE	D	–	S	SS	●	●				●					
CHROMIC ACID	D	2.7	L	SM	●	●			●	●		●	●		
CHROMIC SULFATE	D	1.7	S	SS	●	●				●					
CHROMOUS CHLORIDE	D	2.87	S	IS	●	●				●					
CHROMYL CHLORIDE	D	1.91	S	SS	●	●				●					
COBALTOUS BROMIDE	C	2.47	S	P	●	●	●			●					
COBALTOUS FLUORIDE	C	4.46	S	P	●	●	●			●					
COBALTOUS FORMATE	C	2.13	S	P	●	●				●					
COBALTOUS SULFAMATE	C	–	S	P	●	●				●					
COUMAPHOS	A	–	S	SS	●								●		
CRESOL	B	1.0	S	SS	●						●	●	●		●
CUPRIC ACETATE	B	1.9	S	P	●	●				●					
CUPRIC ACETOARSENITE	B	–	S	IS	●	●	●			●					
CUPRIC CHLORIDE	B	3.39	S	P	●	●				●					
CUPRIC FORMATE	B	1.83	S	P	●	●				●					
CUPRIC GLYCINATE	B	–	S	P	●	●				●					
CUPRIC LACTATE	B	–	S	P	●	●				●					
CUPRIC NITRATE	B	2.32	S	P	●	●				●					
CUPRIC OXALATE	B	–	S	IS	●	●	●			●					
CUPRIC SUBACETATE	B	1.9	S	P	●	●				●					

APPENDIX D: HAZARDOUS SUBSTANCE/COUNTERMEASURE MATRIX (Cont.)

MATERIAL	EPA CATEGORY	DENSITY	PHYSICAL FORM	P/C/D CATEGORY	MASS TRANSFER MEDIA			NEUTRALIZING AGENT		PRECIPITATING AGENT	BIOLOGICAL TREATMENT AGENT	GELLING AGENT	ABSORBING AGENT	OXIDIZING AGENT	DISPERSING AGENT
					ACTIVATED CARBON	CATIONIC RESIN	ANIONIC RESIN	ACID	BASE						
CUPRIC SULFATE	B	2.28	S	P	●	●				●					
CUPRIC SULFATE AMMONIATED	B	–	S	P	●	●				●					
CUPRIC TARTRATE	B	–	S	IS	●	●				●					
CUPROUS BROMIDE	B	4.72	S	IS	●	●	●			●					
CYANOGEN CHLORIDE	A	1.186	G	SS	●	●									
CYCLOHEXANE	C	0.779	L	INF	●						●	●	●		●
2, 4 D ACID	B	0.82	–	IS									●		
2, 4-D ESTERS	B	–	–	IS									●		
DALAPON	B	1.38	L	SS	●							●	●		
DDT	A	–	S	IS	●							●	●		
DIAZINON	A	1.116	L	IS	●							●	●		
DICAMBA	C	–	S	SS	●								●		
DICHLOBENIL	C	–	S	SS	●								●		
DICHLONE	A	–	S	SS	●							●	●		
DICHLORVOS	A	–	L	SS	●								●		
DIELDRIN	A	1.76	S	SS	●								●		
DIETHYLAMINE	C	0.71	L	SF	●						●	●	●		●
DIMETHYLAMINE	C	0.68	L	SF	●						●	●	●		●
DINITROBENZENE	C	1.54	L	SS	●						●	●	●		●
DINITROPHENOL	B	1.68	L	SS	●						●	●	●		●
DIQUAT	C	–	S	SS	●								●		
DISULFOTON	A	1.14	L	SS	●								●		
DIURON	B	–	S	SS								●	●		
DODECYLBENZENESULFONIC ACID	B	–	L	SS	●		●				●	●	●		●
DURSBAN	B	–	–	SS	●								●		
ENDOSULFAN	A	–	S	SS	●								●		
ENDRIN	A	–	S	IS	●								●		
ETHION	A	1.22	L	SS	●							●	●		
ETHYLBENZENE	C	0.958	L	INF	●						●	●	●		●
ETHYLENEDIAMINE	C	0.86	L	SF	●						●	●	●		●
EDTA	D	–	S	IS	●						●		●		●
FERRIC AMMONIUM CITRATE	C	–	S	P	●	●	●			●					
FERRIC AMMONIUM OXALATE	C	–	S	P	●	●				●					
FERRIC CHLORIDE	C	2.89	S	P	●	●				●					
FERRIC FLUORIDE	C	3.52	S	P	●	●	●			●					
FERRIC NITRATE	C	1.68	S	P	●	●				●					
FERRIC SULFATE	C	2.0	S	P	●	●				●					

APPENDIX D: HAZARDOUS SUBSTANCE/COUNTERMEASURE MATRIX (Cont.)

MATERIAL	EPA CATEGORY	DENSITY	PHYSICAL FORM	P/C/D CATEGORY	MASS TRANSFER MEDIA			NEUTRALIZING AGENT		PRECIPITATING AGENT	BIOLOGICAL TREATMENT AGENT	GELLING AGENT	ABSORBING AGENT	OXIDIZING AGENT	DISPERSING AGENT
					ACTIVATED CARBON	CATIONIC RESIN	ANIONIC RESIN	ACID	BASE						
FERROUS AMMONIUM SULFATE	C	1.87	S	P	●	●	●			●					
FERROUS CHLORIDE	C	1.93	S	P	●	●				●					
FERROUS SULFATE	C	1.899	S	P	●	●				●					
FORMALDEHYDE	C	0.815	L	M	●		●				●	●	●		●
FORMIC ACID	C	1.22	L	M	●				●		●	●	●		●
FUMARIC ACID	D	1.635	L	SS	●				●		●	●	●		●
FURFURAL	C	1.15	L	SS	●						●	●	●		●
GUTHION	A	1.44	L	IS	●							●	●		
HEPTACHLOR	A	1.58	S	IS	●								●		
HYDROCHLORIC ACID	D	1.00	L	SS	●		●		●			●	●		
HYDROFLUORIC ACID	D	1.15	L	M	●		●		●			●	●		
HYDROGEN CYANIDE	A	0.70	L/G	M	●		●		●			●	●	●	
HYDROXYLAMINE	D	1.23	S	SS	●								●		
ISOPRENE	C	0.681	L	IVF	●						●	●	●		●
ISOPROPANOLAMINE DODECYL-BENZENESULFONATE	B	0.90	L	SS	●						●	●	●		●
KELTHANE	C	–	–	IS	●								●		
LEAD ACETATE	D	2.25	S	P	●	●	●			●					
LEAD ARSENATE	D	7.8	S	IS	●	●	●			●					
LEAD CHLORIDE	D	5.85	S	P	●	●				●					
LEAD FLUBORATE	D	–	S	P	●	●	●			●					
LEAD FLUORIDE	C	8.2	S	IS	●	●	●			●					
LEAD IODIDE	D	6.16	S	IS	●	●	●			●					
LEAD NITRATE	D	4.53	S	P	●	●	●			●					
LEAD STERATE	D	1.4	S	P	●	●				●					
LEAD SULFATE	D	6.2	S	IS	●	●				●					
LEAD SULFIDE	C	7.1	S	IS	●	●	●			●				●	
LEAD TETRAACETATE	D	2.23	S	P	●	●				●					
LEAD THIOCYANATE	D	3.8	S	IS	●	●				●					
LEAD THIOSULFATE	D	5.18	S	IS	●	●				●					
LEAD TUNGSTATE	D	8.24	S	IS	●	●	●			●					
LINDANE	A	1.87	S	SS	●								●		
LITHIUM BICHROMATE	D	2.34	S	SM	●	●	●			●					
LITHIUM CHROMATE	D	–	S	SM	●	●	●			●					
MALATHION	A	1.23	L	SS								●	●		
MALEIC ACID	D	1.59	S	SS	●				●		●		●		●
MALEIC ANHYDRIDE	D	0.934	S	SF	●				●		●		●		●

APPENDIX D: HAZARDOUS SUBSTANCE/COUNTERMEASURE MATRIX (Cont.)

MATERIAL	EPA CATEGORY	DENSITY	PHYSICAL FORM	P/C/D CATEGORY	MASS TRANSFER MEDIA: ACTIVATED CARBON	MASS TRANSFER MEDIA: CATIONIC RESIN	MASS TRANSFER MEDIA: ANIONIC RESIN	NEUTRALIZING AGENT: ACID	NEUTRALIZING AGENT: BASE	PRECIPITATING AGENT	BIOLOGICAL TREATMENT AGENT	GELLING AGENT	ABSORBING AGENT	OXIDIZING AGENT	DISPERSING AGENT
MERCURIC ACETATE	A	3.25	S	P	●	●				●			●		
MERCURIC CYANIDE	A	4.09	S	P	●	●	●			●			●	●	
MERCURIC NITRATE	A	4.3	S	P	●	●				●			●		
MERCURIC SULFATE	A	6.47	S	P	●	●				●			●		
MERCURIC THIOCYANATE	A	–	S	IS	●	●	●			●			●		
MERCUROUS NITRATE	A	4.79	S	P	●	●				●			●		
METHOXYCHLOR	A	1.41	S	IS	●								●		
METHYL MERCAPTAN	B	0.87	L/G	INF	●							●	●		●
METHYL METHACRYLATE	D	0.936	L	INF	●							●	●		●
METHYL PARATION	B	1.358	L	IS	●							●	●		
MEVINPHOS	A	–	L	M	●							●	●		
MONOETHYLAMINE	C	1.01	–	M	●								●		●
MONOMETHYLAMINE	C	–	–	SF	●								●		●
NALED	A	–	S/L	IS	●							●	●		
NAPTHALENE	B	1.162	S	IS	●								●		
NAPTHENIC ACID	A	1.4	S	SS	●							●	●		
NICKEL AMMONIUM SULFATE	D	1.92	S	P	●	●				●					
NICKEL CHLORIDE	D	3.55	S	P	●	●				●					
NICKEL FORMATE	C	2.15	S	P	●	●				●					
NICKEL HYDROXIDE	C	4.36	S	IS	●	●				●					
NICKEL NITRATE	D	2.05	S	P	●	●				●					
NICKEL SUFLATE	D	1.948	S	P	●	●				●					
NITRIC ACID	C	1.502	L	M	●				●			●			
NITROBENZENE	D	1.19	L	SS	●							●	●		
NITROGEN DIOXIDE	C	1.448	L/G	M	●										
NITROPHENOL	B	1.4	L	SS	●						●	●	●		●
PARAFORMALDEHYDE	C	1.46	S	SS	●						●		●		●
PARATHION	A	1.26	L	IS	●							●	●		
PENTACHLOROPHENOL	A	1.978	S	IS	●							●	●		
PHENOL	B	1.071	S	SS	●		●				●	●	●		
PHOSGENE	D	1.392	G/L	SS	●								●		●
PHOSPHORIC ACID	D	1.834	L	M	●				●			●	●		
PHOSPHOROUS	A	1.8 - 2.7	S	IS											
PHOSPHOROUS OXYCHLORIDE	D	1.67	L	SS	●	●						●			
PHOSPHOROUS PENTASULFIDE	C	2.03	S	SS	●										
PHOSPHOROUS TRICHLORIDE	D	1.574	S	SS	●	●	●								
POLYCHLORINATED BIPHENYLS	A	–	S	IS									●		

APPENDIX D: HAZARDOUS SUBSTANCE/COUNTERMEASURE MATRIX (Cont.)

MATERIAL	EPA CATE-GORY	DENSITY	PHYSICAL FORM	P/C/D CATE-GORY	MASS TRANSFER MEDIA			NEUTRALIZING AGENT		PRECIPI-TATING AGENT	BIOLOGICAL TREATMENT AGENT	GELLING AGENT	ABSORBING AGENT	OXIDIZING AGENT	DISPERSING AGENT
					ACTIVA-TED CARBON	CATIONIC RESIN	ANIONIC RESIN	ACID	BASE						
POTASSIUM ARSENATE	C	2.87	S	P	●		●								
POTASSIUM ARSENITE	C	–	S	P	●		●								
POTASSIUM BICHROMATE	D	2.68	S	SS	●		●								
POTASSIUM CHROMATE	D	2.73	S	SS	●		●								
POTASSIUM CYANIDE	A	1.52	S	SS	●		●							●	
POTASSIUM HYDROXIDE	C	2.04	S	SM	●			●							
POTASSIUM PERMANGANATE	B	2.7	S	SS	●		●								
PROPRIONIC ACID	D	0.993	L	M	●				●		●	●	●		●
PROPRIONIC ANHYDRIDE	D	1.013	L	M	●				●		●	●	●		●
PROPYL ALCOHOL	D	0.8	L	M	●						●	●	●		●
PYRETHRINS	C	–	L	SS								●	●		
QUINOLINE	A	1.09	L	SS	●							●	●		●
RESORCINOL	B	1.27	S	SS	●						●		●		
SELENIUM OXIDE	C	3.954	S	SS	●	●				●					
SODIUM	C	0.971	S	SS											
SODIUM ARSENATE	C	1.76	S	SS	●		●								
SODIUM ARSENITE	C	1.87	S	SS	●		●								
SODIUM BICHROMATE	D	2.52	S	SM	●	●									
SODIUM BIFLUORIDE	D	2.08	S	SS	●		●			●					
SODIUM BISULFITE	D	1.48	S	SS	●		●							●	
SODIUM CHROMATE	D	1.483	S	SS	●		●								
SODIUM CYANIDE	A	1.48	S	SS	●		●							●	
SODIUM DODECYLBENZENE-SULFONATE	B	–	S	SS	●		●				●		●		●
SODIUM FLUORIDE	D	2.78	S	SS	●		●			●					
SODIUM HYDROSULFIDE	D		S	SS	●		●						●		
SODIUM HYDROXIDE	C	2.13	L	SS	●			●				●			
SODIUM HYPOCHLORITE	A	–	S	SM	●		●								
SODIUM METHYLATE	C	2.4	S	SS	●		●				●		●		●
SODIUM NITRITE	B	2.17	S	SS	●										
SODIUM PHOSPHATE MONOBASIC	D	2.04	S	SS	●										
SODIUM PHOSPHATE DIBASIC	D	2.06	S	SM	●										
SODIUM PHOSPHATE TRIBASIC	D	1.5	S	SS											
SODIUM SELENITE	C	1.63	S	SS			●								
SODIUM SULFIDE	C	1.856	S	SS	●		●			●				●	
STANNOUS FLUORIDE	D	2.79	S	SS		●	●			●					
STRONTIUM CHROMATE	D	–	S	IS	●	●	●			●					

APPENDIX D: HAZARDOUS SUBSTANCE/COUNTERMEASURE MATRIX (Cont.)

MATERIAL	EPA CATEGORY	DENSITY	PHYSICAL FORM	P/C/D CATEGORY	MASS TRANSFER MEDIA: ACTIVATED CARBON	MASS TRANSFER MEDIA: CATIONIC RESIN	MASS TRANSFER MEDIA: ANIONIC RESIN	NEUTRALIZING AGENT: ACID	NEUTRALIZING AGENT: BASE	PRECIPITATING AGENT	BIOLOGICAL TREATMENT AGENT	GELLING AGENT	ABSORBING AGENT	OXIDIZING AGENT	DISPERSING AGENT
STRYCHNINE	C	1.36	S	SS	●								●		
STYRENE	C	0.909	L	INF	●							●	●		●
SULFURIC ACID	C	1.834	L	M	●				●			●	●		
SULFUR MONOCHLORIDE	D	1.69	S	SS	●				●						
2,4,5-T ACID	A	–	S	IS									●		
2,4,5-T ESTERS	A	–	S	IS									●		
TDE	A	–	S	IS	●								●		
TETRAETHYL LEAD	A	1.659	L	IS	●							●	●		
TETRAETHYL PYROPHOSPHATE	B	1.2	L	M	●							●			
TOLUENE	C	0.86	L	INF	●						●	●	●		●
TOXAPHENE	A	1.66	L	IS	●							●	●		
TRICHLORFON	B	1.73	S	SS	●								●		
TRICHLOROPHENOL	A	1.1	L	IS	●							●	●		
TRIETHANOLAMINE DODECYL-BENZENESULFONATE	B	–	L	SS	●							●	●		
TRIETHYLAMINE	C	1.13	L	SF	●						●	●	●		●
TRIMETHYLAMINE	C	0.66	L	SF	●						●	●	●		●
URANIUM PEROXIDE	D	2.5	S	IS	●	●				●					
URANYL ACETATE	D	2.89	S	P	●	●				●					
URANYL NITRATE	D	2.80	S	P	●	●				●					
URANYL SULFATE	D	3.28	S	P	●	●				●					
VANADIUM PENTOXIDE	C	3.36	S	P	●	●				●					
VANADYL SUFATE	C	–	S	P	●	●				●					
VINYL ACETATE	C	0.94	S	SF	●						●	●	●		●
XYLENE	C	0.86	L	INF	●							●	●		●
XYLENOL	C	1.02	L	SS	●							●	●		
ZECTRAN	C	–	–	SS	●								●		
ZINC ACETATE	C	1.735	S	P	●	●				●					
ZINC AMMONIUM CHLORIDE	C	1.80	S	P	●	●	●			●					
ZINC BICHROMATE	C	–	S	P	●	●	●			●					
ZINC BORATE	C	3.64	S	P	●	●	●			●					
ZINC BROMIDE	C	4.22	S	P	●	●	●			●					
ZINC CARBONATE	C	4.42	S	IS	●	●				●					
ZINC CHLORIDE	C	2.907	S	P	●	●				●					
ZINC CYANIDE	A	1.85	S	IS	●	●	●			●				●	
ZINC FLURODIE	C	4.84	S	P	●	●	●			●					
ZINC FORMATE	C	2.21	S	P	●	●				●					

APPENDIX D: HAZARDOUS SUBSTANCE/COUNTERMEASURE MATRIX (Cont.)

MATERIAL	EPA CATEGORY	DENSITY	PHYSICAL FORM	P/C/D CATEGORY	MASS TRANSFER MEDIA			NEUTRALIZING AGENT		PRECIPITATING AGENT	BIOLOGICAL TREATMENT AGENT	GELLING AGENT	ABSORBING AGENT	OXIDIZING AGENT	DISPERSING AGENT
					ACTIVATED CARBON	CATIONIC RESIN	ANIONIC RESIN	ACID	BASE						
ZINC HYDROSULFITE	C	–	S	P	●	●	●			●				●	
ZINC NITRATE	C	2.07	S	P	●	●				●					
ZINC PHENOLSULFONATE	C	–	S	P	●	●	●			●					
ZINC PHOSPHIDE	C	4.55	S	IS	●	●	●			●					
ZINC POTASSIUM CHROMATE	C	–	S	IS	●	●	●			●					
ZINC SILICOFLUORIDE	C	2.1	S	P	●	●	●			●					
ZINC SULFATE	C	3.54	S	P	●	●				●					
ZINC SULFATE MONOHYDRATE	C	3.28	S	P	●	●				●					
ZIRCONIUM ACETATE	D	–	S	P	●	●				●					
ZIRCONIUM NITRATE	D	–	S	P	●	●				●					
ZIRCONIUM OXYCHLORIDE	D	–	S	P	●	●				●					
ZIRCONIUM POTASSIUM FLUORIDE	D	–	S	P	●	●				●					
ZIRCONIUM SULFATE	D	3.22	S	P	●	●				●					
ZIRCONIUM TETRACHLORIDE	D	2.8	S	P	●	●				●					

APPENDIX D: HAZARDOUS SUBSTANCE/COUNTERMEASURE MATRIX (Cont.)