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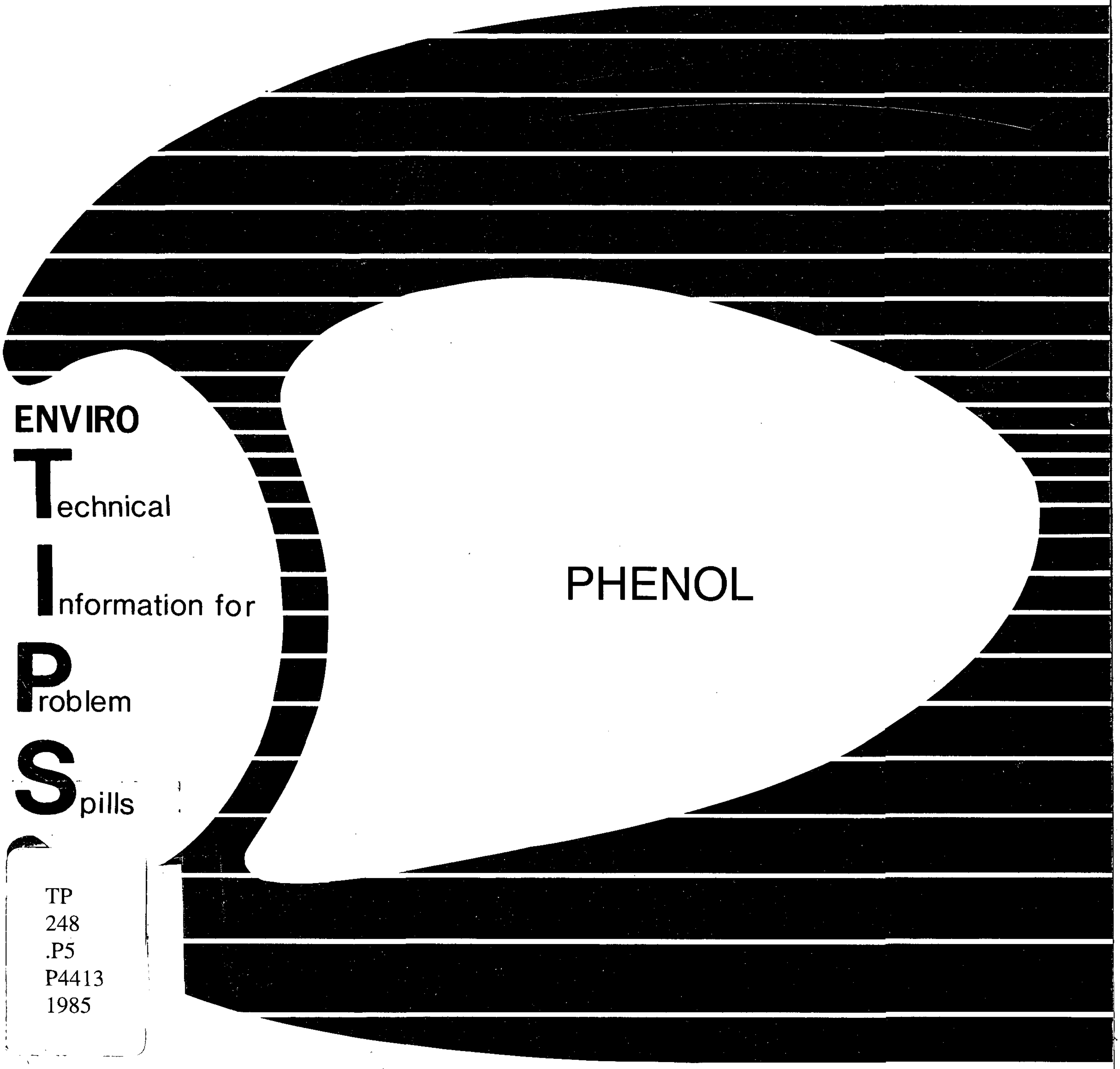

ENVIRO

Technical
Information for
Problem
Spills

PHENOL

June 1985

Canada

ENVIRONMENTAL AND TECHNICAL INFORMATION FOR PROBLEM SPILLS MANUALS

The Environmental and Technical Information for Problem Spills (EnviroTIPS) manuals provide detailed information on chemical substances. This information is intended to assist the reader in designing countermeasures for spills and to assess their impact on the environment. The report has been reviewed by the Technical Services Branch, Environmental Protection Service, and approved for publication. Approval does not signify that the contents reflect the views and policies of the Environmental Protection Service. Mention of trade names or commercial products does not constitute endorsement for use.

EnviroTIPS manuals are available from:

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Ottawa, Ontario
CANADA
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PHENOL

ENVIRONMENTAL AND TECHNICAL INFORMATION FOR PROBLEM SPILLS

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Environmental Protection Service
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FOREWORD

The Environmental and Technical Information for Problem Spills (EnvrioTIPS) manuals were initiated in 1981 to provide comprehensive information on chemicals that are spilled frequently in Canada. The manuals are intended to be used by spill specialists for designing countermeasures for spills and to assess their effects on the environment. The major focus of EnviroTIPS manuals is environmental. The manuals are not intended to be used by first-response personnel because of the length and technical content; a number of manuals intended for first-response use are available. The information presented in this manual was largely obtained from literature review. Efforts were made, both in compilation and in review, to ensure that the information is as correct as possible. Publication of these data does not signify that they are recommended by the Government of Canada, nor by any other group.

ACKNOWLEDGEMENTS

The final version of this manual was prepared by the staff of the Environmental Protection Service who wrote extensive revisions to the text, drafted illustrations and incorporated all comments and additions.

The level of detail present was made possible by the many individuals, organizations and associations who provided technical data and comments throughout the compilation and subsequent review of and input to this manual. The draft of this manual was prepared under contract to Environment Canada by M.M. Dillon Consulting Engineers and Planners, Concord Scientific Corporation and Waterloo Engineering Limited.

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1 SUMMARY

PHENOL (C_6H_5OH)

White to pink crystals, molten liquid with a tarry or medicinal odour.

SYNONYMS

Carbolic Acid, Hydroxybenzene, Monohydroxybenzene, Benzophenol, Oxybenzene, Phenic Acid, Phenyl Hydrate, Phenyl Hydroxide, Phenylic Acid, Phenylic Alcohol, Acide Carbolique (Fr.)

IDENTIFICATION NUMBERS

UN No. 2312 (molten), 1671 (solid), 2821 (solutions); CAS No. 108-95-2; OHM-TADS No. 7216849; STCC No. 4921220 or 4921210

GRADES & PURITIES

Technical, Solid, or Molten, >98 percent

IMMEDIATE CONCERNS

Fire: Combustible. Poisonous vapour produced.

Human Health: Highly toxic by all routes.

Environmental: Harmful to aquatic life in very low concentrations.

PHYSICAL PROPERTY DATA

State (15°C, 1 atm): solid
Boiling Point: 181.8°C
Melting Point: 40.9°C
Flammability: combustible
Flash Point: 79°C (CC)
Vapour Pressure: 0.05 kPa (20°C)
Density: 1.132 g/cm^3 (25°C), 1.058 g/cm^3 (41°C)

Solubility (in water): 6.7 g/100 mL (16°C)
Behaviour (in water): sinks and dissolves slowly
Behaviour (in air): when heated, flammable vapours will form
Odour Threshold Range: 1-16 ppm

ENVIRONMENTAL CONCERNS

Phenol is toxic to aquatic life, microorganisms and invertebrates at very low concentrations. Degradation in aquatic systems may be fast enough to cause oxygen deficiencies.

HUMAN HEALTH

TLV®: 5 ppm (19 mg/m^3) (skin)

IDLH: 100 ppm

Exposure Effects

Inhalation: Irritation to the nose, throat and respiratory tract. Other effects may include headache, coughing, difficult breathing, vomiting, nausea, diarrhea, pulmonary edema and possibly death.

Contact: Contact of solid, liquid or vapour with the skin will cause irritation and burns. If absorbed, it will cause dizziness, nausea, vomiting, possible dermatitis, gangrene, partial paralysis, convulsion, coma and death. Contact with the eyes will cause irritation, severe burns, conjunctival swelling, corneal problems, and possibly loss of vision.

IMMEDIATE ACTION

Spill Control

Restrict access to spill site. Issue warning "POISON". Call fire department and notify manufacturer. Stop the flow and contain spill, if safe to do so. Avoid contact with the material in any form. Keep contaminated water from entering sewers or watercourses.

Fire Control

Use alcohol foam, dry chemical, carbon dioxide, water spray or fog to extinguish. Cool fire-exposed containers with water.

COUNTERMEASURES

Emergency Control Procedures in/on

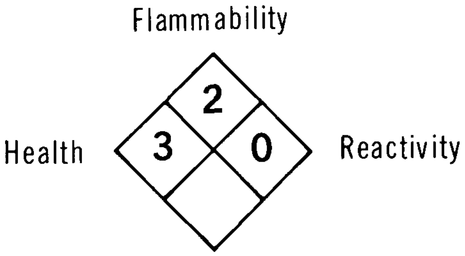
Soil: Construct barriers to contain spill or divert to impermeable holding area. Remove material by manual or mechanical means.

Water: Contain by damming, water diversions, sand bag barriers or natural barriers. If possible, remove contaminated water for treatment. Dredge or vacuum pump contaminated sediments.

NAS HAZARD RATING

Category	Rating
Fire	1
Health	
Vapour Irritant	2
Liquid or Solid Irritant	3
Poison	3
Water Pollution	
Human Toxicity	2
Aquatic Toxicity	3
Aesthetic Effect	3
Reactivity	
Other Chemicals	2
Water	0
Self-reaction	0

NFPA
HAZARD
CLASSIFICATION



2 PHYSICAL AND CHEMICAL DATA

Physical State Properties

Appearance	Colourless to white to light pink solid crystals (Dow MSDS 1878)
Usual shipping states	Liquid: Shipped in the molten state under elevated temperature (USS 1979) Solid: Crystals
Physical state at 15°C, 1 atm	Solid
Freezing point	40.91°C (Kirk-Othmer 1982)
Boiling point	181.84°C (Kirk-Othmer 1982)
Vapour pressure	0.05 kPa (20°C) (Dow MSDS 1978) 0.33 kPa (50°C) (Kirk-Othmer 1982)

Densities

Density	1.132 g/cm^3 (25°C), 1.0576 g/cm^3 (41°C) (Kirk-Othmer 1982)
Specific gravity	1.132 (25°/4°C) (Dow MSDS 1978) 1.0009 (25°/25°C) (1 percent aqueous solution) (Kirk-Othmer 1982)
Vapour density	3.24 (Ullmann 1975)

Fire Properties

Flammability	Yields flammable vapours when heated (NFPA 1978)
Flash point CC	79°C (NFPA 1978)
OC	85°C (Dow MSDS 1978)
Autoignition temperature	715°C (NFPA 1978)
Burning rate	3.5 mm/min (CHRIS 1978)
Lower flammability limit	1.8 percent (v/v) (NFPA 1978) 1.36 percent (v/v) (Ullmann 1975)
Heat of combustion	3053 kJ/mole (25°C) (CRC 1980)
Combustion products	Carbon dioxide and water (CRC 1980)
Behaviour in a fire	Flammable toxic vapours are given off at elevated temperature (MCA 1964)
Electrical ignition hazard	May be ignited by static discharge

Other Properties

Molecular weight of pure substance	94.14 (Kirk Othmer 1982)
Constituent components of typical commercial grade	> 98 percent phenol (Dow MSDS 1978; Kirk-Othmer 1982), remainder water and other organics
Refractive index	1.5509 (21°C) (CRC 1980) 1.5418 (41°C) (Ullmann 1975)
Viscosity	2.47 mPa•s (60°C) (Kirk-Othmer 1982)
Liquid interfacial tension with air	40.9 mN/m (20°C) (CRC 1980)
Hygroscopicity	Hygroscopic (MCA 1964)
Latent heat of fusion	11.5 kJ/mole (at melting point) (Kirk-Othmer 1982)
Latent heat of sublimation	68.7 kJ/mole (25°C) (Lange's Handbook 1979)
Latent heat of vaporization	45.93 kJ/mole (at boiling point) (Kirk-Othmer 1982)
Heat of formation	-165.0 kJ/mole (25°C) (Sussex 1977)
Ionization potential	8.47 eV (Maier 1973)
Heat of solution	-10.9 kJ/mole (20°C) (Perry 1973)
Heat capacity	
constant pressure (Cp)	132.7 J/(mole•°C) (Solid at 22.2°C) 209.0 J/(mole•°C) (Molten at 70-74°C) (Kirk-Othmer 1982) 104.0 J/(mole•°C) (Vapour at 27°C) (Ullmann 1975)
constant volume (Cv)	121.4 J/(mole•°C) (23°) (Kirk-Othmer 1982; CHRIS 1978)
Thermal conductivity	Vapour: 2 x 10^{-4} W/(cm•K) (100°C) (Yaws 1975) Liquid: 1.9 x 10^{-3} W/(cm•K) (40°C) (Yaws 1975)
Critical pressure	6130 kPa (CRC 1980)
Critical temperature	421.1°C (CRC 1980)
Coefficient of thermal expansion	1.090 x 10^{-3}/°C (Solid at 20°C) (Lange's Handbook 1979) 8.8 x 10^{-4}/°C (Liquid at 50°C) (Ullmann 1975)
Saturation concentration	0.77 g/m^3 (20°C), 2.0 g/m^3 (30°C) (Verschueren 1984)
pH of aqueous solution	6.0 (Merck 1976)

Log 10 octanol/water partition coefficient	1.48 (Hansch and Leo 1979)

Solubility

In water	8.2 g/100 mL (20°C) (Verschueren 1984) 6.7 g/100 mL (16°C) (Dow MSDS 1978) Soluble in all proportions above 63.5°C (Kirk-Othmer 1982)
In other common materials	Soluble in acetone, hot benzene, carbon tetrachloride, ethanol, carbon disulphide and chloroform. Very soluble in diethyl ether (CRC 1980)

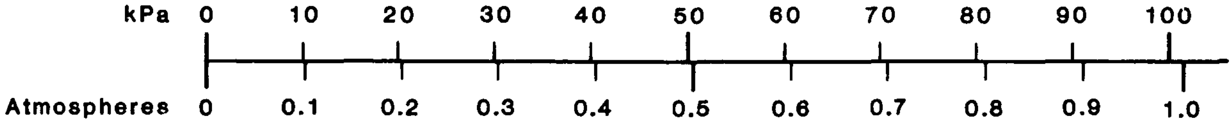
Vapour Volume to Weight Conversion

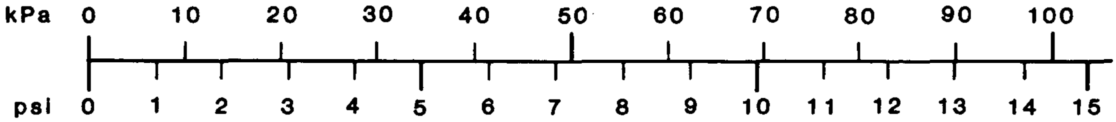
1 ppm = 3.92 mg/m^3
1 mg/m^3 = 0.26 ppm
(Verschueren 1984)

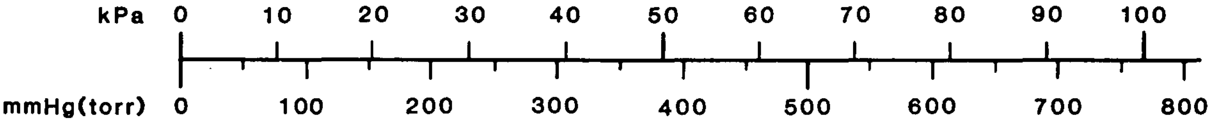
CONVERSION NOMOGRAMS

Temperature

Pressure 1 kPa = 1 000 Pa







Viscosity

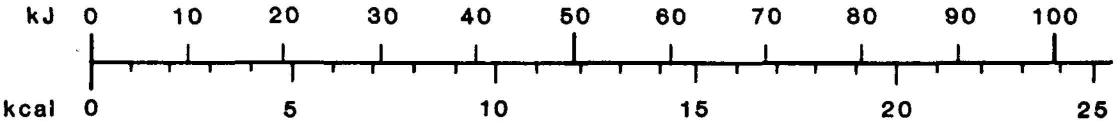
Dynamic 1 Pa·s = 1 000 centipoise (cP)

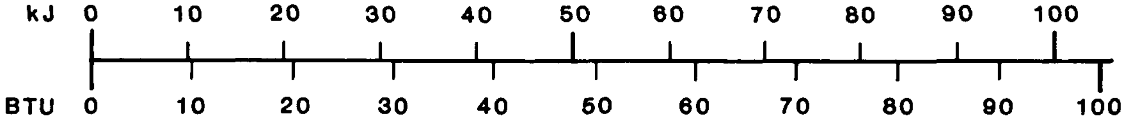
Kinematic 1 m²/s = 1 000 000 centistokes (cSt)

Concentration (in water)

1 ppm ≅ 1 mg/L

Energy (heat) 1 kJ = 1 000 J





Density

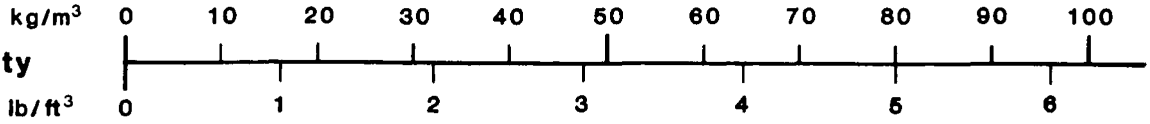


Figure 1

PHENOL

VAPOUR PRESSURE VS TEMPERATURE

Reference: Chem.Eng.1975

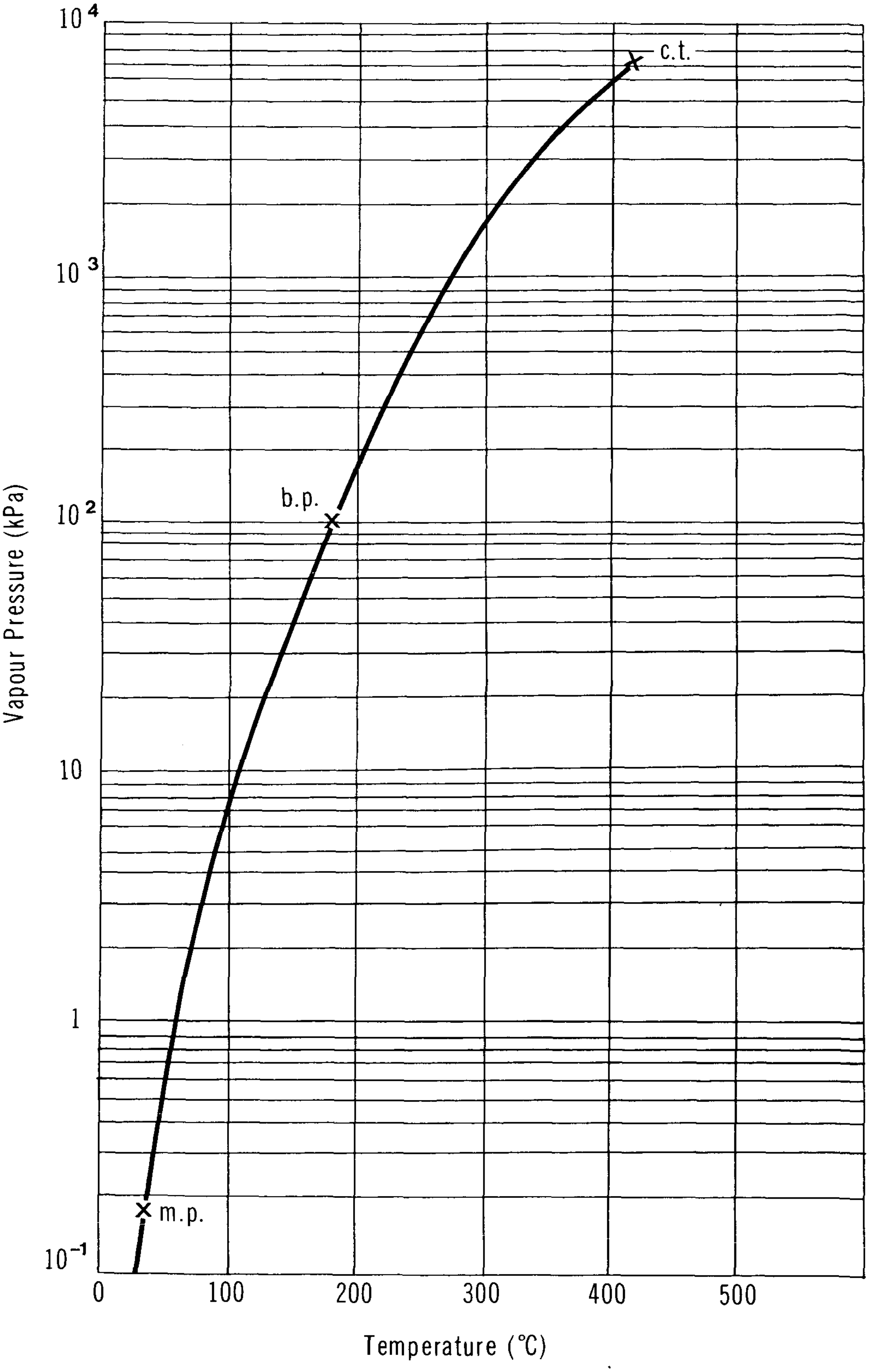


Figure 2

PHENOL

LIQUID DENSITY VS TEMPERATURE

Reference: Chem.Eng.1975

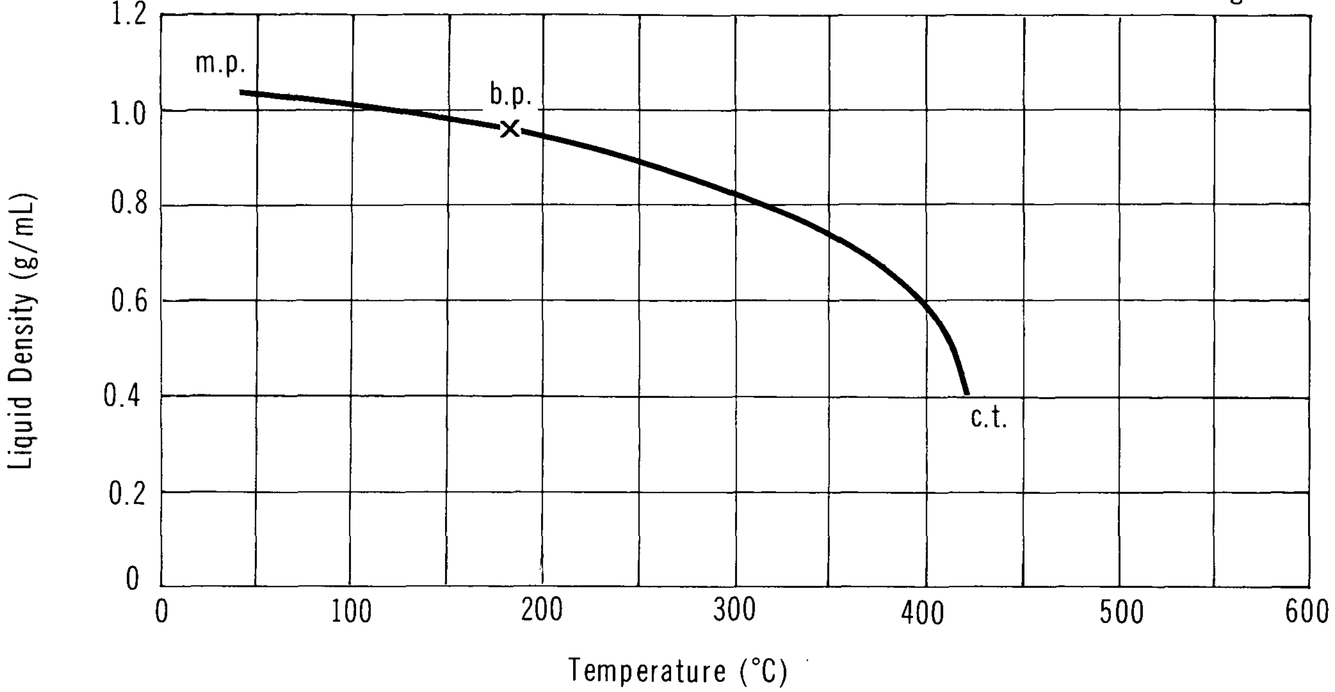


Figure 3

PHENOL

LIQUID VISCOSITY VS TEMPERATURE

Reference: Chem.Eng.1975

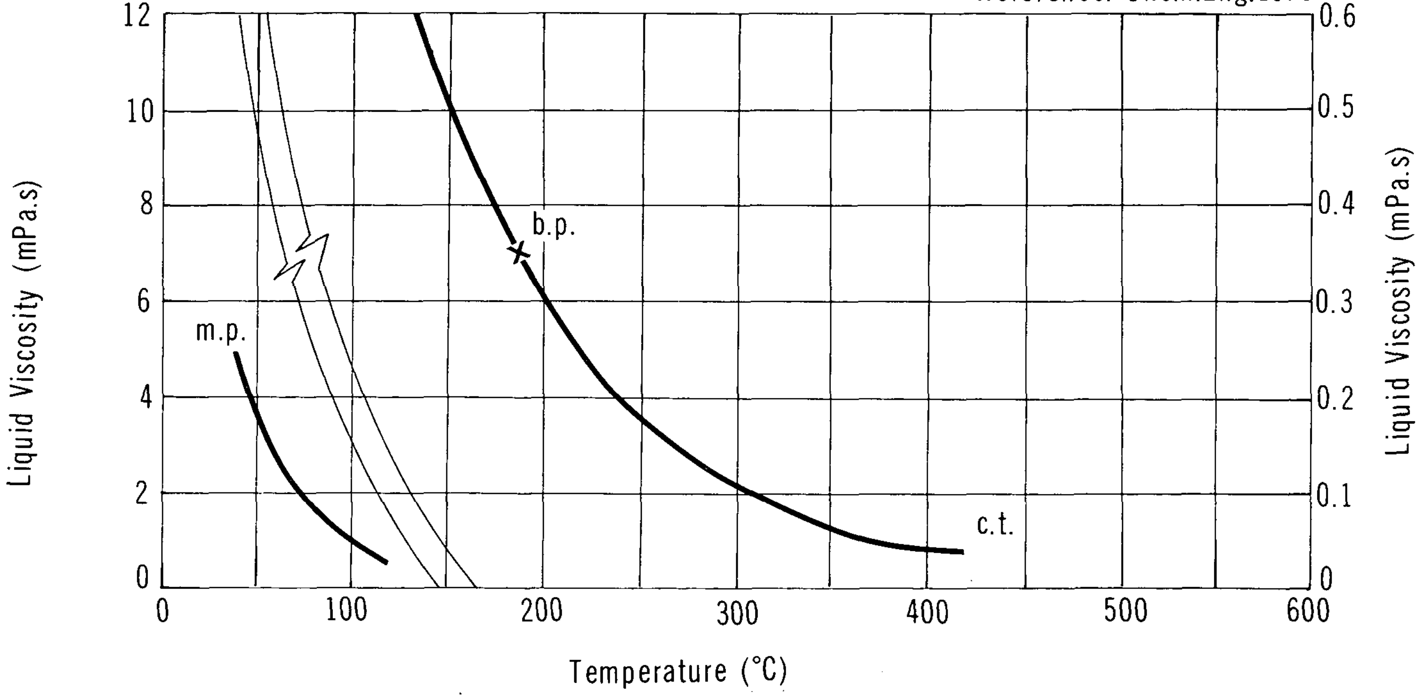


FIGURE 4

PHENOL

LATENT HEAT OF VAPORIZATION

Reference: KIRK-OTHMER 1982

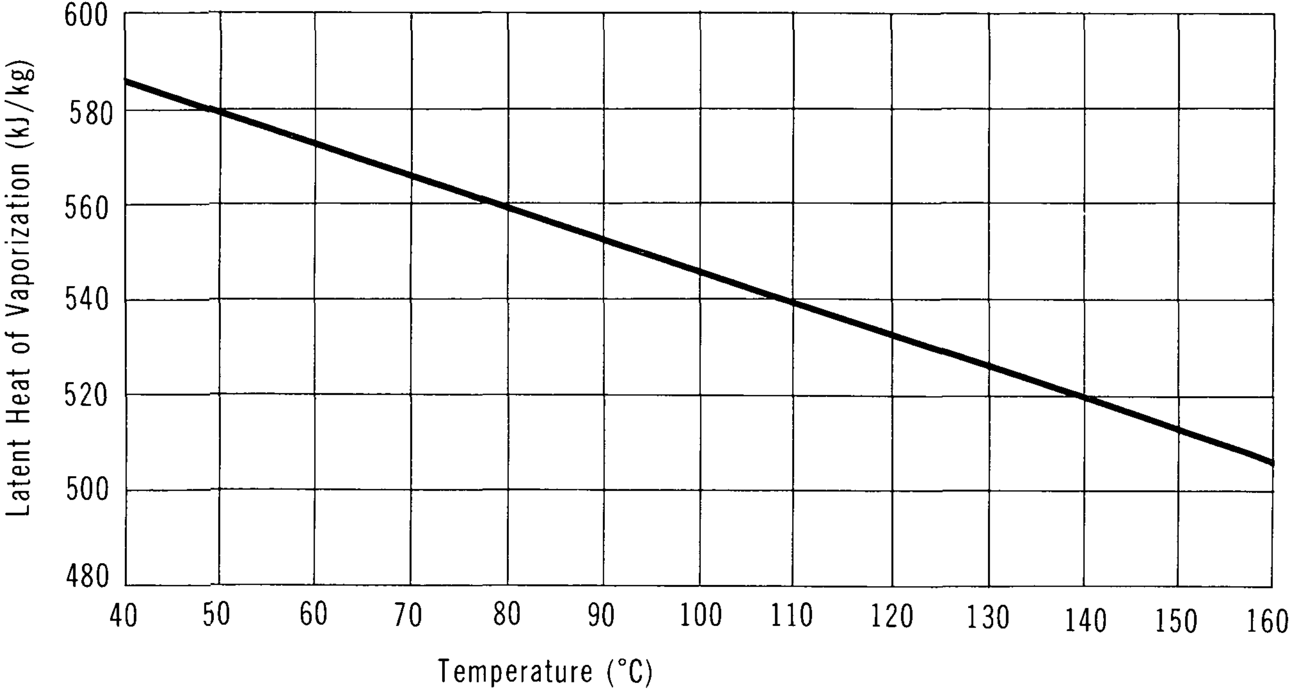
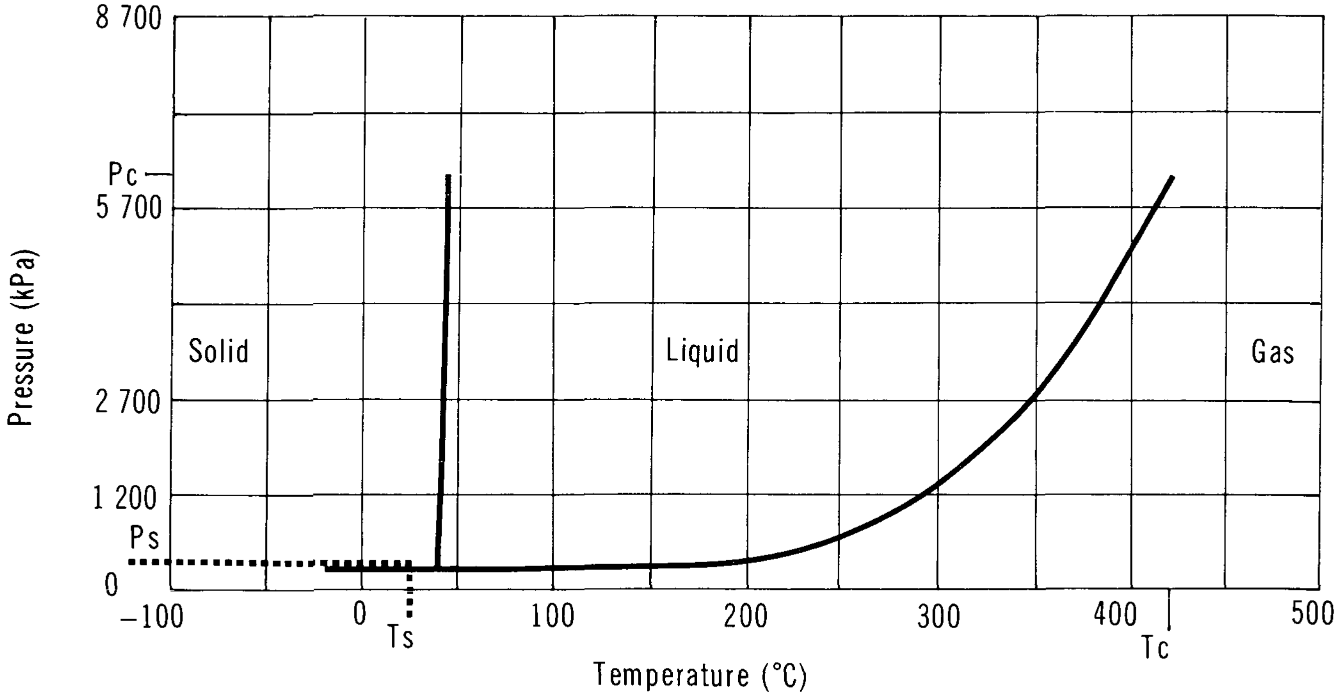


Figure 5

PHENOL

PHASE DIAGRAM



3 COMMERCE AND PRODUCTION

3.1 Grades, Purities

Phenol is available in Canada and is sold either in molten or solid form containing not less than 98 percent phenol (Dow ERIS 1980; Ullmann 1975).

3.2 Domestic Manufacturers (Corpus 1984; Scott 1979)

These are corporate headquarters' addresses and are not intended as spill response contacts:

Dow Chemical Canada Inc.
Box 1012, Modeland Road
Sarnia, Ontario
N7T 7K7
(519) 339-3131

Gulf Canada Ltd.
800 Bay Street
Toronto, Ontario
M5S 1Y8
(416) 924-4141

3.3 Other Suppliers (Corpus 1984; CBG 1980; Scott 1979)

A & K Petro-Chem Industries Ltd.
710 Arrow Road
Weston, Ontario
M9M 2M1
(416) 746-2991

Basile Import/Export Inc.
2695 L'heureux Street
St. Laurent, Quebec
H4K 1H9
(514) 331-0405

Bayer (Canada) Inc.
7600 TransCanada Highway
Pointe-Claire, Quebec
H9R 1C8
(514) 697-5550

Ciscochem Inc.
63 Selby Road
Brampton, Ontario
L6W 1K5
(416) 459-4540

Kingsley & Keith (Canada) Ltd.
310 Victoria Avenue
Montreal, Quebec
H3Z 2M8
(514) 487-1550

Mallinckrodt Canada Inc.
600 Delmar Avenue
Pointe-Claire, Quebec
H9W 1E6
(514) 695-1220

Monsanto Canada Inc.
2000 Argentia Road
Plaza 2, 3rd Floor
Mississauga, Ontario
L5M 2G4
(416) 826-9222

Recochem Inc.
850 Montée de Liesse
Montréal, Québec
H4T 1P4
(514) 341-3550

U.S. Steel International of Canada Ltd.
7 King Street East
Toronto, Ontario
(416) 364-6291

Van Waters & Rogers Ltd.
9800 Van Horne Way
Richmond, British Columbia
V6X 1W5
(604) 273-1441

3.4 Major Transportation Routes

Current Canadian production of phenol is located in Montreal, Quebec. The market area is mainly in Ontario, Quebec and British Columbia, with some amounts transported to Alberta. Since the closing of the Vancouver plant, a large amount of phenol is being imported from the USA.

3.5 Production Levels (Corpus 1984)

Company, Plant Location		Nameplate Capacity kilotonnes/yr (1983)
Dow Chemical Canada, Vancouver, B.C.		32*
Gulf Canada, Montreal, Que.		27
	TOTAL	59
Domestic Production (1983)		34
Imports (1983)		23
	TOTAL SUPPLY	57

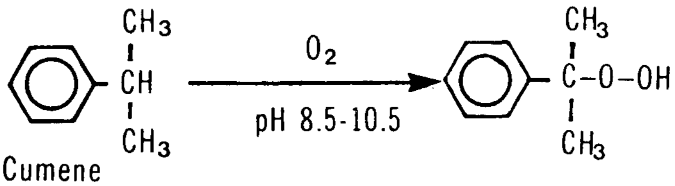
* Plant shut down in 1983

3.6 Manufacture of Phenol (FKC 1975; Kirk-Othmer 1982)

3.6.1 General. Phenol is produced in Canada by two processes: one uses cumene, the other uses toluene as starting material.

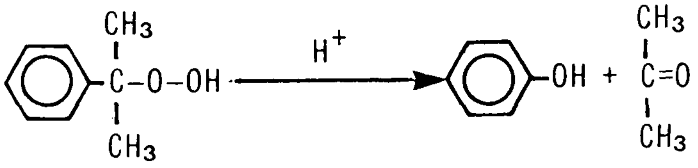
3.6.2 Manufacturing Processes.

3.6.2.1. Cumene process. In this process, cumene (prepared by the alkylation of benzene with propylene) is emulsified in mildly alkaline water and oxidized by an air or oxygen stream. Near atmospheric pressures and temperatures of 70-125°C have been used. The reaction takes place for several hours, until conversion of cumene is about 30 percent:



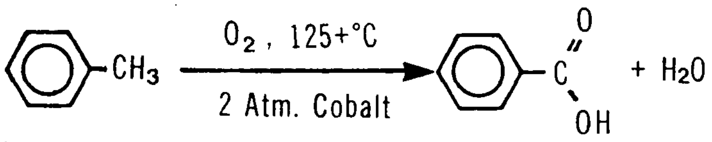
Cumene

The reaction mixture is passed to a cleaving reactor, where it is treated with dilute sulphuric acid at 50-65°C to convert the cumene hydroperoxide to phenol:



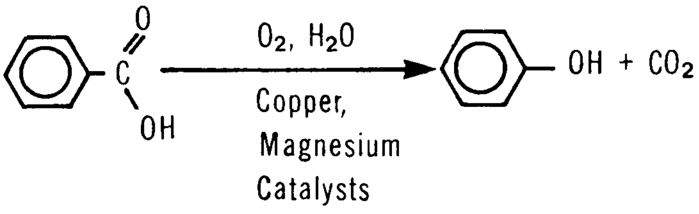
The organic and water layers are decanted and the organic layer is distilled to separate its components. Unconverted cumene is recycled. Phenol yield, based on cumene, is over 90 percent. The major byproduct is acetone (0.6 kg/kg phenol).

3.6.2.2 Toluene process. Toluene oxidation to phenol takes place in two stages. In the first, air is passed through toluene in the presence of a catalyst:



Toluene Benzoic Acid

Benzoic acid is then oxidized by an air-steam stream over catalysts to form phenol:



The phenol is concurrently removed with the air-steam stream (steam distilled), passing into a distillation column which separates water, phenol and benzoic acid. Phenol is subsequently purified by redistillation; benzoic acid is recycled.

3.7 Major Uses in Canada (Corpus 1984)

Phenol is used in the production of phenolic resins, alkylphenols, bisphenol A, and chlorinated phenols. In 1983, 95 percent of domestic demand was used to produce phenolic resins, primarily for plywood and waferboard manufacture.

3.8 **Major Buyers in Canada** (Corpus 1984)

Ashland Chemical, Mississauga, Ont.
Bakelite Thermosets, Belleville, Ont.
Borden Chemical, North Bay, Ont.; Edmonton, Alta.; Vancouver, B.C.; Laval, Que.
Canadian General Electric, Toronto, Ont.
Canadian Occidental (Durez), Fort Erie, Ont.
Cyanamid Canada, St-Jean, Que.
Domtar, Montreal, Que.
Domtar (CDC), Longford Mills, Ont.
Fiberglas Canada, Sarnia, Ont.
Hart Chemical, Guelph, Ont.
Lawter Chemicals, Toronto, Ont.
Reichhold, North Bay, Thunder Bay, Ont.; Ste. Therese, Que.; Port Moody, Kamloops, B.C.
Schenectady Chemicals, Toronto, Ont.
Uniroyal, Elmira, Ont.

4 MATERIAL HANDLING AND COMPATIBILITY

4.1 Containers and Transportation Vessels

4.1.1 Bulk Shipment. Solid and molten phenol are shipped in railway tank cars and tank motor vehicles.

4.1.1.1 Railway tank cars. Railway tank cars used in the transportation of solid and molten phenol are listed in Table 2. Figure 6 shows a 111A60W1 railway tank car. Table 3 indicates railway tank car details associated with this drawing. Cars are equipped for unloading by pump through a bottom outlet furnished with a steam jacket (PC 1982). In addition to bottom unloading, the cars may be unloaded from the top by compressed air, inert gas, or pump (Dow TED 1978). In this case, the molten phenol is withdrawn through an eduction pipe which extends from the bottom of the tank to the top operating platform where it terminates at a blind flange or screw outlet, usually 51 mm (2 in.) or 76 mm (3 in.) in size. Air pressure of 138 kPa (20 psi) is applied through the 25 mm (1 in.) air connection valve (MCA 1964). Top unloading is the preferred method of unloading. Outside heating coils and insulation are required to melt or keep the cargo molten.

4.1.1.2 Tank motor vehicles. Truck motor vehicles or highway tankers are also used to transport solid and molten phenol (MCA 1964). Similar to railway tank cars, these highway tankers are unloaded by pump through a bottom outlet provided with an inner plug valve (MCA 1964). When compressed air is used for unloading, the standpipe, usually extended down over the back of the tanker, is used. Air pressure is not the preferred unloading method (MCA 1964).

Tank motor vehicles are required to conform to the TC 306 specifications (MCA 1964). These tankers are not pressure vessels and are not constructed under the ASME Code. The materials of construction and thickness of material are similar to those required for rail cars. Trucks with 18 000 L (4000 Imp. gal.) stainless steel tanks are generally used (HP 1979). Phenol is not transported under pressure.

4.1.2 Packaging. In addition to bulk shipments, solid and phenol solutions are also transported in drums made from a variety of materials (Table 4) (TDGC 1980). Boxed glass carboys of 50 L (11 Imp. gal.) capacity may also be used for phenol solutions (MCA 1964).

TABLE 2 RAILWAY TANK CAR SPECIFICATIONS

CTC/DOT* Specification Number	Description
111A60W1	Steel fusion-welded tank without dome. Uninsulated or insulated. 2% minimum outage. Gauging device. Test pressure 414 kPa (60 psi).
111A60F1	Steel forge-welded tank without dome. Uninsulated or insulated. 2% minimum outage. Gauging device. Test pressure 414 kPa (60 psi).
111A100W1	Steel fusion-welded tank without dome. Uninsulated or insulated. 2% minimum outage. Gauging device. Bottom outlet or washout optional. Test pressure 690 kPa (100 psi).
111A100W6	Stainless steel fusion-welded tank without dome. Uninsulated or insulated. 2% minimum outage. Gauging device. Safety valve (518 kPa) (75 psi) or safety vent (690 kPa) (100 psi). Bottom outlet or washout optional.
103W	Similar to 111A60W1 but with dome.

*Canadian Transport Commission and Department of Transportation (U.S.)

4.2 Off-loading

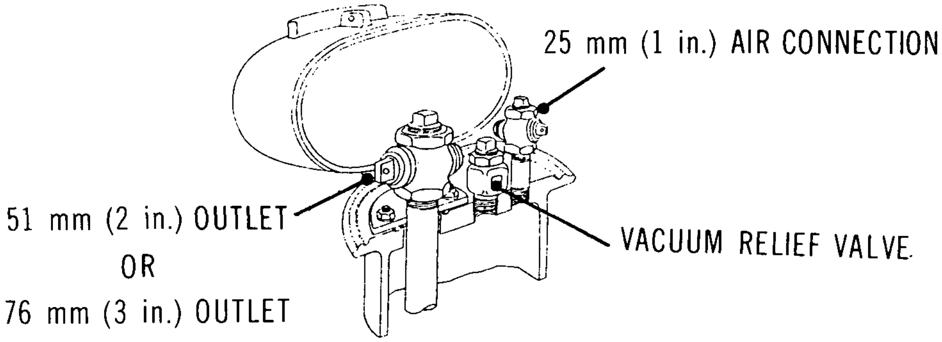
4.2.1 Off-loading Equipment and Procedures for Railway Tank Cars. Prior to off-loading, certain precautions must be taken (MCA 1964; USS 1979):

- For night-time unloading, lights must have an explosion-proof rating.
- Personnel must not enter the car under any circumstances.
- Brakes must be set, wheels chocked, derails employed, and caution placards displayed.
- A safe operating platform must be provided at the unloading point.
- All tools should be spark-resistant.
- Effectively ground the tanker.
- Suitable protective clothing and goggles should be worn.

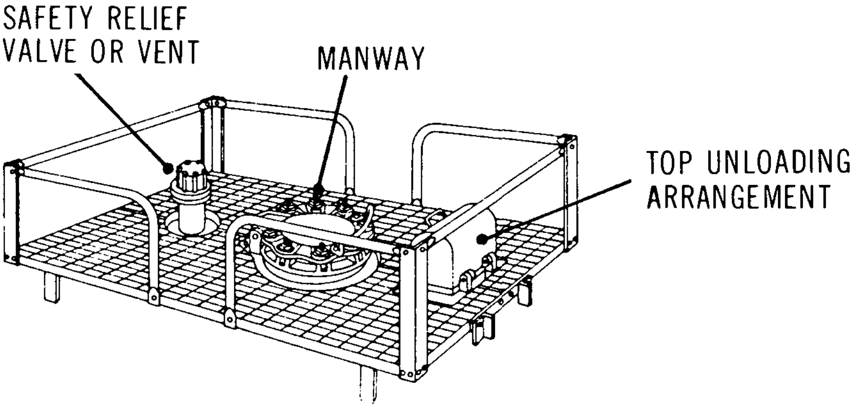
FIGURE 6

RAILWAY TANK CAR - CLASS 111A60W1

(Reference - TCM 1979; RTDCR 1974)



Detail of top unloading arrangement



Detail of loading platform

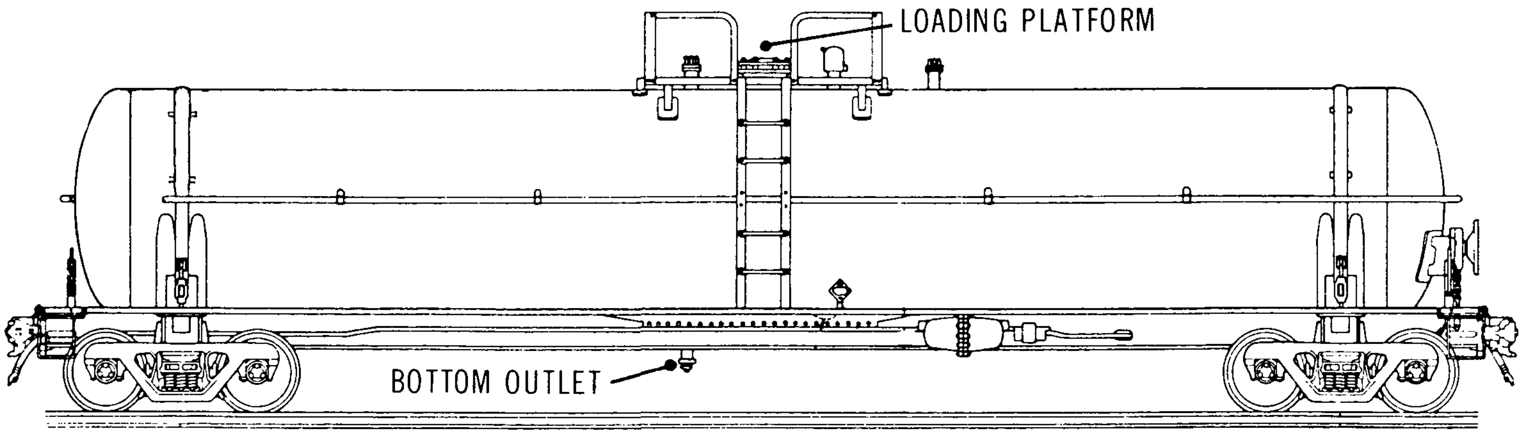


Illustration of tank car layout

TABLE 3 TYPICAL RAILWAY TANK CAR SPECIFICATIONS - CLASS 111A60W1 (TCM 1979; RTDCR 1974)

	Tank Car Size (Imp. Gal.)		
Description	16 700	17 200	20 000
Overall			
Nominal capacity	75 700 L (16 700 gal.)	78 000 L (17 200 gal.)	90 900 L (20 000 gal.)
Car weight - empty	33 900 kg (74 700 lb.)	33 900 kg (74 700 lb.)	38 900 kg (85 800 lb.)
Car weight - max.	119 000 kg (263 000 lb.)	83 500 kg (184 000 lb.)	119 000 kg (263 000 lb.)
Tank			
Material	Steel (Stainless or Lined Carbon)	Steel (Stainless or Lined Carbon)	Steel (Stainless or Lined Carbon)
Thickness	11.1 mm (7/16 in.)	11.1 mm (7/16 in.)	11.1 mm (7/16 in.)
Inside diameter	2.60 m (102 in.)	2.62 m (103 in.)	2.74 (108 in.)
Test pressure	414 kPa (60 psi)	414 kPa (60 psi)	414 kPa (60 psi)
Burst pressure	1640 kPa (240 psi)	1640 kPa (240 psi)	1640 kPa (240 psi)
Approximate Dimensions			
Coupled length	17 m (57 ft.)	17 m (57 ft.)	18 m (60 ft.)
Length over strikers	16 m (53 ft.)	16 m (53 ft.)	17 m (57 ft.)
Length of truck centres	13 m (42 ft.)	13 m (42 ft.)	14 m (45 ft.)
Height to top of grating	4 m (12 ft.)	4 m (12 ft.)	4 m (13 ft.)
Overall height	5 m (15 ft.)	5 m (15 ft.)	5 m (15 ft.)
Overall width (over grabs)	3.2 m (127 in.)	3.2 m (127 in.)	3.2 m (127 in.)
Length of grating	2 to 3 m (8 to 10 ft.)	2 to 3 m (8 to 10 ft.)	2 to 3 m (8 to 10 ft.)
Width of grating	1.5 to 2 m (5 to 6 ft.)	1.5 to 2 m (5 to 6 ft.)	1.5 to 2 m (5 to 6 ft.)
Loading/Unloading Fixtures			
Top Unloading			
Unloading connection	51 mm (2 in.) or 76 mm (3 in.)	51 mm (2 in.) or 76 mm (3 in.)	51 mm (2 in.) or 76 mm (3 in.)
Manway/fill hole	203 to 356 mm (8 to 14 in.)	203 to 356 mm (8 to 14 in.)	203 to 356 mm (8 to 14 in.)
Air connection	25 to 51 mm (1 to 2 in.)	25 to 51 mm (1 to 2 in.)	25 to 51 mm (1 to 2 in.)
Bottom Unloading			
Bottom outlet	102 to 152 mm (4 to 6 in.)	102 to 152 mm (4 to 6 in.)	102 to 152 mm (4 to 6 in.)
Safety Devices	Safety vent or valve		
Dome	None		
Insulation	Optional		

TABLE 4 DRUMS

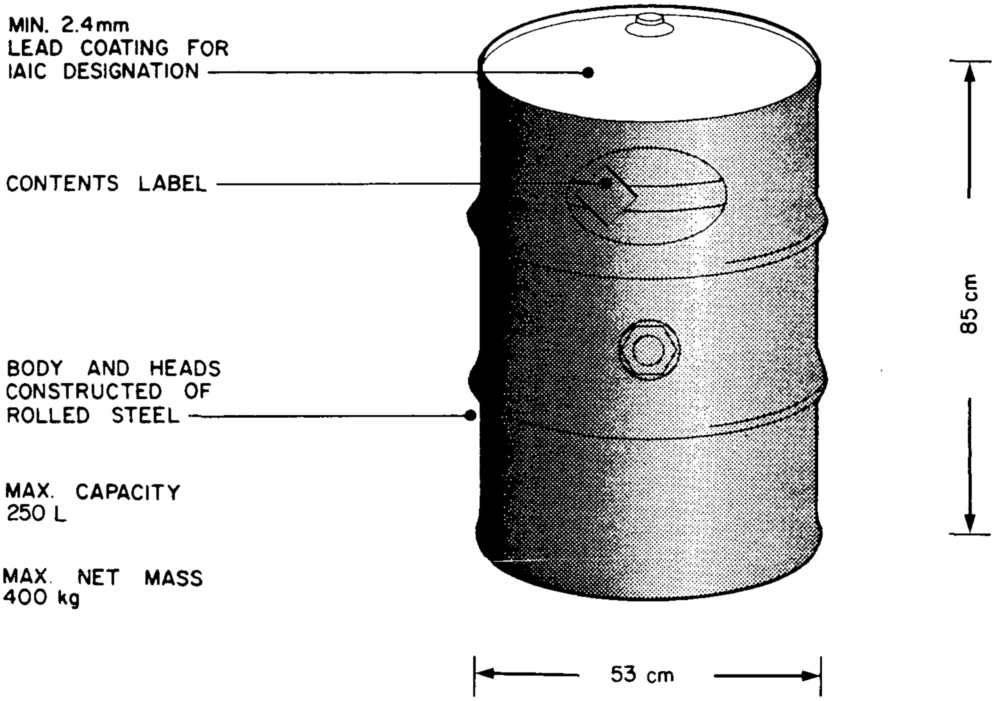
Type of Drum	Designation	Description	Figure No. (if any)
Steel	1A1	Nonremovable head, reusable	7
	1A1A	1A1 with reinforced chime	7
	1A1B	1A1 with welded closure flange	7
	1A1D	1A1 with coating (other than lead)	7
	1A3	Nonremovable head, single use only	7
Steel Drums with inner plastic receptacles	6HA1	Outer steel sheet in the shape of drum. Inner plastic receptacle. Maximum capacity of 225 L (49 gal.)	

FIGURE 7

PHENOL

TYPICAL DRUM CONTAINER

Typical steel drum (Lined for Phenol Service)



Two means of off-loading are used for rail cars, top off-loading and bottom off-loading. Both means are indicated in Figure 8.

Proceed with top off-loading as follows (MCA 1964):

- Ascertain that pressure within the tank has been released and that phenol is completely molten. Heating coils must not raise phenol temperature above 60°C.
- Connect the 51 mm (2 in.) heated unloading line to the discharge outlet.
- Connect the 25 mm (1 in.) air line. Air pressure must be reduced to 207 kPa for unloading. A safety relief valve must be installed in the air line to release at 173 kPa (25 psi).
- After opening the air supply valve, the unloading connection valve can then be opened to unload the car.
- A pump may be used in lieu of compressed air. In this case, the heated suction line is connected to the discharge outlet.
- Once the car is empty, the air supply valve must be closed and the vent valve in the air line opened to allow the line pressure to equalize to atmospheric pressure.
- Reverse the above procedure to close up the car.

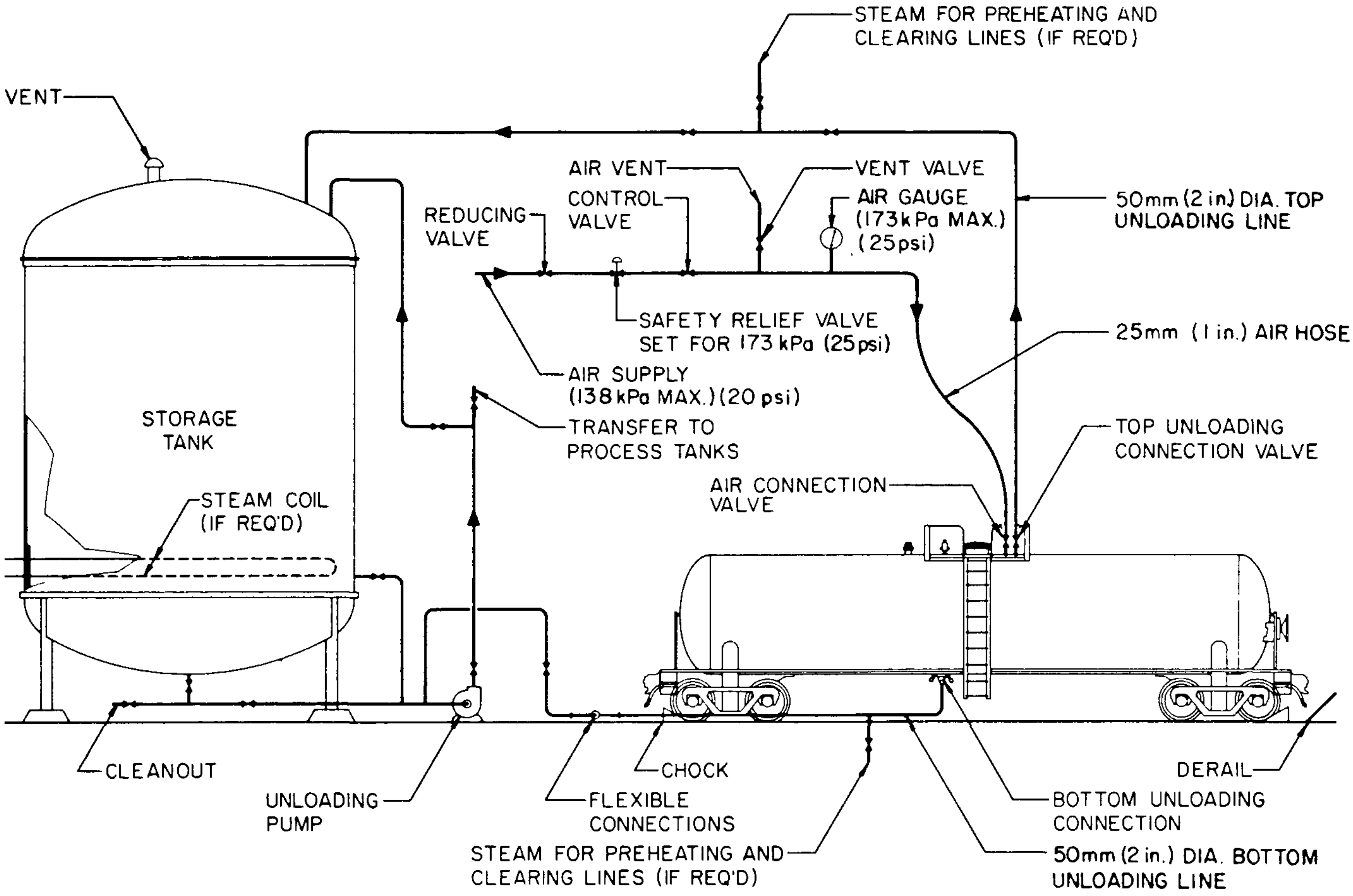
Proceed with bottom off-loading in the following manner using a pump (MCA 1964):

- Ascertain that pressure within the car has been released and that phenol is completely molten.
- In cold weather, apply steam to the bottom unloading connection. Steam coil connection valves (see Figure 8) should also be connected to live steam.
- After connecting the unloading line to the 151 mm (6 in.) bottom outlet, open the inside bottom valve by turning the valve rod handle at the top of the car.
- Off-load the car by pump.
- Reverse the above procedure to close up the car.

4.2.2 Off-loading Equipment and Procedures for Tank Motor Vehicles. The unloading of molten phenol tank trailers is similar to that of tank cars, with the exception that no facilities for steaming are usually provided. The general procedures for tank cars apply equally well to tank trailers.

4.2.3 Specifications and Materials for Off-loading Equipment. The materials of construction for off-loading system components discussed in this section along with specifications refer to those generally used in molten phenol or phenol solution service. It is recognized that other materials may be used for particular applications, as indicated in Table 5. The components of a typical off-loading system that will be discussed include pipes and fittings, flexible connections, valves, gaskets, pumps and storage tanks.

TANK CAR UNLOADING



NOTE:

1 FOR TOP OR BOTTOM UNLOADING METHOD SEE TEXT.

Schedule 40 carbon steel pipes and fittings with glass or nickel linings are recommended (MCA 1964). Flanged joints should be used and these should be welded. Stress relief at the weld will also lengthen the serviceability of the pipe. The pipeline should be tested with water after installation at pressures from 345 to 518 kPa (50 to 75 psi) and all leaks carefully stopped.

The unloading line is usually 51 mm (2 in.) diameter but process pipe may be almost any size. Pipe under 25 mm (1 in.), however, is not recommended (MCA 1964). Outdoor lines must be self-draining, steam-traced and insulated. Use 9 mm (3/8 in.) copper tubing or steel pipe tracing located inside the insulation (MCA 1964).

Specially designed hose of Teflon or cross-linked polyethylene with stainless steel couplings is recommended (Dow TED 1978). Solid pipe with swivel joints may be used for the flexible sections of the unloading line. Either the ball bearing type swivel joint or the simple stuffing box type will give adequate service with proper maintenance.

Stainless steel 316 plug valves or ball valves will serve adequately (JSSV 1979). Asbestos, Teflon or Viton can be used satisfactorily as a gasket material (Dow TED 1978).

Positive displacement or centrifugal pumps with wet end material of 316 stainless steel are recommended for pumping. Pumps should be jacketed for the pumpage to remain liquid (Dow TED 1978).

Welded stainless steel storage tanks are commonly used. A phenol-resistant lining such as baked phenolic resin or nickel is also acceptable. The storage tank should be provided with heating coils to keep the phenol in molten form (HP 1979).

4.3 Compatibility with Materials of Construction. The compatibility of phenol with materials of construction is indicated in Table 5. The unbracketed abbreviations are described in Table 6. The rating system for this report is briefly described below.

Recommended:	This material will perform satisfactorily in the given application.
Conditional:	Material will show deterioration in the given application; however, it may be suitable for intermittent or short-term service.
Not Recommended:	Material will be severely affected in this application and should not be used.

TABLE 5 COMPATIBILITY WITH MATERIALS OF CONSTRUCTION

	Chemical		Material of Construction		
Application	Conc.	Temp.(°C)	Recommended	Conditional	Not Recommended
1. Pipes and Fittings	5% Saturated	24	Chlorinated Polyether PVDC (DCRG 1978)		
		93	PP (DCRG 1978)		
		107	PVDF (DCRG 1978)		
	90%	24	Chlorinated Polyether PVDC (DCRG 1978)		
		79	PVDF PP (DCRG 1978)		
					ABS PVC I PE (MWPP 1978)
	100%	24	Chlorinated Polyether PVDC (DCRG 1978)		
		52	PP (DCRG 1978)		
		79	PVDF (DCRG 1978)		
		23	PE* (DPPED 1967)	PVC I* (DPPED 1967)	ABS PVC II (DPPED 1967)
		49			PE (DPPED 1967)
		60			PVC I (DPPED 1967)
2. Valves			"20" Alloy SS 316 (JSSV 1979)		
3. Pumps	88%		SS CS (Dow TED 1978)		

TABLE 5 COMPATIBILITY WITH MATERIALS OF CONSTRUCTION (Cont'd)

Application	Chemical		Material of Construction		
	Conc.	Temp.(°C)	Recommended	Conditional	Not Recommended
4. Storage			SS CS lined Nickel (Dow TED 1978)		
		up to 60°C	SS CS lined with Glass, Nickel, Baked Resins (HP 1979)	Iron Copper (HP 1979)	
		Over 60°C			Copper Aluminum Lead Zinc (HP 1979)
5. Others	1%	20	uPVC, PE PP, NR NBR, IIR EPDM, CR FPM, CSM (GF)	POM (GF)	
		80	NBR (GF)	PE, PP POM, CR FPM (GF)	uPVC, NR IIR, EPDM CSM (GF)
	Up to 90% Aqueous	45	PE PP (GF)	uPVC FPM (GF)	POM, NR NBR, IIR EPDM, CR CSM (GF)
		100		FPM (GF)	uPVC, PE PP, POM NR, NBR IIR, EPDM CR, CSM (GF)
	Crude	Boiling	SS 302 SS 304 SS 316 SS 410 SS 430 (ASS)		

TABLE 5 COMPATIBILITY WITH MATERIALS OF CONSTRUCTION (Cont'd)

Application	Chemical		Material of Construction		
	Conc.	Temp.(°C)	Recommended	Conditional	Not Recommended
5. Others (Cont'd)	Commercial	20	SS 302 SS 304 SS 316 SS 430 (ASS)	SS 410 (ASS)	
		22	PVC CPVC (TPS 1978)		
		60			PVC (TPS 1978)
		66	PVDF (TPS 1978)		
		82	PP (TPS 1978)		
		85			CPVC (TPS 1978)
			CSM (GPP)		NR, SBR NBR, IIR EPDM (GPP)
	90%-100%	24 to 204	Glass (CDS 1967)		Concrete
	100%	24			Wood (CDS 1967)

*This material has been given a lower rating in a similar application by another reference.

TABLE 6 MATERIALS OF CONSTRUCTION

Abbreviation	Material of Construction
ABS	Acrylonitrile Butadiene Styrene
	Aluminum
	Asbestos
	Chlorinated Polyether
CPVC	Chlorinated Polyvinyl Chloride
CR	Polychloroprene (Neoprene) Rubber
CS	Carbon Steel
CSM	Chlorosulphonated Polyethylene (Hypalon)

TABLE 6 MATERIALS OF CONSTRUCTION (Cont'd)

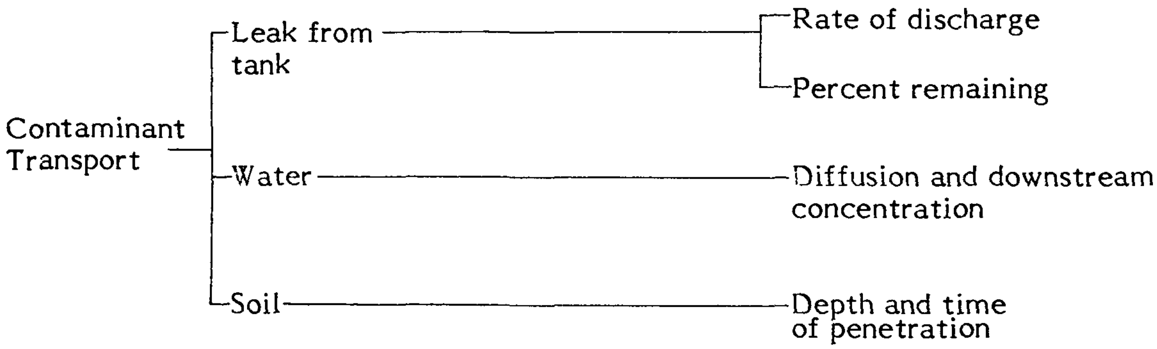
Abbreviation	Material of Construction
	Copper
EPDM	Ethylene Propylene Rubber
FPM	Fluorine Rubber (Viton)
	Glass
	Iron
IIR	Isobutylene/Isoprene (Butyl) Rubber
NBR	Acrylonitrile/Butadiene (Nitrile, Buna N) Rubber
NR	Natural Rubber
	Nickel
PE	Polyethylene
POM	Polyoxymethylene
PP	Polypropylene
	Polytetrafluoroethylene (Teflon)
PVC (followed by grade, if any)	Polyvinyl Chloride
PVDC	Polyvinylidene Chloride
PVDF	Polyvinylidene Fluoride
	Spruce
SBR	Styrene/Butadiene (GR-5, Buna S) Rubber
SS (followed by grade)	Stainless Steel
	"20" Alloy
uPVC	Unplasticized Polyvinyl Chloride

5 CONTAMINANT TRANSPORT

5.1 General Summary

Phenol is transported as a solid, in crystal form, or as a molten liquid in railway cars. Phenol is moderately soluble, and all forms will dissolve in water. When spilled on soil, the molten form will spread on the surface and penetrate into the soil at a rate dependent on the soil type and its water content. Movement of phenol toward the water table may be an environmental concern. Because phenol is essentially nonvolatile, dispersion in air is not a problem.

The following factors are considered for the transport of a phenol spill in water and soil:



It is important to note that, because of the approximate nature of the contaminant transport calculations, the approach adopted throughout has been to use conservative estimates of critical parameters so that predictions are approaching worst case scenarios for each medium. This may require that the assumptions made for each medium be quite different and to some extent inconsistent. As well as producing worst case scenarios, this approach allows comparison of the behaviours of different chemicals under the same assumptions.

5.2 Leak Nomograms

5.2.1 Introduction. Phenol is transported in bulk as a solid or as molten liquid at various concentrations. In molten form, phenol is commonly transported in cylindrical nonpressurized railway tank cars. While the capacities of the tank cars vary widely, one tank car has been chosen throughout the EnviroTIPS series for development of the leak nomograms. It is approximately 2.75 m in diameter and 13.4 m long, with a carrying capacity of about 80 000 L.

If a tank car loaded with a molten solution is punctured on the bottom, all of the contents will drain out by gravity, given that the ambient temperature is high enough and the phenol does not solidify before draining.

The aim of the nomograms is to provide a simple means to obtain the time history of the conditions in the tank car and the venting rate of the liquid. Because of the low volatility of phenol solution and the fact that tank cars are not pressurized, no leak nomograms have been prepared for vapour release from a puncture in the top of the tank.

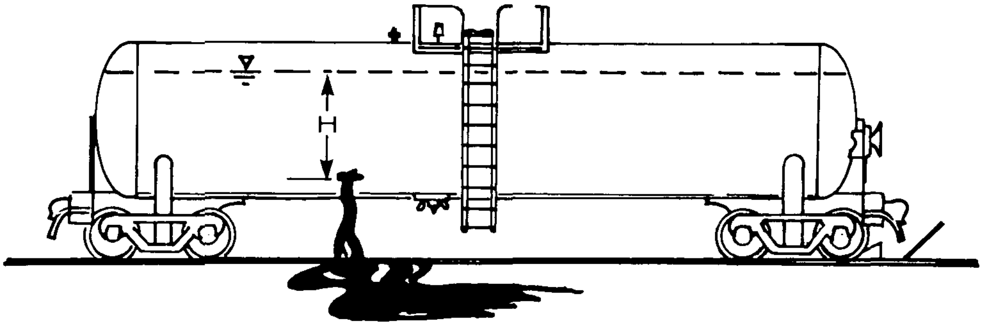


FIGURE 9 TANK CAR WITH PUNCTURE HOLE IN BOTTOM

5.2.2 Nomograms.

5.2.2.1 Figure 10: Percent remaining versus time. Figure 10 provides a means of estimating the percent of liquid remaining in the standard tank car after the time of puncture for a number of different hole diameters. The hole diameter is actually an equivalent diameter and can be applied to a noncircular puncture.

The standard tank car is assumed to be initially full (at t=0) with a volume of about 80 000 L of phenol. The amount remaining at any time (t) is not only a function of the discharge rate over time, but also of the size and shape of the tank car.

5.2.2.2 Figure 11: Discharge rate versus time. Figure 11 provides a means of estimating the instantaneous discharge rate (L/s) at any time (t) after the time of puncture for a number of equivalent hole diameters. The nomogram is only applicable to the standard tank car size with an initial volume of 80 000 L.

FIGURE 10

PHENOL (MOLTEN)

PERCENT REMAINING VS TIME

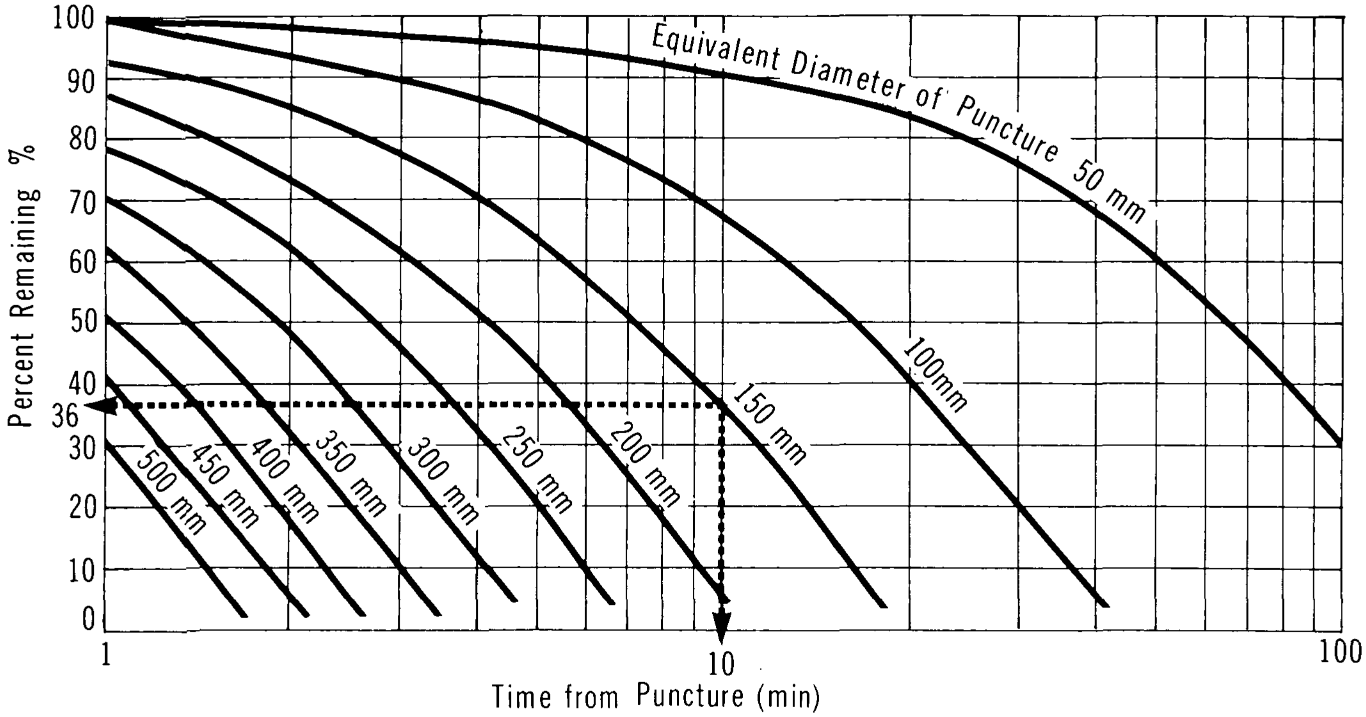
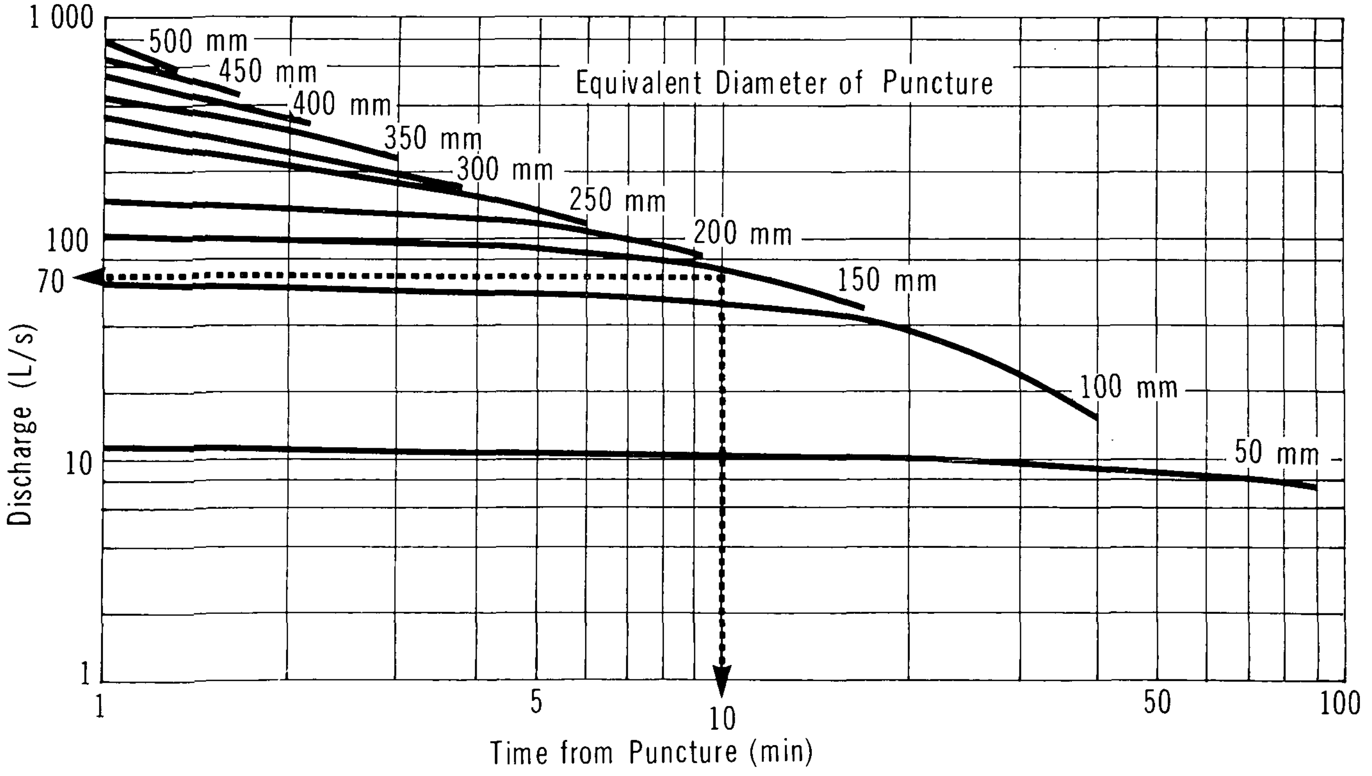


FIGURE 11

PHENOL (MOLTEN)

DISCHARGE RATE VS TIME



5.2.3 Sample Calculations.

i) Problem A

The standard tank car filled with an aqueous solution of phenol has been punctured on the bottom. The equivalent diameter of the hole is 150 mm. What percent of the initial 80 000 L remains after 10 minutes?

Solution to Problem A

- Use Figure 10
- With t = 10 min and d = 150 mm, the amount remaining is about 36 percent or 28 800 L

ii) Problem B

With the same conditions as Problem A, what is the instantaneous discharge rate from the tank 10 minutes after the accident?

Solution to Problem B

- Use Figure 11
- With t = 10 min and d = 150 mm, the instantaneous discharge rate (q) = 70 L/s

5.3 Dispersion in Air

Because phenol is relatively nonvolatile in foreseeable spill circumstances, there is no significant potential for dispersion in air.

5.4 Behaviour in Water

5.4.1 Introduction. When spilled on a water surface, phenol will dissolve. Mixing takes place and the spill is diluted. This mixing can generally be described by classical diffusion equations with one or more diffusion coefficients. In rivers, the principal mixing agent is stream turbulence while in calm water mixing takes place by molecular diffusion.

To estimate the pollutant concentration in a river downstream from a spill, the turbulent diffusion has been modelled. The one-dimensional model uses an idealized rectangular channel section and assumes a uniform concentration of the pollutant throughout the section. Obviously, this applies only to points sufficiently far downstream of the spill where mixing and dilution have distributed the pollutant across the entire river channel. The model is applicable to rivers where the ratio of width to depth is less than 100 (W/d <100) and assumes a Manning's roughness coefficient of 0.03. Details of the model are outlined in the Introduction Manual.

No modelling has been carried out for molecular diffusion in still water. Rather, nomograms have been prepared to define the hazard zone and the average concentration within the hazard zone as a function of spill size, but independent of time.

5.4.2 **Nomograms.** The following nomograms are presented to calculate concentrations in non-tidal rivers and in lakes (still water).

Non-tidal Rivers

Figure 13:	time versus distance for a range of average stream velocities
Figure 14:	hydraulic radius versus channel width for a range of stream depths
Figure 15:	diffusion coefficient versus hydraulic radius for a range of average stream velocities
Figure 16:	alpha* versus diffusion coefficient for various time intervals
Figure 17:	alpha versus delta* for a range of spill sizes
Figure 18:	maximum concentration versus delta for a range of river cross-sectional areas

Lakes or Still Water Bodies

Figure 19:	volume versus radius for the hazard zone for a range of lake depths
Figure 20:	average concentration versus volume for the hazard zone for a range of spill sizes

The flowchart in Figure 12 outlines the steps required to estimate the downstream concentration after a spill and identifies the nomograms to be used. These nomograms (Figures 13 through 20) are described in the following subsections.

5.4.2.1 Nomograms for non-tidal rivers.

Figure 13: Time versus distance. Figure 13 presents a simple relationship between average stream velocity, time, and distance. Using an estimate of average stream velocity (U), the time (t) to reach any point of interest at some distance (X) downstream of the spill can be readily obtained from Figure 13.

Figure 14: Hydraulic radius versus channel width. The model used to estimate downstream pollutant concentration is based on an idealized rectangular channel of width (W) and depth (d). The hydraulic radius (r) for the channel is required in order to estimate the turbulent diffusion coefficient (E). The hydraulic radius (r) is defined as the stream cross-sectional area (A) divided by the wetted perimeter (P). Figure 14 is a nomogram for

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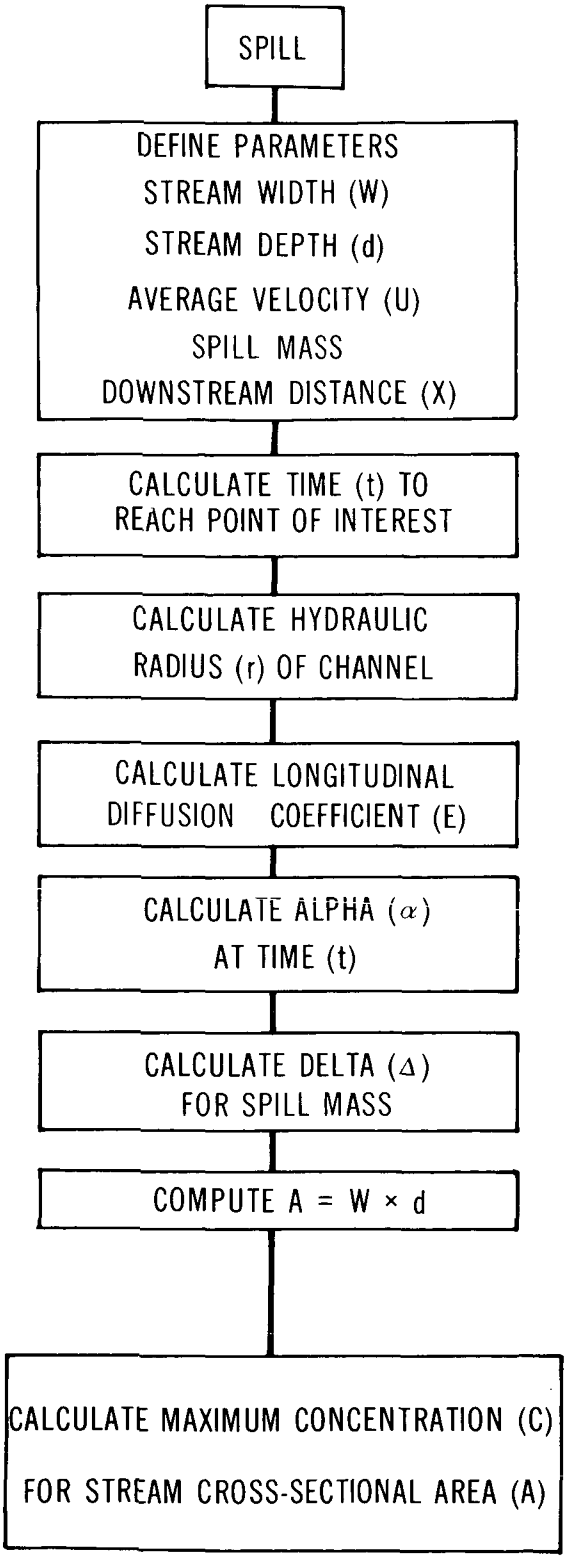
* Alpha and delta are conversion factors only and are of no significance other than to facilitate calculation of downstream concentration.

FIGURE 12

FLOW CHART TO DETERMINE POLLUTANT CONCENTRATION IN NON-TIDAL RIVERS



Step 1: Observed or Estimated

W = __________ m

d = __________ m

U = __________ m/s

MASS = __________ tonnes

X = __________ m

Step 2: Use Figure 13

t = __________ minutes

Step 3: Use Figure 14

r = __________ m

Step 4: Use Figure 15

E = __________ m^2/s

Step 5: Use Figure 16

α = __________

Step 6: Use Figure 17

Δ = __________

Step 7: Compute stream cross-sectional Area (A)

A = W × d _____ m^2

Step 8: Use Figure 18

C = __________ ppm

TIME vs DISTANCE

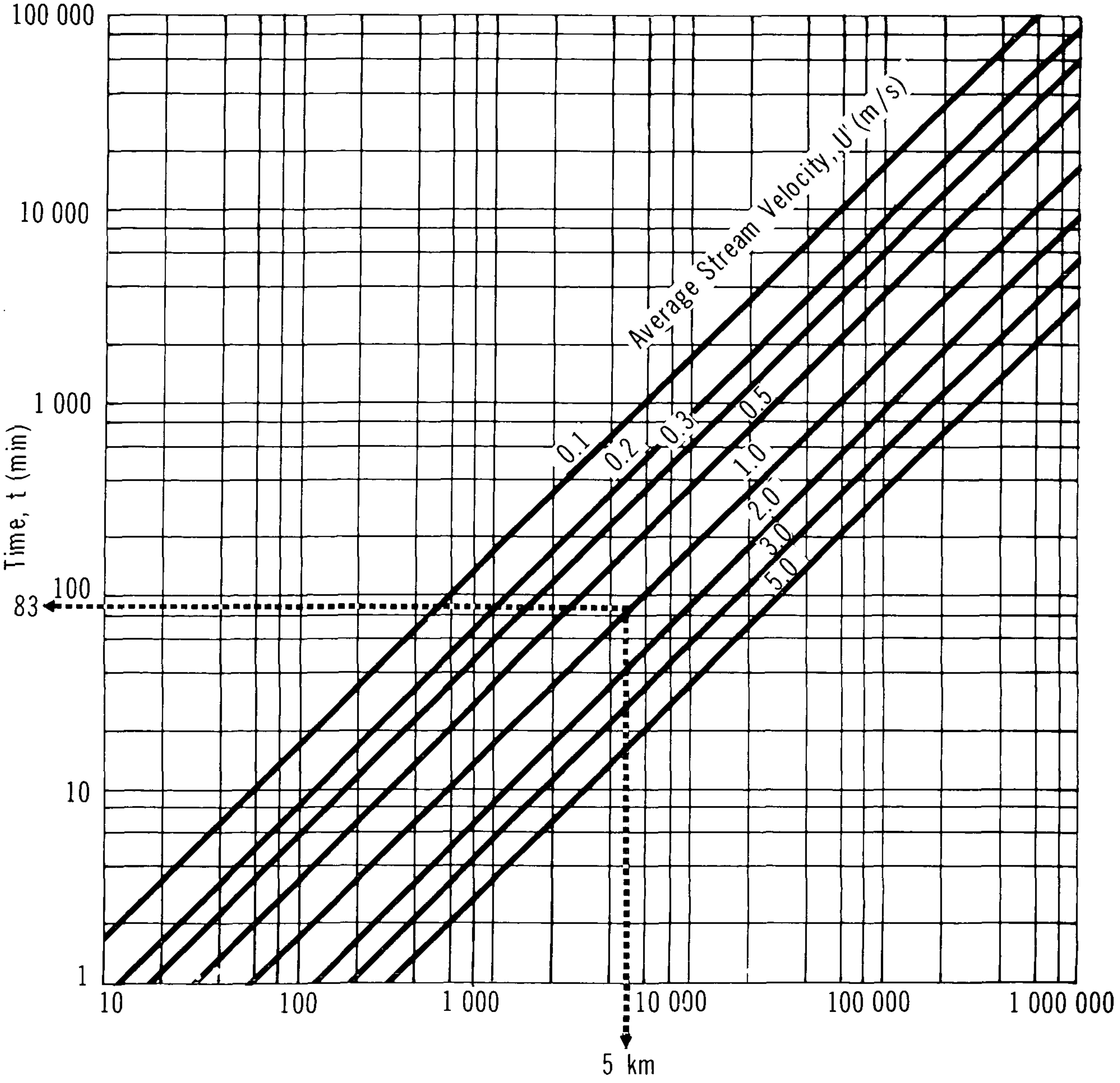
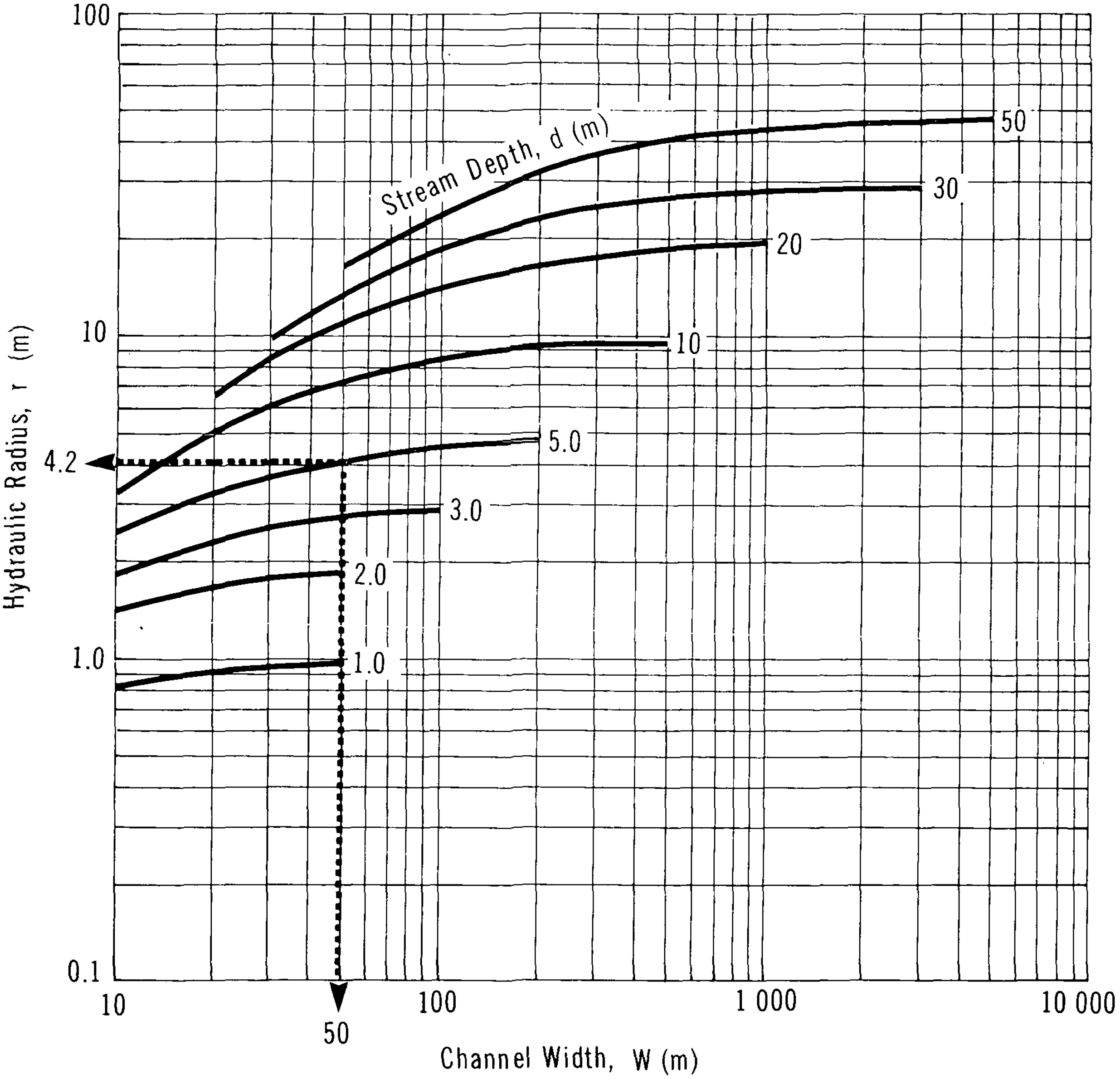


FIGURE 14

HYDRAULIC RADIUS VS CHANNEL WIDTH



computation of the hydraulic radius (r) using the width and depth of the idealized river cross-section.

Figure 15: Diffusion coefficient versus hydraulic radius. Figure 15 permits calculation of the longitudinal diffusion coefficient (E), knowing the hydraulic radius (r) from Figure 14 and the average stream velocity (U).

Figure 16: Alpha versus diffusion coefficient. Figure 16 is used to estimate a conversion factor, alpha (α), which is a function of the diffusion coefficient (E) and the time (t) to reach the point of interest downstream of the spill.

Figure 17: Alpha versus delta. A second conversion factor, delta (Δ), must be estimated from Figure 17 to allow determination of pollutant concentration at the point of interest. Delta (Δ) is a function of alpha (α) and the spill size.

Figure 18: Maximum concentration versus delta. Figure 18 represents the final step for calculation of the maximum downstream pollutant concentration (C) at the point of interest. Using the factor delta (Δ) and knowing the stream cross-sectional area (A), the concentration (C) is readily obtained from the nomogram. The value obtained from Figure 18 applies to neutrally buoyant liquids or solids and will vary somewhat for other pollutants which are heavier or lighter than water.

5.4.2.2 Nomograms for lakes or still water bodies.

Figure 19: Volume versus radius. The spill of a neutrally buoyant liquid in a lake in the absence of wind and current has been idealized as a cylinder of radius (r) and length (d), equivalent to the depth of the lake at the point of spill. The volume of water in the cylinder can be obtained from Figure 19. The radius (r) represents the distance from the spill to the point of interest.

Figure 20: Average concentration versus volume. For a known volume of water (within the idealized cylinder of radius (r) and length (d)), the average concentration of pollutant (C) can be obtained from Figure 20 for a known mass of spill. This assumes the pollutant is spread evenly throughout the cylinder. For pollutants that are more or less dense than water, the actual concentration at the bottom would be higher or lower, respectively.

5.4.3 Sample Calculations.

5.4.3.1 Pollutant concentration in non-tidal rivers. A 20 tonne spill of 45 percent phenol solution has occurred in a river. The stream width is 50 m and the stream depth is

FIGURE 15

PHENOL

DIFFUSION COEFFICIENT VS HYDRAULIC RADIUS

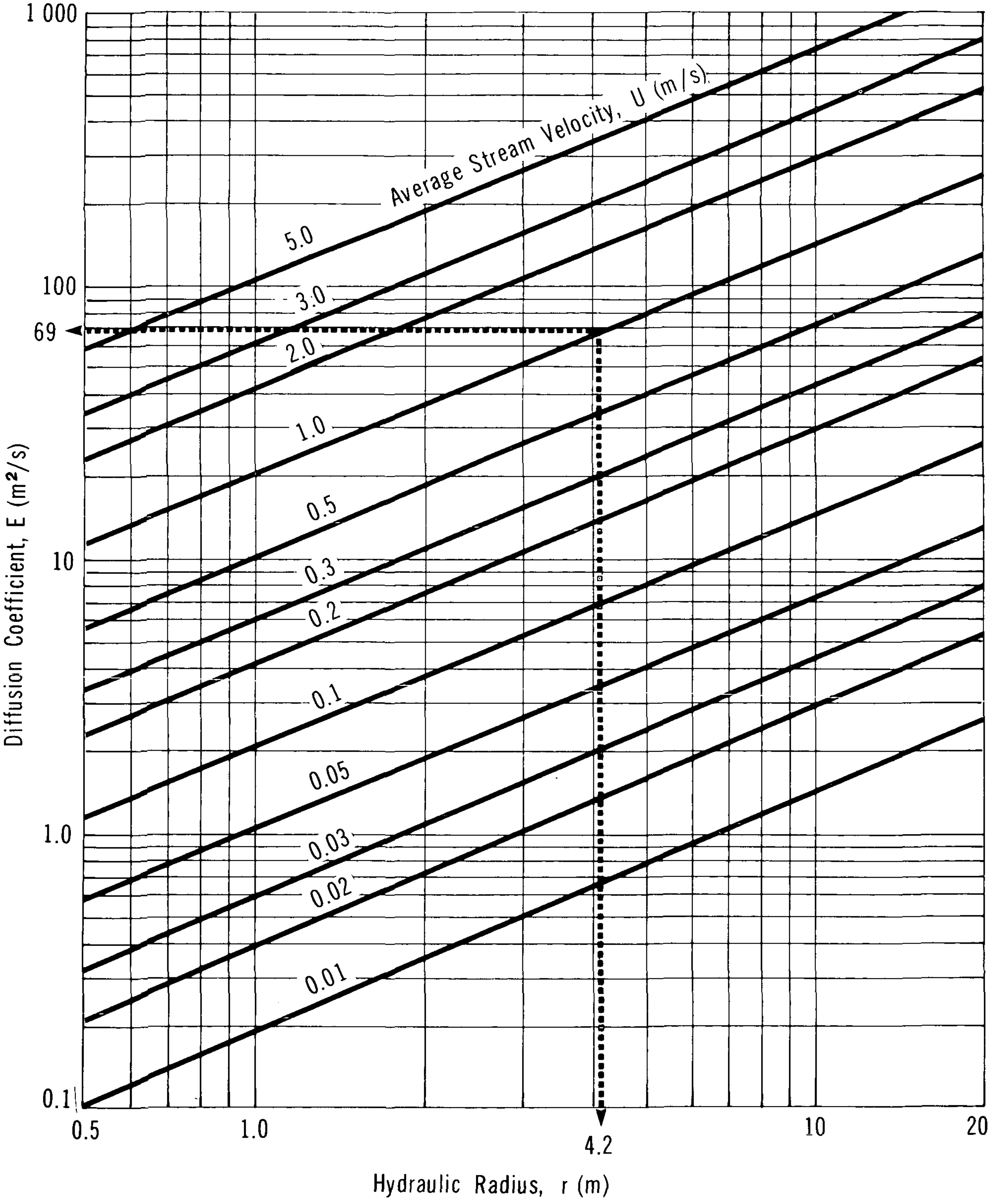
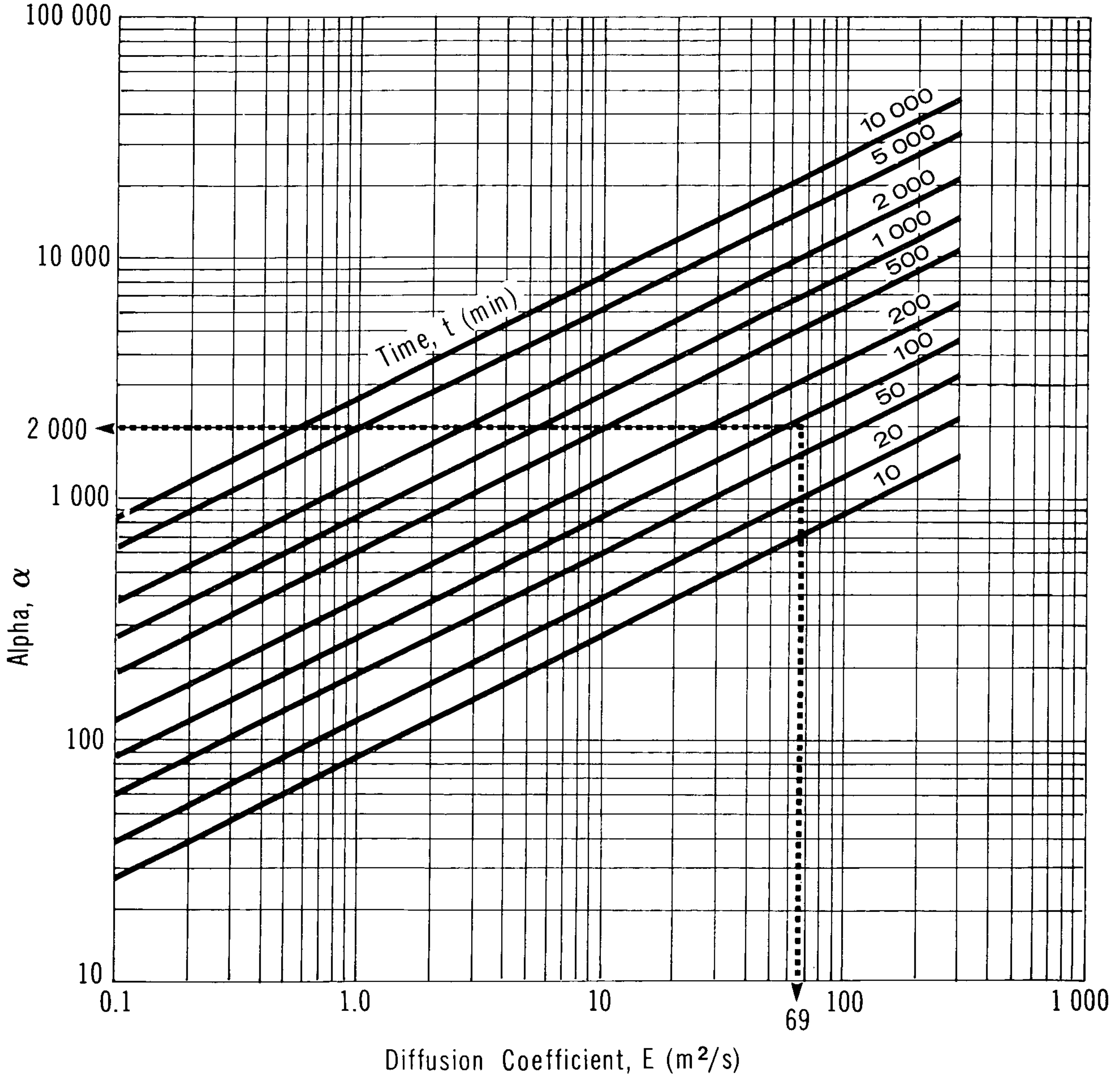


FIGURE 16

PHENOL

ALPHA vs DIFFUSION COEFFICIENT



ALPHA vs DELTA

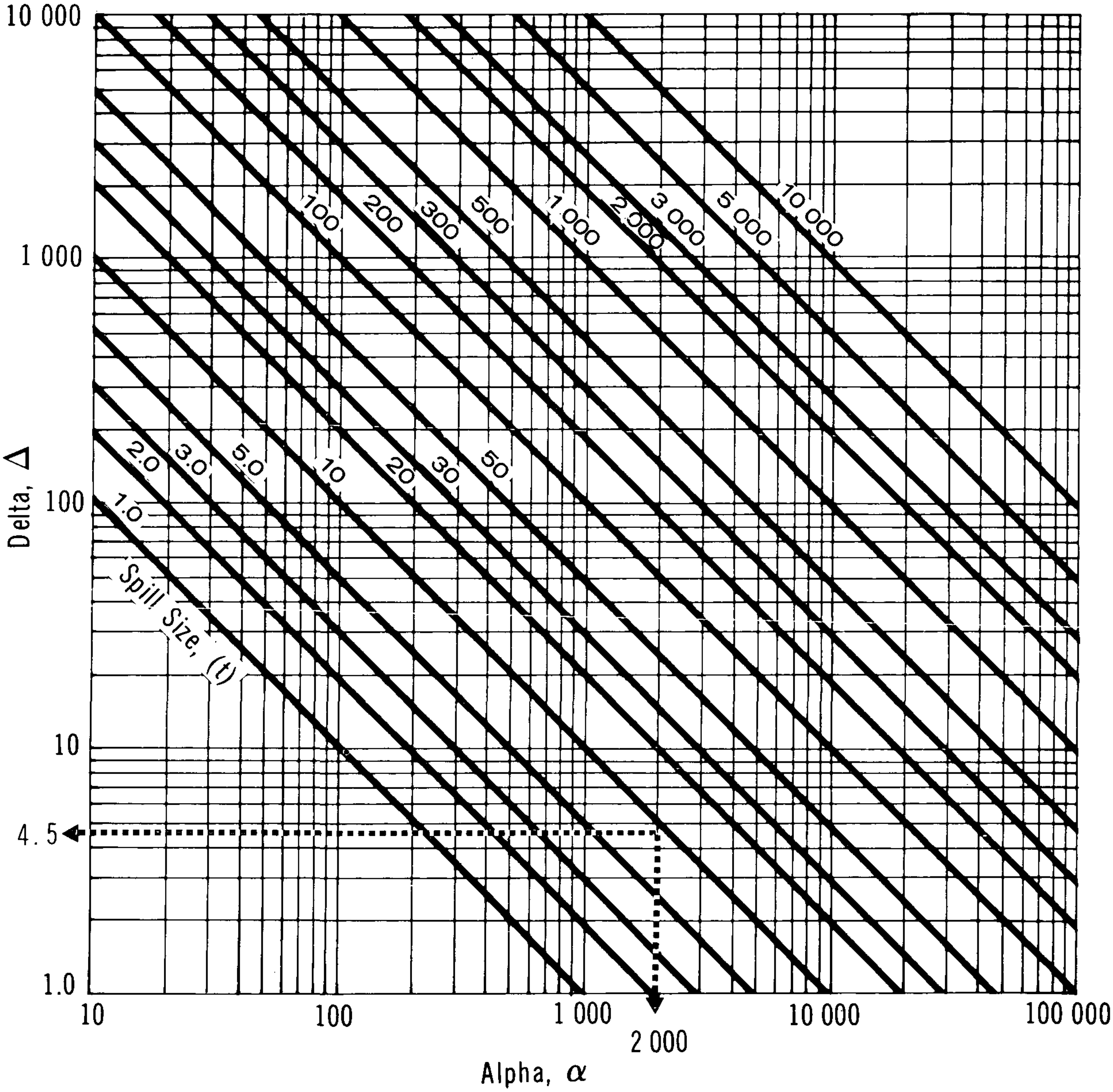


FIGURE 18

PHENOL

MAXIMUM CONCENTRATION vs DELTA

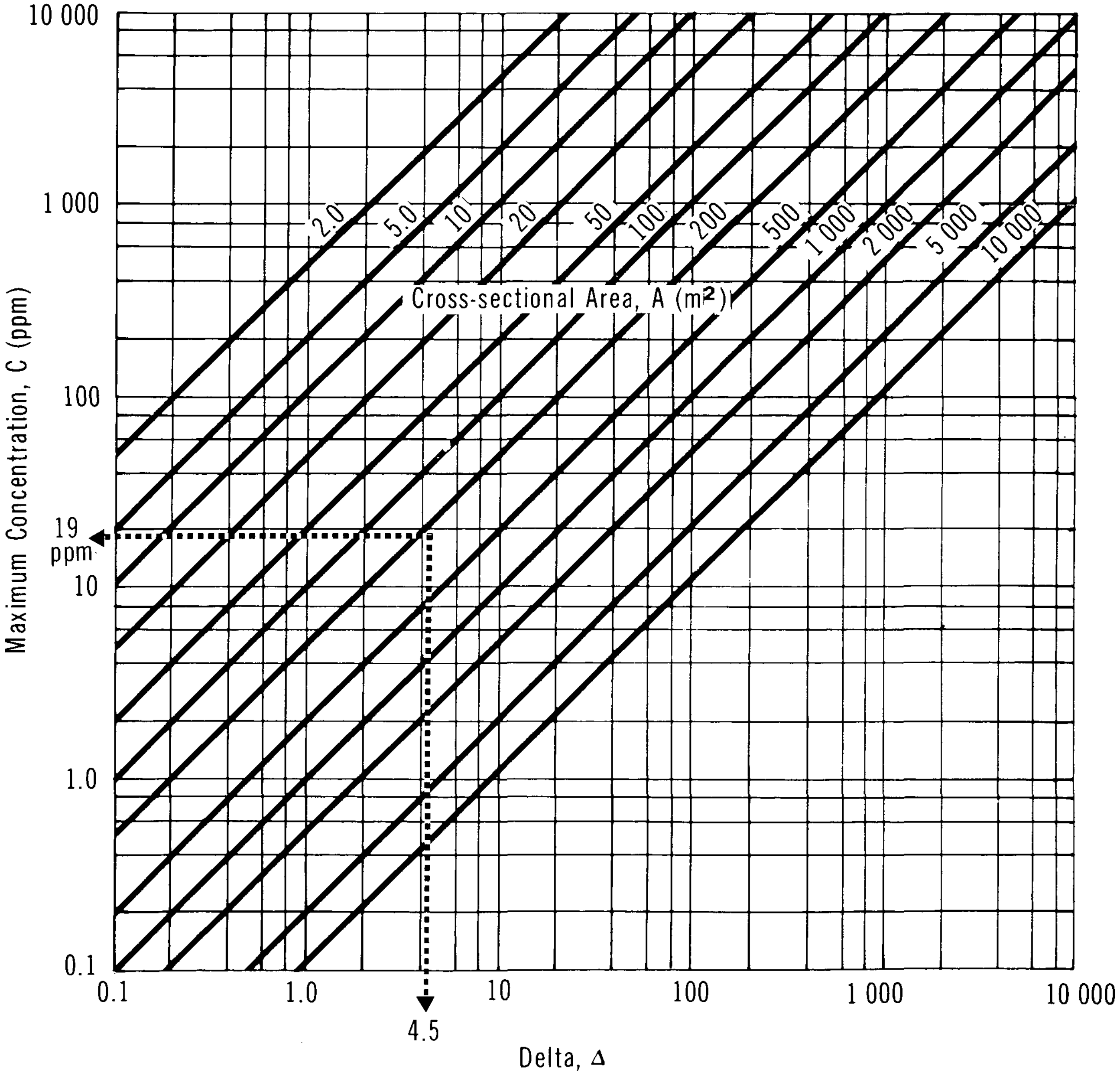


FIGURE 19

PHENOL

VOLUME vs RADIUS

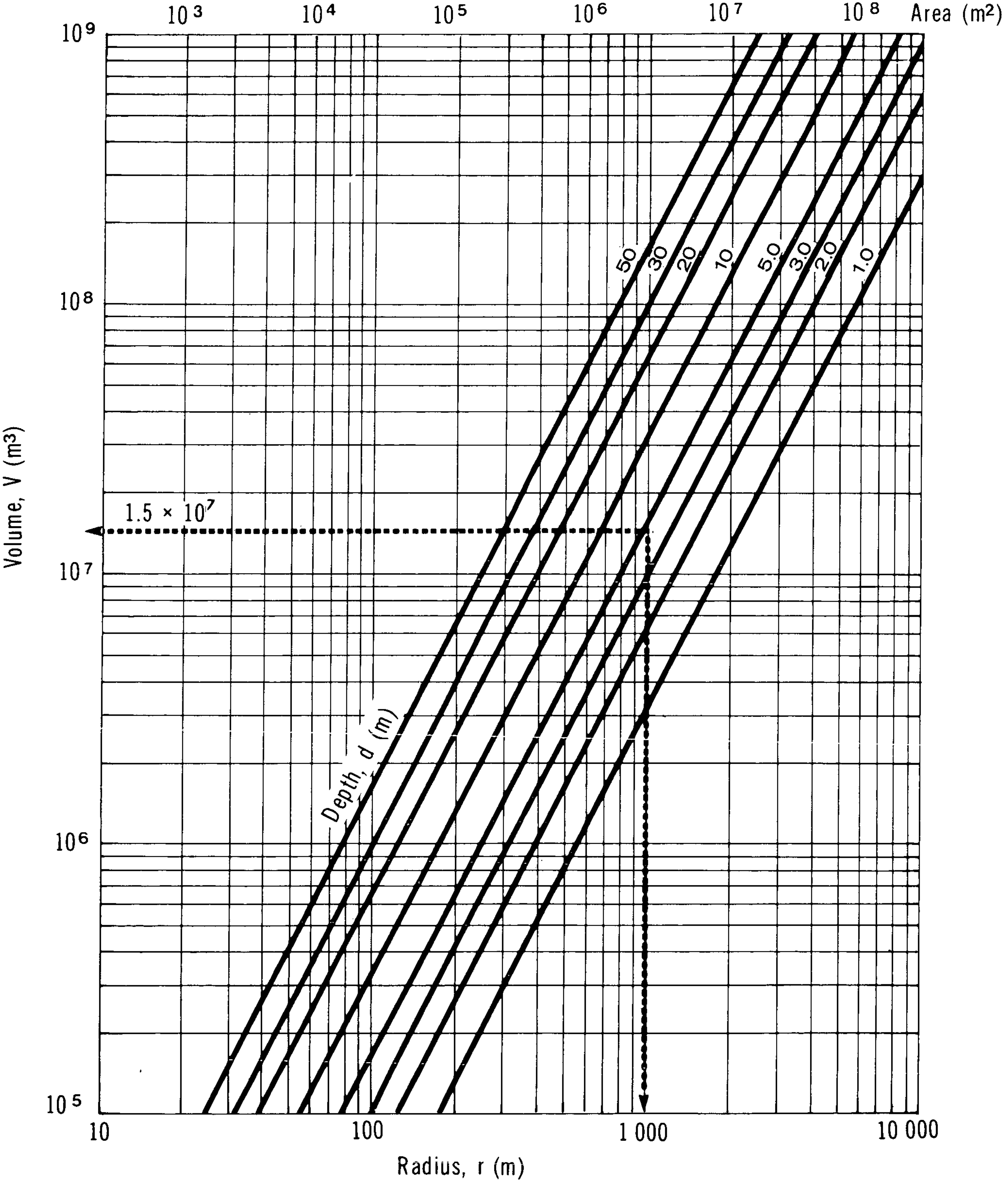
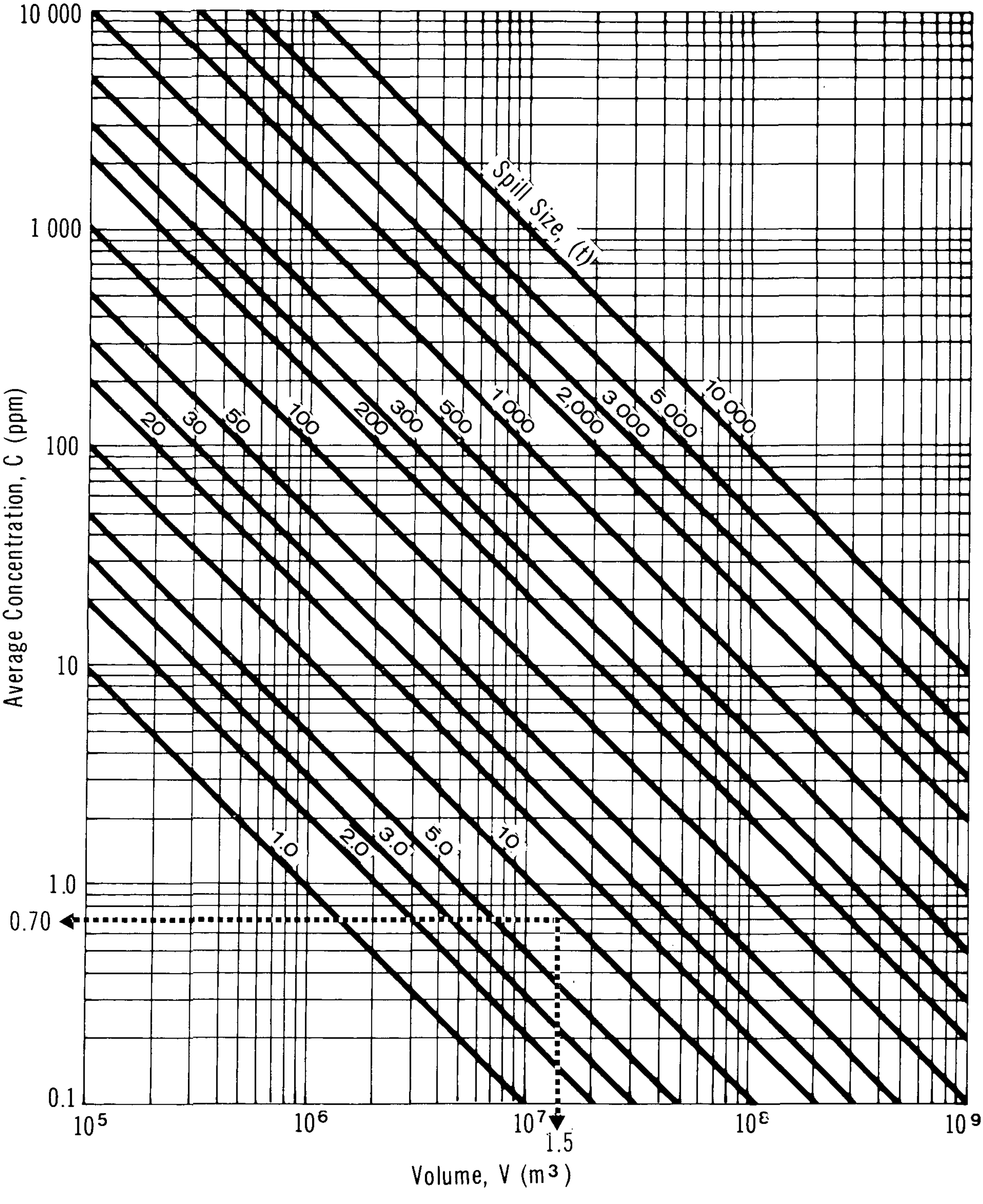


FIGURE 20

PHENOL

AVERAGE CONCENTRATION vs VOLUME



5 m. The average stream velocity is estimated at 1 m/s. What is the maximum concentration expected at a water intake located 5 km downstream?

Solution

Step 1: Define parameters

- $W = 50$ m
- $d = 5$ m
- $U = 1$ m/s
- spill mass = 20 tonnes of 45 percent phenol solution contains the equivalent of 9 tonnes of phenol

Step 2: Calculate the time to reach the point of interest

- Use Figure 13
- With $X = 5000$ m and $U = 1$ m/s, $t = 83$ min

Step 3: Calculate the hydraulic radius (r)

- Use Figure 14
- With $W = 50$ m and $d = 5$ m, $r = 4.2$ m

Step 4: Calculate the longitudinal diffusion coefficient (E)

- Use Figure 15
- With $r = 4.2$ m and $U = 1$ m/s, $E = 69$ m^2/s

Step 5: Calculate alpha (α)

- Use Figure 16
- With $E = 69$ m^2/s and $t = 83$ min, (α) = 2000

Step 6: Calculate delta (Δ)

- Use Figure 17
- With alpha (α) = 2000 and spill mass = 9 tonnes of phenol, delta (Δ) = 4.5

Step 7: Compute the stream cross-sectional area (A)

- $A = W \times d = 50 \times 5 = 250$ m^2

Step 8: Calculate the maximum concentration (C) at the point of interest

- Use Figure 18
- With $\Delta = 4.5$ and $A = 250$ m^2, $C = 19$ ppm

5.4.3.2 Average pollutant concentration in lakes or still water bodies. A 20 tonne spill of 45 percent phenol solution has occurred in a lake. The point of interest is located on the shore approximately 1000 m from the spill. The average depth between the spill site and the point of interest is 5 m. What is the average concentration which could be expected?

Solution

Step 1: Define parameters

- $d = 5$ m
- $r = 1000$ m
- spill mass = 9 tonnes (equivalent)

Step 2: Determine the volume of water available for dilution

- Use Figure 19
- With $r = 1000$ m, $d = 5$ m, the volume is approximately 1.5×10^7 m^3

Step 3: Determine the average concentration

- Use Figure 20
- With $V = 1.5 \times 10^7$ m^3 and spill mass = 9 tonnes, the average concentration is 0.7 ppm

5.5 Subsurface Behaviour: Penetration into Soil

5.5.1 Mechanisms. The principles of contaminant transport in soil and their application to this work are presented in the Introduction Manual. Special considerations related to the spill of phenol onto soil and its transport downward through the soil are presented here.

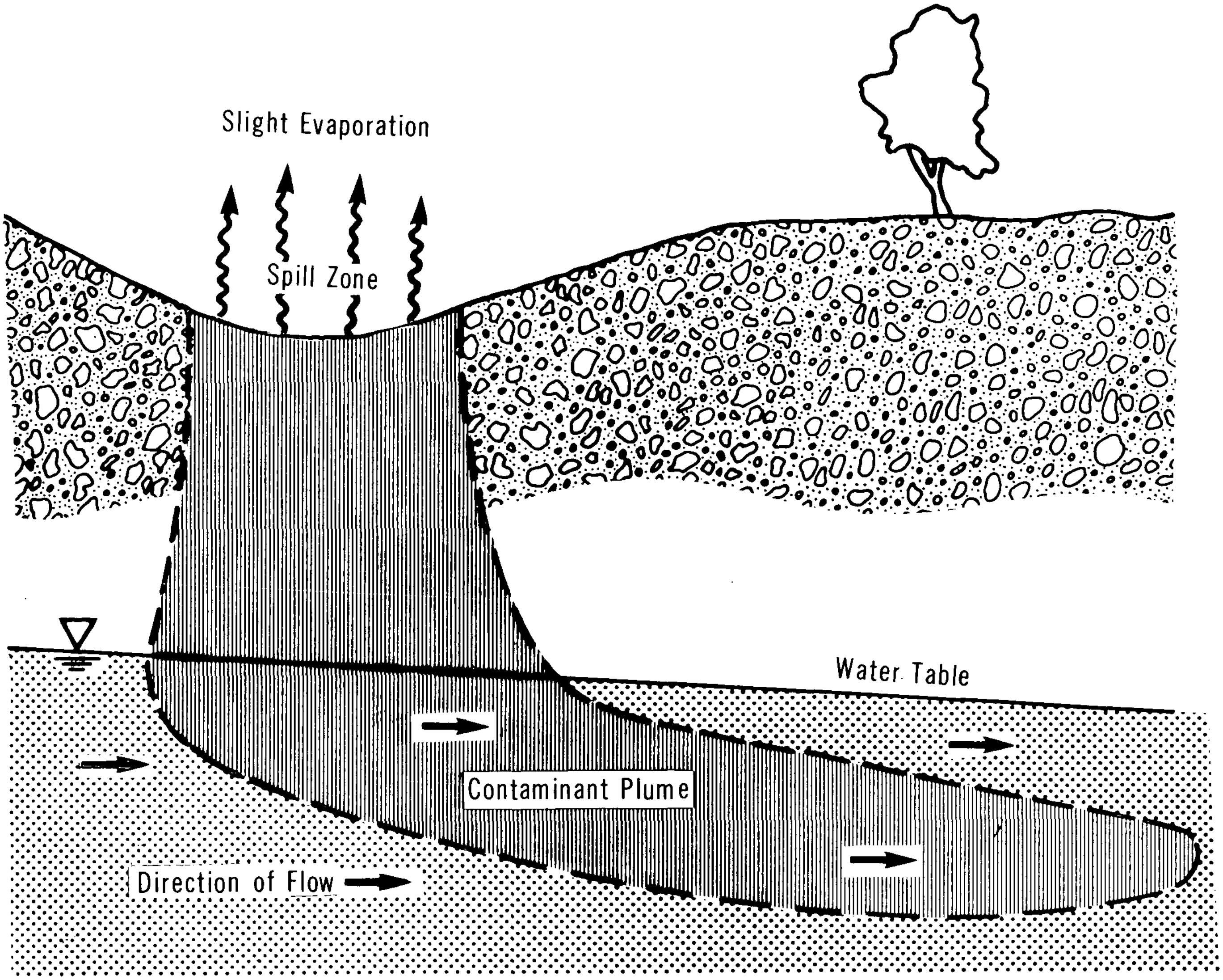
Phenol is a solid below 41°C. Consequently, when spilled, only a limited groundwater contamination hazard exists if the soil is dry and if no precipitation falls prior to cleanup. However, if precipitation or other forms of moisture are present, groundwater contamination can be expected. Since phenol is soluble in water (6.7 g/100 mL at 16°C), dilute solutions can infiltrate the soil. Some interaction between phenol and the soil, probably in the form of adsorption, will occur. However, much of the contaminant can be expected to migrate downward through the soil.

If the soil surface is saturated with moisture at the time of the spill, as might be the case after a rainfall, the spilled chemical can run off into surface water. For this work, the soils have been assumed to be at field capacity. This situation provides very little interstitial water to dilute the chemical during transport or to impede its downward movement and thus represents "worst case" analysis. Upon reaching the groundwater table, the contaminant will continue to move, now in the direction of groundwater flow. A contaminated plume will be produced, with diffusion and dispersion serving to reduce the phenol concentration somewhat. This is shown schematically in Figure 21.

FIGURE 21

PHENOL

SCHEMATIC SOIL TRANSPORT



Soil: Coarse Sand
–Porosity (n) = 0.35
–Intrinsic Permeability (k) = 10^{-9} m^2
–Field Capacity (θ_{fc}) = 0.075

5.5.2 Equations Describing Phenol Movement into Soil. The equations and assumptions used to describe contaminant movement in solution downward through the unsaturated soil zone toward the groundwater table have been described in the Introduction Manual. Transport velocities have been based on Darcy's Law assuming saturated piston flow.

5.5.3 Saturated Hydraulic Conductivity of Phenol in Soil. The saturated hydraulic conductivity (K_o), in m/s, is given by:

$$K_o = \frac{(\rho g)k}{\mu}$$

where: k = intrinsic permeability of the soil (m^2)

ρ = mass density of the fluid (kg/m^3)

μ = absolute viscosity of the fluid (Pa•s)

g = acceleration due to gravity = 9.81 m/s^2

The fluids of concern are concentrated solutions of phenol (>60 percent by weight) spilled during transit and dilute solutions which would be produced during precipitation falling on a spill of solid phenol. Accurate values of ρ and μ for the concentrated solutions have not been found. Estimates based on pure phenol solutions, therefore, have been used. For dilute solutions, the values of ρ and μ are essentially those of water:

Property	Phenol (80 percent by weight) (20°C)	Water (20°C)
Mass density (ρ) kg/m^3	1060	1000
Absolute viscosity (μ), Pa•s	3.0×10^{-3}	1.0×10^{-3}
Saturated hydraulic conductivity (K_o), m/s	$(0.35 \times 10^7)k$	$(0.98 \times 10^7)k$

5.5.4 Soils. The Introduction Manual describes the three soils selected for this work. Their relevant properties are:

Property	Soil Type Coarse Sand	 Silty Sand	 Clay Till
Porosity (n), m^3/m^3	0.35	0.45	0.55
Intrinsic permeability (k), m^2	10^{-9}	10^{-12}	10^{-15}
Field capacity (θ_{fc}), m^3/m^3	0.075	0.3	0.45

5.5.5 Penetration Nomograms. Nomograms for the penetration of phenol into the unsaturated zone above the groundwater table were prepared for each soil. They present penetration time (t_p) plotted against depth of penetration (B). Because of the methods and assumptions used, the penetration depth should be considered as a maximum depth in time t_p.

A flowchart for the use of the nomograms is presented in Figure 22. The nomograms are presented as Figures 23, 24 and 25. The water line on the nomograms represents the maximum penetration of water at 20°C in time t_p. It is a limiting condition as phenol becomes diluted with water.

5.5.6 Sample Calculation. A 20 tonne spill of 80 percent phenol has occurred on silty sand. The temperature is 20°C; the spill radius is 8.6 m. During cleanup, it begins to rain. Calculate the depth of penetration 8 days after the rain has occurred.

Solution

Step 1: Define parameters

- Mass spilled = 20 000 kg (20 tonnes)
- T = 20°C
- r = 8.6 m
- Soil = silty sand
- Groundwater table depth (d) = 13 m
- Time since spill (t_p) = 8 days

Step 2: Calculate the area of spill

- $A = \pi r^2 = 232\ m^2$

FIGURE 22

FLOWCHART FOR NOMOGRAM USE

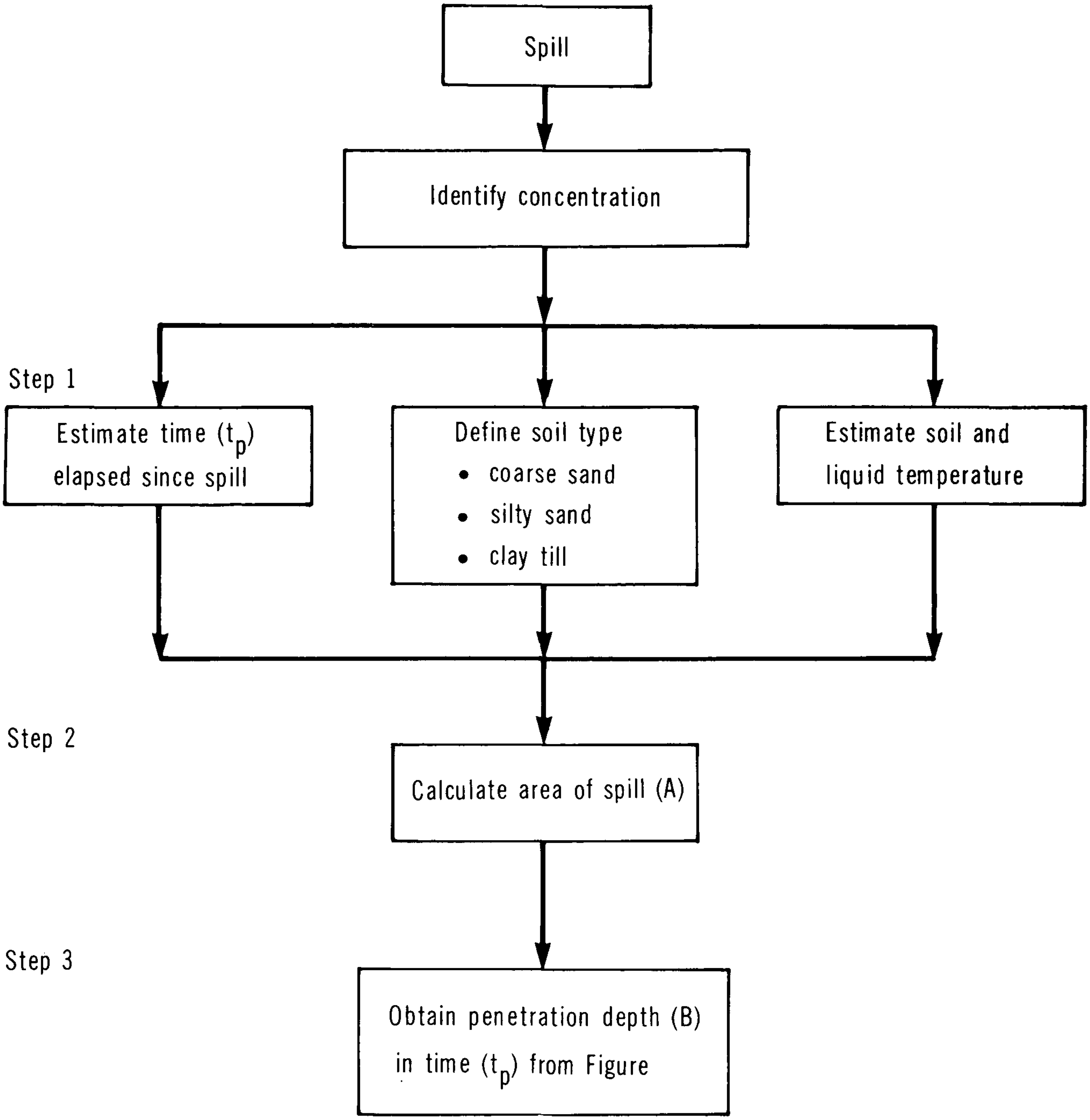


FIGURE 23

PHENOL

PENETRATION IN COARSE SAND

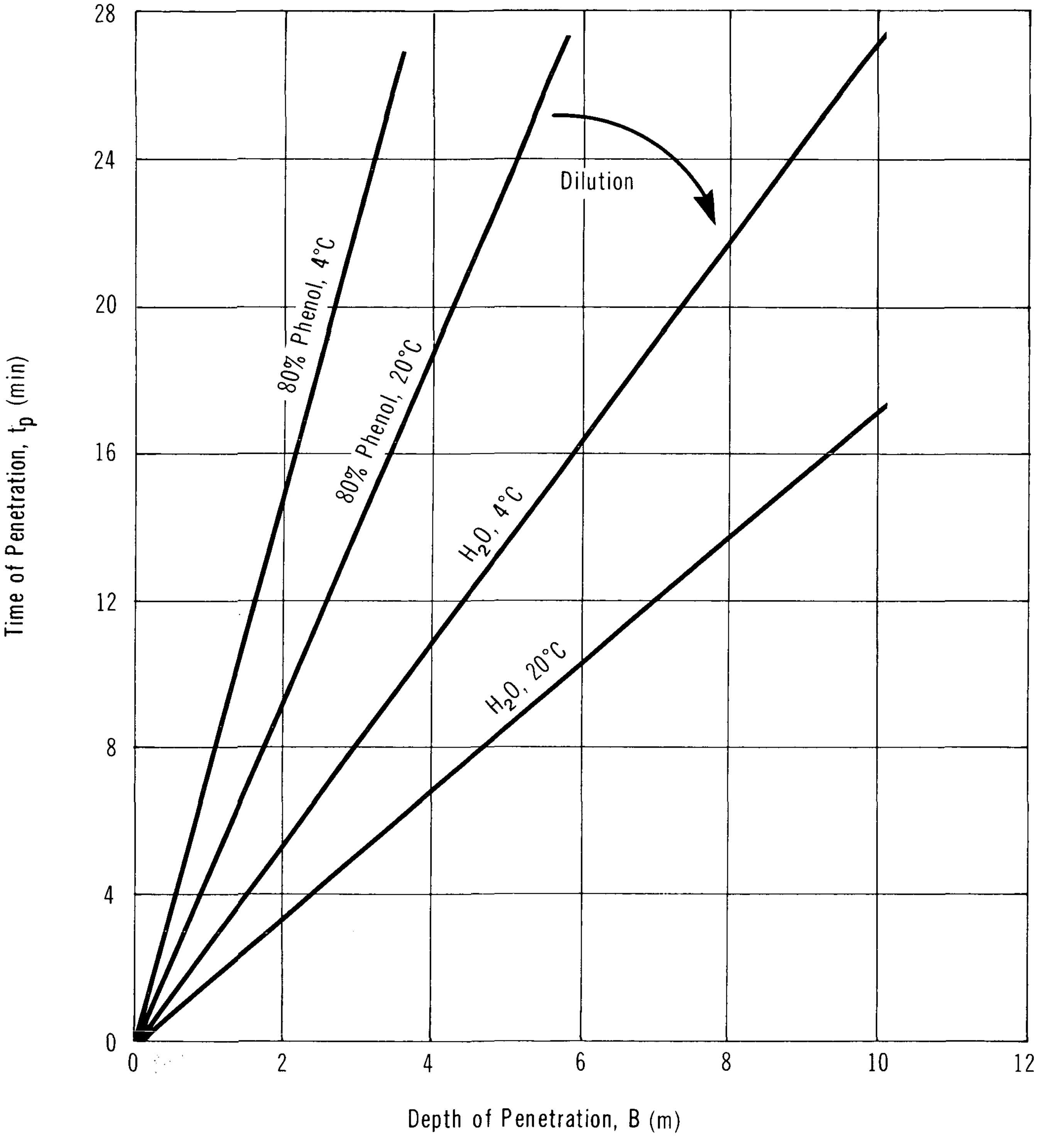
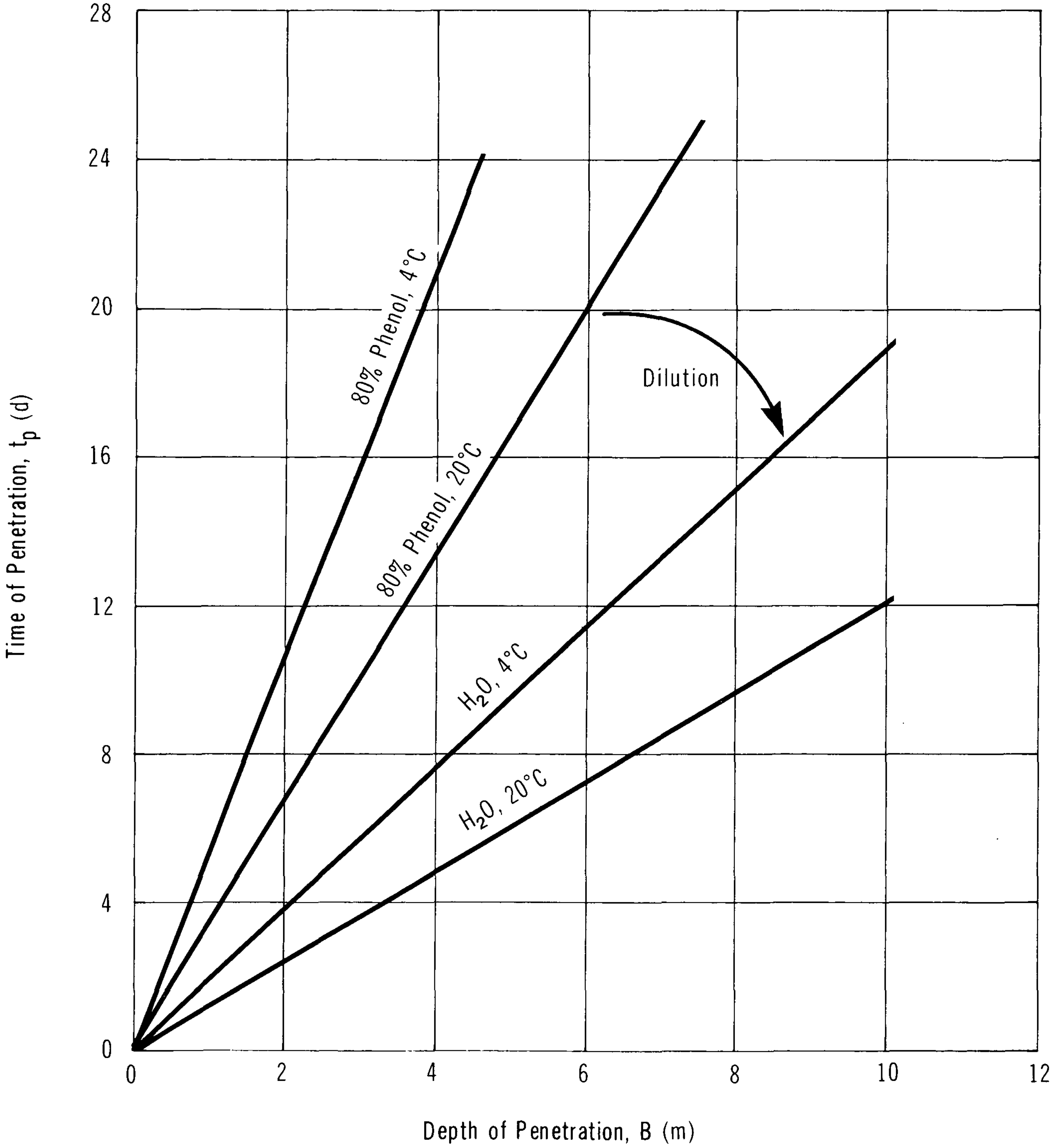


FIGURE 24

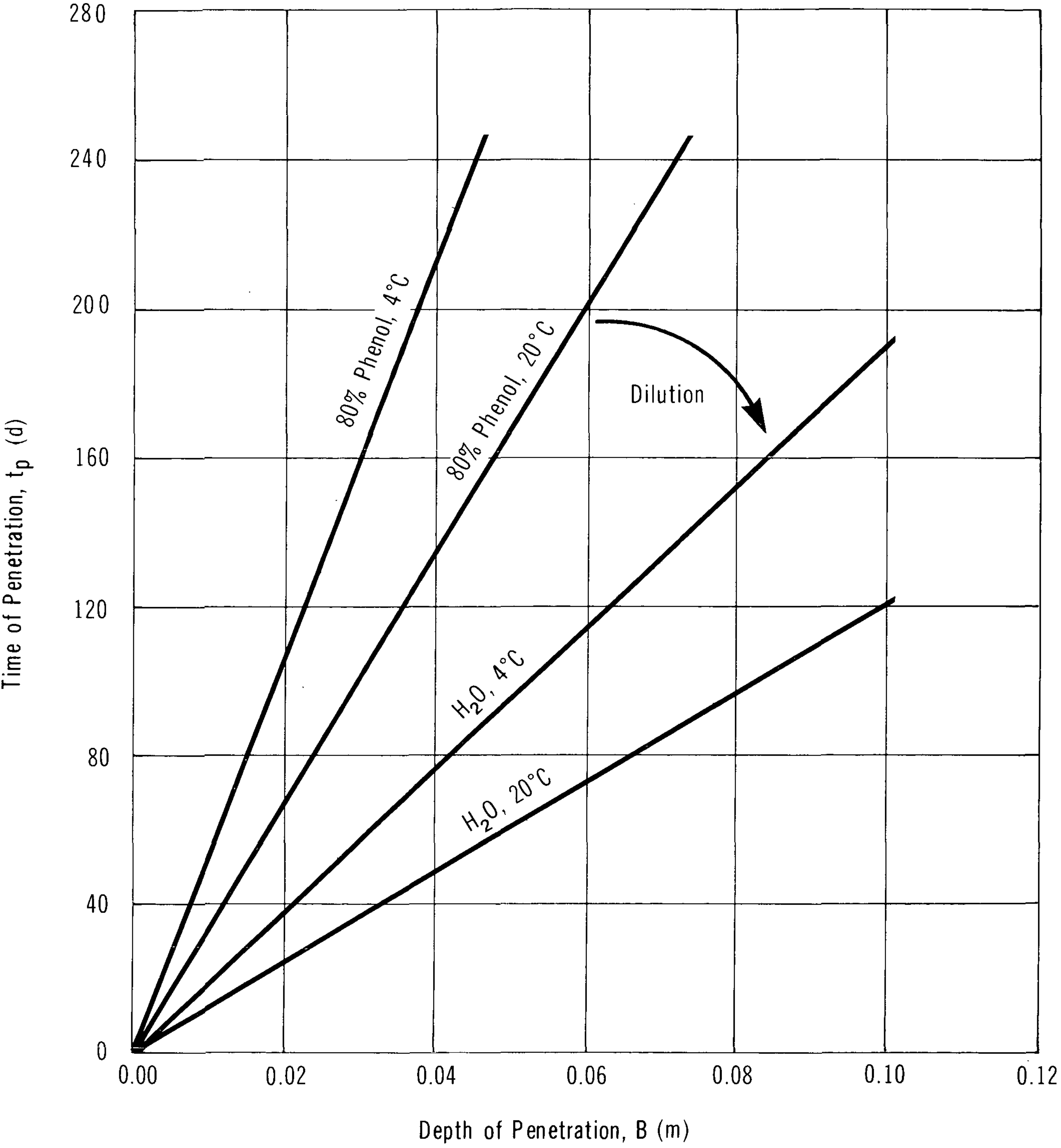
PHENOL

PENETRATION IN SILTY SAND



PHENOL

PENETRATION IN CLAY TILL



Step 3: Estimate the depth of penetration (B) at time (t_p)

- For silty sand and t_p = 8 days, the penetration range is

Phenol, 80 percent	Dilute (Water, worst case)
2.5 m	7.0 m

- Groundwater table has not been reached at this point

6 ENVIRONMENTAL DATA

6.1 Suggested or Regulated Limits

6.1.1 Water. In Canada, the maximum acceptable level of phenol in drinking water is 0.100 mg/L (WQS 1979; Water Management Goals 1978). In the United States, the criteria for phenol are 0.100 mg/L and 0.300 mg/L, based on organoleptic effects (Phenol EPA Criteria 1978).

6.1.2 Air. Ontario limits phenol concentrations in ambient air to 100 µg/m^3 (Ontario E.P. Act 1971).

6.2 Aquatic Toxicity

6.2.1 U.S. Toxicity Rating. Phenol has been assigned a TL_m96 of 10 to 100 ppm (RTECS 1979).

The U.S. EPA criterion for protection of freshwater aquatic life is 600 µg/L as a 24 hour average, and a ceiling of 3400 µg/L not to be exceeded at any time (Phenol EPA Criteria 1978).

6.2.2 Measured Toxicities.

Conc. (mg/L)	Time (hours)	Species	Result	Water Conditions	Reference
Fish Kill Data					
0.4 to 0.6	8	Trout	lethal		Wilber 1969
70 to 75	1	Spotted sunfish	lethal	aerated	Wilber 1969
9.3	42	Rainbow trout	lethal	15°C	Brown 1967
10	72	Goldfish	lethal		Ellis 1967
5 to 20	1	Sunfish	lethal	aerated	WQC 1963
0.079	0.5	Minnows	lethal	river	WQC 1963
51	2	Goldfish	lethal	distilled	WQC 1963
20	-	Minnows	lethal		Klein 1957
Fish Toxicity Tests					
28	24	Bluegill	LC_{50}	static	Cairns 1978

Conc. (mg/L)	Time (hours)	Species	Water Result	Conditions	Reference
60	24	Bluegill	LC_{50}	-	EPA 1980
25.8	24	Bluegill	LC_{50}	soft water	Verschueren 1984
19	24-48	Bluegill	TL_m	-	Verschueren 1984
22.7	24	Bluegill	TL_m	standard reference water	Verschueren 1984
23.9	48-96	Bluegill	TL_m	soft water	Verschueren 1984
5.7	96	Bluegill	TL_m	-	Verschueren 1984
2.43	156	Bluegill	LC_{50}	HD = 50	EPA 1980
1.69	156	Bluegill	LC_{50}	HD = 200	EPA 1980
2.42 to 3.34	72-96	Bluegill embryos, larvae	LC_{50}	flow-through, pH 7-9, HD = 51, 18-26°C	JWPCF 1981
1.69 to 2.43	72-96	Bluegill embryos, larvae	LC_{50}	flow-through, pH 7-8, HD = 194, 18-26°C	JWPCF 1981
11.7	24	Brook trout (*Salvelinus fontinalis*)	LC_{50}	-	EPA 1980
4.2	27	Brook trout, juvenile	LC_{50}	static	Miller 1975
10	tns	Creek chub	LD_{10}	Detroit River water	Verschueren 1984
20	tns	Creek chub	LD_{100}	Detroit River water	Verschueren 1984
25	24	Crucian carp	TL_m	-	Verschueren 1984
65.34	24	Fathead minnow	LC_{50}	-	EPA 1980
40.6	24-48	Fathead minnow	TL_m	soft water	Verschueren 1984
38.6	24-48	Fathead minnow	TL_m	hard water	Verschueren 1984
41	48	Fathead minnow	LC_{50}	flow-through, 15°C	Verschueren 1984
28	48	Fathead minnow	LC_{50}	flow-through, 25°C	Verschueren 1984

Conc. (mg/L)	Time (hours)	Species	Result	Water Conditions	Reference
33	72	Fathead minnow	LC_{50}	static, 18-22°C, Lake Superior water	Mattson 1976
32	96	Fathead minnow	LC_{50}	static, 18-22°C, Lake Superior water	Mattson 1976
36	96	Fathead minnow	TL_m	flow-through, 15°C	Verschueren 1984
24	96	Fathead minnow	TL_m	flow-through, 25°C	Verschueren 1984
28 to 29	96	Fathead minnow	LC_{50}	flow-through, 25°C	JWPCF 1982
67.5	96	Fathead minnow	LC_{50}	flow-through, HD = 707, 14° C	JWPCF 1981
24.9	96	Fathead minnow	LC_{50}	flow-through, 25°C	JWPCF 1981
34.3	96	Fathead minnow	LC_{50}	soft water	Verschueren 1984
32	96	Fathead minnow	LC_{50}	hard water	Verschueren 1984
29	96	Fathead minnow	LC_{50}	hard water	Phipps 1981
22	122-127	Fathead minnow	LC_{50}	hard water	EPA 1980
22 to 23	192	Fathead minnow	LC_{50}	flow-through, 25°C	JWPCF 1982
0.75 to 2.5	720	Fathead minnow	LC_{50}	flow-through, 14°C, pH 8.0, HD = 725	JWPCF 1981
36.3	48-96	Flagfish *(Jordanella floridae)*	LC_{50}	flow-through, 25°C	Verschueren 1984
11.2 to 25	48	Golden orfe	LC_{50}	-	JWPCF 1983
16 to 60.5	24	Golden shiner	LC_{50}	static	Cairns 1978
35 to 129	24	Golden shiner	LC_{50}	static, 5-15°C	JWPCF 1979
49.9	24	Goldfish	LC_{50}	soft water	Verschueren 1984

Conc. (mg/L)	Time (hours)	Species	Result	Water Conditions	Reference
46	24	Goldfish	LC_{50}	static, 20°C, pH = 7.0	Bridie 1979
60	24	Goldfish	LC_{50}	reaerated, 20°C	JWPCF 1980
46	24	Goldfish	LC_{50}	static, 20°C	JWPCF 1980
49.1	48	Goldfish	LC_{50}	soft water	Verschueren 1984
44.5	48	Goldfish	TL_m	-	Verschueren 1984
44.5	96	Goldfish	LC_{50}	soft water	Verschueren 1984
44 to 49	96	Goldfish	TL_m	25°C	Middlebrooks 1973
0.840	180	Goldfish embryos, larvae	LC_{50}	HD = 50	EPA 1980
0.34	180	Goldfish embryos, larvae	LC_{50}	HD = 200	EPA 1980
0.84 to 1.22	96	Goldfish embryos, larvae	LC_{50}	flow-through, 18-26°C	JWPCF 1981
0.39 to 1.22	84	Goldfish embryos, larvae	LC_{50}	HD = 50 to 200	EPA 1980
30	24	Guppy	LC_{50}	pH 7.3	Verschueren 1984
49.9	24-48	Guppy	LC_{50}	soft water	Verschueren 1984
39.2	96	Guppy	LC_{50}	soft water	Verschueren 1984
47.5	96	Guppy	LC_{50}	-	JWPCF 1983
32.7	97	Kharda	LC_{50}	static, 24°C, pH 6.8-7.6	JWPCF 1982
28.9	96	Kharda	LC_{50}	reaerated, pH 6.0	JWPCF 1982
63	25	Mollies	LC_{50}	-	EPA 1980
22	50	Mollies	LC_{50}		EPA 1980
22.7	96	Mosquito fish	LC_{50}	-	Verschueren 1984
22.2	48	Mosquito fish	LC_{50}	-	Verschueren 1984
56	24	Mosquito fish	LC_{50}	-	Verschueren 1984
12.5	96	*Nopterus nopterus*	LC_{50}	static	Verma 1983
46	48	*Ophicephalus punctatus*	LC_{50}	static	Verschueren 1984

Conc. (mg/L)	Time (hours)	Species	Result	Water Conditions	Reference
12.5	96	Patra	LC_{50}	static, 24°C	JWPCF 1982
11.5	96	Patra	LC_{50}	reaerated, pH 6.0	JWPCF 1982
9	1	Perch	LC_{100}	-	Verschueren 1984
12.2	2	Rainbow trout	LC_{50}	-	EPA 1980
5.6 to 11.3	24	Rainbow trout	LC_{50}	-	EPA 1980
8.21	24	Rainbow trout	TL_m	flow-through, 20-25°C	JWPCF 1977
4	24	Rainbow trout	respiratory distress	HD = 3.8, 20°C, pH 8	Sloof 1979
9.0 to 10.4	48	Rainbow trout	LC_{50}	flow-through, 15°C, pH 7.4-7.7	JWPCF 1980
7.7	48	Rainbow trout	LC_{50}	flow-through, HD = 75-89	JWPCF 1980
9.2 to 10.8	48	Rainbow trout	LC_{50}	flow-through, HD = 75-89, 15°C	Alexander 1978
8.9	96	Rainbow trout	LC_{50}	flow-through, 14°C, pH 8	JWPCF 1981
5.62	96	Rainbow trout	TL_m	flow-through, 25°C	JWPCF 1977
4.0	2160	Rainbow trout	TL_m	-	Verschueren 1984
0.07	528	Rainbow trout embryo	LC_{50}	HD = 200	EPA 1980
0.33	552	Rainbow trout embryo	LC_{50}	flow-through, 13-15°C	JWPCF 1981
0.31	96	Rainbow trout larvae	LC_{50}	flow-through, 13-15°C	JWPCF 1981
<0.2	1392	Rainbow trout embryos and larvae	LC_{50}	flow-through, 14°C, pH 7.8, HD = 580	JWPCF 1981
15	24	Roach	TL_m	-	Verschueren 1984
39.4	96	Singii	LC_{50}	static, 24°C, HD = 66	JWPCF 1982

Conc. (mg/L)	Time (hours)	Species	Result	Water Conditions	Reference
37.4	96	Singii	LC_{50}	reaerated, pH 6.0	JWPCF 1982
17	24	Tench	TL_m	-	Verschueren 1984
30.9	48	Zebra fish	LC_{50}	flow-through, 25°C	Verschueren 1984
29.0	96	Zebra fish	LC_{50}	flow-through, 25°C	Verschueren 1984
27.8	96	Zebra fish	LC_{50}	-	JWPCF 1983
Freshwater Invertebrates					
21 to 61	25-50	*Daphnia magna*	TL_m	-	Verschueren 1984
92.3	48	*Daphnia magna*	LC_{50}	static	JWPCF 1980
8 to 10	tns	*Daphnia*	lethal	-	Wilber 1969
96 to 110	48	*Daphnia magna*	LC_{50}	static	Cairns 1978
5 to 14	96	*Daphnia magna*	LC_{50}	-	EPA 1980
341 to 360	48	Annelid (*Aeolosoma headleyi*)	LC_{50}	-	Cairns 1978
205 to 300	48	Rotifer (*Philodina acuticornis*)	LC_{50}	-	Cairns 1978
350	48	Snail (*Limnaea stagnalis*)	LC_{50}	-	EPA 1980
351 to 389	48	Snail (*Nitrocris* sp.)	LC_{50}	-	EPA 1980
260 to 320	48	Snail (*Physa fontinalis*)	LC_{50}	-	EPA 1980
780	48	Clam (*Sphaerium corneum*)	LC_{50}	-	EPA 1980
15 to 78	48	Isopod (*Asellus aquaticus*)	LC_{50}	-	EPA 1980
Saltwater species					
18 000	0.15	*Gobius minatus*	LC_{50}	15°C	Verschueren 1984
320	0.45	*Gobius minatus*	LC_{50}	15°C	Verschueren 1984

Conc. (mg/L)	Time (hours)	Species	Result	Water Conditions	Reference
85	1	*Gobius minatus*	LC_{50}	15°C	Verschueren 1984
20	3	*Gobius minatus*	LC_{50}	15°C	Verschueren 1984
15	6	*Gobius minatus*	LC_{50}	15°C	Verschueren 1984
13	12	*Gobius minatus*	LC_{50}	15°C	Verschueren 1984
10	40	*Gobius minatus*	LC_{50}	15°C	Verschueren 1984
9	96	*Gobius minatus*	LC_{50}	15°C	Verschueren 1984
10	tns	Minnow (*Phoxinus phoxinus*)	lethal threshold	-	JWPCF 1981
0.51	12	Nehu (*Stolephorus purpureus*)	LC_{50}	-	EPA 1980
17.5	48	Prawn	LC_{50}	aerated	Portman 1970
90	48	Crab	LC_{50}	aerated	Portman 1970
85 to 100	tns	Isopod (*Mesidotea entomon*)	lethal threshold	-	JWPCF 1981
32 to 41	tns	Amphipod (*Gammarus duebeni*)	lethal threshold	-	JWPCF 1981
56 to 157	24	Brine shrimp	TL_m	static	Price 1974
55	288	Hard clam larvae (*Mercenaria mercenaria*)	TL_m	static	WQCDB-5 1973
53	48	Hard clam eggs	TL_m	static	Verschueren 1984
58	48	American oyster egg (*Crassostrea virginica*)	TL_m	static	Verschueren 1984
100	24	Hard clam	cellular damage	-	EPA 1980
5600	0.05	Shrimp (*Crangon crangon*)	LC_{50}	15°C	Verschueren 1984
400	0.45	Shrimp (*Crangon crangon*)	LC_{50}	15°C	Verschueren 1984

Conc. (mg/L)	Time (hours)	Species	Result	Water Conditions	Reference
120	1	Shrimp (*Crangon crangon*)	LC_{50}	15°C	Verschueren 1984
80	3	Shrimp (*Crangon crangon*)	LC_{50}	15°C	Verschueren 1984
40	6	Shrimp (*Crangon crangon*)	LC_{50}	15°C	Verschueren 1984
30	48	Shrimp (*Crangon crangon*)	LC_{50}	15°C	Verschueren 1984
25	96	Shrimp (*Crangon crangon*)	LC_{50}	15°C	Verschueren 1984
Microorganisms					
258	120	Diatom (*Nitzschia linearis*)	LC_{50}	static	WQCDB-5 1973
205 to 300	48	Rotifer (*Philodina acuticornis*)	LC_{50}	-	EPA 1980
1500	48	Algae (*Chorella pyrenoidosa*)	complete destruction of chlorophyll	-	EPA 1980
470	80	Algae (*Chlorella vulgaris*)	20 percent inhibition of growth	-	EPA 1980
233	tns	Algae (*Chlorella pyrenoidosa*)	toxic	-	Jones 1971
100	tns	Algae (*Selenastrum capricornutum*)	92 percent inhibition of photosynthesis	-	Verschueren 1984
200	19-163	Paramecium (*Chilomonas paramecium*)	>50 percent decrease in growth	-	EPA 1980
64	tns	Bacteria (*pseudomonas putida*)	inhibition of cell multiplication	-	Verschueren 1984

Conc. (mg/L)	Time (hours)	Species	Result	Water Conditions	Reference
4.6	tns	Algae (*Microcystis aeruginosa*)	inhibition of cell multiplication	-	Verschueren 1984
7.5	tns	Algae (*Scenedesmus quadricauda*)	inhibition of cell multiplication	-	Verschueren 1984
33	tns	Protozoa (*Entosiphon sulcatum*)	inhibition of cell multiplication	-	Verschueren 1984
144	tns	Protozoa (*Uronema parduczi*)	inhibition of cell multiplication	-	Verschueren 1984
>1000	tns	Bacteria (*E. coli*)	inhibition of cell multiplication	-	Verschueren 1984
70	tns	Bacteria (*Pseudomonas fluorescens*)	inhibition of degradation of glucose	-	Verschueren 1984
500	17	Natural soil bacteria	72 percent inhibition of cellulose degradation, 41 percent inhibition of starch degradation	-	Verschueren 1984
500	200	Natural soil bacteria	44 percent inhibition of cellulose degradation, 40.3 percent inhibition of starch degradation	-	Verschueren 1984

Conc. (mg/L)	Time (hours)	Species	Result	Water Conditions	Reference
2000	17	Natural soil bacteria	98.6 percent inhibition of cellulose degradation, 98 percent inhibition of starch degradation	-	Verschueren 1984
2000	200	Natural soil bacteria	89 percent inhibition of cellulose degradation, 85 percent inhibition of starch degradation	-	Verschueren 1984

6.3 Mammalian Toxicology

A maximum limit of 1000 ppm has been suggested for livestock (WQC 1963).

6.4 Other Land and Air Toxicity

A maximum of 50 ppm has been suggested for irrigation water (WQC 1963). The recommended chronic toxicity limit for waterfowl is 25 ppm (Todd 1970). A concentration of 479 mg/L in water caused a 50 percent reduction in duckweed growth; 1504 mg/L is given as the LC_{50} for duckweed (EPA 1980).

6.5 Effect Studies

In a study using trout, phenol rapidly damaged gills. At phenol levels killing 20 percent of the fish in 2 days, sufficient damage occurred in a week to impair survival and affect reproduction (Mitrovic 1968). The tainting of fish (odour and taste) occurs at levels of 15-25 mg/L; carp and trout were found to taint at 25 mg/L (Verschueren 1984). Avoidance tests were conducted on rainbow trout; avoidance levels of 3.2-6.5 mg/L were determined. Levels of 0.01 mg/L depressed the respiration of the common carp; levels of 0.084 mg/L affected the growth of fathead minnows (JWPCF 1983).

6.6 Degradation

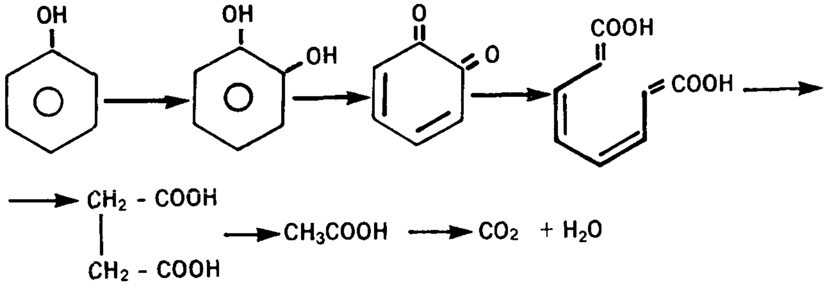
B.O.D. (kg/kg)	% Theor.	Days	Seed	Method	Reference
1.4,1.6, 1.8	33-96	5	Standard dilution sewage	various	Verschueren 1984
>1	90	5	Sewage seed		Price 1974
>1	96	20	Sewage seed		Price 1974
>1	55	5	Sewage seed acclimated	salt water	Price 1974
<1	39	0.5	Phenol activated sludge	sewage plant	Ryerman 1966
<1	34	8	Aniline acclimated activated sludge	sewage plant	Ryerman 1966

Tests on anaerobic organisms showed no serious inhibition of digestion at phenol levels of 100 mg/L (Johnson 1983).

6.7 Long-term Fate and Effects

Phenol reacts rapidly with chlorine to form chlorophenols which have much lower taste thresholds. It is readily oxidized to products such as quinones, especially under basic conditions.

Phenol degradation in the environment may be fast enough to cause local oxygen deficiencies. The rate is up to 3-5 mg/L/day in the presence of soil and plants, and 2 mg/L/day in water; 1 ppm may be biologically assimilated in 1-7 days at 20°C, and in 1-3 weeks at 4°C (WQC 1963). Degradation in estuarine water has been measured at 100-500 mg/L/day over 17-25 days (Verschueren 1984). Bioconcentration factors of about 2 have been established with goldfish. This indicates that no residue problems should result from phenol exposure (Phenol EPA Criteria 1978). The oxidative biodegradation pathway of phenol in the environment is given as follows (Verschueren 1984):



7 HUMAN HEALTH

Phenol (carbolic acid) is a chemical of great historical significance in the practice of medicine. Prior to the 1900s, it was widely used as a dressing disinfectant; some experimentation with orally administered doses for disease treatment has been reported (NIOSH 1976). During that same time period, phenol was a popular and effective suicidal agent when taken orally (NIOSH 1976). Consequently, oral symptomology has been well documented.

Phenol is a crystalline solid at 25°C. It has a medicinal, sickening sweet odour which is readily detectable at concentrations below recommended exposure standards (Verschueren 1984); it is therefore considered to have good warning properties (NIOSH/OSHA 1981).

The most frequently reported adverse health effect from exposure to phenol are those from skin contact (NIOSH 1976). Health effects due to ingestion of the compound are well known. Phenol's low volatility appears to reduce the hazard of exposures by inhalation (Doc. TLV 1981).

Phenol has been tested for carcinogenicity, mutagenicity, and teratogenicity in animals. It is a probable skin carcinogen in mice; at high dosages in rat experiments, it has caused death of animals at birth. The 1976 NIOSH Criteria Document pertaining to phenol, however, reports that there is no evidence that phenol acts as a specific carcinogen or mutagen, particularly at low concentrations within normal physiological limits (NIOSH 1976). Phenol is included in the U.S. EPA TSCA Inventory.

The toxicological data summarized here have been extracted from reliable standard reference sources. It should be noted that some of the data are for chronic (long-term), low-level exposures and may not be directly applicable to spill situations.

7.1 Recommended Exposure Limits

The exposure standards for phenol are based upon its local and systemic effects on contact with the skin (Doc. TLV 1981). Canadian provincial guidelines generally are similar to those of the USA-ACGIH, unless otherwise indicated.

Guideline (Time)	Origin	Recommended Level	Reference
Time-weighted Averages (TWA)			
TLV® (8 h) (Skin)	USA-ACGIH	5 ppm (19 mg/m^3)	TLV 1983
PEL (8 h)	USA-OSHA	5 ppm (19 mg/m^3)	NIOSH/OSHA 1981

Guideline (Time)	Origin	Recommended Level	Reference
PEL (10 h)	USA-NIOSH	20 mg/m^3	NIOSH 1976
Action level	USA-OSHA	2.5 ppm (9.5 mg/m^3)	GE 1980
Short-term Exposure Limits (STEL)			
STEL (15 min)	USA-ACGIH	10 ppm (38 mg/m^3)	TLV 1983
Ceiling (15 min)	USA-NIOSH	60 mg/m^3	NIOSH 1976
Other Human Toxicities			
IDLH	USA-NIOSH/OSHA	100 ppm	NIOSH Guide 1978
TD_{LO} (oral)	-	14 mg/kg	ITII 1981
May be lethal (oral)	-	1 g	Patty 1981

Inhalation Toxicity Index

The Inhalation Toxicity Index (ITI) is a measure of the potential of a substance to cause injury by inhalation. It is calculated as follows:

ITI = 1315.12 (Vapour Pressure, in mm Hg/TLV®, in ppm)

At 20°C, ITI = 1315.12 (0.38 mm Hg/5 ppm)

At 20°C, ITI = 1 x 10^2

7.2 Irritation Data

7.2.1 Skin Contact. Phenol may be absorbed through the intact skin, leading to severe systemic effects. These are treated in Section 7.4.4. Only irritation effects are presented here.

Exposure Level (and Duration)	Effects	Reference
SPECIES: Human		
100 percent (30 min) (crystals)	In glove, resulted in gangrene.	Abraham 1972. <u>IN</u> NIOSH 1976
97 percent (< 5 min)	Burns on hands, blurred vision and fatigue.	Watorski 1952. <u>IN</u> NIOSH 1976

Exposure Level (and Duration)	Effects	Reference
1 drop of 90 percent		Roberts 1926. IN NIOSH 1976
(20 s)	Some local irritation.	
(12 min)	Edema, anesthesia.	
(31 min)	Burning sensation.	
(1 h)	Increasing pain and edema.	
(2 h)	Increased sensitivity to the touch.	
(44 h)	Desquamation.	
(5 to 7 d)	Crusting and sloughing.	
<5 percent (16 to 20 h)	Closed, soaked dressing on finger resulted in gangrene.	Harrington 1900. IN NIOSH 1976
Unspecified	Pigmentary changes.	Telegina and Boiko 1972. IN NIOSH 1976
Unspecified	On contact with the skin, does not cause pain, but causes a whitening of the exposed area. If not removed promptly, it may cause a severe burn or systemic poisoning.	NIOSH/OSHA 1981
Unspecified	Intense burning is felt, followed by local anesthesia and still later by gangrene.	Sax 1981
SPECIES: Rabbit		
535 mg	On open skin produced severe irritation.	RTECS 1979
500 mg (24 h)	Severe irritation.	RTECS 1979

7.2.2 Eye Contact.

Exposure Level (and Duration)	Effects	Reference
SPECIES: Human		
50 percent phenol (35 percent cresol and 10 percent xylene)	Severe burns of the eyes, edematous conjunctiva, corneal opacities, insensitivity to light, and hemorrhaging beneath the conjunctiva.	Winkler 1939. IN NIOSH 1976

Exposure Level (and Duration)	Effects	Reference
Concentrated phenol solution	Severely irritating to the eye, causing conjunctival swelling; the cornea becomes white and hypesthetic; loss of vision has occurred in some cases.	NIOSH/OSHA 1981
SPECIES: Rabbit		
5 mg	Severe irritation.	RTECS 1979

7.3 Threshold Perception Properties

7.3.1 Odour.

Odour Characteristics: Medicinal, sickening sweet (Verschueren 1984). Sweet, tarry (CHRIS 1978).

Odour Index: 16 (20°C) (Verschueren 1984).

Parameter	Media	Concentration	Reference
Odour Threshold	-	3 ppm	NIOSH/OSHA 1981
Odour Threshold	-	5 ppm	NIOSH/OSHA 1981
Recognition	-	0.048 to 16.4 ppm	Verschueren 1984
Odour Threshold	in water	1 to 10 ppm	EPA 1980
Threshold	in water	60.0 ppm	ASTM 1980
Threshold	-	106 ppm	ASTM 1980
Detectable	-	5 ppm or more	Patty 1981
Detection Threshold	in aqueous solution	25 mg/L	Patty 1981

7.3.2 Taste.

Taste Characteristics: Sharp, burning taste (Verschueren 1984).

Parameter	Media	Concentration	Reference
Detection Threshold	in water	5.90 ppm	ASTM 1980
Recognition Threshold (as a taste)	in air	0.0470 ppm	ASTM 1980
Detection Threshold	in air	1.00 ppm	ASTM 1980
Recognition Threshold	in air	0.0470 ppm	ASTM 1980
Taste Threshold	in water	0.3 to 1 ppm	EPA 1980

7.4 Long-term Studies

7.4.1 Inhalation.

Exposure Level (and Duration)	Effects	Reference
Acute Exposures		
SPECIES: Human		
0.024 mg/m^3 (15 s)	Conditioned electrocortical reflex.	Mukhitov 1964. IN NIOSH 1976
0.0155 mg/m^3 (5 min)	Increased sensitivity to light in dark-adapted people.	Mukhitov 1964. IN NIOSH 1976
6 to 20 mg/m^3 (8 h with two 30 min breaks)	No ill effects; 60 to 88 percent of phenol absorbed by lungs. Rise in urinary excretion of phenol during exposure, with a return to pre-exposure levels within 24 hours.	Piotrowski 1971. IN NIOSH 1976
Chronic Exposures		
SPECIES: Human		
48 ppm (5 to 10 min/h) (average concentration)	Intermittent exposures. Workers showed marked irritation of the eyes, nose and throat. No respiratory irritation was found although the odour of phenol was noticeable.	Doc. TLV 1981

Exposure Level (and Duration)	Effects	Reference
SPECIES: Human		
5 ppm	Provides sufficiently large factor of safety to prevent systemic poisoning if skin absorption is avoidable according to authors cited.	Thomas and Beck 1964. IN Doc. TLV 1981
2 to 3 ppm	Poisoning among Russian workers where phenol was believed to be implicated.	Doc. TLV 1981
185 mg/m^3 (5 to 10 min/d, 8 h/d) (with 9.8 mg/m^3 HCHO)	Marked irritation of the nose, throat, and eyes. HCHO may be primary cause.	ACGIH 1971. IN NIOSH 1976
0 to 12.5 mg/m^3 (8 h/d)	No ill effects. Rise in urinary phenol.	Petrov 1963. IN NIOSH 1976
8.8 to 12.2 mg/m^3 (8 h/d)	"Poisoning" (Exposure from vapours rising from coke quench effluents).	Petrov 1963. IN NIOSH 1976

7.4.2 **Ingestion.**

Exposure Level (and Duration)	Effects	Reference
Acute Exposures		
SPECIES: Human		
128 g (100 percent phenol)	Death	Stevens and Callaway 1940. IN NIOSH 1976
64 g (100 percent phenol)	Death	Hunt and Gettler 1923. IN NIOSH 1976
56 g (88 percent phenol)	Collapse	Bennett et al. 1950. IN NIOSH 1976
39 g (90 percent phenol)	Death	Schleicher 1891. IN NIOSH 1976

Exposure Level (and Duration)	Effects	Reference
32 g (100 percent phenol)	Death	Hunt and Gettler 1923. <u>IN</u> NIOSH 1976
32 g (100 percent phenol)	Coma	Sheppe 1935. <u>IN</u> NIOSH 1976
26 g (82 percent phenol)	Death	Taylor 1919. <u>IN</u> NIOSH 1976
11 to 21 g (100 percent phenol)	Death	Stajduhar-Carie 1968. <u>IN</u> NIOSH 1976
16 g (100 percent phenol)	Death	Bennett et al. 1950. <u>IN</u> NIOSH 1976
4.8 g (15 percent phenol)	Death	Anderson 1869. <u>IN</u> NIOSH 1976
1 g	May be lethal.	Verschueren 1984
140 mg/kg	LD_{LO}	RTECS 1979
14 mg/kg	LD_{LO}	ITII 1981
SPECIES: Dog		
500 mg/kg	LD_{LO}	RTECS 1979
SPECIES: Cat		
100 mg/kg	LD_{50}	AAR 1981
80 mg/kg	LD_{LO}	RTECS 1979
SPECIES: Rabbit		
280 to 620 mg/kg	All 20 at the high dose died, 5 out of 10 died at a dose of 420 mg/kg and the remaining 4 survived the low dose.	Deichmann and Witherup 1944. <u>IN</u> NIOSH 1976
400 to 600 mg/kg	LD_{50}	Verschueren 1984
420 mg/kg	LD_{LO}	RTECS 1979
SPECIES: Rat		
1500 mg/kg (100 percent solution)	Death of about 50 percent within 7 days.	Deichmann and Witherup 1944. <u>In</u> NIOSH 1976

Exposure Level (and Duration)	Effects	Reference
530 to 550 mg/kg	Death of about 50 percent within 7 days.	Deichmann and Witherup 1944. <u>IN</u> NIOSH 1976
414 mg/kg	LD_{50}	RTECS 1979
340 mg/kg (20 percent emulsion)	Death of about 50 percent within 7 days.	Deichmann and Witherup 1944. <u>IN</u> NIOSH 1976
SPECIES: Mouse		
300 mg/kg	LD_{50}	RTECS 1979
<u>Chronic Exposures</u>		
SPECIES: Human		
0.43 g (3 to 4 times/d) (0.9 percent phenol)	Burning sensation followed by giddiness, cold, profuse perspiration, weak pulse, green tint to urine.	Fuller 1869. <u>IN</u> NIOSH 1976

7.4.3 Subcutaneous.

Exposure Level (and Duration)	Effects	Reference
SPECIES: Cat		
80 mg/kg	LD_{LO}	RTECS 1979
SPECIES: Rabbit		
620 mg/kg	LD_{LO}	RTECS 1979
SPECIES: Rat		
650 mg/kg	LD_{LO}	RTECS 1979

7.4.4 Skin Exposure. Phenol may be absorbed through the intact skin, resulting in adverse systemic effects. Irritation and local effects due to skin exposure are reported in Section 7.2.1.

Exposure Level (and Duration)	Effects	Reference
Acute Exposures		
SPECIES: Human		
4 to 5 L, 78 percent (aqueous) (2 to 5 min)	Contact for 2 to 5 min due to a 4 to 5 L spill on the upper body resulted in coma.	Duverneuil and Ravier 1962. IN NIOSH 1976
100 percent (liquefied) (5 to 10 min)	Spilled on cheeks and scalp for 5 to 10 min before being treated; resulted in death.	Gibson 1905. IN NIOSH 1976
80 to 100 percent (aqueous) (20 min)	Spilled on hip, thigh and scrotum. Contact for 20 min resulted in death.	Turtle and Dolan 1922. IN NIOSH 1976
"Strong" (aqueous) (10 min)	Spilled on scalp, face, neck, shoulders and back for 10 min resulted in death.	Gottleib and Storey IN NIOSH 976
43.5 percent (in a mixture of waste water containing 14 percent cresols, 11.5 percent low boiling organics, 11 percent high boiling organics, and 20 percent water (1 min)	A spill for about 1 min on the lower body, irrigated with warm water for 30 min, followed by swabbing with ethanol for 10 min followed by repetition of the procedure, resulted in shock.	Evans 1952. IN NIOSH 1976
20 percent (in lard) (1.5 h)	Covered with impervious dressing; resulted in coma.	Evans 1952. IN NIOSH 1976
5 percent (aqueous) (14.5 h)	Phenol-soaked compress was placed on thigh abscess resulting in coma.	Lucas and Lane 1895. IN NIOSH 1976
5 percent (aqueous) (70 min)	Phenol-soaked compress on broken skin resulted in coma.	Lucan and Lane 1895. IN NIOSH 1976
5.8 to 6.8 ppm (5.5 h)	No inhalation dose. Volunteers were clothed in underwear and denim overalls. Resulted in increased urinary phenol but no other effects.	Piotrowski 1971. IN NIOSH 1976

Exposure Level (and Duration)	Effects	Reference
SPECIES: Human		
1.2 to 1.4 ppm (5.5 h)	No inhalation dose. Volunteers were clothed in overalls and underwear. Resulted in increased urinary phenol output, but no other effects.	Piotrowski 1971. IN NIOSH 1976
SPECIES: Rabbit		
1600 to 6400 mg/kg (24 h)	Were exposed to 20 percent emulsion in water. All died.	Dow 1975. IN NIOSH 1976
850 mg/kg	LD_{50}	RTECS 1979
200 to 800 mg/kg (24 h)	Were exposed to a 20 percent emulsion in water. All survived.	Dow 1975. IN NIOSH 1976
64 to 380 mg/kg (24 h)	Were exposed to 1.8 to 7.12 percent solution in water. One death was reported. Tissue necrosis was found at highest dose, severe tremor at intermediate doses, and hyperemia and mild tremor at lower doses.	Deichmann et al. 1950. IN NIOSH 1976
SPECIES: Rat		
669 mg/kg	LD_{50}	RTECS 1979
670 mg/kg (24 h)	Muscle tremor and convulsions.	Conning and Hayes 1970. IN NIOSH 1976
Chronic Exposures		
SPECIES: Human		
11 percent (solution with olive oil) (7 wk)	Exposed through a covered dressing. Resulted in vomiting, dysphagia and dark urine.	Reid et al. 1907-08. IN NIOSH 1976
5 percent (solution with oil) (30 yr)	Exposed through a closed dresssing on ulcerated skin resulted in ochronosis.	Goldberg 1929. IN NIOSH 1976
5 percent (solution with oil) (12 yr and 10 yr)	Closed dressing on ulcerated skin resulted in death and ochronosis respectively.	Pope 1906, and Goldberg 1929. IN NIOSH 1976

Exposure Level (and Duration)	Effects	Reference
1 percent (calamine and zinc lotion) (1/d, 17 d)	Rubbed on scalp, arms, chest, back and legs. Resulted in coma.	Light 1931. IN NIOSH 1976

7.4.5 Mutagenicity, Teratogenicity and Carcinogenicity.

Exposure Level (and Duration)	Effects	Reference
SPECIES: Human		
Unspecified	Skin cancer.	Stevens and Callaway 1940. IN NIOSH 1976
SPECIES: Rat		
10 000 ppm (1 yr)	Offspring died at birth.	Heller and Pursell 1938. IN NIOSH 1976
7000 ppm (2 generations)	Stunted growth in young.	Heller and Pursell 1938. IN NIOSH 1976
3000 to 5000 ppm (5 generations)	No significant change.	Heller and Pursell 1938. IN NIOSH 1976
2500 or 5000 ppm (103 wk)	In drinking water, bioassay conducted by NCI indicated phenol was not carcinogenic.	GE 1980
0 to 4000 ppm (5 generations)	No change.	Heller and Pursell 1938. IN NIOSH 1976
SPECIES: Mouse		
2500 to 5000 ppm	Via ingestion. NCI bioassay indicated phenol was not carcinogenic.	GE 1980
4000 mg/kg (24 wk intermittently)	TD_{LO}; neoplasms (skin exposure).	RTECS 1979
16 g/kg (40 wk intermittently)	TD; cancer (skin exposure).	RTECS 1979

Exposure Level (and Duration)	Effects	Reference
SPECIES: Non-mammalian		
3 to 64 ppm	Inhibition effects were found in *Pseudomonas putida* and perturbation effects were found in *Paramecium candatum* and *Vorticella campanula*.	AAR 1981

7.5 Symptoms of Exposure

General symptoms of exposure found in most information sources have not been specifically referenced. Only those of a more specific or unusual nature have their sources indicated.

7.5.1 Inhalation.

1. Excessive salivation.
2. Headache (Sax 1981).
3. Increased sensitivity to light in dark-adapted people (NIOSH 1976).
4. Conditioned electrocortical reflex (NIOSH 1976).
5. Skin eruptions (ITII 1981).
6. Coughing.
7. Irritation of eyes, nose and throat.
8. Respiratory irritation.
9. Difficulty breathing (Sax 1981).
10. Vomiting.
11. Diarrhea.
12. Loss of pain sensation (CHRIS 1978).
13. Cyanosis (AAR 1981).
14. Pulmonary edema (AAR 1981).
15. Death.

7.5.2 Ingestion.

1. Giddiness (AAR 1981).
2. Nausea.
3. Vomiting.

4. Abdominal pain.
5. Jaundice.
6. Burns in mouth, pharynx and gastrointestinal tract.
7. Perforation of intestinal tract (AAR 1981).
8. Weak pulse.
9. Tremor.
10. Convulsions.
11. Death.

7.5.3 Skin Contact.

1. Dizziness.
2. Irritation.
3. Dermatitis.
4. Burns.
5. Nausea.
6. Vomiting.
7. Loss of sensation of pain.
8. Gangrene.
9. Partial paralysis (ITII 1981).
10. Convulsions.
11. Coma.
12. Death.

7.5.4 Eye Contact.

1. Irritation.
2. Severe burns (AAR 1981).
3. Loss of pain sensation.
4. Conjunctival swelling (NIOSH/OSHA 1981).
5. Cornea becomes white and hypesthetic (NIOSH/OSHA 1981).
6. Papillomas (Patty 1981).
7. Loss of vision (NIOSH/OSHA 1981).

8 CHEMICAL COMPATIBILITY

8.1 Compatibility of Phenol with Other Chemicals and Chemical Groups

SPECIFIC CHEMICAL OR CHEMICAL GROUP	HEAT GENERATION	FIRE	EXPLOSION	FORMATION OF FLAMMABLE GASES	VIOLENT POLYMERIZATION	DECOMPOSITION	FORMATION OF TOXIC FUMES	FORMATION OF SUBSTANCES OF GREATER TOXICITY	PRESSURIZATION IN CLOSED VESSELS	SOLUBILIZATION	VIOLENT REACTION	NON-HAZARDOUS REACTION	SPECIFICS	REFERENCE
<u>GENERAL</u>														
Fire		●	●										Combustible, vapours may burn explosively.	Sax 1979; NFPA 1978
Heat		●					●						Yields flammable vapours when heated, emits toxic phenol fumes.	Sax 1979; NFPA 1978
<u>SPECIFIC CHEMICALS</u>														
Aluminium Trichloride and Nitrobenzene			●										Mixture of three explodes.	Bretherick 1979
Butadiene			●						●				When catalyzed and in a solvent.	NFPA 1978
Calcium Hypochlorite	●	●					●						Exothermic reaction with emission of phenol vapour.	
Formaldehyde		●							●				Runaway reaction can occur.	Bretherick 1979

8.1 Compatibility of Phenol with Other Chemicals and Chemical Groups (Cont'd)

SPECIFIC CHEMICAL OR CHEMICAL GROUP	HEAT GENERATION	FIRE	EXPLOSION	FORMATION OF FLAMMABLE GASES	VIOLENT POLYMERIZATION	DECOMPOSITION	FORMATION OF TOXIC FUMES	FORMATION OF SUBSTANCES OF GREATER TOXICITY	PRESSURIZATION IN CLOSED VESSELS	SOLUBILIZATION	VIOLENT REACTION	NON-HAZARDOUS REACTION	SPECIFICS	REFERENCE
Peroxodisulphuric Acid			●											Bretherick 1979
Peroxomonosulphuric Acid			●											Bretherick 1979
Sodium Nitrite				●									On heating.	Bretherick 1979
<u>CHEMICAL GROUPS</u>														
Alkali and Metal Hydroxides					●								Hazardous polymerization may occur with hydroxides - e.g., aluminum hydroxide.	CCPA 1983
Epoxides	●												Reaction may occur with acids or bases. Polymerization is possible.	EPA 600/2-80-076
Metal Chlorides					●								Hazardous polymerization may occur with anhydrous metal chlorides such as iron, tin, and aluminum.	CCPA 1983

8.1 Compatibility of Phenol with Other Chemicals and Chemical Groups (Cont'd)

SPECIFIC CHEMICAL OR CHEMICAL GROUP	HEAT GENERATION	FIRE	EXPLOSION	FORMATION OF FLAMMABLE GASES	VIOLENT POLYMERIZATION	DECOMPOSITION	FORMATION OF TOXIC FUMES	FORMATION OF SUBSTANCES OF GREATER TOXICITY	PRESSURIZATION IN CLOSED VESSELS	SOLUBILIZATION	VIOLENT REACTION	NON-HAZARDOUS REACTION	SPECIFICS	REFERENCE
Oxidizing Agents	●	●											Exhaustive oxidation may cause fire.	EPA 600/2-80-076
Polymerizable Compounds	●				●								Polymerization may occur.	EPA 600/2-80-076
Reducing Agents	●			●									Formation of flammable hydrogen gas may occur.	EPA 600/2-80-076

9 COUNTERMEASURES

9.1 Recommended Handling Procedures

The following procedures have been derived from a literature review. To avoid any deviation from the intended meaning, the wording of the original source has been presented essentially unchanged - in so doing, it is recognized that there may be some discrepancies between different sources of information. It is recognized that countermeasures are dependent on the situation, and thus what may appear to be conflicting information may in fact be correct for different situations. The following procedures should not be considered as Environment Canada's recommendations.

9.1.1 Fire Concerns. Phenol is a combustible material (Dow ERIS 1980). When heated, phenol can yield flammable vapours which will form explosive mixtures with air (NFPA 1978). Contact with strong oxidizing agents may generate explosive mixtures.

9.1.2 Fire Extinguishing Agents. Use water spray to cool containers involved in a fire.

Small fires: Dry chemical, CO_2, water spray or foam (alcohol).

Large fires: Water spray, fog or foam.

Move containers from fire area if this can be done without risk (ERG 1980).

9.1.3 Spill Actions.

9.1.3.1 General. Stop or reduce discharge of material if this can be done without risk. Eliminate all sources of ignition. Avoid skin contact and inhalation (GE 1980). If leakage of a container occurs, remove the container to the outdoors or to an isolated, well-ventilated area, and transfer contents to suitable containers (MCA, 1964).

The following materials are recommended for plugging leaks of phenol: styrofoam urethane foam, and butyl rubber (EPA 68-01-0106).

A fluorocarbon water foam can be applied to the spill area to diminish vapours and fire hazards (EPA 670/2-75-042). Cellosize, an absorbent material, has shown possible applicability for vapour suppression and/or containment of phenol in spill situations (ICI 1982).

9.1.3.2 Spills on land. When spilled in solid form, shovel promptly into containers with covers for recovery or disposal (NIOSH/OSHA 1981).

When spilled in molten form at ambient temperatures below 41°C, phenol solidifies and can be shoveled into containers for recovery or disposal. At temperatures above 41°C, liquid phenol can be absorbed on vermiculite, dry sand, or earth, and shoveled into metal containers with covers for disposal (NIOSH/OSHA 1981; GE 1980). The spill area can be neutralized with lime, sodium bicarbonate or calcium carbonate (EPA 670/2-75-042; CG-D-38-76).

For large (molten) spills, contain if possible by forming mechanical and/or chemical barriers to prevent spreading. Use fly ash or cement powder to absorb the liquid bulk (EPA 670/2-75-042).

9.1.3.3 Spills in water. Contain if possible. Application of activated carbon at 10 percent the spill amount over the region occupied by 10 mg/L or greater concentrations is recommended (EPA 670/2-75-042). Other sorbents which should be considered are: Floridin XXF, Tonsil AC, Polyurethane foam, Amberlite XAD-1-8, Poly(styrenesulphonate), Amberlite IR 45, Dowex 1, and other macroreticular resins (CG-D-38-76). Neutralization with lime or sodium bicarbonate is also recommended as *in situ* treatment (EPA 670/2-75-042).

9.1.4 Cleanup and Treatment.

9.1.4.1 General. For treatment of contaminated water, gravity separation of solids followed by dual media filtration and carbon adsorption is recommended. The recommended carbon ratio is : 1.0 to 10.0 kg soluble materials. The wastewater from backwash of the filtration and adsorption units is returned to the gravity separator (EPA 600/2-77-227).

The following treatment processes have shown possible applicability for spill countermeasures:

Process	Percent Removal (TSA 1980)
Biological	62 to 100
Reverse Osmosis	6 to 100
Ultrafiltration	75
Stripping	Steam Strippable
Solvent Extraction	4 to 98
Carbon Adsorption	80 to 100
Resin Adsorption	>99

Process	Percent Removal (TSA 1980)
Clarification/Sedimentation	>99
Clarification/Sedimentation with Chemical Addition (Alum)	>90
Clarification/Sedimentation with Chemical Addition (Alum, Polymer)	89
Clarification/Sedimentation with Chemical Addition (Alum, Lime)	96
Gas Flotation with Chemical Addition (Calcium Chloride, Polymer)	80
Gas Flotation with Chemical Addition (Polymer)	72
Granular Media Filtration	>93
Activated Sludge	>99
Lagoon (Aerated)	>99
Solvent Extraction	>99
Granular Activated Carbon Adsorption	>96
Powdered Carbon Addition (with Activated Sludge)	>85
Reverse Osmosis	80

9.1.4.2 Removal of phenol with exchange resin (EPA 670/2-75-042). An anionic exchange resin (Amberlite IRA 400-OH) was applied loosely to a solution containing 1000 mg/L phenol. Resin dosage was at 10 g/L. Agitation was provided by magnetic stirrers. After 5 min, 76 percent of phenol was removed. The resin continued to remove phenol to the conclusion of the experiment (85 min).

9.1.4.3 Phenol destruction by peroxide (OGJ 1975). Experiments have shown that hydrogen peroxide with the presence of catalysts can oxidize phenol to carbon dioxide and water. Reduction of 99.94 percent in phenol content was obtained using a solution containing 500 mg/L phenol and a 2.0 to 1.0 hydrogen peroxide to phenol weight ratio. The reaction was completed in less than 5 min and was independent of temperature over the range of 21°C to 49°C. Ferrous sulphate appeared to be the most practical catalyst for this system.

9.1.4.4 Phenol degradation with $KMnO_4$ (JAWA 1975). Experiments have shown that 90 percent phenol removal can be accomplished at 25°C using a 7 to 1 ratio of $KMnO_4$ to phenol. $KMnO_4$ must be in basic solutions to perform as a powerful oxidizing agent. The reaction becomes 90 percent complete in less than an hour when the pH is 8.5 and over. Raising the pH to the optimum is accomplished with lime, soda ash or caustic soda. If the pH goes beyond 10.0, reactions other than phenol degradation will take place.

9.1.4.5 Oxidation of phenol. Ozone has been shown in laboratory studies to reduce phenol concentrations in the range of 2 to 7 ppm by more than 90 percent (CG-D-56-78). Aeration can be advantageous for oxidizing phenol in appropriate spill situations. The process is slow and the water has to be contained. An aeration of 1 to 6 h is apparently sufficient. Carbon acts catalytically and reduces the sparging requirements considerably. For low concentration, warm-water phenol pollution, aeration or oxidation enhanced by exposure to sunlight or ultraviolet light may be advantageous (CG-D-38-76).

9.1.4.6 Reduction of phenol (CG-D-38-76). Sulphite anions and ferrous cations both reduce phenol and have been used in waste water treatment.

9.1.4.7 Biodegradation of phenol (CG-D-56-78). Although not considered as a high-potential response technique at this time, pond tests revealed the possibility of indigenous bacteria assisting in phenol decomposition. Furthermore, these same tests suggested *in situ* applications of both bacteria acclimated to the hazardous material and unacclimated bacteria would be effective in biodegradation. The technique is plagued by problems of acclimation of bacterial cultures, difficulties in storage and handling, and uncertainties regarding BOD levels and the introduction of pathogenic bacteria.

9.1.4.8 Vapour-phase oxidation of phenol (Indus. Eng. Chem. 1973). Studies have shown that vapour-phase oxidation rate of phenol in low concentration in an air-water vapour stream over supported copper oxide was first order and relatively rapid between 150°C and 270°C. At 250°C and a space velocity of 116.1 m^3/s per m^3 of catalyst, the phenol conversion was 99.6 percent with little evidence of any intermediate organics in the condensate.

9.1.4.9 Reverse osmosis (Fang 1976). Reverse osmosis shows promise in the removal of phenol from water. Tests on various membranes yield the following removal efficiencies on a single pass: cellulose acetate, <20 percent; cross-linked polyethylenimine, 70-85 percent; bibenzimidazol and sulphonated polyphenylene oxide, 20 percent; and aromatic polymides, 45-85 percent.

9.1.5 Disposal. Waste phenol must never be discharged directly into sewers or surface waters. Burn contaminated waste in an approved incinerator (GE 1980). Following treatment, either at the spill site or at a waste management facility, the resultant sludge can be disposed of to a secure landfill.

9.1.6 Charcoal Filtration Data (EPA 600/8-80-023). The following recommended values for the removal of phenol in water by either the single stage powdered carbon contactor or the granular carbon column adsorption system were obtained using the Freundlich Adsorption equation. These carbon doses were reported in water with neutral pH.

SINGLE STAGE POWDERED CARBON CONTACTOR SYSTEM

Initial Concentration (mg/L)	Carbon Doses (mg/L)	Final Concentration (mg/L)
1.0	150	0.1
1.0	570	0.01
1.0	2000	0.001
0.1	52	0.01
0.1	200	0.001
0.01	18	0.001

GRANULAR CARBON COLUMN SYSTEM: (ESTIMATED)

Initial Concentration (mg/L)	Carbon Doses or Requirements to Achieve Breakthrough (mg/L)
1.0	47
0.1	17
0.01	5.8

9.1.7 Protective Measures. For entry into a situation where the spilled material and its characteristics are unknown, self-contained breathing apparatus and a totally encapsulated chemical suit should be worn.

If the spilled material is known to be phenol:

- Response personnel should be provided with and required to use impervious clothing, gloves, face shields (20 cm minimum), and other appropriate protective clothing necessary to prevent any possibility of skin contact with solid or liquid phenol or liquids containing phenol (NIOSH/OSHA 1981).
- Dust- and splash-proof safety goggles are recommended where there is any possibility of solid or liquid phenol or liquids containing phenol contacting the eyes (NIOSH/OSHA 1981).
- The following clothing materials show breakthrough times of greater than 1 hour: butyl rubber and neoprene. The following show breakthrough times of about 1 hour: natural rubber, neoprene with natural rubber, polyethylene and chlorinated polyethylene. The following show breakthrough times of less than 1 hour: nitrile, polyvinyl alcohol and polyvinyl chloride (Little 1983).
- Neoprene or polyethylene is recommended for gloves (OHM-TADS 1981).
- Protective equipment should not have exposed aluminum, zinc, lead or alloys (OHM-TADS 1981).
- The following chemical suit materials are recommended for protection against phenol (EE-20): cloropel, PVC (acceptable resistance) and butyl (good resistance).
- When gross phenol contact occurs, remove contaminated clothing under safety shower. Continue washing until all odour of phenol has disappeared (GE 1980).
- Nonimpervious clothing which becomes contaminated with phenol should be removed immediately and not reworn until the phenol is removed from the clothing (NIOSH/OSHA 1981).
- Eye wash stations and chemical safety showers should be readily available in areas of use and spill situations (GE 1980).
- The following is a list of minimum respiratory protection recommended for personnel working in areas where phenol is present (NIOSH/OSHA 1981).

Condition	Minimum Respiratory Protection* Required Above 5 ppm
Vapour or Particulate Concentration 50 ppm or less	Any chemical cartridge respirator with an organic vapour cartridge(s) and dust and mist filter(s). Any supplied-air respirator. Any self-contained breathing apparatus.
100 ppm or less	A chemical cartridge respirator with a full facepiece, organic vapour cartridge(s) and dust and mist filter(s). A gas mask with a chin-style or a front- or back-mounted organic vapour canister and dust and mist filter. Any supplied-air respirator with a full facepiece, helmet, or hood. Any self-contained breathing apparatus with a full facepiece.
Greater than 100 ppm** or entry or escape from unknown concentrations	Self-contained breathing apparatus with a full facepiece operated in pressure-demand or other positive pressure mode. A combination respirator which includes a Type C supplied-air respirator with a full facepiece operated in pressure-demand or other positive pressure or continuous-flow mode and an auxiliary self-contained breathing apparatus operated in pressure-demand or other positive pressure mode.
Fire Fighting	Self-contained breathing apparatus with a full-facepiece operated in pressure-demand or other positive pressure mode.
Escape	Any gas mask providing protection against organic vapours and particulates. Any escape self-contained breathing apparatus.

* Only NIOSH-approved or MSHA-approved equipment should be used.

** Use of supplied-air suits may be necessary to prevent skin contact while providing respiratory protection from airborne concentrations of phenol; however, this equipment should be selected, used, and maintained under the immediate supervision of trained personnel. Where supplied-air suits are used above a concentration of 100 ppm, an auxiliary self-contained breathing apparatus operated in positive pressure mode should also be worn.

9.1.8 Storage and Handling Precautions. Store in a cool, dry, well-ventilated area, away from heated surfaces, open flames and ignition sources. Separate outdoor storage is preferred. Areas of use or handling should not allow smoking or eating (GE 1980).

Overheating of phenol tank cars is a dangerous practice and all precautions must be taken to avoid heating phenol in tank cars over 60°C. Prevent physical damage to containers. Do not drop or bump drums (MCA 1964).

9.2 Specialized Countermeasures Equipment, Materials or Systems

The following items are taken from a previous study (Dillon 1982) and should not be considered to be the only suitable specialized countermeasures equipment, materials or systems available. More details on the specifications, performance and availability of these items can be found in the referenced study.

Land Containment	"MSAR" Dike-Pak System Portafoam System
Containment of Spills in Water	Sea Curtain Barrier
Temporary Storage	Portable Collection Bag System
Chemical/Physical Modification	Zimmerman Wet Air Oxidation System Dynactor
Removal from Water	EPA Mobile Physical-Chemical Treatment Trailers
Treating Agents	Hazorb (sorbent) Polybac, Mutant Bacterial Hydrocarbon Degrader

10 PREVIOUS SPILL EXPERIENCE

10.1 General

A number of spill accidents for this chemical have been documented. The incident discussed here has been selected primarily because significant information, potentially useful in future spill circumstances, has been learned from it.

10.2 Train Derailment (PC TDWR 1982; HMIR 1981)

A train derailment occurred in a remote area. A tank car containing approximately 60 000 L of pure phenol spilled most of its contents into a dry creek bed adjacent to the rail line. The spill contaminated an area of 820 m^2 (approximately 137 m long by 6 m wide).

Cleanup crews arrived at the spill site several hours later and were able to recover about 11 000 L remaining in the tank car. The spilled phenol was found to have been absorbed in the sand; further migration to lower depths was restricted by a clay bottom. Earthen dams were built between the spill site and a nearby lake to prevent any possible spreading of phenol towards the lake. Sodium hypochlorite was used briefly as a treating agent; its effectiveness in neutralizing the phenol was not evaluated.\ Soil samples were taken to determine the extent of contamination through the soil and the amount of soil to be excavated. Based on the soil analysis findings, approximately 1700 m^3 of contaminated soil were removed and trucked to a waste management facility (290 km away). It took 10 days to complete the tasks of soil removal and cleanup of the site. The spill site was then covered with fresh fill to its original condition and seeded. No fish kill or contamination of the nearby lake were observed.

Damming of the spill route prevented direct lake contamination by the phenol, and removal of soil prevented longer term leaching. The effectiveness of sodium hypochlorite as a treatment for phenol was not stated. It could be expected to react to produce chlorophenols, which would cause more environmental problems than the original phenol spill. Higher pH (from hypochlorite) would also enhance phenol solubility and movement in groundwater.

11 ANALYTICAL METHODS

The general approach adopted for each of the Priority Chemicals was as follows.

Methods have been documented here for the analysis of samples from air, water and soil in a normally equipped chemical laboratory remote from the spill site. Customary sources of standard or recommended analytical methods were consulted, and outlines are presented for each chemical. These sources included publications of the U.S. National Institute for Occupational Safety and Health (NIOSH), the U.S. Environmental Protection Agency (EPA), the American Water Works Association (AWWA), the American Society for Testing and Materials (ASTM), and the American National Standards Institute (ANSI).

If the standard or recommended methods were judged to be reliable and specific enough for the analysis of environmental and materials samples from spill sites and if they do not require highly specialized laboratory equipment, no additional methods were sought.

If especially simple, reliable tests (e.g., commonly used industrial methods) were found, they have been presented as well.

11.1 Quantitative Method for the Detection of Phenol in Air

11.1.1 Gas Chromatography (NIOSH 1977). A range of 9.46 to 37.8 mg/m^3 (2.46 to 9.83 ppm) of phenol in air may be determined using gas chromatography.

A known volume of air is drawn through a midget bubbler containing 15 mL of 0.1 N sodium hydroxide. A sample size of 100 L at 1 L/min is recommended. The sample is quantitatively transferred to a 25 mL volumetric flask. The bubbler is rinsed with two 1 mL portions of distilled water and the rinsings added to the 25 mL volumetric flask. A 0.1 mL volume of concentrated sulphuric acid is added to the flask and the pH checked to be sure it is less than 4. The sample is diluted to volume with distilled water and mixed.

A 5 L aliquot of sample is injected into a suitable gas chromatograph equipped with a flame ionization detector and a 4 ft. x 1/4 in. O.D. stainless steel column packed with 35/60 mesh Tenax. The phenol is determined using a suitable electronic integrator which measures peak-areas in conjuction with a standard curve. Typical gas chromatograph operating conditions are: nitrogen carrier gas flow at 50 mL/min, hydrogen gas flow at 65 mL/min, air flow at 500 mL/min, injector temperature at 215°C, detector temperature at 225°C, and a column temperature of 200°C.

11.2 Qualitative Method for the Detection of Phenol in Air

A range of 0 to 5 ppm of phenol in air may be determined using a Drager detector tube for phenol. A known volume of air is drawn through a Drager detector tube for phenol using a Drager multi-gas detector pump. A colour change of the pale grey indicating layer to bluish violet indicates phenol. The colour change is based on the reaction between phenol and 2,6-dibromoquinonechlorimide (Drager 1979).

11.3 Quantitative Method of the Detection of Phenol in Water

11.3.1 Gas-liquid Chromatography (ASTM 1979). Concentrations greater than 1 ppm of phenol in water may be determined by direct aqueous injection chromatography.

A minimum of 2 L of representative sample is collected in a clear glass bottle having a screw cap lined with aluminum foil or TFE-fluorocarbon. The sample should be kept cool and protected from atmospheric oxygen.

A 3 to 5 L aliquot of sample is injected into a suitable gas chromatograph with a flame ionization detector. The analytical column is 10 ft. x 1/8 in. O.D. stainless steel packed with 60/80 mesh Chromosorb coated with 20 percent Carbowax 20M-TPA. The phenol is determined using a suitable electronic integrator which measures peak area, retention time and a calibration curve. Typical gas chromatograph conditions are: helium carrier gas flow at 25 mL/min, hydrogen gas flow at 25 mL/min, detector temperature at 250°C, column temperature at 210°C, oven temperature at 210°C.

11.4 Qualitative Method for the Detection of Phenol in Water

The sample is collected as in Section 11.3.1. A 1 mL volume of dilute ferric chloride solution is added to a small amount of sample. The mixture is shaken. A vividly coloured solution (blue, green or violet) indicates a phenol (Owen 1969).

11.5 Quantitative Method for the Detection of Phenol in Soil

11.5.1 Partition Infrared (AWWA 1981). A range of 40 to 400 ppm of phenol in soil may be determined using partition infrared spectrophotometry.

Approximately 20 g sample of soil, accurately weighed, is collected in a glass jar and dried by the addition of magnesium sulphate. The phenol is extracted with three 30 mL portions of Freon® 113 (1,1,2-trichloro-1,2,2-trifluoroethane) and the extracts combined in a 100 mL volumetric flask. The sample is taken to volume with Freon®.

The sample is scanned from 3200 to 2700 cm^{-1} on a suitable double-beam recording infrared spectrophotometer using matched 1 cm cells with Freon® in the reference cell. The phenol is determined using a calibration curve.

11.6 Qualitative Method for the Detection of Phenol in Soil

The sample is collected as in Section 11.5.1 and extracted. A 1 mL volume of dilute ferric chloride solution is added to a small amount of sample. The mixture is shaken. A vividly coloured solution (blue, green or violet) indicates a phenol (Owen 1969).

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EnviroTIPS

Common Abbreviations

BOD	biological oxygen demand
b.p.	boiling point
CC	closed cup
cm	centimetre
CMD	count median diameter
COD	chemical oxygen demand
conc	concentration
c.t.	critical temperature
eV	electron volt
g	gram
ha	hectare
Hg	mercury
IDLH	immediately dangerous to life and health
Imp. gal.	imperial gallon
in.	inch
J	joule
kg	kilogram
kJ	kilojoule
km	kilometre
kPa	kilopascal
kt	kilotonne
L	litre
lb.	pound
LC_{50}	lethal concentration fifty
LC_{LO}	lethal concentration low
LD_{50}	lethal dose fifty
LD_{LO}	lethal dose low
LEL	lower explosive limit
LFL	lower flammability limit
m	metre
m	meta
M	molar
MAC	maximum acceptable concentration
max	maximum
mg	milligram
MIC	maximum immission concentration
min	minute or minimum
mm	millimetre
µg	microgram
µm	micrometre

°Be	degrees Baumé (density)
MMAD	mass median aerodynamic diameter
MMD	mass median diameter
m.p.	melting point
MW	molecular weight
N	newton
NAS	National Academy of Sciences
NFPA	National Fire Protection Association
NIOSH	National Institute for Occupational Safety and Health
nm	nanometre
o	ortho
OC	open cup
p	para
P_c	critical pressure
PEL	permissible exposure level
pH	measure of acidity/ alkalinity
ppb	parts per billion
ppm	parts per million
P_s	standard pressure
psi	pounds per square inch
s	second
STEL	short-term exposure limit
STIL	short-term inhalation limit
T_c	critical temperature
TC_{LO}	toxic concentration low
Td	decomposition temperature
TD_{LO}	toxic dose low
TL_m	median tolerance limit
TLV	Threshold Limit Value
Ts	standard temperature
TWA	time weighted average
UEL	upper explosive limit
UFL	upper flammability limit
VMD	volume mean diameter
v/v	volume per volume
w/w	weight per weight