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Environmental Protection
Agency

Office of Solid Waste and
Emergency Response
(5201G)

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Environmental Remediation Technologies (165.3) Student Manual

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FOREWORD

This manual is for reference use of students enrolled in scheduled training courses of the U.S. Environmental Protection Agency (EPA). While it will be useful to anyone who needs information on the subjects covered, it will have its greatest value as an adjunct to classroom presentations involving discussions among the students and the instructional staff.

This manual has been developed to provide the best available current information; however, individual instructors may provide additional material to cover special aspects of their presentations.

Because of the limited availability of the manual, it should not be cited in bibliographies or other publications.

References to products and manufacturers are for illustration only; they do not imply endorsement by EPA.

Constructive suggestions for improvement of the content and format of the Environmental Remediation Technologies (165.3) manual are welcome.



ENVIRONMENTAL REMEDIATION TECHNOLOGIES (165.3)

This introductory-level course provides participants with an overview of the treatment technologies most frequently used for cleanups of contaminated media. The emphasis of the course is on the technology description, applicability, and limitations of appropriate treatment technologies, rather than on the design of such systems. It is intended for new on-scene coordinators, remedial project managers, waste site managers, and other personnel interested in remediation.

Topics that are discussed include site stabilization; site characterization; fate and transport; technology screening; capping and containing; basic water treatment; chemical reactions and separations; aqueous biological treatment; phytoremediation; bioremediation; physical separation; soil washing and solvent extraction; thermal treatment; immobilization; in-situ treatments; innovative treatments; and process testing.

Training methods include lectures and group problem-solving exercises. Case studies are used to demonstrate applications of the treatment technologies. Group discussions relevant to the course are encouraged.

After completing the course, participants will be able to:

- Evaluate appropriate techniques to assess, stabilize, and screen potential remedies for contaminated sites.
- Identify the processes and explain the limitations of the most frequently used treatment technologies.
- Identify resources that describe innovative treatment technologies.

Note: Calculators are recommended.

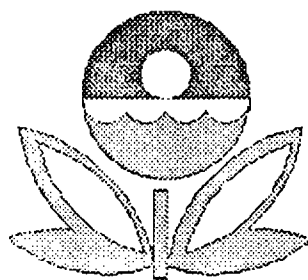
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Environmental Remediation Technologies

(165.3)

U.S. Environmental Protection Agency's
Environmental Response Center



Presented by:
Tetra Tech NUS, Inc.
EPA Contract No. 68-C7-oo33

ENVIRONMENTAL REMEDIATION TECHNOLOGIES

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GLOSSARY AND ACRONYMS	



SITE STABILIZATION

SITE STABILIZATION

- Control technologies
 - Prevent contact
 - Prevent migration
- Removal technologies
 - Eliminate threat to health or environment

CONTROL TECHNOLOGIES

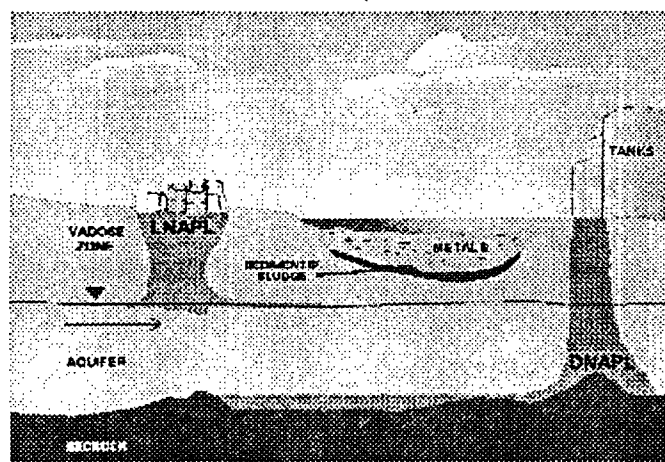
- Applications
 - Site security – Keep people (and animals) off the site
 - Runoff controls – Prevent migration of hazardous waste
- Limitations
 - Do not remediate the site

CONTROL TECHNOLOGIES (cont.)

- Site security
 - Fences
 - Warning signs
 - Guards

CONTROL TECHNOLOGIES (cont.)

- Runoff control
 - Ditches, berms, dikes
 - Caps
 - Containment walls



REMOVAL TECHNOLOGIES

- Applications
 - Remove immediate (acute) threats
 - Overpacking, staging, bulking, removal
- Limitations
 - Generally do not remediate long term (chronic) threats

REMOVAL TECHNOLOGIES (cont.)

- Eliminate concentrated chemicals by removal and treatment
- Drums, tanks, lagoons, and soil

REMOVAL TECHNOLOGIES (cont.)

- Damaged or corroded drums, cans, cylinders, or other containers

REMOVAL TECHNOLOGIES (cont.)

- Overpack
 - Vessels cover or protect hazardous material containers held in overpacks

SAMPLING AND BULKING

- Stage or organize containers in double rows for sampling

SAMPLING AND BULKING (cont.)

- Sample containers
- Identify chemicals

SAMPLING AND BULKING (cont.)

- Test for compatibility
- Separate into "waste streams" with similar chemicals

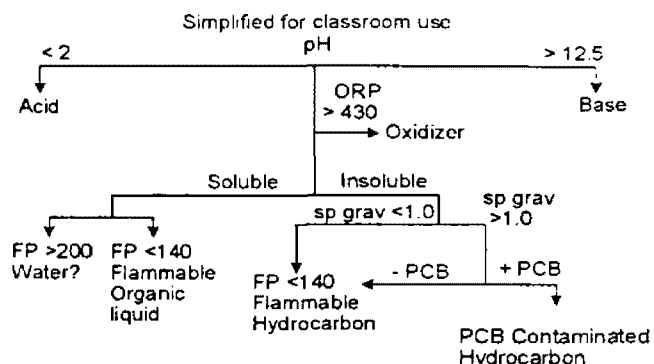
SAMPLING AND BULKING (cont.)

- Bulking
 - Combining contents of many small containers, ponds, or lagoons into a few large quantities with compatible materials

BULKING EXERCISE

- Divide into teams of 4 to 6 students per team.
- Use the Compatibility Chart to select an appropriate waste category for each of the drums of chemicals listed.
- Group drums of compatible chemicals into waste streams for bulking.

COMPATIBILITY CHART



REPORT: DRUMS OF CHEMICALS

Drum	pH	ORP	Sol	sp grav	FP	PCB
1	7.1	400	Yes	NA	+200	No
2	1.0	390	Yes	NA	+200	No
3	6.9	395	No	0.6	-100	No
4	7.0	400	No	0.8	120	No
5	1.2	405	Yes	NA	+200	No
6	7.1	550	Yes	NA	+200	No
7	6.8	390	No	1.9	125	No
8	6.9	395	No	1.7	+200	Yes
9	7.0	400	No	0.6	-100	No
10	6.9	390	No	0.7	110	No
11	1.5	400	Yes	NA	+200	No
12	7.1	390	No	0.6	-100	No

ANSWER SHEET

Waste Stream

Drum Number(s)

Acid	
Base	
Oxidizer	
Water?	
Flammable Organic Liquid	
Flammable Hydrocarbon	
PCB Contaminated Hydrocarbon	

SITE CHARACTERIZATION

SITE CHARACTERIZATION

- Basic information
- Contamination
- Site conditions
- Risk assessment

BASIC INFORMATION

- Site history
- General condition
- General surroundings
- Future land use

SITE HISTORY

- Title search
- Business records
- Sanborn maps
- Aerial photographs
- Enforcement documents
- Employee/public interviews

CHEMDYNE RECYCLING



GENERAL CONDITION

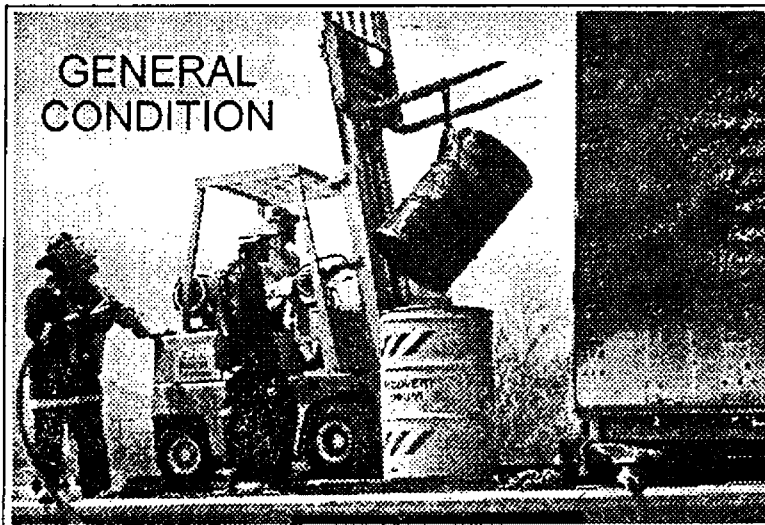
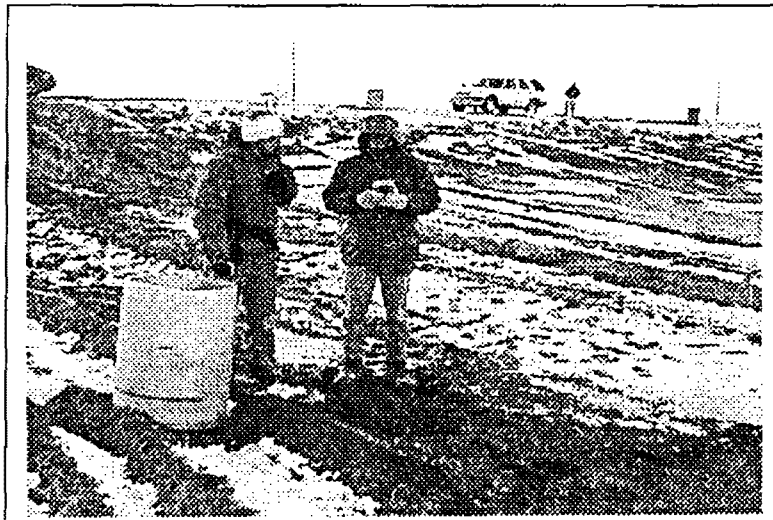


TABLE 1.1: SUMMARY OF ANALYTICAL DATA FOR SELECTED SAMPLES						
Sample ID	Location	Depth (ft)	Parameter	Value	Unit	Notes
101	Area A	0-1	Asbestos	0.1	mg/L	Below detection limit
102	Area A	1-2	Asbestos	0.1	mg/L	Below detection limit
103	Area A	2-3	Asbestos	0.1	mg/L	Below detection limit
104	Area A	3-4	Asbestos	0.1	mg/L	Below detection limit
105	Area A	4-5	Asbestos	0.1	mg/L	Below detection limit
106	Area A	5-6	Asbestos	0.1	mg/L	Below detection limit
107	Area A	6-7	Asbestos	0.1	mg/L	Below detection limit
108	Area A	7-8	Asbestos	0.1	mg/L	Below detection limit
109	Area A	8-9	Asbestos	0.1	mg/L	Below detection limit
110	Area A	9-10	Asbestos	0.1	mg/L	Below detection limit
111	Area A	10-11	Asbestos	0.1	mg/L	Below detection limit
112	Area A	11-12	Asbestos	0.1	mg/L	Below detection limit
113	Area A	12-13	Asbestos	0.1	mg/L	Below detection limit
114	Area A	13-14	Asbestos	0.1	mg/L	Below detection limit
115	Area A	14-15	Asbestos	0.1	mg/L	Below detection limit
116	Area A	15-16	Asbestos	0.1	mg/L	Below detection limit
117	Area A	16-17	Asbestos	0.1	mg/L	Below detection limit
118	Area A	17-18	Asbestos	0.1	mg/L	Below detection limit
119	Area A	18-19	Asbestos	0.1	mg/L	Below detection limit
120	Area A	19-20	Asbestos	0.1	mg/L	Below detection limit
121	Area A	20-21	Asbestos	0.1	mg/L	Below detection limit
122	Area A	21-22	Asbestos	0.1	mg/L	Below detection limit
123	Area A	22-23	Asbestos	0.1	mg/L	Below detection limit
124	Area A	23-24	Asbestos	0.1	mg/L	Below detection limit
125	Area A	24-25	Asbestos	0.1	mg/L	Below detection limit
126	Area A	25-26	Asbestos	0.1	mg/L	Below detection limit
127	Area A	26-27	Asbestos	0.1	mg/L	Below detection limit
128	Area A	27-28	Asbestos	0.1	mg/L	Below detection limit
129	Area A	28-29	Asbestos	0.1	mg/L	Below detection limit
130	Area A	29-30	Asbestos	0.1	mg/L	Below detection limit
131	Area A	30-31	Asbestos	0.1	mg/L	Below detection limit
132	Area A	31-32	Asbestos	0.1	mg/L	Below detection limit
133	Area A	32-33	Asbestos	0.1	mg/L	Below detection limit
134	Area A	33-34	Asbestos	0.1	mg/L	Below detection limit
135	Area A	34-35	Asbestos	0.1	mg/L	Below detection limit
136	Area A	35-36	Asbestos	0.1	mg/L	Below detection limit
137	Area A	36-37	Asbestos	0.1	mg/L	Below detection limit
138	Area A	37-38	Asbestos	0.1	mg/L	Below detection limit
139	Area A	38-39	Asbestos	0.1	mg/L	Below detection limit
140	Area A	39-40	Asbestos	0.1	mg/L	Below detection limit
141	Area A	40-41	Asbestos	0.1	mg/L	Below detection limit
142	Area A	41-42	Asbestos	0.1	mg/L	Below detection limit
143	Area A	42-43	Asbestos	0.1	mg/L	Below detection limit
144	Area A	43-44	Asbestos	0.1	mg/L	Below detection limit
145	Area A	44-45	Asbestos	0.1	mg/L	Below detection limit
146	Area A	45-46	Asbestos	0.1	mg/L	Below detection limit
147	Area A	46-47	Asbestos	0.1	mg/L	Below detection limit
148	Area A	47-48	Asbestos	0.1	mg/L	Below detection limit
149	Area A	48-49	Asbestos	0.1	mg/L	Below detection limit
150	Area A	49-50	Asbestos	0.1	mg/L	Below detection limit
151	Area A	50-51	Asbestos	0.1	mg/L	Below detection limit
152	Area A	51-52	Asbestos	0.1	mg/L	Below detection limit
153	Area A	52-53	Asbestos	0.1	mg/L	Below detection limit
154	Area A	53-54	Asbestos	0.1	mg/L	Below detection limit
155	Area A	54-55	Asbestos	0.1	mg/L	Below detection limit
156	Area A	55-56	Asbestos	0.1	mg/L	Below detection limit
157	Area A	56-57	Asbestos	0.1	mg/L	Below detection limit
158	Area A	57-58	Asbestos	0.1	mg/L	Below detection limit
159	Area A	58-59	Asbestos	0.1	mg/L	Below detection limit
160	Area A	59-60	Asbestos	0.1	mg/L	Below detection limit
161	Area A	60-61	Asbestos	0.1	mg/L	Below detection limit
162	Area A	61-62	Asbestos	0.1	mg/L	Below detection limit
163	Area A	62-63	Asbestos	0.1	mg/L	Below detection limit
164	Area A	63-64	Asbestos	0.1	mg/L	Below detection limit
165	Area A	64-65	Asbestos	0.1	mg/L	Below detection limit
166	Area A	65-66	Asbestos	0.1	mg/L	Below detection limit
167	Area A	66-67	Asbestos	0.1	mg/L	Below detection limit
168	Area A	67-68	Asbestos	0.1	mg/L	Below detection limit
169	Area A	68-69	Asbestos	0.1	mg/L	Below detection limit
170	Area A	69-70	Asbestos	0.1	mg/L	Below detection limit
171	Area A	70-71	Asbestos	0.1	mg/L	Below detection limit
172	Area A	71-72	Asbestos	0.1	mg/L	Below detection limit
173	Area A	72-73	Asbestos	0.1	mg/L	Below detection limit
174	Area A	73-74	Asbestos	0.1	mg/L	Below detection limit
175	Area A	74-75	Asbestos	0.1	mg/L	Below detection limit
176	Area A	75-76	Asbestos	0.1	mg/L	Below detection limit
177	Area A	76-77	Asbestos	0.1	mg/L	Below detection limit
178	Area A	77-78	Asbestos	0.1	mg/L	Below detection limit
179	Area A	78-79	Asbestos	0.1	mg/L	Below detection limit
180	Area A	79-80	Asbestos	0.1	mg/L	Below detection limit
181	Area A	80-81	Asbestos	0.1	mg/L	Below detection limit
182	Area A	81-82	Asbestos	0.1	mg/L	Below detection limit
183	Area A	82-83	Asbestos	0.1	mg/L	Below detection limit
184	Area A	83-84	Asbestos	0.1	mg/L	Below detection limit
185	Area A	84-85	Asbestos	0.1	mg/L	Below detection limit
186	Area A	85-86	Asbestos	0.1	mg/L	Below detection limit
187	Area A	86-87	Asbestos	0.1	mg/L	Below detection limit
188	Area A	87-88	Asbestos	0.1	mg/L	Below detection limit
189	Area A	88-89	Asbestos	0.1	mg/L	Below detection limit
190	Area A	89-90	Asbestos	0.1	mg/L	Below detection limit
191	Area A	90-91	Asbestos	0.1	mg/L	Below detection limit
192	Area A	91-92	Asbestos	0.1	mg/L	Below detection limit
193	Area A	92-93	Asbestos	0.1	mg/L	Below detection limit
194	Area A	93-94	Asbestos	0.1	mg/L	Below detection limit
195	Area A	94-95	Asbestos	0.1	mg/L	Below detection limit
196	Area A	95-96	Asbestos	0.1	mg/L	Below detection limit
197	Area A	96-97	Asbestos	0.1	mg/L	Below detection limit
198	Area A	97-98	Asbestos	0.1	mg/L	Below detection limit
199	Area A	98-99	Asbestos	0.1	mg/L	Below detection limit
200	Area A	99-100	Asbestos	0.1	mg/L	Below detection limit



MAPS

- Street
- Topographic

STREET MAPS

- Roads
- Businesses
- Recreational areas
- Residential areas

TOPOGRAPHICAL MAPS

- Geographical relief
- Vegetation
- Recreational and residential
- Updated from aerial photographs

CONTAMINATION

- Types
- Inorganic
 - Volatiles
 - Semivolatiles
 - Chlorinated

CONTAMINATION (cont.)

Extent

- Sample plans
- Data quality objectives

SAMPLING METHODOLOGIES

Sampling design:

- Judgmental
- Random sampling
- Stratified random sampling
- Systematic sampling
- Systematic random sampling

THE DQO PROCESS

1. State the problem
- ↓
2. Identify the decision
- ↓
3. Identify inputs to the decision
- ↓
4. Define the study boundaries
- ↓
5. Develop a decision rule
- ↓
6. Specify limits on decision errors
- ↑↑
7. Optimize the design for obtaining data



PHYSICAL CONDITIONS

- Surface water data
- Soil data
- Groundwater data

SURFACE WATER DATA

- Speed and direction of flow
- Sediment amount and locations
- Discharge to groundwater
- Flooding possibilities

SOIL DATA

- Particle size and density
- Homogeneity
- Porosity and permeability
- Carbon and moisture content
- Eh, pH, K_{ow} , K_{oc}

GROUNDWATER DATA

- Rate of groundwater flow
- Hydraulic conductivity
- Hydraulic gradient
- Effective porosity
- Discharge to surface water

SAMPLING TECHNIQUES

- Hand augers
- Direct push methods
- Hollow stem auger, split spoon
- Wells and well construction
- Methods
 - US EPA SW 846
 - US EPA ERT SOP
 - ASTM

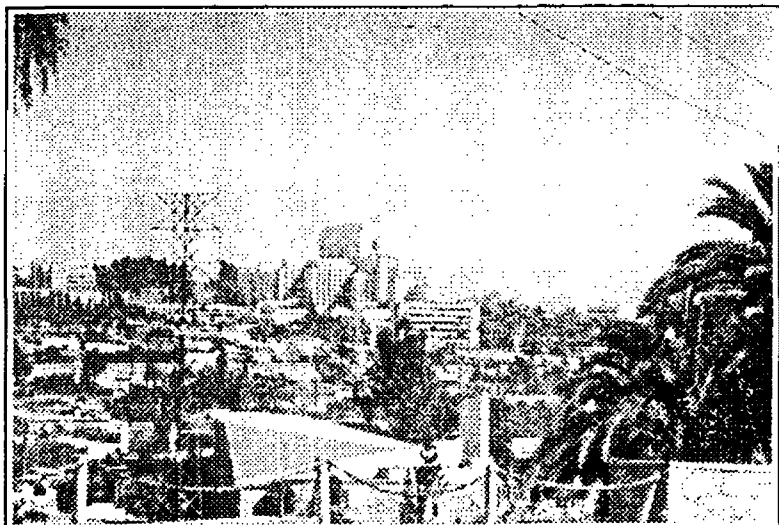
RISK ASSESSMENTS

"Risk assessment is the use of a factual base to define the health effects of exposure of individuals or populations to hazardous materials or situations."

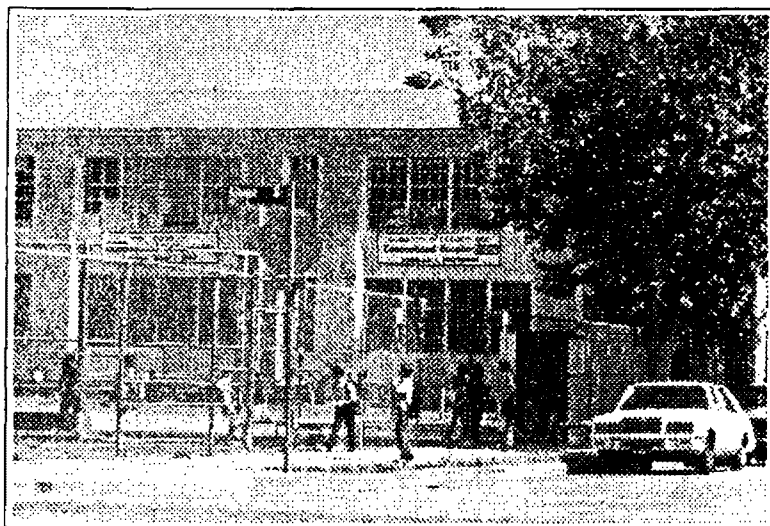
Source NRC 1983

RISK ASSESSMENT

- Contaminant
- Receptors
- Toxicity information
- Fate and transport
 - Pathways



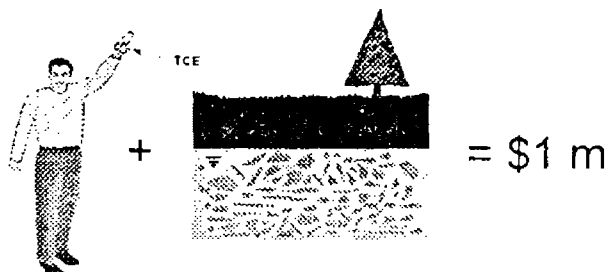






FATE AND TRANSPORT OF CHEMICAL CONTAMINANTS

MILLION-DOLLAR PROBLEM:

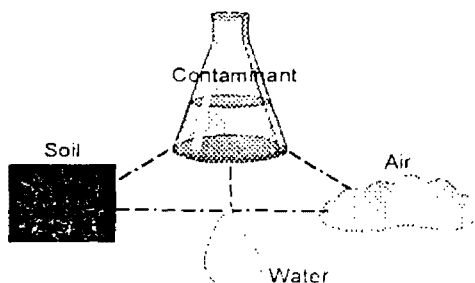


*Pour one cup of TCE onto the ground and it
will cost you \$1 million to get it out.*

WHY?

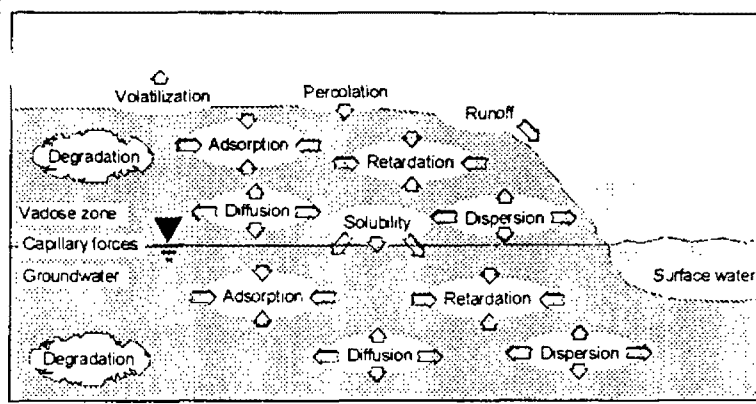
MILLION-DOLLAR QUESTION:

Why would it cost so much?



Contaminant behavior is a function of the properties of
both the contaminant and the environmental media

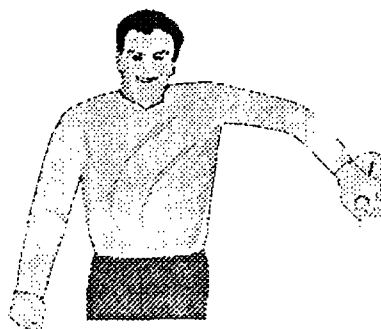
PROCESSES IN THE ENVIRONMENT



FATE AND TRANSPORT

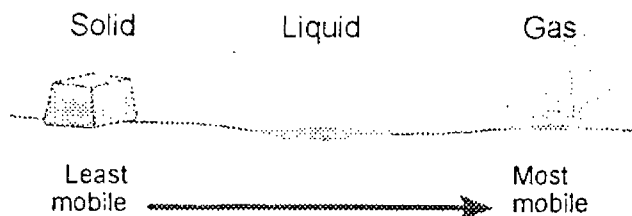
- Surface
- Subsurface
- Distribution
- Degradation

CONTAMINANT BEHAVIOR ON SURFACE



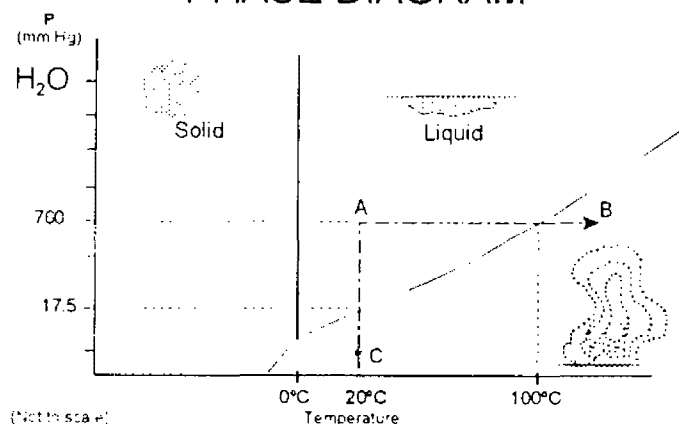
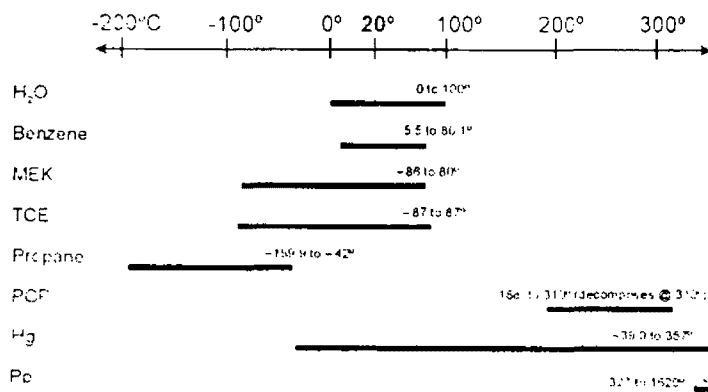
- Physical state
- Volatilization
- Runoff
- Solubility
- Percolation

PHYSICAL STATE

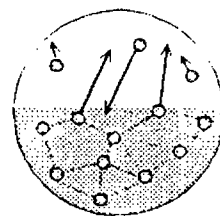
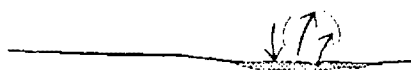


- Organic vs. inorganic
- Transition temperatures, e.g., melting point, boiling point

PHASE DIAGRAM

QUANTIFYING PHYSICAL STATE
LIQUID RANGE (at variable vapor pressure)

VOLATILIZATION



Function of:

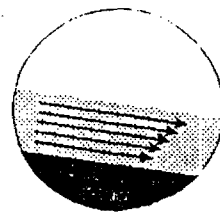
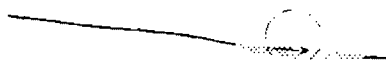
- Molecular weight
- "Cohesive forces"
 - Van der Waals forces
 - Polarity
- Temperature

QUANTIFYING VOLATILIZATION

Vapor Pressure (VP): Pressure exerted above a compound in liquid or solid phase

Compound	VP (mmHg @ 20°C)	
Benzene	80.0	↑ MORE VOLATILE
TCE	63.0	
H ₂ O	17.5	↓ LESS VOLATILE
PCP	.00011	

RUNOFF



Function of:

- Hydraulic gradient
- "Cohesive forces" (e.g., internal friction)

QUANTIFYING RUNOFF

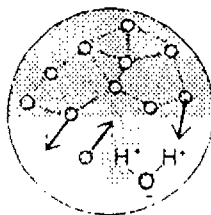
Dynamic viscosity (μ): Indicates degree of resistance to flow

Compound	μ (centipoise @ 20°C)	
TCE	.57	↑ MOST MOBILE
Benzene	.65	
H ₂ O	1.0	↓ LEAST MOBILE
Kerosene	2.5	
Phenol	8.5	

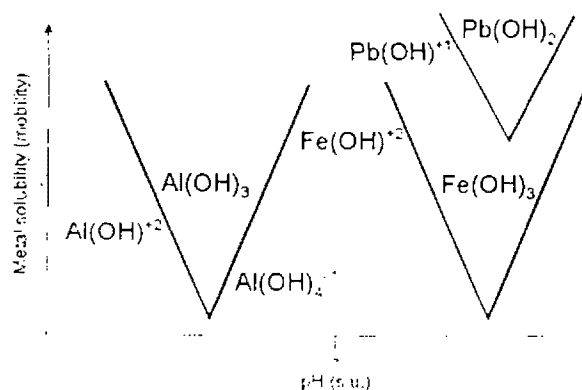
SOLUBILITY

Function of:

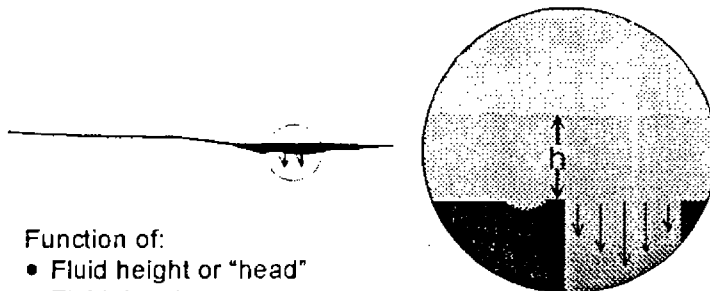
- Cohesive forces
- Adhesive forces
 - Van der Waals
 - Polarity
 - Ionization



INORGANIC SOLUBILITY vs. pH



PERCOLATION



Function of:

- Fluid height or "head"
- Fluid density
- Cohesive forces ("surface tension")
- Adhesive forces ("wetting")

QUANTIFYING PERCOLATION

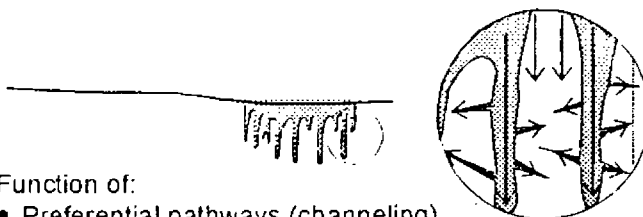
Kinematic viscosity (ν): Indicates degree of resistance to downward flow (combines density with dynamic viscosity)

Compound

ν (centistokes @ 20°C)

TCE	.39	↑ MOST MOBILE
Benzene	.74	
H ₂ O	1.0	↓ LEAST MOBILE

SUBSURFACE

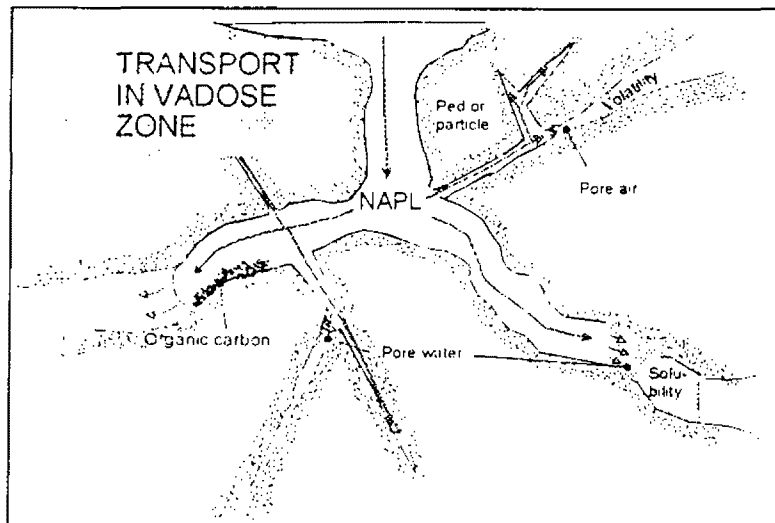


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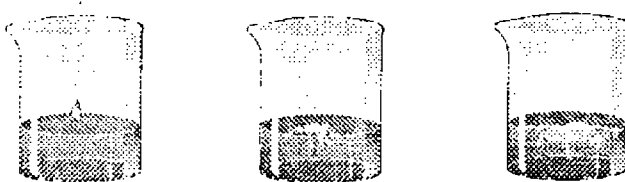
- Preferential pathways (channeling)
 - Macropores
 - Micropores
- Solubility
- Sorption
- Volatility

SUBSURFACE DISTRIBUTION

- Physical movement stops when matric potential and hydrodynamic head are balanced
- Molecular movement continues as long as relative concentration remains "unbalanced"

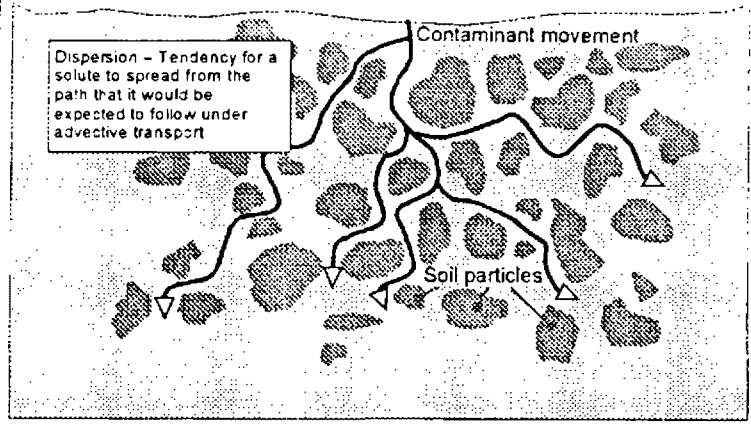


DIFFUSION

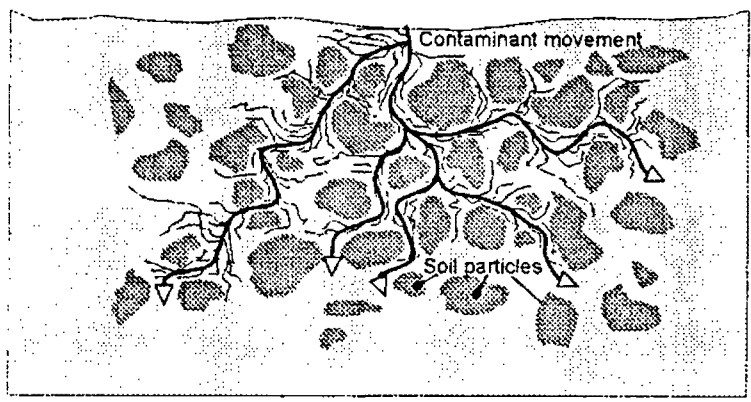


DISPERSION

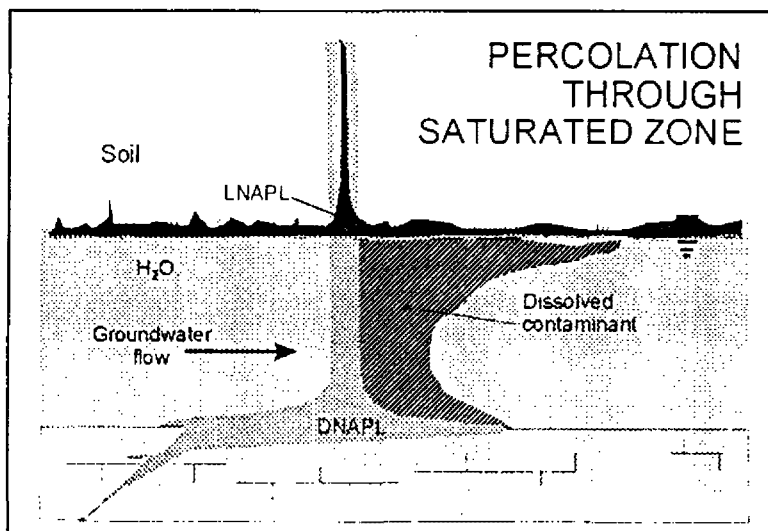
Dispersion - Tendency for a solute to spread from the path that it would be expected to follow under advective transport



DISPERSIVITY DISPERSION AND DIFFUSION



PERCOLATION THROUGH SATURATED ZONE



QUANTIFYING DISTRIBUTION

Air	Vapor pressure (VP)
Water	Solubility (Sol.)
Water/Air	Henry's Law (H_L)
Water/soil	Sorption (K_{oc} , CEC)

HENRY'S LAW

$$H_L = \frac{VP}{\text{Solubility}}$$

Compound	VP (mmHg)	Sol.(mg/L)	H_L ($\frac{\text{atm}\cdot\text{m}^3}{\text{mol}}$)
VC	2,300	1,100	6.9×10^{-1}
Benzene	76	1,780	5.4×10^{-3}
TCE	58	1,100	8.9×10^{-3}
MEK	71.2	268,000	2.7×10^{-5}
PCP	0.00011	1	2.8×10^{-6}

SORPTION

The degree of attraction between a non-polar chemical and the natural organic matter associated with an aquifer (retardation)

Function of:

- Contaminant
- Fraction of organic carbon in medium (f_{oc})
- Properties of soil, e.g., structure, texture (k_{oc})

SORPTION (cont.)

CATION EXCHANGE CAPACITY (CEC)

Total cations adsorbed on a unit mass of soil (centimoles/kg)

Function of:

- Soil texture (e.g., clay, silt, sand)
- Soil surface area (clay type, e.g., kaolinite)
- Organic matter content

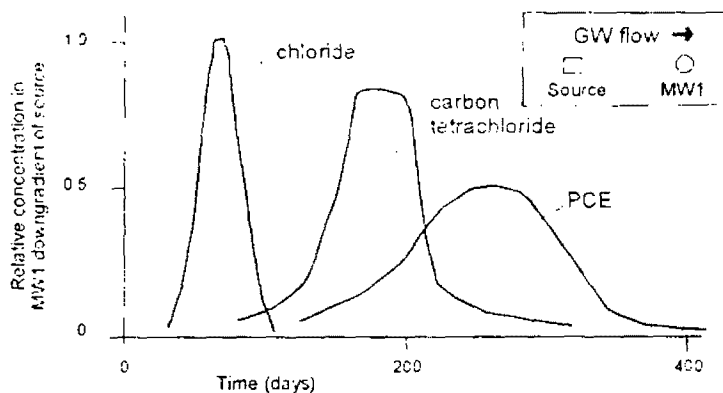
DEGRADATION OF CONTAMINANTS

- Break down chemically (organics only)
- Examples of degradation processes:
 - Hydrolysis
 - Redox
 - Biodegradation

DEGRADATION (cont.)

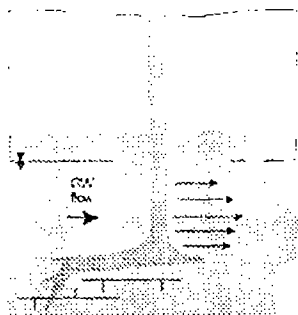
- Function of:
 - pH
 - Bond strengths of contaminant
 - Properties of attacking agent
 - Redox potential
 - "Hospitable" environment (biodegradation)

FATE AND TRANSPORT OF CONTAMINANTS



MILLION-DOLLAR PROBLEM: WHAT ARE YOU GOING TO DO?

Problem: Saturated soil contaminated with TCE (enough to contaminate groundwater to solubility limit for 15 years)



ANOTHER MILLION-DOLLAR PROBLEM: WHAT ARE YOU GOING TO DO?

Problem: Chrome plating bath solutions have been disposed into unlined lagoon (now dry).

Most of chromium has been adsorbed by underlying clay soils.

Groundwater contamination was not detected.



TECHNOLOGY SELECTION

TECHNOLOGY SELECTION

- Presumptive remedies
- Potential remedies
- Treatability studies
- Technology searches

PRESUMPTIVE REMEDIES

- Wood treater sites
- Municipal landfills
- Ex-situ groundwater treatment
- Volatile organic compounds in soil

WOOD TREATER SITES

- Pentachlorophenol, creosote, and/or chromated copper arsenate
- Biological treatment, incineration, and/or immobilization

MUNICIPAL LANDFILLS

- Containment
 - Landfill
 - Groundwater control
 - Leachate collection and treatment
 - Gas collection and treatment

EX-SITU GROUNDWATER TREATMENT

- LNAPL recovery
- Air stripping, carbon adsorption, chemical precipitation, ion exchange

VOLATILE ORGANIC COMPOUNDS IN SOILS

- Soil vapor extraction
- Low temperature desorption
- Incineration

POTENTIAL REMEDIES

- For organics and inorganics
- For water and soils/sludges

ORGANIC CONTAMINANTS

- Volatile organics
- Semivolatile to non-volatile organics
- Pesticides

VOLATILE ORGANICS

- Aqueous
 - Air stripping, air sparging, bioslurping, or in-situ biological treatment
- Soils and sludges
 - Soils vapor extraction, soils heating, or bioventing
 - Thermal treatment or in-situ biological treatment

SEMI-VOLATILE TO NON-VOLATILE ORGANICS

- Aqueous
 - Carbon adsorption, UV oxidation, chemical or electron beam destruction, and in-situ biological treatment
- Soils and sludges
 - Soils flushing, soil washing, chemical extraction
 - Thermal treatment, ex-situ biological treatment

PESTICIDES

- Aqueous
 - UV oxidation, thermal, carbon adsorption, or biological treatment
 - Dehalogenation
- Soils and sludges
 - Thermal treatment, biological treatment, or dehalogenation
 - Chemical extraction

INORGANICS

- Aqueous
 - Chemical treatment, ion exchange, or membrane separation
 - Dewatering
- Soils and sludges
 - Immobilization, soil washing, chemical or biological extraction

TREATABILITY STUDIES

- Screening and remedy selection studies
- Pilot and full scale studies

SCREENING AND REMEDY SELECTION STUDIES

- Used when several remedies may work
- Help identify which remedies, if any, meet site clean-up goals
- Help identify the need for the use of multiple remedies

PILOT AND FULL SCALE STUDIES

- Used to verify that selected remedies will actually meet clean-up goals
- Help determine design specifications and operating parameters

TECHNOLOGY SEARCHES

- Literature searches
- Internet searches

LITERATURE SEARCHES

- Presumptive remedies for CERCLA sites
- Engineering bulletins for potential remedies
- Treatability studies under CERCLA

INTERNET SEARCHES (http://)

- EPA.gov
- clu-in.org
- epareachit.org
- frtr.gov
- gwrtao.org

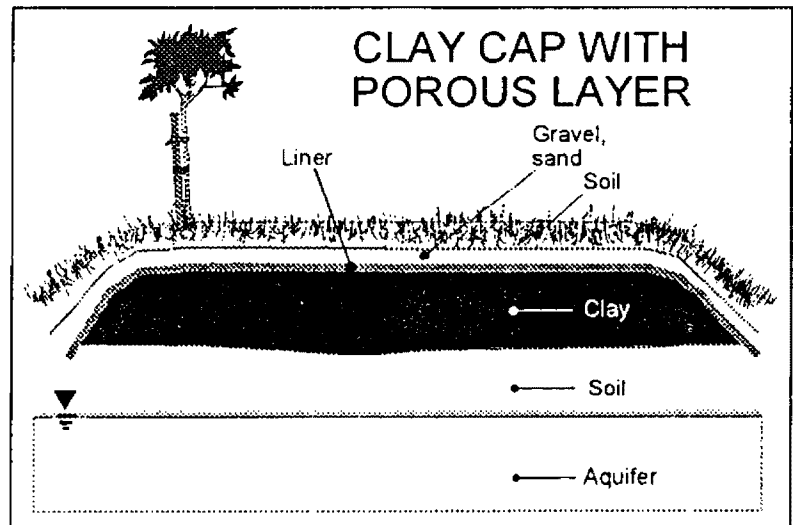
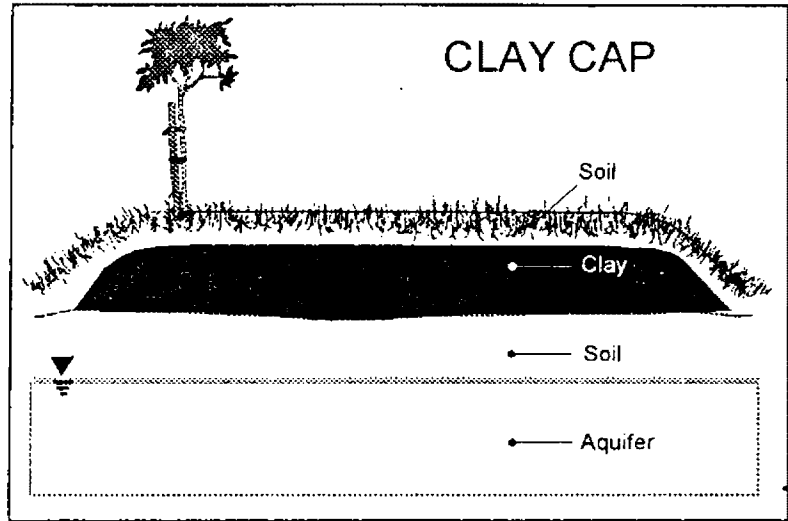
CAPPING AND CONTAINMENT

CAPPING

- Capping controls airborne contamination and surface water infiltration
- Containment controls groundwater movement

CAPPING (cont.)

- Applications
 - Slows the movement of airborne or dustborne contaminants
 - Slows the movement of surface water into the ground
- Limitations
 - Does not directly remediate contaminants
 - Makes soil recovery and further treatment difficult



CONTAINMENT

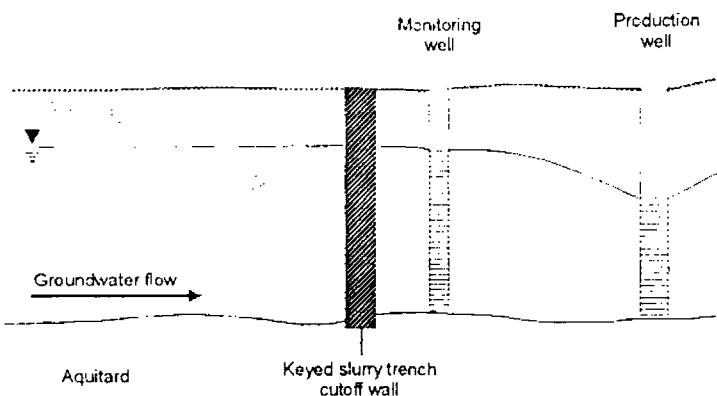
Subsurface walls to control groundwater movement

- Slurry trench cutoff wall
- Grout curtain
- Sheet piling

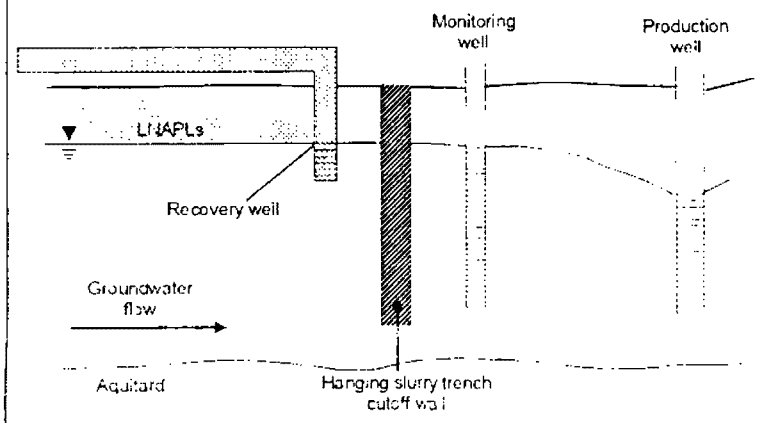
CONTAINMENT (cont.)

- Applications
 - Slows the movement of groundwater-borne contaminants using subsurface walls
 - Can be used to dewater a site for remediation
- Limitations
 - Does not directly remediate contaminants

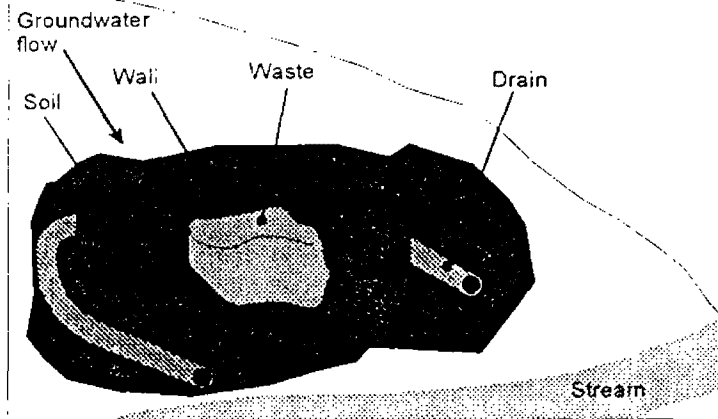
SLURRY TRENCH CUTOFF WALL



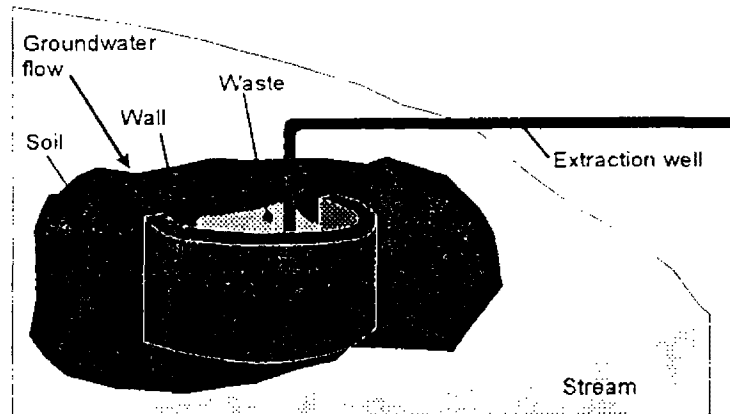
HANGING WALL



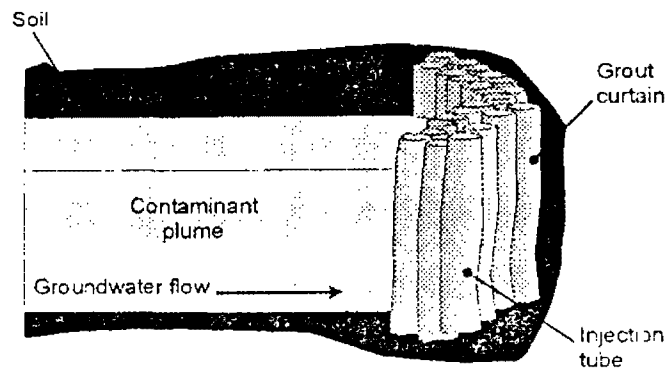
UPGRADIENT WALL



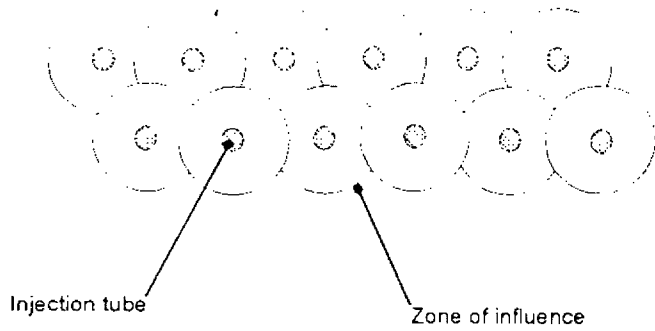
DOWNGRAIDENT WALL



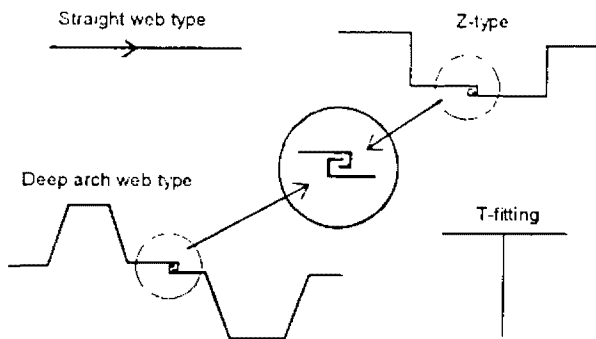
GROUT CURTAIN



GROUT INJECTION



STEEL PILING SHAPES AND INTERLOCKS



BASIC WATER TREATMENT

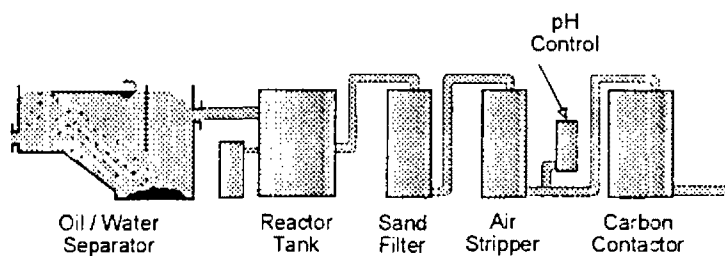
Basic Water Treatment Advantages

- Treats most contaminants
- Highly flexible and reliable

Basic Water Treatment Disadvantages

- Could be very expensive
- Energy- and labor-intensive
- Regulatory problems with discharge
- Fine-grained material a problem

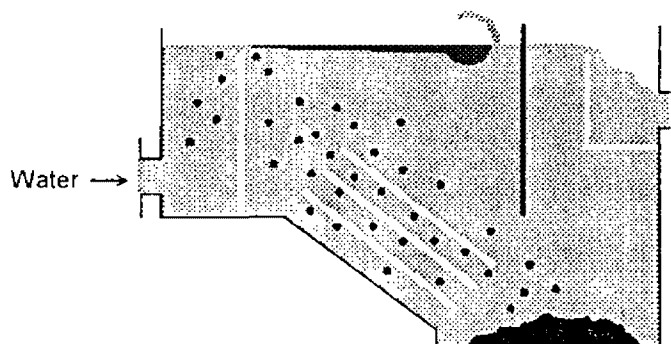
Basic Water Treatment System Diagram



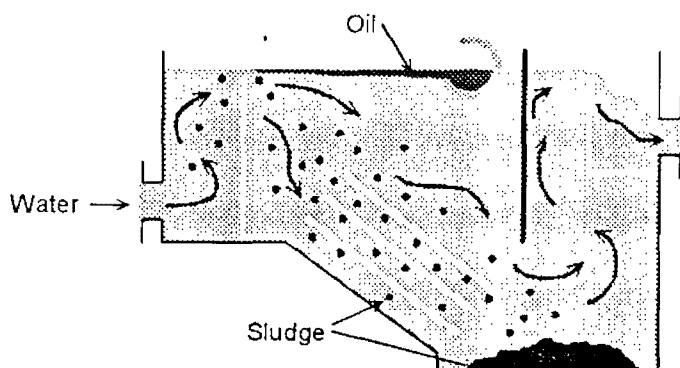
Oil / Water Separator



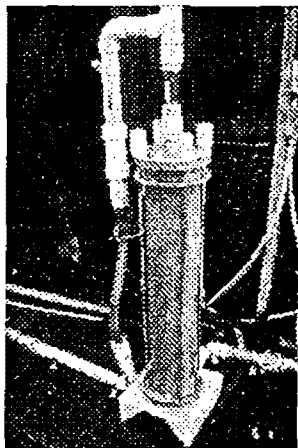
Weir-type Oil / Water Separator



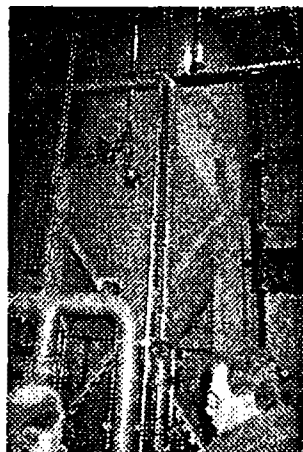
Weir-type Oil / Water Separator



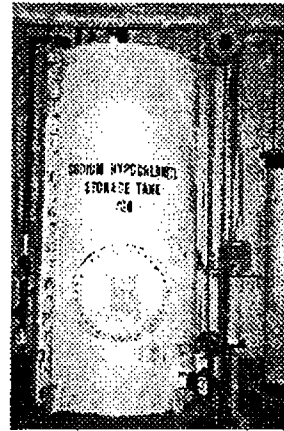
Oil Filter



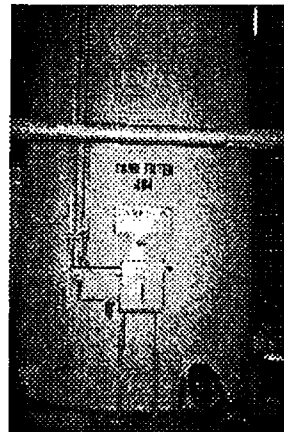
Reaction Tank



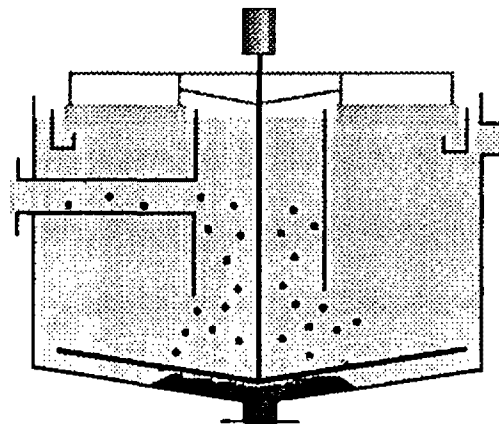
Sodium Hypochlorite Storage Tank



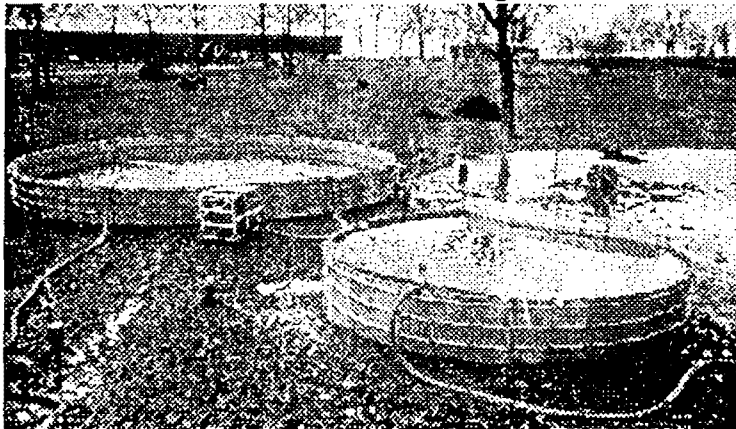
Sand Filter



Clarifier Diagram



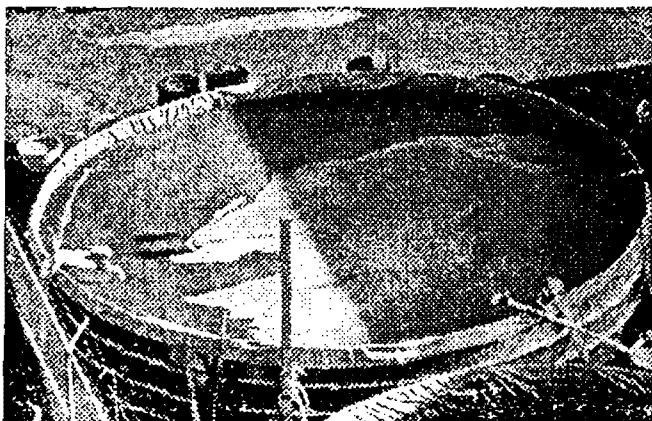
Clarifier and Settling Basin



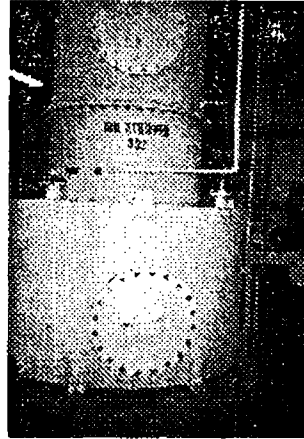
Clarifier



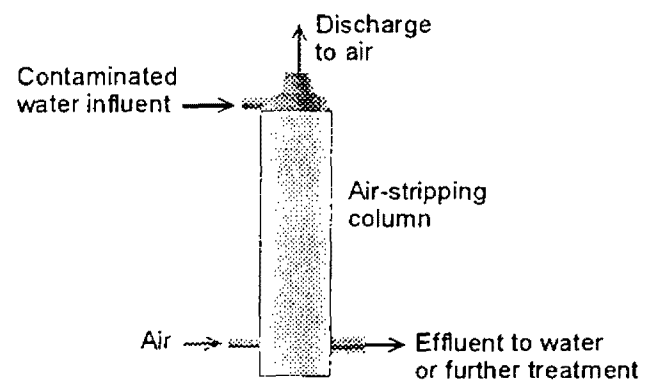
Settling Tank



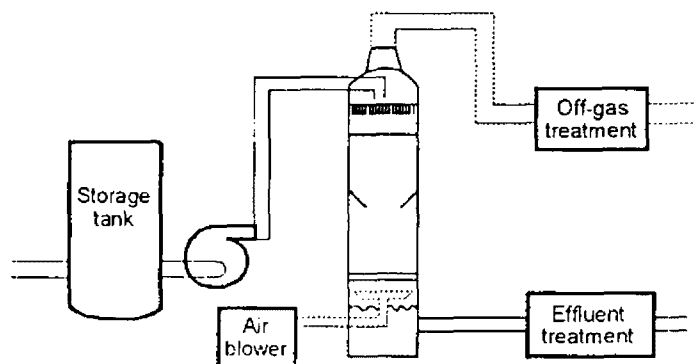
Air Stripper



Air Stripper Diagram



Air Stripper Diagram Internal Components



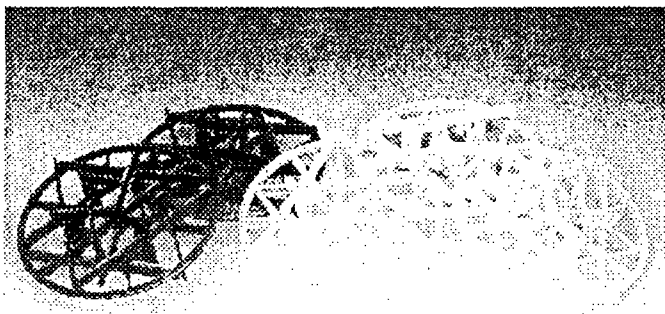
Packing Saddles



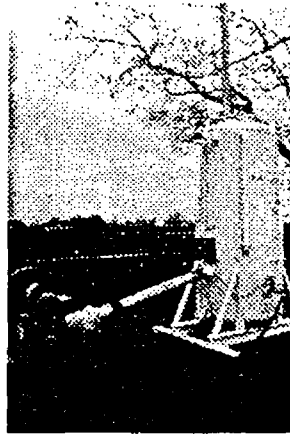
Packing Rings



Packing Snowflakes



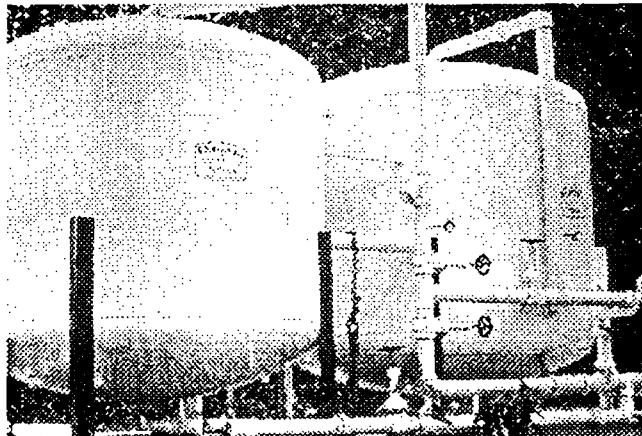
Air Stripper (another view)



Carbon Dioxide Cylinders



Carbon Adsorption Unit

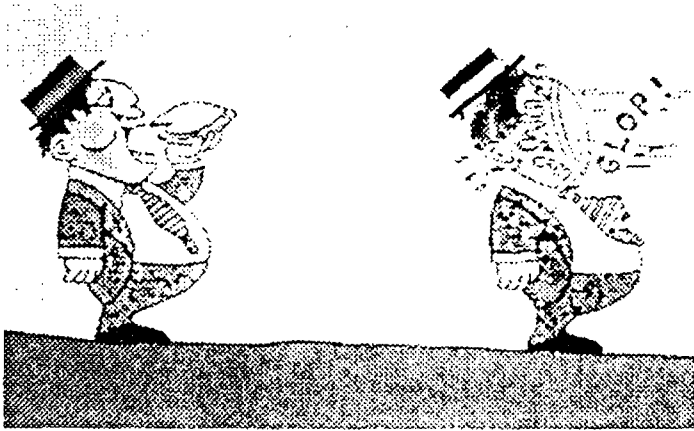


Carbon Adsorption

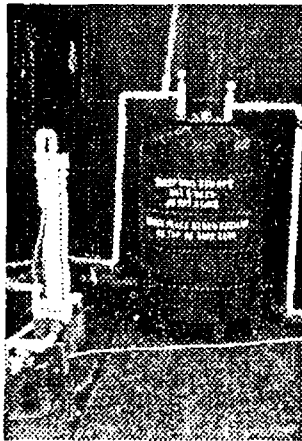


aDsorption

Carbon Adsorption



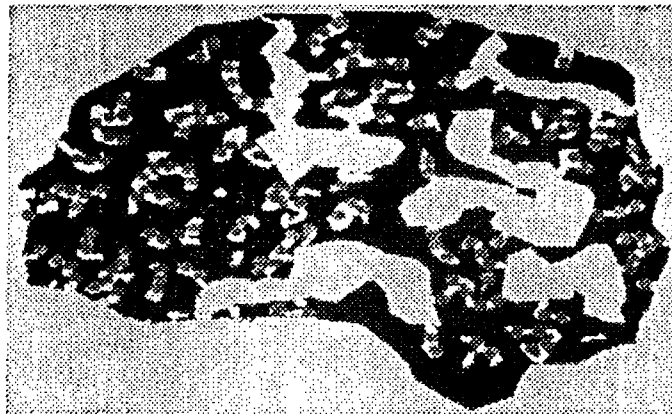
Carbon Adsorption Unit



Magnified Carbon Particle



Magnified Carbon Particle In Use



Carbon Adsorption Unit and Prefilters
mounted on a flatbed trailer



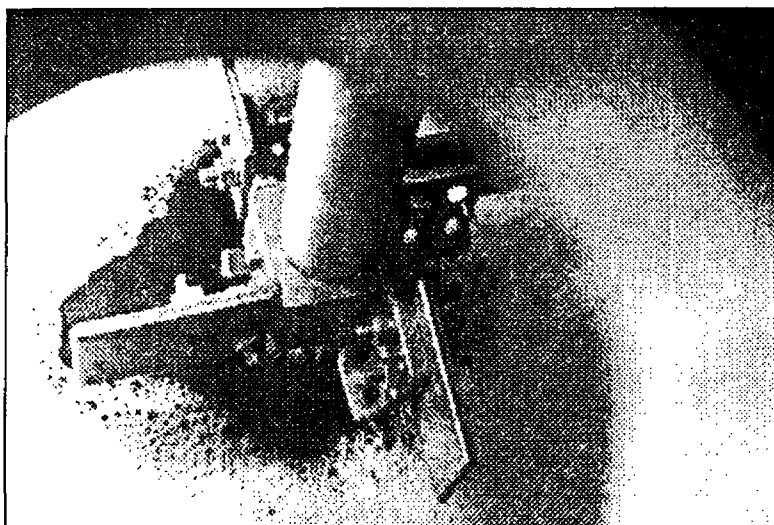
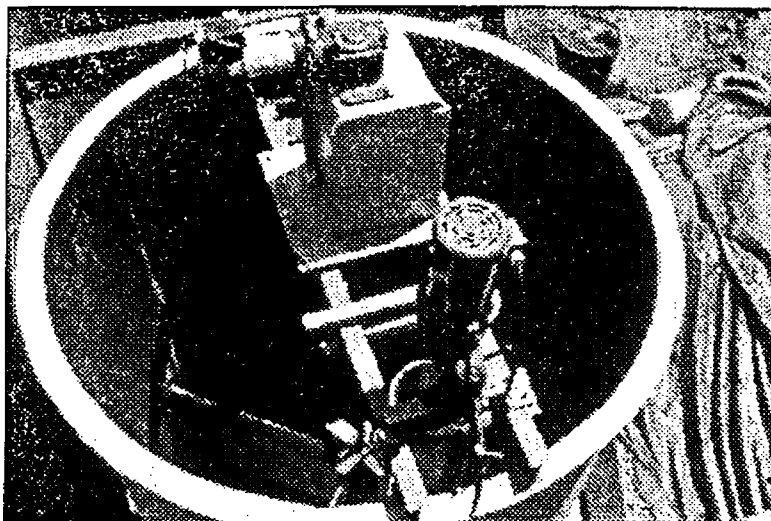
CHEMICAL REACTIONS AND SEPARATIONS

CHEMICAL REACTION SYSTEMS

- Neutralization
- Precipitation
- Reduction
- Oxidation

NEUTRALIZATION

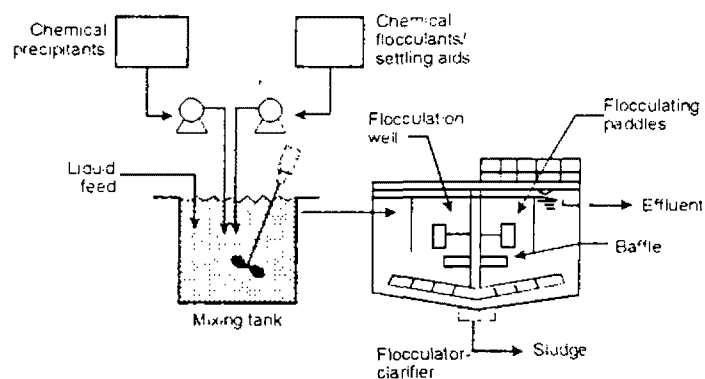
- Advantage
 - Eliminates corrosives
- Disadvantages
 - Process chemicals are hazardous
 - Generates a lot of heat
 - Heavy-duty process equipment may be needed



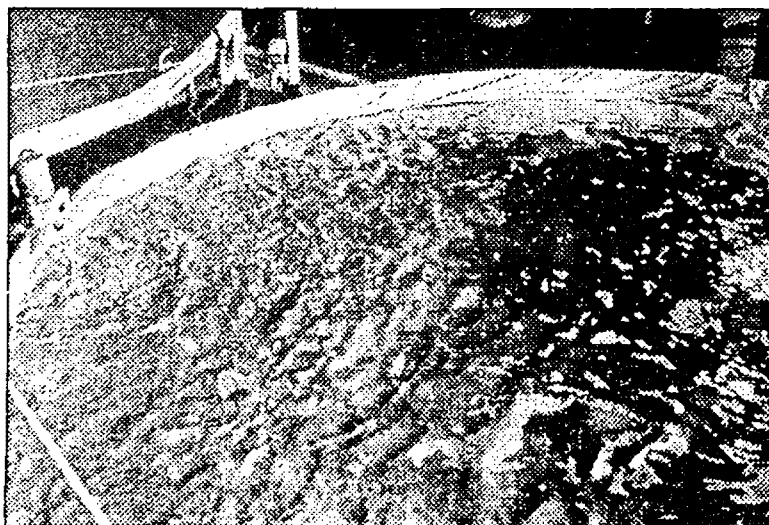
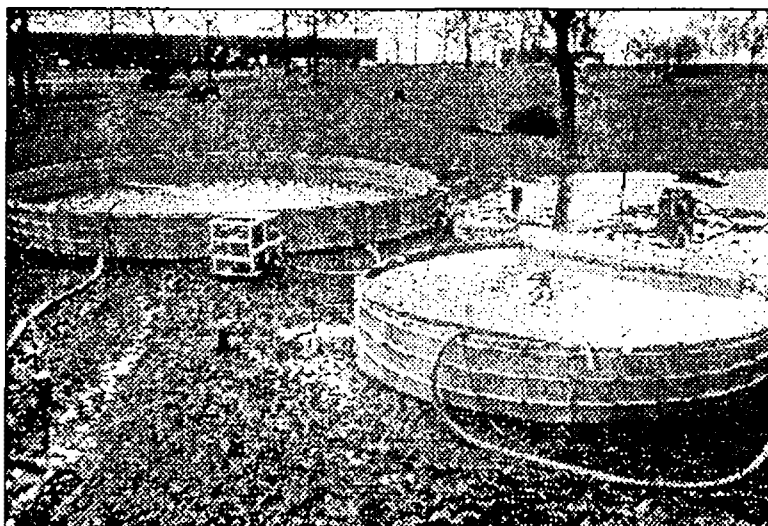
PRECIPITATION

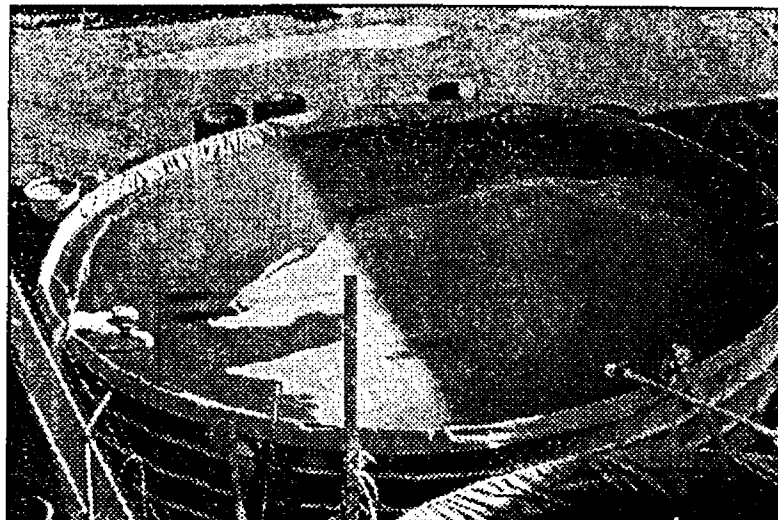
- Advantage
 - Removes dissolved heavy metals
- Disadvantages
 - Produces metal sludge
 - Often produces high pH wastewater
 - Doesn't always work on highly soluble metals

SAMPLE PRECIPITATION SYSTEM



Source: U.S. EPA 1991

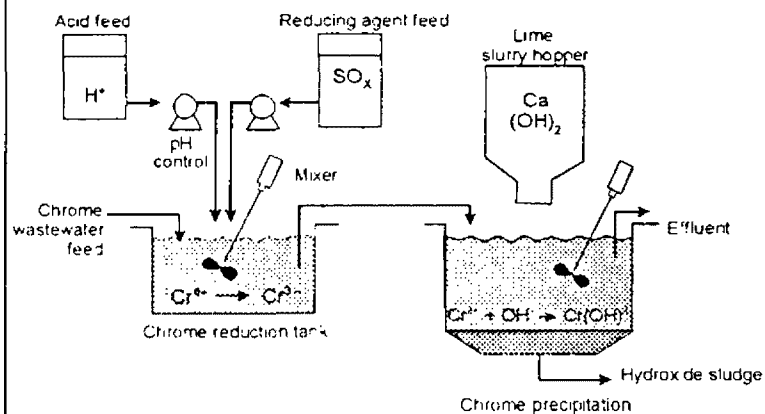


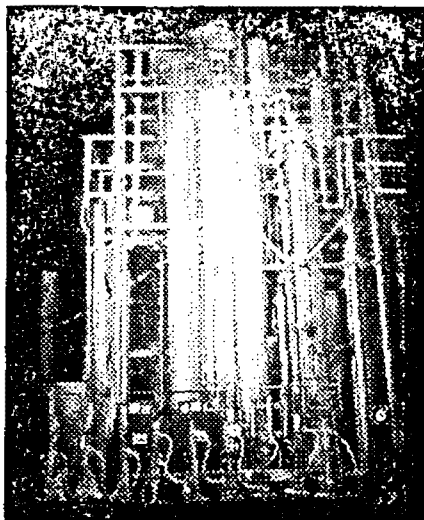


REDUCTION/OXIDATION

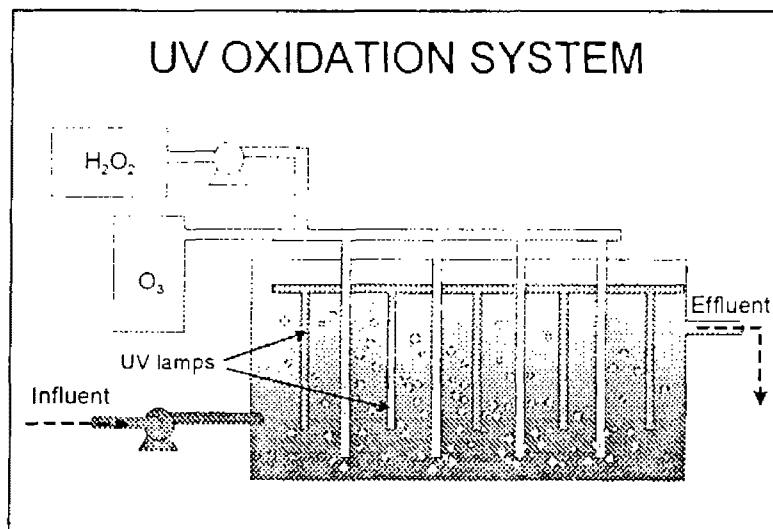
- Chemical reactions
- Advantages:
 - Reduces solubility of heavy metals
 - Oxidizes and destroys organics
- Disadvantage:
 - Unintended reactions

Cr (IV) REDUCTION SYSTEM





ULTRAVIOLET OXIDATION SYSTEM

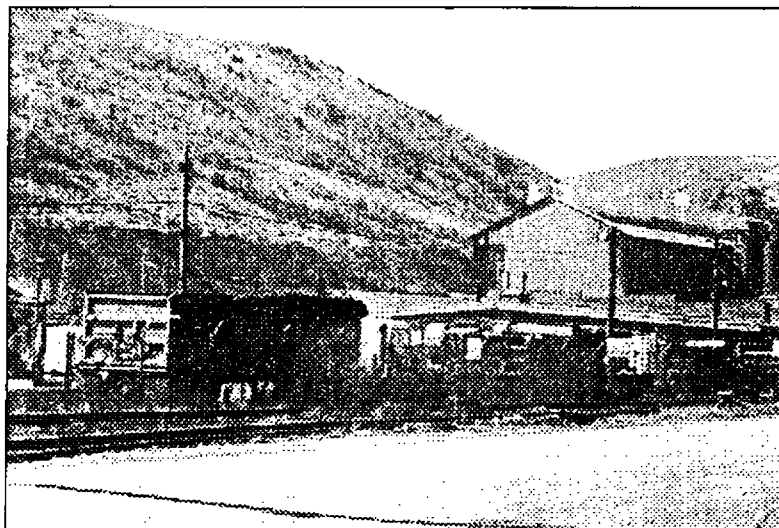


SEPARATION

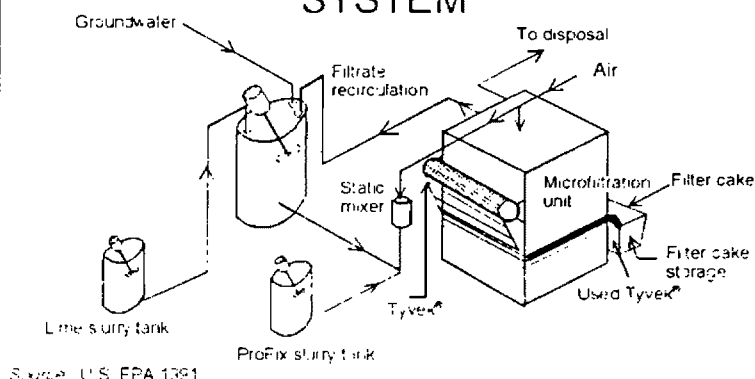
- Microfiltration
- Reverse osmosis
- Ion exchange

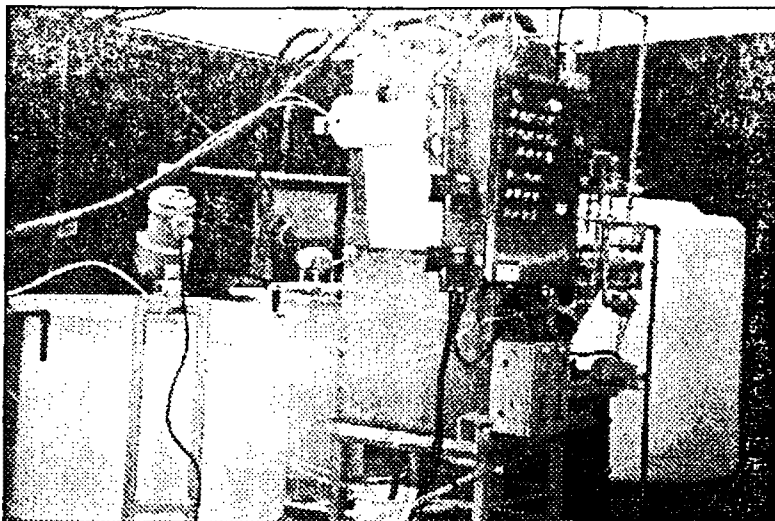
MICROFILTRATION

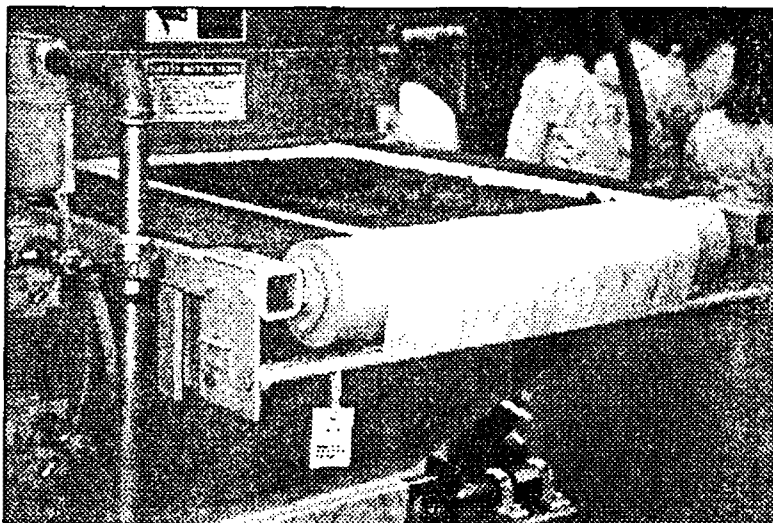
- Advantage
 - Removes very small particles
- Disadvantage
 - Does not remove dissolved contaminants

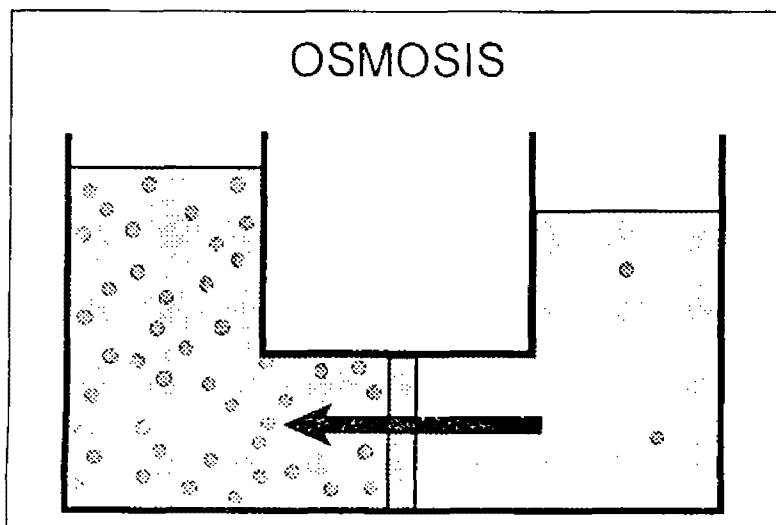


DU PONT/OBERLIN MICROFILTRATION TREATMENT SYSTEM





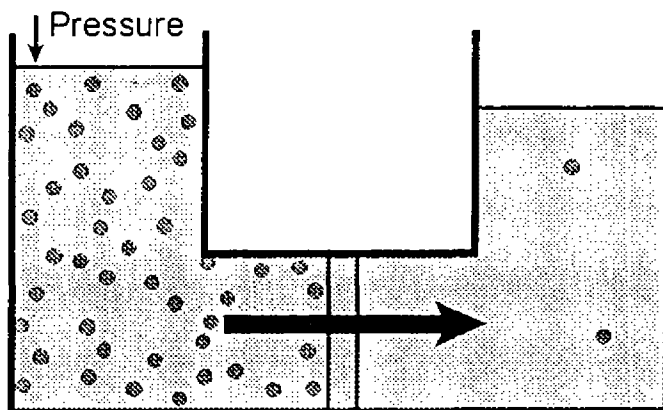




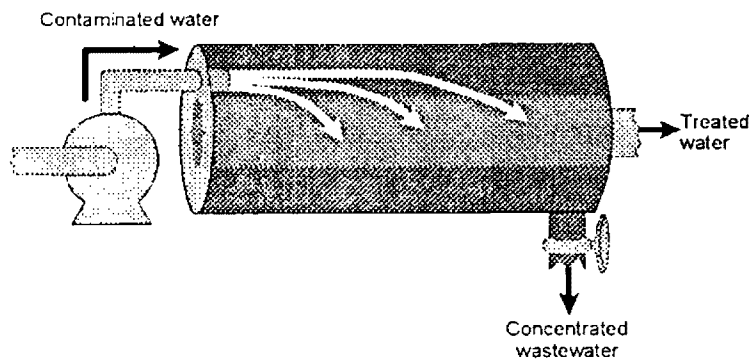
REVERSE OSMOSIS

- Advantages:
 - Ion removal
 - Treats large volumes
- Disadvantages:
 - Non-destructive
 - Costly

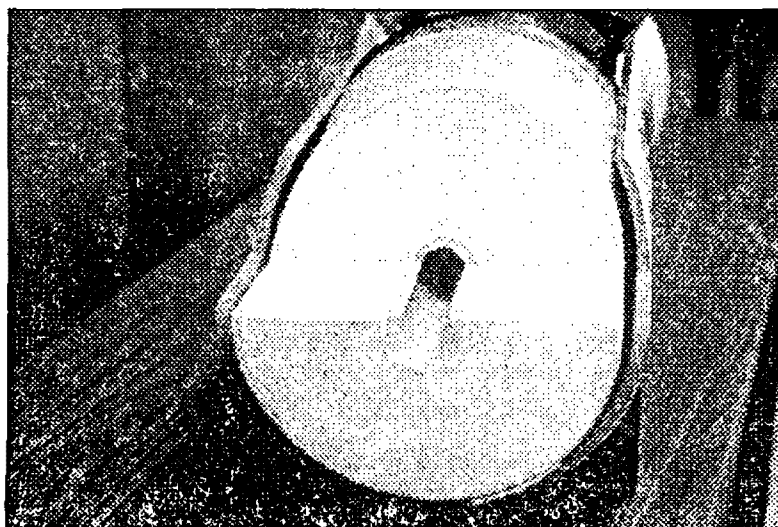
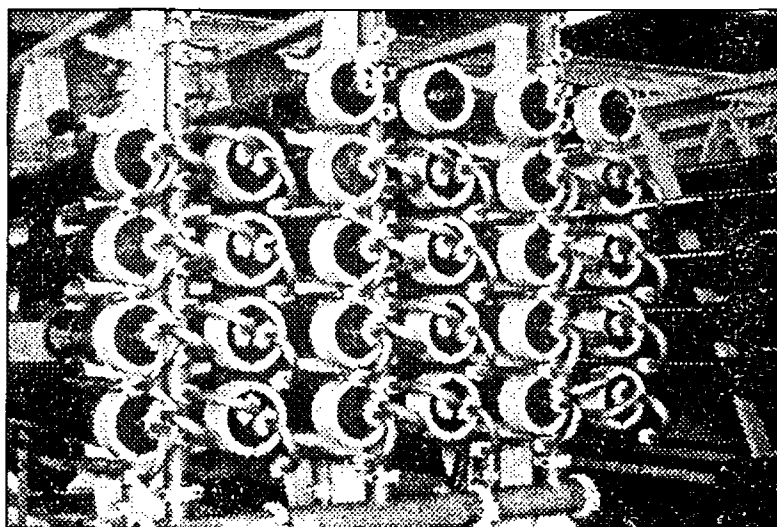
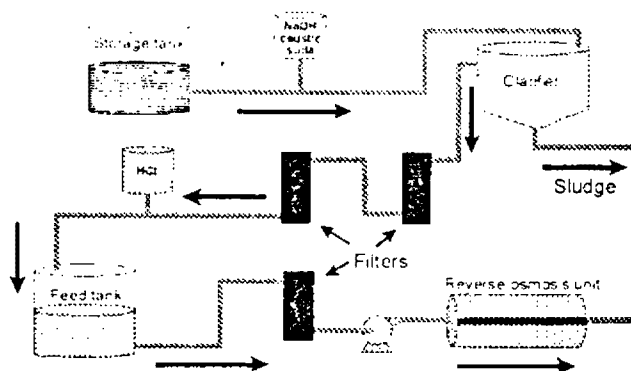
REVERSE OSMOSIS



REVERSE OSMOSIS UNIT



REVERSE OSMOSIS SYSTEM



ION EXCHANGE

- Removes dissolved metals via transfer of ions
- Uses resin beads

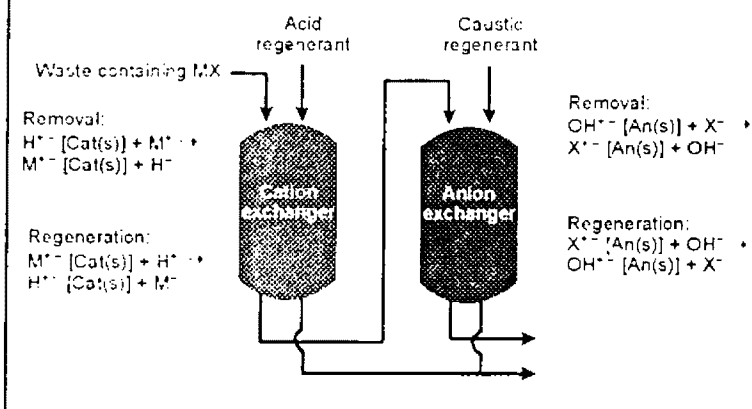
ION EXCHANGE ADVANTAGES

- Removes low concentrations of soluble metals
- Recovers concentrated metal streams for recycling

ION EXCHANGE DISADVANTAGES

- Suspended solids and organics
- Regeneration chemicals are hazardous

ION EXCHANGER







AQUEOUS BIOLOGICAL TREATMENT

DEFINITIONS

- Biodegradation-all processes where microorganisms break down compounds
- Bioremediation-site cleanup using biodegradation processes

APPLICATIONS FOR AQUEOUS

- Soils/sediment
- Leachate
- Runoff
- Dewatering
- Groundwater

ADVANTAGE OF BIODEGRADATION

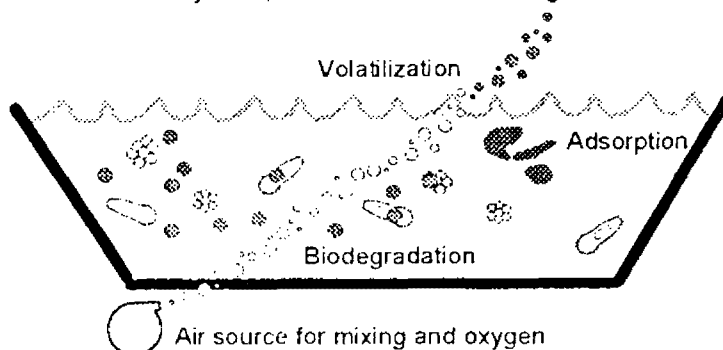
- Destructive treatment
- Usually lower cost
- Onsite treatment
- Native/indigenous organisms

DISADVANTAGES OF BIODEGRADATION

- May require pretreatment or additional treatment
- Sludge generation/solids treatment and handling

REMOVAL PROCESS

Physical, Chemical, and Biological



FACTORS THAT AFFECT BIODEGRADATION

- Waste composition
- Water solubility
- Modes of respiration
- Temperature
- Nutrients

WASTE COMPOSITION

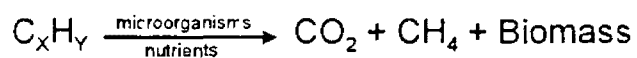
- Aerobic
 - Gaseous compounds
 - Aliphatic hydrocarbons
 - Sulfides and cyanides
 - Neutral pH
- Anaerobic
 - Organic waste mixtures
 - Halogenated hydrocarbons
 - Neutral pH

SOLUBILITY

- Controls bioavailability
- Polarity
- pH

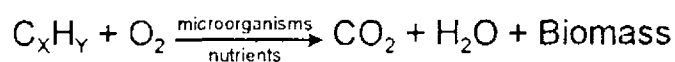
MODES OF RESPIRATION

Anerobic = fermentation/methanogenesis



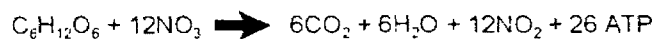
MODES OF RESPIRATION (cont.)

Aerobic

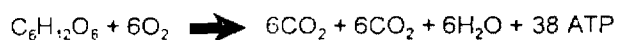


ATP PRODUCTION

Anaerobic (less efficient process)



Aerobic



TEMPERATURE

- Organisms have higher metabolic rate at slightly elevated temperature
- Too high causes cell death
- Aerobic (68°– 95°F)
- Anaerobic (86°– 158°F)

NUTRIENTS

- Essential nutrients: C, H, N, O, P, S
- Electron acceptors
- Nitrogen and phosphorus are usually deficient in systems
- Added to enhance microbes

pH

- Maintained so organisms can survive
- Optimal pH is between 6 and 8
- Acid or alkali conditions can kill microbes
- Buffer needed to maintain optimal pH

COMMON AQUEOUS TREATMENT SYSTEMS

- Aerobic
 - Trickle filters/fixed film reactor
 - Activated sludge/slurry phase reactor
 - Aerated lagoons/oxidation ponds
- Anaerobic
 - Digestors/bioreactors

BIOREMEDIATION FOR SOILS AND SLUDGES

SITE CONSIDERATIONS

- Soil properties
- Soil conditions
- Microbe types
- Nutrients
- Contaminants

SOIL PROPERTIES

- Particle size
- Types
- Tilth
- Moisture

SOIL CONDITIONS

- Temperature
- pH
- Salinity
- Redox potential

MICROBES

- Bacteria
- Fungi
- Indigenous
- Aerobic / anaerobic

NUTRIENTS

- Fertilizers
- Co-substrates
- Bulking agents
- Animal manure

CONTAMINANTS

- Heavy metals
- Corrosives
- Oxidizers / reducers
- Concentrations

EX-SITU SYSTEMS

- Composting
- Land farming
- Two-stage systems
- Slurry systems

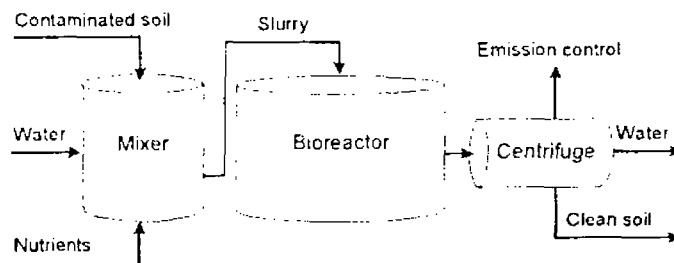
COMPOSTING/LAND FARMING

- Composting
 - Open windrow
 - Static windrow
 - In-vessel
- Land farming

SLURRY BIODEGRADATION

- Similar to aqueous
- Most organics
- Inorganic cyanides

SLURRY BIODEGRADATION SYSTEM



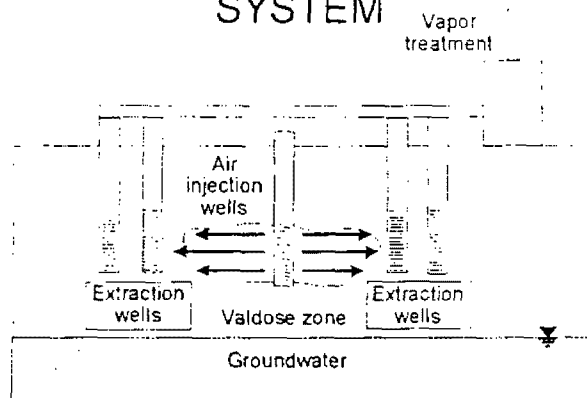
BIOVENTING

- In-situ
- Unsaturated zone
- Soil vapor extraction

BIOVENTING CONSIDERATIONS

- Homogeneous soils
- Soil gas readings
- Soil permeability
- Other conditions

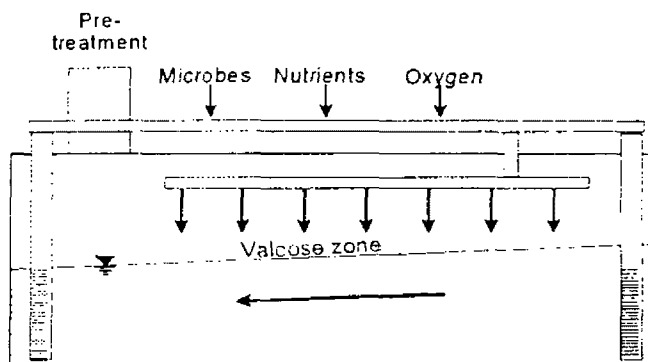
BIOVENTING SYSTEM



TRADITIONAL IN-SITU SYSTEM

- Unsaturated / saturated zones
- Pumping / soil flushing
- Petroleum and solvents
- Wood-treating wastes
- Chlorinated solvents

TRADITIONAL IN-SITU SYSTEM

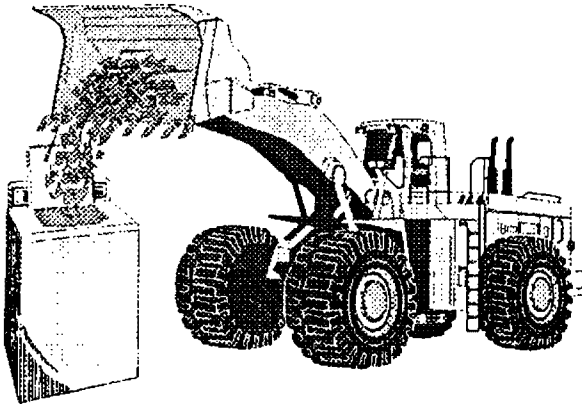


BIOREMEDIATION FOR SOILS

- Considerations
- Composting / land farming
- Two-stage systems
- Slurry systems
- Bioventing
- Traditional in-situ systems

SOIL WASHING AND SOLVENT EXTRACTION

SOIL WASHING TREATMENTS

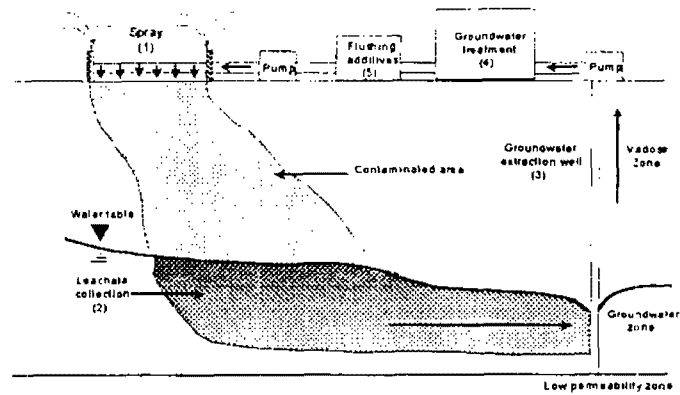


SOIL TREATMENTS

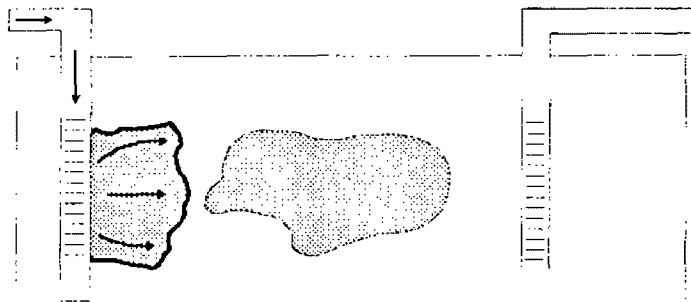
- In-situ soil flushing
- Soil washing
- Solvent extraction

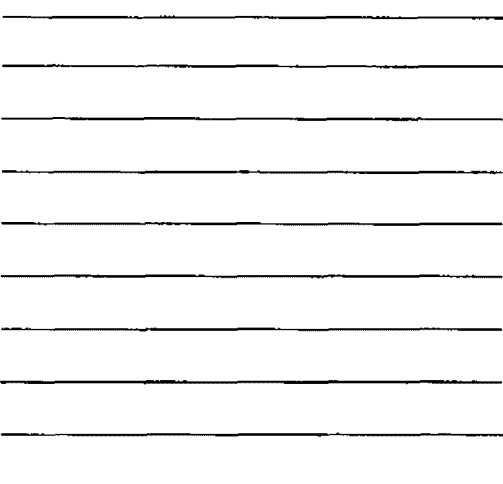
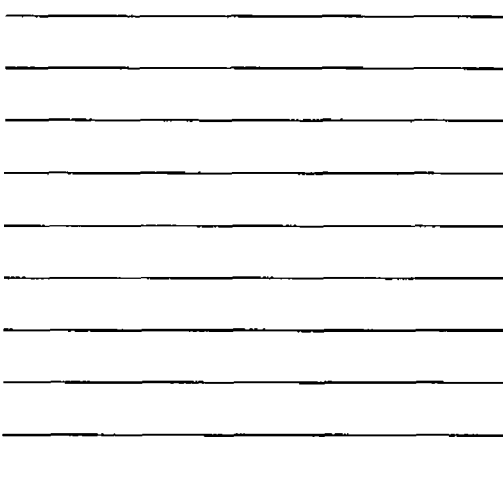
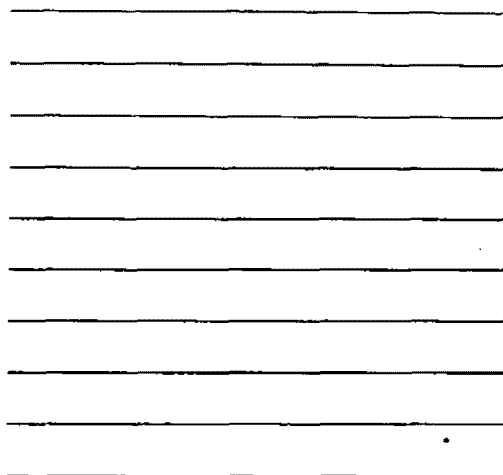
IN-SITU SOIL FLUSHING

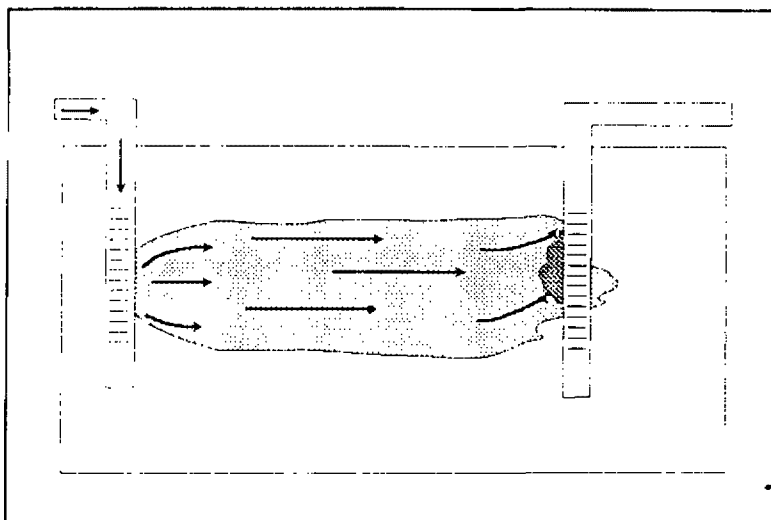
In-situ soil flushing is the extraction of contaminants from the soil with water or other suitable aqueous solutions



U.S. EPA 1991a







SOLVENT SELECTION

- Water
 - Soluble (hydrophilic) organics
 - Octanol/water partition coefficient <10
- Water with surfactant
 - Low solubility (hydrophobic) organics

SOLVENT SELECTION (cont.)

- Acids, chelating agents, or reducing agents
 - Metals
 - Inorganic metal salts

DEMONSTRATED EFFECTIVENESS

- Volatile halogenated organics (perchloroethylene, chloromethane)
- Semivolatile nonhalogenated organics (phenols, nitrobenzene)
- Nonvolatile metals (arsenic, lead)

U.S. EPA 1991a

SOIL PARAMETERS

- Permeability – affects treatment time and efficiency of contaminant removal
 - $\geq 1 \times 10^{-3}$ cm/sec = effective soil flushing
 - $< 1 \times 10^{-5}$ cm/sec = limited soil flushing

SOIL PARAMETERS (cont.)

- Moisture content – affects flushing fluid transfer requirements
- Groundwater hydrology – critical in controlling the recovery of injected fluids and contaminants

PROCESS RESIDUALS

- Groundwater treatment
- Flushing additives:
 - Reuse
 - Degradability

SITE REQUIREMENTS

- Underground Injection Control (UIC) permit
- National Pollution Discharge Elimination System (NPDES)
- Slurry walls or sheet piling for containment
- Berms, dikes, or caps for surface water control

SOIL FLUSHING LIMITATIONS

- 1–2 years as concentrations decrease
- Hydraulic control required
- High silt and clay content not applicable
- Surfactants or organic solvents removed
- Bacteria and/or iron fouling
- Additives may interfere with wastewater treatment

SOIL WASHING

Soil washing is a water-based process for mechanically separating and scrubbing soils ex-situ to remove undesirable contaminants

SOIL WASHING TREATMENT

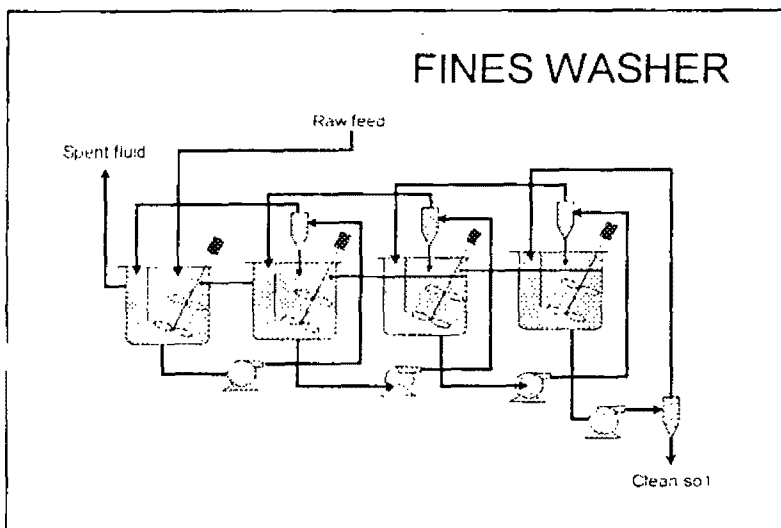
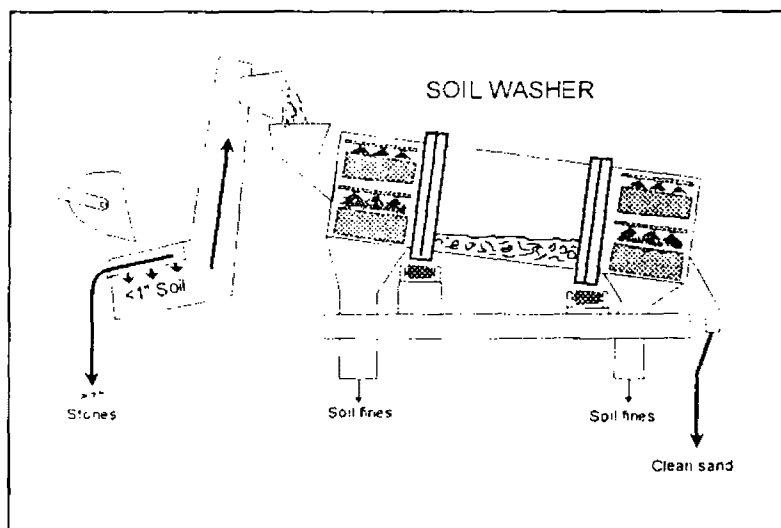
- Onsite, ex-situ, water-based process
- Contamination reduction by particle size separation
- Mechanical washing and separation techniques
- Combines mining and chemical plant technologies

APPLICABILITY

- Stand alone or treatment train
- Effective for coarse sand and gravel
- Demonstrated contaminant removal
 - Halogenated volatile organics (perchloroethylene, trichloroethylene)
 - Nonhalogenated volatile organics (phenols, nitrobenzene)
 - Volatile and nonvolatile metals (mercury-volatile, lead-nonvolatile)

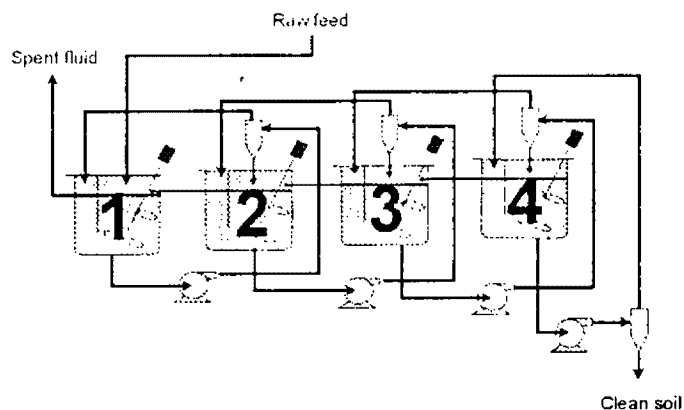
WASTE SOIL CHARACTERIZATION PARAMETERS

Particle Size Distribution	Comments
>2 mm	Oversize pretreatment requirements
0.25–2 mm	Effective soil washing
0.063–0.25 mm	Limited soil washing
<0.063 mm	Clay and silt fraction, difficult soil washing



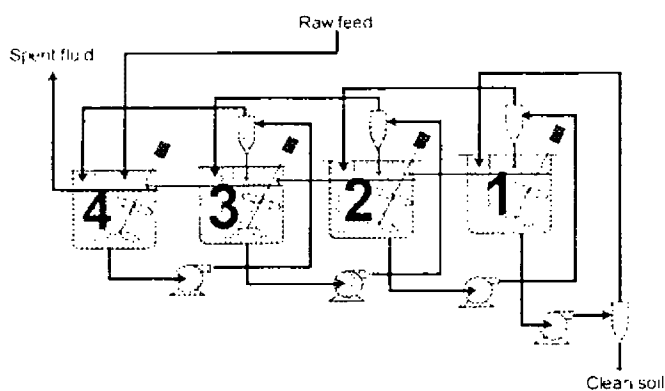
SOIL FLOW

The diagram illustrates a four-stage soil flow process. It begins with a 'Raw feed' input at the top, which splits into two paths. One path leads to a 'Spent fluid' output on the left, and the other path enters a series of four rectangular processing units, numbered 1 through 4 from left to right. Each unit contains a vertical column with a downward arrow, suggesting a gravity-fed process. Between each unit, there is a pump or valve symbol (a circle with a horizontal line) that directs the flow from the bottom of one unit to the top of the next. The final unit (4) has a pump that leads to a 'Clean soil' output at the bottom right. The entire process is enclosed in a rectangular frame.

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LIQUID FLOW

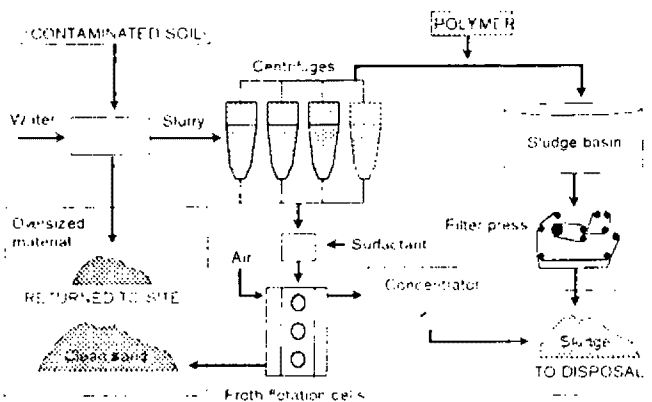
The diagram illustrates a four-stage liquid flow system for soil decontamination. The stages are numbered 1, 2, 3, and 4 from right to left. Each stage consists of a rectangular tank with a stirrer at the bottom and a spray nozzle at the top. The flow of liquid is as follows: 'Raw feed' enters the top of stage 1. The output from the bottom of stage 1 flows into stage 2. The output from the bottom of stage 2 flows into stage 3. The output from the bottom of stage 3 flows into stage 4. The output from the bottom of stage 4 is labeled 'Spent fluid' and exits the system. The flow between stages is indicated by arrows and the numbers 1, 2, 3, and 4. The final output from stage 4 is labeled 'Clean soil'.

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SOIL WASHING SYSTEM

The flowchart illustrates the process of soil washing. It begins with 'CONTAMINATED SOIL' entering a 'Washer'. A 'WATER' input also feeds into the 'Washer'. The output of the 'Washer' is 'Slurry', which is sent to a bank of 'Centrifuges'. The 'Centrifuges' have two outputs: one goes to a 'Filter press' and the other to a 'Concentrator'. A 'POLYMER' input feeds into the line between the 'Centrifuges' and the 'Filter press'. The 'Filter press' outputs 'Sludge TO DISPOSAL'. The 'Concentrator' has two inputs: 'Surfactant' and 'Air'. Its output goes to 'Froth flotation cells'. The 'Froth flotation cells' have two outputs: 'Clean Sand' and 'Returned to site'.

```
graph TD
    CS[CONTAMINATED SOIL] --> W[Washer]
    W --> S[Slurry]
    S --> C[Centrifuges]
    C --> FP[Filter press]
    C --> CO[Concentrator]
    P[POLYMER] --> FP
    FP --> SD[Sludge TO DISPOSAL]
    CO --> FFC[Froth flotation cells]
    Sur[Surfactant] --> CO
    Air --> CO
    FFC --> CSand[Clean Sand]
    FFC --> R[Returned to site]
```

[illegible]

SOIL WASHING RESIDUALS

- Wastewater – treatment and recycle
- Vapors – collect and treat
- Oversize soils – return to site
- Fines – further treatment

SOIL WASHING LIMITATIONS

- High percentage of silt and clay particles
- Hydrophobic contaminants
- Complex contaminant mixtures
- Additives may interfere with wastewater treatment

SOLVENT EXTRACTION

Solvent extraction uses an organic solvent in combination with standard soil washing techniques to remove and concentrate organic contaminants for further treatment

SOLVENT EXTRACTION (cont.)

- Contaminants separated for volume reduction
- One in a series of unit operations
- Organic chemical solvent
- Site-specific solvent selected

APPLICABILITY

- Sediments, sludges, and soils
- Semivolatile halogenated organics (dichlorobenzene)
- Volatile nonhalogenated organics (benzene)
- Semivolatile nonhalogenated organics (phenols)
- Polychlorinated biphenyls (PCBs)
- Pesticides

PRETREATMENT

- Physical
 - Size reduction and classification
 - Dewater or water addition
- Chemical
 - pH adjustment

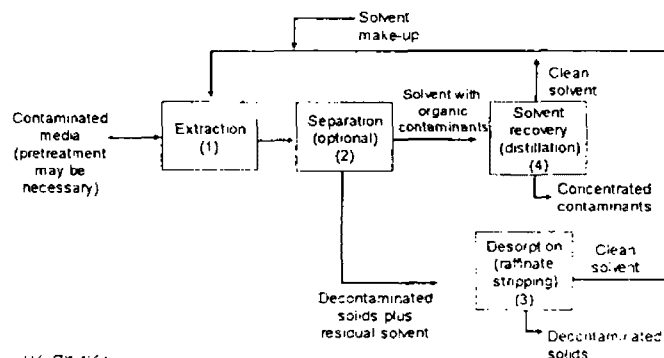
SOLVENT SELECTION

- Standard solvents
- Liquefied gas (LG)
- Critical solution temperature (CST) solvents

PROCESS STEPS

- Extraction
- Separation
- Desorption
- Solvent recovery

STANDARD SOLVENT EXTRACTION PROCESS



U.S. EPA 1964a

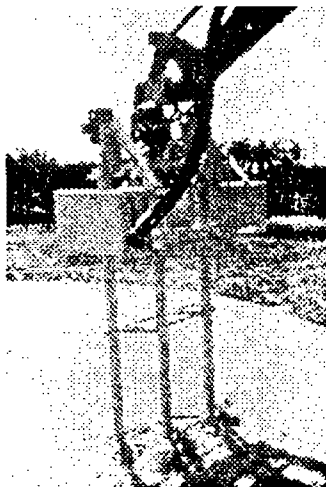
PROCESS RESIDUALS

- Treated solids
 - Dewatering
 - Residual solvent removal
 - Metal contaminant removal
- Organic solvents
 - Organically bound metals
- Solvent/water mixture
- Air emissions

PROCESS LIMITATIONS

- Organically bound metals
- Detergent and emulsifiers
- Extraction solvents on treated solids
- High molecular weight organics
- Hydrophilic substances

IMMOBILIZATION



GENERAL APPLICATIONS

- Soils, sludges, and sediments
- Lead, cadmium, and similar heavy metals
- Limits mobility (leachability)

GENERAL LIMITATIONS

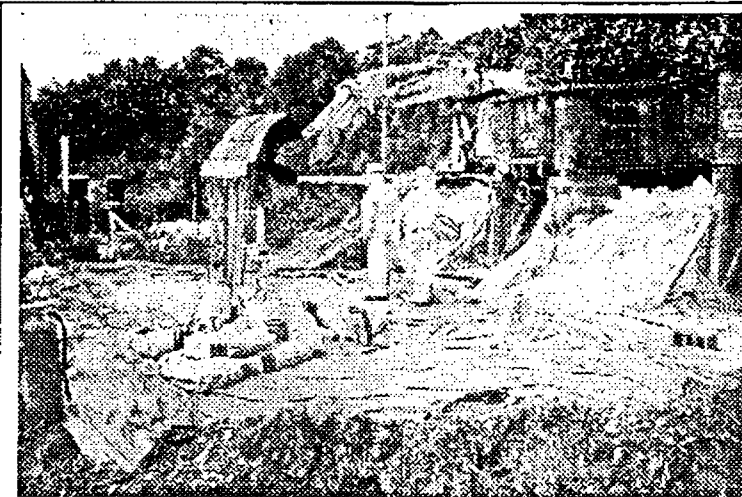
- Increases waste volume
- Not for organics
- Non-destructive

PREDOMINANT TECHNOLOGIES

- Physical
- Chemical
- Thermal
- Biological (emerging technology)

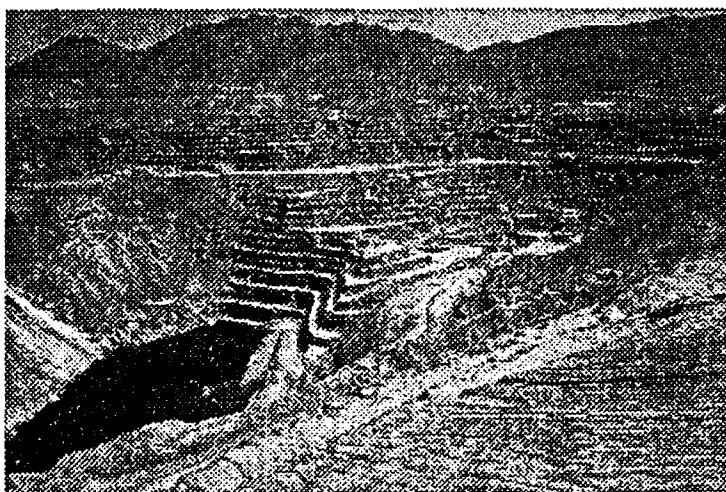
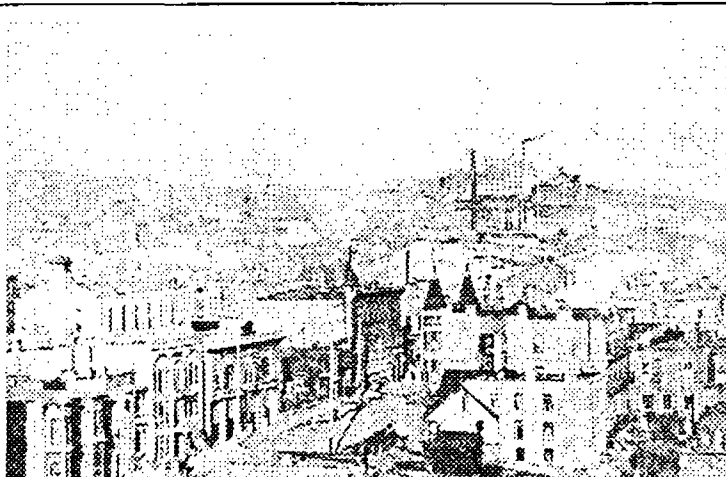
PHYSICAL IMMOBILIZATION

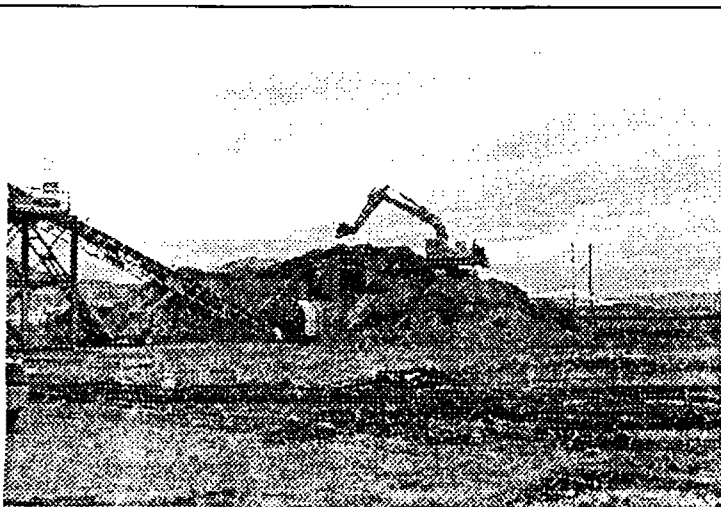
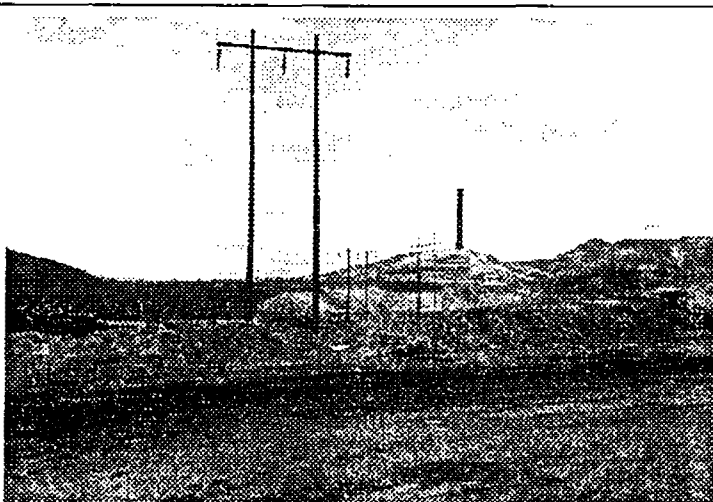
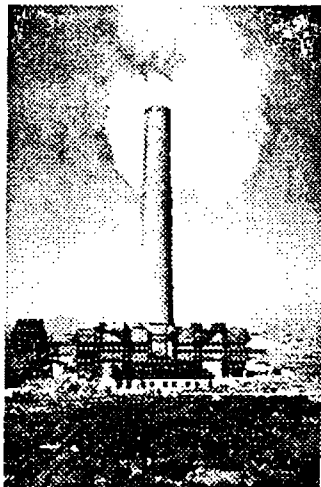
- Solidification
- Sludges and sediments
- Clays, vermiculite, and saw dust

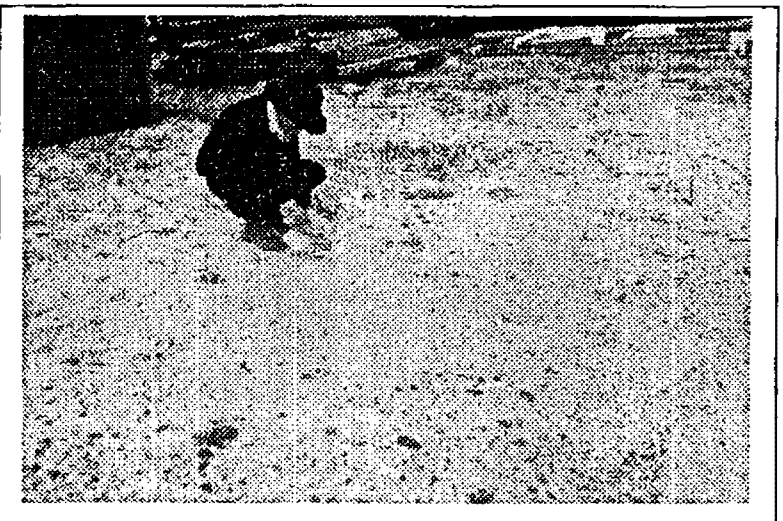
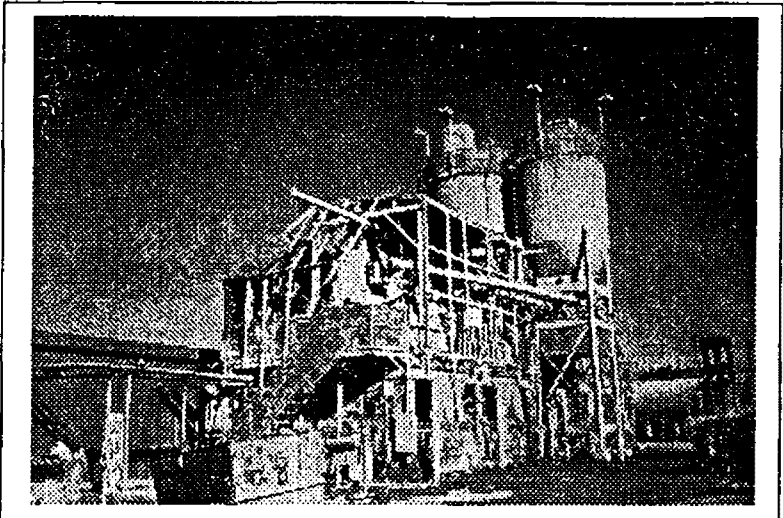
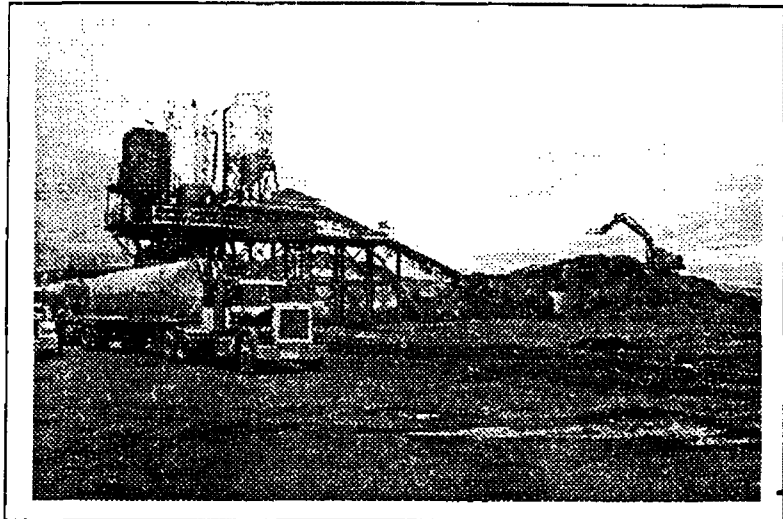
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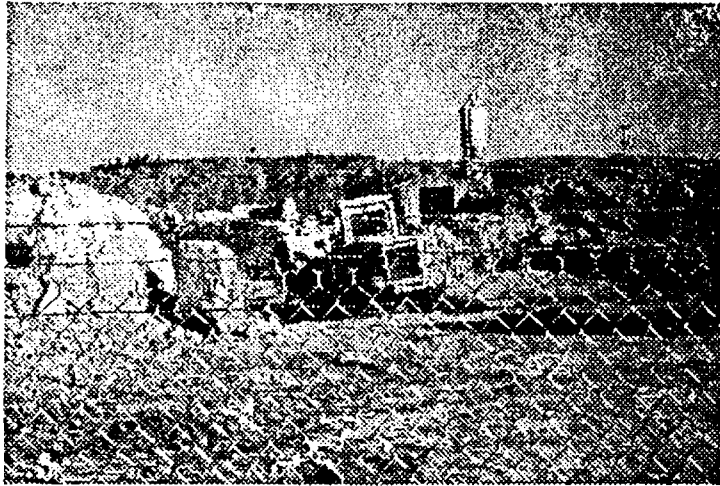
CHEMICAL IMMOBILIZATION

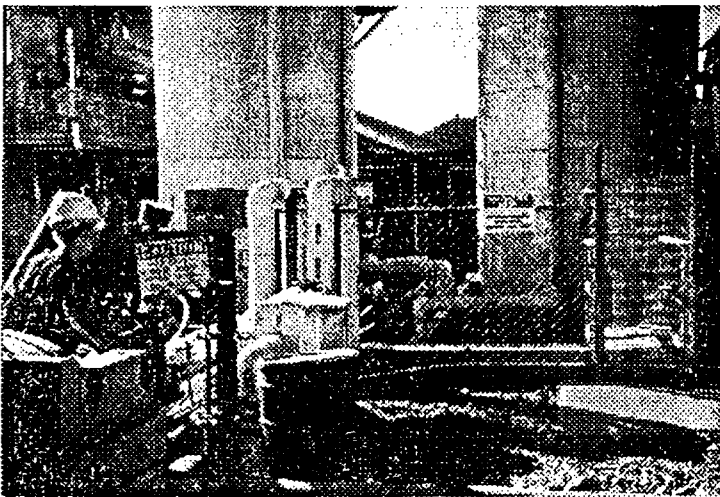
- Stabilization
- Cement technologies
- Phosphate technologies
- Matrix formation

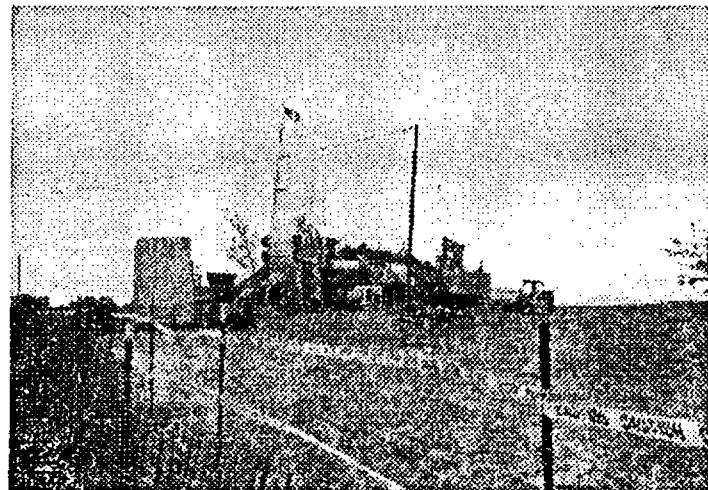


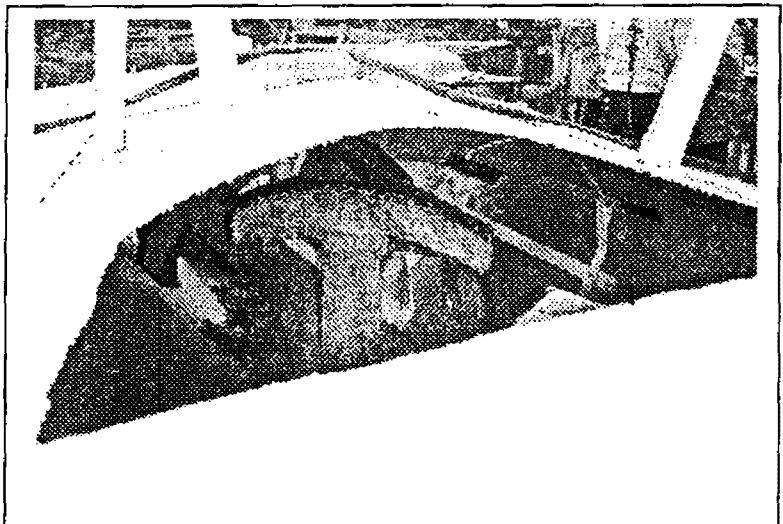
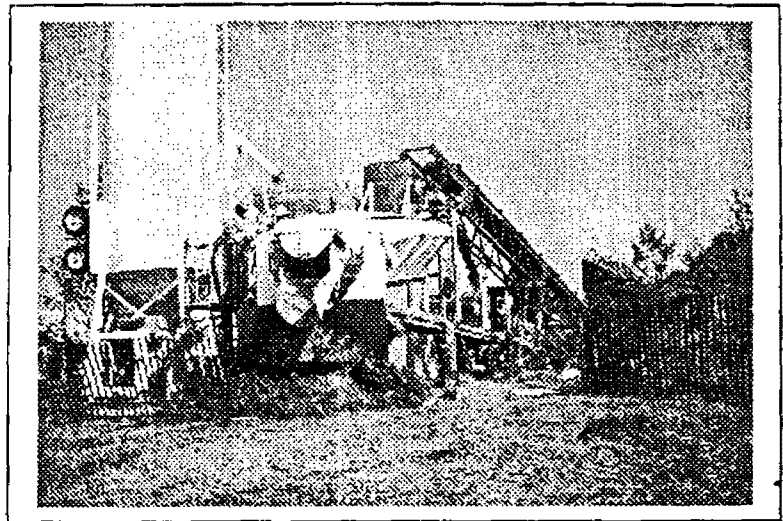






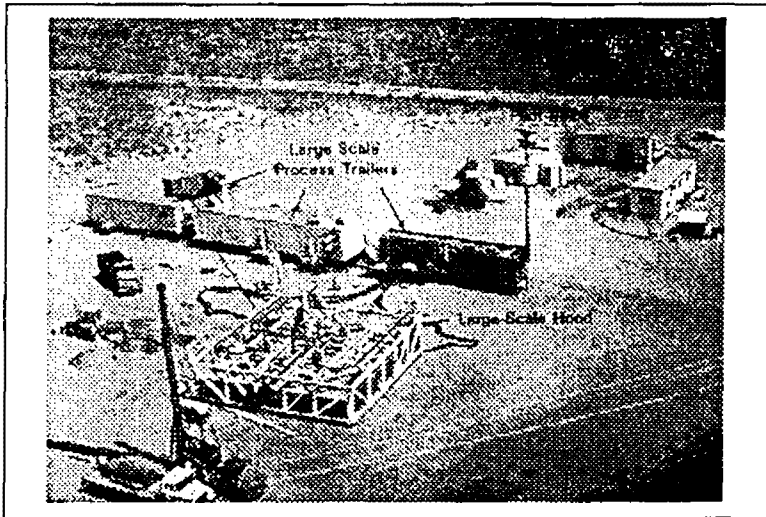




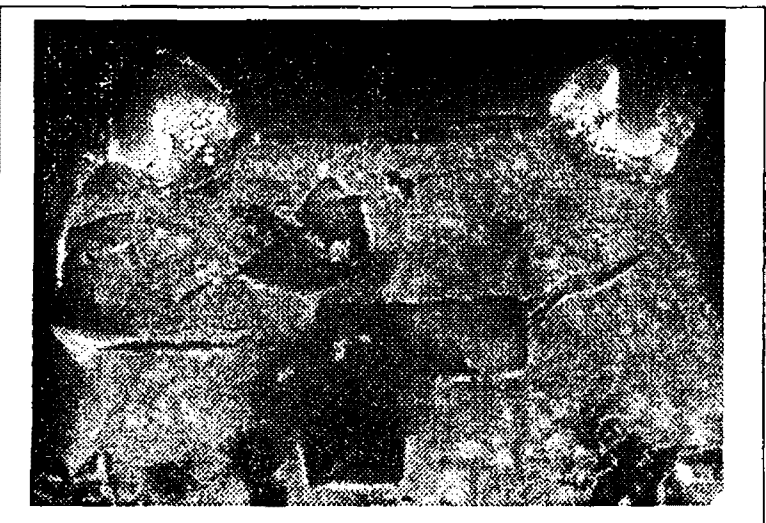


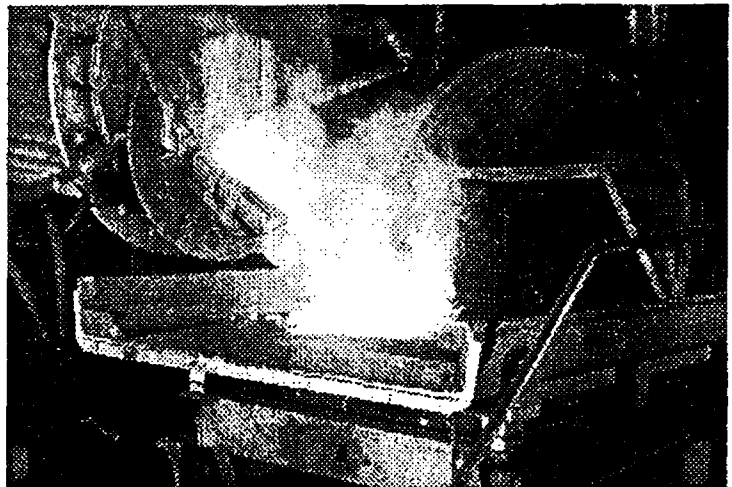
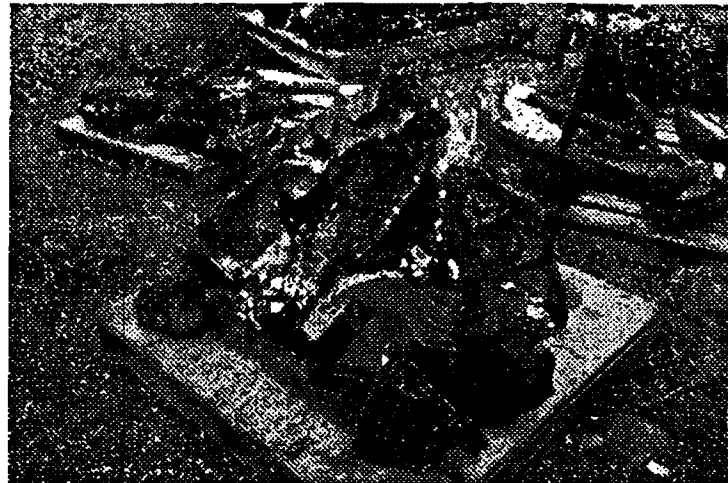
THERMAL IMMOBILIZATION

- Vitrification
- Primarily radioactive waste
- Electrical resistance or combustion heating



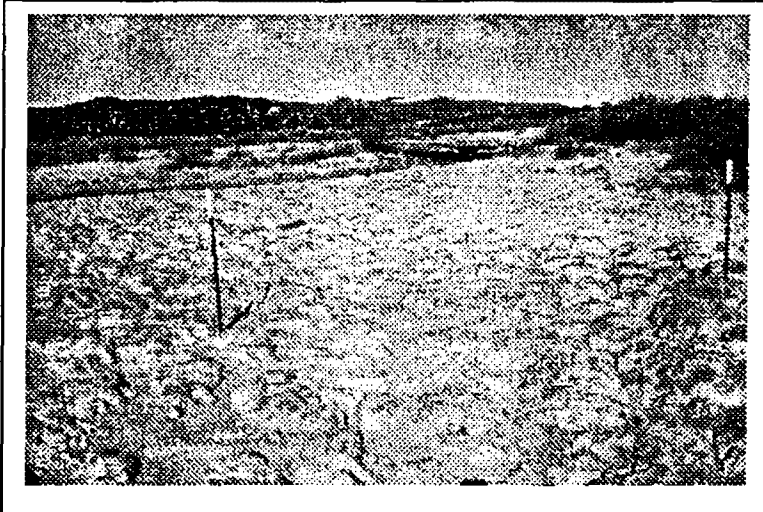


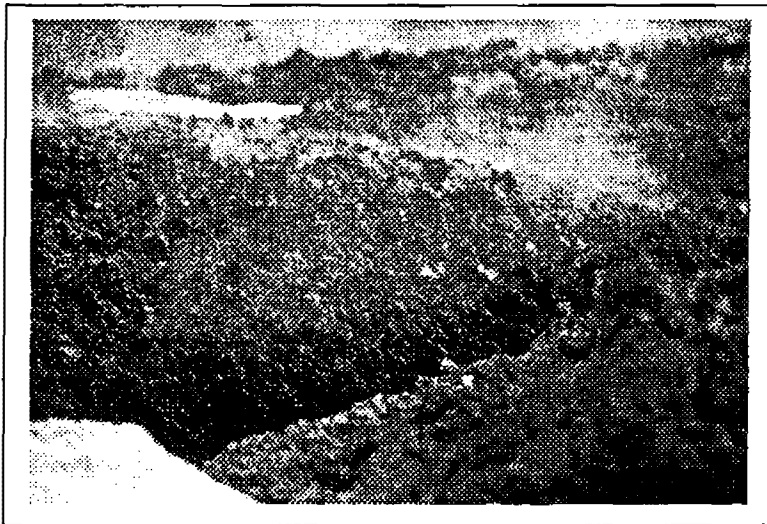


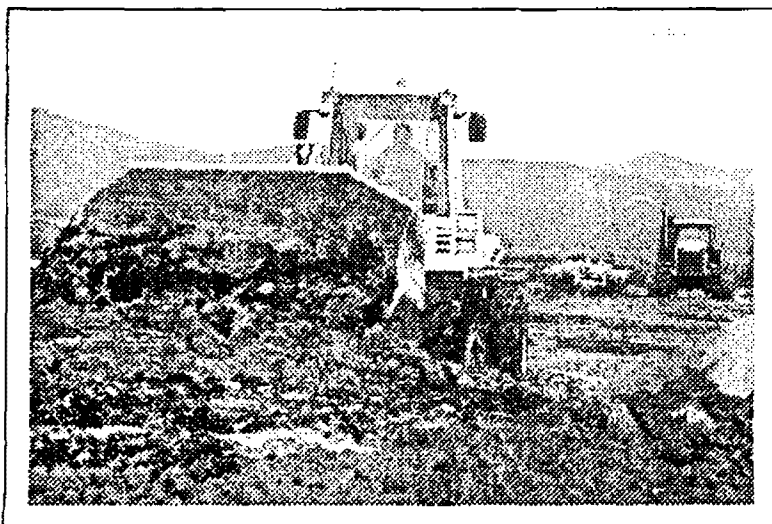


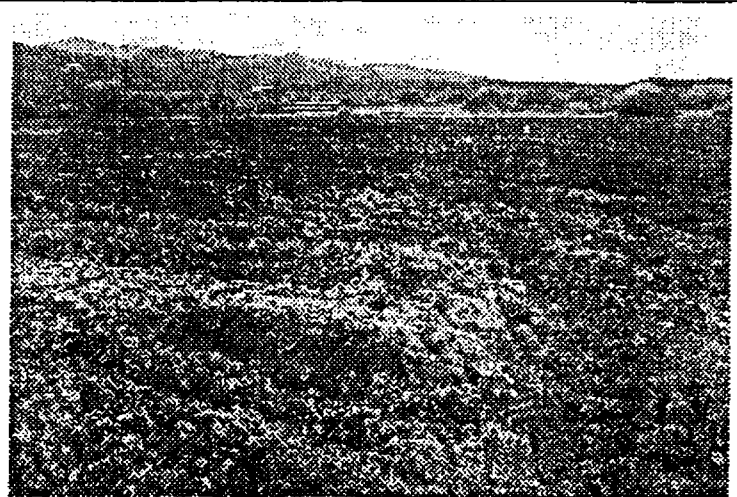
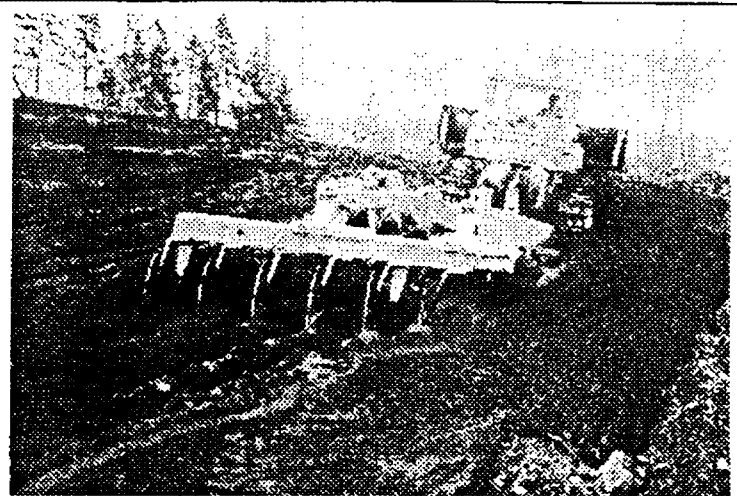
BIOLOGICAL IMMOBILIZATION

- Contains as well as immobilizes
- Treats large volume mine tailings in place









IMMOBILIZATION ADVANTAGES

- Treats metals in soils, sludges, and sediments
- Can be used for radioactive and mixed wastes
- Treats large volume mine tailings

IMMOBILIZATION DISADVANTAGES

- Increases waste volume
- Not suitable for treating organics
- Requires secondary containment

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ACRONYMS AND ABBREVIATIONS

A	absorption coefficient
AA	atomic absorption
AA	Assistant Administrator (EPA)
AAQCD	Ambient Air Quality Criteria Document (EPA, CAA)
ACGIH	American Conference of Governmental Industrial Hygienists
ACHP	Advisory Council on Historic Preservation
ACL	alternate concentration limit (EPA, RCRA)
ACO	administrative consent order
ADI	acceptable daily intake (EPA)
AEA	Atomic Energy Act (NRC, ERDA, DOE)
AG	Attorney General
AHERA	Asbestos Hazard Emergency Response Act (EPA, TSCA)
AHPA	Archaeological and Historical Preservation Act
AIC	acceptable intake for chronic exposure (EPA)
AIIA	American Industrial Hygiene Association
AIRFA	American Indian Religious Freedom Act
AIS	acceptable intake for subchronic exposure (EPA)
AL	action level (EPA)
ALJ	administrative law judge
ANPRM	advance notice of proposed rulemaking
ANSI	American National Standards Institute
AO	administrative order
AOC	area of contamination
AOC	area of concern
APA	Administrative Procedure Act
APA	Acid Precipitation Act
AQCR	air quality control region
AQMD	air quality management district
AQUIRE	acute aquatic toxicity values database (CIS)
ARAR	applicable or relevant and appropriate requirements
ARCS	Alternative Remedial Contracting Strategy
ARPA	Archaeological Resources Protection Act
AT	averaging time
ATSDR	Agency for Toxic Substances and Disease Registry
AWQC	Ambient Water Quality Criteria (EPA, CWA)
AWQCD	Ambient Water Quality Criteria Document (EPA, CWA)
B	body weight of receptor
BACT	best available control technology (EPA, CAA)
BAT(EA)	best available technology (economically achievable) (EPA, CWA)
BCPCT	best conventional pollutant control technology (EPA, CAA)
BCT	best conventional technology (EPA, CWA)
BDAI	best demonstrated available technology (EPA, RCRA)
BLM	Bureau of Land Management (DOI)
BM	Bureau of Mines
BMP	best management practices

BOD	biochemical (or biological) oxygen demand
BPA/T	best practicable available technology
BPJ	best professional judgment
BPT(CA)	best practicable technology (currently available) (EPA, CWA)
BRA	baseline risk assessment
BQRA	baseline quantitative risk assessment
BTC	briefly tolerable concentration (NRC)
BTEX	benzene, toluene, ethylbenzene, and xylenes
BTX	benzene, toluene, and xylenes
C	corrosivity hazardous waste code (EPA, RCRA)
C	concentration of a pollutant in the environment
CA	corrective action (EPA, RCRA)
CAA	Clean Air Act
CA/FO	consent agreement/final order
CAG	Carcinogen Assessment Group (EPA, ORD)
CAMU	corrective action management unit (EPA, RCRA)
CAP	corrective action plan (EPA, RCRA)
CAP	capacity assurance plan (EPA, CERCLA)
CAPA	critical aquifer protection area
CATEX	categorical exclusion (EPA, NEPA)
CCRIS	Chemical Carcinogenesis Research Information System (NLM, Toxnet)
CDC	Centers for Disease Control (HHS, PHS)
CERCLA	Comprehensive Environmental Response, Compensation and Liability Act
CERCLIS	CERCLA Information System
CERI	Center for Environmental Research Information (EPA-ORD, Cincinnati)
CESARS	Chemical Evaluation Search and Retrieval System (CIS)
CEQ	Council on Environmental Quality
CESQG	conditionally exempt small quantity generator
CFC	Chlorofluorocarbon
CFR	Code of Federal Regulations
CHEMID	Chemical Identification (includes SUPERLIST) (NLM, ELHILL)
CHEMLINE	Chemical Dictionary Online (NLM, ELHILL)
CHEMTRAC	Chemical emissions toxicity inventory database (EPA)
CHEMTREC	Chemical Transportation Emergency Center
CHRIS	Chemical Hazard Response Information System (USCG)
CHS	CERCLA hazardous substance
CIL	Chemical Inventory List (EPA, EPCRA)
CIS	Computer Information System (commercial user network)
CMA	Chemical Manufacturers Association
CMi	corrective measures implementation (EPA, RCRA)
CMS	corrective measures study (EPA, RCRA)
CO	compliance order
CO	carbon monoxide
COD	chemical oxygen demand
COE	Corps of Engineers
CP	conventional pollutant (EPA, CWA)
CP	criteria pollutant (EPA, CAA)

CPI cancer (carcinogenic) potency factor
 CPSC Consumer Product Safety Commission
 CQAP construction quality assurance plan
 CRA classification review area (EPA, SDWA)
 CRAVI carcinogen risk assessment verification endeavor (EPA, ECAO)
 CRP community relations plan(ning) (EPA, CERCLA)
 CRS Congressional Research Services
 CSF cancer slope factor
 C TCP Clinical Toxicology of Commercial Products (Gleason et al., CIS)
 CWA Clean Water Act
 CZMA Coastal Zone Management Act

D disposer, disposal
 D dose of a pollutant in a receptor (mg/kg/day)
 D--- waste ID for characteristic hazardous wastes (EPA, RCRA)
 DAF dilution-attenuation factor (EPA, RCRA)
 DART Development and Reproductive Toxicology (NLM, Toxnet)
 DCQAP data collection quality assurance plan
 DE destruction efficiency
 DEIS draft environmental impact statement
 DERA defense environmental restoration account
 DERMAL dermal absorption and toxicity database (CIS)
 DERP defense environmental restoration program
 DIRLINI Directory of Information Resources Online (NLM)
 DMP data management plan
 DMR discharge monitoring report (EPA, CWA)
 DNEA determination of no further action (EPA, RCRA)
 DOC U.S. Department of Commerce
 DOD U.S. Department of Defense
 DOE U.S. Department of Energy
 DOI U.S. Department of the Interior
 DOJ U.S. Department of Justice
 DOL U.S. Department of Labor
 DOR Determination of Release (EPA, RCRA)
 DOT U.S. Department of Transportation
 DQO data quality objective (EPA)
 DRE destruction removal efficiency
 DW drinking water
 DWCD Drinking Water Criteria Document (EPA, SDWA)
 DWHAS Drinking Water Health Advisory Summary (EPA, SDWA)

E toxicity characteristic hazardous waste code (EPA, RCRA)
 EA environmental assessment (EPA, NEPA)
 EA endangerment assessment
 EC₅₀ median effective concentration
 EcA ecological assessment
 ECAO Environmental Criteria and Assessment Office (EPA)
 ED exposure duration

LD ₅₀	median effective dose
EECA	engineering evaluation cost analysis
EEGL	emergency exposure guidance level (NRC)
EEL	emergency exposure level (WHO)
EERU	Environmental Emergency Response Unit
EF	exposure frequency
EFD	exposure frequency and duration
EHS	extremely hazardous substance (EPA, EPCRA)
EIA	environmental impact assessment (EPA, NEPA)
EIES	Electronic Information Exchange System (EPA)
EIS	environmental impact statement (study) (EPA, NEPA)
EMIC	Environmental Mutagen Information Center (NLM, Toxnet)
EMICBACK	Environmental Mutagen Information Center Backfile (NLM, Toxnet)
ENU	elementary neutralization unit (EPA, RCRA)
ENVIROFATE	bioconcentration and half-life factors database (CIS)
EO	executive order
EP	extraction procedure (EPA, RCRA)
EP-TOX	extraction procedure toxicity (EPA, RCRA)
EPA	U.S. Environmental Protection Agency
EPCRA	Emergency Planning and Community Right-to-Know Act
EPTC	extraction procedure toxicity characteristics
ERCS	Emergency Response Cleanup System
ERT	Environmental Response Team
ESA	Endangered Species Act (FWS)
ESD	explanation of significant differences (EPA, CERCLA)
ETICBACK	Environmental Teratology Information Center Backfile (NLM, Toxnet)
ExA	exposure assessment
F---	waste ID for nonspecific-source hazardous wastes (EPA, RCRA)
FACA	financial assurance for corrective action (EPA, RCRA)
FCL	final cleanup level
FCO	Federal Coordinating Officer
FEIS	final environmental impact statement
FEMA	Federal Emergency Management Agency
FEPCA	Federal Environmental Pesticide Control Act
FFA	federal facilities agreement
FFCA	federal facilities compliance agreement
FFCM	federal facilities compliance manual
FFSRA	federal facilities site remediation agreement
FIFRA	Federal Insecticide, Fungicide, and Rodenticide Act
FIT	Field Investigation Team
FLPMA	Federal Land Policy Management Act
FOIA	Freedom of Information Act
FONSI	finding of no significant impact (EPA, NEPA)
FR	Federal Register
FRG	final remediation goals
FRL	final remediation level (EPA, CERCLA)
FRSS	Federal Register Search System

FS	feasibility study (EPA, CERCLA)
FWPCA	Federal Water Pollution Control Act
FWS	U.S. Fish and Wildlife Service
G	generator
G/Tp	generator/transporter
GAC	granular activated carbon
GACT	generally available control technology
GC	gas chromatograph(y)
GC/MS	gas chromatography/mass spectrometry
GENETOX	genetic toxicology database (NLM, Toxnet)
GLABS	gastrointestinal absorption database (CIS)
GOCO	government-owned, contractor-operated facility
GSA	Government Services Administration
GW	groundwater
GWA	Groundwater Act of 1987
GWPS	groundwater protection standard (EPA, RCRA)
GWQA	groundwater quality assessment (EPA, RCRA)
H	acute hazardous waste code (EPA, RCRA)
HA	hazard (or health) assessment
HAD	Health Assessment Document (EPA)
HAP	hazardous air pollutant (EPA, CAA)
HARM	hazard assessment rating methodology
HASP	health and safety plan
HAZINF	Hazardous Chemical Information and Disposal Guide (U. of Alberta)
HAZWOPER	hazardous waste operations and emergency service
HC	hazardous constituent (EPA, RCRA)
HC	hydrocarbons
HCh	hazardous chemical (OSHA)
HEA	health effects assessment (EPA)
HEA	health and environment assessment (EPA)
HEAD	Health Effects Assessment Document (EPA)
HEAST	Health Effects Assessment Summary Tables (EPA)
HEED	Health and Environment Effects Document (EPA)
HEEP	Health and Environmental Effects Profile (EPA)
HH&E	human health and the environment
HHS	U.S. Department of Health and Human Services
HHWE	human health, welfare and the environment
HI	hazard index
HM	hazardous material (DOT, HMTA)
HMTA	Hazardous Materials Transportation Act (DOT)
HQ	hazard quotient
HRS	Hazard Ranking System (EPA, CERCLA)
HS	hazardous substance (EPA, CWA)
HSDB	Hazardous Substances Data Bank (NLM, Toxnet)
HSWA	Hazardous and Solid Waste Amendments (EPA, RCRA)
HW	hazardous waste (EPA, RCRA)

HWMF	hazardous waste management facility (EPA, RCRA)
HWNU	hazardous waste management unit (EPA, RCRA)
I	ignitable hazardous waste code (EPA, RCRA)
I	intake rate
IAG	interagency agreement (EPA, CERCLA)
IARC	International Agency for Research on Cancer
ICL	initial cleanup level
IDLH	immediately dangerous to life or health (NIOSH)
IFB	Invitation for Bids
IHCS	imminently hazardous chemical substance (EPA, TSCA)
ILR	individual lifetime risk
IRIS	Integrated Risk Information System (NLM, Toxnet)
IRP	installation restoration program
IS	interim status (EPA, RCRA)
I&SE	imminent and substantial endangerment
ISHOW	Information System for Hazardous Organics in Water (CIS)
IUPAC	International Union of Pure and Applied Chemists
K---	waste ID for specific-source hazardous wastes (EPA, RCRA)
LAER	lowest achievable emission rate (EPA, CAA)
LC ₅₀	median lethal concentration
LD ₅₀	median lethal dose
LDF	land disposal facility (EPA, RCRA)
LDU	land disposal unit (EPA, RCRA)
LEPC	local emergency planning committee (EPA, EPCRA)
LF	landfill
LFD	local fire department
LLRWPA	Low Level Radioactive Waste Policy Act
LOG P	bioconcentration factors database
LOIS	loss of interim status (EPA, RCRA)
LQG	large quantity generator
LT	lifetime
LTU	land treatment unit
LUST	leaking underground storage tank(s)
MACT	maximum achievable control technology (EPA, CAA)
MARPOL	Marine Pollution Treaty (USCG)
MCL	maximum contaminant level (EPA, SDWA)
MCLG	maximum contaminant level goal (EPA, SDWA)
MCS	media cleanup standard (EPA, RCRA)
MEI	maximum exposed individual (EPA, RCRA)
MEDLARS	Medial Literature Analysis and Retrieval System (NLM)
MEP	maximum extent practicable
MF	modifying factor (EPA)
mg/kg	milligrams per kilogram
mg/l	milligrams per liter

MOA	memorandum of agreement
MOS	margin of safety
MPSRA	Marine Protection, Research, and Sanctuaries Act (EPA)
MPS	media protection standard (EPA)
MSDS	material safety data sheet (OSHA)
MSHA	Mining Safety and Health Administration
MTD	maximum tolerated dose (EPA)
MTR	minimum technology requirements (EPA, RCRA)
MSW	Municipal Solid Waste
NAAQS	National Ambient Air Quality Standard (EPA, CAA)
NAS	National Academy of Science
NBAR	nonbinding allocation of responsibility
NCA	Noise Control Act (EPA)
NCI	National Cancer Institute (NIH)
NCP	National (oil and hazardous substances) Contingency Plan (CERCLA)
NEPA	National Environmental Policy Act (all federal agencies)
NESHAP(S)	national emission standards for hazardous air pollutants (EPA, CAA)
NEPA	National Fire Protection Association
NHPA	National Historic Preservation Act
NIH	National Institute of Health
NIOSH	National Institute of Occupational Safety and Health
NIPDWS	national interim primary drinking water standards (EPA, SDWA)
NLM	National Library of Medicine (HHS, PHS)
NOAA	National Oceanic and Atmospheric Administration (DOC)
NOAEL	no observed adverse effect level
NOD	notice of deficiency (EPA, RCRA)
NOEL	no observed effect level
NOI	notice of intent (to prepare an EIS)
NONC	notice of noncompliance
NOV	notice of violation
NOx	nitrogen oxides
NPDES	National Pollution Discharge Elimination System (EPA, CWA)
NPL	National Priorities List (EPA, CERCLA)
NRC	Nuclear Regulatory Commission
NRC	National Response Center
NRC	National Research Council (NAS)
NRDA	natural resource damage assessment
NRI	National Response Team
NSF	National Science Foundation
NSPS	new source performance standards (EPA, CAA)
NTIS	National Technical Information Service
NTP	National Toxicology Program
NWPA	Nuclear Waste Policy Act
O&G	oil and grease
O&M	operation and maintenance
OE	Office of Enforcement (EPA)

OECH	Office of Enforcement and Compliance Monitoring (EPA)
OERR	Office of Emergency Response and Remediation (EPA, OSWER)
OGC	Office of General Counsel (EPA)
OIH/TADS	Oil and Hazardous Materials/Technical Assistance Data System (EPA)
OMB	Office of Management and Budget
O&MP	operation and maintenance plan
O/O	owner/operator (EPA, RCRA)
ORD	Office of Research and Development
OSC	On-Scene Coordinator
OSHA	Occupational Safety and Health Administration (DOL)
OSHA	Occupational Safety and Health Act
OSM	Office of Surface Mining (DOI)
OSW	Office of Solid Waste (EPA, OSWER)
OSWER	Office of Solid Waste and Emergency Response (EPA)
OTA	Office of Technology Assessment (Congress)
OTS	Office of Toxic Substances (EPA, OPTS)
OU	operable unit (EPA, CERCLA)
OUST	Office of Underground Storage Tanks (EPA)
OWPE	Office of Waste Programs Enforcement (EPA, OSWER)

P---	waste ID for acutely hazardous commercial chemical products (RCRA)
PA	preliminary assessment (EPA, CERCLA)
PAAT	Public Affair Assistance Team
PAC	powdered activated carbon
PAH	polycyclic aromatic hydrocarbons
PCBs	polychlorinated biphenyls
PCDD	polychlorinated dibenzo- <i>p</i> -dioxin

PCDF	polychlorinated dibenzofurans
PCP	pentachlorophenol
PDR	Physicians' Desk Reference
PECMT	preliminary evaluation of corrective measures technology
PEL	permissible exposure limit (OSHA)
PHRED	Public Health Risk Evaluation Database (EPA)
PSHA	Public Service Health Act
PHYTOTOX	Terrestrial plant toxicology database (CIS)
PI	preliminary injunction
PIAT	Public Information Assistance Team
PIC	product(s) of incomplete combustion
PIG	program implementation guidance
PIP	public involvement plan
PL	public law
PM	project manager
PMN	premanufacture notices
PMP	program management plan
PN	public notice
PNA	polynuclear aromatic (use PAH)
PNC	public notice and opportunity of comment

POC	point of compliance (EPA)
POD	point of departure (EPA)
POE	point of exposure
POHC	principle organic hazardous constituent
POM	polycyclic organic matter
POTW	publically owned treatment works (EPA, CWA)
PP	priority pollutant (EPA, CWA)
PP	proposed plan (EPA, CERCLA)
ppb	parts per billion
PPE	personal protective equipment
PPIC	Pollution Prevention Information Clearinghouse (EPA)
ppm	parts per million
PPP	pollution prevention planning (EPA)
ppt	parts per trillion
PQL	practical quantitation limit
PR	preliminary review (EPA, RCRA)
PRAO	preliminary remedial action objectives (EPA, CERCLA)
PRG	preliminary remediation goal (EPA, CERCLA)
PRP	potentially responsible party (EPA, CERCLA)
PSD	prevention of significant deterioration (EPA, CAA)
q, q*, q ₂	Same as SF and CPF
QAPP	quality assurance project plan (EPA)
QA/QC	quality assurance quality control
QRA	quantitative risk assessment
QSAR	Quantitative Structure Activity Relationships (Montana State Univ.)
R	reactivity hazardous waste code (EPA, RCRA)
R	acceptable risk level (EPA)
RA	remedial action (EPA, CERCLA)
RA	risk assessment
RA	Regional Administrator
RACI	reasonably available control technology (EPA, CAA)
RAn	risk analysis
RAO	remedial action objective (EPA, CERCLA)
RAP	remedial action plan
RBC	rotating biological contactor
RC	risk communication
RCh	risk characterization
RComp	remedy completion
RCRA	Resource Conservation and Recovery Act
RD	remedial design (EPA, CERCLA)
RD&D	research, development and demonstration
RE	risk evaluation
REL	recommended exposure limit (NIOSH)
RI/MTT	Field Investigation Team for EPA Remedial Action
RIA	RCRA facility assessment (EPA, RCRA)
RIC	(Inhalation) reference concentration (generic or chronic) (EPA)

RIC _{dev}	reference concentration (developmental teratogenic) (EPA)
RIC _{sub}	reference concentration (subchronic) (EPA)
RID	(Oral) reference dose (generic or chronic) (EPA)
RID _{dev}	reference dose (developmental teratogenic) (EPA)
RID _{sub}	reference dose (subchronic) (EPA)
RFI	RCRA facility investigation (EPA, RCRA)
RFP	Request for Proposal
RI	remedial investigation (EPA, CERCLA)
RI/FS	remedial investigation/feasibility study
RIM	regulatory interpretative memorandum
RJ	risk judgment
RM	risk management
RME	reasonable maximum exposure (EPA)
RMI	risk management implementation (EPA, RCRA)
RMCL	recommended maximum contaminant level (same as MCLG)
RN	risk negotiation
RO	reverse osmosis
ROD	record of decision (EPA, CERCLA)
RP	risk perception
RP	responsible party (EPA, CERCLA)
RPAR	rebuttable presumption against registration (EPA, FIFRA)
RPJ	risk perception and judgment
RPM	Regional Project Manager
RQ	reportable quantity (EPA, CERCLA)
RR	residual risk
RR	risk reduction
RRC	Regional Response Center
RRS	risk reduction studies
RRT	Regional Response Team
RS	regulated substances (EPA, UST)
RS	remedy selection
RS	risk substitution
RSD	risk specific dose (EPA)
RTECS	Registry of Toxic Effects of Chemical Substances (NLM, Toxnet)
RU	regulated unit (EPA, RCRA)
RW	remediation waste
RWMU	remediation waste management unit (EPA, RCRA)
S	storer, storage
SAB	Science Advisory Board
SARA	Superfund Amendments and Reauthorization Act
SC	specific conductance
SDWA	Safe Drinking Water Act
SERC	State Emergency Response Commission (EPA, EPCRA)
SES	Senior Executive Service
SF	safety factor (EPA)
SF	slope factor (EPA)
SHPO	State Historic Preservation Officer

SI	sampling inspection (EPA, RCRA)
SI	site inspection (EPA, CERCLA)
SI	surface impoundment
SIC	standard industrial classification (code)
SIP	state implementation plan (EPA, CAA)
SIIE	Superfund Innovative Technology Evaluation Program (EPA-ORD)
SMCL	secondary maximum contaminant level
SMCRA	Surface Mining Control and Reclamation Act (DOI-OSM)
SNARL	suggested no adverse reaction level
SNC	significant noncomplier (EPA)
SNUR	significant new use rule (EPA, TSCA)
SOLUB	aqueous solubility database (Univ. of Arizona)
SPCC	spill prevention, control, and countermeasure (plan) (EPA, CWA)
SQG	Small quantity generator
SSC	Scientific Support Coordinator
SW	solid waste (EPA, RCRA)
SWDA	Solid Waste Disposal Act
SWMF	solid waste management facility (EPA, RCRA)
SWMU	solid waste management unit (EPA, RCRA)
T	toxicity hazardous waste code (EPA, RCRA)
T	treater, treatment
TA	toxicity assessment
TAG	technical assistance grant (EPA, CERCLA)
TAR	technical amendment to the regulations
TAT	Technical Assistance Team
TBC	advisory, criteria, or guidance to be considered (EPA, CERCLA)
TC	toxicity characteristic (EPA, RCRA)
TCA	trichloroethane
TCE	trichloroethylene
TCh	toxic chemical (EPA, EPCRA)
TC ₅₀	median toxic concentration
TCDD	2,3,7,8-Tetrachlorodibenzo- <i>p</i> -dioxin
TCL	toxic chemical list (EPA, EPCRA)
TCL	target cleanup level (EPA, RCRA)
TCLP	toxicity characteristic leaching procedure (EPA, RCRA)
TD50	median toxic dose
TDS	total dissolved solids
T&E	test and evaluation facility
TEGD	Technical Enforcement Guidance Document (EPA, RCRA)
THM	trihalomethane
TIP	Toxicology Information Program (NLM)
TLV	threshold limit value (ACGIH)
TLV-C	TLV-ceiling (ACGIH)
TLV-STEL	TLV-short-term exposure limit (ACGIH)
TLV-TWA	TLV-time-weighted average (ACGIH)
TMV	toxicity, mobility, and volume
TOC	total organic carbon

TOX	total organic halogen
TOXLINE	Toxicology Information Online (NLM, ELMILL)
TOXLIB	toxicology literature from special sources (NLM, ELMILL)
TOXNET	Toxicology Data Network (NLM, MEDLARS)
TP	transporter
TP	toxic pollutant (EPA, CWA)
TPQ	threshold planning quantity (EPA, EPCRA)
TRI	Toxic Chemical Release Inventory (EPA, EPCRA, NLM, Toxnet)
TRIFACTS	Toxic Chemical Release Inventory Fact Sheets (NLM, Toxnet)
TRO	temporary restraining order
TS	toxic substance (EPA, TSCA)
TSCA	Toxic Substances Control Act
TSCATS	Toxic Substances Control Act submissions
TSD	treatment, storage, or disposal
TSDF	treatment, storage, or disposal facility
TSP	total suspended particulates
TSS	total suspended solids
TSS	total settleable solids
TU	temporary unit (EPA, RCRA)
TUHC	total unburned hydrocarbons
TV	toxicity value
U---	waste ID for toxic commercial chemical products
UF	uncertainty factor
UIC	Underground Injection Control Program (EPA, SDWA)
ur ³	use, reuse, recycle, reclaim
USC	United States Code
USCA	United States Code Annotated
USCG	U.S. Coast Guard
USDW	underground source of drinking water (EPA, SDWA)
USGS	United States Geological Survey
UST	underground storage tank (EPA, RCRA)
VOA	volatile organic analyzer
VOC	volatile organic carbon (or compound)
VSI	visual site inspection (EPA, RCRA)
W	weight of receptor
WHO	World Health Organization
WL	warning letter
WP	waste pile
WQA	Water Quality Act
WQC	water quality criterion (EPA, CWA)
WQS	water quality standard (EPA, CWA)
WWTU	wastewater treatment unit (EPA, RCRA)