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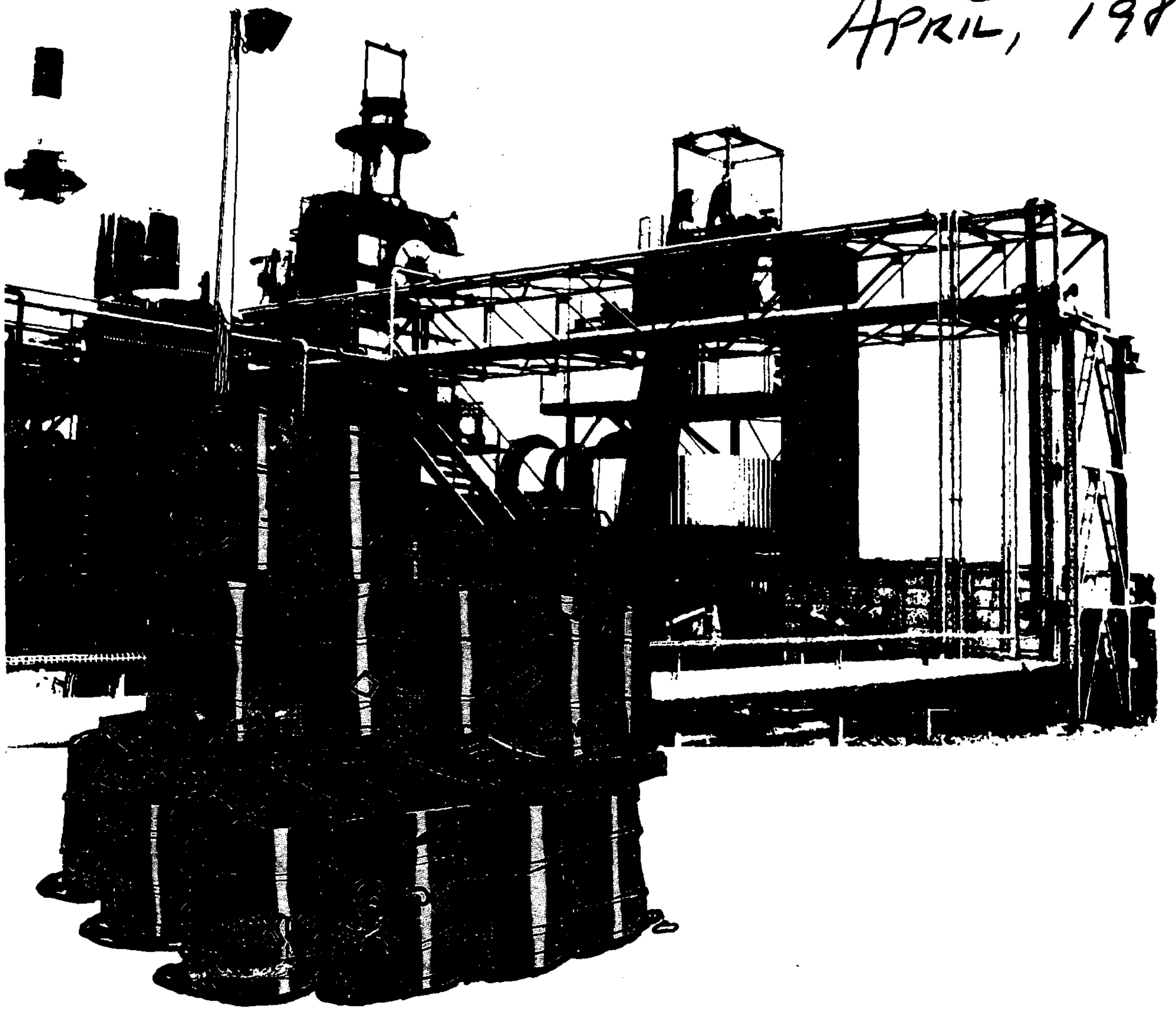
The Safe Disposal of Hazardous Wastes

The Special Needs and Problems of Developing Countries

Volume III

Roger Batstone, James E. Smith, Jr., and David Wilson, editors

April, 1989



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ANNEX 7.1A

Leachate from a Hazardous Waste Landfill -- Technical and Economical Comparison of Treatment Process

Annex 7.1A was written by E. Boith, H. Ludwig, and K.-D. Wolz, Fichtner Consulting Engineers, Stuttgart, West Germany

Leachate is formed in landfills when rain water percolates through the waste, is collected in a drainage system, and then exits the landfill. Depending on the nature of the waste and the way the landfill is constructed, the water picks up various contaminants as it passes through the different layers of the landfill. Since the consistence, composition and toxicity of hazardous wastes differ significantly from that of municipal wastes, the leachates from these two types of landfills are very different in terms of the types and concentrations of contaminants. The flow rate, the composition and the content of toxic substances of leachates from hazardous waste landfills are influenced by the waste composition, the landfilling method, the surface sealing, and the drainage system.

A general comparison of the types and concentration ranges of possible constituents of leachates from municipal refuse and hazardous waste landfills is given in Table 7.1A-1.

Historical Background and Local Conditions of the Malsch Landfill

Operator

The Malsch Landfill was constructed in a former clay pit which was in operation until 1969. After a permit was granted to the Boll company for the construction of a controlled landfill for municipal refuse and hazardous waste and for backfilling the pit, this company leased the site to the WDG company (Westdeutsche Deponiegesellschaft, Offheim) which is a subsidiary of Westab, Duisburg. Backfilling operations commenced in December 1971 and were terminated initially in October 1974 following a blockade by citizen action groups from the surrounding communities. In March 1975 the SMB (Sondermull-Betriebsgesellschaft mbH, Mannheim, operators of hazardous waste landfills) took over the landfill. The shareholders of this organization consisted of SBW (organization for the disposal of hazardous waste in the state of Baden-Wuerttemberg), and Westab GmbH, Duisburg, who each held 50% of the shares. During the course of this year SMB carried out site improvement measures and in October 1975 the Heidelberg local authority granted permission for reopening the landfill. Operations were resumed in February 1976.

In January 1984 the landfill was full and finally closed. In May 1987 SBW took over full ownership of SMB.

Deposited Materials

Initially, a pit covering some 55,000 m^2 with a depth of up to 25 m was excavated. The pit could contain about 500,000 m^3 of waste.

During the first filling period, about 190,000 tons of hazardous wastes were deposited. It was during this initial period when the wastes were first

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TABLE 7.1A-1

Leachate from Malsch Site - Constituents

		Municipal Waste Landfill	Hazardous Waste Landfill
Conductivity	mS/cm	4.3 - 24	32 - 112
pH	-	6.3 - 7.8	7.3 - 6.8
Residue on evaporation	g/l	1.9 - 9.5	27 - 210
Residue on ignition	g/l	0.6 - 3.2	26 - 180
Chloride	mg/l	380 - 1600	13 000 - 122 000
Sulphate	mg/l	400 - 1500	1100 - 4250
Ammonium	mg/l	400 - 3000	100 - 7550
Iron	mg/l	2.5 - 7	0.5 - 240
Nickel	mg/l	0.1 - 0.4	20.1 - 0.4
Copper	mg/l	0.01 - 0.05	20.05 - 0.4
Zinc	mg/l	0.2 - 1.4	0.5 - 16
Chromium	mg/l	0.2 - 0.7	20.5
Cadmium	mg/l	0.001	< 0.1
Mercury	mg/l	0.005 - 0.01	< 0.005
Lead	mg/l	0.01 - 0.05	< 0.5
COD	mg 0_2/1	850 - 4500	700 - 25 000
Bod$_5$	mg 0_2/1	100 - 1000	160 - 6200
AOX	mg C1/1	0.4 - 1.5	50 - 650

Source: Fichtner Consulting Engineers. 1987. Stuttgart, West Germany. Prepared for the World Bank.

delivered, which contributed to the contamination of the leachate. The leachate was contaminated principally with residues from pesticides and herbicides, acidic tars, residues from paint production, and heavy metal precipitates. Unfortunately, a thorough quantification of the wastes delivered to the site and assessment of their physical and chemical characteristics is not possible; at that time there was no mandatory declaration of wastes. Even daily operating records did not have to be kept prior to July 1972. During operation by SMB over 510,000 tons of wastes were dumped. The total amount of landfilled wastes reached about 710,000 tons.

Wastes from the second filling period can be grouped into four categories:

Category 1

Wastes from processing light metals (e.g., salt slags from smelting aluminum or magnesium) contribute around 23% of the total. They are characterized by a marked propensity to react with water, during which time heat is evolved and volatile gases are generated, as well as by their relatively high solubility in water ($NaCl$, KCl).

Category 2

Wastes from water and effluent treatment (e.g., filter cakes containing hydroxides of heavy metals from electroplating plants) make up some 28% of the total landfill contents. They are characterized by their relatively high water content -- 70 to 80% -- and their pasty consistency.

Category 3

Wastes from clean-up measures and accidents (e.g., soils contaminated with oil or with gasworks residues) constitute about 24% of the total volume.

Category 4

This category comprises all "miscellaneous wastes", accounting for 25% of the total and containing over 30 classes of material species. Without doubt, this category has the most relevance from the standpoint of environmental contamination. During the first filling period, this category accounted for up to 80% of the annual quantity landfilled. Counted in this category are, for instance, distillation residues, waste salts containing solvent, oily production materials and sludges. Often these wastes are flammable and spontaneously ignitable, and they contributed greatly to the organic species which contaminated the leachate.

These wastes were primarily supplied as bulk deliveries; with some also stored in drums (around 3% of the total quantity and some 30-40% during the first filling period). Figure 7.1A-1 shows an overview of the deposited quantities.

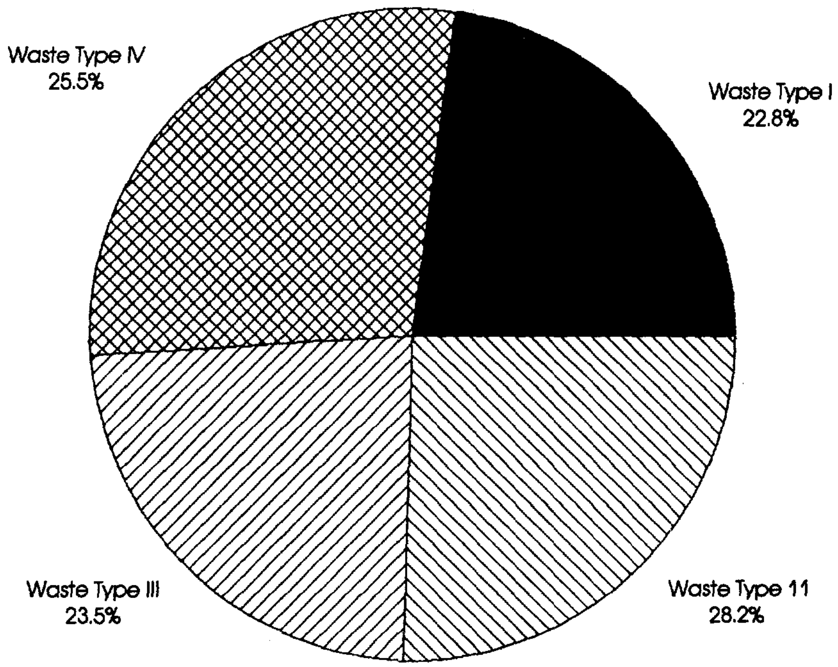
Situation on Site

During operation and following closure of the landfill, most of the site area was re-cultivated. This was done as it was regarded as a suitable measure for the diversion of rainwater from the landfilled wastes.

FIGURE 7.1A-1

Leachate from Malsch Site
Infilled Wastes Following Interim Restitution

Feb. 1976 - Jan. 1984



Source: Fichtner Consulting Engineers. 1987. Stuttgart, West Germany. Prepared for the World Bank.

Likewise for this purpose the following steps were taken:

(i) Grading of the landfill surface. Around peripheries 1:3 with radiusing 1:7 at foot of slope; on the plateau area of the landfill (where the height of the dumped material is greatest) a camber of around 5% up to the centerline of the landfill (roof-shaped section) is provided.

(ii) Placement of the re-cultivation cover layer. In areas where the gradient is slight, the sandy cover for the filled-in wastes (clean layer) is covered with a clay layer about 0.6 m thick, followed by another sandy layer about 0.2 m thick and finally a sandy loam cap 1.5 to 2 m. Where slopes are steep there is no bottom sealing as inclinations and top vegetation guarantee that water will run off the surface. Along the apex of the roof-shaped profile the cap is deliberately interrupted by a gravel-filled drain trench to allow for a future gas recovery system (if gas production should make active measures necessary).

(iii) Planting trees and shrubs, which put out roots at various levels, is intended to develop the top soil layer, provide a high water take-up capacity, increase evapo-transpiration and, by rapidly binding the slopes, prevent soil erosion.

The manner of re-cultivation is shown in Figure 7.1A-2.

Part of the site, with an area of about 5000 m^2, has not yet been re-cultivated and is considered as a leachate catchment area. Water from two wells in the immediate vicinity of the landfill is treated together with the leachate because of the possibility of contamination.

Surface run-off is intercepted by a ditch and is subsequently discharged into a stream -- the Kahlbach -- as receiving water.

The following remedial action measures have already been carried out or are planned:

Remedial actions in 1975:

(i) Installation of a drainage system in the north and east/south area of the site for diversion of the pore water flowing through the permeable soil strata. The combined flow of these two drainage systems exceeds 1 l/s, and thus diverts over 30,000 m^3 water per annum around the landfilled wastes.

(ii) Lateral cutoff walls in the region of the permeable cover layers in the form of an artificial clay embankment some 2.5 m wide.

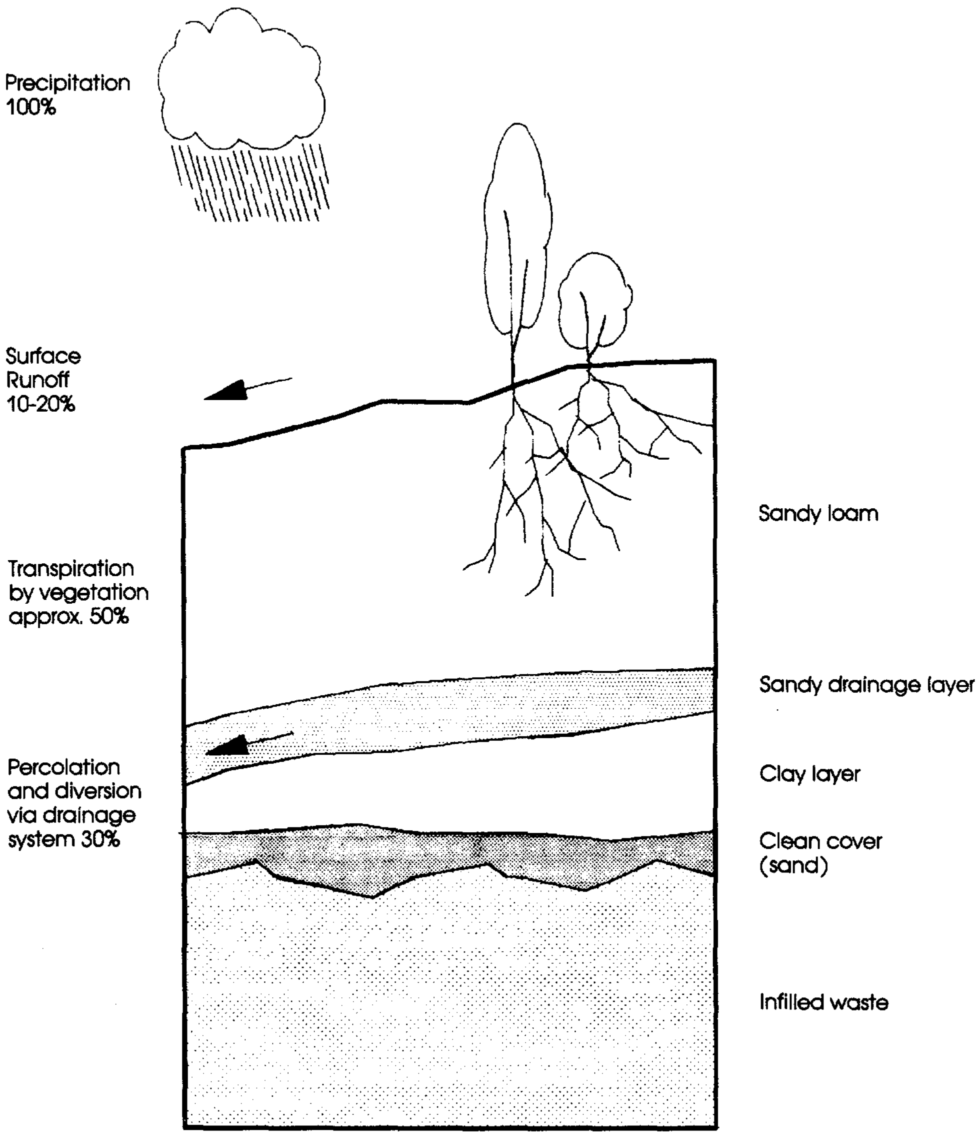
(iii) Emplacement of a subgrade at the filling level of that time, emplacement of the first drainage systems (gravel-filled drain trenches with drainage pipes along the access roads) and of a leachate extraction well.

(iv) Fencing of site and erection of an administration building with a laboratory.

During October 1983, analyses at sampling wells and the results of soil

FIGURE 7.1A-2

Leachate from Malsch Site Recultivation



Source: Fichtner Consulting Engineers. 1987. Stuttgart, West Germany. Prepared for the World Bank.

measurements in test pits, as well as further drilling work indicated that there were leaks in the strata below the landfill. A total of 38 further test drills carried out up to February 1984 confirmed the initial finding and the University of Stuttgart was commissioned to prepare an expert analysis entitled "Investigation of the hazard potential of the Malsch hazardous waste landfill and the development of a remedial action concept". Under the terms of reference of this expert analysis, at present a comprehensive program is underway to reveal the geological and hydrogeological characteristics of the site.

Leachate Collection

As already mentioned above, a drainage system was installed for the first time during the original site restitution project in 1975. This means that there is no drainage beneath the level of the landfill wastes which had been deposited up to that time, or if so, then only as a result of compaction and displacement of the pore water to higher levels. As landfilling continued, further drainage systems were installed as deemed necessary, for instance, in the event of leachate forced to the surface. These were connected to the (decentral) leachate extraction well.

As part of the present exploratory measures, it is intended that another two sampling wells will be sunk, which could then be used for further collection and removal of leachate.

The leachate is pumped from the extraction pit for onsite pre-treatment. At present, this comprises solvent extraction using fuel oil in order to remove dioxins and it is planned to replace the existing plant with one of higher capacity. Following pre-treatment, the water is stored prior to being hauled from the site by vacuum suction takers and taken to various municipal sewage works. Upon arrival at the sewage treatment plants the wastes are pumped into the plants' inlets via metering devices.

Composition and Quantity of Leachate

Of the total pollution content, leachate from the Malsch Landfill is characterized by its extremely high salt content with a solid residue from evaporation of up to 210,000 mg/l and an average of around 170,000 mg/l, as well as a residue from ignition of up to 180,000 mg/l or 145,000 mg/l on average.

The ammonium content, too, is rather high; between 1,700 and 7,600 mg/l. In addition, the general organic loading is very high: values of up to 24,3000 mg/l (15,500 mg/l on average) and maximum BOD values of 6,200 mg/l (4,090 mg/l on average). Further data on the minimum, maximum and average contents of specific organic pollutants such as chlorinated aliphatic and aromatic hydrocarbons, phenols, PCBs and so on is given in Table 7.1A-2.

The content of inorganic and organic pollutants is subject to very wide fluctuations, as illustrated in Figures 7.1A-3 to 7.1A-11. The parameters include conductivity, chloride, ammonium, sulphate, residue from evaporation, residue from ignition, phenol, COD/BOD_5, for various chlorinated hydrocarbons,

TABLE 7.1A-2

Leachate from Malsch Site - Analysis

		Min	Max	Average
pH		6.6	6.8	6.7
Conductivity	µS/cm	22800	112000	80940.0
Phenols (total)	mg/l	104	460	210.4
Phenols (steam-volatile)	mg/l	33	330	104.7
Chloride	mg/l	55300	122000	91710.0
Sulphate	mg/l	2160	4250	3445.8
Ammonium	mg/l	1780	7550	5363.5
Zinc	mg/l	4.5	15.8	7.9
Iron	mg/l	89	239	157.0
Residue on evaporation	mg/l	104500	210500	167907.7
Residue on ignition	mg/l	92400	180200	145283.3
COD	mgO$_2$/l	9100	24300	15550.0
BOD$_5$	mg/O$_2$/l	2100	6200	4090.0
Polar hydrocarbons	mg/l	46.3	460	195.0
Unpolar hydrocarbons	mg/l	10	585	179.5
Methylene chloride	µg/l	20100	65300	40252.5
Chloroform	µg/l	190	2100	671.8
Tetrachloromethane	µg/l	0	55	8.1
1,1,1 Trichloroethane	µg/l	11	605	119.1
1,2-Dichloroethylene	µg/l	20	950	311.0
Trichloroethylene	µg/l	1350	23100	5552,5
Tetrachloroethylene	µg/l	1210	35800	9873.5
Hexachlorocyclohexane	µg/l	1500	9600	4250.0
Hexachlorobenzene	µg/l	0.3	1.7	1.1
Pentachlorophenol	µg/l	110	280	187.5
Polychl. biphenyls	µg/l	120	290	205.0
Benzene	µg/l	1100	4900	2925.0
Toluene	µg/l	6570	43900	17817.5
Xylene	µg/l	3100	38500	13817.5
LEACHATE FLOW	t/d	16.4	40.5	24.4

Source: Fichtner Consulting Engineers. 1987. Stuttgart, West Germany. Prepared for the World Bank.

for polar and unpolar hydrocarbons as well as for the total iron content and AOX.

For the solvent extraction process previously used for leachate treatment at the Malsch site, the iron content of the leachate is presently in the range between 90-240 mg/l and primarily occurs as Fe^{+2} (see Figure 7.1A-12). This has given rise to considerable problems because of the continuous precipitation of ferric hydroxide due to successive oxidation of the ferrous content during effluent treatment. Thus, a crucial process stage in the chemical and physical treatment procedure described below is the removal of iron.

Just as the constituents of the leachate are subject to wide fluctuations, so too is its flow. The daily flow for 1985 and 1986 -- which varies between 16 and 41 m^3 per day -- is shown in Figure 7.1A-13.

Waste Water Discharge Conditions and Effluent Standards

Apart from the knowledge of the changes of concentration and flow rate of the leachate, the existing discharge conditions and the official requirements with regard to its residual contamination are also important in selecting an appropriate treatment process. A differentiation is to be made between indirect and direct discharge; (i.e., supplying the treated effluent to a municipal sewage treatment plant via a sewer system or tanker vehicles or direct discharge into surface waters). Local conditions preclude the possibility of direct discharge into surface waters. The small stream flowing past the landfill is too small and too highly polluted already to be used as a receiver for direct discharge, even if the leachate were treated extensively.

Table 7.1A-3 summarizes the conditions for indirect discharge. Standards are compared for indirect discharge according to ATV code 115 issued by the association of waste water technology, as well as the guidelines for sewage discharge in the German states of Baden-Wuerttemberg and Bavaria.

The key parameters for discharging into a sewer system include contents of ammonium and sulphate. These limits in Baden-Wuerttemberg of 50 mg/l NH_3-N and 400 mg/l SO_4^{2-}, respectively, could not be held without extensive leachate treatment. However, the reason for limiting these two parameters is due principally to the operational requirements of the sewer system. Thus, the limitation on ammonium is intended to prevent, among other things, the liberation of gaseous ammonia in the event of local alkalinity of the sewage water in the sewer itself, while the limitation on sulphate is to prevent corrosion of the concrete walls of the sewer. As a consequence, an alternative to reducing the content of these two constituents by an additional process step in an onsite treatment facility is to supply the pre-treated effluent directly to a municipal sewage treatment works by tanker vehicle, store it in a buffer tank and admix it uniformly to the main flow of sewage at the inlet of the treatment plant.

FIGURE 7.1A-3

Leachate from Malsch Site - Ammonium/Sulphate

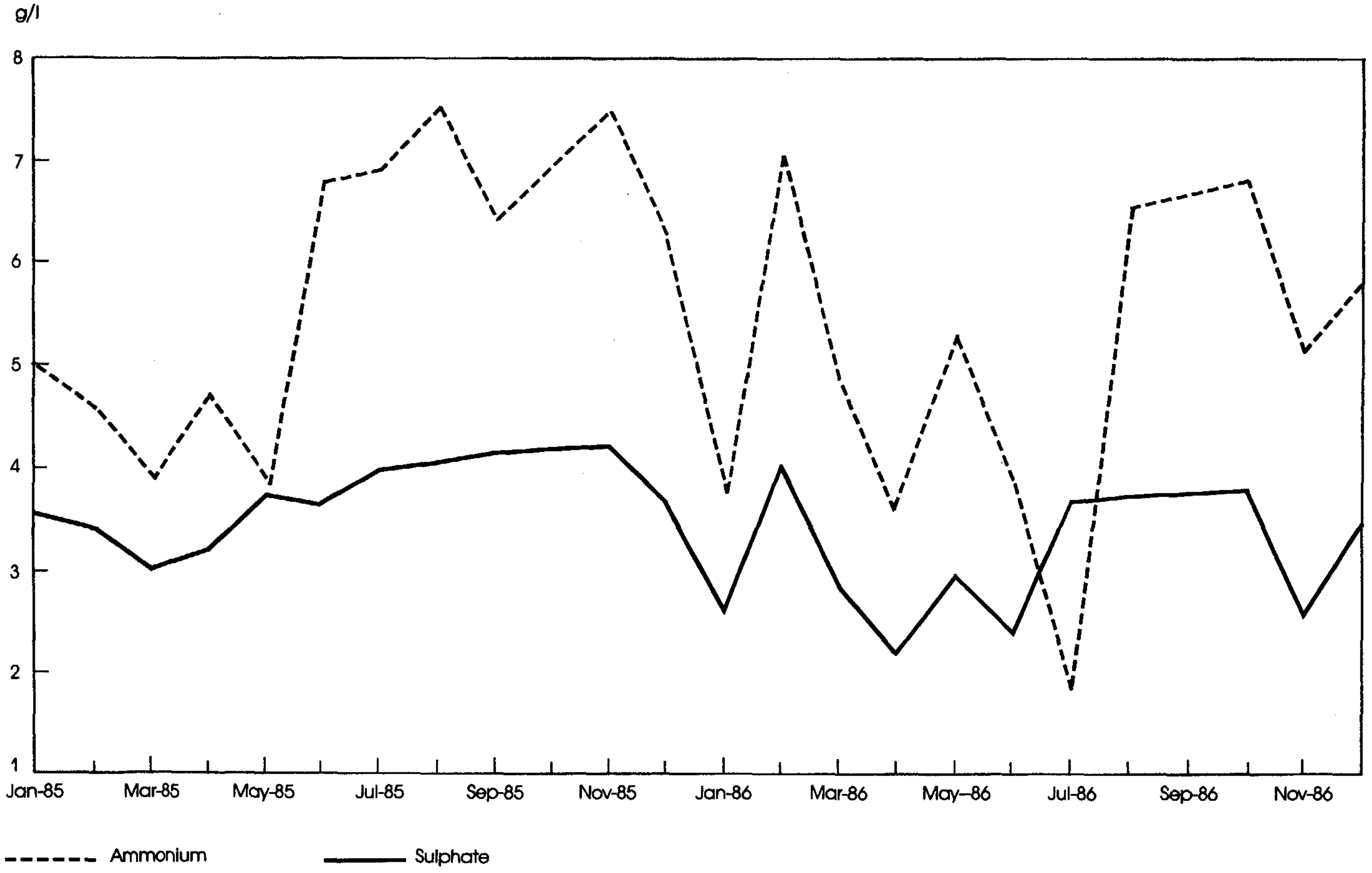


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FIGURE 7.1A-4

Leachate from Malsch Site - AOX

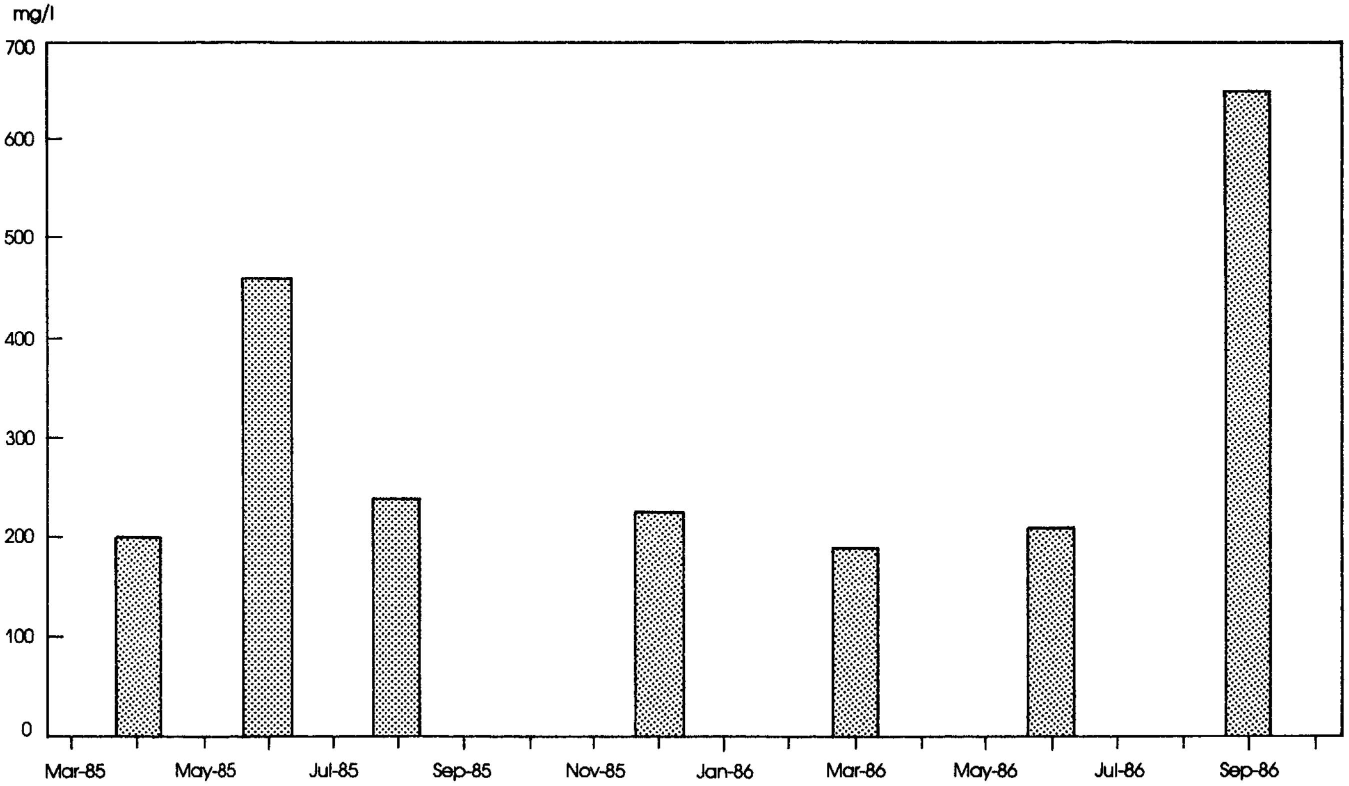

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FIGURE 7.1A-5

Leachate from Malsch Site - Residues from Evaporation and Ignition

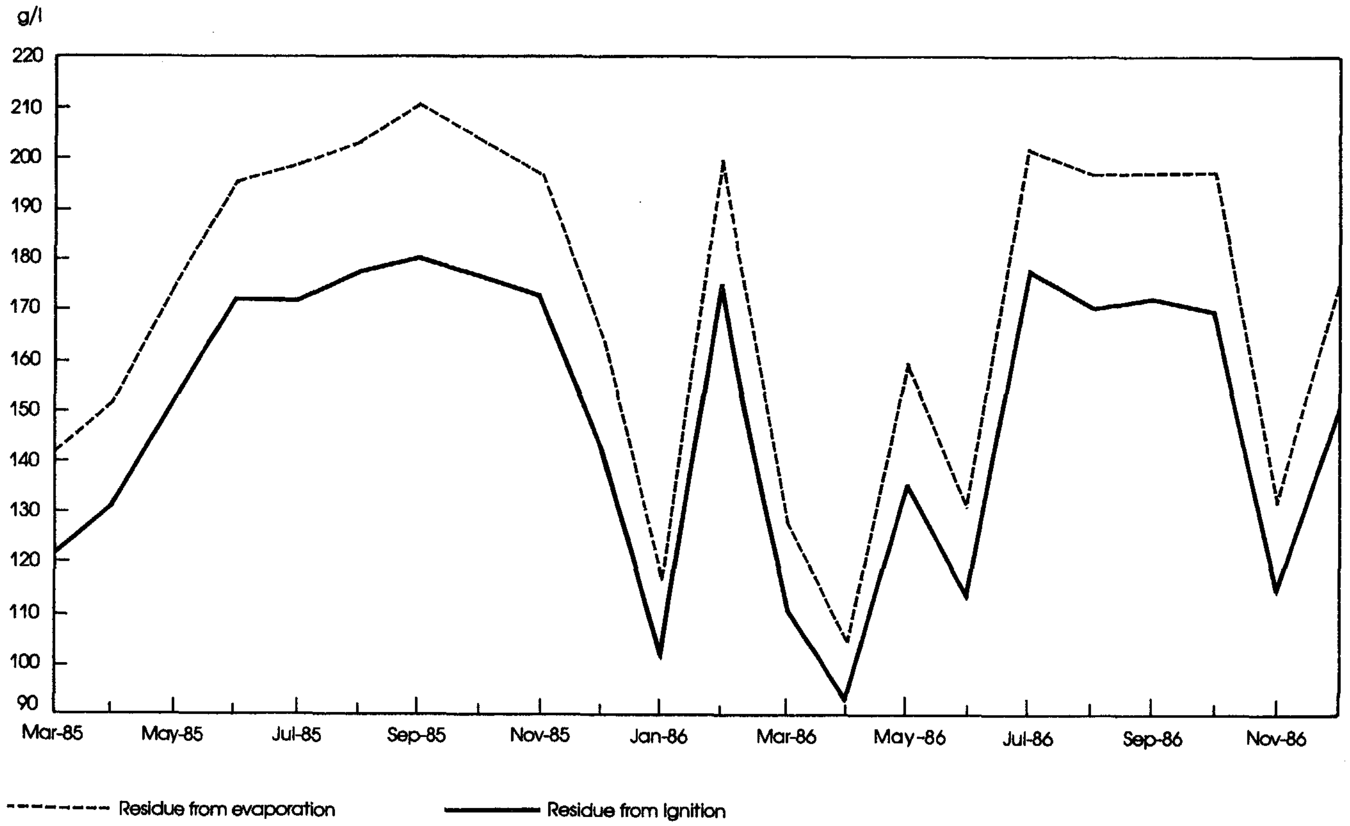

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FIGURE 7.1A-6

Leachate from Malsch Site - COD/BOD5

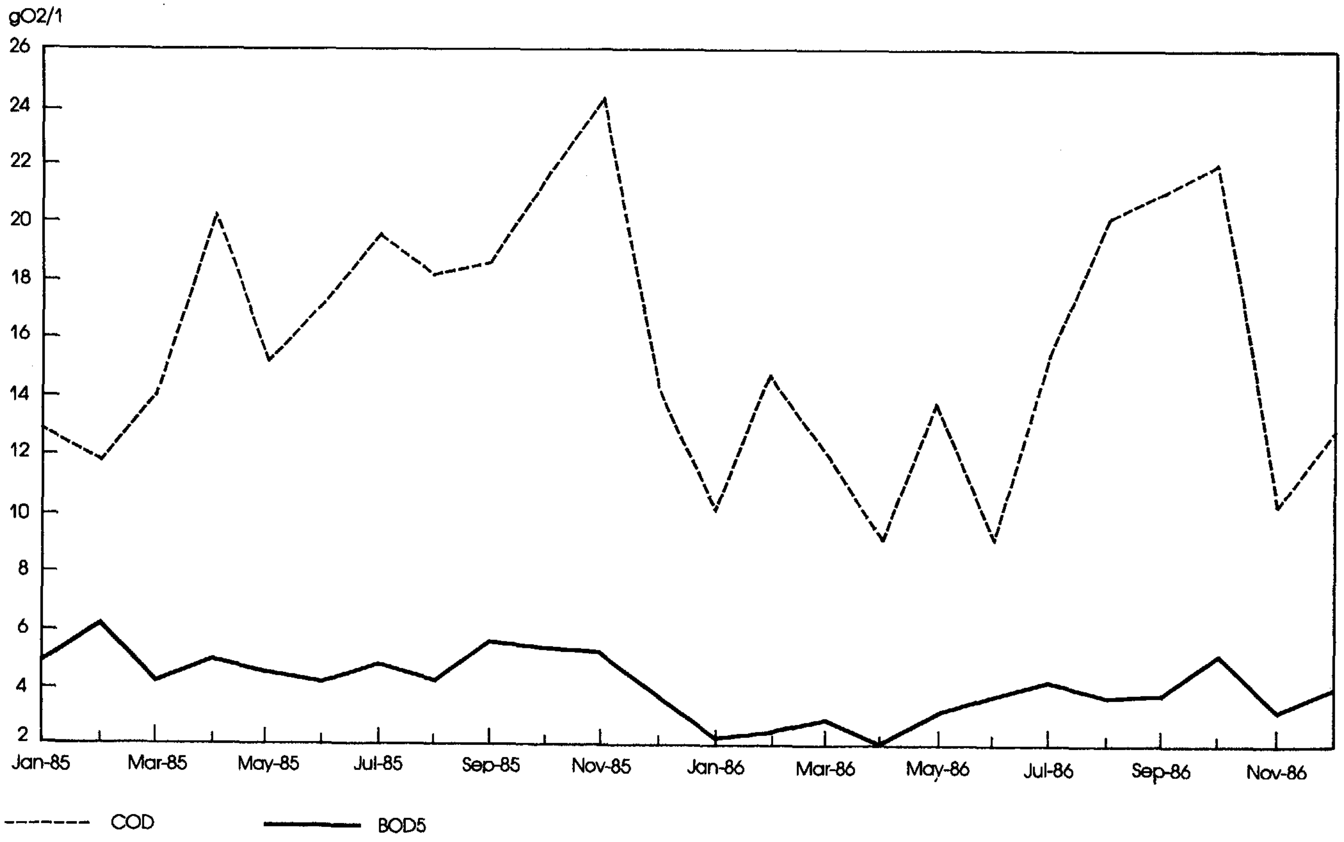

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FIGURE 7.1A-7

Leachate from Malsch Site - Chlorinated Hydrocarbons 1

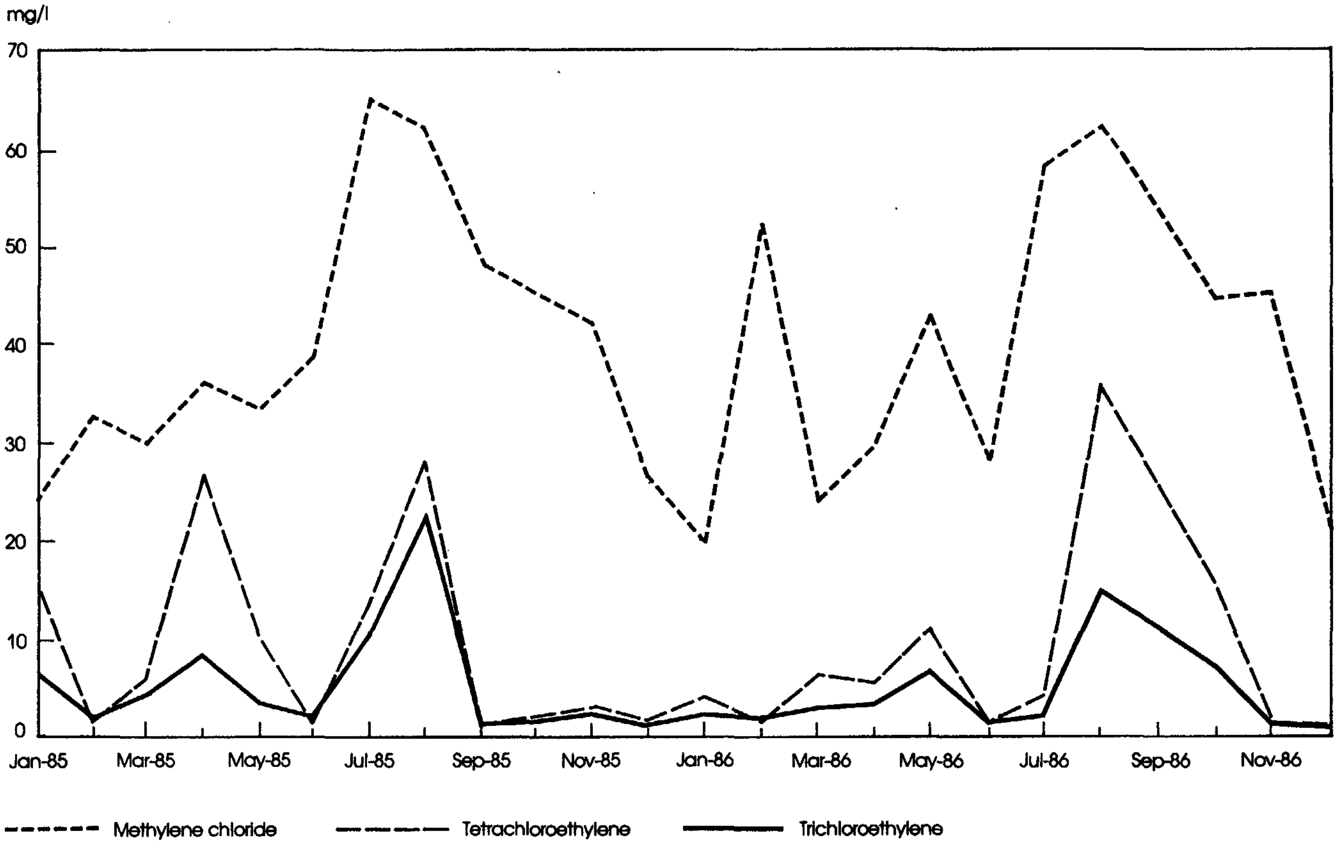

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FIGURE 7.1A-8

Leachate from Malsch Site - Chlorinated Hydrocarbons 2

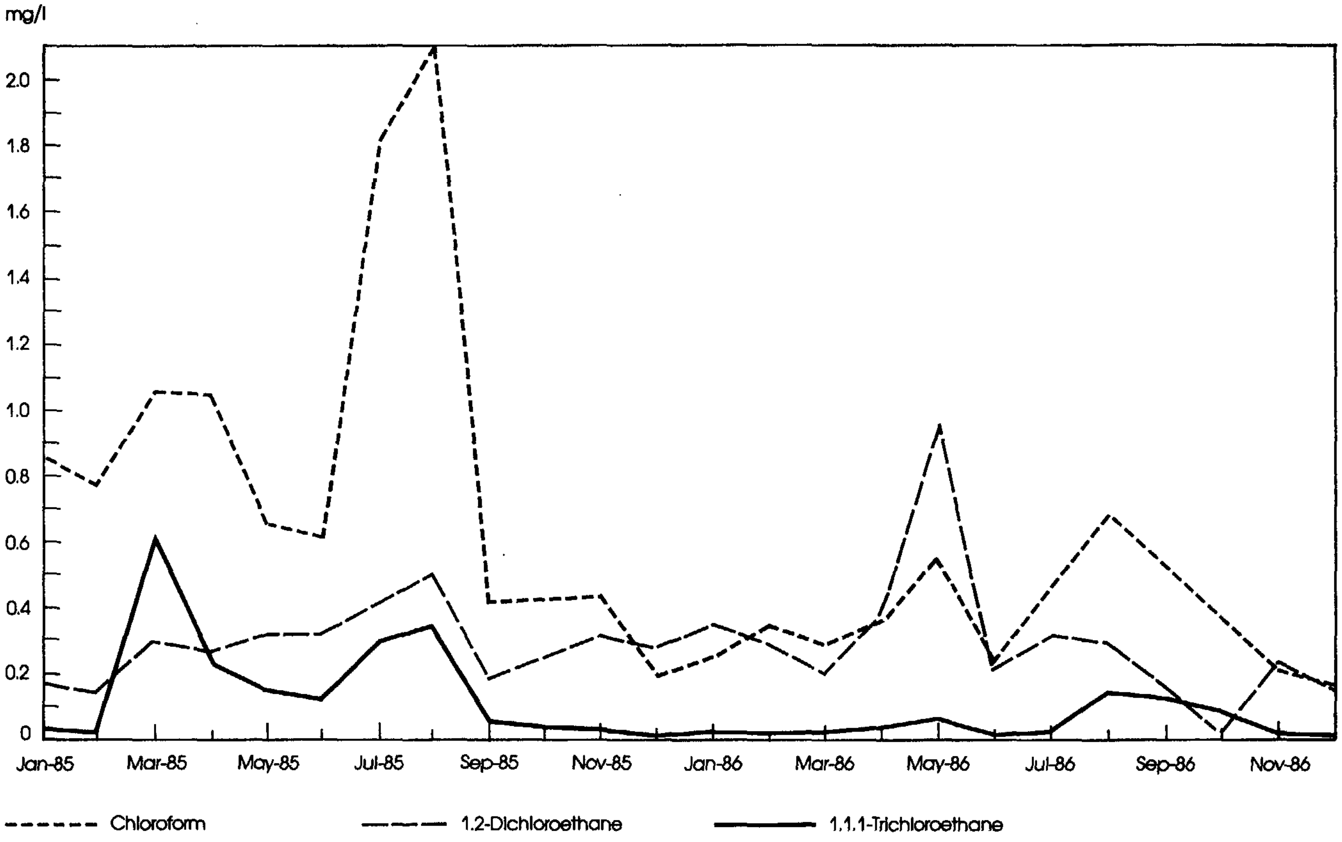

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FIGURE 7.1A-9

Leachate from Malsch Site - Polar/Unpolar Hydrocarbons

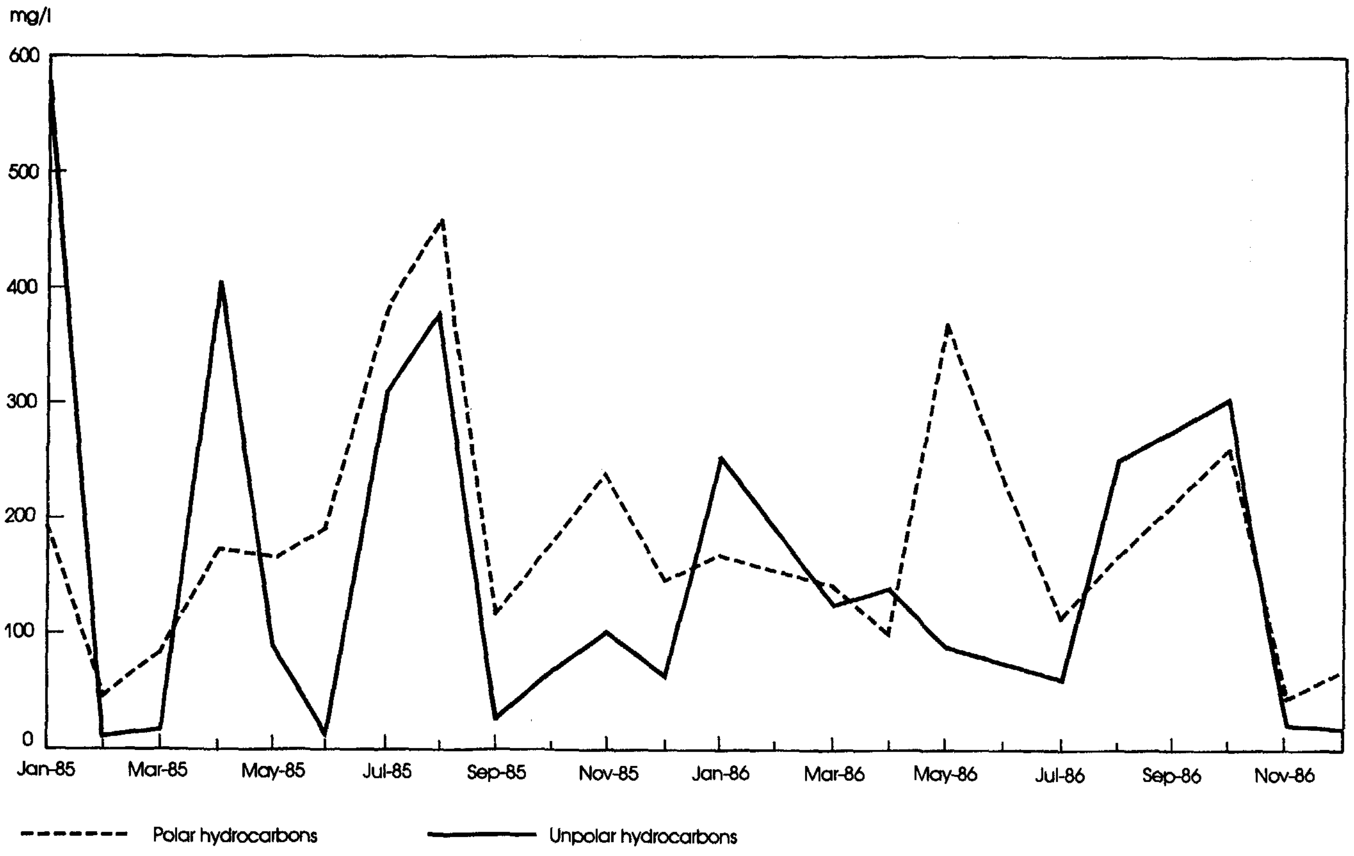

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FIGURE 7.1A-10

Leachate from Malsch Site - Total/Steam Volatile Phenols

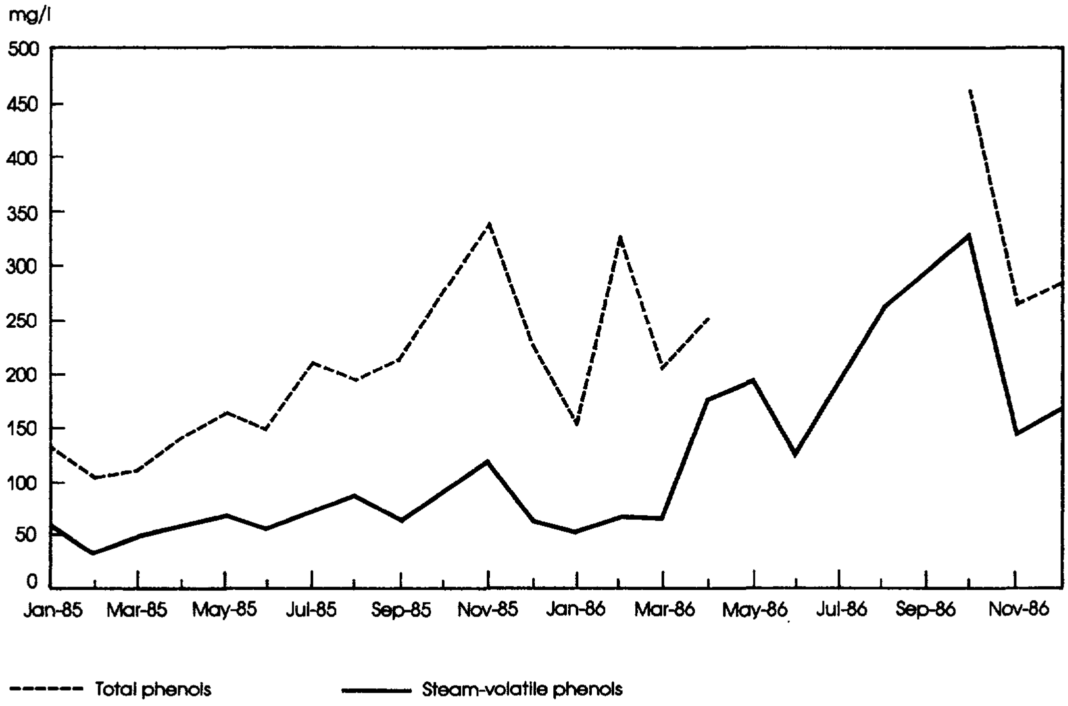

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FIGURE 7.1A-11

Leachate from Malsch Site - Conductivity/Chloride Content

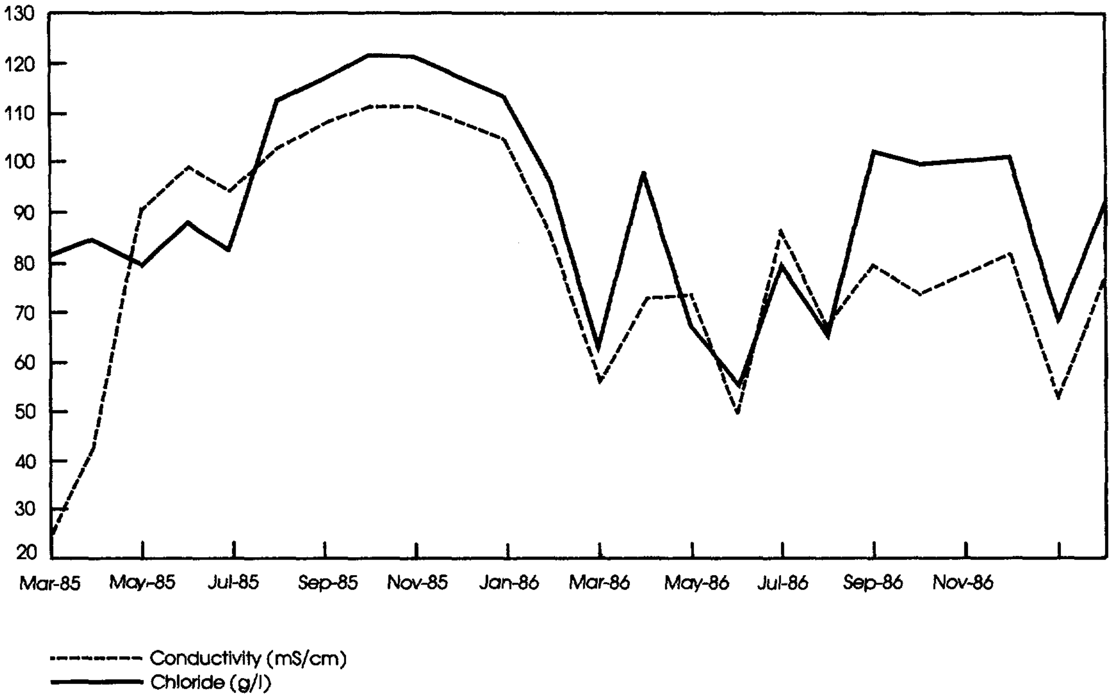

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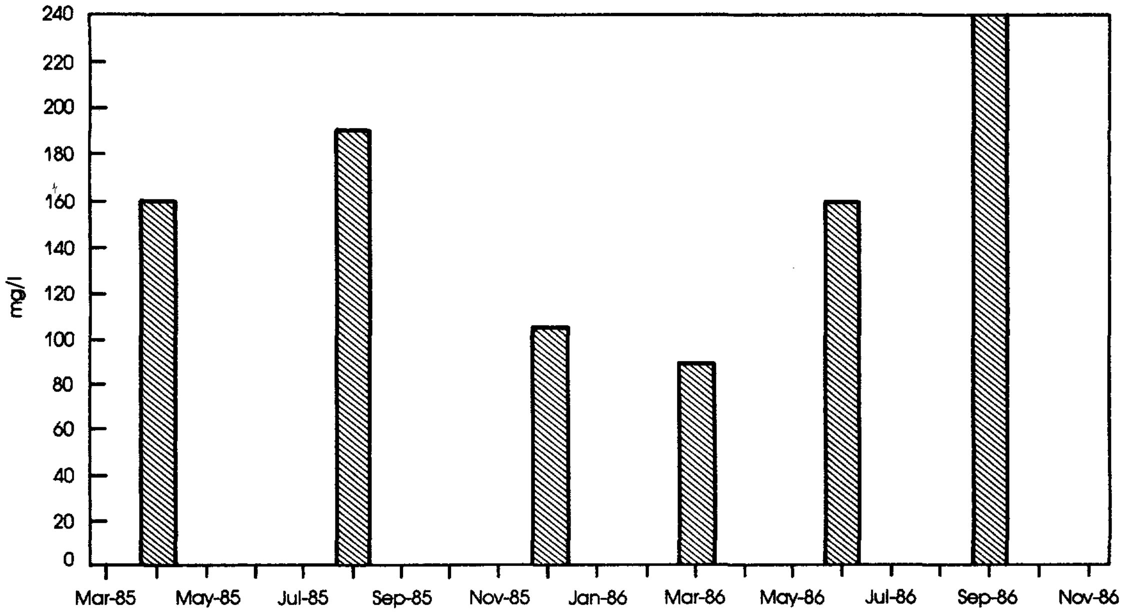
FIGURE 7.1A-12

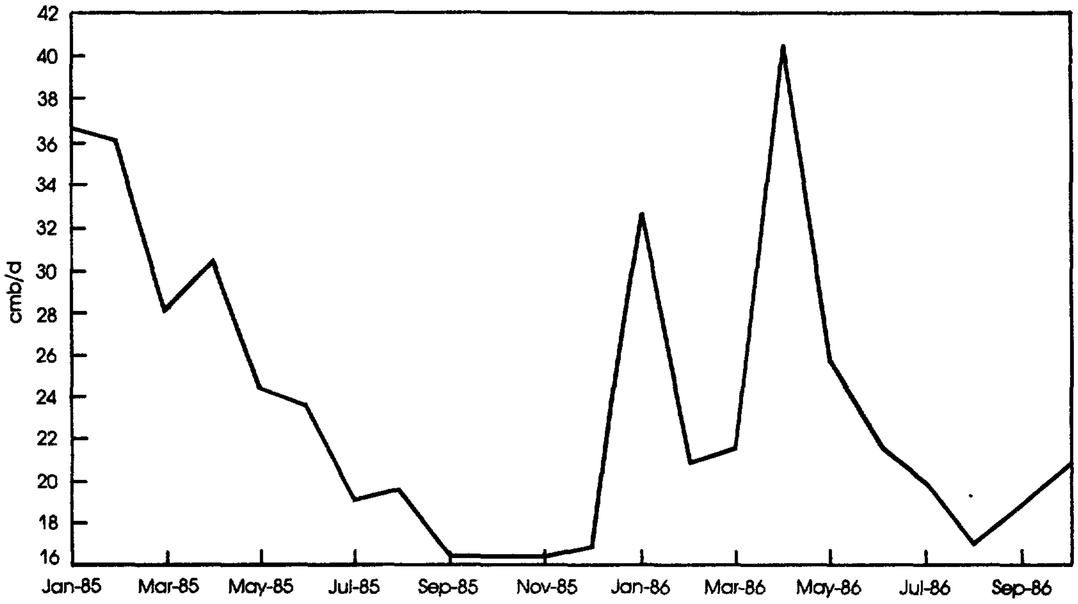
Leachate from Malsch Site - Total Iron Content



Source: Fichtner Consulting Engineers. 1987. Stuttgart, West Germany. Prepared for the World Bank.

FIGURE 7.1A-13

Leachate from Malsch Site - Average Daily Flow 1985-1986



Source: Fichtner Consulting Engineers. 1987. Stuttgart, West Germany. Prepared for the World Bank.

TABLE 7.1A-3

Leachate from Malsch Site - Standards for Indirect Discharge

		ATV A 115	Baden-Wuerttemberg	Bavaria
Temperature	° C	35	35	-
Settleable solids	ml/l	10	1	-
pH		6.5 - 10	6.0 - 9.5	-
Arsenic	mg/l	1	-	0.05
Lead	mg/l	2	2	0.2
Cadmium	mg/l	0.5	1	0.02
Chromium III	mg/l	3	2	0.2
Chromium VI	mg/l	0.5	0.5	-
Iron	mg/l	-	10	-
Cobalt	mg/l	5	-	-
Copper	mg/l	2	2	0.3
Nickel	mg/l	3	3	0.2
Mercury	mg/l	0.05	0.05	0.005
Zinc	mg/l	5	5	-
Cyanide, total	mg/l	20	-	-
Cyanide, volatile	mg/l	1	0.2	-
Fluoride	mg/l	60	50 ***	-
NH_4/NH_3-N	mg/l	200	50	-
NO_2-N	mg/l	20	10	-
Sulphate	mg/l	600 ***	400 ***	-
Active chlorine	mg/l	5	5	0.2
Phenol (as C_6H_5OH)			total 100	-
- steam-volatile	mg/l	100		-
- not steam-volatile	mg/l	-		-
Halogenated hydrocarbons* (AOX)	mg/l	5	5	0.5 **
Mineral oils (Total HC), pol.	mg/l	20	20	-

* as organically-bound chlorine

** AOX = adsorbable organically-bound halogen, not precipitated

*** depending on sewer material, dilution and local conditions (Higher values may be permissible)

Source: Fichtner Consulting Engineers. 1987. Stuttgart, West Germany. Prepared for the World Bank.

In this way, it is possible to avoid corrosion damage and other hazards arising from these two effluents. Furthermore, should a nitrification/denitrification stage be included in the sewage works, the removal of the ammonium from the effluent has a lower environmental impact than would be possible for its removal on site by a physical/chemical process.

In order to exclude the possibility of accidents during post-treatment in a municipal sewage works, the leachate treatment at the landfill site must incorporate the separation of toxic organic constituents, such as halogenated hydrocarbons (HHC, mostly measured as adsorbable organic halogens AOX), aromatic compounds, PCBs, phenols, mineral oils and heavy metals. As a matter of course, this processing line includes adjustment of the pH to a value suitable for discharge along with reduction of the suspended solids.

Treatment Possibilities and Process Selection

Various unit operations and process combinations come into consideration in order to fulfill these requirements.

Possible processes for leachate treatment, as well as an evaluation of their potential for pre-treatment, main treatment and post-treatment of the leachate from the Malsch hazardous waste landfill are shown in Table 7.1A-4.

The basis for evaluating various types of processes to handle Malsch leachate is provided by laboratory and pilot trials, which have been conducted for some time by various companies and university institutes, funded in part by the Federal Ministry for Research and Technology. Alongside possibilities for physical and chemical treatment of the leachate by oxidation, precipitation, flocculation, sedimentation, stripping and adsorption, researchers also looked at the potential for biological degrading of the organic pollutants, as well as the possible treatment effect by evaporation in single- and multi-stage evaporators.

Due to the very high salt content of the Malsch leachate and its wide fluctuations, it is not possible to employ the membrane processes of reverse osmosis and electrodialysis for reducing the total salt content, or for separating out toxic organic constituents. This high salt content and its wide fluctuations similarly have detrimental effects on biological processes, whether anaerobic or aerobic.

Additionally, the leachate contains inorganic and organic inhibitors, such as phenol, benzene, xylene and heavy metals which negatively influence microorganisms in biological treatment stages.

In any event, biological treatment of the Malsch leachate would only be possible following intensive physical and chemical pre-cleaning. However, even then it could be applied only if the high salt content and its wide fluctuations permitted an adequate biological activity.

Due to the theoretical problems of biological treatment and the lack of references for this type of process under the particular conditions of the Malsch leachate, on-site biological treatment was not considered in the concept

TABLE 7.1A-4

Leachate from Malsch Site - Possible Treatment Process

	Use as		
Process	Pre-treatment	Main treatment	Post-treatment
- Oil separation			
- Light-heavy liquid trap	+	-	-
- Centrifuge	+	-	-
- Coalescence separator	-	-	-
- Phys./chem. treatment			
- Oxidation (Ferrous)	+	+	-
(org. constituents)	0	0	0
- Flocculation and precipitation	-	+	0
- Sedimentation/flotation	-	+	+
- Solvent extraction	0	0	0
- Stripping (CHC)	-	+	-
(NH_3)	-	-	+
- Membrane processes			
- Reverse osmosis	-	-	-
- Ultrafiltration	-	-	-
- for oil separation during solvent extraction	0	0	0
- Membrane filtration (cross-flow)	0	-	-
- in combination with flocculation and precipitation	-	+	+
- Electrodialysis	-	-	-
- Thermal treatment			
- Evaporation	-	+	-
- Incineration	-	+	-
- Biological processes	-	-	+
- Adsorption			
- Activated carbon	-	-	0
- Special adsorber	-	-	+

+ suitable 0 possibly suitable - unsuitable

Source: Fichtner Consulting Engineers. 1987. Stuttgart, West Germany. Prepared for the World Bank.

design. Also, from the point of view of capital and operating costs, it was considered more appropriate to pre-treat the leachate. This way further degradation of the organic loading can then take place without inhibition in a municipal sewage works, possibly in combination with ammonium removal in a nitrification/denitrification stage.

For the pre-treatment processes, the coalescence separator for oil and light materials was not taken into consideration for further concept design due to considerable difficulties with uncontrollable precipitations of ferric hydroxide.

Microfiltration in combination with flocculation and precipitation was excluded for the main treatment stage due to its high capital and operating costs as well as doubts with regard to its operational reliability for the very large fluctuations prevailing in the Malsch leachate. As a post-treatment process for ensuring reliable removal of toxic trace substances such as PCBs and AOX, ultrafiltration was not considered further owing to doubts with regard to its treatment effect. These toxic substances will already have been largely removed due to their capture during oil separation in the pre-treatment stage and the flocculation-precipitation removal of solids in the main treatment stage. Any such trace substances that remain will usually have too low a molecular weight for effective separation by means of ultrafiltration.

Alongside possible treatment effects, important criteria for the selection of the treatment components and for the configuration of the processing lines are the quantities and types of liquid, solid and gaseous residues arising during leachate treatment. Transferring the toxic constituents of the leachate to another medium without reducing the environmental impact must be avoided. The residues produced by the chosen treatment processes have to allow for environmentally sound and cost-efficient disposal. Residues and emissions from various treatment processes are shown in Table 7.1A-5.

From the remaining process components, several processing lines are put together and compared on the basis of their capital and total operating costs. The individual options and processing lines are built up as follows:

Option 1a

Physical and chemical treatment with separation of iron, volatile and non volatile chlorinated hydrocarbons as well as other toxic organic trace substances, but without affecting the sulphate and ammonium content of the leachate, and use of lime for neutralization (Figure 7.1A-14).

Option 2a

Combination of processing line 1b using caustic soda for neutralization in a two-stage facility followed by precipitation with lime for reducing the sulphate content and alkalization and subsequent steam stripping for reducing the ammonium content (Figures 7.1A-15 and 7.1A-16).

TABLE 7.1A-5

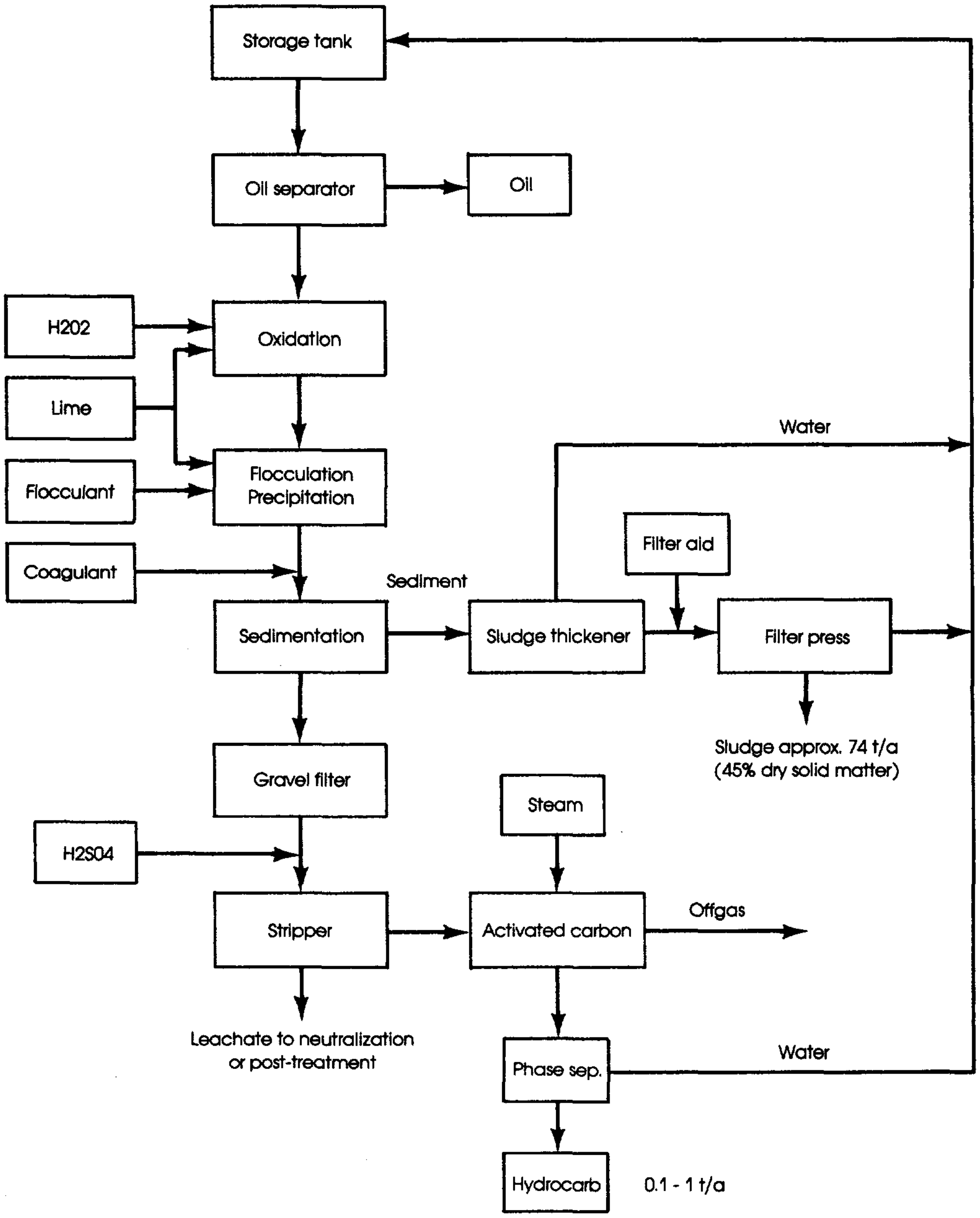
Leachate from Malsch Site - Residues

		Effluent	Flue gases	Offgas	Other residuals	Remarks
3.1	Biological treatment processes					
	- aerobic treatment	x		x	Sewage sludge	
	- anaerobic treatment	x	x 1)		Sewage sludge	1) From biogas incineration 2) From vapour incineration 3) From atmospheric oxidation Residues dependent on vapour treatment 4) From thermal regeneration 5) From incineration of extraction oil
3.2	Chem.-phys. treatment					
	- Flocculation, precipitation, sludge separation	x			Sludge	
	- Stripping processes	x	x 2)	x	Condensate	
	- Oxidation	x		x 3)		
3.3	Adsorption					
	- Activated carbon	x	x 4)	x 2)	Spent solvent, Spent act. carbon	
	- Special adsorber					
	- Adsorber resins	x			Spent solvent, Spent adsorber	
	- Activated alumina	x	x 5)			
3.4	Ion exchange	x				
3.5	Membrane processes					
	- Microfiltration	x			Concentrate	
	- Reverse osmosis	x			Concentrate	
	- Ultrafiltration	x			Concentrate	
	- Electrodialysis	x			Concentrate	
3.6	Solvent extraction	x	x 5)		Extraction oil	
3.7	Thermal concentration and separation					
	- Evaporation	x			Salt-laden residues	
	- Distillation, rectification	x		x	+ organic residues	
3.8	Incineration		x		Slag, ash	

Source: Fichtner Consulting Engineers. 1987. Stuttgart, West Germany. Prepared for the World Bank.

FIGURE 7.1A-14

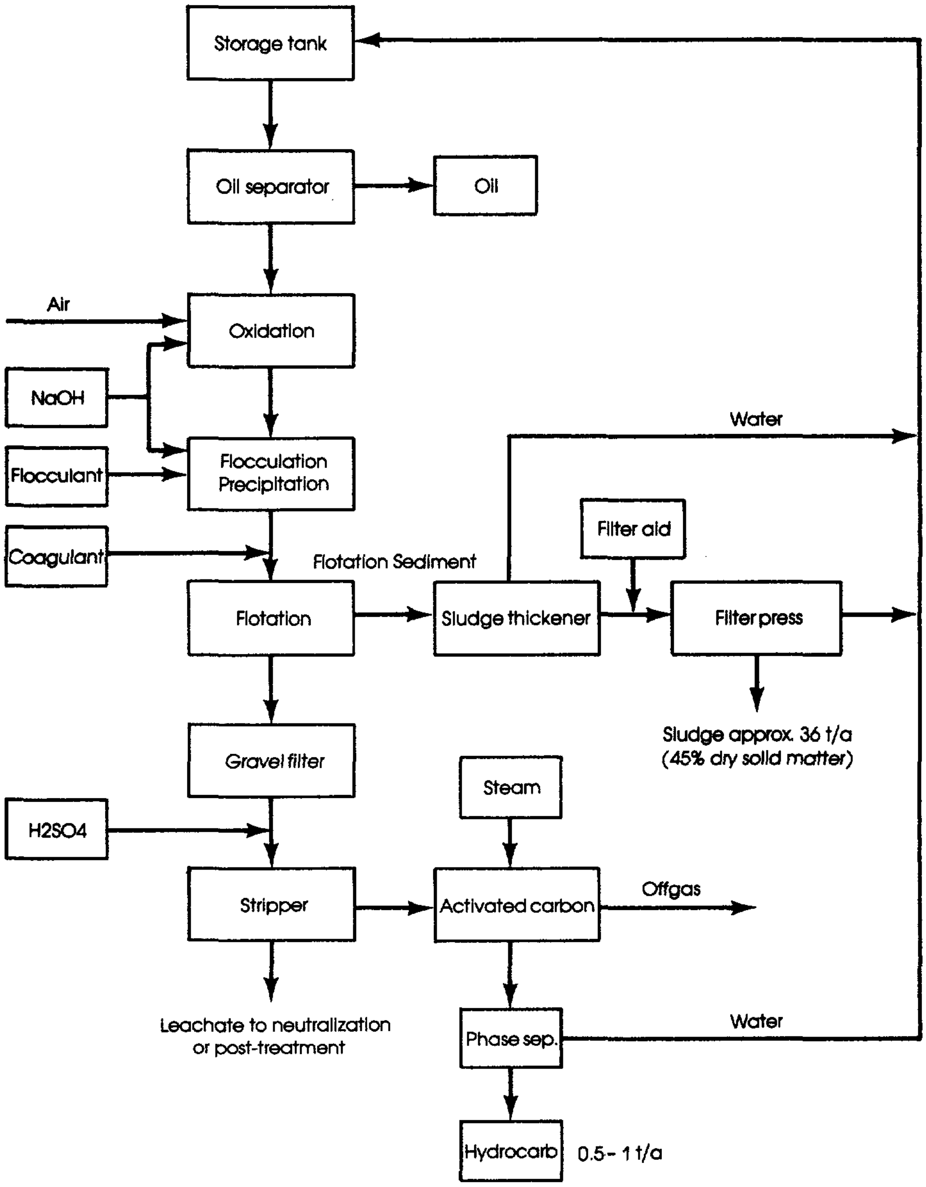
Leachate from Malsch Site - Malsch 1a



Source: Fichtner Consulting Engineers. 1987. Stuttgart, West Germany. Prepared for the World Bank.

FIGURE 7.1A-15

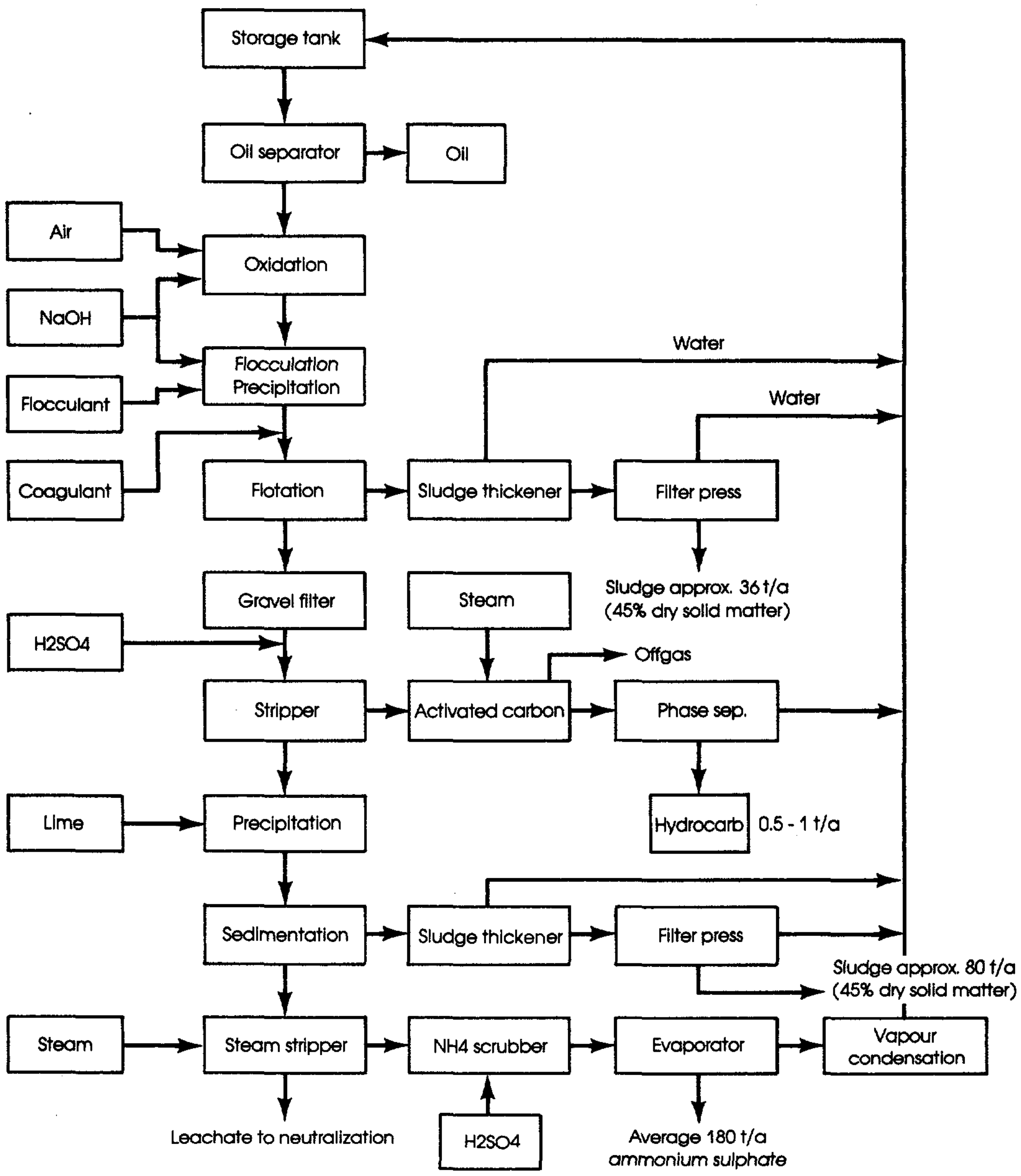
Leachate from Malsch Site - Malsch 1b



Source: Fichtner Consulting Engineers. 1987. Stuttgart, West Germany. Prepared for the World Bank.

FIGURE 7.1A-16

Leachate from Malsch Site - Malsch IIa



Source: Fichtner Consulting Engineers. 1987. Stuttgart, West Germany. Prepared for the World Bank.

Option 2b

Common single-stage precipitation of iron, toxic organic leachate constituents, reduction of sulphate content and alkalization by precipitation and flocculation with lime followed by a stripping stage for reducing the ammonium (Figure 7.1A-17).

Option 3

Two-stage evaporator (distillate staging) with the first stage operating at acidic conditions and the second stage at alkaline conditions reducing both the organic and the inorganic constituents (Figure 7.1A-18).

All the above process trains have to be designed for a leachate flow of 2 m^3/h in order to cope with the leachate flow rate fluctuations (on average approx. 9000 m^3 per year.

Process Options 1a and 1b differ essentially in the quantity of sludge to be disposed of, amounting to 74 t/a for 1a and 36 t/a for 1b, each with 45% of dry solid matter for a plant throughput of 9000 m^3/annum. Additionally, volatile organic concentrates from the stripper -- amounting to 0.5 - 1.0 t/a -- has to be disposed of in each option.

For Options 2a and 2b, the sulphate and ammonium content of the leachate is reduced, with the sulphate precipitating in the form of gypsum slurry and the ammonium in the form of ammonium sulphate. For Option 2a, treatment takes place in two stages, with the higher toxic constituents (36 t/a with 45% dry solid matter) being removed in the first stage. In the second stage an inorganic sludge is created (80 t/a with 45% dry solid matter) and can be disposed of with little difficulty.

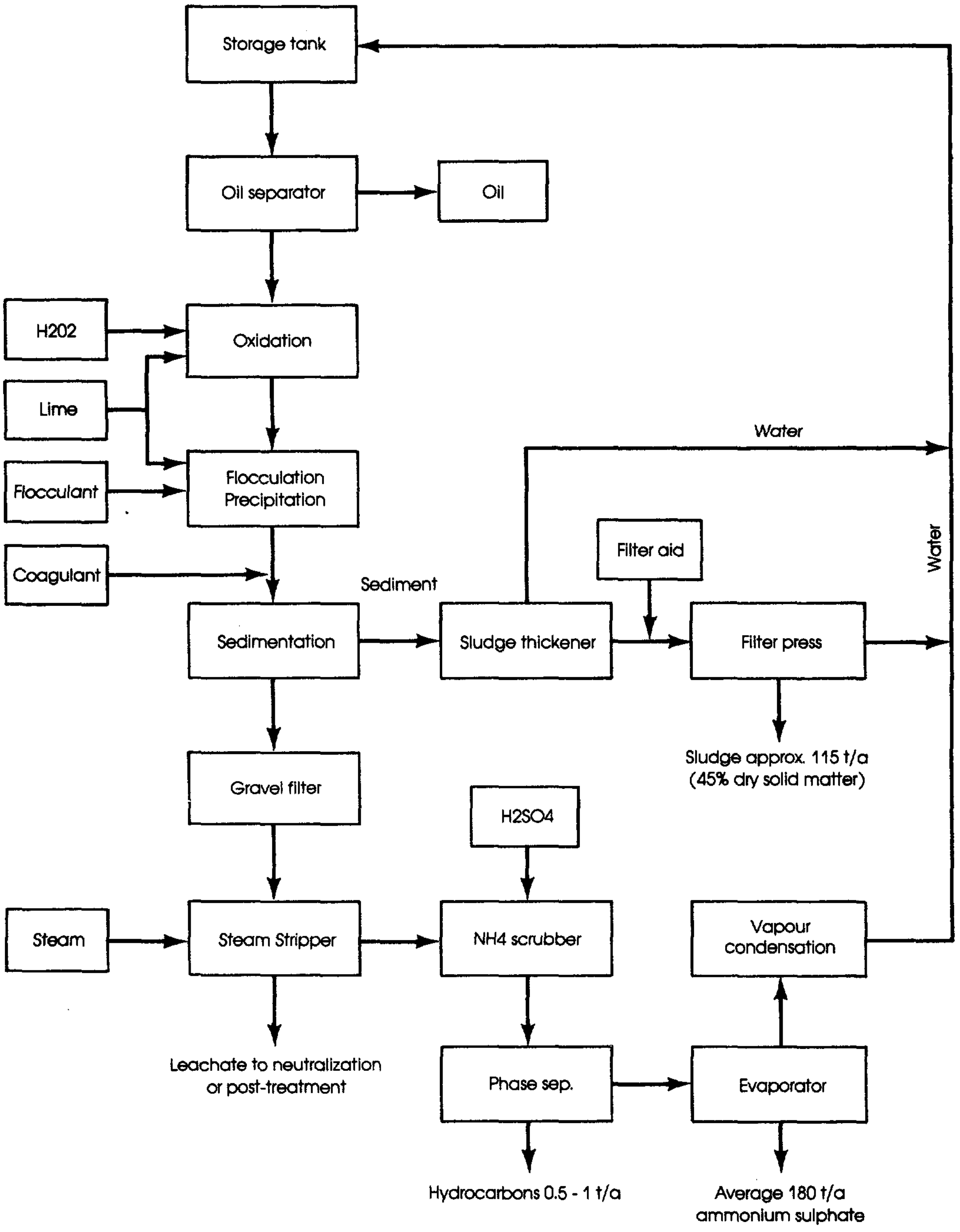
For Option 2b, treatment is in just one stage, but instead of 36 t/a of highly toxic sludge as for Option 2a, in this case 115 t/a is to be disposed of (see Figures 7.1A-16 and 7.1A-17).

The configuration of the process options is given in more detail in Figures 7.1A-14 to 7.1A-18.

In order to remove any possible remnants of toxic organic compounds and to keep the content of remaining AOX as low as possible, for each of the processing lines, post-treatment stages are planned. For Options 1 and 2, for example, the physical and chemical treatment processes could comprise special adsorber stages capable of regeneration using solvents, whereas for the distillate from the evaporator an activated carbon stage regenerable with steam is provided. Following post-treatment, the effluent is fed to a transfer station comprising two tanks which are filled alternately, and from which it is discharged, after an analytic check, either to tanker vehicles for haulage to the municipal sewage works or for distillate from the evaporation plant to the sewer system.

FIGURE 7.1A-17

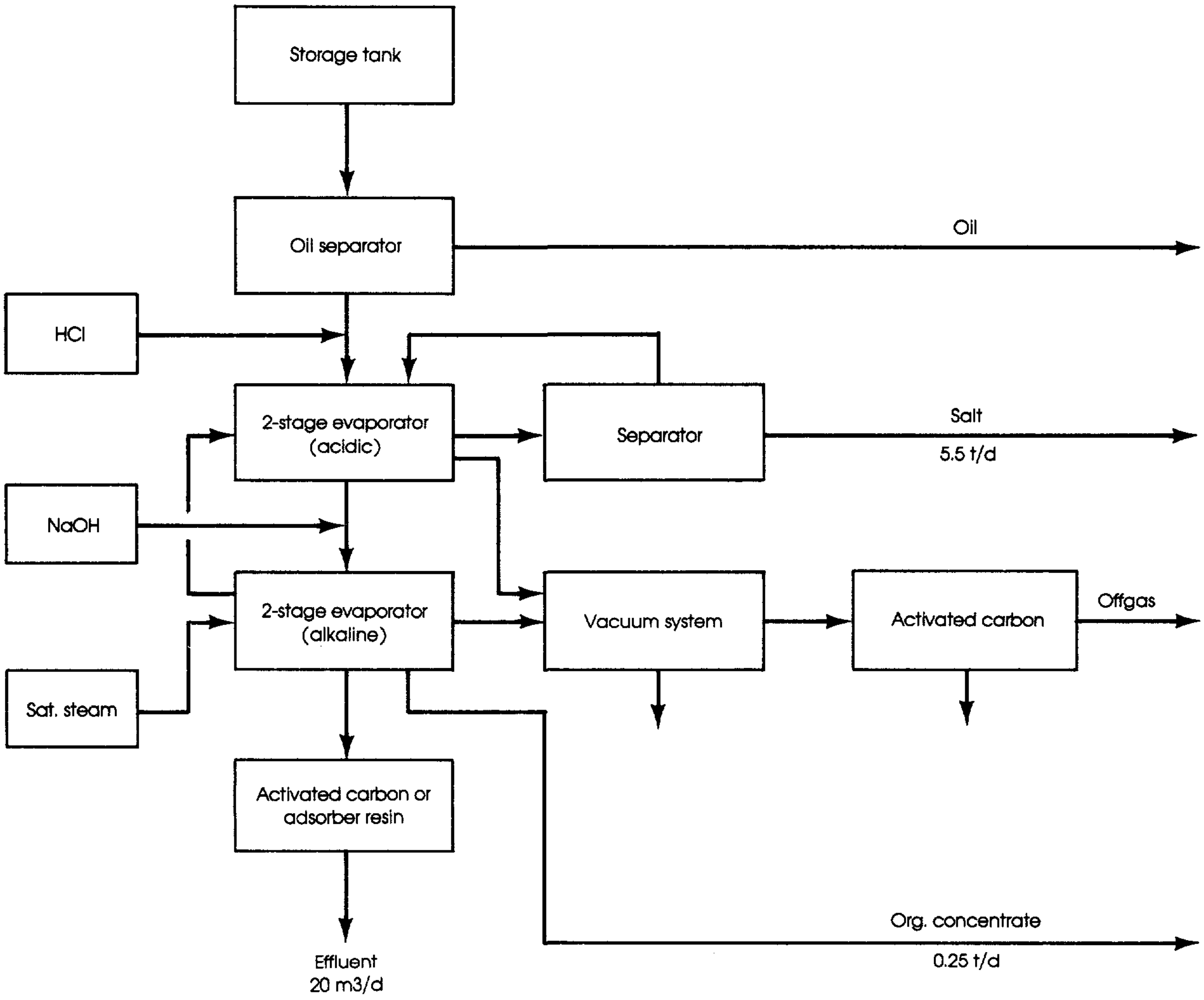
Leachate from Malsch Site - Malsch IIb



Source: Fichtner Consulting Engineers. 1987. Stuttgart, West Germany. Prepared for the World Bank.

FIGURE 7.1A-18

Leachate from Malsch Site - Malsch III



Source: Fichtner Consulting Engineers. 1987. Stuttgart, West Germany. Prepared for the World Bank.

Comparison of Overall Costs for the Process Options

The overall operating costs for the leachate treatment options described, as well as the cost components making up these are shown in Figure 7.1A-19 for a plant capacity of 2 m^3/h (with an annual throughput of 9000 m^3). The capital costs include mechanical components, civil works, electrical and I&C systems, costs of working stocks, chemicals, energy, personnel and spare parts.

At 330 DM/m^3, the overall operating costs of the evaporation plant including post-treatment and transfer station are the highest. The principal cost factor is the disposal of solids and effluent as well as the capital costs. For the disposal of solids, it was assumed that the residual product from the first evaporation stage is disposed of in an underground repository at a specific cost of 600 DM/t, including haulage and packing of the material. The organic residues from the second stage are transported to a hazardous waste incineration facility with specific disposal costs of 4000 DM/t.

As a comparison of the physical and chemical treatment stages shows, Option 1b is superior to Option 1a by virtue of its lower costs for disposal. The total treatment costs amount to 110 DM/m^3 of leachate. If sulphate and ammonium are removed too, the treatment costs increase to 160 DM/m^3 for the most favorable alternative. Despite the higher capital costs for this case, the two-stage Option 2a has an overall advantage in respect to total operating costs. For this process option, the lower volume -- but with a higher concentration of toxic solid constituents -- of residue from the first stage is incinerated at a price of 4000 DM/t, as for the sludge arising in Options 1a and 1b. The less polluted sludge from the second stage of Option 2a is dumped at a hazardous waste landfill, incurring disposal costs of 400 DM/t. As a result of the cost situation described, only Options 1b and 2a merit further consideration for the physical/chemical treatment option. The cost situation of the evaporator option is investigated in more detail in comparison to physical and chemical treatment.

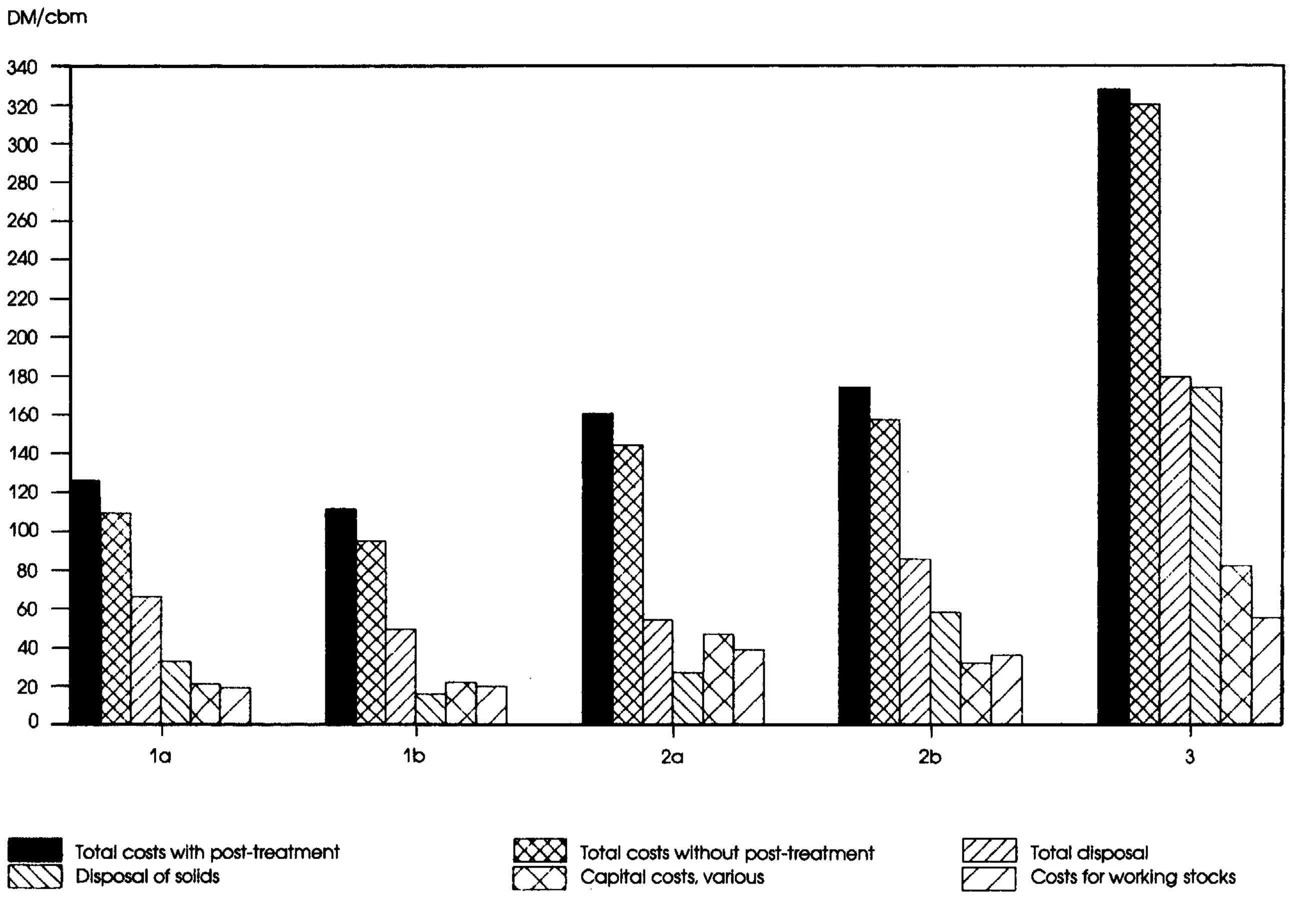
It is also interesting to know how overall costs and the cost structure vary for higher plant capacities. Figure 7.1A-20 shows a cost comparison for plant capacities of 2 and 5 m^3/h, equivalent to 9000 and 27,000 m^3/a, respectively.

For the higher capacity, the specific overall operating costs in the case of physical and chemical treatment are reduced by almost 30% due principally to halving the specific capital costs and a marked reduction in the costs of chemicals and other feedstocks. In the case of evaporation, the drop in overall operating costs of just over 10% is not so appreciable; the specific capital costs are reduced by around one-third.

Since the costs of disposal of the solid residues have a decisive influence on the overall operating costs, in a sensitivity analysis an investigation was made into how a change in residue disposal costs affects the overall operating cost situation of each of the options. For Option 1b without reduction of sulphate and ammonium, the disposal costs for the residual product varied within the range of 400-400^0 DM/t. Should the residue not be incinerated at a specific cost of 4000 DM/t but instead dumped for 1/10 of this cost in a hazardous waste landfill, then the overall operating costs of this version are reduced from 110 to 95 DM/m^3 of treated leachate (see Figure 7.1A-21).

FIGURE 7.1A-19

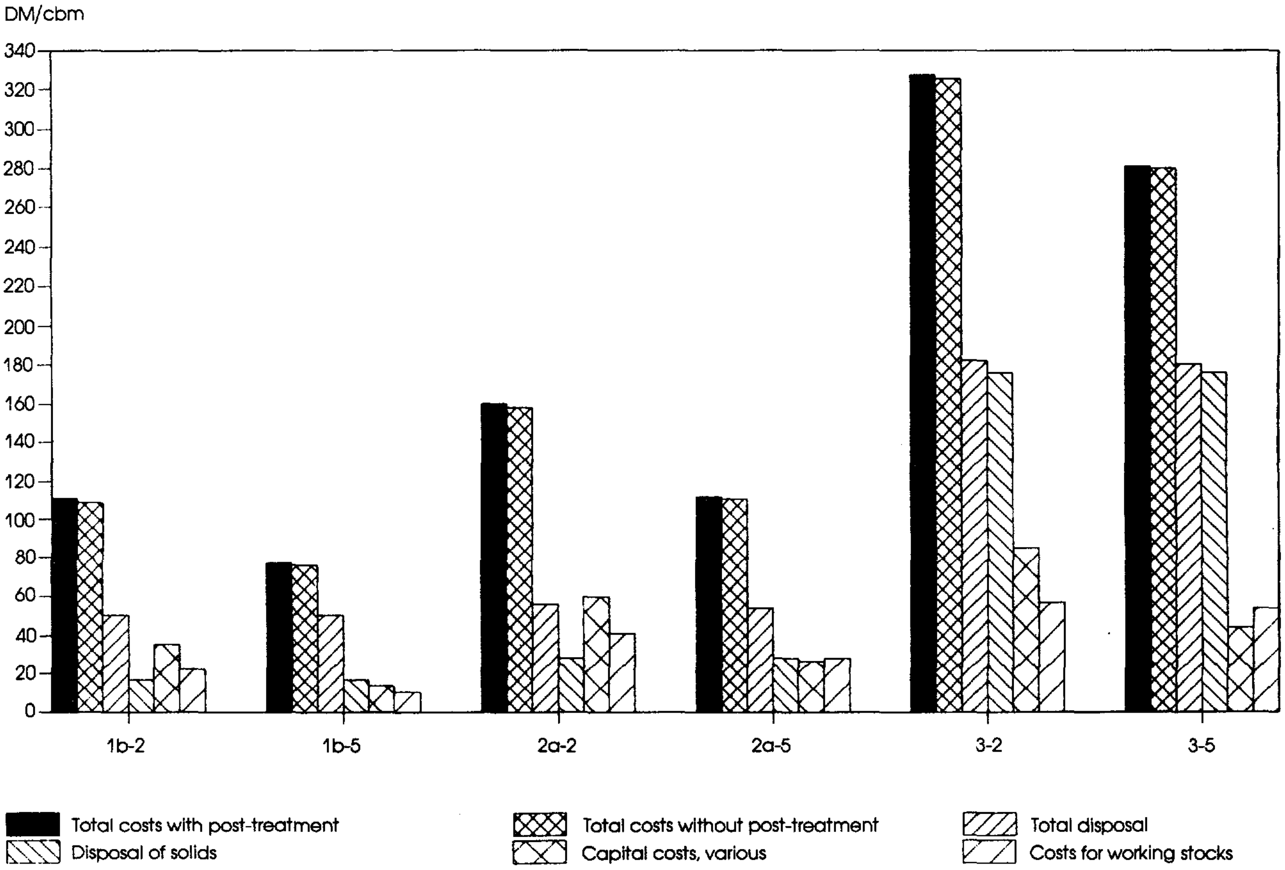
Leachate from Malsch Site
Operating Costs for Main Treatment and Post-treatment
Process Options 2cbm/h



Source: Fichtner Consulting Engineers. 1987. Stuttgart, West Germany. Prepared for the World Bank.

FIGURE 7.1A-20

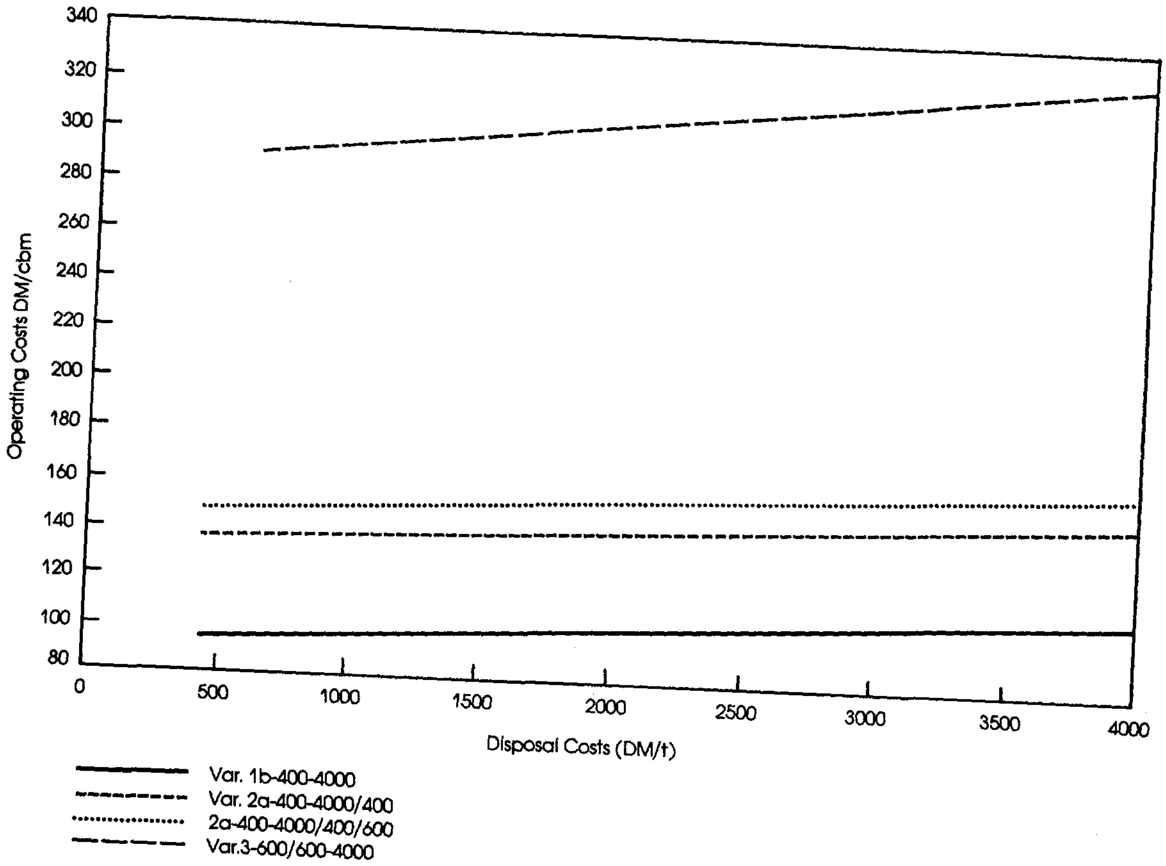
Leachate from Malsch Site
Operating Costs for Main Treatment and Post-treatment
Comparison for Different Capacities 2cbm/h and 5 cbm/h



Source: Fichtner Consulting Engineers. 1987. Stuttgart, West Germany. Prepared for the World Bank.

FIGURE 7.1A-21

Leachate from Malsch Site
Influence of Disposal Costs on Operating Costs



Source: Fichtner Consulting Engineers. 1987. Stuttgart, West Germany. Prepared for the World Bank.

For the two-stage option (with reduction of sulphate and ammonia), if the higher toxicity sludge is not incinerated but disposed of at a lower cost, then it is apparent that there is no significant change in the overall operating costs. This represents an advantage for the two-stage treatment plant, as the greater part of the solids in this case has only a low toxicity and its disposal has less impact on the total costs despite the higher weight proportion in the total arisings of solids. Should it be necessary to dispose of the ammonium sulphate arising in this physical/chemical treatment option in an underground repository (i.e., if no possibility for its cost-neutral recycling could be found), then the specific operating costs for this option would increase by around 10 DM/t, which is less than 10% of the total operating costs.

The operating costs of the evaporation plant are greatly influenced if the higher toxicity organic components from the second evaporator stage are not incinerated but disposed of at a lower cost in, for instance, an underground repository. The total operating costs are then reduced by around 10%, from 320 to 290 DM/m^3 of treated leachate.

Conclusions and Selected Solution

As a comparison of the various process options for the treatment of leachate from a hazardous waste landfill demonstrates, the specific treatment costs are considerably greater than those known for the treatment of even highly concentrated industrial waste waters. This is due primarily to the very high loading of these leachates with a complex mixture of inorganic and organic pollutants. For physical and chemical treatment methods, this results in very complex processing lines with the production of high toxicity residues which require costly disposal in underground repositories or destruction in incineration plants.

Given the following preconditions overall treatment costs of around 100 DM/m^3 are possible:

- a treatment system is acceptable only if complying with the present indirect discharge requirements;
- reducing the content of sulphate and ammonium is not required due to an appropriate admixture with the main flow into a municipal sewage works after removal of the leachate's toxic constituents; and
- the main organic load is decomposed in such a facility.

If, however, the leachate has to be supplied to a sewer system necessitating the reduction of ammonium and sulphate contents, there is a considerable rise in costs from 130-150 DM/m^3.

If, on the other hand, more extensive leachate treatment is required, namely:

- the reduction of the salt content
- the reduction of the sulphate content to below 1500-2000 mg/l as achievable by lime precipitation

- the reduction of the chloride content
- the reduction of the general organic loading to values beyond those attainable with physical/chemical processes and an appropriate post-treatment stage

then total operating costs of 290 to 320 DM/m^3 are to be expected.

For the Malsch hazardous waste landfill, plans are underway to install a physical and chemical treatment process suitable for the removal of toxic substances and biological inhibitors by appropriate treatment, to the extent that the pre-treated effluent from the facility can be admixed at the inlet to a biological sewage treatment plant. In this case, damage to the sewer system by sulphate and ammonium is excluded and biological breakdown of the organics loading and the ammonium then takes place in the municipal sewage works under conditions which are more suitable for such treatment. For biological breakdown of the ammonium, no disposal problems are anticipated.

After completing the planning phase, FICHTNER has drawn up detailed technical specifications. Tenders have already been invited for a facility for the physical and chemical treatment of the leachate from the Malsch site. Some suppliers have already submitted their bids.

ANNEX 7.1B - Disposal and Management of Pesticide Waste and Containers

Annex 7.1B was written by Virgil H. Freed, Oregon State University in Corvallis, Oregon.

Introduction

Manufacture, transport, storage, use and disposal of pesticides requires care in order to avoid human exposure and environmental contamination. The possibility of spills and the necessity of disposal are much more likely, not only with the use of pesticides, but also with transport, storage and formulation of pesticides. Moreover, it is not uncommon for small amounts of leftover pesticide to deteriorate, for materials to be banned from use, or for material to be substituted with an available and more effective material.

Chemicals that require disposal, as well as containers, are often leftover. The containers, particularly those that contain liquid, are likely to retain one to five percent of the original material. Bags that have been used for wetable powders or dust may also retain some of the original material.

In the disposal of chemicals, it is essential to avoid contamination of water supplies that afford unnecessary exposure to man, to other organisms and the general environment. A variety of technologies are available for disposal, but the best choice for each situation depends upon the kind and amount of chemicals, the resources available, whether the disposal will be near to human residents or in an area accessible to animals, and whether the disposal will jeopardize environmental quality. Frequently, small lots of chemicals may be disposed in special biodegradation pits or in designated areas where the chemicals may be degraded or stored safely.

Consideration of disposal methods, requires an understanding of the chemical's behavior in the environment so that the handling, transport and disposal can be made in the safest possible manner. For this reason, a brief review of the properties of chemicals and how they relate to the chemicals' environmental transport and behavior is provided in this annex. Taking into account the information presented here with what is likely to be known about the properties of the chemical, the disposal method can be selected to fit the necessary requirements. In the case histories given later in this section, the reader may find an illustration of the application of such a synthesis of knowledge.

"Physical Properties of Chemicals in Relation to Behavior and Fate"

Disposal of chemicals necessitates knowledge of the possible behavior and fate of chemicals (Freed and Chiou 1980), which permits development of disposal and management methods that avoid unnecessary human exposure and environmental contamination. Such information can be obtained by taking appropriate measurements under actual conditions. However, this practice is inordinately expensive in both time and money and can be done more readily in the laboratory (Hague and Freed 1975).

Each chemical has a unique set of physical properties by which it may be identified and manipulated. Some of these same properties are related to the behavior and distribution of the chemicals, and possibly, their chemicals' ultimate fate (Talekar et al. 1981; Freed and Chiou 1980; and Hague and Freed 1975). Utilizing this information, one can make an estimate of the pesticide's probable behavior and distribution and, thus, devise a management and disposal method that both minimizes the likelihood of escape and permits a safer method of disposal. Among the properties that have been found useful are: solubility or, better, partition coefficient as related to adsorption by soil and other surfaces; bioaccumulation; vapor pressure or rate of volatilization as a measure of escape into the atmosphere; solubility and solution behavior as related to water; and chemical reactivity (Swann and Eschenroeder 1983; Hague and Freed 1975; Troester et al. 1984; and Neely 1980).

The properties of chemicals determine their availability for transport and distribution and bioaccumulation or the type of breakdown they follow in the environment. The actual transport occurs through wind, water, and only infrequently by other organisms, all of which are influenced by the energy flux of sunlight and gravitation.

Using Chemical Properties in Assessment of Behavior

A number of studies have been conducted which demonstrate the relationship of the unique properties of a given chemical to its behavior under a given set of conditions (Hague and Freed 1975; Neely 1980), whether in the general environment or in disposal practice. Even though each chemical may have a unique set of physical and biological properties, it has been demonstrated that a pattern of behavior related to certain properties exists, and that this fact is of value in assessing or estimating the probable transport, distribution and fate of each chemical. Among the properties of chemicals that can be measured in the laboratory, in addition to such things as melting point, boiling point, and calculated molecular weights, are things such as:

(i) Partitioning coefficient between octanol and water and water solubility. This information, utilizing the appropriate relationships, is an estimate of the adsorption of the chemical to soil and other surfaces, including dust particles in the atmosphere and the tendency to be bioaccumulated by organisms.

(ii) Vapor pressure. Vapor pressure, which may be more difficult to determine, is, nonetheless, useful in estimating the rate by which the chemical will vaporize into the atmosphere and be transported by air movement.

(iii) Chemical reactivity. The particular chemical reactions that the material undergo may include a hydrolysis of the compound, as occurs with organophosphate and carbamate materials, or a particular susceptibility to oxidative attack. Knowing something about a chemical's reactivity may permit an estimation of its persistence or the ease with which it may be detoxified.

Adsorption

When a chemical is released or escapes into any kind of environment, it will encounter a variety of surfaces, such as soil, dust particles, sediment in water or even inert surfaces like glass or metal. Practically all chemicals will interact in a reversible way with these surfaces. The strength and extent of the interaction varies with the properties of the chemical. The partition coefficient gives a fair measure of such chemical reaction, particularly with soil, and specifically with soil organic matter.

Adsorption can be important in the handling and disposal of chemicals. It may be used, for example, to remove a chemical from water or air. Similarly, if a chemical is not strongly or extensively adsorbed by soil, the chemical may be moved through the soil profile by water. Such a movement could result in either underground water contamination or movement of a contaminant to a nearby body of water. Such a process of movement with water through the soil is called leaching.

Leaching

Leaching is an important consideration, if one is disposing of chemicals on soil, using a biodegradation site, or if these chemicals are in a storage area in which the soil may become contaminated. If the area is one of high rainfall and the soil tends to be sandy, leaching will become a greater problem. Also, the properties of the chemical, that is, water solubility and the partition coefficient, will influence how readily the chemical may be leached.

Volatilization (Vaporization)

All chemicals have a tendency to vaporize at temperatures above absolute zero, which is a function of their vapor pressure. However, with many chemicals, particularly certain elements and inorganic chemicals, the vapor pressure will be so low that it appears negligible at normal ambient temperatures. Other materials, such as water or those with the lighter fractions of petroleum, have a higher vapor pressure and can be observed to evaporate or vaporize readily at normal temperatures. Advantage of vaporization should be taken in the case of soil and space fumigants.

The vapor pressure and, hence, the rate of volatilization increases with the increase of temperature. Adsorption, on the other hand, reduces the rate of vaporization, but does not always prevent vaporation altogether. Thus, certain chemicals mixed with soil or other solids may not vaporize as quickly, but vapors do continue to escape.

Because some chemicals may have a tendency to escape, particularly the more volatile ones, vaporization must be considered when a chemical is being disposed of on the surface of the soil, or even within the soil.

Reactivity

Reactions to which a given chemical is susceptible can be utilized in management and disposal of the chemicals. For example, if a chemical is readily hydrolyzed by water, an alkaline or acid medium, often it can be detoxified quite simply. On the other hand, if the chemical tends to be somewhat unreactive, such as the chlorinated organic materials (e.g, DDT), then more vigorous reactions may be required for its destruction.

All organic chemicals are subject to burning or oxidation. Hence, incineration of chemicals is a very effective means of disposal where the proper conditions can be obtained. However, hydrolysis and oxidation are not the only reactions that organic chemicals and pesticides may undergo. Living organisms, like the bacteria and fungi of soil or even higher organisms, carry out a variety of metabolic reactions, many of which result in detoxification or destruction of organic chemicals. If these conditions are present, it is wise to use them to one's advantage in biodegradation practices.

Methods of Disposal

The object in the disposal of chemicals is to do so in an environmentally safe and economically sound manner. The method used should prevent human exposure and air or water contamination following disposal (The World Bank 1985). Many methods of disposal have been evaluated and are being evaluated. A number of methods are presently in use, though perhaps the most widely employed methods, especially for industrial waste, have been incineration and hazardous waste landfills (Curi 1985; Sittig 1979). These methods range from incineration and chemical destruction through biodegradation to secure storage sites for solidified or containerized waste. Each method has its advantages and disadvantages, either economically or environmentally, which must be weighed in choosing the method(s) of disposal. Some of the factors to be considered in choosing a method include the nature of the chemical, the amount requiring disposal, costs, environmental and human factors such as likelihood of contamination of air or water, nearness to dense populations, and climatic and geological factors.

The following is a discussion of some disposal methods that have been employed or are undergoing evaluation. For more detail on the methods, refer to the list of references at the end of Annex 7.1B. Each publication contains a full description of the method and its advantages and disadvantages.

(i) Use as Intended

If there is control over the quantity of the chemical such that it may be used as intended, the problem of disposal is minimized or eliminated (Edwards 1973; Matsumura and Murti 1982).

(ii) Recovery and Recycling

Where larger quantities of chemicals of sufficient value are involved, recovery and/or recycling is a desirable way of managing the problem. This method of handling excess chemical(s) is probably available only to the larger, better equipped formulating and manufacturing plants, unless it is possible to find a facility that makes a practice of reprocessing chemicals.

(iii) Incineration

With effective incineration, organic chemicals are converted into carbon dioxide, water, and as a function of the chemicals' composition, sulfur oxide, hydrochloric acids and other simple inorganic compounds. Incineration is neither an easy or a cheap method of disposal. It requires large and expensive equipment with appropriate pollution control devices. Proper combustion is essential and, thus, it is recommended that there be a flame temperature of 900-1000°C with a residence time in the fire box of at least 2 seconds (Curi 1985; Dawson and Mercer 1986; Dillion 1981; Krueger and Seiber 1984; and Sittig 1979).

A number of different types of incinerators will meet the requirements of a sufficiently high temperature and a long-enough residence time in the fire box to be satisfactory. The first, and undoubtedly the best, is the specially designed stationary incinerator, the purpose of which is the destruction of hazardous waste. However, some other types of incinerators, including the rotary kiln incinerator or fluidized bed incinerator, are quite satisfactory. Another type of incinerator that has been used is the cement kiln, which is used to make cement. This kiln also has a high-enough temperature and long enough residence time for most organic chemicals to be broken down into their elements.

(iv) Wet Oxidation

Any organic compound can be oxidized under proper conditions. One method of disposal is the so-called wet oxidation method in which the chemical is oxidized by air in the presence of water or steam. The operating conditions call for an elevated pressure of 1 to 300 pounds per square inch, temperatures of over 100°C and an excess of air or oxygen for the oxidation (Dawson and Mercer 1986; Krueger and Seiber 1984).

(v) Microwave Plasma Destruction

Microwave plasma destruction is a relatively new technique, which is being evaluated but shows promise of complete destruction of organic compounds (Krueger and Seiber 1984).

(vi) UV/Ozone Treatment

The UV/ozone treatment is a relatively new technique, which is in practice. Most organic compounds absorb energy in the ultraviolet region of the spectrum, which combined with ozone, brings about ready oxidation of the chemicals.

(vii) Chemical Treatment

A number of chemical treatments for destruction and disposal of organic compounds exist. The choice of the chemical reaction depends, in large measure, on the chemistry of the subject compound. Treatment with chlorine gas (chloronolysis) has been used, particularly for the organochlorine compounds. The resulting products, however, such as chloroform and carbon tetrachloride pose in themselves a problem of disposal. For some compounds, hydrolysis, reduction or treatment with metallic sodium have proven effective. For materials such as the organophosphates and carbamates, alkaline hydrolysis results in products of greatly reduced biological activity and environmental hazard. Some inorganic compounds may be treated to form insoluble products for safer disposal. This procedure includes a formation of insoluble sulfides, oxides, etc. (Curi 1985; Dawson and Mercer 1986; Dillion 1981; and Kennedy 1978).

(viii) Molten Salt Treatment

Many organic compounds can be destroyed in a bath of molten salt.

(ix) Hazardous Waste Landfill

Use of a hazardous landfill has been a widely practiced, but many of these landfills have been poorly located and designed in the past. Some of the current research indicates that there is a need for a bottom liner of chemical resistant plastic, over which a thick layer of packed clay is placed and, for double insurance, another plastic liner is placed. The chemical to be disposed of is placed in such a fill, covered with soil, and, when the site is completely full, the area is mounded to prevent intrusion of water (Dawson and Mercer 1986; Krueger and Seiber 1984).

(x) Biodegradation and Land Disposal

Many organic compounds are degraded by micro-organisms in the soil. Considerable effort is being made to either discover or bring about by genetic engineering micro-organisms specifically designed for degradation of organic compounds.

In some instances, the diluted waste that needs disposal may be placed on the surface of the soil and either left or tilled in, thus, allowing microbial degradation. Such areas should be managed to encourage maximum biological activity and to avoid the possibility of chemical vaporization from the soil or leaching into ground water. Usually the addition of nutrients and organic matter will accomplish these objectives.

Another technique for biodegradation is the construction of appropriate pits, which are usually concrete, lined with a heavy plastic, and in which soil is placed. The chemical is then added to the pit by the appropriate means for destruction. These pits require management through the addition of nutrients, organic matter, and pH adjustment to foster the degradation. In the case of the organochlorine compounds, the pit should be maintained in an anaerobic condition by covering it with water to foster breakdown.

The biodegradation/land disposal is a technique that is probably suitable only for relatively small amounts of chemical. In addition, the area should be secure so as to prevent intrusion by humans or animals that may be exposed to the chemical (Callahan et al. 1979; Curi 1985; Matsumura and Murti 1982; Morrill et al. 1982; and Talekar et al. 1981).

(xi) Solidification and Cementation

With some waste, concentrating through adsorption on clay, the use of ion exchange resins or carbon is a means for reducing the volume that must be managed. With chemicals that may be precipitated as insoluble compounds, the volume can be reduced to a manageable amount. But with a particularly hazardous waste, sealing in cement or a ceramic material provides a solid that may be stored in a secure site (Dawson and Mercer 1986; Kennedy 1978; Krueger and Seiber 1984; and Wilkinson et al. 1978).

Some Points on Chemistry of Disposal

Metals

The metal-containing compounds, whether inorganic or organic, pose a problem in disposal. Metals are not destroyed in incineration, but are merely changed in form. Thus, mercury, arsenic, copper, zinc, and manganese, even if they are in organic form, will upon incineration form the corresponding oxides as illustrated in the following equation:

$$Me^+ + O_2 \rightarrow MeO \text{ (e.g., } AS_2O_5\text{, } HgO\text{, } CuO\text{)}$$

Combustion, thus, does not destroy the metal, but merely changes the form in which it is found. In the combustion process, the metal oxides escape. In the case of mercury, it may escape as the metal itself to contaminate the environment. On the other hand, it must be remembered that a number of metals are found in nature as their corresponding sulfides. The sulfides are poorly soluble in water, which accounts for their immobility in natural deposits. Table 7.1B-1 gives the solubility product constant for some metals.

If these metals can be converted to their corresponding sulfides by chemical or biochemical means, their burial in soil can serve as a means of disposal for modest quantities of the metal. Thus, small amounts of metal-containing compounds can be disposed of in a biodegradation pit lined with sulfur, enriched with organic matter, and maintained to have an anaerobic condition. This type of pit yields H_2S, which can react with the metal to form the appropriate insoluble sulfide.

Organic Pesticides

Organic compounds may be destroyed or disposed of through incineration (Curi 1985; Dawson and Mercer 1986; Krueger and Seiber 1984; Sittig 1979; and Wilkinson et al. 1978). However, to assure better than 99 percent destruction of the organic compounds, relatively high temperatures (700-900^{o}C) are required (Dillon 1981; Krueger and Seiber 1984; and Sittig 1979). Also, the chemical must have a residence time of one or more seconds in the flame, even at these temperatures. Table 7.1B-2 illustrates the temperatures required for destruction of some of the pesticides.

TABLE 7.1B-1

Solubility Products of Some Metal Sulfides

Compound	Formula	Solubility
Arsenic trisulfide	$As\ S_3$	3.2×10^{-34}
Arsenic pentasulfide	As_2S_5	1.6×10^{-38}
Cupric sulfide	CuS	8.5×10^{-45}
Mercuric sulfide	HgS	4.0×10^{-53}
Manganese sulfide	MnS	1.4×10^{-15}
Lead sulfide	PbS	4.2×10^{-28}
Zinc sulfide	ZnS	1.2×10^{-23}

TABLE 7.1B-2

Temperatures Required to Decompose 98% or More of a Pesticide

Compound	Temperature °C
DDT	600
Picloram	900
Malathion	>1000
Diuron	>1000
Paraquat	700
2, 4-D	600

Source: Kennedy, M. V., B. J. Stojanovic, and S. L. Shuman, Jr. 1969. Chemical and thermal methods for disposal of pesticides. *Residue Reviews*, 29:98.

Certain pesticides of concern are quite susceptible, first to hydrolysis, and subsequently, to further chemical alteration through microorganism attack (Callahan et al. 1979; Curi 1985; Telekar et al. 1981; and Matsumura and Murti 1983). Thus, the organophosphates and organocarbamates have an accelerated hydrolysis in the presence of basic materials. They can be hydrolyzed in basic solution, but also by soil that has had a heavy lime amendment to attain a basic pH. Following the hydrolysis, the fragments undergo a metabolic attack by microorganisms if the soil is kept anaerobic and additional energy sources are supplied in the form of carbon compounds (e.g., plant material and animal wastes).

Organochlorine compounds, particularly the chlorinated hydrocarbons such as lindane, dieldrin and DDT, can also be treated by chemical means or by biodegradation processes. Incineration is another possibility. In chemical treatment, the conditions must to be rigorous to destroy the chemical, and some of the products from the chemical treatment, in turn, may pose a disposal problem. For example, one chemical treatment is chlorolysis, which yields both hydrochloric acid and carbon tetrachloride, both of which create only slightly less of a disposal problem of than does the original material.

The chlorinated hydrocarbons appear to be susceptible to biodegradation under anaerobic conditions (Edwards 1973; Matsumura and Murti 1982; and Morrill et al. 1982). Anaerobic conditions in soil can be achieved by flooding and holding the soil saturated with water. However, to bring about decomposition, the soil must be enriched with organic matter (Matsumura and Murti 1982; and Morrill et al. 1982). Plant material can be used, but animal wastes are substantially more effective. These compounds also may be biodegraded in sewage sludge digesters.

Organochlorine compounds, such as dalapon, 2,4-D, 2,4,5-T diuron, are more susceptible to biodegradation than the chlorinated hydrocarbons. The organic acids, dalapon, 2,4-D, 2,4,5-T, biodegrade in periods of two to eight weeks in fertile soils with ample moisture. Diuron is a more refractory compound requiring several months before decomposition is complete. Table 7.1B-3 illustrates the persistence of some compounds in soil.

The bipyridilium compounds, such as paraquat (gramoxone), are quite susceptible to photochemical breakdown. They are strongly adsorbed by soils, particularly certain clays, and undergo slow biodegradation in soil.

Considerations Regarding Disposal Method

Chemicals

Open dumps, such as public dumps where burning occurs, or sanitary landfills, are not satisfactory methods of disposing of even moderate quantities of disused concentrate or containers in a region where the water table may be anywhere from five to ten feet below the surface and where substantial rainfall occurs (Kennedy 1978; Krueger and Seiber 1984; Wilkenson et al. 1978; World Bank 1985; and Grisham 1986). In this type of situation, it is likely that the chemical will escape from the disposal site, resulting in surface and groundwater contamination. Further, public access to at least some of the sites may result in direct human exposure.

TABLE 7.1B-3

Breakdown of Pesticides in Soil

Type of Pesticide	Time Required for One-Half to Breakdown in Soil (Days) Average	Maximum
Organophosphate	47	290
Triazines	82	212
Carbamates	172	817
Arylsubstituted Ureas	355	3103
Chlorinated Hydrocarbons	2256	7987

Source: Adapted from A. Mercado and Ykahanovitch. 1977. Behavior of Pesticides in Soil, Special Publication #82, Division Sci. Pub.

All factors considered, disposal of some pesticides in small amounts is best accomplished through managed biodegradation procedures. The alternatives in this case are to select a site where application to soil or specially constructed decomposition pits could be used. This site, however, should be dedicated for many years to this purpose. Further, it should be fenced in to limit access and have appropriate equipment to deal with spills, fires and other emergencies. Such a site should also have test wells for groundwater sampling in order to determine whether leakage is occurring. There should be a berm surrounding the area to prevent overland flooding. The site might include evaporation pits for reduction of volume or specially lined trenches for disposal of chemicals and containers.

Rate of Biodegradation in Soil

There have been many studies of biodegradation of pesticides in soils (Dillion 1981; Kennedy 1978; Matsumura and Murti 1982; Telekar et al. 1981; and Hague and Freed 1975). Most of these studies have been conducted in normal soils without any amendment to accelerate degradation. Few studies have been undertaken to assess the acceleration of biodegradation by appropriate soil amendment. However, existing work indicates that it is worthwhile to maintain appropriate moisture levels, add fertilizer and organic matter, and amend the pH through the addition of lime. In most instances, such management or amendment of the soil results in a significant increase in biodegradation. With organochlorine compounds, managing the soil to maintain an anaerobic condition appears to greatly enhance the rate of biodegradation. The addition of organic matter appears to insure more complete degradation of the organochlorines.

Table 7.1B-4 is a summary of some of the findings on biodegradation of pesticides. This table may provide some background in considering the use of cement tanks for biodegradation disposal methods. It is apparent that under proper conditions, significant quantities of chemicals will be biodegraded. More to the point is the indication of the percent breakdown per day under optimal conditions of moisture, pH, nutrients and organic matter. For several compounds, optimal conditions have been found in the range of one to three percent per day at 30°C with a concentration of 10 to 100 PPM of the compound. Concentration is a critical factor in that too much of it may suppress microbiological activity and, thus, reduce or even eliminate the biodegradation.

Considerations: Operation of Biodegradation System

In biodegradation, the system should probably be managed in order to be accommodated to the characteristics of the chemical(s) to be disposed. For example, with organophosphates and carbamates, maintaining a pH above seven for most of these compounds would accelerate hydrolysis and further decomposition. Beyond this, however, because of dependence upon microbiological action, the biodegradation system would require supplements of nutrients and organic matter to foster co-metabolism. The nutrients required would probably be the normal major ones such as nitrogen, phosphorus, and as needed, potassium. Organic matter could be supplied with a number of different materials including animal wastes, straw, leaves of plants and trees, and even garbage. Even though the biodegradation system is protected

TABLE 7.1B-4

Biodegradation of Pesticides

Chemicals	Initial Concentration in PPM	Conditions	Biodegradation: Days to 50% Loss
DDT	8.00	30°C Aerobic	Over 100 days
DDT	6.28	Anaerobic Plus Matter - 30°C	8 days
Diazinon	19.00	25°C, pH 8.1	24 days
Diazinon		25°C, pH 5.5	22 days
Dalaphon	2000.00	26°C, pH 6.3	2.5 days

from excessive moisture, adequate moisture should be maintained, probably by providing some sort of a roof. The system should be maintained aerobic for such compounds as the organophosphates, carbamates, organic acids, and probably the dithiocarbamate fungicides, as well.

If a biodegradation system is utilized for disposal of the organochlorine compounds, (chlorinated hydrocarbons), it seems reasonable on the basis of work done thus far to maintain the system in an anaerobic condition. The anaerobic condition could be achieved by flooding, while assuring adequate supplies of nutrients and organic matter to foster the co-metabolism. In the case of the chlorinated hydrocarbons, animal waste, if available, is probably the best source of organic matter.

It is desirable to have some type of monitoring to determine the effectiveness of the biodegradation. Two simple monitoring systems recommend themselves. The first is a bioassay, using an organism such as the water flea for insecticides, and a bioassay with plants for herbicides. The second type of monitoring system involves thin layer chromatography utilizing spray reagents to visualize and measure the chemicals present.

Case Histories

Often the use of pesticides is a highly dispersed activity, and the amount of waste pesticide is relatively small. Thus, the problem of collection and transport to a centralized disposal facility, such as an incinerator, can be a cost beyond available resources. Again, it can be particularly true of developing countries where finances, a technically trained infrastructure, and transport systems may pose a constraint. There has been increasing interest in appropriate disposal methods when particular problems exist (i.e., when chemicals are to be disposed of or the number of containers limited). The chemicals involved can be highly varied from such materials as the organophosphate or carbamate insecticides to leftover stock of the chlorinated hydrocarbon insecticides, various herbicides, and mercury-containing fungicides. The following case histories illustrate an attempt to use appropriate technology for disposal of some of these chemicals in a manner agreeable with available resources; yet these illustrations attempt to avoid hazard to either man or the environment. The case histories deal with the type of compound and the method in which the disposal was accomplished.

(1) Chlorophenols

In one instance, a small plant handling pesticides had a water effluent that was high in chlorophenols. The discharge, although in a holding pond, ultimately leached through the soil to contaminate a nearby stream. In an effort to overcome this environmental contamination, a rather simple liquid-extractor was constructed. It consisted of a wooden tank of several hundred gallons. The tank was partially filled with rock and gravel so as to reduce the volume of liquid and give better mixing. Fuel oil was introduced into the tank to give a layer of oil, about one-half meter in depth. The water effluent containing the chlorophenol was then trickled into the tank from the top where it fell through the layer of oil. A drain pipe on the side extended from the bottom to about 50 cm below the top of the rock. In the passage through the oil layer, a great deal of the chlorophenol was extracted. On the side of the tank was a syphon, just to the height of the water layer, so that the excess effluent could be drained off. This construction turned out to be successful in removing the bulk of the chlorophenol, which purified the effluent stream. Further, the economically valuable chlorophenol was then recovered for recycling within this plant.

In another instance, a sawmill was located alongside a river. The sawed lumber was being treated with a wood preservative, pentachlorophenol. As the material was used initially it posed both a human hazard and environmental contamination. Modification of treatment practices and equipment reduced the human health hazard. But because the tanks needed to be cleaned out from time to time, the material was dumped into the river and environmental contamination persisted. To overcome this problem, a waste pond was constructed. Lime was first added to form insoluble salts of the pentachlorophenol, and then organic matter was added to further adsorb the material. More elaborate technical means could have been used, but with limited resources and finances, this construction was the best available technology.

(2) Mercury and Other Metallic Compounds

Mercury, a metallic element, long known and used frequently, occurs in nature in the ore cinnabar. After the smelting process, mercury may be used as the element in thermometers or mercury vapor lamps. For many years it was also used as a fungicide in the form of various chemical derivatives. As other chemicals, particularly organic chemicals, proved to be effective fungicides, the use of mercury compounds declined. For this reason, one Latin American country wished to dispose of several kilograms of a mercury fungicide. Having no suitable detoxification unit, nor an incinerator that would handle mercury compounds, the technical staff used the reaction of mercury with sulfur to form mercuric sulfide, the basic chemical in cinnabar. As the highly insoluble and nonvolatile cinnabar, the chemical was then disposed of in a restricted hazardous waste site.

(3) The Organophosphates and Carbamates

Two classes of chemicals known as organophosphates and organocarbamates have been widely used for years as insecticides. These chemicals are highly effective insecticides and of short persistence because of volatility or chemical breakdown, often by hydrolysis. Because of their wide use, one would expect an excess of diluted spray or distressed stock that has been in storage too long and that needs to be disposed of. Likewise, because many of these compounds, have a high toxicity to animals including man, any excess material or residue remaining in containers must be decontaminated to avoid possible human hazard or environmental contamination. Incidentally, these compounds are susceptible to hydrolysis, particularly in alkaline solutions. Thus, it is possible to bring about the breakdown of the compound by exposing it to an alkaline solution of water, which destroys its toxicity.

Such a procedure was used extensively in a country that utilized large quantities of organophosphate insecticides. Small lots of the waste material could have been treated with water solution of lye, salsoda, the carbonate of sodium (not bicarbonate), or even trisodiumphosphate. Any of these materials produce a high alkalinity that hydrolysis favors. In this case, the daytime temperatures were high enough to accelerate the hydrolysis. The large metal containers that had been used for the organophosphate insecticide were also decontaminated by treatment with an alkaline water solution, which allowed hydrolysis, rinsing, and steam cleaning to occur. In a relatively small area where transport is not too expensive, these large containers can be brought back to a central facility for this purpose.

Some of the organic insecticides, including the organophosphates, can cause air pollution problems, particularly around sites where concentrated materials are used. Such was the case with a packaging plant in a far eastern country. The plant was located in a residential area of the city. The escape of the organophosphate proved objectionable, not only to those in the plant, but also to the residents who lived nearby. The plant had installed an air removal system, but it only served to carry the chemicals out of doors where they spread to the surrounding area. Fortunately, carbon or charcoal is a good sorbent for many of these chemicals. In order to solve this air pollution problem, a simple carbon filter, consisting of about a four-foot section was inserted into the air effluent stream and successfully abated the air pollution problem. The spent carbon filter had to be incinerated.

(4) Chlorinated Hydrocarbons

Chlorinated hydrocarbons, such as DDT, dieldrin, chloridane and toxaphene were among the first highly effective organic insecticides. They came into wide use during the late 1940s and through the 1950s. While effective in control of many insects, one of their notable characteristics was their persistence in the environment. In many instances, this fact contributed to the degree of insect control that was achieved. However, it became apparent, as more and more of these materials were used, that they did not remain just on the site where used, but also at distances quite removed from the point of application. Because they were not only toxic to insects, but also to fish and other forms of life, environmental pollution was a particularly troublesome problem. Most of these chemicals have now been banned in many countries. However, some countries with particularly severe insect problems bought large quantities of the materials years ago. They find this surplus still in storage and requiring disposal.

Undoubtedly, incineration at high temperatures would be the best way to insure destruction and disposal of the chlorinated hydrocarbons.

Another disposal method is to entomb chlorinated hydrocarbons in some refractory material such as cement, ceramic or asphalt. This method was the most likely choice in a Caribbean country that found itself with some old stocks of 50% wetable chlorinated hydrocarbon powder. The proposed approach was to incorporate the chemical into asphalt that was being used for roadways. The asphalt was laid down as the lowest level and was followed by a finished coat on top to seal in the material. The solubility of the chlorinated hydrocarbon in the asphalt further insured against escape.

A country in the Western Pacific that had a similar problem, but with smaller amounts, elected to incorporate the material into concrete. Thus, in construction of a cement slab for industrial purposes, the chemical was mixed with the concrete and again used as a lower layer to be covered with a seal coat of concrete.

The technique of entombment for chemicals is not that much different from the entombment of radioactive materials in a ceramic material for long-term storage.

(5) Pyridylium Compounds and Related Herbicides

Pyridylium compounds and related herbicides are generally less toxic to mammals than are many insecticides, but they can still cause damage if they are not disposed of correctly. Fortunately, many of the pesticides are amenable to rapid biodegration in soil. A Western Pacific country, which had both dilute herbicides and herbicide containers that required both rinsing and disposal of rinse water, chose to establish a biodegradation site for this purpose. The site was managed in a manner that would foster microbiological activity, which was accomplished by maintaining adequate moisture fertility and adding to the site organic matter that further facilitated the biodegradation.

The foregoing are a few examples of how countries with relatively small quantities of pesticides and limited resources have safely disposed of waste. For larger quantities and for hazardous material, it is necessary to consider incineration as the disposal method. To achieve safe destruction, it is recommended that technical staffs use rotary or cement kilns or an incinerator constructed especially for this purpose.

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7.2 Land Treatment

7.2.1 Introduction

Land treatment of hazardous waste is a managed process that involves the controlled application of a waste onto or incorporated into the soil surface. Land treatment is primarily considered a treatment process since it results in the biological and chemical degradation of organic waste constituents and the immobilization of inorganic waste constituents. However, land treatment is also a disposal process since some of the original waste and certain waste by-products remain at the site at closure. Indiscriminate dumping of waste on land is not land treatment. Land treatment differs from landfills in that with land treatment, the assimilative capacity of the soil is used to detoxify, immobilize, and degrade all or a portion of the applied waste. Landfills contain and store hazardous wastes and control the migration of the waste or by-products from the sites. Liners, which are recommended for landfills, are not required for land treatment. Some other major differences between land treatment and landfills are noted in Table 7.2-1.

The terms "land farm" or "land farming" have also been used to describe this technology. These terms are technically incorrect in that the sites are not farmed in the agricultural sense of the term. To maximize biological and chemical processes and take advantage of the soil's assimilative capacity, wastes are applied frequently. The surface traffic, the incorporation of the wastes in the soil, and the possibility of crop uptake transmitting undesirable contaminants through the food chain preclude the growing of agricultural crops on the site during active use. The term "land treatment" is more descriptive and appropriate for this waste management process. The degradative and detoxifying processes in the soil are used to treat the applied wastes.

Since the mid 1970's, considerable progress has been made in:

(a) understanding the fundamentals that affect the performance of land treatment systems;

(b) defining suitable design and operating requirements; and

(c) actually applying hazardous wastes to land treatment areas. Many texts and summaries of this technology are now available (Page et al. 1983, Loehr et al. 1979. Overcash and Pal 1979, Loehr and Overcash, Parr et al. 1983, and Brown et al. 1983). This section summarizes the key points associated with land treatment when used for the degradation and immobilization of hazardous wastes.

An owner or operator of a hazardous waste land treatment (HWLT) facility must ensure that hazardous constituents placed in or on the HWLT site are degraded, transformed, or immobilized within the treatment zone. The treatment zone is the active part of the soil horizon above the groundwater table in which the degradation, transformation and immobilization of the applied waste will occur. In the United States, the

TABLE 7.2-1

Differences Between Land Treatment and Landfills Used for Hazardous Wastes

Item	Land Treatment	Landfill
Waste Treatment Occurs	Yes	No
General Concept	Treatment (degradation, transformation, immobilization)	Containment
Waste Limitations	Limited to wastes that can be degraded, transformed or immobilized	No liquids in landfills
Waste Quantity	Limited to the assimilative capacity of the soil by adjusting waste loading rate and frequency	Unlimited and not related to the assimilative capacity of the soil
Waste Application Method	Incorporation into the soil	Not mixed with soil
Liquids Acceptable	Yes	No
Monitoring	Soil cores, soil pore water, ground water	Leak detection
Liner Needed	No	Yes
Leachate Collection and Treatment	None	Needed
Run-on and Runoff Control	Yes	Yes
Waste Degradation	Considerable	Some
Waste Immobilization	Yes	Only due to liner
Post Closure Care	Minimal	Long term
Permit Required	Yes	Yes

maximum depth of the treatment zone is defined as no more than 1.5 meters (5 feet) from the initial soil surface and as more than 1 meter (3 feet) above the seasonal high water table. There will be additional attenuation of constituents in the applied waste at depths greater than 1.5 meters.

Because of the nature of the wastes applied at a HWLT facility, the design and operating conditions for such a facility should be reviewed carefully. A permit for the facility should be obtained from the appropriate regulatory agency or organization. The permit application should demonstrate that the facility is capable of handling the wastes it intends to receive. The application should indicate the design measures and operating practices that will be employed to maximize the success of degradation, transformation, and immobilization processes in the treatment zone, as well as the provisions for monitoring the surrounding unsaturated zone.

Hazardous waste land treatment is the controlled application of hazardous waste to the aerobic soil horizon, accompanied by continued monitoring and management in order to render the waste less hazardous. Land treatment is a widely used practice for the treatment and disposal of non-hazardous and hazardous wastes. Table 7.2-2 indicates the suitability of various types of soils for land treatment of hazardous wastes.

The hazardous wastes that are applied can be liquids, semi-solids or solids. Since the possibility exists that waste constituents or by-products can be transmitted to groundwater as leachate and to surface waters by erosion and leachate interflow, and can also be emitted as gases, the design of a land treatment system should minimize the potential for such transmission and losses.

Land treatment has these advantages:

(a) the application of waste can be repeated safely at frequent intervals; and

(b) minimum energy is needed to dispose of the wastes. Well designed and operated HWLT facilities should have low short-term and long-term liabilities relative to other available waste disposal methods. Land treatment has relatively low initial and operational costs, and low energy consumption. With proper management, land treatment can be an environmentally sound and technically feasible method of hazardous waste management. With sound controls over application rates and the type and volume of wastes applied to the land, HWLT sites can be reclaimed for productive uses after closure.

7.2.2 Treatment Demonstrations

The basic philosophy of land treatment of hazardous waste is that it is a waste management practice only for those wastes that are treatable in a soil system. Hazardous waste should not be placed in or on a land treatment site unless the waste can be made less hazardous or non-hazardous by the reactions occurring in or on the soil.

TABLE 7.2-2

Suitability of Various Textured Soils for Land Treatment of Hazardous Industrial Wastes

Texture	Advantages	Disadvantages
sand	very rapid infiltration usually oxidized & dry low runoff potential	very low CEC very high hydraulic conductivity low available water poor soil structure
loamy sand	high infiltration low to medium runoff	low CEC moderate to high hydraulic conductivity rate low to medium available water
loam	moderate infiltration fair oxidation moderate runoff potential generally accessible good CEC	fair structure
silt loam	moderate infiltration fair oxidation moderate runoff potential generally accessible good CEC	some crusting fair to poor structure
silt	low infiltration fair to poor oxidation good CEC good available water	high crusting poor structure high runoff
silty clay loam	medium to low percolation fair structure high CEC	medium to low infiltration some crusting potential
silty clay	good to high available water	moderate runoff often wet fair oxidation
clay loam	medium to low percolation good structure medium to poor aeration high CEC high available water	medium to low infiltration moderate to high runoff often wet

TABLE 7.2-2 (continued)

Texture	Advantages	Disadvantages
clay	low percolation high CEC high available water	low infiltration often massive structure high runoff sometimes low aeration
sandy clay	medium to low percolation medium to high CEC	fair structure moderate to high runoff
sandy clay loam	medium to high available water good aeration	medium infiltration

Source: U.S. Environmental Protection Agency. 1983. Hazardous Land Waste Treatment SW-874 (April). Cincinnati, Ohio: Office of Research and Development.

Land treatment can result in the neutralization of wastes with high or low pH values and in the conversion of inorganic constituents to a less mobile or toxic form. However, land treatment is best used for those wastes that are biologically degraded or chemically stabilized. The greater the treatment a waste undergoes in a soil, the more acceptable the waste is for land treatment. A waste that contains components that are degraded, neutralized, made less mobile, and/or made less toxic in the soil is an ideal candidate for land treatment. Organic wastes from the organic chemical, petroleum refining, textile, pharmaceutical and wood preserving industries are examples of wastes that have been land treated successfully.

Although filtration and dilution will occur when wastes are applied to the land, such mechanisms are not acceptable for the treatment of hazardous wastes if they are the only or primary mechanisms that occur. Filtration and dilution provide little net reduction in hazard since they do not alter the chemical state of the waste.

For each waste that will be applied to the treatment zone, the owner or operator of the HWLT facility should demonstrate, prior to application of the waste, that hazardous constituents in the waste can be completely degraded, transformed, or immobilized in the treatment zone. To do so field tests, operating data, laboratory analyses or other available information can be used. The treatment demonstration should simulate the characteristics and operating conditions for the proposed HWLT facility including:

(a) the waste characteristics;

(b) the climate conditions at the facility;

(c) the topography of the site;

(d) the characteristics of the soil in the treatment zone; and

(e) the operating practices likely to be used. The demonstration should indicate that hazardous constituents in the waste to be tested will be completely degraded, transformed, or immobilized in the treatment zone of the proposed HWLT facility. Laboratory and field tests can identify the potential for migration of hazardous constituents to ground or surface waters.

7.2.3 General Operating Requirements

A number of common sense approaches are involved in the operation of a HWLT facility (Table 7.2-3. Run-on must be diverted to avoid:

(a) excess water entering the site;

(b) anaerobic or ponding conditions;

(c) increased erosion; or

TABLE 7.2-3

Land Treatment Site Operating Requirements

- Run-on should be diverted from active portions of the site.
- Runoff from active portions of the site should be collected and disposed of in an environmentally sound manner.
- Periodic analysis of the applied waste should be conducted.
- Records of the application dates, rates, quantities, and location of the applied wastes should be kept.
- The use of the site for food chain crops should be avoided.
- An unsaturated zone monitoring plan must be implemented.
- A closure and post-closure plan must be prepared and implemented at the proper time.

(d) increased contaminated runoff that may require treatment.

Run-off from the active portions of a site must be collected and, if determined to be a hazardous waste, must be managed as such. If it is not a hazardous waste runoff should still be monitored and analyzed to identify proper treatment and disposal methods. Not all the run-off collected at a land treatment site will require treatment prior to discharge. Field experience suggests that if the waste is thoroughly incorporated into the soil, contamination of runoff is minimized. Once the wastes have been incorporated in the soil and degraded or immobilized or the soil surface stabilized by a proper cover, runoff should require little or no treatment. If the collected runoff is discharged to surface waters, it may be subject to some treatment requirements.

The applied wastes should be analyzed periodically for conventional parameters, such as pH, BOD, COD, suspended solids and nutrients, and for those constituents that cause the waste to be defined as hazardous such as metals, specific organics and other inorganics. The results of such analyses permit:

(a) verification of the design and operating application rates; and

(b) prediction of the degradation and stabilization rates of the applied wastes.

Records of where and when wastes are applied, the rates of application, and the types of wastes that are applied should be kept. Such records provide a historical record of what occurred at a site and are used for closure and post-closure plans and to interpret monitoring results.

7.2.4 Surface Vegetation

Because of the possibility of transmitting hazardous waste constituents through the food chain, food chain crops should not be grown on a HWLT site. Only if it can be demonstrated that the hazardous waste constituents that cause human or animal health problems will not be transferred to the food portion of the crop by plant uptake or direct contact and will not be ingested by grazing animals should the cultivation of crops on land treatment sites be considered.

Forest and other non-food chain land can be considered for the application of liquid or semi-solid industrial wastes. The hydrologic properties of forest soils allow waste assimilation over a wider range of climatic conditions. The major disadvantage of forest sites is that slopes tend to be steeper and soils tend to be shallower.

7.2.5 Monitoring

Unsaturated zone monitoring (UZM) is desirable since such monitoring will detect migration of the applied waste and waste by-products. The monitoring should include soil cores and soil pore water samples. The number of samples to be taken and analyzed is a function of the hazardous waste constituents expected to migrate, the soil type and permeability, the climatic conditions, and the waste application rate and frequency. Characteristics of common soil sampling equipment are noted in Table 7.2-4.

Monitoring of the groundwater around the HWLT site also is desirable to assure that groundwater contamination does not occur.

7.2.6 Conceptual Design

Land treatment is a dynamic system consisting of the soil, the atmosphere and any vegetation that may grow at the site. The soil is the key component of the system and performs the treatment that occurs.

Hazardous wastes are applied to the soil at controlled rates. The soil and waste are mixed to maximize biological, physical and chemical reactions.

To have adequate biodegradation, sufficient nutrients must be available in the soil. Nitrogen, phosphorus or potassium may have to be added to the soil if the hazardous wastes are deficient in these compounds. Following each application, the organics will be degraded. The organic degradation or loss normally is approximated by a first order rate reaction and the relative degradation rate identified in terms of a half-life (i.e., the time required for the concentration of an organic to decrease by half). The rate of degradation will depend upon the temperature and the biodegradability of the organic constituents. Half-life values for organic compounds in land-treated petroleum industry wastes are illustrated in Table 7.2-5.

Climatic conditions, experience and soil monitoring to identify the concentration of waste constituents in the soil of a HWLT site will determine the frequency of waste applications. Application rates are limited by the amount of material that can be easily applied and incorporated and that will not inhibit the microorganisms involved in the biodegradation.

Degradation of organics results from the action of indigenous microbes and other biological forms such as protozoa, mites and earthworms. Volatile constituents and gases from biological and chemical reactions can be emitted to the atmosphere. Major chemical reactions include adsorption, precipitation, ion exchange, and gas transfer. The soil also functions as the ultimate sink for immobile, non-degradable wastes and waste by-products. Mobile constituents will move with water percolating through the site.

Atmospheric conditions affect the reactions in the soil by controlling the water content and temperature of the soil. Surface winds increase the transfer of oxygen to the soil as well as volatile compounds, $C^{O}2$ and other gaseous by-products from the soil. The wind also affects the moisture content and heat balance of the soil. Solar radiation can enhance photo-oxidation of waste constituents exposed at the soil surface.

TABLE 7.2-4

Attributes of Soil Sampling Equipment

Type of Sample	Obtains Core Sample		Most Suitable Core Types		Operation in Stoney Soils		Most Suitable Soil Moisture		Relative Sample Size		People Needed	
	Yes	No	Coh.	Non-Coh+	Fav.	Unfav.**	Wet	Moist	Lg	Sm	One	More
A. Hand Auger												
1. Screw-Type Augers	-	X	X	X	-	X	X	X	X	-	X	-
2. Barrel Augers												
Post-Hole Auger	-	X	X	-	X	-	X	X	-	X	X	-
Regular Barrel Auger	-	X	X	-	X	-	-	X	X	-	X	-
Sand Augers	-	X	-	X	X	-	-	X	-	X	X	-
Mud Augers	-	X	X	-	X	-	X	-	-	X	X	-
3. Tube-Type Augers												
Soil Probes	X	-	X	X	-	X	X	X	X	-	X	-
Thin-Walled Tube Samplers	X	-	X	-	-	X	-	X	-	X	-	X
Peat Samplers	X	-	X	-	-	X	X	-	-	X	-	X
B. Power Auger												
Hand-Held Screw Type Power Auger	-	X	X	X	X	-	-	X	-	X	-	X
Truck Mounted Auger	-	-	X	X	-	-	X	X	-	X	-	X
Tripod Mounted Drive Sampler	X	-	X	X	-	-	-	X	-	X	-	X

+Coh- cohesive; Non-Coh-non-cohesive
**Fav-favorable; Unfav.-unfavorable

Adapted from source: U.S. Environmental Protection Agency. 1984. Permit guidance manual in unsaturated zone monitoring for hazardous waste land treatment units. Draft. EPA - 530-SW-84-016 (December). Washington, D.C.: Office of Solid Waste and Emergency Response.

TABLE 7.2-5

Degradation Rates of Specific Organic Compounds in Soils

Organic	Reported Half-Life (days)
Toluene	0.7 - 7
Phenol	1.0 - 2.2
2,4-dimethylphenol	1 - 2
2,4-dinitrophenol	3 - 28
Diethyl phthalate	4 +
Benz (a) anthracene	41 - 252
Chrysene	5 - 10
Fluoranthene	44 - 182
Benz (a) pyrene	2 - 100+

Source: American Petroleum Institute. 1984. The Land Treatability of Appendix VIII Constituents Present in Petroleum Industry Wastes. Washington, D.C.

Permeable and tillable soils such as loams, sandy loams or clay loams are best for land treatment. Such soils allow easy incorporation of the waste, permit aerobic conditions to be maintained after waste application, and drain well after high rainfall events.

Preserving some options for the post-closure use of a HWLT site is an important concept in land treatment. This concept of "non-degradation" implies that wastes shall be applied to the site at environmentally sound rates and over such limited time spans that no land is irreversibly removed from potential use for development or the growth of non-food-chain crops including forests, or as open space or parks.

Because non-degradation cannot always be guaranteed as a project is designed and implemented, monitoring must be part of a land treatment system to determine performance and to extend or shorten the life of the site as appropriate. The design of a land treatment system involves:

(a) identifying the waste constituents that limit the feasibility and life of a site; and

(b) evaluating methods, such as pre-application treatment processes that can modify the limit.

Environmentally sound application rates and required land areas are site specific. With some wastes, the necessary land areas may be so large that land treatment will not be cost-effective. Decisions to use land treatment for industrial wastes are often based more on economic rather than technical feasibility.

(i) Land Limiting Constituents

The land limiting constituent or limiting parameter concept is based upon the fact that soil has a finite assimilative capacity for inorganic and organic constituents. As the amount of waste applied to the soil increases, the maximum assimilative capacity or parameter can be exceeded. The constituent that results in the lowest application rate and the largest required land area is the limiting constituent. Other waste constituents are applied to this land area at a conservative rate that would not cause them to reach levels of environmental concern. Details about the land limiting constituent concept are discussed in other publications (Loehr et al. 1979, Overcash and Pal 1979, Loehr and Overcash, and Brown et al. 1983).

A variety of parameters can limit waste application rates. Examples include:

(a) nitrate-nitrogen leached to groundwater;

(b) cadmium in food chain crops;

(c) synthetic organic compounds in surface, groundwater and crops;

(d) salts that inhibit seed germination; and

(e) metals that may be phytotoxic to crops.

Accepted limits for such constituents can be found in standard water quality criteria and in regulations for food chain crops. Because food chain crops are rarely grown on hazardous waste land treatment sites, the important short-term limiting constituents at such sites are water-quality related (i.e., constituents that impact surface and ground water quality).

However, the long-term limiting constituents may be related to non food chain crops since the intent of the non-degradation concept is not to preclude such use after closure of the site. Monitoring of the soil and subsurface water will identify if and when limits to such use are being approached. Reduction in application rates or cessation of application can preserve the future use of the site before the limit is exceeded.

Figure 7.2-1 illustrates the use of the limiting constituent concept with a hazardous waste. In this example, one or more of the synthetic organics is the limiting constituent requiring the largest land area to avoid exceeding one of the concerns (i.e., water quality criteria, drinking water standards or food chain impacts). Metals would be the next limiting constituent if the constraint due to the synthetic organics were relieved by reducing their concentration in the applied waste.

The determination of the land limiting constituent is made on a site specific basis to select the parameter or class of constituents that requires the largest land area. A site and waste specific analysis is necessary since soil, waste, climate and other factors vary from site to site. Pre-treatment options which could reduce or eliminate land limiting constituents should be determined and their costs compared to those of the relative land areas needed for the limiting constituents.

The major constituent classes that should be considered in determining the limiting constituents are those that:

o degrade biologically in the soil (i.e., biodegradable organics);

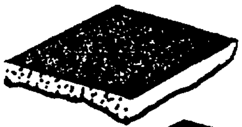
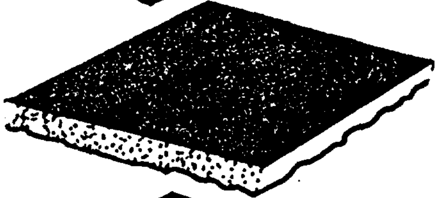
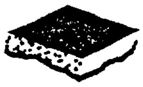
o are relatively immobile and non-degradable and therefore accumulate in the soil (i.e., metals, refractory organics); and

o are mobile and non-degradable and impact surface and groundwater uses (i.e., salts, synthetic organics).

With hazardous wastes the limiting constituents usually are synthetic organics, metals and nitrogen; with non-hazardous wastes the limiting parameters are usually soil permeability and nitrogen. Salts can be a limiting constituent in arid regions. The rate of degradation of organics usually is so large that biodegradable organics rarely are a limiting constituent. Non-biodegradable organics will accumulate in the soil and, unless they leach in unacceptable concentrations, also will not be a limiting constituent. Since most hazardous wastes applied to land

FIGURE 7.2-1

An Example of the Limiting Constituent Concept in which Synthetic Organics are the Limiting Constituents

WASTE CONSTITUENT	ITEM LIMITING APPLICATION RATE	ESTIMATED LAND AREA NEEDED
Nitrogen	-nitrate in groundwater	
Synthetic organics	-surface water quality criteria -drinking water standards -food chain impact	
Metals	-food chain impact -water quality criteria or standards	
Water	-soil permeability	
Biodegradable organics	-maintenance of aerobic conditions -surface clogging of soil	

Source: Loehr, R. C., and M. R. Overcash. 1985. Land treatment of wastes: Concepts and general design. Journal of Environmental Engineering III (2) (April): 141-160.

treatment sites are not liquid, hydraulic application rates rarely limit the land area at such sites.

(ii) Pre-Application Treatment

The land limiting concept is an approach that identifies a constituent that limits the use of land treatment as a hazardous waste management technology. The approach also identifies that constituent, which if reduced or removed, will decrease the necessary land area and system costs.

If the limiting parameter or constituent is eliminated, through pre application treatment, industrial process changes or other methods, then another parameter becomes the limiting parameter and the required land area is smaller. If synthetic organics and metals in the applied wastes were reduced in quantity and concentration by appropriate means, nitrogen would become the limiting parameter and the required land area would be considerably smaller. Specific examples of how pre-application treatment altered the limiting parameter and the required land area are available (Overcash and Pal 1979). There are a number of methods that can be used to reduce specific limiting constituents (Table 7.2-6).

These reductions make a waste more amenable (in an economic sense) to land treatment. If the combined removal or reduction of a waste constituent and the resultant land treatment system is less expensive than the land treatment system for the initial waste, then the reduction or removal is cost-effective. In-plant and process modifications and specific constituent removal should not be considered as technical requirements prior to land treatment. They should be viewed as cost improvement procedures once the critical constituents have been identified.

(iii) Summary

Information and experience from soil chemistry, soil analysis, agronomy, hydrology, agricultural engineering, environmental engineering, environmental science and microbiology may be needed to determine the land limiting constituents and design the system. Accurate waste characteristics are important in determining what constituents or classes of constituents should be evaluated as a limiting constituent. Table 7.2-7 provides a list of the waste characteristics that should be determined. It should be considered only a partial list since there may be other compounds of concern in the applied waste. All chemicals likely to be present in the wastes are candidates for analysis.

The limiting constituent concept has several advantages (Shukrow et al. 1982, and Overcash and Pal 1979).

- It provides a standard methodology for considering important site specific soil data, climatic conditions, waste characteristics, and environmental concerns.

TABLE 7.2-6

Methods to Modify Land Limiting Constituents at HWLT Sites

CONSTRAINT	MODIFICATION
Nitrogen	o reduce prior to application
	o enchance losses after application
Metals	o remove or reduce prior to application
	o modify processes that cause metals to be in the hazardous wastes
Synthetic organics	o remove or reduce prior to application
	o modify processes that cause synthetic organics to be in the hazardous wastes
	increase degradation rates
Pathogens	o remove or reduce prior to application
Salts	o remove or reduce prior to application
Soil Permeability	o underdrain*

*not used at a hazardous waste land treatment site if a hazardous waste leachate or highly contaminated leachate will result.

TABLE 7.2-7

Waste Characteristics that Should be Known to Determine the Land Limiting Constituents and to Design a Land Treatment System

CLASSES	CHARACTERISTICS
General	Volume, dry solids, moisture content, pH
Nitrogen	Organic nitrogen, ammonia nitrogen, nitrate nitrogen
Nutrients	Phosphorus, potassium, sulfur
Metals	Copper, lead, nickel, zinc, cadmium
Ions	Sodium, chloride, calcium, magnesium, carbonate, sulfate
Synthetic organics	Those relevant to the industry and waste production processes
Biodegradable organics	A measure of oxygen demand (BOD, COD, oxygen uptake rate)
Other	Substances which cause a waste to be listed as hazardous

- It provides a direct relationship between waste characteristics and the soil assimilative capacity.

- The methodology is based upon scientific fundamentals rather than empirical, black box approaches that cannot be extrapolated due to variations in soil, climate, and waste characteristics.

- Attention can be focused on management techniques, site selection, and pre-treatment aspects that improve the assimilative capacity of the site and avoid environmental and public health problems.

- Monitoring programs can be focused on the critical parameters, such as the limiting constituents.

7.2.7 System Design and Management

A land treatment system is a dynamic system in which the waste, soil, climate and management interact. Previous sections have focused on the basic soil and waste interactions and on the conceptual design. This section focuses on general system components, operation and management.

7.2.8 Site Conditions

Proper site selection and evaluation is essential to sound system design and management. When sites are being considered for land treatment, it is essential that a detailed site investigation be performed so that:

(a) areas unsuitable for waste application are avoided and;

(b) the soil and hydrogeological characteristics are identified for the limiting constituent analysis and for design and operating decisions.

The components of a land treatment system are noted in Table 7.2-8. Wastes to be treated are applied intermittently to each unit of land. This permits waste degradation and soil interactions to occur and aerobic soil conditions to be restored prior to the next application. Wastes may be applied during only one season of the year or at more frequent intervals. The actual intervals are determined by the degradation and immobilization rates of the applied material and the need to empty storage units and dispose of wastes. Because a land treatment site is not usually used for crop production, wastes are often applied frequently. Such applications minimize the need for excessively long storage between applications.

The HWLT area can be subdivided into smaller areas to which the waste is applied sequentially, one sub-area after another during a season, until a soil constituent limit is reached or monitoring indicates that the groundwater quality may be degraded. At such time the site is closed. Alternatively, each sub-area can be used until the limits are reached, the sub-area closed, and application transferred to the next sub-area.

TABLE 7.2-8

Components of a Land Treatment System

- Active application site areas
- Future application site areas
- Buffer areas
- Waste storage areas
- Sufficient areas near waste storage and the application site for emergency procedures if needed
- Run-on diversion
- Runoff retention ponds with emergency spillway
- Roads to bring waste to the site and to apply the wastes
- Equipment washing and storage areas

The HWLT site should have adequate buffer areas between the site and the public. A buffer area minimizes potential aesthetic and odour problems. Many HWLT sites are on the property of the industry producing the waste and aesthetic problems may be minimal. The buffer zones also should permit adequate area for possible emergency procedures. Such procedures include waste removal, cleanup and treatment.

Equipment washing facilities should be provided at the site so that no hazardous waste leaves the site on the equipment. Adequate roads and equipment storage areas also should be provided. Fences may be needed to prevent public access to the site.

Waste storage areas may exist either where the wastes are generated or at the HWLT site. The storage volume will be determined by the frequency of application which is influenced by climatic conditions.

7.2.9 Water Control

Water control is important at the land treatment site since the site should be isolated hydrologically. Run-on diversion structures and runoff retention ponds must be included at the site. The run-on diversions can be grassed waterways or open ditches designed to divert the upgrade surface drainage. Figure 7.2-2 indicates the run-on and run-off control that occurs at a land treatment site.

Every HWLT runoff retention pond should have an emergency spillway for overflows. Since the runoff can contain hazardous waste constituents as well as conventional pollutants, environmental damage may result from pond failure. The spillway should be vegetated to prevent erosion and pond failure in the event of an overflow and, if possible, should drain to another retention pond or to a land treatment sub-area. Figure 7.2-2 illustrates the components of a land treatment site.

Runoff retention ponds are designed to accommodate specific precipitation events such as the 24-hour, 25-year return period storm and to have an adequate freeboard for extreme events. The ponds act as flood control reservoirs and, between storm events, the collected run-off should be reduced by natural evaporation and by draining or irrigating the pond contents onto adjoining land.

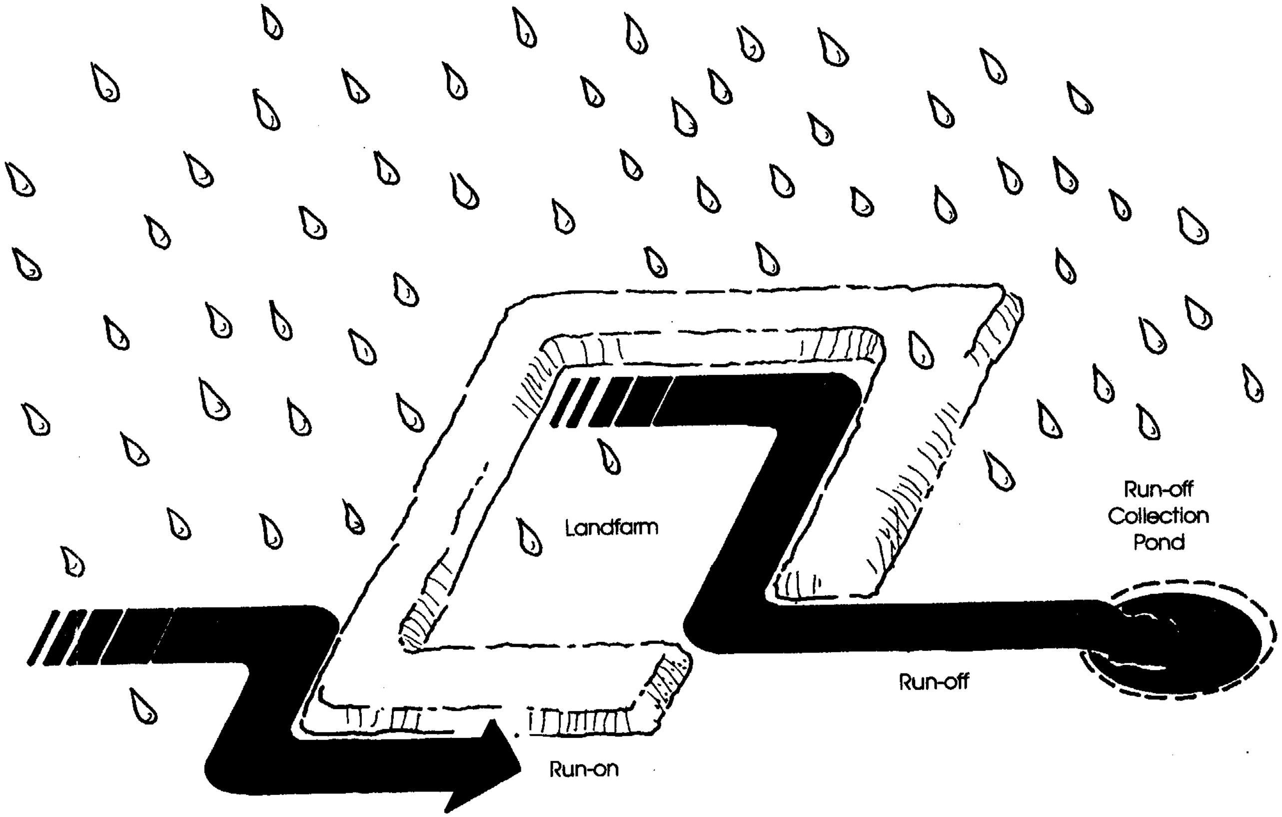
The collected runoff can be treated by several methods. If the industry operates a wastewater treatment plant, the runoff may be able to be pumped to such a plant on a controlled basis so that the treatment plant is not overloaded. The collected runoff also can be applied to the existing land treatment site in a controlled manner. As a last resort, an on-site treatment system can be constructed for discharge to surface waters.

7.2.10 Application Methods

The waste characteristics will determine the appropriate application methods. Liquids can be surface applied by irrigation techniques. Semi-solid wastes can be spread over the site by trucks equipped with

FIGURE 7.2-2

Land Treatment Site



floatation tires or can be subsurface injected. Wastes too thick to pump and low-moisture solids can be spread over the surface of the land. Surface applied wastes should be mixed with the soil by ploughing, rototilling or disking as soon after spreading as possible to minimize contaminated run-off. Surface spreading is not appropriate for wastes whose volatile constituents cause environmental problems or endanger those working at or adjacent to the site.

Uniformity of application is important to continued and proper use of the site. The most appropriate application equipment will:

(a) be able to handle the solids content of the waste;

(b) minimize any risk to operator health and safety and to the environment;

(c) minimize contact of the operator with the waste;

(d) have a long service life;

(e) not be clogged or corroded by the waste; and

(f) have reasonable capital and operational costs.

Erosion and dust control should be incorporated in site management plans. Dust can occur during disking and mixing operations and from roads during dry periods. Dust from the site can contain some fraction of the applied hazardous waste and should be suppressed. Both wind and water erosion control are needed during site use and post-closure.

7.2.11 Closure and Post-Closure

When the site is no longer used, it must be closed and managed properly after closure to control subsequent migration of waste constituents from the site. During closure and post-closure, the HWLT owner or operator should:

(a) continue all operations necessary to maximize degradation, transformation, or immobilization of hazardous constituents within the treatment zone;

(b) minimize run-off of hazardous constituents or other contaminants;

(c) maintain the run-on control system and the run-off management system;

(d) control wind dispersal of the applied waste;

(e) comply with any prohibitions or conditions concerning growth of food-chain crops;

(f) continue unsaturated zone monitoring; and

(g) establish a vegetative cover on the closed HWLT site. Access to the site should be restricted to appropriate post-closure users.

If the land limiting constituent is properly identified and if the land treatment system is properly designed and operated, the HWLT site should be closed before any soil constituents reach concentrations of concern. Therefore there should be no contaminated soils that require removal and disposal.

HWLT sites can be closed by revegetating the existing site surface, or if necessary by application of a suitable cover. The cover should be designed to minimize the vertical movement of water yet be capable of providing a rooting medium for permanent vegetation. Loams and clay loams or related soils are appropriate natural cover materials.

If there continues to be active decomposition of the applied organics, application of any cover material should be delayed until adequate stabilization has occurred.

7.2.12 Practical Application

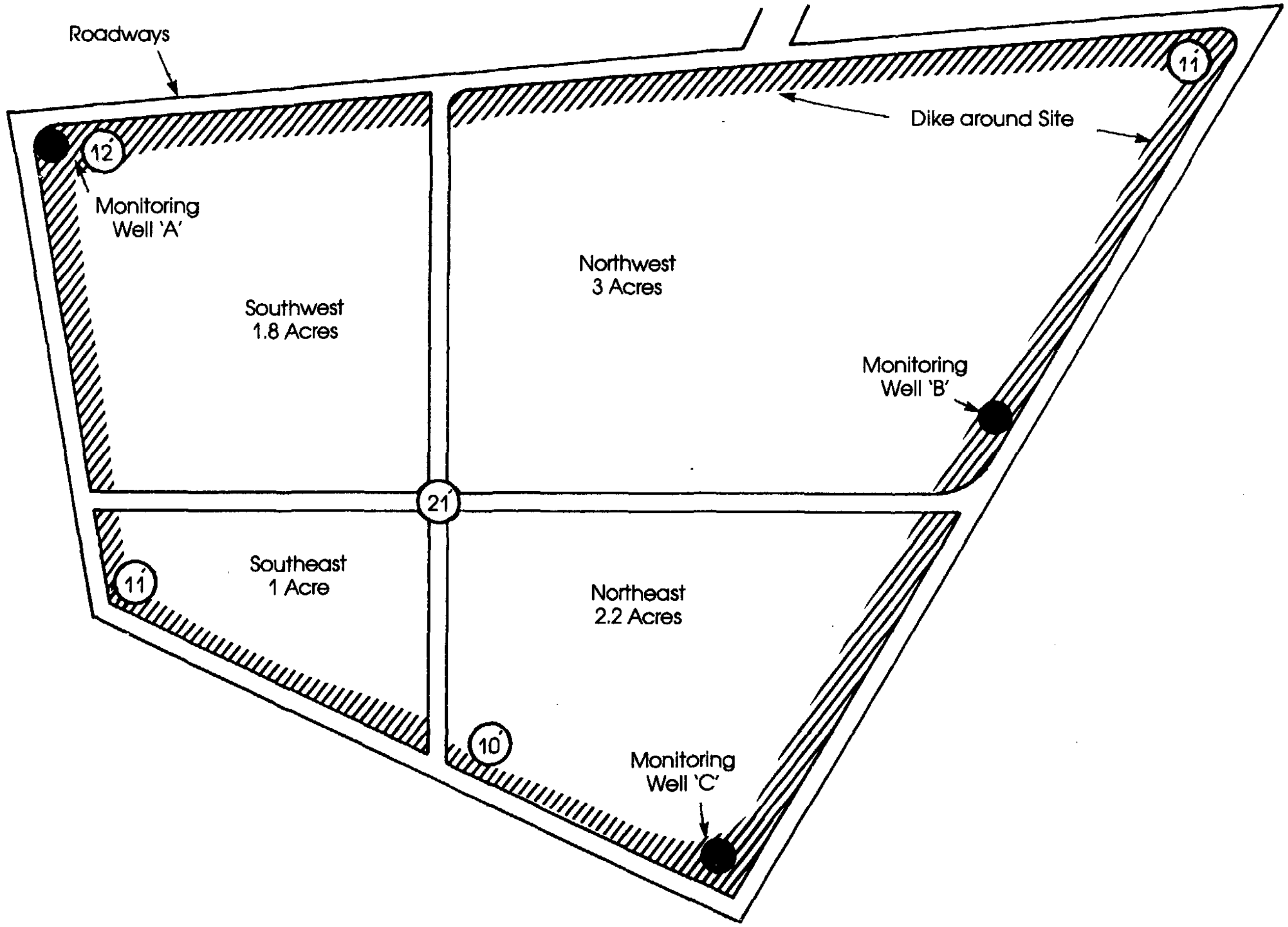
Land treatment is not a new technology. Its greatest use has been with municipal wastewaters, sludges and other non-hazardous wastes. In the United States, there are about 200 industrial land treatment sites, many of which treat hazardous wastes. The petroleum industry uses about half of these and other sites treat wastes from chemical, pulp and paper, tanning and food processing industries. A land treatment site at a petroleum refinery is shown in Figure 7.2-3. Land treatment of hazardous and non-hazardous wastes also is practiced in Canada, France, Denmark, the Netherlands and other countries.

Documented field experience with land treatment systems has established effective design and operating principles. Experience with oily wastes and biological sludges from the petroleum industry (American Petroleum Institute 1983) has shown that land treatment can be a viable treatment and disposal method for such wastes. High oil removal efficiencies have been experienced at all such facilities. In addition, the organics were degraded, refractory hydrocarbons were retained within the zone of incorporation, and the metals were immobilized. Conservative waste application rates for the site, appropriate monitoring and conscientious management are essential to the success of the effort.

During land treatment, the loss of total oil and specific hydrocarbons in petroleum industry wastes generally follows first order reactions. Different constituents have different loss rates. For example in a detailed field study (Loehr et al. 1985), the half life of total oil ranged from about 260 to about 400 days. The half life of napthalenes, alkanes, and specific aromatics generally was less than 30 days.

FIGURE 7.2-3

A Petroleum Refinery Landfarm Layout



The use of land treatment for halogenated hydrocarbons is of interest because of their general persistence in the environment. The adsorption, mobility, and degradation of hexachlorobenzene (HCB) and polybrominated biphenyls (PBB) in soils have been studied (Griffin and Chou 1980). Both PBB and HCB were strongly adsorbed by soil materials with HCB being adsorbed to a greater extent than PPB. The adsorption capacity and mobility of PBB and HCB were correlated with the organic carbon content of the soil materials.

Information in the following citations indicate that for many wastes, including those identified as hazardous, land treatment can be a technically, economically and environmentally sound treatment and disposal technology: American Petroleum Institute 1983, Loehr et al. 1985, Griffin and Chou 1980, Overcash and Pal 1979, Loehr and Overcash, Parr et al. 1983, Brown et al. 1983, U.S. Environmental Agency (October) 1985, and American Petroleum Institute 1984. Proper application rates, the use of the land limiting constituent concept and good operation and management are important to the success of this technology.

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7.3 Other Land Disposal Processes and Monitoring

7.3.1 Surface Impoundments

(i) Description

Surface impoundments are temporary storage basins that hold liquid wastes and wastes containing free liquids prior to the environmentally sound disposal of the contained wastes. The impoundments are also known as pits, ponds and lagoons. Evaporation of water and loss of volatile constituents can occur while the wastes are stored. Leakage to groundwater generally poses the most serious threat to human health and the environment. Air emissions from volatile compounds stored in these units also can be a concern as can surface water contamination that results from dike failure and from the liquids overtopping the sides of the impoundment. Proper design and operation will minimize these environmental and health problems.

(ii) Design and Operating Requirements

Potential groundwater problems are avoided by:

(a) installation of a primary liner system to prevent leaching of the contents of the impoundment;
(b) appropriate liner inspection and testing;
(c) strict adherence to specific liner performance requirements; and
(d) a leachate detection, collection, and removal system beneath the primary liner. Figure 7.3-1 indicates the type of liners and leachate collection systems that can be used with surface impoundments.

Potential surface water contamination problems are minimized by:

(a) maintaining an adequate freeboard on the impoundment;
(b) having dikes that are structurally sound;
(c) protecting the dikes from erosion and burrowing animals;
(d) diverting run-on away from the impoundments; and
(e) requiring a method to shut off the inflow to the impoundment when the waste level in the impoundment gets too high.

Air emissions can be controlled by installing floating covers to suppress and to capture any volatile emissions.

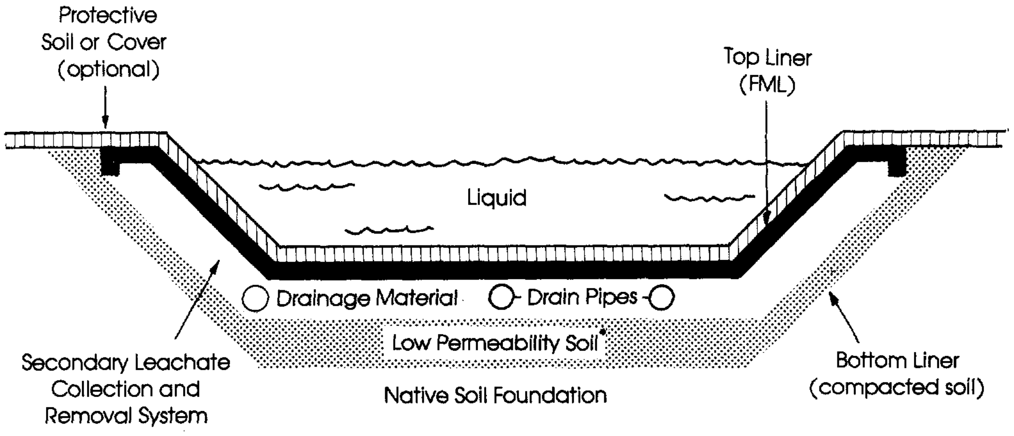
(iii) Liners

A surface impoundment should have a liner that is designed, constructed, and installed to prevent any migration of wastes out of the impoundment to the adjacent subsurface soil, to groundwater or to surface water anytime during the active life of the impoundment including the closure period.

The liner should be constructed of materials that have appropriate chemical properties and sufficient strength and thickness to prevent

FIGURE 7.3-1

Liners and Leachate Collection Systems for Surface



*Thickiness to be determined by
breakthrough time for EPA synthetic/clay liner
Thickness≥3 feet for HSWA* double liner

SCHEMATIC DIAGRAM OF A HSWA* DOUBLE LINER
SYSTEM AND AN EPA SYNTHETIC/CLAY LINER FOR A SURFACE IMPOUNDMENT

*HAZARDOUS AND SOLID WASTE AMENDMENTS (USA)

Source: EPA.

failure due to pressure gradients such as static head and external hydrogeologic forces, physical contact with the waste or leachate, climatic conditions, the stress of installation, and the stress of daily operation. To prevent failure of the liner due to settlement, compression or uplift, the liner should be placed upon a foundation or base capable of providing support to the liner and resistance to pressure gradients above and below it. The liner also should be installed to cover all surrounding earth likely to be in contact with the waste. The information on liners for landfills should be used as guidance for the selection of liners for surface impoundments (see section 7.1.5).

An impoundment should be taken out of service when the waste level in the impoundment drops suddenly and the decrease is not caused by changes in normal flows out of the impoundment. In such a case, rapid discharge through the liner must be presumed.

Any leakage of liquids through an above ground impoundment dike should also be investigated since such leakage indicates liner failure and the possibility of massive dike failure. Under such conditions the waste level in the impoundment should be lowered to investigate the cause and repair the leakage.

When a surface impoundment is removed from service:

(a) the addition of wastes must be stopped;
(b) any surface leakage should be contained; and
(c) all appropriate steps should taken to prevent catastrophic failure of the containment system including the liner and supporting dikes.

(iv) Overtopping

A surface impoundment should be designed, constructed, maintained, and operated to prevent overtopping resulting from:

(a) normal or abnormal operations;
(b) overfilling;
(c) wind and wave action;
(d) rainfall;
(e) run-on;
(f) malfunctions of level controllers, alarms, and other equipment; or
(g) human error.

Surface impoundment dikes should have sufficient structural integrity to prevent massive failure of the dikes. In determining the requirements for structural integrity, it should not be presumed that the liner system will function without leakage during the active life of the unit.

Constructing dikes to provide adequate freeboard above expected operating liquid levels is one means of controlling overtopping. Automatic level controllers or alarms will help prevent overtopping when large storms occur.

With large surface impoundments, waves can be generated by local winds. The interior banks of a surface impoundment should be protected from wave erosion.

At no time should unintentional discharges from a hazardous waste surface impoundment occur. Methods for minimizing human error and for controlling equipment malfunctions should be considered in the design and operation of a hazardous waste surface impoundment. Emergency spillways, overflow piping and emergency collection systems all can avoid direct discharge in the event of human error and equipment malfunction.

(v) Air Emission Control

One approach to controlling air emissions from surface impoundments is to use floating covers. Such covers consist of a synthetic lining placed in one piece over an impoundment, with proper anchoring at the edges and with floats to prevent the lining from submerging. Floating covers can be cost-effective when considerable time, such as a year or more, will elapse before final closure of the impoundment. Figure 7.3-2. A illustrates a floating cover with a gas collection system. The synthetic cover materials should be compatible with the impounded wastes.

(vi) Performance

Important factors in achieving good site performance of hazardous waste surface impoundments have been identified (Ghassemi and Haro 1985) as:

(a) proper site selection;
(b) geotechnical support throughout the entire planning, design and construction;
(c) construction supervision to ensure adherence to specifications;
(d) proper compaction of clay liners;
(e) compatibility of the impounded wastes with the liner material;
(f) rigorous quality control and quality assurance to ensure proper design and liner installation; and
(g) provision and maintenance of a protective cover for the impoundment liner.

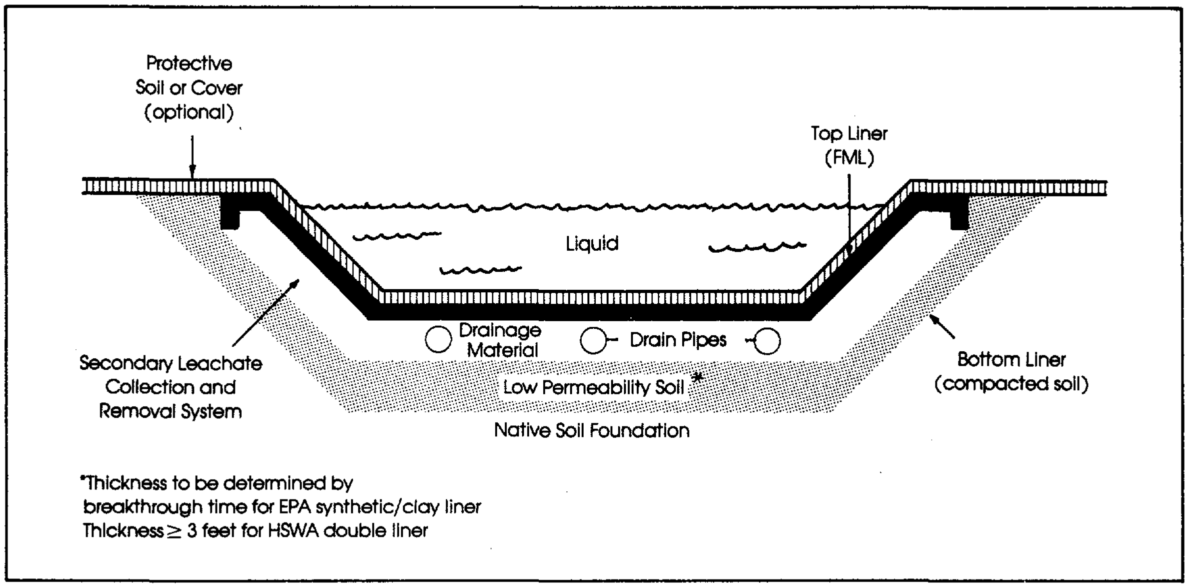
(vii) Closure and Post-Closure

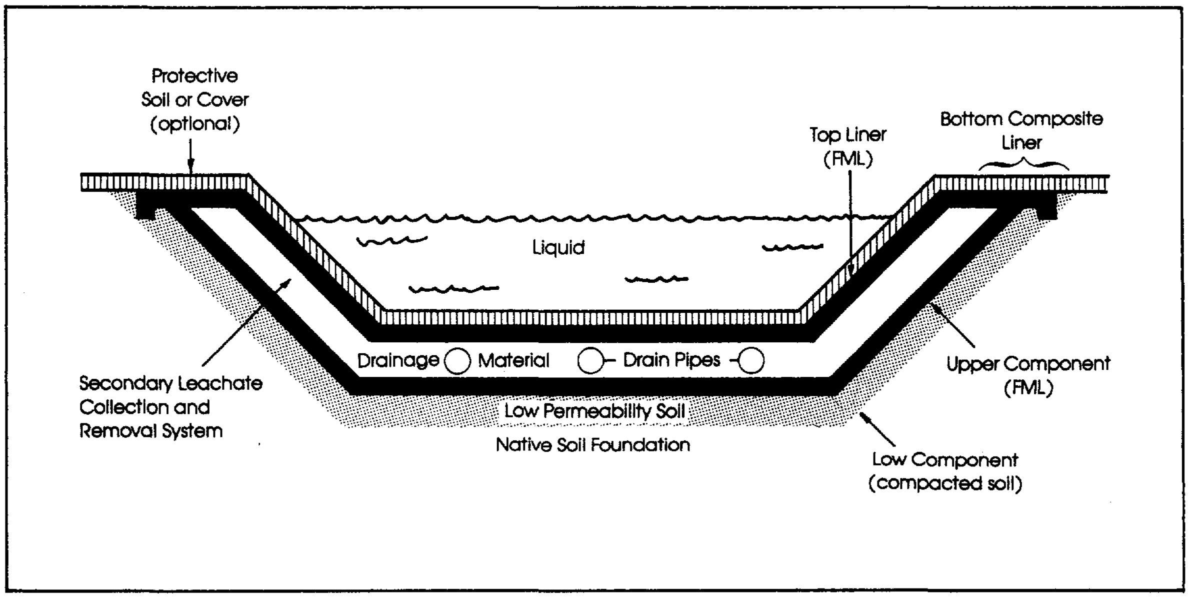
When storage impoundments are closed, all wastes, waste residues, contaminated system components such as liners, contaminated subsoils and contaminated structures and equipment must be removed or decontaminated. After the components are removed or decontaminated, added soils and a cover may be needed on the impoundment area to restore topography and vegetation to natural local conditions. The cover should be able to accommodate settling and subsidence so that its integrity is maintained.

After closure, it may be desirable to maintain and use any groundwater monitoring system that was installed during the active life of the impoundment. Use of such a monitoring system will help assure that no subsequent groundwater contamination results from any residue left at the impoundment site.

FIGURE 7.3-2

Schematic Diagram of a Composite Double Liner System <u>for a Surface Impoundment</u>





7.3.2 Deep Well Injection

(i) Description

Injection wells have been used to dispose of liquid wastes for many decades. In the United States in 1984, there were over 450 industrial waste disposal wells. Of these about 195 were used for the injection of hazardous wastes (U.S. Environmental Protection Agency 1985). In addition, thousands of other injection wells dispose of brine that results from oil or gas production. Injection wells also are used in other countries such as Canada, Japan, Spain and the United Kingdom. Deep well injection is a method of isolating wastes from the upper geologic and soil environment by placing them into deep formations where they are to remain.

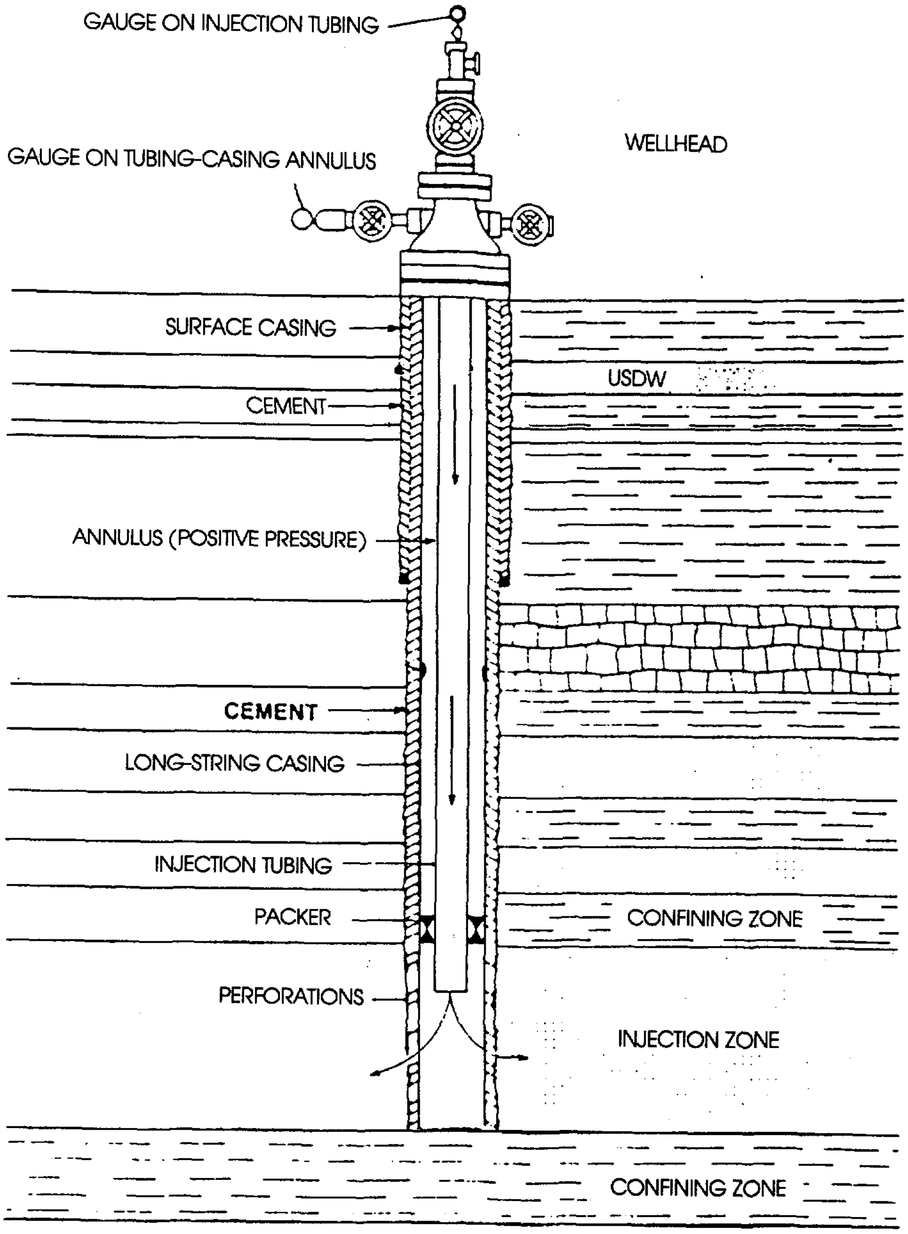
Deep well injection is a disposal and not a treatment method, and for this reason, its application is becoming increasingly restricted by regulatory authorities in developing countries. The injected waste is a liquid that may receive some pre-injection treatment so that the waste does not clog or harm the injection pump or tubing. Some chemical reactions may occur after the wastes are injected into the injection zone. However, injection wells are not designed or expected to accomplish any waste treatment. Disposal is their sole purpose.

The practice is based on simple hydrogeologic principles. The wastes are injected into deep geological formations that are isolated from upper formations, such as those that may be an underground source of drinking water (USDW), by one or more impermeable and confining formations. The deep formations frequently are highly saline and are not usable as a source of drinking or cooling water. A typical injection well (Figure 7.3-3) is several thousand feet deep and injects wastes into highly saline permeable injection zones. The average depth of hazardous waste injection wells in the United States (6) is about 4,000 feet (1,200 meters) from the ground surface to the top of the injection zone. In addition, the average separation between a formation containing a USDW and an injection zone is about 3,000 feet (900 meters).

The well (Figure 7.3-3) consists of concentric pipes. The outer pipe or surface casing should extend below a USDW formation and is cemented along its entire length. Two pipes extend from the surface to the injection zone. The long string casing also is cemented along its entire length to assure that no waste enters formations above the injection zone. The injection tubing is contained within the long string casing and extends from the wellhead to the injection zone. The space (annulus) between the tubing and the casing is closed off at the bottom by a "packer" which prevents injected fluids from filling the annulus. The annulus normally is filled with an inert pressurized fluid which is kept at a higher pressure than the injection pressure in the tubing to prevent escape of the waste into the annulus if a leak should occur. The wellhead caps the well and contains valves and gauges to control and monitor the injection operation.

FIGURE 7.3-3

Schematic of a Hazardous Waste Injection Well



Source: U.S. Environmental Protection Agency. 1985. Report to Congress on injection of hazardous waste. Washington, D.C.: Office of Drinking Water.

(ii) Hydrogeologic Conditions

Liquids injected into subsurface formations do not move into waiting voids. The injection liquid displaces the fluids in the injection zone. The displacement process requires pressure in excess of the natural pressure that exists in the injection zone. The amount of excess pressure required to inject the liquid waste and the distance to which it extends into the injection formation depends on the properties of the formation and the injected waste and the length of time that injection has continued.

Sandstone, limestone and sandstone shale are the geologic formations commonly used as injection zones. Shale, limestone and sandstone shales, clay and silt are common confining zone materials.

Knowledge of the geologic and hydrologic characteristics of the subsurface environment at an injection well site and in the area surrounding the site is important. Such knowledge affects decisions concerning:

(a) the suitability of the site for waste injection; and
(b) the design, construction, operation and monitoring of injection wells.

Information concerning local and regional hydrogeologic conditions should be obtained from federal and regional agencies and organizations responsible for evaluating and collecting such data. Basic references such as (Warner and Lehr 1981) describe the data that needs to be obtained and how it can be used when considering injection wells for disposal of hazardous wastes.

(iii) Site Evaluation

The search for a feasible site for deep well injection of hazardous wastes begins at the regional level, is narrowed to the vicinity of the site and then focuses on a specific well location. The more feasible regions for injection wells should fulfill criteria such as those shown in Table 7.3-1. Once a suitable region has been identified for deep well injection, the more feasible local sites can be evaluated. In general the same geologic and engineering properties that are examined at the regional level also are evaluated at the local level but in more detail. A potential injection site should have the characteristics summarized in Table 7.3-2.

Once a suitable injection site is identified, a test well should be drilled at the site to verify actual hydrogeologic conditions if such knowledge is not available from previous drilling records. The final decision as to whether or not waste injection is feasible is based on subsurface data that have been acquired during drilling and which have been used to project the response of the subsurface geologic and hydrogeologic system to sustained injection.

TABLE 7.3-1

Regional Hydrogeological Criteria for Waste Injection Wells

- There should be a thick sedimentary sequence to provide an injection zone that has sufficient capacity for the wastes that are to be injected.
- The region should have a continuous and thick confining zone that can contain the injected waste.
- There should be a simple geologic structure reasonably free from complex and extensive faulting and folding that complicate evaluation and that might permit escape of the injected waste.
- The injection zone should not contain important natural resources nor be a potential source of usable water (i.e., it is not likely that the injection zone has future demands for use).
- The region should not be seismically active or have a high seismic risk.
- Normal fluid flow in the injection zone should be negligible or very slow so that there is little movement of the injected wastes.
- The injection zone should not be an actual or potential source of discharge to surface water or to usable ground water.
- There should be no abandoned or unplugged wells that penetrate the confining zone and the injection zone.

Source: Warner, D. L., and J. H. Lehr. 1981. Subsurface Wastewater Injection. Berkely, California: Premier Press.

TABLE 7.3-2

Desirable Characteristics of a Suitable Deep Well Injection Site

- The injection zone is large enough and sufficiently thick with adequate porosity and permeability to accept waste at the proposed injection rate.
- The injection zone has few characteristics that my prevent uniform movement from the well.
- The strata under and over the injection zone should be sufficiently thick and impermeable to confine the injected waste.
- The site has simple geologic conditions reasonably free of complex folds and faults.
- The site is not seismically active or have high seismic risk.
- Normal fluid flow in the injection zone is negligible or very low.
- The injected wastes are compatible with the liquid and solids in the injection zone.
- The injection zone will not be adversely affected by future removal of subsurface mineral resources or by future use of the geological formations.
- The liquid in the injection zone will not be used for future industrial, agricultural or potable uses.
- There are no abandoned or or improperly plugged wells in the vicinity of the proposed injection well.

Source: Warner, D. L., and J. H. Lehr. 1981. Subsurface Wastewater Injection. Berkely, California: Premier Press.

(iv) Waste Characteristics

The typical user of hazardous waste injection wells is a large industry which produces large volumes of low concentration liquid waste. The financial investment in an injection well is high and generally requires continuous operation to be economically feasible. The industries using such wells for hazardous wastes in the United States are identified in Figure 7.3-4.

Certain wastes are environmentally suitable for deep well injection. These include salt bearing solutions, brines and spent acids. Concentrated acids and liquids containing metals and organics are the most common hazardous wastes that are disposed of by deep well injection (U.S. Environmental Protection Agency 1985).

Waste and injection zone compatibility is a concern in deciding on the feasibility of injection wells. Specific incompatibility problems include:

(a) plugging of the injection zone with suspended solids;

(b) precipitation and polymerization of constituents in the injected waste after injection; and

(c) alteration of the injection or confining zone material.

In some cases, the injected wastes can react with the injection zone material. An example is the swelling of clays from contact with the injected wastes thereby reducing the permeability of the injection zone.

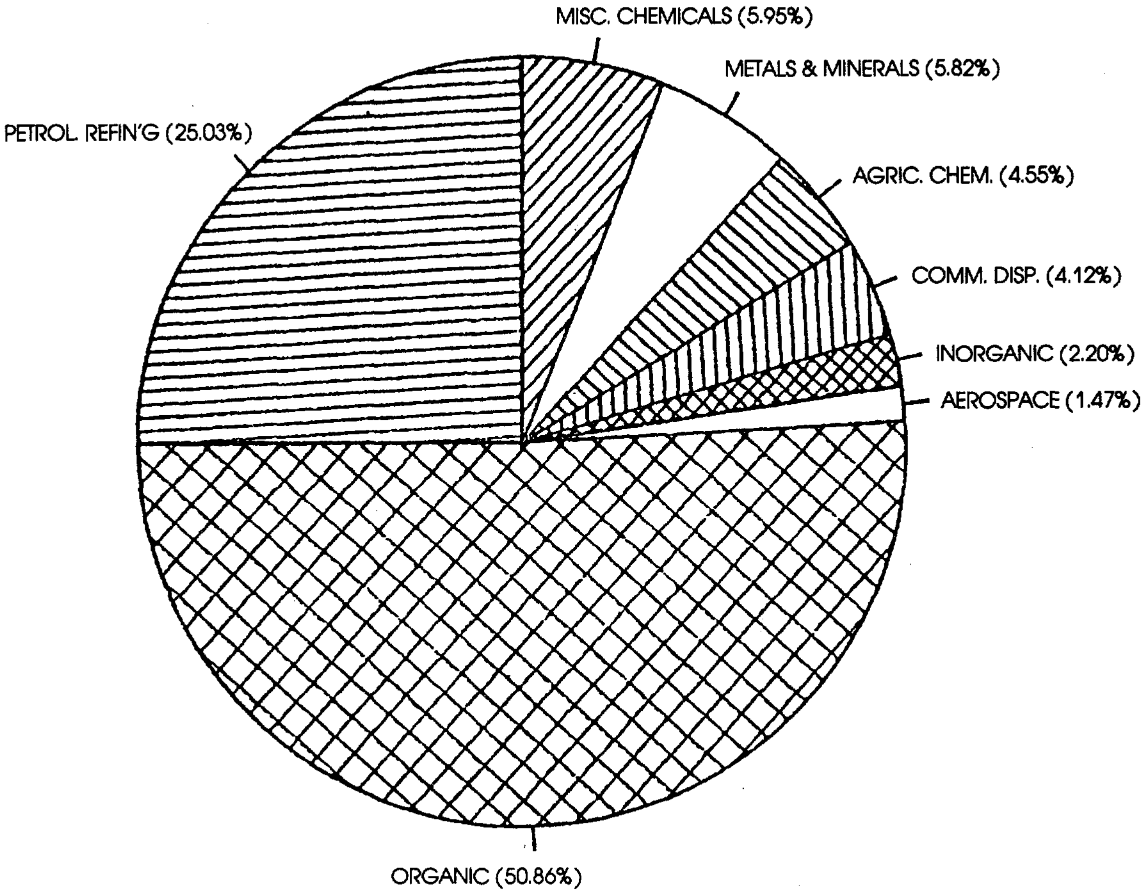
Another example is the injection of acids which may dissolve the injection zone material. With cemented materials, the dissolution can result in migration of particles which block pore spaces and reduce the permeability of the injection zone. In other cases, dissolving the confining zone material has the potential to allow escape of the injected wastes.

To avoid incompatibility problems, the liquids to be injected and the material in the injection and confining zones should be tested before any wastes are injected. The factors that should be considered in evaluating the suitability of liquids for deep well injection are indicated in Table 7.3-3.

If constituents of the wastes will be incompatible with the injection zone or the materials used for well construction, it may be possible to treat and/or remove such constituents before the wastes are injected. The type of pre-injection treatment processes that can be used to insure the compatibility of a waste for deep well injection are indicated in Table 7.3-4. Filtration (removal of suspended solids) is the most common pre-injection treatment used (U.S. Environmental Protection Agency 1985).

FIGURE 7.3-4

Industries Actively Using HW Wells Volumes Injected
(Total Volume 11.5 BG)



Source: U.S. Environmental Protection Agency. 1985. Report to Congress on injection of hazardous waste. Washington, D.C.: Office of Water Drinking.

TABLE 7.3-3

Parameters that Should be Considered When Evaluating the Suitability of Liquids for Deep Well Injection

- Volume to be injected

- Physical and Chemical Characteristics
  - density
  - viscosity
  - temperature
  - suspended solids
  - gas content
  - toxicity
  - dissolved constituents
  - pH
  - chemical stability
  - reactivity with injection
  - zone constituents and
  - well components

- Biological Characteristics
  - bacteria and viruses
  - organic content

Source: Warner, D. L., and J. H. Lehr. 1981. Subsurface Wastewater Injection. Berkely, California: Premier Press.

TABLE 7.3-4

Pre-injection Treatment Processes that Can be Used to Insure Compatibility of a Waste with Deep Well Injection

- Storage and equalization
- Oil separation
- Suspended solids removal
- Corrosion control
- Bacterial growth control
- Degasification
- Chemical and biological treatment

Source: Warner, D. L., and J. H. Lehr. 1981. Subsurface Wastewater Injection. Berkely, California: Premier Press.

(v) Monitoring

Monitoring deep well injection operations includes monitoring:

(a) the injection and annulus pressures;
(b) the volume, flow rate and characteristics of the injected wastes; and
(c) the characteristics of USDW and other waters that lie above the injection and the confining zones.

Annulus pressure is monitored to detect changes that might indicate leakage through the injection tubing or the packer.

The volume and characteristics of the injected wastes are monitored to note changes in characteristics that may affect the performance of the well and to help interpret the pressure data. Monitoring wells in geologic formations above the confining zone help detect escape of the injected waste.

The proper construction of injection wells (Figure 3.3-3) and stringent monitoring are necessary to avoid contamination of USDWs or of surface waters. Ways that contamination can occur are:

(a) faulty well construction that results in well casing leaks or packer failure;
(b) improperly completed or plugged wells;
(c) use of faulty or fractured confining zones thereby allowing the injected liquid to escape;
(d) lateral displacement of the injected liquid from the injection zone to other geologic formations; and
(e) direct injection into or above USDWs (See also section 7.1.6).

(vi) Closure

Eventually, injection wells are permanently removed from use due to technical, economic or regulatory reasons. At that time the wells are plugged to prevent contamination of USDWs and to prevent flow of liquids from pressurized zones to the surface. When hazardous waste injection wells are plugged, the objective is to contain the injected waste within the injection zone and to segregate all water bearing geologic zones from each other. When a well is plugged in a proper, environmentally sound manner, it is considered abandoned.

7.3.3 Monitoring

(i) Introduction

A monitoring program is an essential component of any land disposal option and has many objectives (Table 7.3-5). The details of a specific monitoring program are a function of the characteristics of the waste, the type of system (landfill, land treatment, surface impoundment or deep well injection), soil characteristics, and climate. When developing a

TABLE 7.3-5

Objectives of a Monitoring System for the Land Disposal of Hazardous Wastes

- Corroborate the initial design assumptions and criteria
- Establish performance of the system
- Verify long-term use
- Identify changes in soil and water characteristics
- Demonstrate ground and surface water protection
- Meet regulatory requirements
- Provide for public health protection
- Establish public, industry and regulatory confidence in the system
- Identify that detoxification and/or containment of the hazardous wastes does occur
- Indicate acceptable closure methods and need for post-closure monitoring

monitoring program, consideration should be given to collecting and analyzing samples of:

(a) the waste;
(b) any run-off water;
(c) the groundwater;
(d) vegetation grown on or near the site;
(e) soil at the site, especially in the zone of incorporation for a land treatment facility; and
(f) soil pore water in the unsaturated zone below the landfill and below the zone of incorporation at a land treatment site.

The prime objective of a monitoring program is to monitor the hazardous waste components that are likely to be mobile under the conditions at a site.

A secondary objective is to monitor parameters that:

(a) can affect the mobility of hazardous waste components (such as pH);
(b) may be indicative of contaminant migration (such as chloride or nitrate); and
(c) may identify overall system performance. These latter parameters are monitored with less frequency than those that are part of the prime objective.

Only essential monitoring is needed. There should be resistance to monitoring non-relevant parameters and to sampling at unnecessarily frequent intervals. Changes in soil and groundwater characteristics normally are slow and appropriate sampling frequencies can range from four times per year to less often.

At a minimum, a monitoring program should be able to detect the migration of hazardous waste constituents and provide information on the background concentrations of such constituents in similar but nearby untreated soils. This latter information permits changes in characteristics and potentially adverse trends to be identified.

It is imperative that good record keeping be practiced so that the monitoring data is properly identified and accessible. It also is important to have sound quality control and quality assurance as part of the monitoring program.

(ii) Waste

Routine sampling and analysis of the wastes to be disposed of by a land disposal option is mandatory. The frequency of sampling and analysis depends upon expected variations in the quantity and quality of the waste. Adequate samples should be obtained to determine the consistency and uniformity of the waste. Sampling techniques should assure that the samples are representative. The waste should be analyzed for substances which caused the waste to be listed as a hazardous waste and for constituents that are mobile and are potentially toxic to humans, animals and the environment.

(iii) Groundwater

A groundwater monitoring program protects the quality of the groundwater. Groundwater monitoring is needed during the active life of the facility and, if hazardous wastes or decomposition products remain after closure, also during the post-closure period.

Wells are the primary tools used to monitor groundwater contamination. The monitoring system should consist of an array of wells strategically placed to identify groundwater movement. A sufficient number of wells to characterize the potential contamination of the groundwater quality should be used. One group of wells should be located downgradient from the land disposal site.

Wells located upgradient from the land disposal site also should be installed. The upgradient wells will provide an estimate of the direction and head potential of groundwater flow. The upgradient wells, or those installed in areas not affected by the disposal site, will provide samples indicative of background water quality while the downgradient wells will identify movement of any contaminants from the site. The selection of the monitoring well locations will depend on the hydrogeology that exists at a particular site.

Figure 7.3-5 illustrates a ground water monitoring system that can exist at a landfill. Also illustrated is the dispersion of a leachate plume that originated from the landfill.

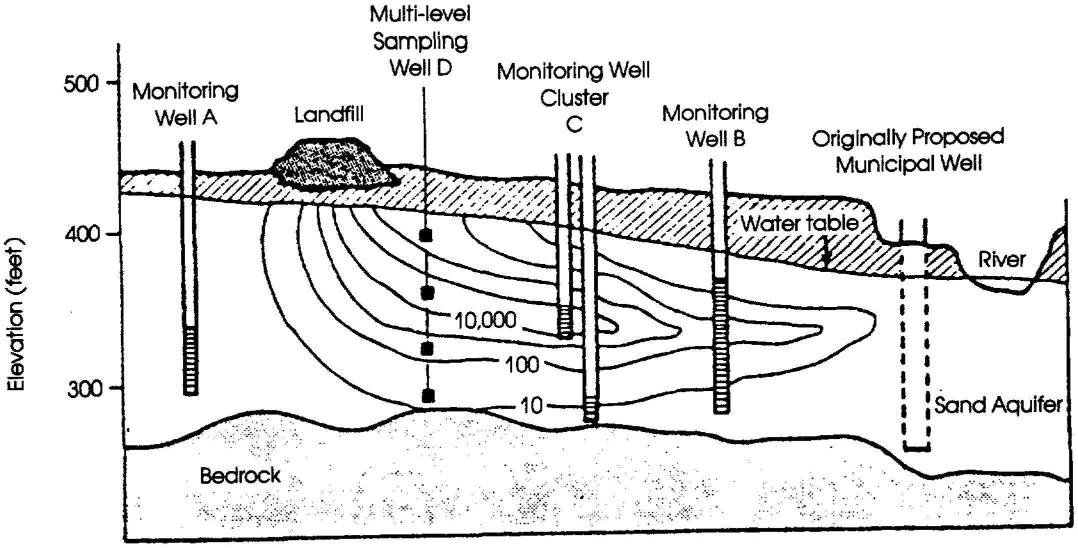
The exact number of monitoring wells needed at a given site depends on soil type, complexity of the groundwater hydrological system, waste characteristics, and past history of the site. Monitoring wells may be needed at more than one depth. Mobile waste constituents first enter the upper portion of the groundwater and are diluted as they move with the groundwater flow. Samples from the upper portion of the groundwater can be a better indicator of contamination than samples from the lower portion of the groundwater.

Monitoring wells must be cased in a manner that maintains the integrity of the borehole. The casing must be screened or perforated and packed with gravel or sand to enable sample collection at depths where groundwater flow exists. The space above the sampling depth must be sealed with cement grout, bentonite, or other suitable material to prevent surface contamination of samples of groundwater.

To reduce the cost and analytical burden of groundwater sampling and analysis, only those parameters generally used to establish groundwater quality or which are especially unique to the applied waste should be measured. Simple indicator parameters can be used to determine if a potential problem is occurring. These indicators can be chloride, iron, manganese, phenol, sodium, sulphate, pH or an easily identified parameter

FIGURE 7.3-5

Schematic of a Possible Ground Water Monitoring System at a Landfill



found in the waste. These parameters commonly are used to characterize groundwater suitability for various uses. Specific conductance and a general measure of organic contamination such as total organic carbon (TOC) also can be used as indicators.

A statistically significant change in these parameters from background conditions indicates that inorganic and/or organic substances are being introduced into the groundwater at the disposal site. The methodology to sample and analyze these parameters is available. If monitoring these indicator parameters indicates that contamination is likely or has occurred, a more detailed sampling and analysis program can be initiated.

Unless there is reason to suspect a rapid change in groundwater characteristics, the monitoring wells need not be sampled more often than quarterly. If an adverse change in characteristics appears to occur or is occurring, more frequent sampling is warranted to substantiate the change and its rate.

(iv) Run-off

If lateral movement of waste constituents is expected, run-off and surrounding surface waters should be sampled. Analysis of the run-off samples is necessary to determine if the run-off can be discharged and to satisfy any discharge requirements.

(v) Unsaturated Zone

Unsaturated zone monitoring can be important when landfills, land treatment and surface impoundments are used for the disposal of hazardous wastes. Liquids from a landfill may bypass the leachate collection system and the bottom barrier and move toward the groundwater. At a land treatment site, water added to the soil by precipitation, irrigation or with the applied waste will pass through the soil and incorporated waste and may transport mobile waste constituents or by-products through the unsaturated zone to the groundwater.

Groundwater monitoring does not provide an early warning of such movement. Unsaturated zone monitoring (i.e., collection and analysis of the percolate as it passes through the unsaturated zone, can measure the concentration and type of contaminants moving toward the groundwater and provide early warning of potential problems). Various types of equipment (U.S. Environmental Protection Agency 1984) can be used for such monitoring.

(vi) Soil

At a land treatment facility, monitoring of the soil characteristics serves several purposes:

(a) to determine the degradation rate of constituents in the applied wastes;
(b) to verify estimated system performance;

(c) to estimate possible site uses after closure; and
(d) to indicate post-closure monitoring needs.

Samples of the soil immediately after waste incorporation and at periodic intervals should be taken and analyzed for specific waste constituents, particularly those that were identified as the limiting constituents.

Samples of the lower soil horizons should be taken, using cores or borings, to indicate contaminant migration and because oils are not homogenous. Soil sampling is done on a random basis with several subsamples being composited to obtain one sample for analysis. Samples should be taken for each major soil type in the land treatment site. The soil samples should be analyzed for the waste constituents that are expected to be degraded and immobilized and for those that can be mobile and have an adverse effect on humans, animals and the environment.

(vii) Summary

A sound, well designed monitoring program is an integral part of any land disposal system for hazardous wastes. Such systems are designed, constructed and operated in an engineered, controlled manner to avoid contamination of surface and groundwaters and to avoid an adverse impact on adjacent property and environment. Proper monitoring will verify that the applied wastes:

(a) are being contained or degraded; and
(b) do not represent a public health or environmental threat.

Reasonable approaches, suitable equipment, and analytical methods exist to develop the necessary monitoring program. It is equally important to analyze the monitoring data, to note trends that occur, and to identify and implement appropriate remedial action if adverse health or environmental effects begin to appear.

7.3.4 References 7.3.1-7.3.3

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7.4 Incineration

7.4.1 Introduction

(i) Aims and Objectives

The aims and objectives of this section are to:

- Characterize those wastes which are amenable to incineration.
- Discuss design criteria and process parameters for incineration.
- Outline both the types of existing process plants which may be adapted for the co-incineration of wastes and alternative designs for dedicated incinerators, commenting on their advantages and disadvantages and provide guidance for selection.
- Describe air pollution control equipment and support services.
- Discuss incinerator operation and control.
- Provide outline design information and estimates of capital, operating and unit costs.

(ii) What is Incineration

Incineration is an ultimate disposal process, applied to certain wastes that cannot be recycled, reused or safely deposited in a landfill site. It is a high temperature, thermal oxidation process in which hazardous wastes are converted, in the presence of oxygen in the air, into gases and an incombustible solid residue. The product gases are released to the atmosphere, with or without gas cleaning, and the solid residues are landfilled.

Properly managed, incineration can serve several purposes - destruction of the wastes accompanied by a significant reduction in its weight and volume, and the production of a sterile solid residue. On the other hand, the risk of causing nuisance and environmental pollution form emission of particulates, acidic gases, unburnt waste and trace quantities of hazardous organic by-products should be appreciated when selecting equipment and siting hazardous waste incineration facilities.

Typically, incineration is chosen if (Royal Commission on Environmental Pollution 1985):

- the waste is biologically hazardous;
- it is resistant to biodegradation, and persistent in the environment;
- it is volatile and therefore easily dispersed;
- it has a flash point below 40°C;

- it cannot safely be disposed of in a landfill site;
- it contains organically bound halogens, lead, mercury, cadmium, zinc, nitrogen, phosphorus or sulphur.

Incineration may take place either in dedicated, purpose-built facilities or in suitably adapted existing high-temperature process plants such as cement or lime kilns, blast furnace or industrial boilers. The high capital and operating costs of dedicated incinerators and their relatively high throughputs, typically upwards of 10,000 tonnes per annum, tends to limit their feasibility in smaller, less industrialized countries. Thus, although operating experience with coincineration of hazardous wastes (with the exception of waste oils) in existing facilities is relatively limited, this would appear to be a more promising approach for many developing countries.

(iii) Selection of Wastes

In general, if the hazardous chemical is organic (i.e., it has carbon, hydrogen and/or oxygen), then it can be incinerated. The types of wastes that are incinerated include:

- solvent wastes;
- waste oils, oil emulsions and oil mixtures;
- plastic, rubber and latex wastes;
- hospital wastes;
- pesticide wastes;
- pharmaceutical wastes;
- refinery wastes such as acid tar and spent clay;
- phenolic wastes;
- grease and wax wastes;
- organic wastes containing halogens, sulphur, phosphorus or nitrogen compounds;
- solid materials contaminated with hazardous chemicals (e.g., soil containing oil, capacitors containing polychlorinated biphenyls [PCBs];
- water contaminated with hazardous chemicals.

Whether or not these wastes can be properly incinerated depends on the choice of incinerator and its gas cleaning system - an important qualification, since the act of disposal should not in itself cause a threat to the environment. Wastes containing halogens, phosphorus, sulphur or nitrogen require more sophisticated technology than wastes with just carbon, hydrogen and oxygen, though all types can, under less than optimum incineration conditions, generate noxious by-products.

Wastes that are not suitable for incineration include those that do not contain a significant proportion of organics, or are highly explosive or radioactive. Waste of low radioactivity can safely be incinerated (contaminated clothing, scintillation liquids, certain hospital wastes, etc.), provided that its input is carefully regulated to control the emissions of radioactive isotopes.

7.4.2 How Incineration Works

(i) Products of Combustion

An organic chemical can be considered as being made up of molecules of different elements, mainly carbon and hydrogen. In addition, some chemicals also contain oxygen, halogens, nitrogen, phosphorus, sulphur or a variety of metals.

During incineration, oxygen in the air converts or oxidizes these wastes into simple gases and solids. The product gases consist primarily of carbon dioxide, water and excess air, together with noxious halogen acids, sulphur, nitrogen and phosphorus oxides, vapourized metal oxides, and traces of unburnt waste and organic by-products. Particulate matter such as ash and metal oxides are also carried out in the gas stream. The potentially harmful combustion products are reduced to a regulated safe level by gas cleaning.

The material left behind on the hearth of the incinerator comprises ash, metals, oxides and non-combustibles. The hearth solids are generally sufficiently sterile to be safely landfilled.

Sometimes, when conditions are not adequate, traces of unburnt wastes or new organic compounds may also be released in the gas. Great care must be taken to reduce the formation of these new compounds, because they can be more hazardous than the parent compound. An example of this is in the incineration of PCBs - below about 900°C, chlorinated dioxins and dibenzofurans are formed as trace by-products. These compounds are extremely toxic, and therefore more sever incineration conditions are maintained when PCBs are burnt, to minimize their emissions.

(ii) Factors Affecting Incineration

The primary aim of incineration is to destroy the waste as completely as possible, to have products (solids and gases) that are harmless when released from the incinerator, and to minimize the formation of new hazardous organic compounds. To achieve these aims, attention must be given to what are called the **Three Ts of combustion:**

- Temperature;
- Time;

- Turbulence;

to which a fourth parameter can be added,

- Availability of Oxygen.

The higher the **temperature** at which the waste is burnt, the more completely it will be destroyed, and the less chance there is of any unburnt waste being released or of trace organic by-products being formed.

The longer the waste is held at high temperature, the greater will be the degree of destruction and the less likelihood there is of trace organics being formed. The **residence time** in the gas phase is of particular importance.

Turbulence rates to the degree of mixing between the waste and oxygen in the combustion air, and to the absence of temperature gradients within the furnace. Greater turbulence provides better control, better access to air, and more complete destruction of the burning waste.

Finally, the **availability of oxygen** is an important factor in determining the degree of destruction of the waste and of the formation of by-product organics. Not only should there be sufficient oxygen to satisfy the theoretical requirements of the combustion process, but an excess level of about 100% over the theoretical air requirements, in terms of air, should generally be maintained, to ensure that oxidative as opposed to pyrolytic (i.e., oxygen-starved) conditions prevail at all times.

(iii) Optimum Conditions for Incineration

From the formulation of the Three Ts and oxygen availability, the conditions for optimum incineration are:

- high temperature;
- sufficient (gas) residence time in the incinerator;
- good turbulence;
- an excess of oxygen.

All four conditions should be observed when the waste is incinerated. Based on experience gained in the laboratory and on industrial units, the following empirical parameters have been developed.

- Temperatures of 900°C - 1100°C for hydrocarbon wastes, and 1100°C - 1200°C for certain intractable wastes such as PCBs, that contain halogens.
- Minimum gas phase residence time of 2 seconds. Residence time for hearth solids is measured in hours rather than seconds.

- Combustion air 100% in excess of stoichiometric requirements.

Turbulence is achieved through good incinerator design, using tangential fans and liquid injectors to produce cyclonic burn paths, and manually raking over hearth solids on stationary hearths. In rotary kilns and multiple hearths, intimacy of mixing between solids and air is achieved through mechanical means.

When the above conditions are observed, it has been shown that even the most difficult and refractory wastes, such as PCB, are adequately and safely destroyed. The is an inter-relationship between temperature and residence time (i.e., by increasing residence time some reduction in temperature can be made to achieve the same level of destruction). However, as stated previously, 900°C is generally regarded as the lower limit. Below 900°C, hazardous organic by-products may be formed from some wastes, and below 800°C, soot formation can be induced.

One exception to this rule is where the purpose is **calcination** rather than incineration. An example is the conversion of organic lead compounds, for example in sludges removed from leaded gasoline storage tanks, to inorganic lead. In this case the temperature must be high enough to destroy the organic lead, but not so high as to cause excessive loss of lead by volatilization or as particulates. A temperature around 600-650°C is used in dedicated calcination units.

The efficiency of combustion of a particular organic compound, often called the destruction and removal efficiency (DRE), is calculated by determining the amount of waste in the emission gas and applying the formula

$$\mathrm{DRE} = \frac{W\ \mathrm{in} - W\ \mathrm{out}}{W\ \mathrm{in}} \times 100\%$$

where W in = concentration of that compound in the waste feed
x mass rate of feed

W out = concentration of compound in stack gas
x volumetric flow rate of stack gas

The manner in which the incinerator is controlled is discussed in Section 7.4.10.

7.4.3 The Principles of Incinerator Design

In any design of incinerator, the basic requirements of good combustion must be met. Residence time and turbulence are generally fixed, within narrow limits, by the configuration of the combustion chamber, whereas temperature and excess air can be controlled during operation. In particular, the following design principles are important.

- The volume of the combustion chamber should be sufficient to receive the physical bulk of the waste, and provide adequate gas phase residence time.

- o High temperature should be maintained.
- o Combustion air requirements must be met, and in excess of the stoichiometric quantity.
- o Maximum turbulence and mixing should be achieved in the combustion chamber by proper siting of fans and burners.

The basic design of a closed incinerator comprises a primary heated chamber into which wastes are introduced, and an afterburner section for the combustion gases, which provides an insurance against incomplete combustion. The primary chamber is sized so as to provide the necessary turbulence and residence time. The afterburner or secondary chamber, fired by auxiliary burners, maintain the same, or higher temperatures than the primary chamber and offers additional gas phase residence time to ensure that the waste is properly burnt, and to minimize the formation of hazardous organic by-products. In general, the designs discussed here have combustion chambers lined with refractories, the choice of which is dependent on the temperature of operation and the characteristics of the waste.

In the following sections, we consider:

- o co-incineration in existing high-temperature industrial facilities;
- o co-incineration in existing incinerators;
- o small-scale purpose built incinerators including open-pit incinerators and mobile units;
- o large-scale purpose-built incinerators.

Sub-section 7.4.8 discusses energy recovery, an optional item that contributes to the overall commercial viability of incineration.

Each design of incinerator has some limitation on the type of waste that it can accept. Table 7.4-1 adapted from Hitchcock (1979) summarizes the applicability of various designs to waste type. In indicating the suitability for a particular wastes, it is understood that the necessary auxiliary equipment such as support fuel burners and afterburner chamber, has been installed, and the waste is properly presented to the incinerator. Table 7.4-2 lists typical operating ranges of dedicated hazardous waste incinerators.

7.4.4 Co-Incineration in Existing Industrial Facilities

(i) Introduction

Several industrial processes can provide temperatures and residence times similar to those required for hazardous waste incinerators.

TABLE 7.4-1

Applicability of Incinerator Systems to Waste Type

Waste Type	Adaptation of Existing Facilities		Refuse/ Sludge Incinerators	Open Pit	Rotary Kiln	Large-Scale Facilities		Fluidized Bed	Liquid Injection
	Cement Kilns	Boilers				Multiple Chamber	Multiple Hearth		
Solids									
Granular homogeneous			X		X	X	X	X	
Irregular Bulky (pallets, etc.)			X	X	X	X			
Low melting points (tars, etc.)	X		X		X	X	X	X	
Organics with fusible ash			X	X	X	X			
Gases									
Organic vapour laden			X		X	X			X
Liquids									
Aqueous, contaminated with organics	X	X	X		X	X			X
Organic liquids including halogenated	X	X	X	*	X	X		X	X
Solids/Liquids									
Waste containing halogenated organics	X	X	X		X	X		X	X
Aqueous/organic sludges	X	X	X		X	X	X	X	X

*Only if waste is low in chlorine, sulphur and nitrogen.

TABLE 7.4-2

Typical Operating Ranges for Dedicated Incinerators

Type	Capacity KG/h	Capacity GJ/h	Temperature °C	Gaseous Residue Time
Liquid injection	3,500	9	600-1,500	0.1-2 s
Fixed hearth	1,750	5	500-1,000	0.5-2 s
Rotary kiln	3,500	10	800-1,600	0.5-2 s (gas) h (solids)
Fluidized bed	65,000	45	500-1,000	0.5-1 s (gas) min (solids)

Source: Oppelt, E. T. 1986. Thermal destruction of hazardous waste. Presented at US/Spain Joint Seminar on Hazardous Wastes, Madrid.

Examples include cement, lime and aggregate kilns, industrial boilers and blase furnaces. Operational experience is generally limited, but a number of trials and feasibility studies and tests have demonstrated that co-incineration in some industrial facilities with high-temperature combustion processes can provide a cost-effective and environmentally acceptable alternative to the disposal of hazardous wastes in dedicated incinerators. These industrial processes have the potential for recovering the heating value of the waste, removing chlorides, and providing a destruction and removal efficiency (DRE) equivalent to hazardous waste incinerators.

Advantages of this approach are that:

- capital investment in new, dedicated hazardous waste incinerators is not needed:
- existing processes can reap extra economic benefits, since the cost of accepting and destroying wastes is credited against process costs.

Disadvantages are that:

- the introduction of waste streams into an existing high-temperature facility has the potential to disrupt the process or degrade the product. A thorough investigation and good scientific evidence is essential if plant management is to be persuaded to change an existing, proven process;
- the lack of adequate gas cleaning equipment on many types of plants (e.g., boilers) necessitates careful selection and control of waste inputs.

Table 7.4-3 lists some alternative incineration processes and their typical operating ranges.

(ii) Cement Kilns and Lime Kilns

Cement and lime kilns are excellent furnaces for the destruction of hazardous wastes, particularly halogenated organics such as PCB (USEPA 1985 b & c). Cement manufacture is a high energy consumer, and the revenue generated from the reception of hazardous wastes can significantly offset these costs.

The kilns operate at high temperatures (1,400^{o}C or above), and the alkalinity of the kiln material neutralizes acid gases such as hydrochloric acid, that are produced when the hazardous waste is incinerated. Kilns therefore offer both excellent destruction efficiency and effective gas cleaning.

Kilns used in the wet-process manufacture of cement are typically 155m long and 4m in diameter, the majority of this length being used to dry the clinker material. Solid charge temperatures of above 1,000^{o}C are only achieved in the last 25% of its length, whereas gas phase temperatures

TABLE 7.4-3

Alternative Incineration Processes and Their Typical Operating Ranges

Industry	Process or Furnace	Temperature Range (^{o}C)	Residence Time (in s)
Industrial Boilers	Fire tube (oil/gas)	1,000-1,400	0.1-0.5
	Water tube (oil/gas)	900-1,300	0.3-0.2
	Pulverized coal	1,000-1,300	0.9-4.0
	Spreader stoker	900-1,100	0.7-3.0
Cement	Cement kiln (wet)	1,400-2,000	6.0-10.0
Lime	Rotary kiln	700-1,800	6.0-10.0
Iron and Steel	Blast furnace	100-1,900	1.8
	Blast hearth	1,200-1,800	2.0
Primary Copper	Multiple hearth	200-800	4.0
	Fluidized bed	500-700	5.0-15.0
	Reverberatory	1,200-1,300	2.3
Primary Lead	Blast furnace	700-1,200	5.6
Brick	Tunnel kiln	900-1,400	1.0

Source: Oppelt, E. T. 1986. Thermal destruction of hazardous waste. Presented at US/Spain Joint Seminar on Hazardous Wastes, Madrid.

rise above 1,000°C after 50% of the length. Total gas phase residence times are usually in the region of 20 seconds.

To date, waste solvents and tars, which in themselves contribute significant heat to the process and provide savings in prime fuel consumption, and halogenated wastes have been successfully incinerated in cement kilns.

Advantages are (Trovaag 1983):

- kiln temperature is ideal for incineration;
- acidic gases are absorbed in the clinker, and therefore existing particulate arrestment equipment is usually sufficient;
- credit due to the use of heat from wastes, and treatment charges, improves the economics of the kiln.

Disadvantages are that:

- since the primary aim of the process is to manufacture cement or calcine lime, hazardous wastes must be controlled so as not to impact on the quality of the product. Large or bulky items are therefore excluded;
- the production cost for the clinker (product) may be increased because of additional maintenance and the need to dispose of flue dust containing inorganic chlorides. There is also some reduction in clinker output. These are generally offset by the economic advantages of handling hazardous wastes.

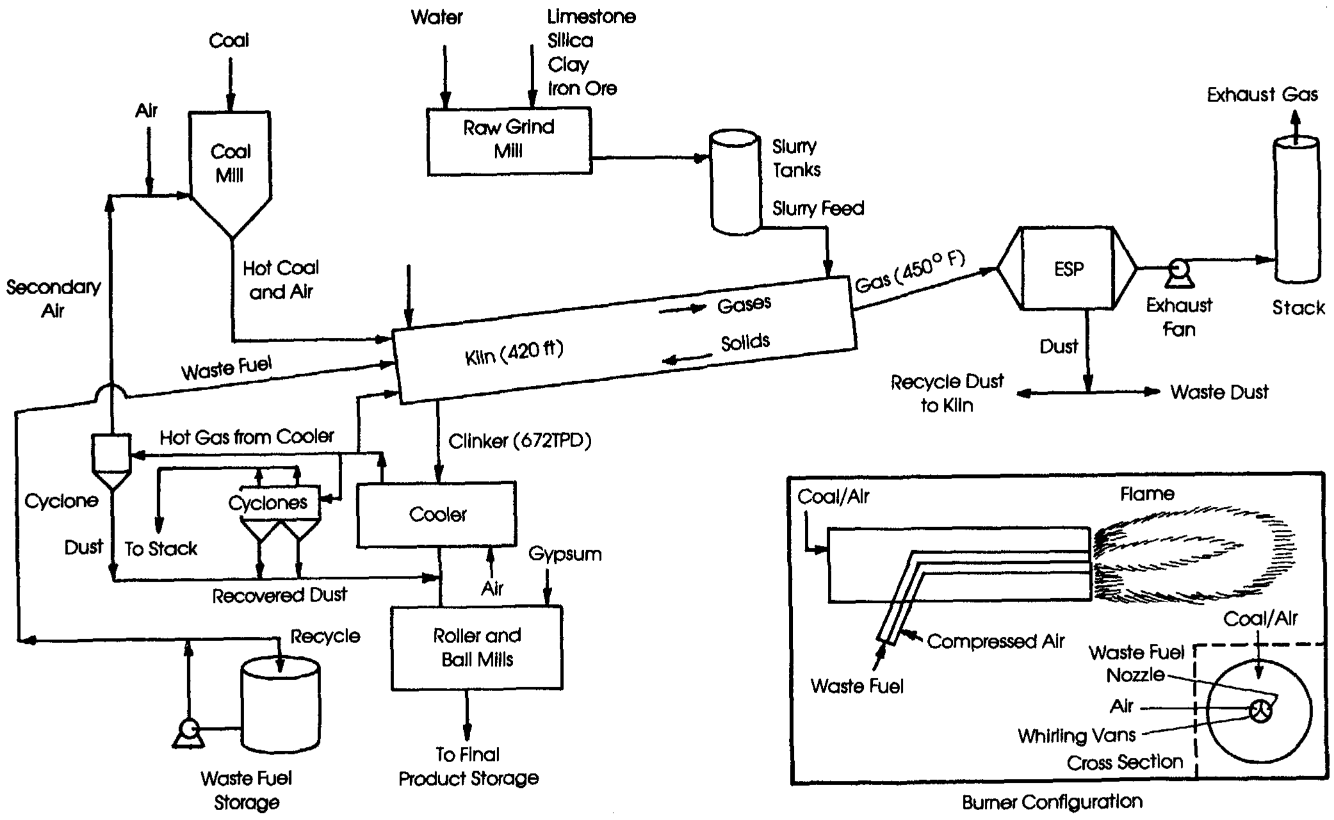
The use of cement kilns for incineration of hazardous wastes is still limited. Commercial facilities are operating, or have operated in France, Italy, Norway, Sweden, Canada and the U.S. For example, five kilns in France burn a total of about 20,000 tonnes per annum, largely comprising acid tars which are otherwise difficult to dispose. In the U.S., a few facilities accept a wide range of wastes, while in Italy application is limited to waste oils.

A number of kilns have been tested during waste combustion to provide more data on the effects of waste combustion. Some of these tests have been comprehensive in their attempt to determine effects on emissions, product quality, fate of metals and chlorine, and products or incomplete combustion (USEPA 1985 b & c; Oppelt 1986).

Figures 7.4-1 and 7.4-2 illustrate the layout of typical wet and dry process cement kilns configured to accept waste fuel (USEPA 1985c). Hydrocarbons are generally used to supplement prime fuel requirements, and chlorinated hydrocarbons are either introduced as contaminants on in discrete streams.

FIGURE 7.4-1

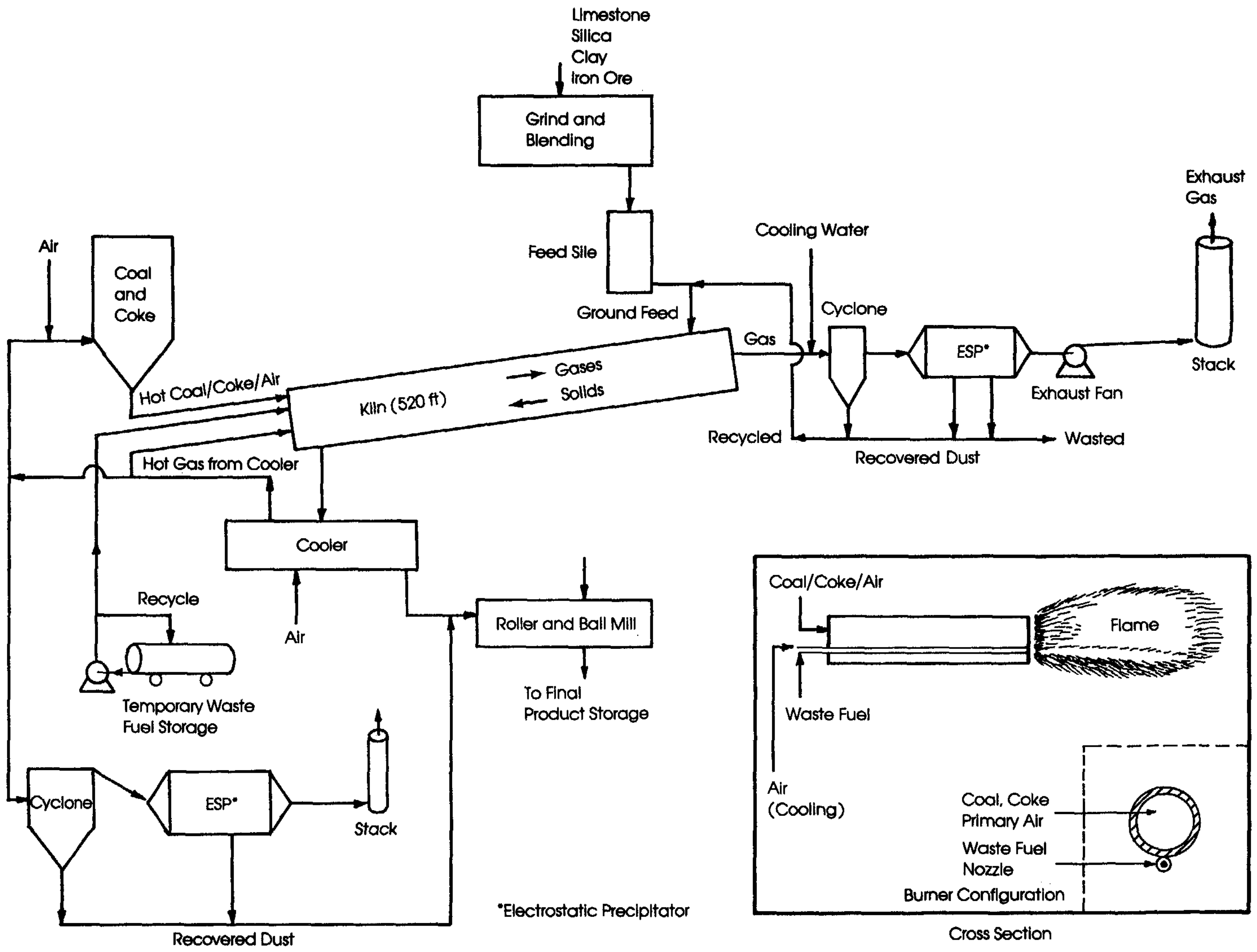
Wet Process Cement Kiln Modified to Burn Waste Fuel



Source: USEPA. 1985 <u>Summary Report on Hazardous Waste Combustion in Calcining Kilns</u>. Contract no. 68-03-3149.

FIGURE 7.4-2

Dry Process Cement Kiln Modified to Burn Waste Fuel



*Electrostatic Precipitator

Source: USEPA. 1985. Summary Report on Hazardous Waste Combustion in Calcining Kilns. Contract no. 68-03-3149.

Extensive tests on destruction efficiency and flue-gas emissions have been carried out in the US. Tables 7.4-4 and 7.4-5 summarize the facilities tested and the results from one series of tests; Table 7.4-6 summarizes DREs achieved at different plants for a range of waste components; and Table 7.4-7 collates hydrogen chloride emissions with and without waste combustion from a number of trials.

Not all incinerable waste is suitable for use as a fuel in cement kilns. The most suitable waste fuel is liquid with a high calorific value and low water and metals content. Separable water should be limited to 1% by volume and metals content must be sufficiently low to prevent blockage in burners. Generally, the waste should contain less than 20% solids, and it must be fine enough to pass through a No. 8 mess screen. These limitations, which may vary from plant to plant, are established primarily because of handling constraints. A maximum viscosity of about 1,400 SSU ensures that the supplementary fuel is readily pumpable at normal ambient temperatures.

One of the major waste selection considerations is what effect, if any, the use of waste will have on the manufacturing process and on the quality of the final product. For example, some heavy metals may be established in the clinker, or become concentrated in the wastes dust, changing the character of the emissions. Test data have shown that the ash, heavy metal or chlorine in the waste **do not adversely affect cement quality.**

Less information is available regarding the impact of waste introduction on line product quality. Many end users of lime require a high-quality produce, and are intolerant of impurities such as unburnt waste. Proper feeding, atomization and burning of the waste can surmount this potential problem (USEPA 1985b).

(iv) Blast Furnaces

At least one steel company in the United States utilizes waste liquids as a heat and carbon content source to partially replace the coke that is used to charge the blast (basic oxygen) furnace. Temperature and residence time in the blast furnace favour high DREs for waste materials, but reduction reactions that also occur may promote the formation of products of incomplete combustion (Adams et al. 1985). DREs for a variety of wastes are shown on Table 7.4-8.

Figure 7.4-3 illustrates the flow diagram of a typical blast furnace operation configured for the utilization of an auxiliary waste stream. Temperatures in the combustion zone are in the region of 1650^{o}C.

(iv) Co-firing in Industrial Boilers

Co-firing of waste oils in industrial boilers has long been used as a method of utilizing their heat content. However, concern is now being expressed and specific controls introduced over the contamination of oils with chlorinated organic materials (particularly PCB's from transformer 'oils') and heavy metals, leading to pollution problems as many industrial boilers do not have efficient emission control devices.

TABLE 7.4-4

Description of Industrial Kiln Facilities Tested

Facility	Capacity (GJ/HR)	Primary Fuel	Control Device	Waste
(1) Wet Process Cement Kiln (Non-atomized Waste)	140	No. 6 Oil	Fabric Filter	Waste liquids including Methylene Chloride, Chloroform, Carbon Tetrachloride
(2) Wet Process Cement Kiln (Atomized Waste)	170	Coal	ESP	Waste liquids including Methylene Chloride, MEK[(a)], Trichloroethane, Toluene, Freon 113
(3) Dry Process Cement Kiln (Non-atomized Waste)	228	Coal/Coke	ESP	Waste liquids including Methylene Chloride, Freon 113, MEK, Toluene, Trichloroethane
(4) Dry Process Cement Kiln (Atomized Waste)	300	Coal/Coke	Fabric Filter	Waste liquids including Trichloroethane, Trimethylbenzene, Xylene, Methylene Chloride
(5) Lime Kiln (Atomized Waste)	50	Coke/ Natural Gas	Fabric Filter	Waste liquids including Methylene Chloride, MEK, Trichloroethylene
(6) Shale Aggregate Kiln (Atomized Waste)	35	Coal	Scrubber	Waste liquids including Perchloroethylene, Methylethyl
(7) Clay Aggregate Kiln	20	Coal	Scrubbers	Waste liquids including Methylethyl Ketone, Perchloroethylene, and Toluene
(8) Clay Products Kiln (Atomized Waste)	37.5	Waste Oil	Fabric Filter	Waste liquids, waste oil, Freon 113, Perchloroethylene, Carbon Tetrachloride, Benzene Toluene, Trichloroethylene

MEK = methylethyl ketone

Source: Oppelt, E. T. 1986. Thermal destruction of hazardous waste. Presented at US/Spain Joint Seminar on Hazardous Wastes, Madrid.

TABLE 7.4-5

Summary of Results of Tests on Industrial Kiln Performance

FACILITY TYPE	TEST(a)	DRE(b) (NO. NINES)	PARTICULATES(d) (kg/Mg)	HCl_1 (kg/hr)	NO_x (ppm)	SO_2 (ppm)	W/F (%) (C)
(1) Wet Process Cement Kiln (Non-atomized Waste)	W	2.2	.27	.36	68	450	25
	B	-	.26	.09	136	279	-
(2) Wet Process Cement Kiln (Atomized Waste)	W	4.6	.27	2.1	478	265	15
	B	-	.26	.6	371	636	-
(3) Dry Process Cement Kiln (Non-atomized Waste)	W	4.8	-	11.5	814	19	45
	B	-	-	1.3	620	7	-
(4) Dry Process Cement Kiln (Atomized Waste)	W	4.2	-	.47	486	27	15
	B	-	-	.25	680	27	-
(5) Line Kiln (Atomized Waste)	W	4.7	.11	.20	446	596	30
	B	-	.10	.09	386	553	-
(6) Shale Aggregate Kiln (Atomized Waste)	W	>4.0	.33	2.1	-	-	100
(7) Clay Aggregate Kiln (Atomized Waste)	W	4.8	0.58	0.023	162	1130	59
(8) Clay Products Kiln (Atomized Waste)	W	>4.0	.002	0.84	-	-	100

(a) W = waste testing, B = baseline (no waste firing)
(b) DRE = destruction and removal efficiency (e.g., 4.5 nines = 99.995%)
(c) % of total heat input provided by waste fuel
(d) Stack emissions of particulate matter expressed as kg of emission per Mg of clinker produced

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Source: Oppelt, E. T. 1986. Thermal destruction of hazardous waste. Presented at US/Spain Joint Seminar on Hazardous Wastes, Madrid.

TABLE 7.4-6

Summary of DREs for Industrial Kilns

Plant	Waste Component	Destruction Efficiency
St. Lawrence Cement	Chlorinated aliphatics	>99.990
	Chlorinated aromatics	>99.989
	PCB's	>99.986
Peerless Cement	PCB's	99.9981-99.9986
Stora Vika	Methylene chloride	>99.995
	Trichloroethylene	>99.9998
	All chlorinated hydrocarbons	>99.988
	PCB	>99.99998
	Chlorinated phenols	>99.99999
	Phenoxy acids	>99.99998
	Freon 113	>99.99986
San Juan Cement	Methylene chloride	93.292-99.997
	Trichloromethane	92.171-99.96
	Carbon tetrachloride	91.043-99.996
Los Robles	Methylene chloride	>99.99
	1,1,1-Trichloroethane	99.99
	1,3,5-Trimethylbenzene	>99.95
	Xylene	>99.99
Paulding	Methylene chloride	99.956-99.998
	Freon 113	>99.999
	Methyl ethyl ketone	99.978-99.997
	1,1,1-Trichloroethane	99.991-99.999
	Toluene	99.940-99.988
Oglesby	Methylene chloride	99.94-99.99
	Freon 113	99.999
	Methyl ethyl ketone	99.997-99.999
	1,1,1-Trichlorothane	>99.999
	Toluene	99.986-99.998
Rockwell Lime	Methylene chloride	99.9947-99.9995
	Methyl ethyl ketone	99.9992-99.9997
	1,1,1-Trichloroethane	99.9955-99.9982
	Trichloroethylene	99.997-99.9999
	Tetrachlroethylene	99.997-99.9999
	Toluene	99.995-99.998

Source: USEPA. 1985. Summary Report on Hazardous Waste Combustion in Calcining Kilns. Contract no. 68-03-3149.

TABLE 7.4-7

Collection of Published Test Results Comparing HCI Emissions from Production Kilns during Co-firing of Chlorinated Wastes Versus Those During Baseline Conditions (Firing of Traditional Fuel)

Plant	Process	Fuel	CI in Wastes	HCI Emissions Average, kg/h		Chlorine Input to Kiln, kg/Mg of Clinker		HCI Emissions (Average), kg/Hg of Clinker		Reference No.
				Base Line	Waste Firing	Base Line	Waste Firing	Base Line	Waste Burns	
General Portland, Inc. Paulding, Ohio	Cement kiln wet process	Coal	1-4% (coal + wastes)	<1.84+0.17 n = 4	3.63+5.25 n = 5	0.21-0.68	2.24-2.74	0.06	0.09	10
San Juan Cement Co. Dorado, Puerto Rico	Cement kiln wet process	No. 6 oil	0.004-6.6% (oil + wastes)	0.15 n = 1	0.38+0.35 n = 9	0.80	12.1	0.005	0.013	22
Lonestar Industries Ogelsby, Illinois	Cement kiln dry process	Coal/coke	0.11-.7% (coal + waste)	1.335=0.76 n = 2	11.5+26 n = 3	0.401	1.43	0.023	0.069	21
Rockwell Lime Co. Rockwood, Wisconsin	Lime kiln	Coal and natural gas	3.07% (Avg.) in waste	0.104+0.11 n = 3	0.195+0.089 n = 5	2.93	2.61	0.012	0.025	6
St. Lawrence Cement Co. Mississauga (Ontario) Canada	Cement kiln	No. 6 oil	37.9%	N.D.[a]	N.D.	0.665	4.96	N.D.	N.D.	18
			42.6%	N.D.	N.D.		5.14	N.D.	N.D.	2
			35%	N.D.	N.D.		2.75	N.D.	N.D.	2

[a] N.D. = None detected

Source: USEPA. 1985. Guidance Manual for Co-firing Hazardous Wastes in Cement and Lime Kilns. Contract no. 68-02-3995.

TABLE 7.4-8

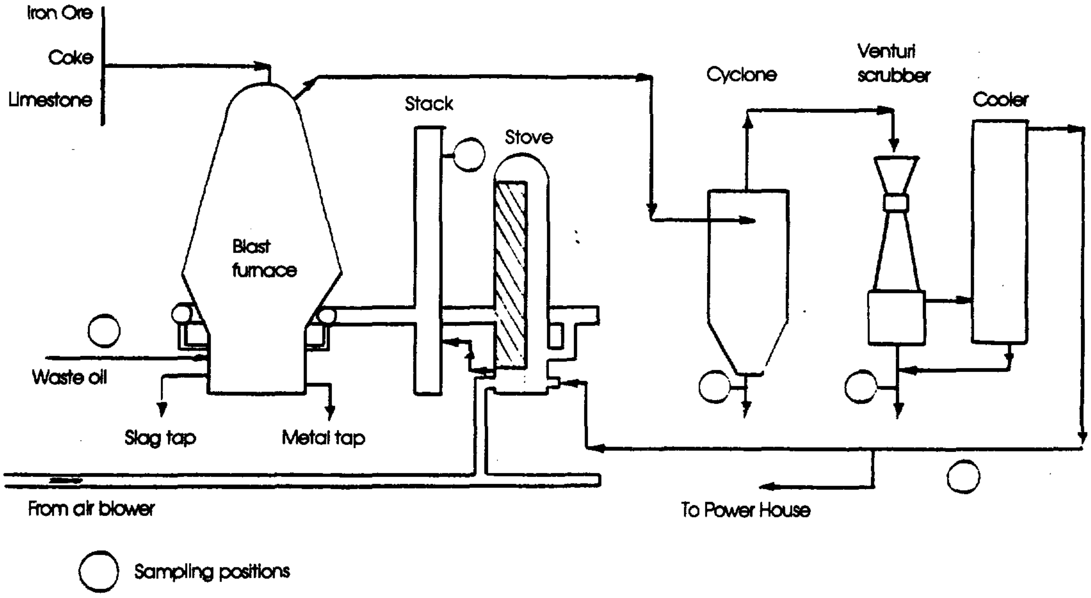
Summary of Blast Furnace Performance

Compound	Waste Fuel (ppm by wt.)	Feed Rate (Kg/hr)	DRE, %
1,1-Dichloroethene	1,210	15.7	>99.999
Chloroform	254	3.3	99.994-99.998
1,1,-Trichloroethane	999	13.0	99.98-99.99
Trichloroethene	1,185	15.4	>99.999
Benzene	553	7.2	99.53-99.998
Tetrachloroethene	2,800	36.3	>99.999
Toluene	56,200	731.0	>99.999
m/p-Xylene	940	12.2	99.96->99.999
0-Xylene	5,280	68.8	99.993-99.998
Naphthalene	880	11.4	99.96-99.993
Total Chlorine	835	10.3	-

Source: Adams, R. C. et al. 1985. In: Proceedings of the 11th Annual Research Symposium, 600/9-85/028. USEPA.

FIGURE 7.4-3

Blast Furnace Process Utilizing Waste Oil



Source: Adams, R. C. et al. 1985. In: Proceedings of the 11th Annual Research Symposium, 600/9-85/028.

Co-firing of wastes can safely be used for a range of hazardous wastes, provided that the waste is well characterized and the process properly controlled.

Typical waste streams include waste oils containing less than 500 ppm of PCBs, paint solvents, phenolic wastes and petrochemical liquids and sludges. Wastes containing metals, chlorine, phosphorus nitrogen and sulphur should only be incinerated in boilers if adequate gas cleaning devices have been attached.

Advantages of co-firing include:

- the recovery of the heating value of the waste to operate the boiler;
- extra revenue generated from treatment charges;
- the use of existing plant for the destruction of pumpable wastes. Primary fuel can be gas, oil or solid;
- high destruction efficiencies for even the most difficult wastes, such as dilute PCBs in oil, typically above 99.99%.

Disadvantages are that:

- very few industrial boilers have anything other than rudimentary gas cleaning equipment to remove particulates; the majority have no pollution control devices. This places a limitation on the type of, and rate at which, wastes can be incinerated;
- only pumpable wastes are acceptable.

Watertube boilers are most likely candidates for hazardous wastes incineration. Their larger heat input capacities allow higher waste firing rates while still retaining low waste/fuel ratios. Furthermore, these units are often equipped with multiple burners, allowing one or more burners to fire waste fuel only. Stream-atomized oil guns for waste firing are used in combination with natural gas firing for single burner units. Modifications to single burner arrangements to allow oil land liquid wastes co-firing are also possible.

Firetube boilers are less likely to constitute a major equipment category for co-firing practices because of generally smaller capacities (Santoleri 1985).

Additional cost items that may be necessary for existing boilers include:

- waste handling equipment (tank storage, blending, filtration and pumping systems to the burners);
- retrofitting of burners for better atomization of the waste;

- retrofitting of gas cleaning devices to keep gaseous emissions below statutory limits, or to increase the range of wastes that may be handled.

Regulations should also be formulated to specify the types of waste and the design of boilers which are acceptable. For example, the US Environmental Protection Agency specifies, for PCB destruction in high-efficiency boilers:

- a PCB concentration in oil less than 500 ppm (below 50 ppm is no longer a hazardous waste);
- a minimum boiler rating of 50 GJ/h;
- carbon monoxide concentration in the flue gases;
- oxygen in the flue gas greater than 3%;
- the waste oil input should be 10% (V/V) or less of the fuel feed rate (Hunt et al. 1984).

Such regulations must obviously be enforced.

A number of boiler types have been tested on a variety of wastes (USEPA 1985 a & d). Tables 7.4-9 and Table 7.4-10 list details of basic units with burners, fuel and gas cleaning facilities, and boiler performance. Additional information on field tests may be obtained from USEPA (1985 a & d).

7.4.5 Co-incineration in Existing Incinerators

Co-incineration involves the joint incineration of hazardous wastes in any form with refuse and/or sewage sludge.

Modern refuse incinerators are of the moving grate type. Operating temperatures are generally in the range of 850-900°C, with a minimum of 750°C. The design usually excludes the possibility of co-incineration of hazardous wastes, unless the quantities are very small, or the waste is of 'low hazard' with a physical form and calorific value similar to refuse.

Sewage sludge incineration, where they exist, offer more scope for co-incineration. The most common type is a **multiple hearth incinerator** which consists of a refractory lined cylinder equipped with a series of vertically fixed solid hearths. Sludge or solid waste fed in at the top is moved downwards by rotating rabble arms. Support fuel and liquid wastes are introduced through atomizing burners into the side of the unit. Figure 7.4-4 details the main features. Normal incineration usually requires minimum of six hearths.

The major application of multiple hearth incinerators has been in the incineration of sewage sludges. Hazardous wastes such as still bottoms, chemicals and oil refinery sludges, pharmaceutical wastes and pesticide

TABLE 7.4-9

Description of Industrial Boilers Included in a Testing Programme

Boiler Type	Steam Capacity kg/s (10^1lb/hr)	Furnace Volume m^3(ft^3)	Furnace Waterwall Surface m^2(ft^2)	Primary Fuel	Number of Burners (Injection Ports)	Typical Waste Fuels	Injection Mechanism	Control Device	Typical Operation
Watertube stoker	1.3 (10)	17.4 (613)	106 (1,144)	Wood waste	2	Creosote sludge	Mixed with wood	Multi-cyclone	Fluctuating loads, combustion air and waste feed
Packaged tiretube	1.1 (85)	1.1 (39)	80 (83)	Natural gas	1	Alkyd wastewater	Air atomized oil gun	None	Low boiler load. Maximum waste fire rate of 42 ml/s (40 gph)
Field erected watertube	29 (230)	322 (11,400)	170 (1,800)	Natural gas or oil	6	Phenolic waste	One or two steam atomized burners	None	Low load with reduced number of burners. High excess air.
Field erected converted watertube stoker	11.4 (90)	62 (2,200)	140 (1,520)	No. 6	4	Methanol and toluene wastes with chlorinated organics	One of the lower level steam atomized burners	None	About 50% capacity with 3 or 4 burners in service
Packaged watertube	139 (110)	42 (1,480)	665 (7,160)	No. 6 oil	1	Methylmethacrylate byproduct wastes	Two steam atomized waste guns in main burner throat	None	Part load with maximum 250 ml/s (240 gph) waste firing rate for loads above 50 %
Field-erected converted watertube	7.6 (60)	96 (3,390)	100 (1,100)	No. 6 oil, gas, or propane	2	Paint solvents	Lower steam atomized oil burner	None	Part load with maximum 190 ml/s (180 gph) waste firing rate for loads above 50%

TABLE 7.4-9 (continued)

Description of Industrial Boilers Included in a Testing Programme

Boiler Type	Steam Capacity kg/s $(10^1$ lb/hr)	Furnace Volume $m^3(ft^3)$	Furnace Waterwall Surface $m^2(ft^2)$	Primary Fuel	Number of Burners (Injection Ports)	Typical Waste Fuels	Injection Mechanism	Control Device	Typical Operation
Modified packaged firetube chlorine	5.0 (40)	6.4 (226)	20 (220)	None	1	Highly chlorinated organics	Available air atomized oil gun	2 scrubbers in series	Part load with startup on natural gas. Total up to 80% of waste fuel
Field erected tangentially fired watertube	32 (250)	520 (18,400)	515 (5,540)	Pulverized coal	12 coal, 6 oil	Methylacetate waste fuel	One or two steam atomized oil burners	ESP	At boiler capacity with maximum 440 ml/s (420 gph) waste firing rate
Packaged watertube	78 (62)	41 (1,430)	76 (820)	Natural gas	2	Aniline waste high in nitrate organics	Either upper or lower steam atomized burner	None	Staged combustion for low NO, with maximum 130 ml/s (120 gph) waste flow
Packaged firetube	1.3 (10)	1.5 (51)	2.6 (91)	None	1	Artificially blended fuels	Available oil burner	None	Typical excess air of 17%
Packaged watertube	7.6 (60)	65 (2,270)	47 (508)	No. 6 oil	1	Blended waste with light oil	Mixed with heavy oil	None	Typical 70/30% heavy and light oil mixture

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Source: USEPA. 1985. Project EPA/600/S2-82/177.

TABLE 7.4-10

Results of Tests on Co-firing of Wastes in Industrial Boilers

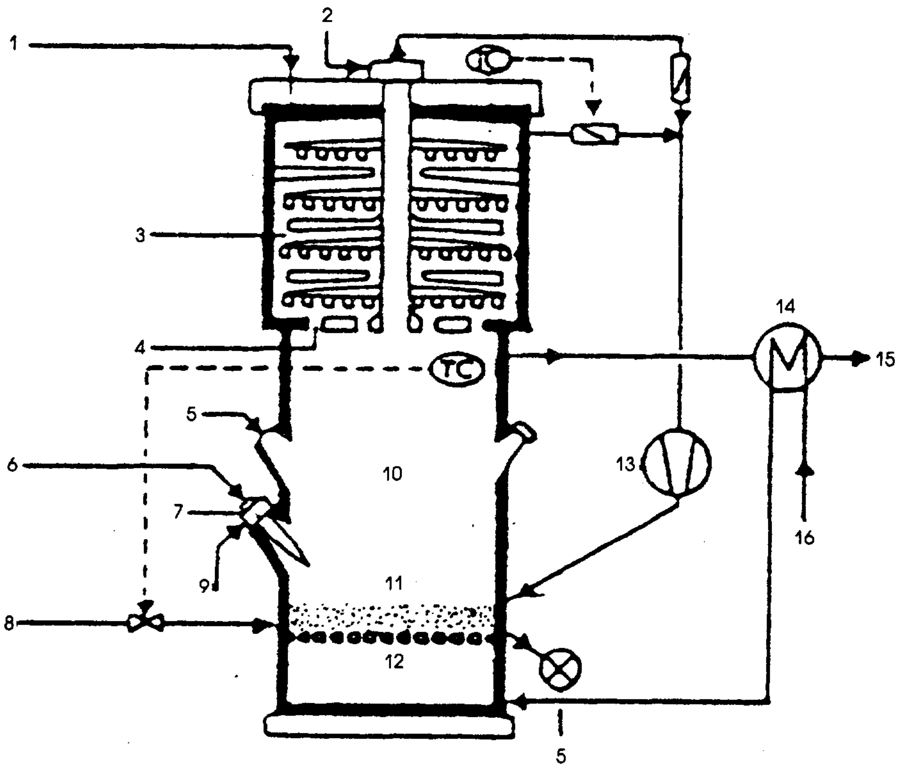
Facility Type	Load (%)	O_2 (%)	Residence Time (sec)	Average Volumetric Heat Release Rate KW/m^3	DRE (d) (No. Nines	W/F (a) (%)	NO_x (b) (ppm)	CO (b) (ppm)
(1) Watertube Stoker	100	6-16	1.2	509	3.8	40	163-210	900-1200
(2) Packaged Firetube	25	4-6	0.8	739	4.1	0.1-05	40-65	47-88
(3) Field Erected Watertube	26	10	2	78	5.6	37	61-96	18-21
(4) Converted Stoker	78	4-6	1.1	339	4.8	18-48	193-250	75-127
(5) Packaged Watertube	36-73	6-7	0.5-1.1	960	4.5	19-56	164-492	83-138
(6) Converted Watertube	53	7-11	2	107	3.8	8.7-10.1	243-328	109-139
(7) Modified Firetube	44	8	0.4	807	4.8	100	67-74	146-170
(8) Tangetially Fired Watertube	100	6	2	180	4.1	2.4-4.3	393-466	142-201
(9) Packaged Watertube	65	2	1.8	343	4.8	8.2	64-78 410-1125 (c)	46-750
(10) Packaged Firetube	50-100	3-8	0.3-0.7	1240	5.0	100	85-203	20-135
(11) Packaged Watertube	82	4	1.8	269	5.7	49	154-278	102-119

(a) W/F = waste heat input as a % of total heat input
(b) range of average values across individual sites and runs including baseline
(c) higher values are for high nitrogen waste firing
(d) DRE = destruction and removal efficiency (e.g., 4.5 nines = 99.995% DRE)

Source: Oppelt, E. T. 1986. Thermal destruction of hazardous waste. Presented at US/Spain Joint Seminar on Hazardous Wastes, Madrid.

FIGURE 7.4-4

Multiple Hearth Sewage Sludge Incinerator



1. Waste feeding
2. Cooling air
3. Drying zone
4. Distribution hearth
5. Sand
6. Fuel
7. Start-up burner
9. Air
10. Incineration zone
11. Fluidized bed
12. Grid
13. Recirculation blower
14. Air heater
15. Flue gas
16. Air for fluidizing and combustion

residues, have generally been co-incinerated with sewage sludge, to good effect, provided that an afterburner is installed. Tests have also been carried out on chlorinated wastes such as Kepone, DDT and 2,4,5-T (Bonner et al. 1981).

Advantages of co-incineration in a multiple hearth incinerator include (Worral, et al. 1985):

- existing incinerators can be used;
- high hearth retention times;
- good fuel efficiency;
- hearth temperatures can be varied individually;
- feed rate can be varied by ± 30%.

The **disadvantages** are that:

- such incinerators are uncommon;
- temperature response is slow, making it difficult to control liquid burners;
- high maintenance costs;
- the incinerator cannot handle irregular bulky solids;
- a separate afterburner chamber is necessary

7.4.6 Small Scale Purpose-Built Incinerators

(i) Open-Pit Incinerators

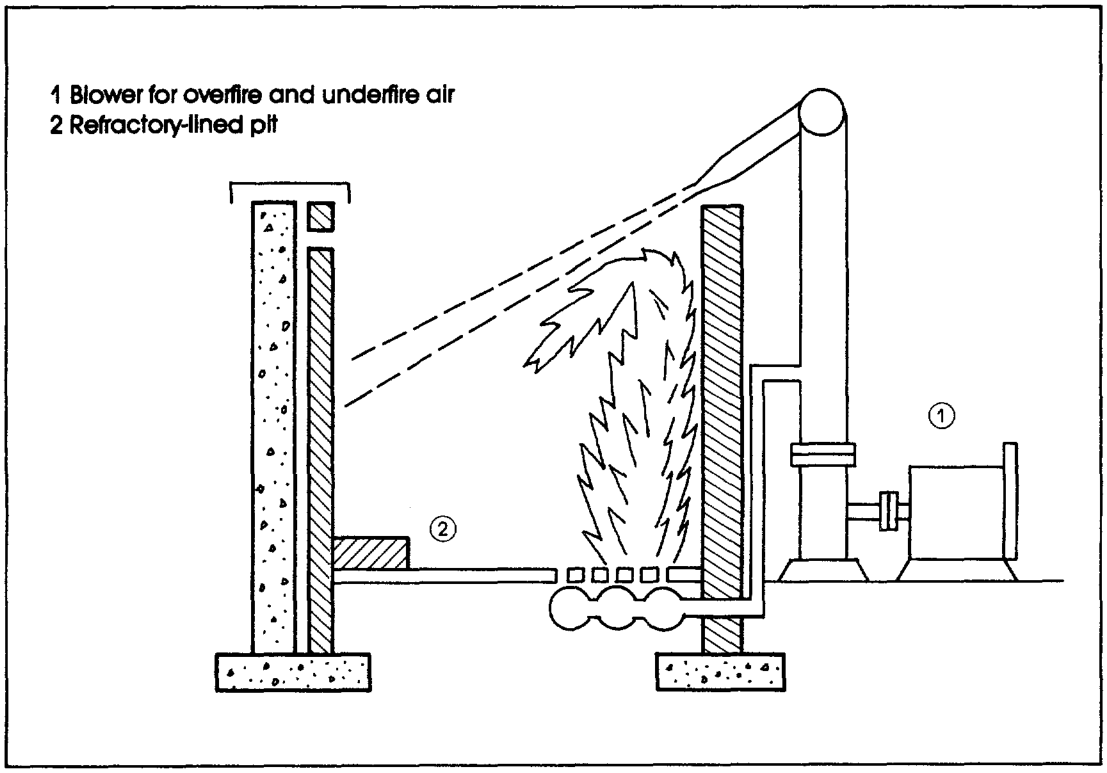
Open-pit incinerators have been used since prehistoric times, and properly engineered designs still have a legitimate place in modern-day hazardous waste management, provided that wastes are carefully selected, and the pit is located at some distance from habitation.

A modern design of an engineered open-pit incineration is shown in Figure 7.4-5. A typical size is 5m long, 2.5m wide and 2.8m deep. The waste is place on a tiled floor equipped with perforated pipes to supply forced underfire air (Lucier 1970). Overfire air is directed over the top at an angle of 25^o - 35^o from a manifold throat that runs the length of the pit. Thus, an air curtain is formed in the overfire position, creating maximum turbulence and recirculation of combustion gases. The high velocity air jet ensures that oxygen is always in excess.

Particulates and combustion gases are largely returned to the combustion zone and particulate emissions are controllable, by proper waste selection, to within 600 mg/m^3 unless and until the curtain is disrupted,

FIGURE 7.4-5

Open-pit Incineration



for example during feeding. Combustion air requirements are estimated at 1800Nm^3/h/m of pit length. Apart from pit lining, capital items include a 56 kW blower drive with flows, pressures and velocities variable according to use. Normal capacity is estimated at 11GJ/h/m of pit length.

Commercial applications include the disposal of polypropylene, and other non-chlorinated plastics, rubber and wood wastes, and hydrocarbon solvents. The disposal of heavy pitch and tar residues, has met with mixed success (Niessen 1978).

Partial fluidization of the waste due to underfire air results in excessive particulate emissions if wastes with an ash content in excess of about 2%, are burned. The lack of gas-cleaning and of a stack to disperse noxious gases limits the types of wastes that can be incinerated to readily combustible solids and liquids low in chlorine, sulphur and nitrogen.

Open-pit incinerators should be sited some distance away from local communities, and operation should be curtailed if weather conditions are much that a nuisance could be created downwind of the facility.

(ii) Small Scale Units

It is often necessary to incinerate wastes in small quantities, at rates from about 10-200 kg/h. Small incinerators designed for these duties are of the box or retort variety, comprising either a primary chamber alone, or primary and secondary (afterburner) chambers. An indication of primary chamber volume for various burning rates is given in Figure 7.4-6.

Utilitarian items can be used as the basis for a unit. Figure 7.4-7 illustrates two small-scale units:

- a 10 kg/h unit devised from a 0.2m^3 steel drum lined with 50mm of firebrick, equipped with a preheat chamber and a rudimentary air pollution control device (Corey 1969);
- a more sophisticated unit capable of burning waste ranging from garbage to wood, paper, plastic and hospital wastes.

Figure 7.4-8 illustrates a water-walled incinerator where, in addition to good turbulence and controlled combustion, the water walled construction ensures quick dissipation of heat. The unit can be used to incinerate plastics and rubber (Corey 1969).

Space and installation requirements are minimal, but air pollution control equipment can, for the smaller units, far exceed basic incinerator capital costs. This places a limitation on the composition of the wastes, if a minimum of gas cleaning is to be sufficient for emissions to comply with local regulations. In particular, wastes containing chlorine, sulphur and nitrogen are to be avoided.

FIGURE 7.4-6

Burning Rate versus Chamber Size for Small Incinerators

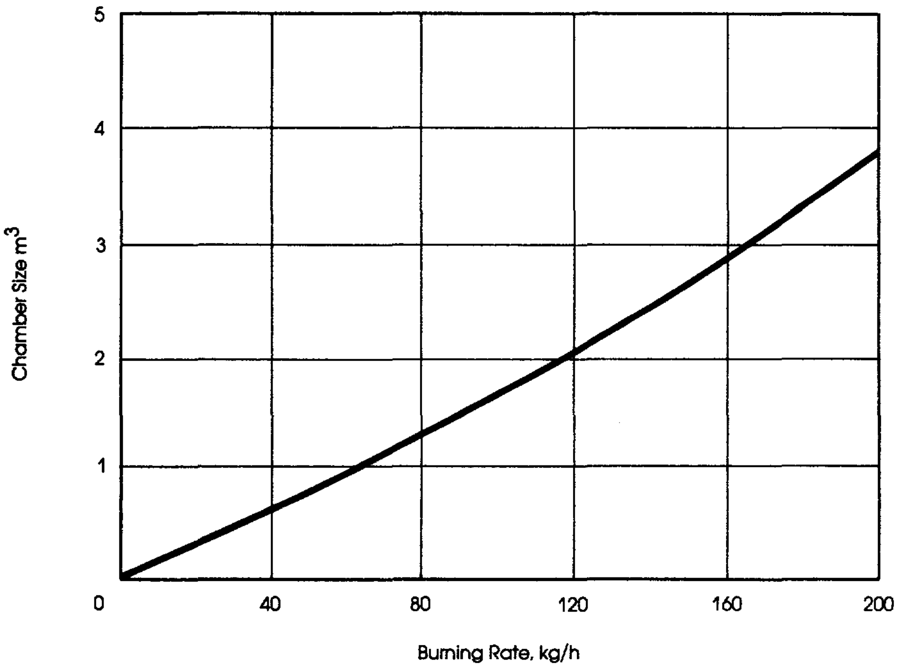
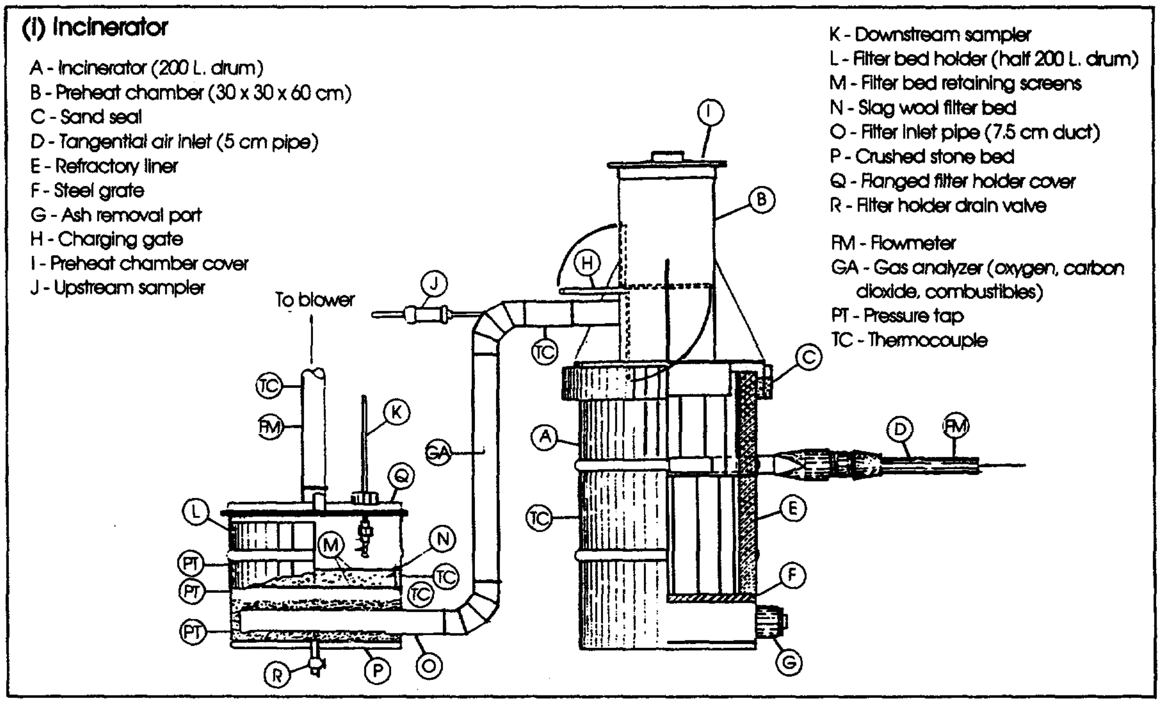
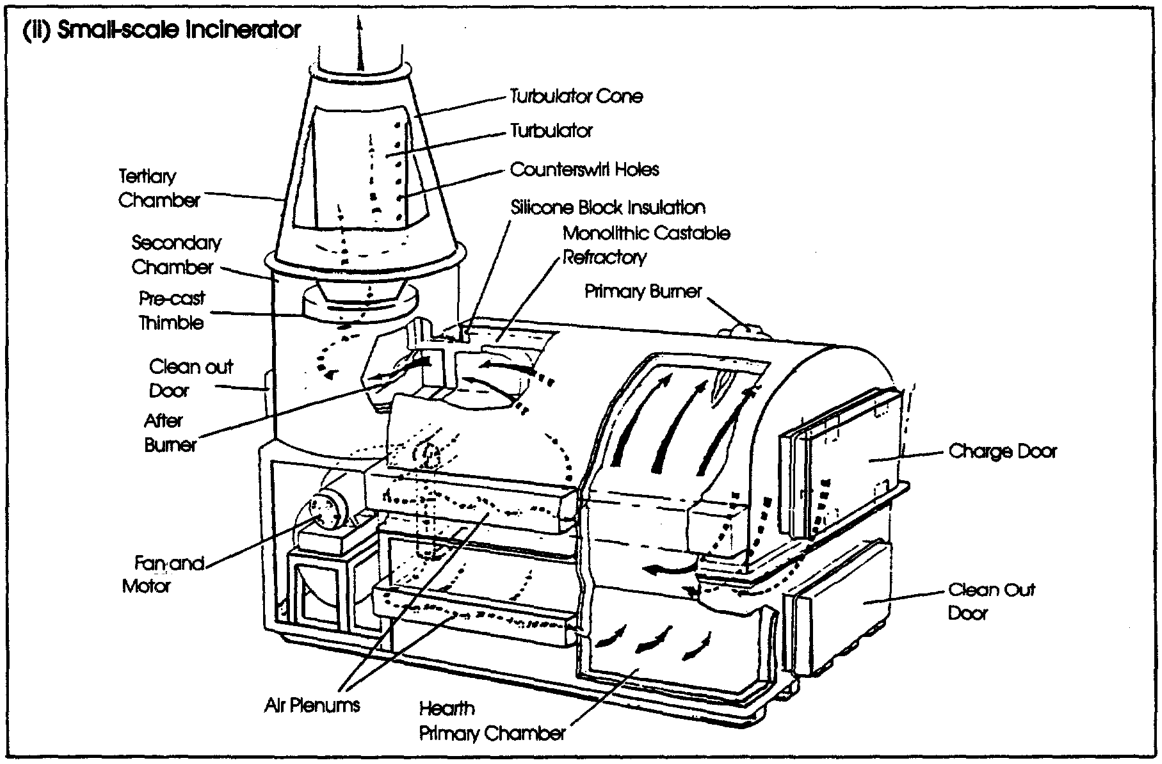


FIGURE 7.4-7

Two Examples of Small-scale Incineration Units



(i) Incinerator

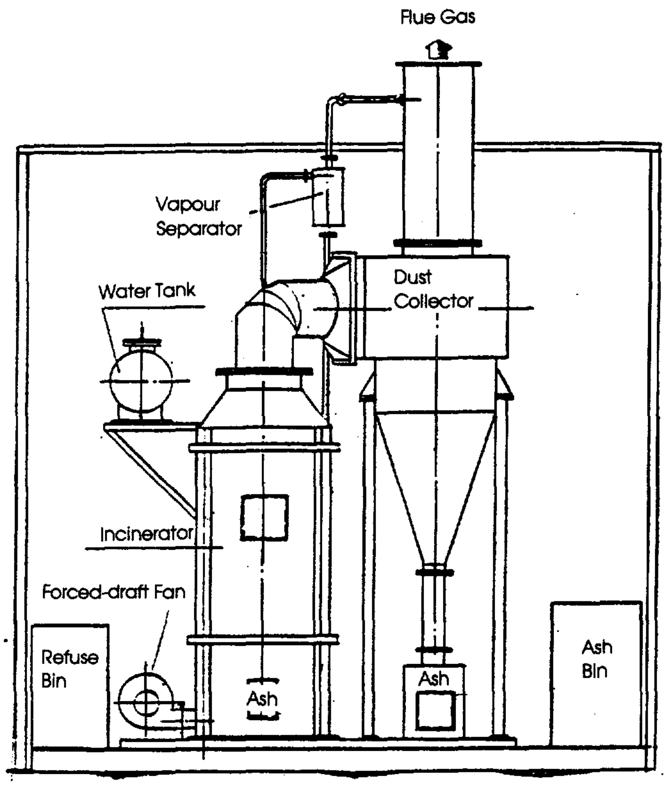


(ii) Small-scale Incinerator

Source: Corey, R. C. 1969. Principles and Practices of Incineration. New York: Wiley - Interscience.

FIGURE 7.4-8

Small-scale Water-walled Incinerator



Source: Corey, R. C. 1969. Principles and Practices of Incineration. New York: Wiley - Interscience.

Small scale incinerators are often ideal for in-house incineration of well characterized process wastes. They are less applicable to a mixed waste feed.

(iii) Mobile Units

Mobile incineration units are useful when the cost of transporting waste to a central treatment facility is prohibitive. Typical applications include the incineration of large volumes of soil contaminated with organics. In order to be cost-effective, the unit should be capable of operating at fairly high burning rates, and provide adequate gas cleaning to broaden the range of wastes that can be handled. As potential sites will frequently be near or within residential areas, a stack for the dispersal of gaseous emission is obligatory.

Figure 7.4-9 illustrates a mobile unit developed by the U.S. Environmental Protection Agency for the incineration of difficult wastes, which is mounted on a series of trailers. The unit has been successfully used at Denny Farm, Missouri, for the treatment of $20m^3$ of liquids and 30t of soil contaminated with dioxins. In 1985, fabrication costs for a new system were estimated at $1.1 million. Operating costs (labour and materials) were running at approximately $2000/t, projected to decrease as capacity increased.

Less sophisticated systems, based on the EPA design, may profitably be employed for the incineration of all but the most intractable organic wastes. The EPA unit is designed to incinerate 1-2 t/h of soil and $0.5\text{-}1m^3/h$ of liquids. Organic destruction efficiency, DRE, is consistency above 99.9999%.

7.4.7 Large Scale Purpose-Built Incinerators

Large, land-based incineration facilities may be regarded as operating above a burning rate of about 0.5t/h, with or without (but generally with), gas cleaning. On site facilities catering for specific wastes are more easily controlled, and may not require the elaborate ancillary plant set up by service enterprises burning a broad range of hazardous wastes. Performances data is given in Table 7.4-11. Section 7.4.7 discusses some aspects of design and sizing. Detailed design information on large units may be obtained from Corey (1969) and Niessen (1978).

(i) Multiple Chamber Incinerators

Multiple chamber incinerators are scale-ups of the small retort varieties discussed in Section 7.4.6. The unit consists of a primary chamber followed by a series of secondary chambers separated by refractory baffles, the last of which is operated as an afterburner cell. Solid wastes are charged through a sliding gate onto the fixed hearth of the primary chamber. Liquid wastes requiring the maximum residence time, and support fuel or clean high calorific value liquid wastes. Liquids are pumped into the incinerator through an atomizing nozzle which uses combustion air to incinerator through an atomizing nozzle which uses facilitate efficient combustion.

FIGURE 7.4-9

EPA Mobile Incinerator

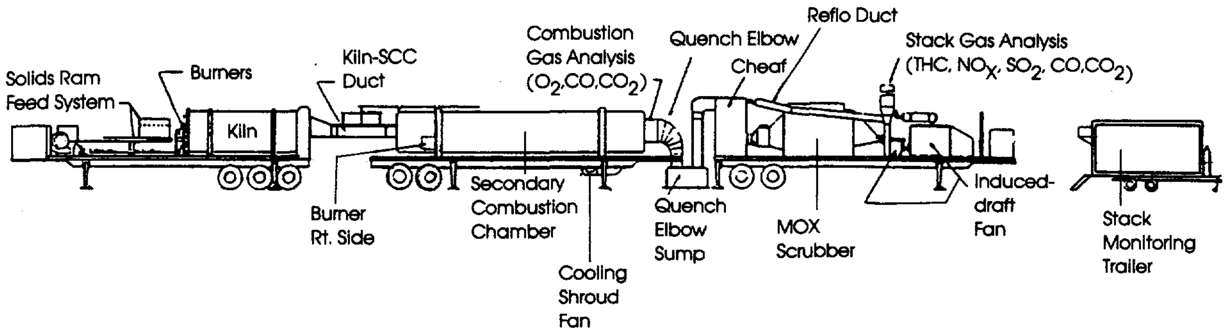


TABLE 7.4-11

Incinerator Performance and Stack Emissions Data for Large-scale Facilities

Facility Type	O_2 %	CO (ppm)	THC (b) (ppm)	DRE (a) (Number of Nines)	Particulate (mg/m^3)	HCI Control
(1) Commercial Rotary Kiln/Liquid Incinerator	10.5	<1.0- 14.8	<1.0	99.9993	1508	99.4%
(2) Commercial Fixed Hearth, Incinerator	11.4	4.7 9.1	1.0	99.994	400	98.3%
(3) On-site Liquid Incinerator	8.3	9.9- 11.2	3.9- 8.9	99.994	61	99.7%
(4) Commercial Fixed Hearth, Incinerator	11.0	7.5- 22.2	<1.0- 1.9	99.997	200	<1.8 kg/hr
(5) On-site Liquid Injection	12.1	6.7- 19.3	<1.0	99.99997	207	<1.8 kg/hr
(6) Commercial Incinerator	9.9	<1.0- 1.8	<1.0	99.998	900	<1.8 kg/hr
(7) On-site Rotary Kiln	9.7	422- 666	47.6- 75.9	99.9993	23	99.9%
(8) Commercial Fixed Hearth Incinerator	13.6	0.9- 4.3	0.8- 2.5	99.996	169	98.3%

(a) Mass weighted averages for all POHCs > 100 pmm in waste
4.5 nines = 99.995% DRE

(b) THC - Total hydrocarbons

Source: Oppelt, E. T. 1986. Thermal destruction of hazardous waste. Presented at US/Spain Joint Seminar on Hazardous Wastes, Madrid.

Advantages of the system are (Worrall et al. 1985):

- simplicity of design and relatively low cost;
- effective destruction of liquid and solid wastes through good control of hearth and gas phase residence times;
- bulky wastes can be easily handled;
- a wide variety of wastes can be incinerated.

The **disadvantages** are that thermal shock during charging and de-ashing can reduce the life of the refractories. Refractory replacement costs are nevertheless lower than for rotary kilns.

Figure 7.4-10 illustrates the basic concept of a multiple chamber incinerator. The primary chamber is often set at right angles to the base of the system, to reduce space requirements. This design has been extensively used in the incineration of the whole range of hazardous organic wastes.

(ii) The Rotary Kiln

The rotary kiln is a very popular design, and has been adopted by the majority of hazardous waste incineration contractors in Europe and N. America. It consists of a rotating cylindrical refractory lined steel drum inclined at an angle of 3^{o} - 5^{o} degrees to the horizontal. The concept is shown in Figure 7.4-11. The length of the drum is usually three to four times its diameter, which may be up to 4m.

Solid wastes are fed in at the raised end. The slowly rotating drum (2-5 rpm) causes the solids to cascade down the tube. By the time they reach the end of the drum they have been burnt out and the residues fall or run out of the lower end of the kiln. Liquid wastes and support fuel is fired horizontally into the kiln through atomizing nozzles. An afterburner chamber is essential for providing adequate gas phase residence time. Solids, including bulk items, can be fed continuously or in batches.

Advantages of the system are that (Worrall et al. 1985):

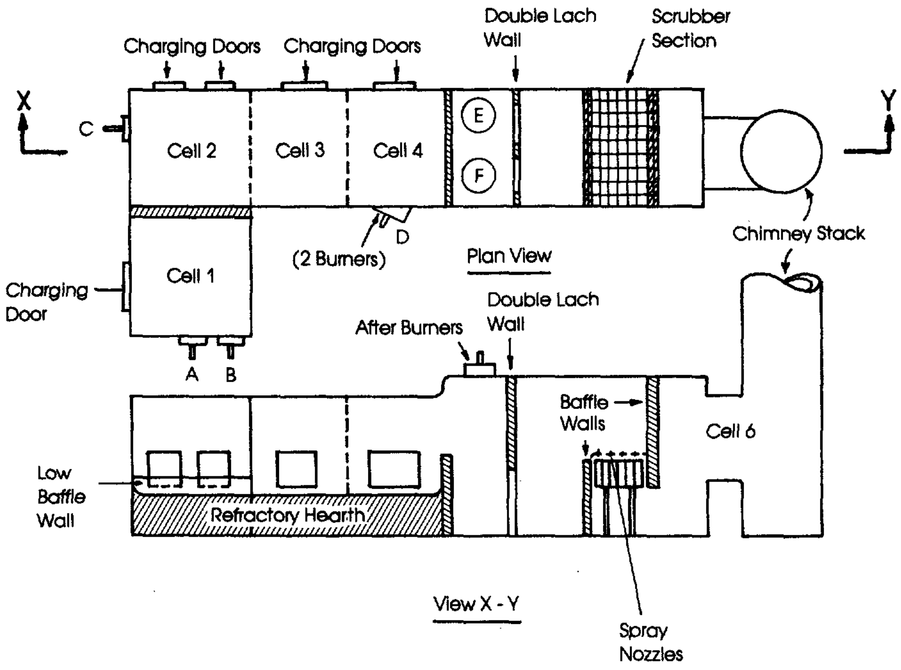
- a variety of liquids and solids can be incinerated, independently or in combination;
- kilns can be operated at temperatures up to $1600^{o}C$;
- operation can be batch or continuous, and de-ashing is continuous;
- bulky wastes can be accommodated.

Disadvantages are that:

- relatively high (mechanical) technology means high capital and maintenance costs;

FIGURE 7.4-10

Multiple Chamber Large-scale Incinerator



Burner Feeds

A Support fuel, residue liquids

B Support fuel, special liquids, 'hazardous' waster, Cylinder gases

C Support fuel, residue liquids

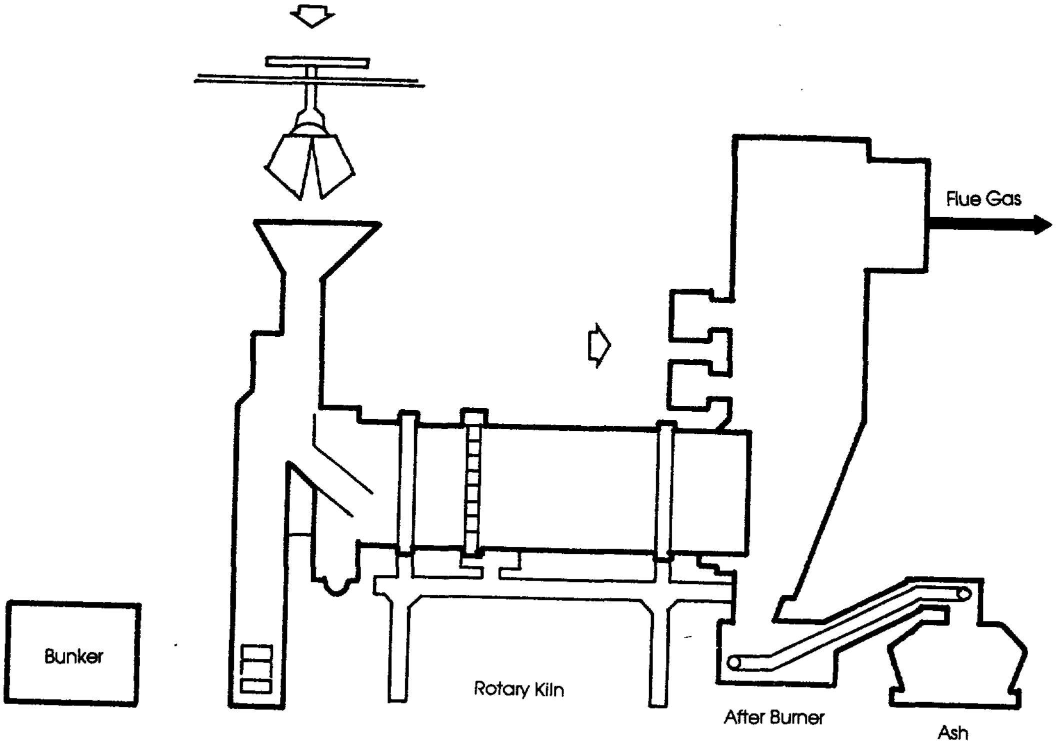
D Support fuel, residue liquids

E Support fuel only

F Support fuel only

FIGURE 7.4-11

Rotary Kiln



Source: Worrall, M., S. Moore, and D. L. Cramond. 1985. Presentation at the Conference on National Strategies for Managing Hazardous Waste, Melbourne.

- the thermal efficiency is relatively low;
- the cascading action of the drum may result in higher concentration of airborne particulates;
- operational difficulties associated with the integrity of air seals, are often encountered;
- the abrasive action of solids results in a high cost due to the need for refractory replacement.

(iii) Fluidized Bed

Fluidized bed incinerators consist of a cylindrical vessel containing an inert bed of granular material which is fluidized or expanded by air fed from below the grate (Figure 7.4-12. Waste feed can be put into or above the bed, liquid wastes and support fuel being pumped radially into the bed. Wastes from the plastics and pharmaceutical industries have been successfully incinerated by this method.

The **advantages** include (Worrall et al. 1985):

- simple design, and low capital and maintenance costs;
- can be applied to liquid, solid or gaseous wastes;
- good combustion efficiency;
- variations in feed rate and composition are easily tolerated.

The **disadvantages** are that:

- operating costs are relatively high;
- relatively low gas temperature necessitate an afterburner chamber;
- certain wastes can react with the bed material;
- not suitability for irregular, bulky or tarry wastes.

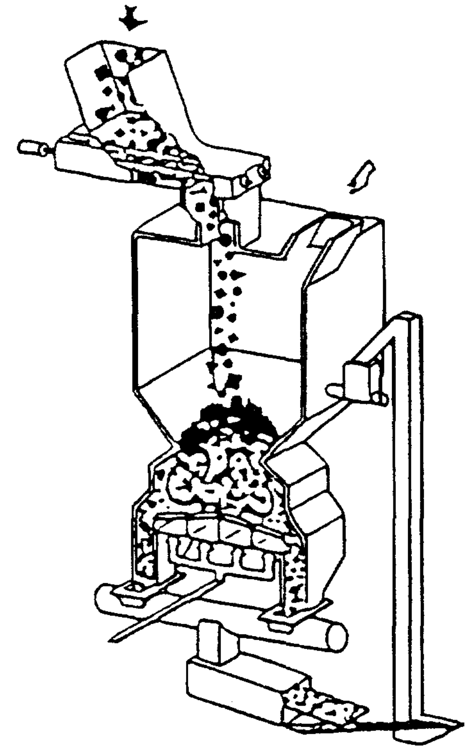
The applicability of fluidized bed incineration for the disposal of hazardous wastes, beyond a relatively narrow range has not been rigorously tested, and operational experience on the more difficult halogenated wastes such as PCBs is particularly limited.

(iv) Liquid Injection Combustors

Liquid injection combustors can incinerate virtually any pumpable waste, and are widely used in industry. The waste is atomized with compressed air in a burner nozzle, to facilitate efficient combustion. If the calorific value of the waste is insufficient for the maintenance of high temperature, support fuel burners are deployed. Efficient mixing is

FIGURE 7.4-12

Fluidised Bed



Source: Worrall, M., S. Moore, and D. L. Cramond. 1985. Presentation at the Conference on National Strategies for Managing Hazardous Waste, Melbourne.

achieved by the use of baffles or the inducement of a cyclonic motion by injecting the wastes at a tangent to the walls of the cylindrical furnace. An afterburner is required if halogenated or other difficult wastes are incinerated.

Advantages of the combustor are that:

- a wide range of liquids, slurries and sludges can be treated;
- the design is simple with low capital and maintenance costs;
- ash buildup is not a problem.

Disadvantages include:

- susceptibility of burners to blockage with slurries or suspensions;
- cannot handle solids.

7.4.8 Energy Recovery

Gases emitted from the hot furnace are typically at temperatures of 1000°C or higher. If this energy is recovered and reused in some form, the operating costs of the incineration facility are off-set, improving the economics of this waste disposal option. It will be seen in Section 7.4.9 that the hot gases have to be quenched to below 300°C before they are admitted to the pollution control section. This quenching can be achieved by spraying the gases with water or more profitability, by energy recovery, in which a boiler converts the energy to steam.

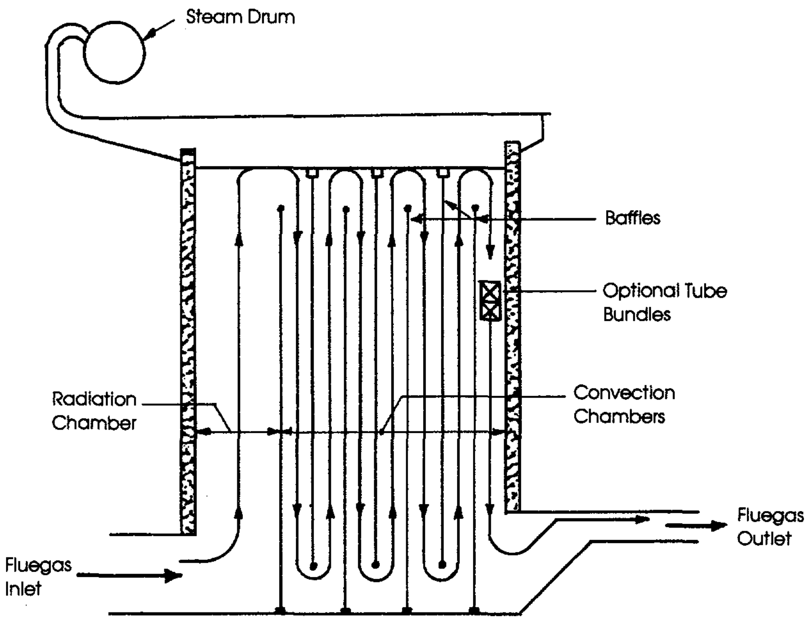
Advantages of energy recovery systems include (Novak et al. 1984):

- lower flue gas volumes due to reduced water-vapour concentrations and gas temperatures, resulting in smaller pollution control systems and reduced operating costs;
- reduced steam plume from the stack;
- conditioning of particulates aids agglomeration and removal downstream of the boiler;
- revenue from sale of energy.

The composition of the furnace gases dictate the type of boiler that is installed. Special care is needed when organochlorine compounds are incinerated, as the bydorchloric acid produced becomes extremely corrosive to metal heat-transfer surfaces when the gas temperature is below 150°C, or metal surfaces are above 350°C. In general, when both acid gases and salts are present, a radiant/convective boiler is necessary (Novak et al. 1984). Firetube and watertube boilers are more prone to failures when used in a "dirty" gas environment. The boiler, illustrated in Figure 7.4-13 has internal baffles consisting of vertical tubes welded together

FIGURE 7.4-13

Radiant/Convective Boiler



Source: Novak, R. G., W. L. Troxler, and T. H. Dehnke. 1984. Chemical Engineering (March 19): 146.

along their lengths to form a continuous heat-transfer surface with the water and steam flowing upwards through the tubes. Fluegas velocities are approximately 3m/s in the radiant chamber and 6-15m/s in the downstream convective section. The recovered steam is either used directly elsewhere on the plant, or superheated to generate electric power in a turbine.

7.4.9 Gas Cleaning

(i) Introduction

The constituents of the flue gas depend on the composition of the wastes and the severity of combustion conditions. The purpose of gas cleaning is to remove, as completely as is practicable, particulates and non-combustible contaminants such as fly ash and metal oxides, and acid gases (principally hydrogen chloride). Unburnt waste and trace organic by-products are not removed to any great extent by conventional gas cleaning equipment, and the control of these latter emissions must be effected by proper operation of the incinerator and its afterburner chamber.

Local environmental quality regulations, coupled with the type of waste burnt, will determine whether or not a gas cleaning system is necessary, and if so, to what level of sophistication. For example, open pit incinerators operate without gas cleaning and are therefore limited to low-ash wastes which do not generate noxious or toxic gases, and are appropriately sited. For small or in-house incinerators operating on carefully controlled wastes that do not generate acid gases, the gas cleaning problem is reduced to one of particulate removal.

Gas cleaning equipment cannot operate at the elevated temperatures of flue gas emanating from a furnace, and therefore some form of quenching is essential to reduce gas temperature to below 300°C. This can be effected by water sprays or by energy (heat) recovery. Water sprays increase the volume of the exit gases by adding water vapour, and also increase the visibility of the plume, but an advantage is that some particulate and acidity removal is effected within the quench.

After quenching, the gas cleaning system consists of two stages: particulate removal and removal of acidic species.

(ii) Particulate Removal

Particulate removal from the quenched gases can be achieved by any of the following methods (Royal Commission on Environmental Pollution 1985):

- mechanical cyclones;
- wet scrubbers, including venturi, packed towers or spray towers;
- bag filters;
- electrostatic precipitators, either dry or irrigated.

Cyclones are generally found on industrial boilers and cement kilns, but rarely on dedicated hazardous waste incinerators, other than the smallest types. Particulate collection efficiency is low.

Wet scrubbers are commonly used on the larger units. Collection efficiency is lowest for venturi scrubbers and highest for packed towers. Since water is used as the scrubbing liquid, up to 50% of the flue gases can comprise of water vapour, increasing the volumetric output and heightening the visibility of the plume. Water can either be discarded after after a single-pass or recirculated within the scrubber system. Figure 7.4-14 illustrates the flow diagrams of typical single-pass and recirculating scrubber systems (Bonner et al. 1985).

Electrostatic precipitators and bag filters are high capital cost items. Bag filters are susceptible to blockage, especially in the presence of a wet flue gas, and are expensive to maintain. Their use on hazardous waste incinerators is generally limited. Electrostatic precipitators are widely used as pollution control devices on municipal solid waste incinerators and cement kilns. Collection efficiency is dependent on resistivity, being lower for particles of high resistivity. The majority of electrostatic precipitators that operate on hazardous waste incinerators are of the dry type.

Tables 7.4-12 and 7.4-13 summarize the salient features of the various particulate removal devices.

(iii) Acid Gas and Volatile Metals

Any of the **wet scrubbers** discussed above can serve the dual role of particulate and acid gas absorption, though separate units are generally used for each function.

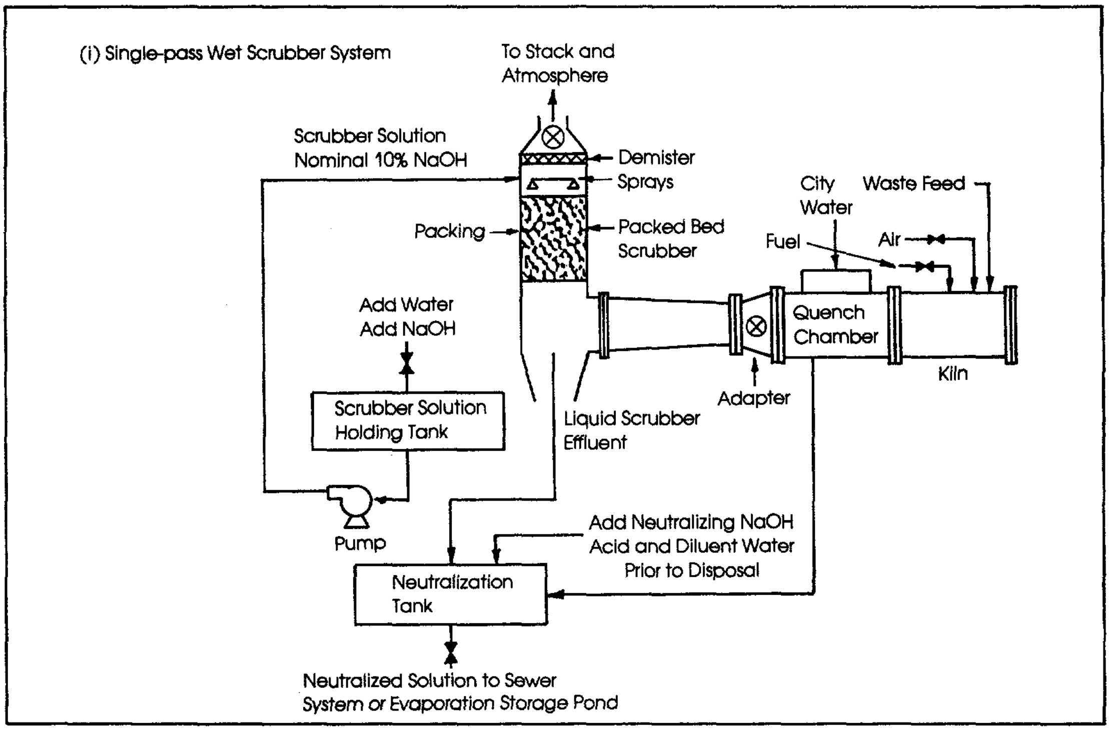
Hydrochloric acid removal exceeds 99% and sulphur dioxide removal approaches 80%. Volatile metals such as mercury, selenium and to a lesser extent cadmium, are condensed out of the gas stream by the temperature reduction induced in the wet scrubber. These metals are thus transferred to the scrubber water.

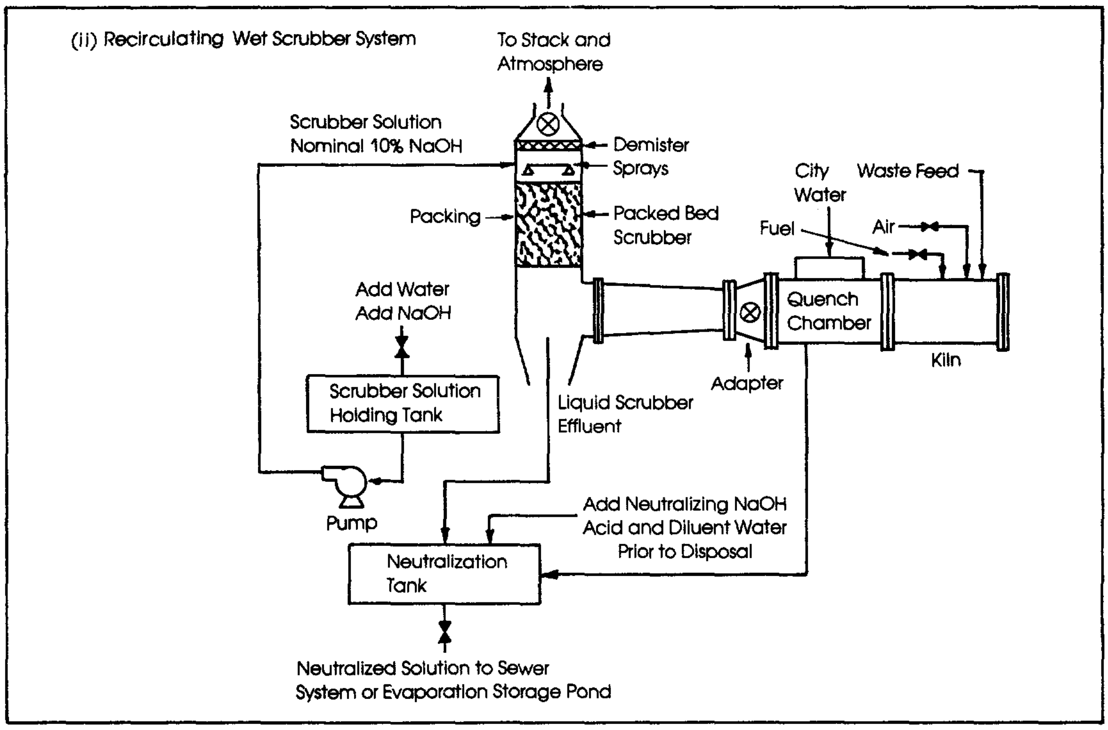
The acid scrubber water can be neutralized in situ by using a sodium hydroxide solution in the sprays; alternatively, water containing particulates, metal salts and acid species can be treated to the standard required by the receiving system (sewer, river, etc.). If mercury or other volatile metals are present, it may be necessary to pass the scrubber water through a sand filter, before releasing it to the receiving system.

Until recently sulphur dioxide emissions from hazardous waste incinerators have generally not been subject to regulatory control, since their contribution to the environmental burden is greatly overshadowed by emissions from coal-fired power stations and facilities manufacturing chemicals containing sulphur. However, the removal of sulphur dioxide can be effected by scrubbing the gases with an alkaline solution. A removal efficiency of about 80% can be achieved.

FIGURE 7.4-14

Flow Diagrams of Typical Single-pass and Recirculating Wet Scrubber Systems


(i) Single-pass Wet Scrubber System


(ii) Recirculating Wet Scrubber System

Source: Bonner, T. et al. 1981. <u>Engineering Handbook on Hazardous Waste Incineration</u>. New Jersey: Noyes Corporation.

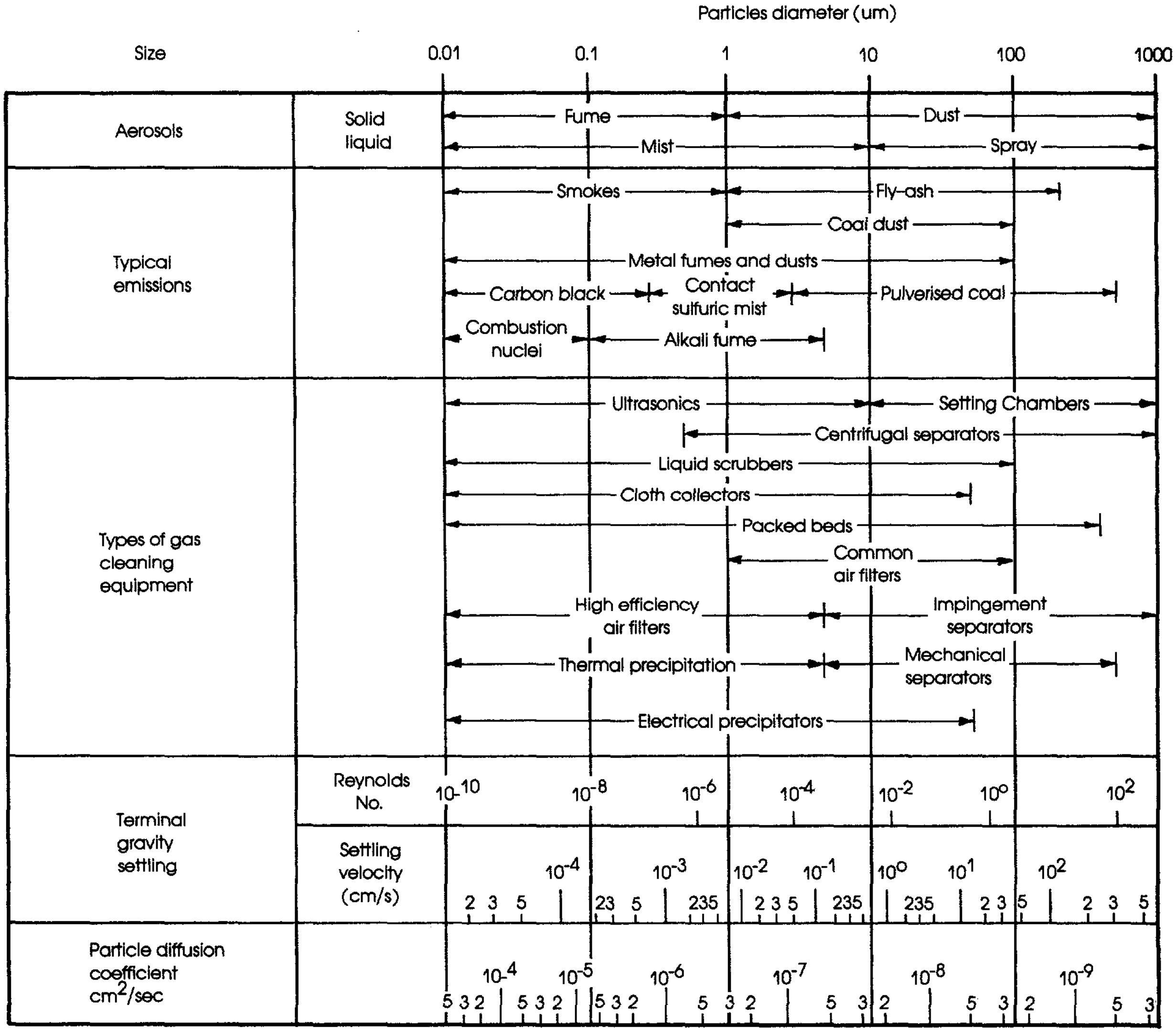
TABLE 7.4-12

Comments on Various Particulate Removal Devices

Type	Comparative Space Requirements	Comments
Cyclone	33	Does not remove soluble gases. Low removal efficiency on small particulates. Possible erosion from abrasive flyash.
Venturi scrubber	33	Simultaneous particulate and soluble gas removal. High efficiency. Clarification and neutralization of wastewater required. High energy consumption.
Spray and Packed Tower	33	Adds water to flue gas. High removal efficiency for soluble gases and aerosols (packed more efficient than spray). Low removal efficiency for fine particulates. Possible blockage of spray nozzles due to scaling.
Electrostatic precipitator, dry	100	Dry variety does not remove soluble gas. Efficient removal of fines. Low pressure drop and operating costs, but relatively high capital cost. Particle resistivity affects removal and economics.
Electrostatic precipitator, irrigated	100	Simultaneous gas absorption and particulate removals. Particle resistivity not a problem. Fines are efficiently removed, but gas absorption efficiency is low. Also removes aerosols.

TABLE 7.4-13

Equipment Utilised to Remove Varying Sizes of Particulates



Source: Palmark, Mogens.1984. Paper presented at the 2nd International Symposium on Operating European Centralized Hazardous (Chemical) Waste Management Facilities in September, Odense, Denmark.

(iv) Induced Draught Fan and Chimney

The induced draught fan draws in air from the front of the system and induces a negative pressure in the furnace (about 10-20 mm water gauge in the afterburner) minimizing emission from loading doors and other openings. It is located downstream of the gas cleaning train. The stack should be of a height and diameter that ensures that gases are emitted with sufficient velocity to overcome phenomena such as down-draughts and plume grounding, and any residual contaminants (particulates, acid species, metal oxides, unburnt waste and organic by-products) in the diluted plume are below acceptable limits at ground level.

A cold wet plume, typical of a unit employing wet gas scrubbing, is particularly susceptible to grounding due to negative buoyancy. A demisting and plume reheating unit is often located just prior to the induced draught fan to overcome this problem.

(v) The Complete Gas Cleaning Train

The complete gas cleaning train consists of a quench and/or energy recovery boiler, a particulate removal unit followed by a scrubber to absorb acid gases, a demist/reheat unit, an induced draught fan and the chimney. Some units are optional (boiler and demister) and on smaller units burning wastes that do not produce noxious gases, a gas absorber is not installed. Natural draught is also employed on some units. Slight pressurization of the furnace can sometimes occur on these systems when wastes that burn vigorously, or explosively, are introduced.

Figure 7.4-15 shows the layout of a typical gas cleaning system, in relation to the incinerator.

7.4.10 Operation and Control

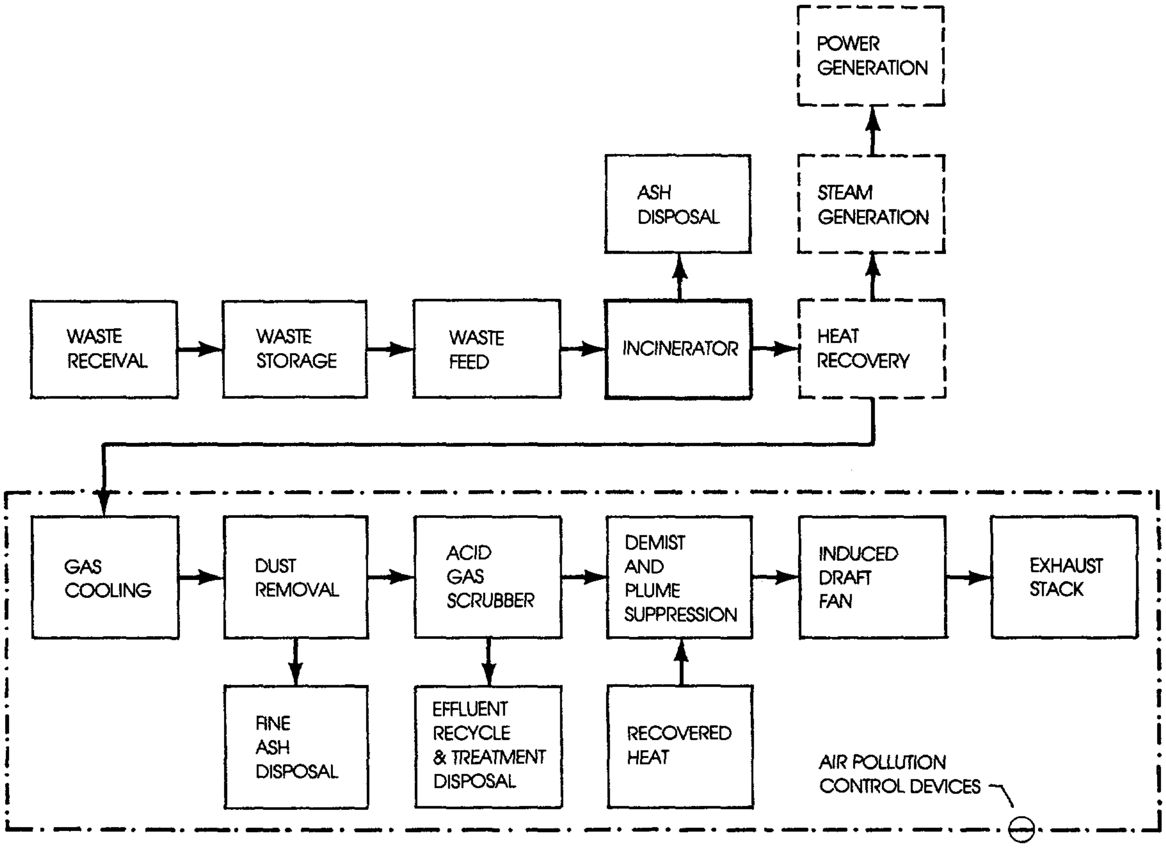
(i) Introduction

The essence of good practice in hazardous wastes incineration is control, in order that the waste be destroyed under optimum conditions. Of the Three Ts, turbulence and gas phase residence time can be regarded as being constant for the type and design of incinerator used. The variables that can be controlled are:

- waste input;
- excess air;
- temperature;
- emissions.

FIGURE 7.4-15

Schematic of Incineration System Showing Storage, Incineration and Gas Cleaning Components



(ii) Control of Waste Input and Emissions

Since no operation is 100% efficient, both the incinerator and gas cleaning system will have an efficiency rating that, although over 99%, will nevertheless allow a time fraction of the combustion products and possibly some unburnt waste to escape through the stack. The extent to which this occurs is fixed by the type and design of the equipment.

It follows that the amount of these products released to the environment is controlled by the amount and type of waste that is fed into the incinerator and also by the manner in which it is fed (see section iv and v). Depending on local regulation governing emission, the design characteristics of the incineration system will dictate an upper limit on the rate at which halogens, sulphur metals and ash-forming material is fed into the incinerator.

It is therefore important to characterize a waste as fully as possible, in order to control its input. The following information is essential:

- **Physical form.** Is it liquid or a solid, and what is its consistency? Can it be pumped or should it be put on the hearth? If liquid, what is its viscosity?

- **Composition.** Does it have metals, halogens, sulphur, nitrogen or phosphorus? If so, how much?

- **Heat content, or calorific value.** When the waste is burnt, how much heat will be generated? Can the high temperature of over 900°C be maintained with the waste alone, or will additional support fuel be needed?

- **How much ash** will the waste produce? More ash means more particulate swept out with the product gases, and greater frequency of de-ashing.

- **Any special features?** Does the waste require special precautions to be taken during handling, because it is toxic or malodorous, or cannot be mixed with other wastes? is it a waste that requires to be burnt at above 1100°C?

After the waste has been characterized by laboratory analyses, this information is used to control the temperature of the incinerator.

(iii) Control of Temperature

In order to maintain high as well as steady temperatures, the requirements are that:

- as far as possible, put in waste that does not vary much in calorific value;

- if necessary, top off the heat with support fuel, pumped in through a separate burner;

- ensure that there is ample combustion air to provide the necessary oxygen for thermal oxidation.

To achieve this, the following steps should be taken.

- After making sure that different liquid wastes can be mixed without fear of a chemical reaction or phase separation, they should be blended to maintain a calorific value of between about 14 and 19 GJ/t.

- Liquid wastes that cannot be blended should be pumped into the incinerator through a separate burner.

- Solid wastes should be introduced into the incinerator over a period of time, and well spread out to ensure even, steady burning and good access to air.

- Whilst combustion air should be in excess, it provides an additional heat burden to the incinerator, since this air has also to be raised to 1000°C and above. A balance has to be struck between the excess air and input of waste. Recovered heat is often used to preheat combustion air.

- Start-up (bringing the incinerator up to temperature from cold) should be performed with clean fuel. Only when the temperature is at the prescribed level, should wastes, particularly those containing halogens, sulphur, nitrogen, phosphorus or metals be introduced.

(iv) Feeding Wastes into an Incinerator

Pumping Sludges and Liquids: Pumps and piping materials of construction should be compatible with the type of waste processed. Positive displacement pumps are preferable to centrifugal pumps for the transfer and feeding of liquids and slurries, since they prevent siphoning when not in use.

Buner Design for Liquid Wastes: Before a liquid waste can be combusted, it must be vapourized. This is achieved by atomizing the liquid to small droplets in the heating zone of the incinerator. Liquid waste atomization can be achieved by the following means (Santoleri 1985):

- rotary cup atomization;

- single-fluid pressure atomization;

- two-fluid, low pressure air atomization;

- two-fluid, high pressure steam atomization.

The **rotary cup** consists of an open cup mounted on a hollow shaft. The cup is spun rapidly and liquid is admitted through the hollow shaft. A thin film of the liquid to be atomized is centrifugally torn from the lip of the cup and surface tension reforms it into droplets. To achieve conical shaped flames an annular high velocity jet of air (primary air) must be directed axially around the cup. For fixed firing rates, the unit can be operated for long pressurization and is ideal for atomizing liquids with relatively high solids content. Burner turndown[1] is about 5:1 and capacities from 0.005-1 m^3/h are available.

In **single-fluid pressure** atomizing nozzle (vortex) burners, the liquid is give a swirl as it passes through an orifice with internal tangential guide slots. Moderate liquid pressures of 7-10 atm provide good atomization with low to moderate liquid viscosity. In the simplest form, the waste is fed directly to the nozzle but turndown is limited to 2.5-3:1 since the degree of atomization drops rapidly with decrease in pressure. In a modified form, involving a return flow of liquid, turndown up to 10:1 can be achieved. Flames tend to be short, bushy and of low velocity.

Typical burner capacities are in the range of 0.09-0.53m^3/h. Disadvantages of single-fluid pressure atomization are erosion of the burner orifice and a tendency toward pluggage with solids or liquid pyrolysis products, particularly in smaller sizes.

In two-fluid air, or steam atomizing burners, atomization can be accomplished:

- **internally** by impinging the gas and liquid stream inside the nozzle before spraying;
- **externally** by impinging gas and liquid outside the nozzle; or/by sonic means.

Figure 7.4-16 illustrates these concepts.

Two-fluid atomizing nozzles may be of the low pressure or high pressure variety, the latter being more common with high viscosity materials. In low pressure atomizers, air from blowers at pressures from 0.03-0.3 atm is used to aid atomization of the liquid. Burner turndown ranges from 3:1-6:1. Atomization air is required at the rate of 2-6m^3 per litre of waste liquid. Less air is required as atomizing pressure is increased. The flame is relatively short as up to 40% of the stoichiometric air may be admixed with the liquid in atomization.

High pressure two-fluid burners require compressed air or steam at pressures from 2-10 atm. Air consumption is from 0.5-1.5 m^3 per litre of waste and steam requirements may be 0.2-0.4 kg per litre with careful control of the operation. Turndown is relatively poor (3:1-4:1) and considerable energy is employed for atomization. Since only a small

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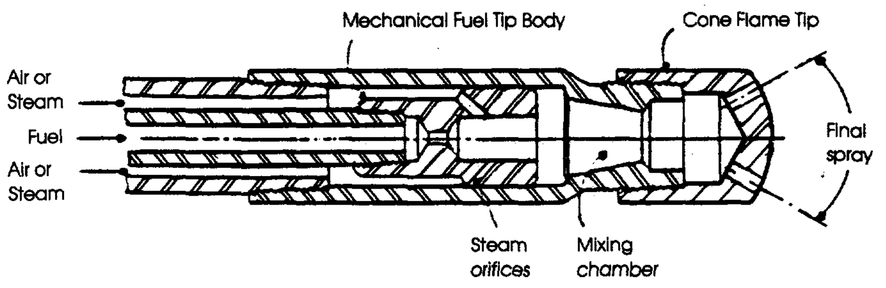
1/ Burner turndown is the ratio of maximum to minimum flow-rates through the burner in order to maintain a stable flame. For hazardous waste applications a relatively high turndown ratio (say 5:1 or higher) helps to ensure smooth operation of the burner. At low turndown (say 3:1 or less) the burner is sensitive to inconsistencies in the feed, which could lead to instability of the flame.

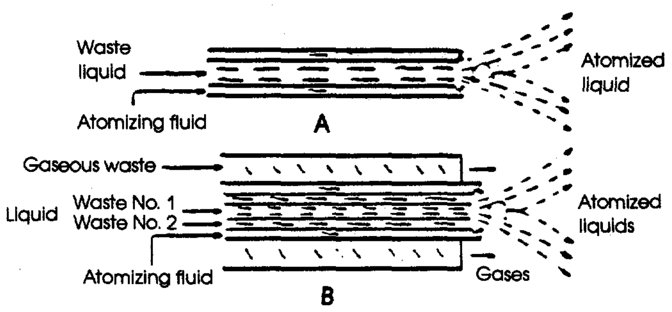
FIGURE 7.4-16

Two-fluid Atomising Burners

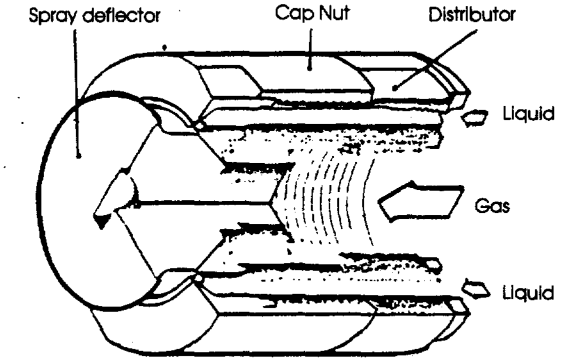
(i) Internal mix nozzle



(ii) External mix nozzles



(iii) Sonic atomizing nozzle



Source: Bonner, T. et al. 1981. Engineering Handbook on Hazardous Waste Incineration. New Jersey: Noyes Corporation.

fraction of stoichiometric air is used for atomization, flames ten to be relatively long. The major advantage of such burners is the ability to burn barely pumpable liquids without further viscosity reduction. Steam atomization also tends to reduce soot formation with wastes that would normally burn with smokey flame.

Table 7.4-14 identifies typical kinematic viscosity and solids handling limitations for the various atomization techniques. The degree of atomization achieved in any burner depends on the kinematic viscosity of the liquid and the amount of solid impurities present. Liquids should generally have a kinematic viscosity of 10,000 SSU or less than ca. 750 SSU. If the kinematic viscosity exceeds this value the atomization may not be fine enough. This may cause smoke or other unburned particles to leave the unit.

Viscosity can be reduced by heating with tank coils or in-line heaters. However, 200-260^{o}C is normally the limit for heating to reduce viscosity, since pumping a hot tar or similar material becomes difficult above these temperatures. If preheating is not feasible, a lower viscosity and miscible liquid may be added to reduce the viscosity of the mixture.

Solid impurities in the waste can interfere with burner operation via pluggage, erosion and ash build-up. Both the concentration and size of the solids, relative to the diameter of the nozzle, need to be considered. Filtration may be employed to remove solids from the waste prior to injection through the burner.

Burner Locations: The location of each burner in the incinerator and its firing angle, relative to the combustion chamber is important. In axial or side-fired nonswirling unit, the burner is mounted either on the end, firing down the length of the chamber or in a sidewall firing along the radius. Such designs, while the simple and easy to construct are relatively inefficient in their use of combustion volume. Improved utilization of combustion space and higher heat release rates can be achieved with the utilization of swirl or vortex burners or designs involving tangential entry.

Regardless of the burner location and/or gas flow pattern, however, the burner should be placed so that the flame does not impinge on refractory walls. Impingement results in flame quenching, and can lead to smoke formation or otherwise incomplete combustion. In multiple burner systems, each burner should be aligned so that its flame does not impact on other burners.

Feeding Solids: Solids can be pneumatically, mechanically or gravity fed into an incinerator. Feeders can be of the rotary, screw, vibrating or belt type. Charging of the solid feed into the incinerator can be performed as a batch process, directly into the combustion chamber or via an air lock or continuously, using belt or screw conveyors.

TABLE 7.4-14

Kinematic Viscosity and Solids Handling Limitations of Various Atomization Techniques

Atomization Type	Maximum Kinematic Viscosity, SSU	Maximum Solids Mesh Size	Maximum Solids Concentration
Rotary cup	175 to 300	35 to 100	20%
Single-fluid pressure	150		Essentially zero
Internal low pressure air (<30 psi)	100		Essentially zero
External low pressure air	200 to 1,500	200 (depends on nozzle ID)	30% (depends on nozzle ID)
External high pressure air	150 to 5,000	100 to 200 (depends on nozzel ID)	70%
External high pressure steam	150 to 5,000	100 to 200 (depends on nozzle ID)	70%

Source: Bonner, T. et al. 1981. Engineering Handbook on Hazardous Waste Incineration. New Jersey: Noyes Corporation.

(v) Ancillary Equipment and Support Services

Control of the various parameters discussed above is only possible if the appropriate ancillary equipment such as blending tanks, storage tanks, etc and installed. It is not enough merely to ensure that the incineration process itself is properly controlled. All aspects of the operation should be handled in a responsible and safe manner. Those areas which require particular attention include the following.

- **Waste Reception.** Transport of wastes to an incineration facility can be by rail, road or more unusually by pipeline. they may be in bulk tankers or in drums. It is necessary to ensure that weights and volumes are recorded, wastes are transferred from the vehicle to appropriate reception tanks or drummed waste areas, properly labelled and safely stored. A handling procedure is illustrated in Figure 7.4-17.

- **Laboratory Control.** The laboratory is a vital aspect of control because its function is to analyze incoming wastes, characterize wastes according to (ii) above, check on compatibility and measure and record emissions.

- **Waste Storage and Blending.** The capacity and range of storage facilities for incoming wastes and for blending will dictate the extent to which waste input can be controlled. Commercial facilities offering a service to a broad range of industries would have a tank farm for storage and blending of liquid wastes, separate storage facilities (possibly in a special zone for flammable liquids) for support fuel, drum and container storage area, drum emptying and shredding equipment, and a secure area for the storage and handling of wastes containing PCBs.

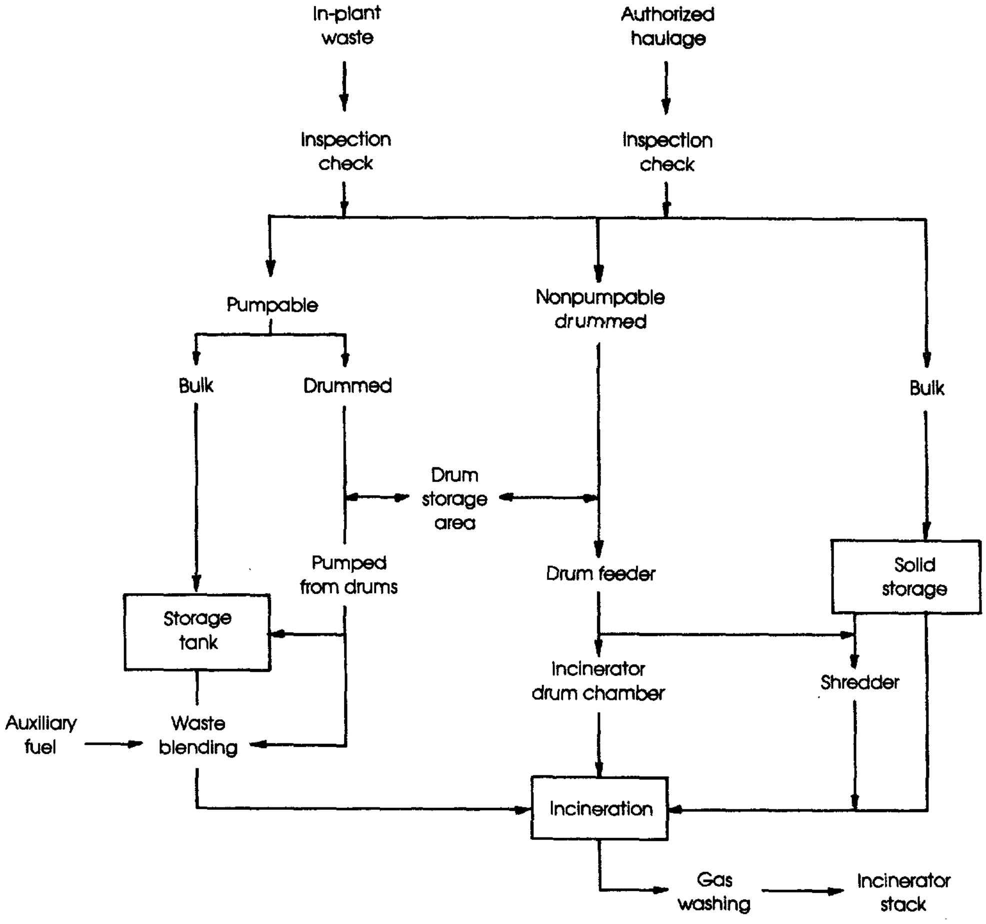
- **Pre-treatment.** The separation of water from refinery sludges and other aqueous/organic wastes is the most common form of pre-treatment, designed to improve the calorific value of the waste. Other activities include simple operations such as the draining of liquid from PCB capacitors and transformers, in order to reduce PCB loading on the hearth and to transfer it instead to the more controllable liquid inputs.

- **Instrumentation.** Many features of incinerator control can be accomplished by the aid of computers, which automatically adjust inputs of waste material, combustion air and support fuel in order to maintain optimum conditions, adhere to emission limits and cut off waste feed in the event of an emergency shutdown. Oxygen and gas (CO and/or CO_2) thermocouples and plume opacity meters should be used to monitor excess air and combustion efficiency, temperature and particulate emissions.

- **Records.** Each stage of the operation, from waste reception to incineration, should be supervised and adequate records detailing its fate must be kept. This includes the recording of incinerator parameters such a temperature, the logging of waste inputs, and the

FIGURE 7.4-17

Flow Diagram Showing Handling Procedures for Incineration of Hazardous Wastes



Source: Bonner, T. et al. 1981. Engineering Handbook on Hazardous Waste Incineration. New Jersey: Noyes Corporation.

monitoring of gas emissions for particulates, unburnt organics and acid species, generally hydrochloric acid.

o **Personnel.** Incineration is a process that requires the attention of thoroughly trained operators. While instrumentation and microcomputer can take over many of the functions of an operator, even the most sophisticated incinerators require careful control and vigilance. Operators should appreciate the basics of incineration, be aware of special condition for certain wastes (for example PCBs) and be able to respond to emergencies.

(vi) The Complete System

A block diagram showing the general arrangement of an incineration facility is given in Figure 7.4-15. Optional items are enclosed in boxes with broken lines. Examples of plant layout are shown in Figure 7.4-18 for a liquid combustion and a rotary kiln. Further details of plant layout and operating procedures were discussed in Section (6), on central treatment plants.

(vii) Malfunctions and Fugitive Emissions

Malfunctions on a hazardous waste incinerator can occur for a variety of reasons: blockages in burners, layering in storage tanks causing a sudden change in feed composition build-up of scale in pumps and pipelines, instrument and equipment failure, etc. Table 7.4-15 lists some possible malfunctions and their remedies (Bonner et al. 1981).

Table 7.4-16 lists some possible sources of fugitive emissions from hazardous waste incineration facilities. Possible process leakage areas are shown in Figure 7.4-19.

The key to the adequate handling and prevention of malfunctions, spillages and other plant problems is the formulation of comprehensive systems of work, decision making trees in the event of an occurrence, clear delegation of responsibility to appropriate operators and supervisor staff, and a regular and routine maintenance programme.

(viii) Siting of Incinerators

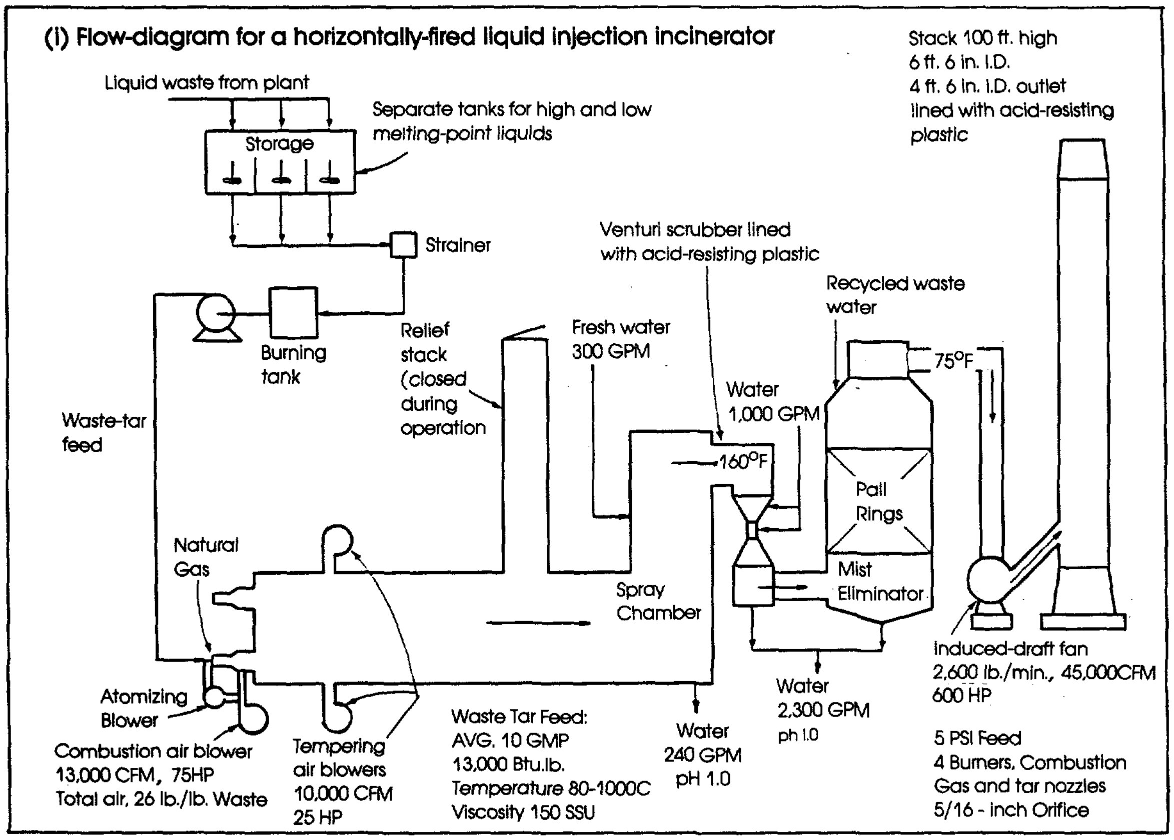
The siting of hazardous waste incinerators is a problem which has taxed many countries embarking on a national waste disposal strategy. Apart from geological considerations and access for industrial waste producers, the proximity of the proposed facility to residential areas and farmland should be taken into account, especially from the viewpoint of possible environmental damage resulting from stack emissions.

Meteorological data can be used to compute the dispersion characteristics of stack emissions. As a general rule of thumb, the point of maximum impact of a plume occurs between 15 and 30 stack lengths from the plant, and therefore the nearest residential area in the most frequent wind direction should be at least 60 stack lengths away. An approximate

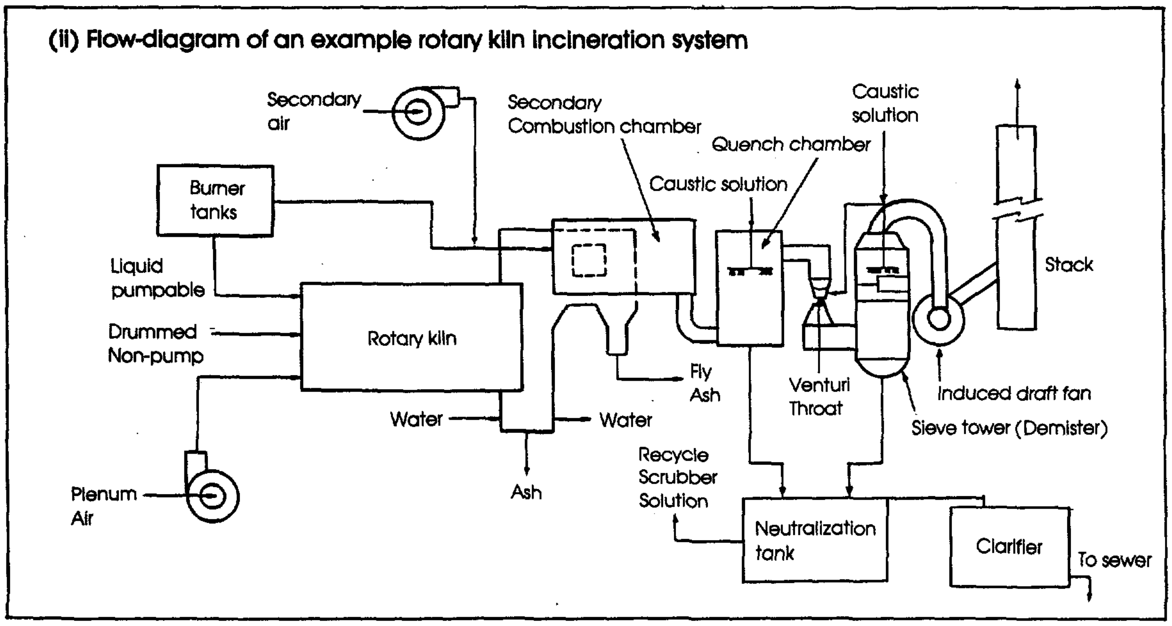
FIGURE 7.4-18

Examples of Plant Layout for Liquid Combustion and Rotary Kilns

(i) Flow-diagram for a horizontally-fired liquid injection incinerator



(ii) Flow-diagram of an example rotary kiln incineration system



Source: Oppelt, E. T. 1986. Thermal destruction of hazardous waste. Presented at US/Spain Joint Seminar on Hazardous Wastes, Madrid.

TABLE 7.4-15

Hazardous Waste Incinerator Malfunctions and Remedial or Emergency Responses

No.	Malfunction	Type Incinerator[a]	Malfunction Indication	Response
1	Partial or complete stoppage of liquid waste feed delivery to all liquid burners	L C	(a) Flowmeter reading out of specified range (b) Pressure build-up in feed lines (c) Change combustion zone temperature (d) Feed pump failure, zero amps	Halt waste feed, start trouble-shooting and maintenance in affected system. Re-initiate or increase auxiliary fuel feed to maintain combustion zone temperatures; continue operation of air pollution control devices (APCD)
2	Partial or complete stoppage of liquid waste to only one burner	L C	As in (a), (b) and (c) above	Halt waste feed to affected burner only
3	Partial or complete stoppage of solid wastes feed to rotary kiln	RK C	(a) Drop in RK combustion temperature (b) Power loss in waste feed conveyor or other feed system	As in 1 above
4	"Puffing" or sudden occurence of fugitive emissions from RK due to thermal instability or excessive feed rate of wastes to RD, or failure of seals	RK C	(a) Pressure surge in kiln (rapid change in manometer level) (b) Visible emission from air seals at either end of kiln	(a) Halt feeding of any solid waste to kiln for 10-30 min. but continue combustion (b) Evacuate unneeded personnel from immediate vicinity of kiln (c) Re-evaluate waste prior to further incineration

TABLE 7.4-15 (continued)

No.	Malfunction	Type Incinerator[a]	Malfunction Indication	Response
5	Failure of forced air supply to liquid waste feed or fuel burners	L RK C	(a) Flowmeter reading for air supply off scale (b) Automatic flame detector alarm activated (c) Zero amps or excessive current draw on blower motor(s)	(a) Halt waste and fuel feed immediately (b) Start trouble shooting immediately and restart as soon as possible (c) Continue operation of APCD's but reduce air flow at induced draft fan by "damping' accessory
6	Combustion temperature too high	L RK C	(a) Temperature indicator(s) at instrument control panel (b) Annunciator or other alarm sounded	(a) Check fuel or waste feed flow rates; reduce if necessary (b) Check temperature sensors (c) Check other indicators in combustor if multiple sensors used (d) Automatic or manual activation of combustion chamber vent
7	Combustion temperature too low	L RK C	(a) - as above (b) - as above	(a) Check other indicators in combustor if multiple sensors are used (b) Check fuel or waste feed flow rates; increase if necessary (c) Check sensor accuracy
8	Sudden loss of integrity of refractory lining	L RK C	(a) Sudden loud noise (b) Partial stoppage of air drawn into combustor resulting in decreasing combustion temperatures, increased particulate emissions and development of hot spots on external of combustor shell	Shut down facility as quickly as possible

TABLE 7.4-15 (continued)

No.	Malfunction	Type Incinerator[a]	Malfunction Indication	Response
9	Excess opacity of stack plume	L RK C	Visual or instrument opacity readings which are above maximum allowable operating point	(a) Check combustion conditions, especially temperatures O_2 (excess air) and CO monitor (b) Check APCD operation (c) Check nature and feed rates of wastes being burned (d) Check ESP rapping interval, cycle duration and intensity
10	CO in exhaust gas in excess of 100 ppm or in excess of normal CO values	L	CO indicator	Check and adjust combustion conditions, especially temperature and excess air (O_2 in stack gas), and adjust accordingly
11	Indication of or actual failure of induced draft fan	L RK C	(a) Motor overheating (b) Excessive or zero current (amps) (c) Total stoppage of fan (d) Pressure Drop across blower inlet and outlet	(a) Switch to standby fan if available (b) If two induced draft fans are used in series, reduce operational levels immediately, stop the failing unit and operate at reduced rate on one fan only, until maintenance can be completed (c) If there is only one fan, and the fan failure appears serious, shift into an emergency shutdown mode for entire incinerator
12	Increase in gas temperature after quench zone affecting scrubber operation	L RK C	(a) Partial or total loss of water supply to quench zone (b) Increase of combustion temperatures	(a) Check water flow to quench zone. Prepare for limited operation rate until water supply is restored (b) Check combustion conditions especially temperature

TABLE 7.4-15 (continued)

No.	Malfunction	Type Incinerator[a]	Malfunction Indication	Response
13	Partial or complete stoppage of water or caustic solution to scrubber(s)	L RK	(a) Decrease in pressure drop across scrubber as indicated by manometers or other instruments (b) Zero or increased amps on water or solution pumps (c) Flowmeter readings out of specified range (d) Large increase in acid components in stack gas as detected by NDIR or other type instruments	(a) Halt waste feed, start trouble shooting and maintenance in affected system (b) Start up redundant pumps, if available (c) Check recycle water or solution tank levels (d) If using alkaline solution, switch to water supply if available (e) Check for deposition of solids from recycled liquors in pump lines (f) Use emergency (standby water supply which will feed water by gravity until the whole system can be shutdown
14	Deposition of solids in scrubber from recycled wastes or caustic solution, or from excess solids emissions from combustor	L RK C	(a) Buildup of pressure drop across scrubber as indicated by manometers or other instruments (b) Increased holdup of liquor in packed or tray towers, up to and including flooded condition. This can also be detected by liquid level indicators.	This requires a shutdown to clean out the tower and internals. The shutdown can be scheduled if the deposit buildup is gradual and monitored.

TABLE 7.4-15 (continued)

No.	Malfunction	Type Incinerator[a]	Malfunction Indication	Response
15	pH of recycled scrubber liquor not in spec	L RK C	(a) Continuous, or spot-checking pH indicator shows actual pH to be outside of desired operating range (b) Drop in scrubber efficiency with excess acid gas in stack gas	(a) Check for adequate supply and metering of alkaline agent (b) Check accuracy of pH meter and alkaline solution metering pump associated with recycling of scrubber liquor
16	Failure of demister operation	L RK C	Increased pressure drop, as measured by manometer, due to solids accumulation in demister element	Back-wash element

[a] L = Liquid injection: RK = Rotary kiln: C = Combination liquid injection and rotary kiln.

TABLE 7.4-16

Possible Sources of Fugitive Emissions from Hazardous Waste Incinerator Systems

Waste Processing and Feed

- o Waste shipping
- o Waste unloading
- o Waste loading to preparation/processing plant
- o Waste processing
    - Crushing
    - Sizing
    - Washing
    - Drying
- o Fine particulate removal or preparation for recyle
- o Material transfer in waste processing plant
- o Fugitives from loading/unloading storage bins
- o Waste feed hopper backflow

Waste Incineration and Pollution Control

- o Waste feed
- o Waste incineration/feed
- o Air flow leaks in the incinerator furnace and associated systems
- o Ash collection
- o Stack flue gas particulate removal and disposal systems
- o Ancillary equipment
    - Scrubber wastes/neutralization water
    - Dust collectors
    - Secondary combustion units (afterburners)
    - Gas/steam storage lines and transport lines
    - Water treatment units
    - Air coolers
    - Mixing chambers
- o Ancillary equipment leaks

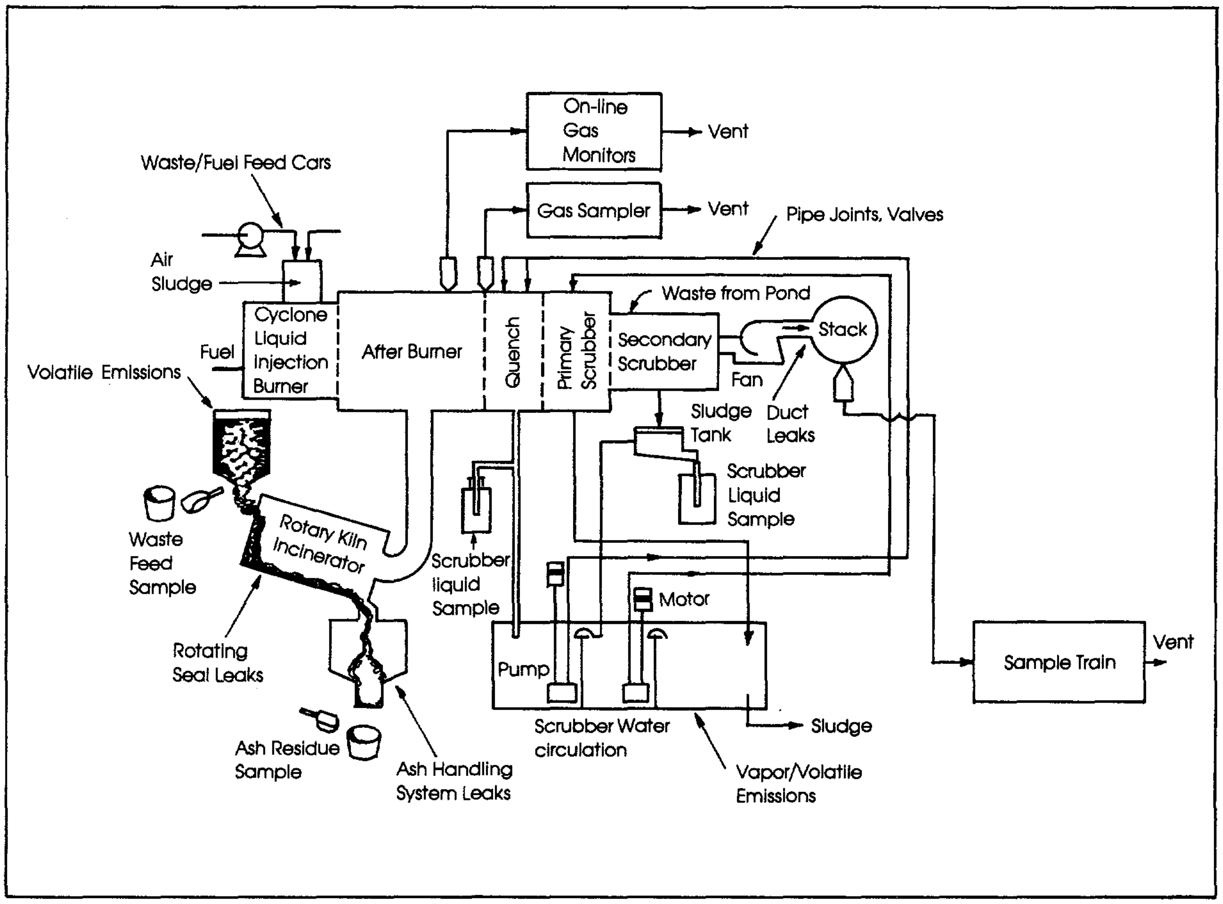
Removal or Disposal Methods

- o Solids removal
- o Ash transfer and storage
- o Recycling systems
- o Transfer lines for scrubber and cooler water
- o Ash transport vehicles
- o Ash transport
- o Ash unloading
- o Ash disposal

Source: Bonner, T. et al. 1981. Engineering Handbook on izardous Waste Incineration. New Jersey: Noyes Corporation.

FIGURE 7.4-19

Possible Process Leakage Areas



Source: Bonner, T. et al. 1981. Engineering Handbook on Hazardous Waste Incineration. New Jersey: Noyes Corporation.

maximum stack emission for a particular (non-carcinogenic) chemical can be calculated from the formula

$$M = 0.56H^2(TLV)$$

where M = emission rate (kg/d)

H = effective stack height (m)

TLV = threshold limit value (mg/m^3)

This formula assumes a safe maximum ground level concentration of TLV/40mg/m^3.

The transportation of hazardous waste to the fully is another potential source of risk to the surrounding community. An analysis of spillage scenarios should be performed taking into account the quantity, type, physical form, and the method of containment of the waste, and emergency measures formulated in anticipation of an incident.

Decisions on siting should be supported by comprehensive environmental quality and safety legislation in order to gain the confidence of the general public.

7.4.11 Incineration at Sea

(i) Introduction

Land-based incineration facilities are high profile operations, often attracting adverse public comment because surrounding communities fear a fallout of hazardous by-products from incinerator malfunction. The attraction of incinerating hazardous wastes at sea is that the operation can be carried out sufficiently far from the coast to ensure that communities are not affected by the emissions.

Under the strict conditions prescribed by the regulatory Conventions, sea incineration is an acceptable option of certain liquid wastes. Nevertheless, some countries consider that, at the present time, incineration at sea should be regarded as only a temporary solution to the problem of waste disposal. Two companies have invested in this disposal route. Chemical Waste Management owns two ships: Vulcanus I (docked in Belgium) and Vulcanus II, currently operating in European waters. At-Sea Incineration owns Apollo I and Apollo II, neither of which are operating. Environmental protection agencies in USA and Australia have had to revoke licences to Chemical Waste Management because of intense opposition from environmental lobbies.

(ii) Incinerator Conditions and Gas Cleaning

The prime requirements on the physical form of the waste is that it should be sufficiently liquid to be pumped on board and into the incinerator. Since wastes that are the most difficult to incinerate (either because they are thermally stable or because they can generate hazardous by-products) cause the most concern to land-based communities, these are the types that are considered for incineration at sea. In the main, they comprise chlorinated liquid organic wastes, including PCBs.

The Three Ts are as applicable at sea as they are on land, and the same conditions discussed in Section 7.4.2 must be met. The essential difference from land-based systems is that in sea incineration, the combustion products escape directly into the atmosphere, without being subjected to gas cleaning. The gaseous emissions are merely allowed to disperse into the atmosphere and the noxious component, hydrogen chloride, is eventually absorbed by the sea.

The incinerator generally consists of two units in parallel, each comprising a combustion chamber and a stack. Aboard the Vulcanus I, each unit has a burning rate of 12t/h and a residence time of 0.9 seconds at 1200°C. Wastes have commonly been destroyed to over 99.99% DRE (Shih et al. 1978).

Advantages of sea incineration are that:

- incineration can be conducted far away from human habitation;
- gas cleaning is not necessary. Incineration at sea is therefore economically attractive for highly chlorinated materials. While capital costs for land-and sea-based units are comparable, unit treatment costs for the former are 2.5 times greater (Shih et al. 1978);
- seawater is an excellent diluent for the hydrogen chloride produced during incineration.

The **disadvantages** include:

- the dispersion of the clouds of gaseous combustion products and their incorporation into seawater are not entirely predictable;
- the transportation of wastes to the vessel, by rail, road or ship, poses additional risks of spillages, possibly leading to environmental damage;
- a catastrophe at sea could cause the entire untreated load to be lost;
- risk of contravention of the Sea Disposal Conventions if heavy metal contamination is significant.

(iii) Regulatory Control

International control over sea incineration is exercised through two Conventions on Dumping at Sea:

- the Oslo Convention (1972), covering the North Sea and the North Eastern Atlantic;

- the London Convention (1975), applicable worldwide.

These conventions require that:

- land-based disposal alternatives should first be considered before sea incineration is undertaken;
- extensive tests must be performed to verify that the equipment on board is suitable for its purpose and that all conditions of the Convention are met. Only then can sea incineration be permitted by **special license;**
- these tests should be repeated at intervals of about two years;
- the critical operational parameters must be recorded, and all operation must be closely monitored to ensure that no damage is caused to the marine environment.

7.4.12 Design Parameters for Incineration Facilities

(i) Introduction

Incineration is generally a high-cost disposal option, the exception being some systems using existing industrial plant, open-pit systems and some small incinerators operating without air pollution control equipment. An economic assessment of incineration, therefore, plays an important part in formulating a waste disposal strategy. In this section, the costs for a hazardous dedicated facility are presented for three kinds of incinerator - the rotary kiln, multiple chamber and liquid injection systems. In addition, costs are presented for conversion of lime or cement kilns to burn hazardous wastes.

The assumptions involved in arriving at the final installed cost must be clearly defined. Monographs presented in this section have been developed from information give in Vogel and Martin (1983, 1984), and are expected within ±30% of actual costs.

(ii) Sizing of Equipment

For a given heat input, an approximate indication of the fluegas volume and chamber size is necessary to calculate costs of refractors and gas cleaning equipment. Simplified graphical procedures have been developed by Vogel and Martin (1983, 1984).

Figure 7.4-20 shows the flue gas volume as a function of heat input, for various excess air concentrations, and also shows the enthalphy, or heat content, of the flue gas for various combustion zone temperatures.

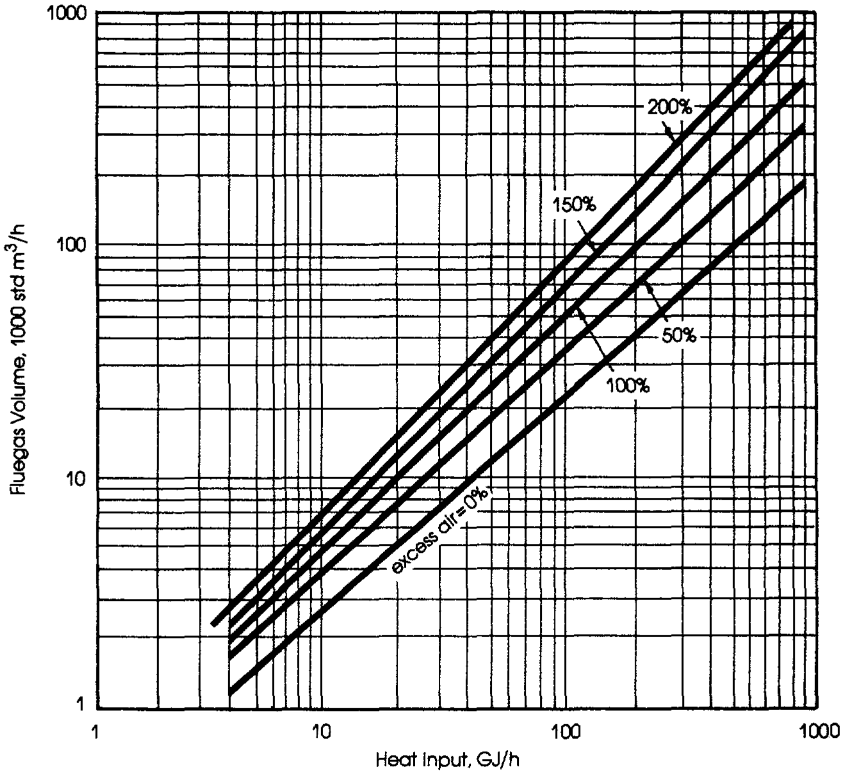
The total heat output from the incinerator is given by:

Heat output = (enthalphy x flue gas volume) + water vapour enthalphy + radiation loss

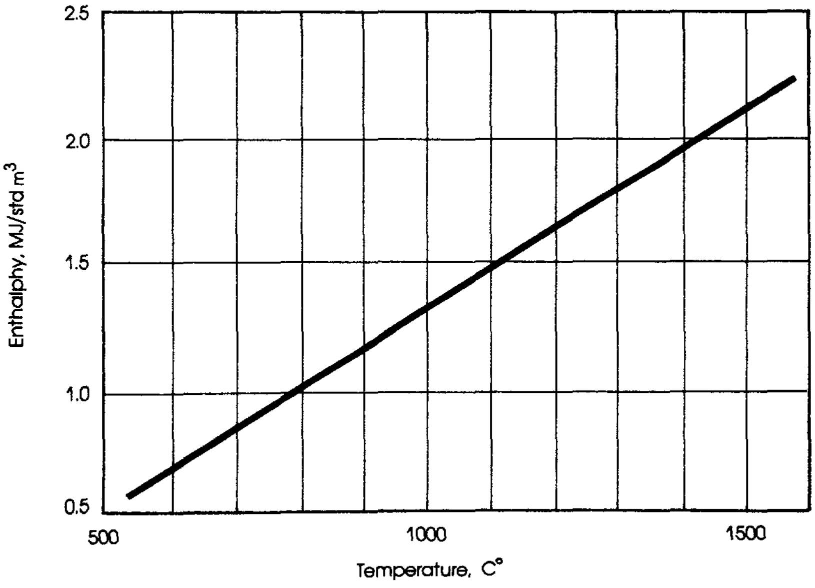
FIGURE 7.4-20

Heat Input versus Flue-gas Volume

(i) Heat input



(ii) Combustion temperature versus Flue-gas enthalpy



A reasonable approximation is to take water vapour enthalphy as 10% of heat input, and radiation loss as 5% of heat input.

Support fuel requirements are estimated from:

Support fuel needed = Heat output - Heat input

In this approach heat is added to the heat output, and the total flue gas flowrate into the scrubber is read off Figure 7.4-20. The flowrate downstream of the scrubber is obtained by adding to the dry flowrate, corrected to the exit temperature, the percentage of water in the saturated gas also at that temperature.

Typical heat-release rates for incinerators are 0.56-0.94 GJ/h/m for hearth types, 0.94-2.3 GJ/h/m for liquid injector combustors. The volume of the primary combustion chamber may be obtained by dividing the entire heat input by the rate of heat release, taking a mid-point value for the latter. Secondary (afterburner) chamber volume is obtained by correcting the total flue-gas flowrate to the combustion zone temperature, and allowing a 2-second residence time.

From the volumes of the primary and secondary chambers, the costs of fabrication, refractories and installation can be estimated. The flue-gas flowrate can be used to size and cost gas cleaning equipment. Heat requirements will determine the number and size of burner systems and fans. Assuming that 320 kg of air is needed for every GJ of heat released (Corey 1969), approximate combustion air requirements for a waste can be computed from the relationship:

$$A = H\ (3.2(\%) + 320)$$

where A = combustion air needed (kg/t of waste);
% = percentage of excess air.

7.4.13 Costs for Incineration Facilities

(i) Cement and Lime Kilns

Capital Costs: If hazardous waste is to be burnt in a cement or lime kiln, provisions must be made for the receiving, storage and handling of large quantities of this material.

For example, a typical large cement kiln would require about 140 litres of wastes with a calorific value of 20 GJ/t, per tonne of clinker if operated at a 50/50 waste/base fuel ratio. A 500,000 t/y kiln would consume about 9 m^3 of waste per hour. Requirements for a hazardous waste system would include a receiving facility, blending tanks, a laboratory, a working tank and a fuel delivery system to the burners. These requirements are discussed are more fully in (USEPA 1985c). Table 7.4-17 itemizes capital costs for a such a facility.

TABLE 7.4-17

Estimated Costs of Hazardous Waste Supplement Fuel System for a 500,000-ton/year Cement Kiln (thousands of 1985 dollars)

A. Capital costs

Four 25,000-gal storage and blending tanks	240
One 150,000-gal working tank	150
Pumps, motor, and auxiliary equipment and instrumentation	180
Containment system, pumps, and paved areas	70
Laboratory building	100
Laboratory equipment and safety equipment	120
Fuel delivery system	50
Contingencies, 20%	180
	1090

B. Annualized costs

Materials and supplies	30
Maintenance	20
Operating labor and G&A	160
Capital recovery	220
	430

[a] Does not include costs related to obtaining permits and community and employee relations.

Operating Costs: A typical 500,000 t/y cement kiln consumes about 2,500,000 GJ/y. Based on a cost of $4/GJ, a fuel saving of $2.5 million/y can be realized by replacing half the total energy requirements with hazardous waste fuel costing only half as much. If the waste is such that generators will pay for this means of disposal, there will be an additional revenue to be credited to the process.

Annual costs of owning and operating the above plant are listed in Table 7.4-17. Estimated annual savings of a hazardous waste fuel programme for process kilns is shown in Figure 7.4-21.

(ii) Dedicated Hazardous Waste Incinerators

Capital costs: For commercial incineration facilities, the initial capital investment and interest payments are crucial factors; for example, depreciation of a $10 million facility over a 10-year period alone amounts to $1 million per annum, a daunting cost to recover from fees charged for treatment. For public owned facilities, this aspect is alleviated by subsidies and low-interest loans. Capital costs are also influenced by the availability of local equipment manufacturers and the extent of importation.

Total equipment costs (TEC), including provision for waste storage and conveyance, the incinerator, complete gas cleaning equipment, energy-recovery boiler and ancillary equipment such as chimney valves and blowers, are shown in Figure 7.4-22 as a function of heat input. The lower limit for rotary kilns is taken as 4 GJ/h which is equivalent to a loading rate of 300 kg/h of solids with a calorific value of 14GJ/t.

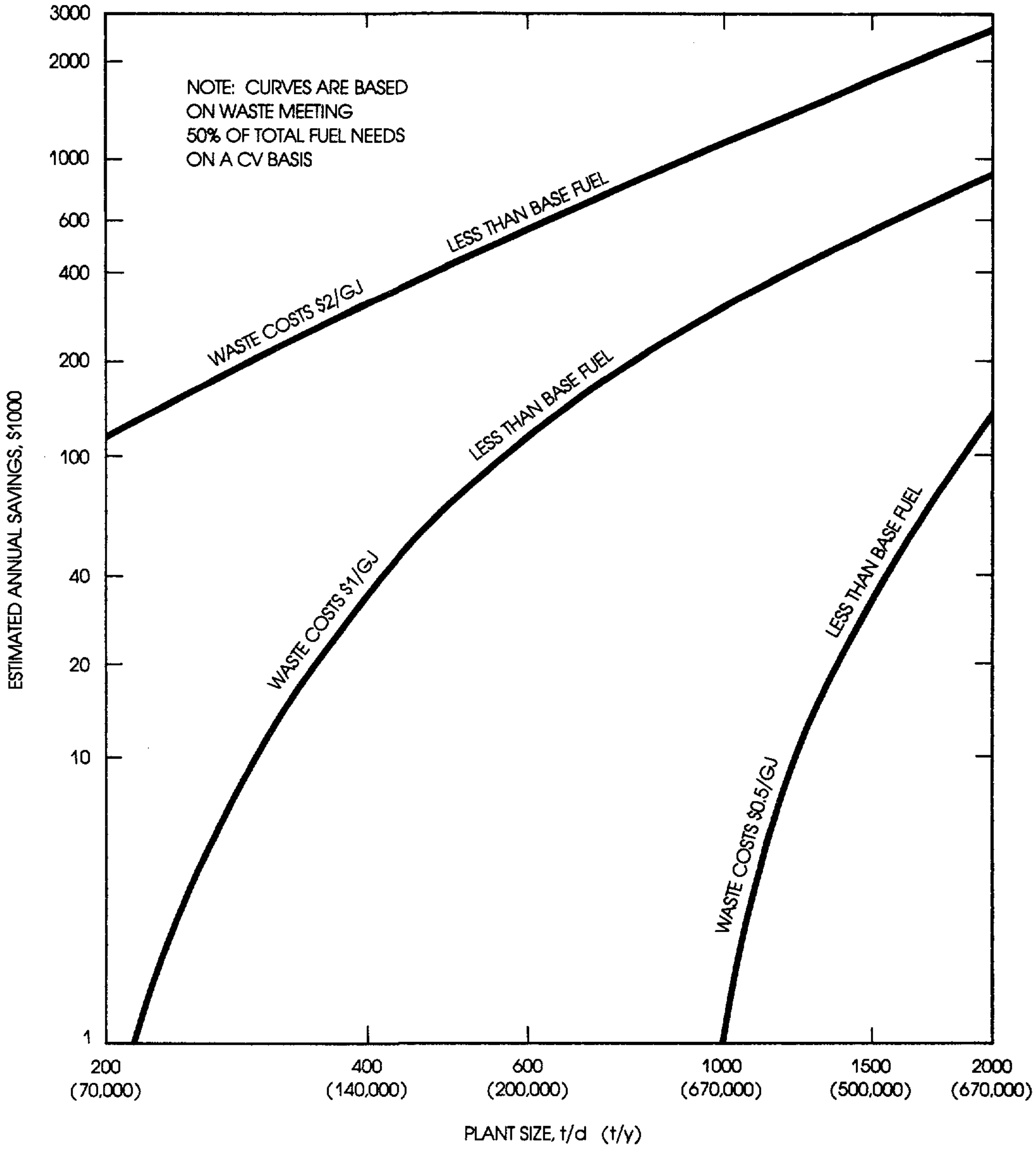
The cost of installation, piping, electrical and instrumentation, building structure and foundations amounts to 100% of the TEC. The Installed Plant Costs (IPC) is made up as follows:

Total Equipment Costs	100% of TEC
Electricals and Instrumentation	15% of TEC
Buildings, structures and foundations	30% of TEC
Piping	40% of TEC
Installation	15% of TEC
Installed Plant Cost (IPC)	**200% of TEC**

With an engineering construction and contingency factor equal to 50% of IPC, **Total Capital Investment = 3 (TEC)** the cost of the gas cleaning system is separated from the total equipment costs, and is given in Figure 7.4-23. The system includes a quench chamber, venturi scrubber, packed-tower absorber and mist eliminator, together with the necessary auxiliary equipment. The eliminator, together with the necessary auxiliary equipment. The capital cost of an electrostatic precipitator is about twice that of a packed tower absorber but total installed costs for the two items are comparable. Investment in gas cleaning equipment is generally between 10%-50% of TEC, depending on its degree of sophistication.

FIGURE 7.4-21

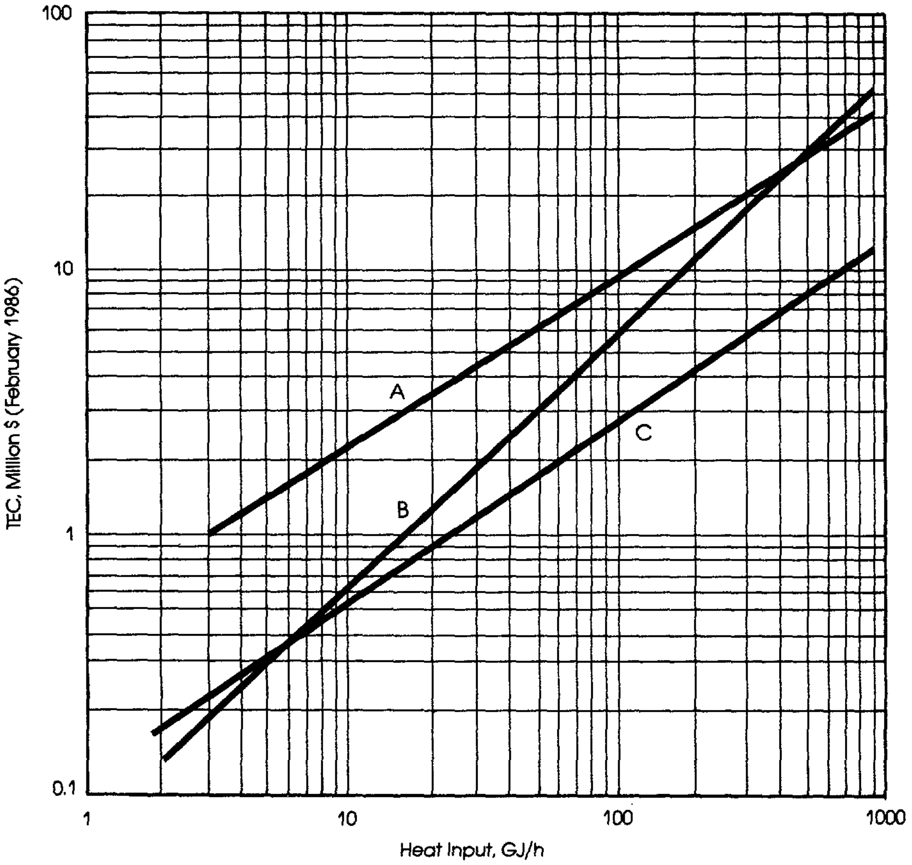
Estimated Annual Savings of Waste Program for Process Kilns



Source: USEPA. 1985. <u>Guidance Manual for Co-firing Hazardous Wastes in Cement and Lime Kilns</u>. Contract no. 68-02-3995.

FIGURE 7.4-22

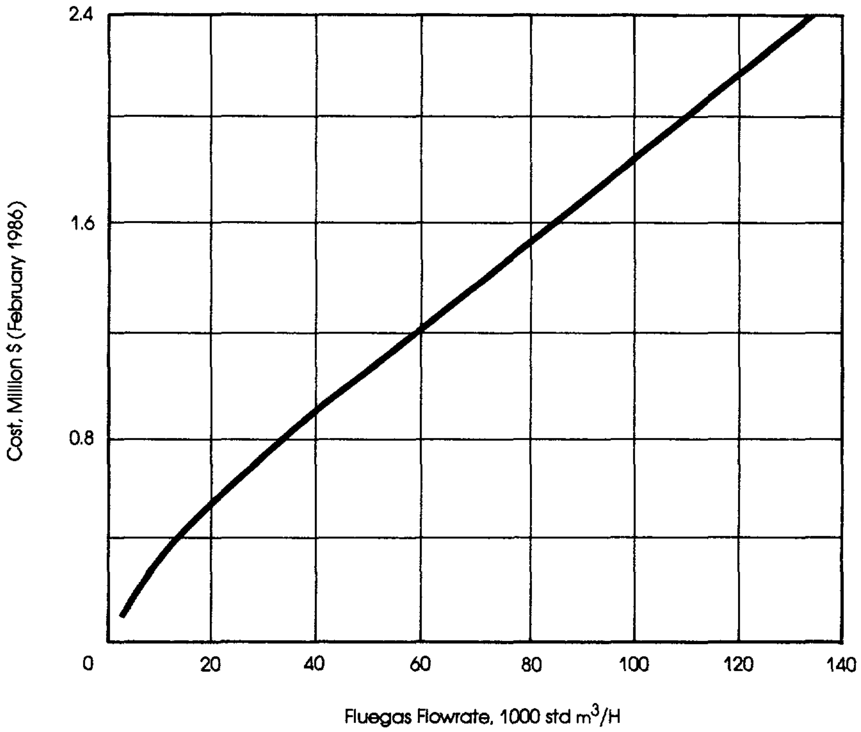
Total Equipment Cost



A= Rotary Kilns; B= Hearth Types; C=Liquid Combustors

FIGURE 7.4-23

Cost of Gas Cleaning Equipment



Operating costs: Direct operating costs include items for personnel, electricity, water, fuel, chemicals, effluent disposal, laboratory support and maintenance (including refractory equipment). Set against these is the credit from recovered steam, if an energy-recovery system has been installed. Indirect operating costs include taxes, insurance, overheads, administration and capital recovery. Annual maintenance may be estimated as being 5% of the IPC. Total annual direct and indirect operating costs are about 50% of IPC for all systems.

Net operating costs are estimated by subtracting from the total annual operating costs the revenue obtained from energy recovery. In Figure 7.4-24 the latter is illustrated as a function of heat input, assuming an energy recovery efficiency of 60% and an equivalent fuel cost of $11/GJ.

(iii) Unit Disposal Costs

The unit cost of disposal is fixed by capital and operating costs. Economy of scale results in a lowering of unit costs with increase in incinerator size, though total annual operating costs increase with plant size. Charges are based on weight, calorific value, water content, halogen content, degree of handling and pre-treatment required prior to incineration (for example, separating out water), incineration costs (support fuel, alkali for neutralization of acid gases, etc.) and overheads.

Unit disposal costs can be estimated by a discounted cash flow (DCF) technique, which determines the annual revenue during the plant life that will generate a discounted cash flow equal to the total capital investment. The unit disposal cost, ($/t) is given by

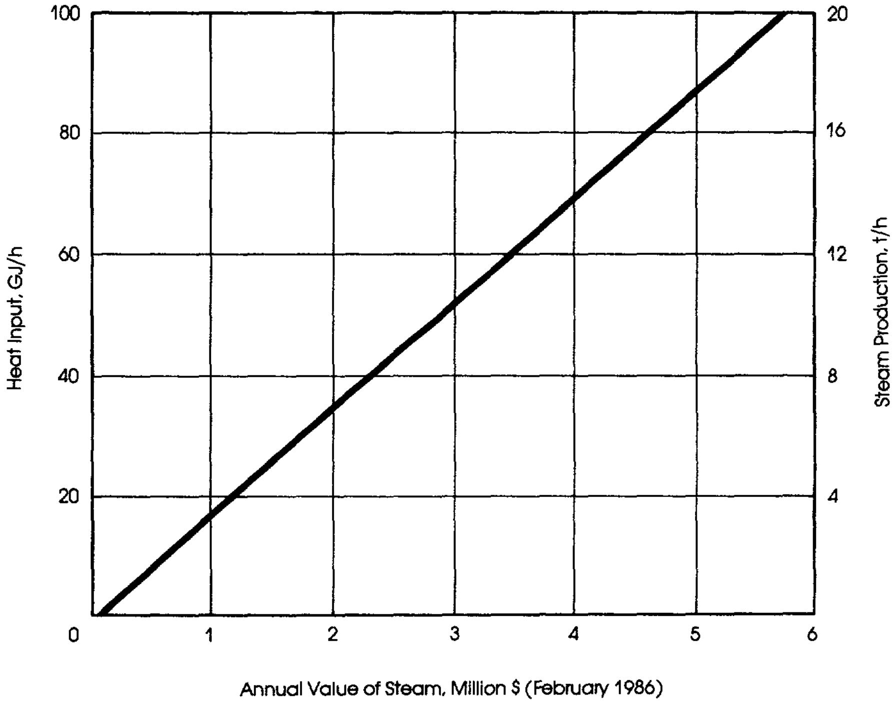
$$(\$/t) = \frac{C + aI + bW + cU + S}{G}$$

where C = total annual operating costs, $
I = capital investment, $
W = working capital, $
U = startup cost, $
S = credits received from the sale of products generated by incineration, $
G = annual quantity of waste disposal, t
a = e2R +0.061 R - 1 - 0.1
1 - e-12R
b = 2R
c = 1 - e-R
1 - e-10R
R = discounted cash flow rate of return, %/100

The assumptions involved in this approach are given in Shih et al. (1978).

FIGURE 7.4-24

Annual Revenue from Heat Recovery



(iv) Worked Exampled for a Dedicated Rotary Kiln Incinerator

The methods discussed above are illustrated in a worked example, making use of Figures 7.4 20 through 7.4-24 and the various equations.

Basis

Incinerator type	rotary kiln
Composition of waste (chlorine and ash)	6% chlorine, 8% ash
Calorific value of waste	14 GJ/t
Calorific value of support fuel	30 GJ/t
Waste feedrate	1 t/h for 8000h/year
Afterburner chamber	1200^{o}C for 2s
Excess air usage	150%
Heat release rate	1.2 GJ/h/m^3
Gas temperature downstream of scrubber	80^{o}C
Total pressure drop through system	0.2 bar
DCF rate of return	15%

Calculations

Heat input = (14 GJ/t) (1t/h) = 14 GJ h
Heat output = (1.7 MJ/std.m^3 x 9000 std, m^3/h) + (14 x 0.1 GJ/h) + (14 x 0.05 GJ/h) = 17.4 GJ/h

Support fuel needed = (17.4 - 14 = 3.4) GJ/h = 3.4/30 = 0.11)t/h

Combustion air needed = 14 GH/t (3.2 x 150 + 320)= 11,200 kg/t

Total heat input = (14 + 3.4 = 17.4) GJ/h

Dry fluegas generated = 12,000 std m^3/h = 61,375 actual m^3/h at 1200^{o}C

Volume of rotary kiln = (17.4 GJ/h)/(1.2 GJ/h/m^3)= 14.5 m^3

Volume of afterburner = (61,375 m^3/h) (2/3600)= 34 m^3

Area of cylindrical rotary kiln surface for estimate of refractory costs = 5.76 (volume) 0.67 = 61 m^2

Dry fluegas flowrate downstream of scrubber, at 80^{o}C = (353/288) (12,000 std m^3/h) = 14,710 actual m^3/h

Water vapour content at 80^{o}C = 50%

Total flowrate downstream of scrubber = (14,710 x 1.5 = 22,100) actual m^3/h

Power rating of fan = (0.2 bar) (22,100 m^3/h) /26 = 173 kW

Ash production = (0.08t/t)(1t/h)(8000h/year) = 640t/year

Lime required for neutralization = (0.06t/t)(1t/h) x (1.04t of lime/t of chlorine)(8000h/year) = 500t/year

Capital Costs

Cost of gas cleaning equipment to treat 12,000 std m^3/h of fluegas =$0.4 million

Total equipment costs, inclusive of gas cleaning equipment for input of 17.4 GJ\h = $3 million
Electrical and Instrumentation = (0.15 x 3) = $0.45 million
Buildings, structures and foundations = (0.3 x 3) = $0.9 million
Piping = (0.4 x 3) = $1,2 million
Installation = (0.15 x 3) = $0.45 million
Installed Plant Cost = $6 million
Total Capital Investment = $9 million

Unit Cost

$$\$/t = \frac{c + aI + bW + cU - S}{G}$$

G = (1 t/h) (8000h/year) = 8000t/year
I = $ 9 million
S = credit for steam recovery from input of 17.4 GJ/h = $1 million
U = 5% of TCI = $0.45 million
W = 15% of annual revenue, assumed to be $9 million = $1.5 million
C = annual operating costs. From a consideration of power, chemical consumption, wages, laboratory costs, etc, assume C = $200/t = $1.6 million/year
R = 15/100 = 0.15
a = 0.36 b = 0.3 c = 0.18

$$\$/t = \frac{1.6 + 0.36(9) + 0.3\ (1.35) + 0.18\ (0.45) - 1}{8000 \times 10^{-6}} = 541$$

The unit cost of incinerating a tonne of waste is thus, for this example, **in excess of $500.**

For a waste containing more chlorine and ash-forming material, unit costs would be higher, because of greater consumption of neutralizing agents and the higher cost of ash disposal.

7.4.14 Concluding Remarks

High temperature incineration is likely to remain the "best practicable environmental option" for a significant portion of hazardous organic wastes. Indeed, for compounds such PCBs, incineration is the only disposal route that can safely and adequately cope with the volumes of waste arisings in some countries.

Incineration is a high-technology option and depends for its safety on good process control. Before deciding to build a sophisticated and expensive incinerator, careful consideration should be given to the need to provide both trained personnel and adequate financial resources for management, operating and maintenance.

Purpose-built incinerators designed to handle a variety of wastes are expensive to build and operate, and require a relatively large waste quantity to justify their existence. In many countries, smaller scale units or the adoption of existing process facilities such as lime, cement or aggregate kilns would seem a more likely option.

Further work to demonstrate the use of such facilities on a small to medium scale in developing countries is recommended.

The need to retain incineration as a disposal option is not necessarily shared by the general public. Hazardous waste incineration has been a particular target for public concern, especially since the revelation that hazardous by-products such as dioxins and dibenzofurans can be emitted when PCBs are not incinerated at optimum conditions. Local communities do not relish the prospect of a hazardous waste incinerator being sited in their midst, and frequently express their opposition through the **Not In My Back Yard (NIMBY)** syndrome. Strong pressure is sometimes placed on politicians and waste disposal authorities to ban hazardous waste incineration altogether or, at least, ban the incineration of the very wastes which can only be treated in this manner. The consequence is that other, less environmentally acceptable options may be pursued.

The need to improve existing technology, in order to lower energy consumption, reduce incinerator size and hence reduce capital and operating costs, has spawned a number of new thermal destruction processes, most of them currently at the bench or pilot stage. The most promising of these new processes include:

- **Molten salt technology,** a process in which waste in injected beneath a bed of molten sodium carbonate. The process requires lower temperatures for waste combustion, and the bed is an effective scrubbing medium for acid gases.

- **Pyrolysis systems,** where waste is broken down into less complex materials through the application of heat in the absence of oxygen. Potential advantages include lower support fuel usage and reduced emissions.

- **Electric reactors,** processes that pyrolyse wastes at very high temperatures from particles such as soil through the use of an electrically heated fluid wall reactor.

- **Plasma systems,** processes that use the extremely high temperature of plasma to destroy wastes. Advantages, shared with electric reactors, are that reactor size is considerably reduced, and conventional fuel is not used.

In addition, there is considerable scope for improvement in conventional incinerator designs, for example, in the development of **more efficient liquid injection systems**, and in the **processing of solid wastes**.

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ANNEX 7.4 - Biomedical Waste

Annex 7.4 was prepared by the Ontario Ministry of the Environment in Toronto, Ontario and Trecan Combustion Limited in Mississauga, Ontario.

Introduction

The criteria expressed in this document supersede those stipulated in the June 1974 Ontario Ministry of the Environment "Criteria for Incinerator Design and Operation for pathological waste incineration. Part of the need to update the existing criteria has been the change in the composition of waste generated in hospitals and other health care facilities. To reflect current waste composition, the Ontario Ministry of the Environment now uses the term "biomedical" waste to replace the existing definitions of "pathological" and "institutional" wastes. The criteria presented in this document were developed for application to biomedical waste.

Scope of Document

The topics covered in this document are summarized as follows:

(i) Characterization of the biomedical waste generated in Ontario, including the component proportion, moisture content, and heating value for each type of biomedical waste;

(ii) Overview of the current technology for the incineration of biomedical waste; and

(iii) Recommendation of design and operating criteria for biomedical waste incinerators.

Biomedical Waste

Introduction

"Biomedical" waste refers to any waste that includes anatomical waste, pathological waste, infectious waste, hazardous waste, and other waste generated in health care facilities and medical laboratories that require special handling. Previously, the terms "pathological" and "institutional" wastes were used to refer to what is now considered "biomedical" waste.

Classifications

The Ministry will classify biomedical waste according to the categories presented in Table 7.4A-1. The Ministry recommends that biomedical waste be segregated and packaged in leakproof, color-coded plastic bags to facilitate identification, handling, storage, decontamination and transportation.

The surveys carried out for these institutions also reflect the situation in Ontario hospitals. This was confirmed in a study carried out by Sirman in 1985 in which he found that the biomedical waste generation rate in Ontario hospitals ranged from 2.3 to 7.7 kg/bed/day (Sirman and Ivan 1985).

TABLE 7.4A-1

Ministry Classification and Colour Coding for Biomedical Waste

Classification		Description	Colour Code
Type A, Class 1		Human anatomical	red
Type A, Class 2		Animal anatomical, infected	orange
Type A, Class 3	a)	Non-anatomical, infected	yellow
	b)	Laboratory wastes	yellow
	c)	Wastes from DNA work	yellow
Type B, Class 1		Animal anatomical, non-infected	blue

The total biomedical waste stream also includes infectious waste generated from special care beds in surgical rooms, isolation wards and special medical procedure rooms. A 1985 survey sponsored by the Ontario Hospital Association showed that the average-size Ontario hospital generates approximately 0.75 kg/day of infectious waste for each special care bed. This value is based on 75 responses from 164 facilities surveyed (Health Care Occupational Health and Safety Association 1985).

Collection and Handling in Hospitals and Other Health Care Facilities

Waste collection and handling at most hospitals in Ontario involve the transport of waste by employees from the point of generation (patients' beds, operating rooms, laboratories, etc.) to initial storage points (usually enclosed containers in utility rooms) in each hospital unit. At some hospitals, waste considered to be "contaminated," such as urine containers, histology laboratory cuttings, tubes and bags containing blood, spinal fluid containers, and waste from isolation patients' rooms, are placed in color-coded plastic bags for separate handling.

To minimize the potential risk of public exposure to hospital waste, some hospitals use rigid containers for transporting the color-coded bags along routes within the hospital that are accessible to the general public. The use of rigid containers in this situation is considered good practice and is recommended for all hospitals.

Existing waste collection and handling procedures vary from hospital to hospital in Ontario and the practice of color coding the disposal bags for separate handling is not consistent. It is therefore recommended that the color-coding system presented in Table 7.4A-1 be adopted so that all biomedical waste can be immediately identified. The use of the colorcode should be exclusive to biomedical waste to preclude public exposure during general purpose disposal.

Waste Generation Rate

(i) Hospitals

Hospital facilities are among the largest generators of solid waste today on a per capita basis. Much of the waste from hospitals comes from the trash basket at the side of the patient's bed, and includes newspapers, magazines, paperbacks, packaging and discarded flowers. In addition, broken syringes, discarded splints, masks, rubber gloves and broken glass ampoules, etc., generated by other routine activities add to the daily waste stream.

During the last decade, there has been an increasing trend towards the use of disposable products or single-purpose items, which now account for more than one-half of the total hospital waste generated. Nightgowns, sheets, bed pads, pillow cases, etc., which used to be sterilized and reused have been replaced with one-time-use, throw-away articles. Depending on the institution's or hospital's preference for using throw-away materials, the waste generation rate can vary substantially from hospital to hospital.

Pollock (1978) and Airan et al. (1980) conducted studies on waste generation rates in some US hospitals between 1968-1980. In addition, McCrate (1980) carried out a similar study at the Royal Jubilee Hospital located in British Columbia during 1980. The findings of these studies are summarized in Table 7.4A-2. As can be seen from the Table, the waste generation rates in these studies fall within a range of 1.5-7.5 kg/bed/day.

The surveys carried out for these institutions also reflect the situation in Ontario hospitals. This was confirmed in a study carried out by Sirman in 1985 in which he found that the biomedical waste generation rate in Ontario hospitals ranged from 2.3 to 7.7 kg/bed/day (Sirman and Ivan 1985).

The total biomedical waste stream also includes infectious waste generated from special care beds in surgical rooms, isolation wards and special medical procedure rooms. A 1985 survey sponsored by the Ontario Hospital Association showed that the average-size Ontario hospital generates approximately 0.75 kg/day of infectious waste for each special care bed. This value is based on 75 responses from 164 facilities surveyed (Health Care Occupational Health and Safey Association 1985).

(ii) Medical Laboratories

The waste produced from private and diagnostic laboratories (Type A, Class 3(b) in Table 7.4A-1 is considered infectious. The waste generation rate is estimated to be 0.2 kg/patient/day and the total quantity of infectious waste from these facilities is higher than that generated in all Ontario hospitals on an annual basis.

Medical laboratory waste contains a very high percentage of plastics (50-60%), the majority of which are non-halogenated. The balance is composed of wet materials such as bodily fluids, blood and used diagnostic reagents, as well as small quantities of paper and cellulose. Most of the medical laboratory waste currently generated is being shipped out of Ontario for disposal. The remaining portion is either incinerated or steam autoclaved and then disposed of in a landfill.

(iii) Summary

Depending on an institution's practice of using throw-away materials, the biomedical waste generation rate varies from hospital to hospital. It is recommended that each facility review and document its own practice in order to more accurately determine its waste generation rate. If the actual rate is not available, the Ministry recommends that the following values be used for sizing the capacity of a new biomedical waste incinerator:

(iv) Predicted Waste Generation Rate From:

(a) Hospitals

- Total biomedical waste* - 6 kg/bed/day
- Special care waste - 1 kg/special care bed/day

(b) Medical laboratories

TABLE 7.4A-2

Summary of Waste Generation Rates at Selected Hospitals in the United States and Canada

Source	Generation Rate (kg/bed/day)
Pollock (1978)	
o 1968 survey	3.0
o 1974 survey	4.1
o 1975 survey	4.3
o West Coast Teaching Hospital	3.7
o 1978 estimate	7.5
o conclusion of Pollock	3.0-7.5
Airan et al. (1980)	
o 1980 survey	4.3-5.8
McCrate (1980)	
o 1980 survey	1.5-3.9

- Total laboratory waste - 0.2 kg/patient/day

Characterization of Biomedical Waste

Introduction

This section discusses the physical and chemical characteristics of biomedical waste generated in Ontario, with emphasis on the human and animal anatomical components, moisture content, proportion of plastics and heating value (as fired).

Physical and Chemical Characteristics

Tables 7.4A-3 and 7.4A-4 summarize the properties of the biomedical waste in terms of higher heating value (HHV), moisture content, component weight percent and bulk density expressed in metric and imperial units, respectively. The breakdown of the waste classifications and color coding in the tables are based on the Canadian Standards Association guidelines for "Handling of Waste Materials within Health Care Facilities" (1981). The ranges of weight percent are based on field measurements as well as data provided by the institutions. The values in Column 7 in each table reflect the weighted HHV range of the waste components (as-fired) under each classification and have been calculated from the data given in columns 3, 4 and 6. The last column (Column 8) represents typical values based on interpretation of actual findings from an Ontario facility.

* This includes special care waste, but excludes kitchen waste.

As can be seen from the wide range of HHV, discretion should be exercised in using the data for the design of a biomedical waste incinerator. A thorough evaluation of the waste should be carried out to identify its characteristics to facilitate the proper design of the incinerator.

Based on the data from Table 7.4A-3 the typical higher heating values for each type of biomedical waste are summarized in Table 7.4A-5. It can be seen that yellow-bag waste generally has a heating value of 21,000 kJ/kg or greater. All other color coded bags 6,700 kJ/kg or less and may require the use of auxiliary fuel when being incinerated.

It may be possible to blend different color coded bags of waste to modify the overall composition of the waste charged into the incinerator. In this way, waste with a low heat content can be combined with waste of higher heat content to form a waste capable of self-sustaining combustion. If all waste types in Table 7.4A-5 are combined equally, the average HHV would be 13,877 kJ/kg, which is higher than that of typical municipal solid waste (11,140 kJ/kg). However, the possibility of blending must be evaluated on a case-by-case basis.

The typical chemical composition of animal anatomical waste and the associated combustion data are given in Table 7.4A-6. It should be noted that this is only one type of biomedical waste and does not include components such as plastics and cellulose gauzes, which have a higher heat content than anatomical waste.

TABLE 7.4A-3

Characterization of Biomedical Waste (Metric Units)

Waste Class	Component Description	Typical Component Weight Percent (as fired)	HHV Dry Basis (kJ/kg)	Bulk Density as Fired (kg/m^3)	Moisture Content of Component (Weight Percent)	Weighted Heat Value Range of Waste Component (kJ/kg)	Typical Component Heat Value of Waste as Fired (kJ/kg)
A1	Human Anatomical	95-100	18600-27900	800-1200	70-90	1770[a]-8370[b]	2800
(Red Bag)	Plastics	0-5	32500-46400	80-2300	0-1	0-2300	400
	Swabs, Absorbants	0-5	18600-27900	800-1000	0-30	0-1400	200
	Alcohol, Disinfectants	0-0.2	25500-32500	800-1000	0-0.2	0-70	50
							3450
A2	Animal Infected Anatomical	80-100	20900-37100	500-1300	60-90	1670-14840	3500
(Orange Bag)	Plastics	0-15	32500-46400	80-2300	0-1	0-6960	1000
	Glass	0-5	0	2800-3600	0	0	0
	Beddings, Shavings Paper, Fecal Matter	0-10	18600-20900	320-730	10-50	0-1880	1400
							5900
A3 (a) (Yellow Bag)	Gauze, Pads, Swabs Garments, Paper Cellulose	60-90	18600-27900	80-1000	0-30	7810-25110	15000
	Plastics, PVC, Syringes	15-30	22500-46400	80-2300	0-1	3340-13920	7540
	Sharps, Needles	4-8	140	7200-8000	0-1	6-10	10
	Fluids, Residuals	2-5	0-23200	1000-1020	80-100	0-230	70
	Alcohols, Disinfectants	0-0.2	16200-32500	800-1000	0-50	0-70	30
							22650
A3 (b)	Plastics	50-60	32500-46400	80-2300	0-1	16090-27840	21000
(Yellow Bag)	Sharps	0-5	140	7200-8000	0-1	0-10	0
Lab Waste	Cellulosic Materials	5-10	18600-27900	80-1000	0-15	790-2790	1500
	Fluids, Residuals	1-20	0-23200	1000-1020	95-100	0-230	70
	Alcohols, Disinfectants	0-0.2	25500-32500	800-1000	0-50	0-70	50
	Glass	15-25	0	2800-3600	0	0	0
							22620

TABLE 7.4A-3 (continued)

Waste Class	Component Description	Typical Component Weight Percent (as fired)	HHV Dry Basis (kJ/kg)	Bulk Density as Fired (kg/m^3)	Moisture Content of Component (Weight Percent)	Weighted Heat Value Range of Waste Component (kJ/kg)	Typical Component Heat Value of Waste as Fired (kJ/kg)
A3 (c)	Gauze, Pads, Swabs	5-30	18600-27900	80-1000	0-30	650-8370	2300
(Yellow Bag)	Plastics, Petri Dishes	50-60	32500-46400	80-2300	0-1	16090-27840	21000
R & D	Sharps, Glass	0-10	140	7200-8000	0-1	0-10	0
on DNA	Fluids	1-10	0-23200	1000-1020	80-100	0-460	230
							23530
B1	Non-Infected Animal Anatomical	90-100	20900-37100	500-1300	60-90	1880-14840	3000
(Blue Bag)	Plastics	0-10	32500-46400	80-2300	0-1	0-4640	2300
	Glass	0-3	0	2800-3600	0	0	0
	Beddings, Shavings, Fecal Matter	0-10	18600-20900	320-730	10-50	0-1880	1400
							6700

TABLE 7.4A-4

Characterization of Biomedical Waste (Imperial Units)

Waste Class	Component Description	Typical Component Weight Percent (as Fired)	HHV Dry Basis (BTU/lb)	Bulk Density as Fired (lb/ft^3)	Moisture Content of Component (Weight Percent)	Weighted Heat Value Range of Waste Component (BTU/lb)	Typical Component Heat Value of Waste as Fired (BTU/lb)
A1 (Red Bag)	Human Anatomical	95-100	8000-12000	50-75	70-90	760[a]-3600[b]	1200
	Plastics	0-5	14000-20000	5-144	0-1	0-1000	180
	Swabs, Absorbants	0-5	8000-12000	5-62	0-30	0-600	80
	Alcohol, Disinfectants	0-0.2	11000-14000	48-62	0.02	0-28	20
							1480
A2	Animal Infected Anatomical	80-100	9000-16000	30-80	60-90	720-6400	1500
(Orange Bag)	Plastics	0-15	14000-20000	5-144	0-1	0-3000	420
	Glass	0-5	0	175-225	0	0	0
	Beddings, Shavings Paper, Fecal Matter	0-10	8000-9000	20-46	10-50	0-810	600
							2520
A3 (a) (Yellow Bag)	Gauze, Pads, Swabs Garments, Paper, Cellulose,	60-90	8000-12000	5-62	0-30	3360-10800	6400
	Plastics, PVC, Syringe	15-30	9700-20000	5-144	0-1	1440-6000	3250
	Sharps, Needles	4-8	60	450-500	0-1	3-5	5
	Fluids, Residuals	2-5	0-10000	62-63	80-100	0-11	30
	Alcohols, Disinfectants	0-0.2	7000-14000	48-62	0-50	0-28	15
							9700
A3 (b)	Plastics	50-60	14000-20000	5-144	0-1	6930-12000	9000
(Yellow Bag)	Sharps	0-5	60	450-500	0-1	0-3	0
Lab Waste	Cellulostic Materials	5-10	8000-12000	5-62	0-15	340-1200	650
	Fluids, Residuals	1-20	0-10000	62-63	95-100	0-100	30
	Alcohols, Disinfectants	0-0.2	11000-14000	48-62	0-50	0-28	20
	Glass	15-25	0	175-225	0	0	0
							9700

TABLE 7.4A-4 (continued)
Characterization of Biomedical Waste (Imperial Units)

Waste Class	Component Description	Typical Component Weight Percent (as Fired)	HHV Dry Basis (BTU/lb)	Bulk Density as Fired (lb/ft^3)	Moisture Content of Component (Weight Percent)	Weighted Heat Value Range of Waste Component (BTU/lb)	Typical Component Heat Value of Waste as Fired (BTU/lb)
A3 (c)	Gauze, Pads, Swabs	3-30	8000-12000	5-62	0-30	280-3600	1000
(Yellow Bag)	Plastics, Petri Dishes	50-60	14000-20000	5-144	0-1	6930-12000	9000
R & D	Sharps, Glass	0-10	60	450-500	0-1	0-6	0
on DNA	Fluids	1-10	0-10000	62-63	80-100	0-200	100
							10100
B1	Non-infected Animal Anatomical	90-100	9000-16000	30-80	60-90	810-6400	1400
(Blue Bag)	Plastics	0-10	14000-20000	5-144	0-1	0-2000	1000
	Glass	0-3	0	175-225	0	0	0
	Beddings, Shavings, Fecal Matter	0-10	8000-9000	20-46	10-50	0-810	600
							3000

TABLE 7.4A-5

Typical Higher Heating Values for Various Biomedical Waste Classifications (as Fired)

Classification		Colour Code	Typical HHV (kj/kg)
Type A, Class 1		Red	3,450
Type A, Class 2		Orange	5,900
Type A, Class 3	a)	Yellow	22,650
	b)	Yellow	22,620
	c)	Yellow	23,530
Type B, Class 1		Blue	6,700

TABLE 7.4A-6

Chemical Composition of Animal Anatomical Waste and Combustion Data

Ultimate Analysis (Whole Dead Animal)

Constituent	As Charged % by Weight	Ash and Moisture Free Combustible % by Weight
Carbon	14.7	50.80
Hydrogen	2.7	9.35
Oxygen	11.5	39.85
Water	62.1	-
Nitrogen	Trace	-
Mineral (ash)	9.0	-

Dry combustible empirical formula - $C_5 H_{10} O_3$

Combustion Data
(Based on 1 kg of Dry Ash-free Combustible)

Constituent		Quantity kg	Volume Nm^3
Theoretical air		7.03	5.77
40% sat at 15.5°C		7.06	5.81
Flue gas with	CO_2	1.86	1.00
Theoretical	N_2	5.40	4.57
Air 40%	H_2O formed	0.76	1.00
Saturated	H_2O air	0.03	0.04
Products of Combustion total		8.05	6.61

Gross Heat of Combustion 20,471 kJ/kg

Microbiological Characteristics

Care should be exercised when handling biomedical waste primarily due to its infectious or hazardous nature. Testing was carried out by Barbeito et al. to evaluate whether sterilization, or a total pathogen kill, could be achieved by incineration (Barbeito and Shapiro 1977). His research indicates that destruction of micro-organisms within the incinerator depends on the temperature and time exposure. Barbeito indicates that any emission of micro-organisms from the incinerator could be attributed to insufficient retention time and temperature as a result of the following conditions:

- initial charging of the incinerator before operating temperatures are achieved;
- failure to preheat the refractory lining;
- temperature fluctuations caused by intermittent use;
- exceeding design linear velocities, thereby reducing the retention time;
- charging beyond incinerator capacity; and
- excessive moisture content of the waste.

Other factors such as the type of refractory lining, the positioning and number of burners, and the precision of temperature controlling devices, can also have a significant bearing on the effectiveness of sterilization.

Barbeito recommends that the following measures be taken to ensure the complete destruction of micro-organisms in the incinerator:

- the minimum temperatures in the primary and secondary chambers should be maintained at no less than 760° (1400°F) and 870°C (1600°F), respectively;
- a minimum of one-half hour should be used as a preheat period for the secondary chamber prior to feeding the waste into the incinerator;
- if an incinerator is not operated continuously, only non-infectious waste should be incinerated initially after the unit is fired up; infectious waste should only be fed into the incinerator after the secondary chamber has been on for one-half hour; and
- each incinerator should be tested with bacterial spores, the most resistant micro-organisms, to establish the minimum temperatures required to achieve complete sterilization.

The destruction of micro-organisms in the incinerator ash also depends on temperature and time exposure. It is therefore desirable to discharge the ash on a batch basis at the end of each incineration cycle (typically 4-6 hours) to provide a long solids retention time in the primary chamber in order to achieve complete destruction of the micro-organisms.

Technical Specification for Biomedical Waste Incinerator

General

The incinerator shall be a controlled-air, grateless type dual chamber thermal-destruction unit that is approved for hospital use for general and pathological waste by the Ministry of Environment, Air Management Branch, Ministry of Health, C.G.A. and Fuel Safety Branch, and other authorities having jurisdiction. The incinerator supplier shall make application and gain approval from the authorities having jurisdiction.

In addition to submitting a full description of the incinerator offered, the vendor must complete the incinerator data sheet (as appended), clearly indicating any deviation from published specification and including a reference list detailing past experience.

Operating Criteria

(i) Capacity

The unit shall be designed to burn a minimum of ----- lbs/hr. of waste with an average density of ------ lbs/cu.ft calorific value of 8,000 btu/lb and moisture content of 20%. The waste stream will be made up of approximately the following types of waste:

----- lbs/day of human/animal anatomical waste.
----- lbs/day of non-anatomical infectious waste.
----- lbs/day of sharps in hard shell containers, ------ containers.
----- lbs/day of non-infectious general hospital waste.

(ii) Design

(a) Secondary Chamber

The incinerator shall provide a minimum secondary chamber retention time of 1 sec. at maximum burning rate. The retention time shall be calculated at 1000°C (1832°F) and shall be accomodated within the confines of the incinerator unless specifically approved otherwise.

The incinerator secondary chamber shall be thermally designed for 1100°C (2012°F). The design shall promote maximum turbulence to ensure complete oxidation of all combustibles.

(b) Primary Chamber

Primary chamber shall be sized to ensure sufficient residence time for complete decomposition of the waste, total heat release should not exceed 25000 btu/cu.ft/hr, and hearth loading should not exceed 10 lbs/hr/ft^2 for type 4 waste, and 15 lbs/hr/ft^2 for general biomedical waste. Provision should be made in hearth design to prevent leakage of fluid from the chamber or into the primary airports. Hearth design to ensure even air distribution throughout the waste bed and in such a way as to prevent `overfire air' conditions developing. Sidewall air energy will not be permitted.

Operating Mode

(i) The incinerator shall be the batch feed type and shall have a primary chamber capacity of ----- cubic feet. Primary chamber and loading door design shall be such as to allow for maximum possible utilization of primary chamber volume and ease of access for loading and de-ashing.

or

(ii) The incinerator shall be supplied with a hydraulically operated ram feeder assembly of ----- cu. yard capacity. The feeder assembly shall include hydraulically operated fire door, manually/hydraulically operated hopper door, hydraulic power pack and all associated controls.

Construction

(i) The incinerator shall be internally lined with 3 1/2 inches of block insulation plus 4 1/2 inches of high quality, low iron content refractory, rated for use at 2500°F, such that the cold face temperature of the incinerator will be approximately 160°F. The manufacturer shall show by calculation that his cold face temperature shall be at or about 160°F, based on prevailing site conditions. The refractory shall be secured to the shell with stainless steel anchors on no more than 12" centers.

(ii) The incinerator shell shall be constructed with mild steel plate of no less than 3/16" thickness. The shell shall be suitably reinforced using structural steel members.

(iii) The primary chamber shall have a charging/de-ashing door at least 48 inches high and 30 inches wide. This door shall be electrically interlocked to prevent the primary burners firing with the door open.

(iv) The secondary chamber shall have an access door for inspection and clean-out.

(v) The incinerator shall be painted with one primer coat and one finish coat of heat resistant enamel paint.

Components and Auxiliary Equipment

(i) To avoid infiltration of tramp air, the primary burners will be of the sealed type; package burners are not acceptable.

(ii) To ensure optimum fuel efficiency the secondary chamber temperature shall be controlled via a fully modulating split-range temperature indicating controller. One signal shall control the burner firing rate, the other signal shall control the secondary chamber combustion air flow.

(iii) Primary chamber temperature control will be effected by control of primary combustion air flow via a temperature-indicating control. Control function may be high-low or fully modulating.

(iv) A dual element thermocouple shall be provided in the primary and secondary chambers. The second element shall send a signal to 24-hour circular open-chart recorder. The recorder shall be supplied by the incinerator manufacturer/by others.

The control panel shall be pre-wired, tested and will house the following controls as a minimum:

(v) Sight glasses shall be provided in both the primary and secondary chambers permitting safe observation of the combustion process throughout the burn.

(vi) Incinerator Controls

- fused disconnect switch
- control transformer
- power on switch
- cycle start push button interlocked to purge timer
- secondary chamber indicating temperature controller
- primary chamber indicating temperature controller
  cycle timer
- burndown and cooldown timers
- emergency stop pushbutton
- auto/manual switches for:

  - primary burner(s)
  - secondary burner
  - combustion air fans

- indicating lights for:

  - power on
  - ready to feed
  - cycle in progress
  - cycle in complete
  - burner on (2)
  - flame failure
  - fans on

- All necessary relays, limit switches, motor starters, transformers and fuses shall also be included.

See Table 7.4A-7.

TABLE 7.4A-7

Biomedical Waste Incinerator Form

MODEL: ____________________

SIZE: ____________________

Capacity lbs/hr. - Waste as specified: ____________________

Type 4 specified: ____________________

Auxiliary Fuel Usage ____________ KW (____________) BTU/HR

Electrical Power Requirement:

Primary Chamber:

- Volume (ft.3): ____________________
- Heat Release BTU/cu. ft.: ____________________
- Hearth Area: ____________________
- Hearth Loading lbs/hr/ft 2: ____________________
- Refractory Thickness (in.): ____________________
- Insulation Thickness (in.): ____________________
- Refractory Temp. limitation (Deg. F): ____________________
- Projected Cold Face Temp: ____________________
- Shell Thickness: ____________________
- Charging/Deashing Door Size: ____________________
- Burner Capacity BTU/hr: ____________________
- Primary Air Fan Capacity (SCFM): ____________________

Secondary Chamber:

- Volume (ft.3): ____________________
- Gas Retention Time (secs @ 1832°F): ____________________
- Refractory Thickness (in.): ____________________
- Insulation Thickness (in.): ____________________
- Refractory Temp. Limitation (Deg. F): ____________________
- Projected Cold Face Temp: ____________________
- Shell Thickness: ____________________
- Cleanout Door Size: ____________________
- Burner Capacity BTU/hr: ____________________
- Secondary Air Fan Capacity (SCFM): ____________________

Breeching/Stack

- Inside Diameter: ____________________

Classifications

The Ministry will classify biomedical waste according to the categories presented in Table 7.4A-1. The Ministry recommends that biomedical waste be segregated and packaged in leakproof, color-coded plastic bags to facilitate identification, handling, storage, decontamination and transportation.

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7.5 Ocean Disposal

7.5.1 Introduction

The dumping of waste at sea is an example of a "dilute and disperse" method of disposal - the waste is dispersed into the ocean so that it is immediately diluted to a concentration at which it caused negligible local harm. The composition of the waste must be such that it pollutants are then degraded, neutralized or otherwise transformed by natural microbiological and chemical processes. The rate of addition must take into account the efficacy of these processes with respect to the chemical, biological and toxicological characteristics of the waste. Unassimilated substances such as certain metals or persistent toxic organics will accumulate in the ocean since nature is not capable of altering them. Degradable wastes, given sufficient time and dilution, can become incorporated in the natural oceanic background.

Ocean dumping is generally regarded as a short or medium-term option for wastes which, for economic or technical reasons, are difficult to treat on land. National authorities, when considering disposal at sea as an alternative for land-based disposal and treatment of wastes should carry out a comprehensive environmental impact assessment to identify a solution which poses least detriment to the environment.

In general, five sources of marine pollution can be identified (International Maritime Organization [IMO] 1985).

(1) Land-based Source - contaminants entering the marine environment through runoff from land (pipelines, outfalls, rivers, etc.).

(2) Vessel-generated Pollution - operational decharges from ships (e.g., deblasting or cleaning of tanks) or resulting from maritime accidents.

(3) Dumping at sea - the disposal of land-based industrial and municipal wastes at sea, from ships.

(4) Sea-bed activities - the releases of contaminants directly arising from activities such as mineral exploration.

(5) Pollution from or via the atmosphere - Fallout or coprecipitation of contaminants released into the atmosphere from land, sea or air-based activities.

This section concentrates on Item (3): Sea Dumping.

7.5.2 International Conventions

The ocean is an international resource. It is an important source of food, it establishes the climate and oxygen-carbon dioxide balance in the atmosphere and provides water for the Earth's hydrocycle. Improper use of the ocean as a receptacle for waste can jeopardize this resource and cause serious ecological damage.

A comprehensive international policy on ocean disposal is therefore needed, to end unregulated dumping, prohibit the disposal of materials harmful to the marine environment and lay down guidelines for the safe disposal of acceptable wastes. Table 7.5-1 lists some of the Conventions that have been promulgated through international cooperation, applying to various oceanic locations (IMO 1985).

Of these, the "International Convention on the Prevention of Marine Pollution by Dumping of Wastes and other Matter," commonly called the "London Convention," is applicable worldwide and has, at present, 61 countries, and their dependencies, as Contracting Parties. The International Maritime Organization (IMO) serves as its secretariat, and meetings are held annually at IMO Headquarters in London. Acceding governments are required to comply with the provisions of the Convention, and conduct sea disposal in a safe and responsible manner. Most Contracting Parties have, in addition, formulated national legislation enforcing the application of the Convention (for example, the Food and Environment Protection Act 1985, in the UK).

Global rules, standards and procedures for the prevention and control of marine pollution from land-based sources, from the atmosphere or from sea bed activities have not yet been developed, although the need to take measures for pollution prevention from these sources has been recognized for many years. The Geneva Convention on the High Seas, 1958, already requests States to draw up regulations to prevent pollution of the seas resulting from the exploitation and exploration of the sea-bed and its subsoil. On the other hand, the recently adopted Convention on the Law of the Sea provides a broad outline for action concerning the marine pollution from all sources at the global level, including land-based sources, the atmosphere and sea-bed activities.

A further initiative aimed at global control of marine pollution was taken by UNEP in 1983 with the convening of a Working Group on the Protection on the Marine Environment against Pollution from Land-based Sources resulting in the formulation of the "Montreal Guidelines (UNEP 1985).

Other global Conventions covering discharges into the sea from ships and the prevention of accidental pollution are MARPOL (International Convention for the Prevention of Pollution from Ships) and SOLAS (Safety of Life at Sea), both of which are administered by IMO.

7.5.3 Categorization of Wastes

(i) Limitation on Waste Type

Ocean disposal should be limited to those wastes which are rapidly rendered harmless by natural, physical, chemical or biological processes. The London Dumping Convention categorized substances according to their potential for causing damage to the marine environment. Dumping of substances on the "black list" (Annex 1 of the Convention) is prohibited because of their toxicity, persistence and bio-accumulation.

TABLE 7.5-1

Some International Ocean Dumping Conventions

Name of Convention	Area of Concern	Date of Entry Into Force
Oslo Convention	NE Atlantic	1974
London Convetion	World-wide	1975
Barcelona Convention	Mediterranean	1978
Paris Convention	NE Atlantic and Dependent Seas	1978
Helsinki Convention	Baltic Sea	1980
Caribbean Convention	Caribbean Region	Signed in 1983

Substances on the "grey list" (Annex II of the Convention) which exhibit similar but less marked characteristics, may only be dumped under a "special permit" when special care is taken to ensure that their introduction into the ocean has no deleterious effects. Black and grey list materials are shown in Tables 7.5-2 and 7.5-3 (IMO 1985). A proposed Directive from the Commission of the European Communities (CEC) includes organo-tin compounds in the black list (CEC 1985).

All substances not covered by the above list fall in a third category called the "white list." These materials require a "prior general permit" from the relevant national authority before they can be disposed of at sea (IMO 1985).

In Annex II certain substances fall under the "special permit" provision only if they are contained in wastes in "significant amounts." The interim interpretation of "significant amounts" is:

- Pesticides and their by-products not covered by Annex I and lead and lead compounds: 0.05% or more weight.

- All other substances in Annex II, paragraph A: 0.01% or more by weight.

Many Contracting Parties have expressed the view that the interim definitions are too arbitrary and have proposed that the term "significant amounts" would be better defined by way of results of tests designed to establish the environmental impact in each specific case taking into account quantities as well as concentrations also the specific characteristics of the receiving area. This item is still under consideration.

(ii) Exceptions to Annex I

Paragraphs (8), (9), and (10) of Annex I provide for the exclusion of certain types of wastes from the prohibition on dumping imposed by the black list. The exclusion applies to substances which are "rapidly rendered harmless" and to wastes that contain black list materials in "trace quantities." Another exclusion covering the incineration at sea of black list substances is detailed in Section 7.5.5.

- **"Rapidly Rendered Harmless" exception.** This exception is set out in Annex I, paragraph 8, referring to black list substances which are rapidly rendered harmless by physical, chemical or biological processes in the sea provided they do not:

  - make edible marine organisms unpalatable; or

  - endanger human health or that of domestic animals.

It is further mentioned that a Contracting Party, if in doubt about the harmlessness of a substance, should follow the consultative procedure developed under the emergency clause (see 7.5.5).

TABLE 7.5-2

Black List (Annex I of the London Convention)

Annex I, the so-called "black list", contains substances which at the time of drafting the Convention were considered as "highly hazardous" substances. Annex I reads as follows:

"1. Organohalogen compounds.

2. Mercury and mercury compounds.

3. Cadmium and cadmium compounds.

4. Persistent plastics and other persistent synthetic materials, for example netting and ropes, which may float or may remain in suspension in the sea in such a manner as to interfere materially with fishing, navigation or other legitimate uses of the sea.

5. Crude oil and its wastes, refined petroleum products, petroleum distillate residues, and any mixtures containing any of these, taken on board for the purpose of dumping.[1]

6. High-level radioactive wastes or other high-level radioactive matter defined on public health, biological or other grounds, by the competent international body in this field, at present the International Atomic Energy Agency, as unsuitable for dumping at sea.

7. Materials in whatever form (e.g., solids, liquids, semi-liquids, gases or in a living state produced for biological and chemical warfare.

8. The preceding paragraphs of this Annex do not apply to substances which are rapidly rendered harmless by physical, chemical or biological processes in the sea provided that they do not

(i) make edible marine organisms unpalatable, or

(ii) endanger human health or that of domestic animals.

The consultative procedure provided for under Article XIV should be followed by a Party if there is doubt about the harmlessness of the substance.

1/ Originally: "Crude oil, fuel oil, heavy diesel oil and lubricating oil, hydraulic fluids, and any mixtures containing any of these, taken on board for the purpose of dumping."

The new version was adopted by the Fifth Consultative Meeting of Contracting Parties and entered into force on 11 March 1981 except for the Federal Republic of Germany and Japan who made a declaration of non-acceptance.

TABLE 7.5-2 (continued)

9. This Annex does not apply to wastes or other materials (e.g., sewage sludge and dredged spoils) containing the matters referred to in paragraphs 1-5 above as trace contaminants. Such wastes shall be subject to the provisions of Annexes II and III as appropriate.

10. Paragraphs 1 and 5 of this Annex do not apply to the disposal of wastes or other matter referred to in these paragraphs by means of incineration at sea. Incineration of such wastes or other matter at sea requires a prior special permit. In the issue of special permits for incineration the Contracting Parties shall apply the Regulations for the Control of Incineration of Wastes and Other Matter at Sea set forth in the Addendum to this Annex (which shall constitute an integral part of this Annex) and take full account of the Technical Guidelines on the Control of Incineration of Wastes and Other Matter at Sea adopted by the Contracting Parties in consultation.[2])

2/ Paragraph 10 was not included in the original Convention. The Third Consultative Meeting of Contracting Parties adopted the addition of paragraph 10 to Annex I. The amendment went into force on 11 March 1980 except for the Federal Republic of Germany and New Zealand who made a declaration of non-acceptance. The Addendum to Annex I containing the Regulations for the Control of Incineration is considered in more details in sections below.

TABLE 7.5-3

Grey List (Annex II of the London Convention)

Annex II, the so-called "grey list", contains the second category of substances and materials regulated under the London Dumping Convention, requiring special care (i.e., the issue of "special permits" for dumping) as follows:

"A. Wastes containing significant amounts of matters listed below:

o arsenic

o lead

o copper)
) and their compounds
o zinc)

o organosilicon compounds

o cyanides

o fluorides

o pesticides and their by-products not covered in Annex I.

B. In the issue of permits for the dumping of large quantities of acids and alkalis, consideration shall be given to the possible presence in such wastes of the substances listed in paragraph A and to the following additional substances:

o beryllium)
o chromium)
o nickel) and their compounds
vanadium)

C. Containers, scrap metal and other bulky wastes liable to sink to the sea bottom which may present a serious obstacle to fishing or navigation.

D. Radioactive wastes or other radioactive matter not included in Annex I. In the issue of permits for the dumping of this matter, the Contracting Parties should take full account of the recommendations of the competent international body in this field, at present the International Atomic Energy Agency.

TABLE 7.5-3 (continued)

E. In the issue of special permits for the incineration of substances and materials listed in this Annex, the Contracting Parties shall apply the Regulations for the Control of Incineration of Wastes and Other matter at Sea set forth in the Addendum to Annex I and take full account of the Technical Guidelines on the Control of Incineration of Wastes and Other Matter at Sea adopted by the Contracting Parties in consultation, to the extent specified in these Regulations and Guidelines.[1]

F. Substances which, though of a non-toxic nature, may become harmful due to the quantities in which they are dumped, or which are liable to seriously reduce amenities".[2]

"Significant amounts"

Pesticides and their by-products not covered by Annex I and Lead and lead compounds: 0.05% or more by weight.

All other substances in Annex II, paragraph A: 0.1% or more by weight.

1/ Paragraph E was included in Annex II by the Third Consultative Meeting of Contracting Parties in 1978 and entered into force on 11 March 1979 except for the Federal Republic of Germany and New Zealand who both made a declaration of non-acceptance.

2/ Paragraph F was included in Annex II by the Fifth Consultative Meeting of Contracting Parties in 1980 and entered into force on 11 March 1981 except for the Federal Republic of Germany and Japan who both made a declaration of non-acceptance.

The Third Consultative Meeting in 1978 adopted Interim Guidelines for the Implementation of Paragraphs 8 and 9 of Annex I of the London Dumping Convention. Under these Interim Guidelines substances listed in Annex I may be regarded as meeting the "rapidly rendered harmless..." requirements.

> "If tests of the wastes or other matter proposed for dumping, including tests on the persistence of the material, show that the substance can be dumped so as not to cause acute or chronic effects or bioaccumulation in sensitive marine organisms typical of the marine ecosystem at the disposal site. A persistent substance should not be regarded as "harmless" except when present as a "trace contaminant."

The Interim Guidelines contain test procedures and procedures for consultation which shall be carried out if a Contracting Party has doubts about the results of the tests.

- **"Trace contaminants" exception.** This exception is included in Annex I, paragraph 9 and excludes certain Annex I substances from the dumping prohibition if these are contained in wastes or other matter as "trace contaminants." Typically, these wastes consist of materials such as sewage sludge and dredged spoils, for which separate technical annexes are provided in the Convention (IMO 1985).

The Consultative Meeting of Contracting Parties on the basis of advice given by GESAMP agreed to consider the interpretation of "rapidly rendered harmless" and "trace contaminants" as one package and to base the interpretation of these terms on the results of tests to determine the impact the substances may have under certain circumstances in specific marine environments.

Test procedures should be designed and run so at to provide evidence of the potential for acute or chronic toxic effects, the persistence of the material (where appropriate), inhibition of life processes, and bioaccumulation in sensitive marine organisms typical of the marine ecosystem at the disposal site.

Dredged spoils are exempt from chemical and biological testing, provided they meet criteria laid down in the Convention (IMO 1985). Specific guidelines for the disposal of dredged material were developed by the Consultative Meeting of Contracting Parties in 1986.

For sewage sludge the test procedures may not be needed if chemical characterization of the material and knowledge of the receiving area allows an assessment of the environmental impact.

Under the Interim Guidelines mentioned in the previous section, substances referred to in Annex I paragraph 9, shall **not** be regarded as trace contaminants under the following conditions:

- If they are present in otherwise acceptable wastes or other materials to which they have been added for the purpose of being dumped;

- if they occur in such amounts that the dumping of the wastes or other materials could cause undesirable effects, especially the possibility of chronic or acute toxic effects on marine organisms or human health whether or not arising from their bioaccumulation in marine organisms and especially in food species; and

- if they are present in such amounts that it is impractical to reduce their concentration further by technical means.

7.5.4 Shallow Versus Deep-Sea Disposal

Ocean dumping can be practiced in shallow continental shelf waters or in deep ocean. The fate and impact of wastes in these two regions is different. There is generally more experience and scientific information available concerning dumping on the continental shelf than in deep ocean. Advantages of disposal on the former are (Kester et al. 1981):

- low to moderate transportation costs;

- localization of potential detrimental effects.

Disadvantages include:

- tendency of substances to accumulate in the benthic organisms and sediments;

- possible degradation of continental shelf resources such as fisheries, mineral deposits and shoreline uses.

Advantages of deep ocean disposal are (Kester et al. 1981):

- large dispersal and dilution of wastes;

- reduction of possible conflicts in the utilization of other marine resources.

Disadvantages include:

- uncertainty about the ultimate fate of and effect of waste in this environment;

- potential large-scale impact of a mishap or bad dumping practice;

- greater adverse impact on planktonic and pelagic organisms than bethnic organisms.

The greater majority of wastes dumped at sea are released in shallow continental shelf waters; deep ocean dumping is mainly employed when containerized wastes are to be disposed of.

7.5.5 Permits For Dumping at Sea

(i) Types of permit

It is one of the principles of the London Dumping Convention that a Contracting Party, whenever dumping wastes or other matter at sea, has first to issue a permit for such dumping. There are two types of permit: special permits and general permits.

Article III of the London Dumping Convention defines "special permits" and "permission granted specifically on application in advance and in accordance with Annex II and Annex III," whereas a "general permit" means "permission granted in advance and in accordance with Annex III." This is interpreted as meaning that:

- Special permits have to be granted:
  - for every single case of dumping (specifically);
  - only in cases in which application has been received;
  - in accordance with the requirements of both Annex II and Annex III; and that
- General permits may be granted:
  - with regard to a series of dumping operations;
  - without an application (e.g., through general regulations); and
  - subject to the requirements of Annex III only.

(ii) Responsibility for issuing permits

Article IV of the London Dumping Convention provides that an appropriate authority or authorities have to be designated by each Contracting Party for the granting of general and special permits, for controlling the dumping operations through record keeping and for the scientific monitoring of the condition of the seas for the purpose of dumping.

The London Dumping Convention does not specify whether a permit will have to be granted to ships, waste manufacturers or any other persons. Article VI, however, does provide that permits will have to be issued by the port State in cases where the wastes or other matter intended for dumping are loaded in the territory of this State provided that it is a Contracting Party.

Alternatively, permits are issued by the flag State of the dumping vessel in the event that the wastes or other matter are loaded by a vessel or aircraft registered in the territory or flying the flag of a Contracting Party and where the State in which the waste are loaded is not a party to the Convention.

When preparing the text of the Convention it had been assumed that in establishing a licensing system for the dumping at sea of all types of wastes and other matter, national authorities would possess a complete control system regarding the sea disposal of such substances. However, in the meantime it has been recognized that in many countries according to their national legislation, a national authority cannot issue permits to itself or even to other State bodies which are involved in the disposal at sea. For example, the disposal at sea of material arising from dredging operations carried out be governmental institutions or by State owned companies in many cases is not covered by permits. Similar situations have arisen with regard to the disposal at sea of sewage sludge when falling under the responsibility of an administration which has also been designated the licensing authority in accordance with Article VI.

(iii) Criteria for issuing permits

o Annex III to the London Dumping Convention contains provisions to be considered in establishing criteria governing the issue of permits for the dumping of matter at sea, taking into account Article IV(2), including:

- Characteristics and composition of the matter;
- Characteristics of dumping site and methods of dumping;
- General considerations and conditions.

The factors that should be considered under each of these general categories are listed in Table 7.5-4.

o Guidelines for the applications of Annex III.

Guidelines have been prepared for the application of Annex III which specify the scientific and technical information to be considered by the responsible national authorities prior to the issuance of permits for dumping. The guidelines amplify the basic requirements listed in Table 9.5(d) and provide a basis for interpreting the relevant data. They are set out in Appendix I of this section.

The main area of disagreement concerning the criteria listed in Annex III of the London Convention is the consideration required with regard to the practical availability of alternative land-based disposal or treatment facilities (Item 4 of Section C in Table 7.5-4. Some Contracting Parties give this requirement very high priority in that no permit is granted for the dumping of those wastes for which alternative land-based methods are available. Others regard the assimilative capacity of the sea for many wastes as a legitimate agent for their disposal, providing that safeguards embodied within the Convention are observed, and if a combination of economic, technical and environmental factors preclude the use of land-based facilities. This matter is still under discussion and guidelines for this criteria are being considered for this criteria are being considered by the IMO.

TABLE 7.5-4

Annex III

Provisions to be considered in establishing criteria governing the issue and renewal of authorizations in accordance with Articles 4 and 5 include:

A. Characterization and Composition of the Matter

1. Total amount and average composition of matter dumped (e.g., per year).
2. Form: Solid, sludge, liquid or gaseous.
3. Properties: physical (e.g., solubility and density), chemical and biochemical (e.g., oxygen demand, nutrients) and biological (e.g., presence of viruses, bacteria, yeasts, parasites).
4. Toxicity
5. Persistence: physical, chemical and biological.
6. Accumulation and biotransformation in biological materials or sediments.
7. Susceptibility to physical, chemical and biochemical changes and interaction the aquatic environment with other dissolved organic and inorganic materials.
8. Probability of production of taints or other changes reducing the commercial value of marine resources (fish, shellfish, etc.).

B. Characteristics of Dumping Site and Method of Deposit

1. Location (e.g., coordinates of the dumping area, depth and distance from the coast), location in relation to other areas (e.g., amenity areas, spawning, nursery and fishing areas and exploitable resources).
2. Rate of disposal per specific period (e.g., quantity per day, per week, per month).
3. Methods of packaging and containment, if any.
4. Initial dilution achieved by proposed method of release, particularly by speed of the ship.
5. Dispersal characteristics (e.g., effects of currents, tides and wind on horizontal transport and vertical mixing.
6. Water characteristics (e.g., temperature, pH, salinity, stratification, indices of pollution - dissolved oxygen (DO), chemical oxygen demand (COD), biochemical oxygen demand (BOD) - nitrogen present in organic and mineral form including ammonia, suspended matter, other nutrients and productivity.

TABLE 7.5-4 (continued)

7. Bottom characteristics (e.g., topography, geochemical and geological characteristics and biological productivity.

8. Existence and effects of other dumping which have been made in the dumping area (e.g., heavy metal background reading and organic carbon contents).

9. Determination of the consequences of dumping in the area concerned, taking into account seasonal variation, by means of an impact study.

C. General Factors and Conditions

   1. Possible effects on amenity and bathing areas (e.g., deterioration in the quality of bathing water, presence of floating or stranded material, turbidity, objectionable odour, discoloration and foaming).

   2. Possible effects on marine life, fish and shellfish culture, fish stocks and fisheries, seaweed harvesting and culture.

   3. Possible effects on other uses of the sea (e.g., impairment of water quality for industrial use, underwater corrosion of structures, interference with ship operations from floating materials, interference with fishing or navigation through deposit or waste or solid objects on the sea floor and protection of areas of special importance for scientific or conservation purposes).

   4. The practical availability of alternative land-based methods of treatment, disposal or elimination, or of treatment to render the matter less harmful for dumping at sea.

(iv) Exceptions to general requirements for permit issuance

- o Safety of human life and vessels. Article V(1) provides that under certain circumstances in which dumping is necessary due to stress of weather and other causes which constitute a danger to human life or a real threat to safety of vessels, aircraft, platforms or other man-made structures at sea, no permit is required.

- o Emergency exception. Another exception provided for in Article V(2) is the issuance of a special permit for the dumping of black list substances in emergency cases, emergency being defined as a situation where unacceptable risk is posed to human health and not other feasible solution is possible. Prior to the issue of such an emergency permit the Party shall conduct:

  - any other country or countries (Contracting Parties or not Contracting Parties) that are likely to be affected; and

  - the Organization (IMO) that will itself enter into consultation with other Parties and other international organizations, as appropriate.

- o Ships and aircraft entitled to sovereign immunity. Dumping at sea is not only used for the disposal of wastes produced on land, and of dredged material from the construction and maintenance of shipping lanes and harbours, but also for the disposal of military wastes. When drafting the Convention it was therefore felt that special provisions would be necessary with regard to military ships and aircraft as well as other ships or aircraft entitled to sovereign immunity. Accordingly, Article VII(4) provides that the Convention does immunity under international law. However, each Contracting Party shall ensure by the adoption of appropriate measure that such vessels and aircraft owned or operated by it act in a manner consistent with the object and purpose of the Convention. The Organization shall be informed of such measures.

7.5.6 Quantities Dumped at Sea

The London Dumping Convention requires that Contracting Parties provide information on records of the nature and quantities of all matter permitted to be dumped and the location, time and method of dumping. A satisfactory format for the recording of such information is yet to be developed. IMO have, however, compiled a tentative list from the available data - only a handful of Member States have submitted returns, and the Secretariat have recommended a tightening-up of the procedure (Johnston 1981). Detailed information is available mainly for parties to the Oslo Convention; Tables 7.5-5 and 7.5-6 list the records for industrial waste for industrial waste for 1981 (IMO 1984). Of the acceding States in Africa, Asia, only submitted information on Annex I and Annex II materials. In North America, the United States dumped 1.05 tonnes of mercury and 7.13 tonnes of cadmium in 1980 at its main site, but these Annex I metals were present as 'trace contaminants' and therefore the wastes were exempt form the prohibition on dumping.

TABLE 7.5-5

Amounts of Industrial Wastes Dumped in 1981

Type of Waste	Amount (Tonnes)	Percentage of Total	Contracting Parties Involved	Amount in % Dumped by Each Contracting Party (Tonnes)
Liquid wastes and sludges	1,071,882	13	Belgium	1.8 (19,214)
			Denmark	0.5 (5,320)
			Federal Republic of Germany	20.2 (216,926)
			Ireland	34.5 (369,920)
			Netherlands	1.3 (14,043)
			United Kingdom	41.7 (446,459)
"Deep water" solid wastes	99	<0.1	United Kingdom	100
Waste from production of TiO_2	2,710,030	31	Belgium	24.0 (651,535)
			Federal Republic of Germany	56.8 (1,540,205)
			Spain	19.1 (518,290)
Phosphogypsum waste	2,854,733	33	France	100
Fly ash and colliery waste	2,048,500	23	United Kingdom	100
Total	8,685,244	100		

Source: Johnston, R. 1981. In Ocean Dumping of Industrial Waste, edited by B. H. Ketchum, D. R. Kester, and P. K. Park. New York: Plenum Press.

TABLE 7.5-6

Amounts of Industrial Wastes Dumped in 1981 (in tonnes)

Country	Total Amount	Hg	Cd	Organo-halogens	Cu	Cr	Ni	Pb	Zn	Other Metals & Metalloids	Toxicity Testing	Remarks
Belgium	670,749	0.008	0.055	-	0.041	164	-	1.36	n.i.	19,812	0/5	A
Denmark	5,320	-	-	-	-	-	-	-	-	-	1/1	
France	2,854,733	0.225	3.857	-	3.549	8.641	3.240	5.863	13.887	347.196	0/1	phospho-gypsum waste
Federal Republic of Germany	1,757,131	0.123	0.082	6.1	3.6	306.9	9.3	5.4	53.8	68,234.8	0/4	B
Ireland	369,920	-	-	-	0.25	-	-	-	6.08	-	1/1	
Netherlands	14,043	n.a./ ndc	0.002	0.007	0.592	0.396	0.260	0.261	0.565	426	2/4	mutagenic substances
Spain	518,290	-	0.004	-	0.101	-	n.i.	2.142	30.433	915.626	0/1	C
United Kingdom	2,495,058	<0.4	<0.4	n.i.	203.7	23.0	79.3	251.1	470.8	<0.35		
Total	8,685,244	<0.756	<4.4	6.107	211.833	502.597	92.1	266.126	575.565	89,735.972		D

n.a. : not analyzed
n.i. : no information
ndc : not detectable
- : none or below significant level

A : 651,535 tonnes of the waste are derived from the manufacture of TiO_2
B : 1,540,205 " " " " " " " " " " "
C : Spanish waste " " " is " " " " " "
D : A total of 2,710,030 tonnes is " " " " " "

Source: Johnston, R. 1981. In Ocean Dumping of Industrial Waste, edited by B. H. Ketchum, D. R. Kester, and P. K. Park. New York: Plenum Press.

Information on the sea dumping of sewage sludge and dredged spoils is given in Tables 7.5-7 and 7.5-8 for 1981. Again, the metals and organohalogens listed were present in 'trace' quantities. On a worldwide basis, the quantity of sewage sludge and dredged spoils dumped in 1984 varied from 15,000 tonnes (FRG) to 8,485,000 tonnes (UK) and from 100,000 tonnes (Italy) to 53,200,000 tonnes (USA), respectively.

7.5.7 Fate of Dumped Wastes

Self-propelled tankers or towed barges transport waste to the disposal site (USEPA 1984). Dispersal in the wake of the barge is a highly effective means of rapidly diluting a waste by a factor of 10,000 or more within a few hours. The persistence of a plume once it reaches a width of about 1 km and a dilution of 100,000 or 1,000,000 is poorly known.

The fate of a dispersed waste is illustrated in Figure 7.5-1 (USEPA 1984). Volatile waste constituents rapidly evaporate from the water surface. Flotable materials such as oil and scum remain on the surface and can be transported long distances by winds and currents. Solids sink to the ocean floor as an expanding cloud.

The physical dispersion of wastes determine the area of impact and concentrations to which organisms will be exposed. Both lateral and vertical mixing processes are important. Vertical diffusion in the upper ocean layer is dependent on the wind stress, wave conditions and density stratification of the water due to changes in temperature and salinity with depth. These areas of constant density are called pycnoclines, or thermoclines when caused by temperatures plateaus. The wastes do not reach the ocean bottom when a pycnoline is present; they are distributed from top to bottom when the ocean is isothermal. During stratified periods, the slow rate of oceanic mixing may allow the waste plume to maintain measurable concentrations for days or possibly weeks.

Lateral diffusion depends on the mean current and its gradients, topography and large scale density distribution. Waste can accumulate along pycnoclines at various depths within the water column, exposing the organisms active in these areas to potentially toxic concentration of pollutants.

7.5.8 Monitoring

Monitoring is the assessment of changes in the marine environment caused by dumping operations. It is an essential part of ocean dumping procedures, for recording the distribution, fate and effect of contaminants, and as part of ongoing scientific investigation and research programmes aimed at increasing knowledge of the physical, chemical and biological process that affect the dumped waste. Drift velocities at various depths in the ocean can be measured by drogues, typically consisting of 0.6m plastic pipes containing electronics that emit radio signals, and buoyed by ballasted flotation chambers. The current sensor is suspended at a controllable depth beneath the drogue hull (Klemas and Philpot 1981). Information on current direction and velocity combined

TABLE 7.5-7

Amounts of Sewage Sludge Dumped in 1981 (in tonnes)

Country	% of Total	Amount	Cd	Hg	Organo-halogens	Cu	Cr	Ni	Pb	Zn	Other Metals & Metalloids
Federal Republic of Germany	0.2	14.822*	^{0}0.400	^{0}0.126	^{0}0.639	^{0}16.3	^{0}10.7	^{0}2.0	^{0}9.4	^{0}43.0	196.75
Ireland	1.5	131,887	0.070	0.029	n.dc	1.3273	0.4014	0.8067	1.5997	3.7840	21.368
United Kingdom	98.3	8,485,083	6.47	2.44	n.i.	199.84	134.9	8.81	159.78	640.77	5.3
Total	100	8,631,792	6.94	2.595	0.639	217.47	146.0	11.62	170.78	687.55	223.42

0 : mean value
n.dc : not detectable (level of detection - 10 ng per litre)
n.i. : no information
* : solids

Source: Johnston, R. 1981. In Ocean Dumping of Industrial Waste, edited by B. H. Ketchum, D. R. Kester, and P. K. Park. New York: Plenum Press.

TABLE 7.5-8

Amounts of Dredgings Dumped in 1981 (in tonnes)

Country	% of Total	Amount	Cd	Hg	Organo-halogens (inc. PCBs)	Cu	Cr	Ni	Pb	Zn	Other Metals & Metalloids	As
Belgium	47.3	52,504,983 (8)	n.i.	11.333 (7)	1.9146 (6)	642.81 (7)	2,546.99 (8)	528.5 (8)	1,614.2 (8)	9,933.9 (6)		
Denmark	0.7	818,205 (6*)	0.010 (1)	0.001 (1)	0.002 (1)	1.304 (1)	0.328 (1)	0.174 (1)	0.421 (1)	4.970 (1)	0.021 (1)	
France	6.1	6,800,000 (6)	0.746 (1)	0.410 (1)	0.051 (1)	24.597 (1)	32.108 (1)	16.813 (1)	40.120 (1)	96.890 (1)		
Ireland	0.1	153,024 (4)	0.002 (1)	^{0}0.325	n.i.	0.04 (1)	0.02 (1)	0.02 (1)	^{0}0.145 (1)	$^{+}$0.165 (1)		
Nether-lands	33.5	37,199,716** (10)	55.255 (8)	11.622 (8)	37.959 (8)	531.81 (8)	982.91 (8)	318.74 (8)	1,382.95 (8)	4,192.4 (8)	269,999.5 (8)	197.86 (8)
Portugal	0.7	788,800	n.i.	n.i.	n.i.	n.i.	n.i.	n.i.	n.i.	n.i.		
United Kingdom	11.5	12,786,112 (45)	7.1 (31)	11.3 (31)	0.2 (31)	451.7 (31)	645.4 (31)	218.8 (31)	723.4 (31)	1,923.0 (31)		n.d.
Total	100	111,050,840	63.113	35.001	40.127	1,652.261	4,207.756	1,083.047	3,761,236	16,151.325		

* One report did not include information about the amount dumped

** Amount indicated in m^3 - presumed density 1.3

^{0} Mean value

A figure between () gives the total number of reports received.

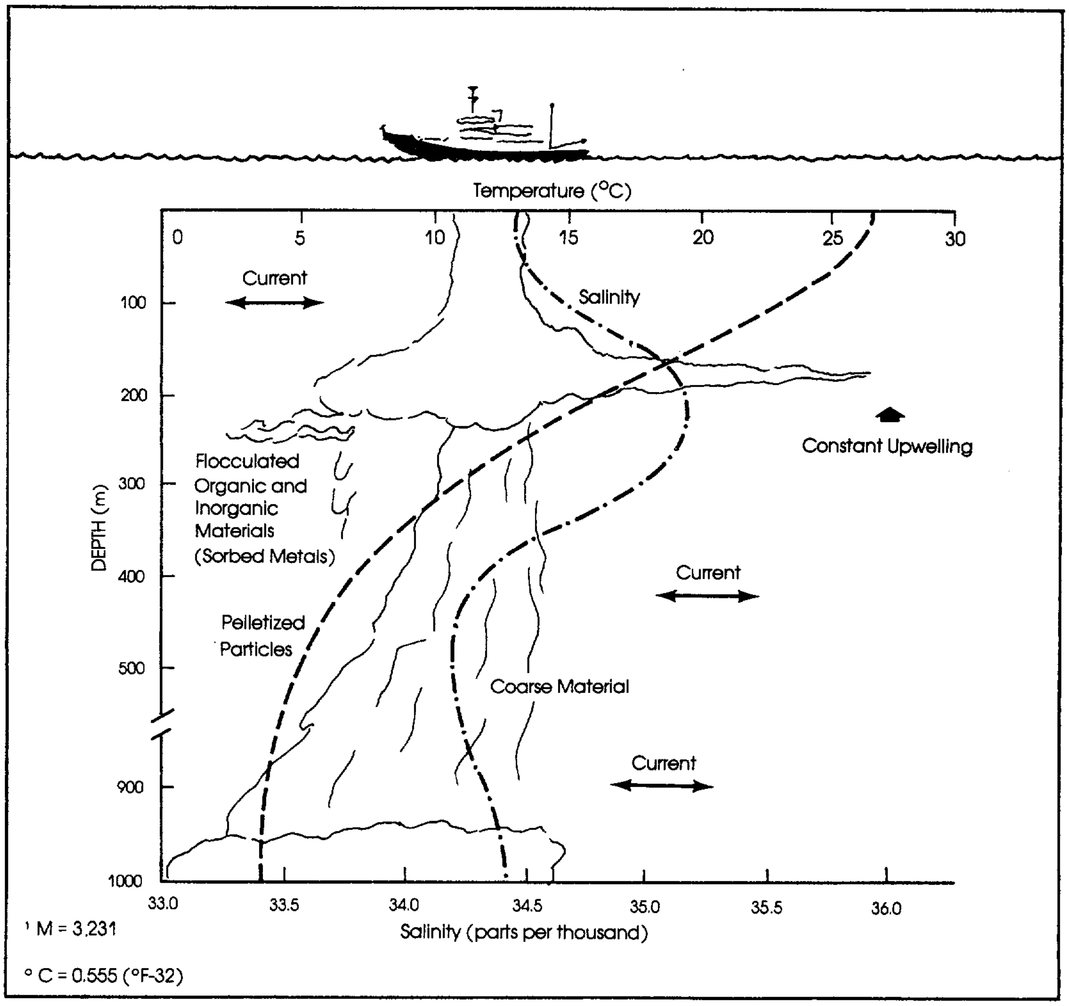
n.i. : no information

n.d. : not determined

Source: Johnston, R. 1981. in Ocean Dumping of Industrial Waste, edited by B. H. Ketchum, D. R. Kester, and P. K. Park. New York: Plenum Press.

FIGURE 7.5-1

Generalized Scheme of the Fate of Sludge Solids Disposed of at Sea



Source: USEPA. 1984. Use and Disposal of Municipal Wastewater Sludge. EPA 625/10-84-003.

with data on pycnoclines can be used to form the basis of a predictive mechanism for the disposal of dumped waste. Figure 7.5-2 illustrates the type of information that can be obtained from sea-truth studies (Kester et al. 1981) - 27 hours after a dump of acid-iron waste, elevated total iron concentrations up to 400 times the natural values is still evident in the upper 20m of ocean.

The biological consequences of ocean dumping are generally regarded as establishing the acceptable limits of waste input. Monitoring of shrimp, flatfish, and mussels around the coastal areas to establish relative levels of uptake of heavy metals, hydrocarbons and organochlorine have been conducted (Johnston 1981, Lear et al. 1981). Figure 7.5-3 shows the results of a mortality study of mahogany clams in the vicinity of a dump site off the US coast (Lear et al. 1981). Stations A, 32, 22, 23, 9,F and G34 reflect the natural distribution of this organism. Stations 2 and C were within the 37km E of the dump sites. Coupled with sea-truth information on containment concentrations, such bioassays prove to be a valuable monitoring scheme for assessing the impact of dumping at sea.

Remote sensing instruments operating from satellites and aircraft can be used to locate, identify and map plumes resulting from ocean dumping of wastes. Coupled with sea-truth data obtained by direct measurement of sea currents and analysis of samples, this technique can also generate quantitive information on pollutant persistence and concentrations as a function of depth and plume are (Johnson and Ohlhorst 1981). Table 7.5-9 lists some studies using remotely sensed data. Figure 7.5-4 illustrates the spectral characteristics of petrochemical and pharmaceutical wastes, and Figure 7.5-5 shows contour mapping of pollution plumes, obtained by calibrating remote spectral signature and addition of any material to it will produce a deviation from this background. Figure 7.5-6 shows LANDSTAT imagining of an iron-acid waste dump. In diagram (i) of Figure 7.5-6 the acid and cloudy materials are both plotted as dark points. In diagram (ii) of Figure 7.5-6, only those pixels actually classified as acid-iron are plotted. The patter that is seen is the course followed by the barge while dumping. After a few hours the trace becomes diffuse and less distinct as the waste disperses over a wider area.

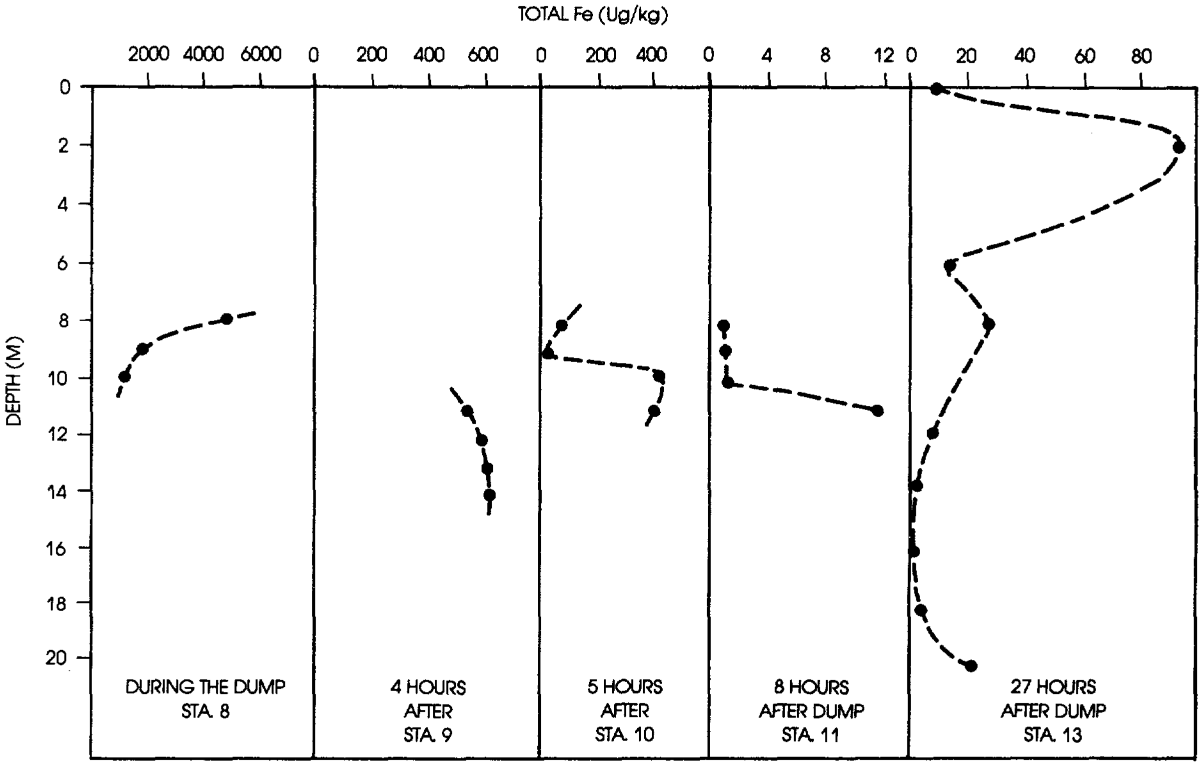
The spatial and temporal resolution of the satellite imaginary can also provide information on plume dispersion. Figure 7.5-7 shows data on acid waste plume width as a function of time and drift velocity. During calm seas the plume width increased at an average rate of about 1.5 cm/s while during wind-dominated, rough sea conditions spreading rates exceeded 4 cm/s (Klemas and Philpot 1981).

7.5.9 Technical Assistance

In a number of circular letters addressed to all countries, the Secretary-General of the IMO has emphasized the value of the London Dumping Convention as a global basis for the application of sea disposal principles and practices with regard to waste management as well as the importance of the Convention in supplying coordination, assistance and the comprehensive approach needed to consolidate the jurisdiction applied at

FIGURE 7.5-2

Vertical Plots of Iron in the Upper 20m at Various Times After an Acid-iron Dump

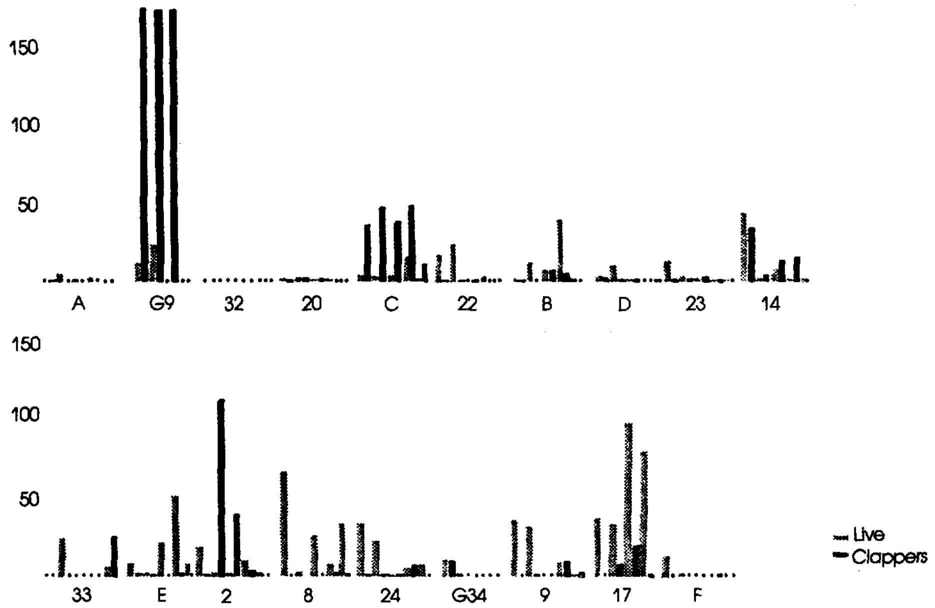


Source: Kester, D. R., R. C. Hittinger and P. Mukherjn. 1981. In Ocean Dumping of Industrial Waste, edited by B. H. Ketchum, D. R. Kester, and P. K. Park. New York: Plenum Press.

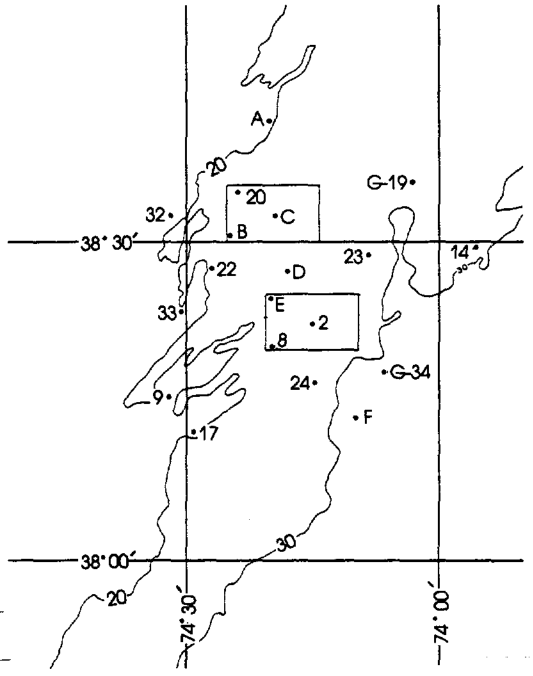
FIGURE 7.5-3

Mortality of Mahogany Clams Around Dump Site Off the US Coast

(i) Apparent recent mortalities of mahogany clams, Artica islandica, as indicated by live clams (solid bars) and hinged shells or 'clappers' (hatched bars).



(ii) Station locations where Artica islandica were sampled.



Source: Lear, D. W., M. L. O'Malley and S. K. Smith. 1981. In Ocean Dumping of Industrial Waste, edited by B. H. Ketchum, D. R. Kester and P. K. Park. New York: Plenum Press.

TABLE 7.5-9

Some Studies Using Data from Remote Sensing

Sensor*	Platform	Region	Parameter	Reference
Camera	Aircraft	Lake Superior	Suspended Sediment	a
Camera MSS	Satellite	Delaware Bay Mid-Atlantic Coastal Zone	Suspended Sediment Acid-iron Waste	b
MSS	Satellite	Kansas	Suspended Sediment	c
MSS	Satellite	Chesapeake Bay	Suspended Sediment	d
MSS	Satellite	Delaware Bay Mid-Atlantic Coastal Zone	Suspended Sediment Acid-iron Waste	e
MSS	Satellite	Lake Huron	River Plume	f
M2S	Aircraft	James River, VA New York Bight	Suspended Sediment Chlorophyll _a_	g
MSS	Satellite	Chesapeake Bay Mid-Atlantic Coastal Zone	Suspended Sediment Chlorphyll _a_ Acid-iron Waste	h

*MSS-Multispectral Scanner (e.g., LANDSAT); M2S - Modular Multispectral Scanner; OCS-Ocean Color Sensor.

(a) Scherg, J. P., J. F. Van Domelan, and S. A. Klooster. 1973. In _Proceedings of the American Society of Photogrammetry Fall Convention_.

(b) Klemas, V., D. Barlett, W. Philpot, R. Roger, and L. Reed. 1978. NASA CR 144910.

(c) Yargar, H. L., J. R. McCauley, G. W. James, and L. M. Magnuson. 1973. In _Symposium of Significant Results Obtained from ERT Satellite - I_. NASA SP - 327.

(d) Williamson, A. N., and W. E. Graban. 1973. In _Third ERT Satellite - I Symposium_. NASA SP - 351.

(e) Klemas, V., M. Otley, W. Philpot, C. Wethe, and R. Roger. 1974. In _Proceedings of Ninth International Symposium on Remote Sensing of Environment_. Ann Arbor, Michigan.

(f) Rogers, R. H., N. J. Shah, J. B. McKeon, C. Wilson, L. Reed, V. E. Smith, and A. Thomas. 1975. In _Proceedings of Tenth International Symposium on Remote Sensing of Environment_. Ann Arbor, Michigan.

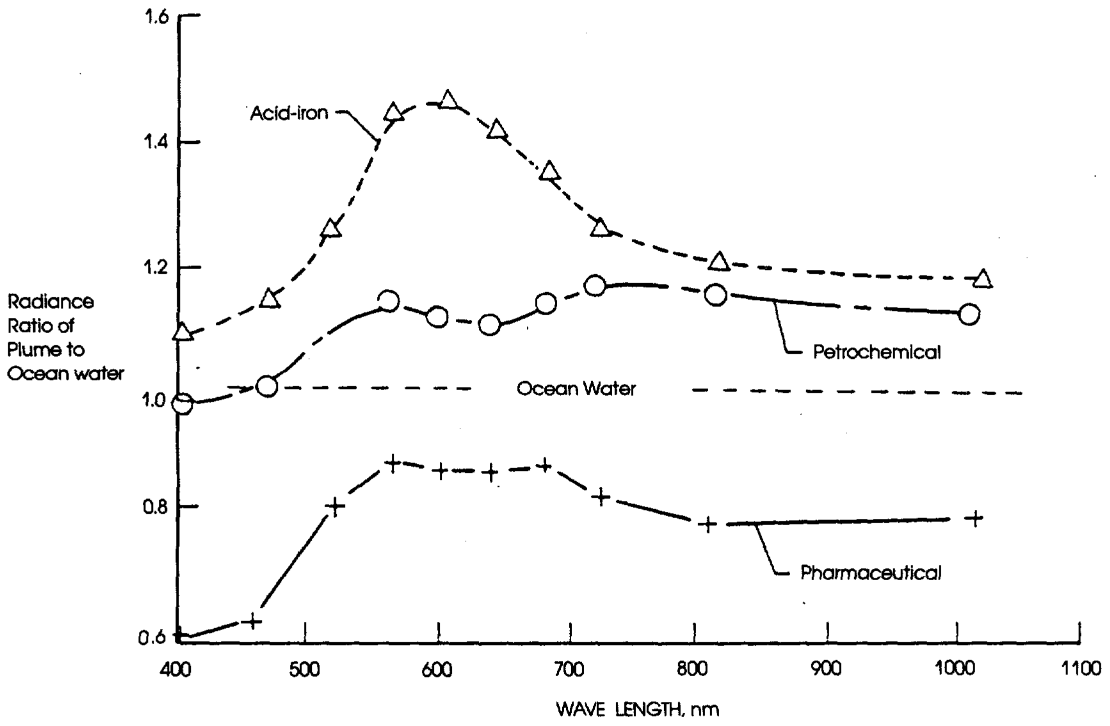
(g) Johnson, R. W. 1978. Photogrammetric Engineering and Remote Sensing (44): 617.

(h) Bowker, D. E. and W. G. Witte. 1977. In _Proceedings of the AIAA Joint Conference on Satellite Applications_. American Institute of Aeronautics and Astronautics.

Source: Johnson, R. W., and C. W. Ohlhorst. 1981. In _Ocean Dumping of Industrial Waste_, edited by B. H. Ketchum, D. R. Kester, and P. K. Park. New York: Plenum Press.

FIGURE 7.5-4

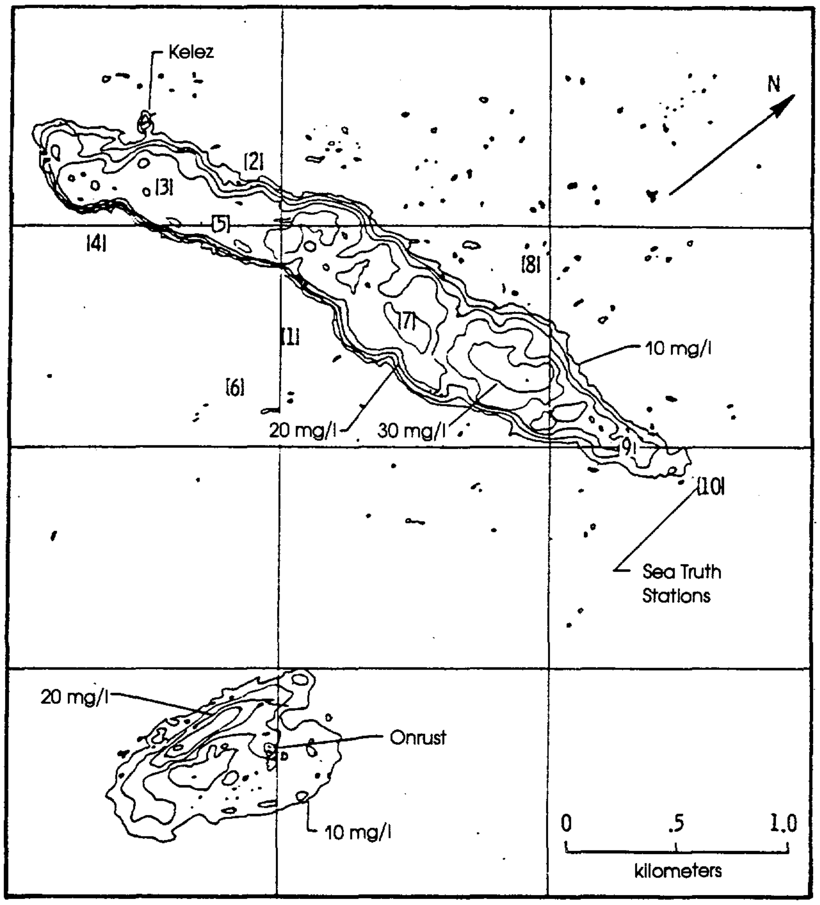
Spectral Characteristics of Petrochemical and Pharmaceutical Waste Plumes



Source: Johnson, R. W., and C. W. Ohlhorst. 1981. In Ocean Dumping of Industrial Waste, edited by B. H. Ketchum, D. R. Kester, and P. K. Park. New York: Plenum Press.

FIGURE 7.5-5

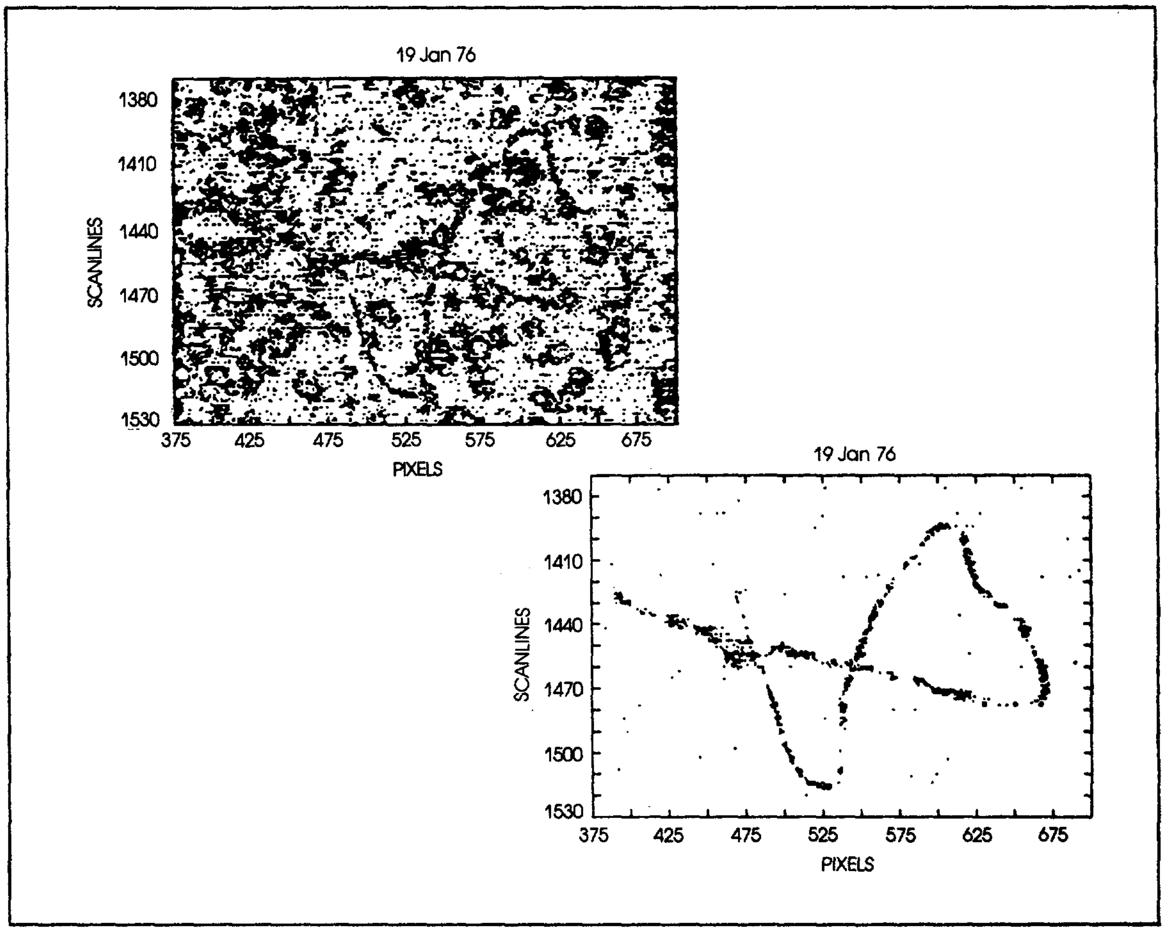
<u>Quantitative Distribution of Suspended Solids in Sewage Sludge Plumes</u>



Source: Johnson, R. W., and C. W. Ohlhorst. 1981. In <u>Ocean Dumping of Industrial Waste</u>, edited by B. H. Ketchum, D. R. Kester, and P. K. Park. New York: Plenum Press.

FIGURE 7.5-6

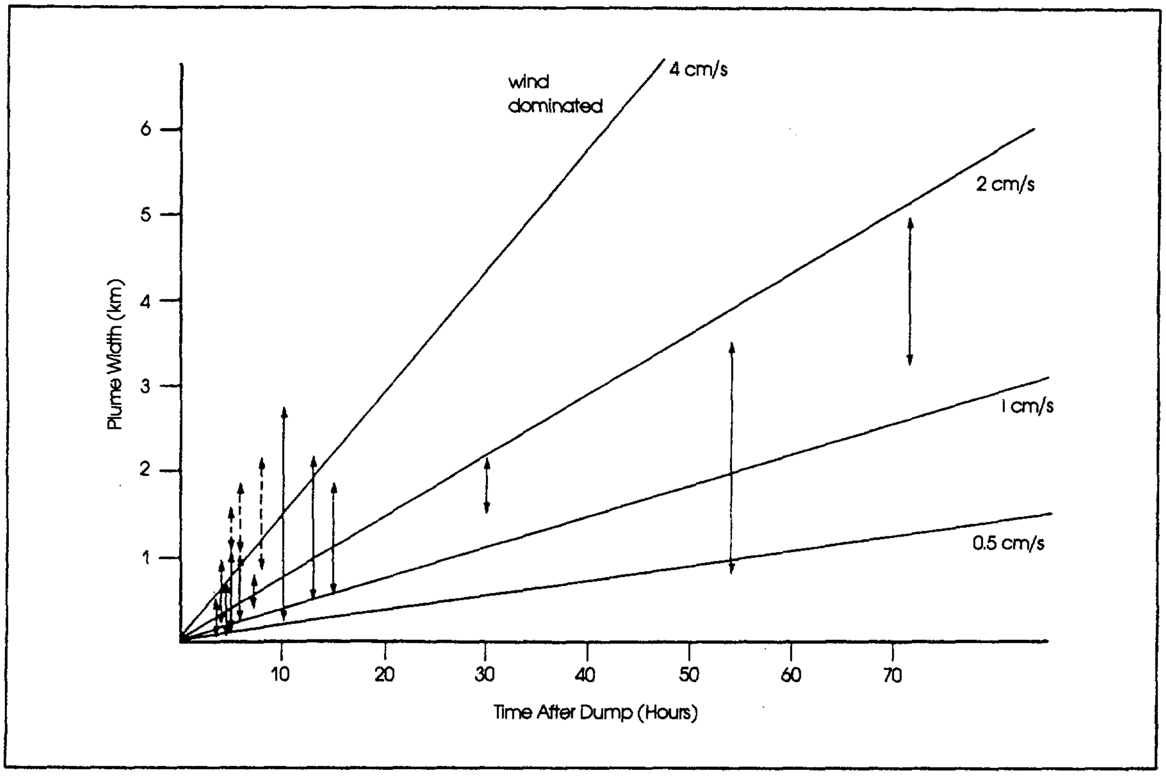
Enhancement of the Iron-acid Waste Plume of 19 January 1976, Against a Cloud Background



Source: Klemas, V. and W. D. Philpot. 1981. In Ocean Dumping of Industrial Waste, edited by B. H. Ketchum, D. R. Kester, and P. K. Park. New York: Plenum Press.

FIGURE 7.5-7

Acid Waste Plume Width as a Function of Time After Dump



Source: Klemas, V. and W. D. Philpot. 1981. In Ocean Dumping of Industrial Waste, edited by B. H. Ketchum, D. R. Kester, and P. K. Park. New York: Plenum Press.

regional and national levels. Convention signatories were invited to indicate whether they have any difficulties or specific problems, which may have prevented them from so doing that which could be alleviated by assistance through IMO.

In circular letter No 1144 of 20 November 1986, the Secretary-General of IMO again reminded Contracting Parties or Non-Contracting Parties faced with problems concerning the disposal and treatment of wastes and other matter (e.g. dredged material, sewage sludge, mine tailings, residues from chemical industries, including hazardous materials) that possibilities exist for IMO to provide technical and scientific advice to developing countries within the framework of the Organization's technical assistance programme. Such countries in need of expertise in the field of waste disposal at sea (e.g., environmental assessment studies, selection of dumping sites, dumping operational techniques, monitoring of dumping sites, etc.) were invited to inform the Secretary-General. The Secretary-General would consider ways and means towards providing the necessary technical assistance (e.g., through expert consultants, granting of fellowships, establishing workshops, seminars, etc.).

The Secretary-General further drew the attention of Governments to certain requirements of the Convention which commit Contracting Parties to "promote, through collaboration within the Organization and other international bodies, support for those Parties which request it for:

(1) the training of scientific and technical personnel;

(2) the supply of necessary equipment and facilities for research and monitoring; and

(3) the disposal and treatment of waste and other measures to prevent or mitigate pollution caused by dumping.

preferably within the countries concerned, so furthering the aim and purposes of the Convention." (London Dumping Convention, Article IX).

7.5.10 References 7.5 - 7.5.9

Commission of the European Communities. 1985. Document COM (85) 373 final. Brussels

International Maritime Organization (IMO). 1984. Document LCD/SG.8/INF.4.

IMO. 1985. Document LDC 9/INF.2.

Johnson, R. W., and C. W. Ohlhorst. 1981. In Ocean Dumping of Industrial Waste, edited by B. H. Ketchum, D. R. Kester, and P. K. Park. New York: Plenum Press.

Johnston, R. 1981. In Ocean Dumping of Industrial Waste, edited by Ketchum, B. H., D. R. Kester, and P. K. Park. Plenum Press, New York.

Kester, D. R., R. C. Hittinger, and P. Mukherjn. 1981. In Ocean Dumping of Industrial Waste, edited by B. H. Ketchum, D. R. Kester, and P. K. Park. New York: Plenum Press.

Klemas, V., and W. D. Philpot. 1981. In Ocean Dumping of Industrial Waste, edited by B. H. Ketchum, D. R. Kester, and P. K. Park. New York: Plenum Press.

Lear, D. W., M. L. O'Malley, and S. K. Smith. 1981. In Ocean Dumping of Industrial Waste, edited by B. H. Ketchum, D. R. Kester and P. K. Park. New York: Plenum Press.

UNEP. 1985. Document UNEP/GC.13/9/Add.3.

USEPA. 1984. Use and Disposal of Municipal Wastewater Sludge. EPA 625/10-84-003.

ANNEX 7.5 - Guidelines for the Implementation and Uniform Interpretation of Annex III to the London Dumping Convention

Article IV (2): Any permit shall be issued only after careful consideration of all the factors set forth in Annex III, including prior studies of the characteristics of the dumping site, as set forth in Sections B and C of that Annex.

Annex III: Provisions to be considered in establishing criteria governing the issue of permits for the dumping of matter at sea, taking into account Article IV (2), include:

Interpretation:

Each authority or authorities designated in accordance with Article IV for the issue of general and special permits for the disposal of wastes and other matter at sea shall, when considering a permit application, carefully study all the factors set out in Annex III. This includes the establishment of procedures and criteria for:

(1) deciding whether an application for sea disposal should be pursued in the light of the availability of land-based disposal or treatment methods;

(2) selecting a sea disposal site, including the choice and collection of relevant scientific data to assess the potential resources and marine life, damage to amenities or interference with other legitimate uses of the sea;

(3) choosing appropriate disposal methods and conditions;

(4) developing an appropriate monitoring programme.

The above mentioned criteria should enable permit applications to be effectively assessed and likely environmental hazards to be evaluated.

(A) Characteristics and Composition of the Matter

----

(1) Total amount and average composition of matter [to be] dumped (e.g., per year).
(2) Form (e.g., solid, sludge, liquid, or gaseous).
(3) Properties: physical (e.g., solubility and density), chemical and biochemical (e.g., oxygen demand, and nutrients) and biological (e.g., presence of viruses, bacteria, yeasts, and parasites).

---

* For the disposal at sea of radioactive wastes additional requirements recommended by the IAEA have to be taken into account (INFCIRC/205/Add.1./Rev.1). For the control of incineration of wastes at sea specific site selection criteria have been established.

Interpretation:

In order to assess environmental transport and fate, including potential effects on water quality and biota, the total amount of wastes proposed to be dumped within a time period and the physical, chemical and biological composition of the waste should be known. The first step for the characterization of a waste or other matter proposed for dumping at a site should be the collection of existing data on the waste composition or a waste analysis.

This should not mean that every waste should be subjected to exhaustive chemical analysis to establish the concentrations of a standard wide-ranging list of chemical elements or compounds. Knowledge of the raw materials and production processes used may often provide a key to the probable composition of the waste. A selective analysis may then be sufficient for a preliminary assessment. As a minimum, it should be established whether any Annex I or Annex II materials are present.

The analysis should include appropriate measurements of the composition of major components. In cases where anthropogenic chemicals of high toxicity are known or suspected to be involved, those minor components that are reasonably identifiable should be measured.

In addition data should, as appropriate, be obtained on physical, chemical and biological properties of the waste or other matter, such as:

- Solubility;
- Percent solids;
- Density (specific gravity) of bulk matter, its liquid and particle phases;
- Grain size fractions of total solid phase (e.g., clay-silt/sand- gravel fractions of dredged material);
- pH;
- Biochemical oxygen demand (BOD);
- Chemical oxygen demand (COD);
- Nutrients; and
- Microbiological components.

---

(4) Toxicity.

(5) Persistence: physical, chemical and biological.

(6) Accumulation and biotransformation in biological materials or sediments.

Interpretation:

If the chemical analysis of the wastes shows the presence of substances whose biological effects are not well known, or if there is any doubt as to the exact composition or properties of the waste, it may be necessary to carry out suitable test procedures for toxicity, persistence and bioaccumulation, which may include the following:

- Acute toxicity tests on phytoplankton, crustaceans or molluscs, fish, or other such organisms as may be appropriate.
- Chronic toxicity tests capable of evaluating long-term sublethal effects, such as bioassays covering an entire life cycle.
- Tests to determine the potential for bioaccumulation of the substances contained in the waste and, if appropriate, the potential for eventual elimination. The test organisms should be those most likely to bioaccumulate the substances concerned.
- Tests for determining the persistence of substances contained in the waste. The potential for degradability of these substances should be determined using bacteria and water typical of the proposed dumping site. The tests should attempt to reflect the conditions at the proposed dumping site.

If appropriate, the test procedures described above should be carried out separately with the solid, suspended and/or liquid phases of wastes proposed for sea disposal.

A number of substances, when entering the marine environment, are known to be converted by biological processes to more toxic substances. This should be taken into particular account when the various tests mentioned above are performed.

---

(7) Susceptibility to physical, chemical and biochemical changes and interaction in the aquatic environment with other dissolved organic and inorganic materials.

Interpretation:

Substances introduced into the sea may be rapidly rendered harmless by physical, chemical, and biochemical processes but others may be changed to products with more hazardous properties then those of the original substances. In these latter cases, it may be appropriate to carry out the tests outlined in paragraph A6 above for the anticipated products.

---

(8) Probability of production of taints or other changes reducing marketability of resources (fish, shellfish, etc.).

Interpretation:

In evaluating the possible effects of the waste concerned on marine biota, particular attention should be paid to those substances that are known to accumulate in marine organisms with the result that seafood is tainted and rendered unpalatable. In many cases there might be a suspicion about the tainting property of a substance without the availability of firm data. In these cases, a taste panel will have to determine threshold limits, if any, of the tainting properties of the substance concerned.

"Other changes reducing the marketability of resources" referred to in paragraph 8 of Section A include discoloration of fish flesh, and fish diseases such as fin rot and tumours.

(B) Characteristics of Dumping Site and Method of Deposit

Matters relating to dump site selection criteria are addressed in greater detail in a study prepared by GESAMP* (Reports and Studies No. 16: Scientific Criteria for the Selection of Waste Disposal Sites at Sea, IMO 1982) which should be considered in conjunction with these guidelines.

---

(1) Location (e.g., coordinates of the dumping area, depth and distance from the coast), location in relation to other areas (e.g., amenity areas, spawning, nursery and fishing areas and exploitable resources).

Interpretation:

Basic site characteristics information to be considered by national authorities at a very early stage of assessment of a new site should include the coordinates of the dumping area (latitude, longitude), as well as its location with regard to:

- distance to nearest coastline;
- recreational areas;
- spawning and nursery areas;
- known migration routes of fish or marine mammals;
- sport and commercial fishing areas;
- areas of natural beauty or significant cultural or historical importance;
- areas of special scientific or biological importance (marine sanctuaries);
- shipping lanes;

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*IMO/FAO/UNESCO/WMO/WHO/IAEA/UN/UNEP Joint Group of Experts on the Scientific Aspects of Marine Pollution.

- military exclusion zones; and
- engineering uses of seafloor (e.g., potential or ongoing seabed mining, undersea cables, desalination or energy conversion sites).

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(2) Rate of disposal per specific period (e.g., quantity per day, per week, per month).

Interpretation:

Although the amounts of matter to be dumped (e.g., per year) are considered under paragraph A1 above, many operations, e.g., those related to dredging, are of shorter periods. In order to assess the capacity of the area for receiving a given type of material the anticipated loading rates (e.g., per day) or in the case of existing sites, the actual loading rates (frequency of operations and quantities of wastes or other matter disposed of at each operation per time period) should be taken into consideration.

---

(3) Methods of packaging and containment, if any.

(4) Initial dilution achieved by proposed method of release.

Interpretation:

The data to be considered under this item should include information on:

- Type, size and form of packaging and containment units;
- presence of any Annex I or Annex II substances as packaging material or in any matrix that might be used;
- marking and labelling of packages; and
- disposal method (e.g., jettisoning over ship's side; discharge of liquids and sludges through pipes, pumping rates, number and location of discharge pipe outlets [under or above waterline, water depth], etc.). In this connection the length and speed of the vessel when discharging wastes or other matter should be used to establish the initial dilution.

---

(5) Dispersal characteristics (e.g., effects of currents, tides and wind on horizontal transport and vertical mixing).

(6) Water characteristics (e.g., temperature, pH, salinity, stratification, oxygen indices or pollution - dissolved oxygen [DO], chemical oxygen demand [COD], biochemical oxygen demand [BOD] - nitrogen present in organic and mineral form including ammonia, suspended matter, other nutrients and productivity).

Interpretation:

For the evaluation of dispersal characteristics data should be obtained on the following:

- Water depths (maximum, minimum, mean);
- water stratification in various seasons and weather conditions (depth and seasonal variation of pycnocline);
- tidal period, orientation of tidal ellipse, velocities of minor and major axis;
- mean surface drift (net): direction, velocity;
- mean bottom drift (net): direction, velocity;
- storm (wave) induced bottom currents (velocities);
- wind and wave characteristics, average number of storm days per year; and
- concentration and composition of suspended solids.

Where the chemical composition of the waste warrants, it may be appropriate to evaluate pH, suspended solids, persistent organic chemicals, metals, nutrients and microbiological components. BOD and COD or organic carbon determination in the suspended or dissolved phase, together with oxygen measurements, may also be appropriate where organic wastes or nutrients are concerned.

---

(7) Bottom characteristics (e.g., topography, geochemical and geological characteristics and biological productivity).

Interpretation:

Maps and bathymetric charts should be consulted, and specific topographic features that may affect the dispersal of wastes (e.g., marine canyons) should be identified.

The geochemical observation of sediments in and around the disposal site should be related to the type of waste(s) involved. The range of chemical constituents should be the same as that provided for the characterization of the waste or other matter, with the minimum range of data set out in paragraph A1 above.

In areas where wastes may reach the bottom, sediment structure (i.e., the distribution of gravel, sand, silt and clay) as well as benthic and epibenthic community characteristics should be considered for the site area.

Mobility of sediments due to waves, tides or other currents should be considered in any waste disposal site assessments. The possibility of seismic activities in the area under consideration should be investigated, in particular when hazardous wastes in packaged form are concerned. The distribution of sediment types in an area provides basic information as to whether dumped solids with certain characteristics will accumulate at a site or be dispersed.

Sorption/desorption processes under the range of dump site redox and pH conditions, with particular reference to exchanges between dissolved and fine particulate phases, are relevant to the evaluation of the accumulative properties of the area for the components of the waste proposed for dumping and for their potential release to overlying waters.

(8) Existence and effluents of other dumpings which have been made in the dumping area (e.g., heavy metal background reading and organic carbon content).

Interpretation:

The basic assessment to be carried out of a site, either a new or an existing one, shall include the consideration of possible effects that might arise by the increase of certain waste constituents or by interaction (e.g., synergistic effects) with other substances introduced in the area, either by other dumpings or by river input and discharges from coastal areas, by exploitation areas, and maritime transport as well as through the atmosphere. The existing stress on biological communities as a result of such activities should be evaluated before any new or additional disposal operations are established. The possible future uses of the sea area should be kept under consideration.

Information for baseline and monitoring studies at already established dumping sites will be important in this evaluation of any new dumping activity at the same site or nearby.

(9) In issuing a permit for dumping, Contracting Parties should consider whether an adequate scientific basis exists for assessing the consequences of such dumping, as outlined in this Annex, taking into account seasonal variations.

Interpretation:

When a given location is first under consideration as a candidate disposal site, the existing data basis should be evaluated with a view to establishing whether the main characteristics are known in sufficient detail or accurately enough for reliable modeling of waste effects. Many parameters are so variable in space and time that comprehensive series of observations has to be designed to quantify the key properties of an area over the various seasons.

If at any time monitoring studies demonstrate that existing disposal sites do not satisfy these criteria, alternative disposal sites or methods should be considered.

(C) General Considerations and Conditions

---

(1) Possible effects on amenities (e.g., presence of floating or stranded material, turbidity, objectionable odour, discolouration and foaming).

(2) Possible effects on marine life, fish and shell fish culture, fish stocks and fisheries, seaweed harvesting and culture.

Interpretation:

Particular attention should be given to those waste constituents that float on the surface or that, in reaction with sea water may lead to floating substances that, because they are confined to a two-dimensional rather than a three-dimensional medium, disperse very slowly. The possibility of convergences that may lead to interferences with amenities as well as with fisheries and shipping should be investigated.

Information on the nature and extent of commercial and recreational fishery resources and activities should be gathered.

Body burdens of persistent toxic substances (and, in the case of shellfish, pathogens) in selected marine life and, in particular, commercial food species from the dumping area should be established.

Certain ground although not in use for fishing may be important to fish as spawning, nursery or feeding areas, and the effects of sea disposal on these grounds should be considered.

The effects that waste disposal in certain areas could have on the habitats of rare, vulnerable or endangered species should be recognized.

Besides toxicological and bioaccumulation effects of waste constituents other potential impacts on marine life, such as nutrient enrichment, oxygen depletion, turbidity, modification of the sediment composition and blanketing of the sea floor, should be addressed.

It should also be taken into account that disposal at sea of certain substances may disrupt the physiological processes used by fish for detection and may mask natural characteristics of sea water or tributary streams, thus confusing migratory species which consequently lose their direction, go unspawned or fail to find food.

---

(3) Possible effects on other uses of the sea(e.g., impairment of water quality for industrial use, underwater corrosion of structures, interference with ship operations from floating materials, interference with fishing or navigation through deposit of waste or solid objects on the sea floor and protection of areas of special importance for scientific or conservation purposes).

Interpretation:

Consideration of possible effects on the uses of the sea as outlined in paragraph C3 should include interference with fishing, such as the damaging or fouling of fishing gear. Any possibility of excluding the future uses of the sea dumping area for other resources, such as water use for industrial purposes, navigation, erection of structures, mining, etc., should be taken fully into account.

Areas of special importance include those of interest for scientific research or conservation areas and distinctive habitats of limited distribution (such as seabird rookeries, kelp beds or coral reefs); information should also be provided on all distinctive habitats in the vicinity of the proposed site that might be affected by the material to be dumped. Attention should also be given to geological and physiographical formations of outstanding universal value from the point of view of science, conservation or natural beauty.

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(4) The practical availability of alternative land-based methods of treatment, disposal or elimination, or of treatment to render the matter less harmful for dumping at sea.

Interpretation:

Before considering the dumping of matter at sea every effort should be made to determine the practical availability of alternative land-based methods of treatment, disposal or elimination, or of treatment to render the matter less harmful for dumping at sea.

The practical availability of other means of disposal should be considered in the light of a comparative assessment of:

- human health risks;
- environmental costs;
- hazards (including accidents) associated with treatment, packaging, transport and disposal;
- economics (including energy costs); and
- exclusion of future uses of disposal areas, for both sea disposal and the alternatives.

If the foregoing analysis shows the ocean alternative to be less preferable, a license for sea disposal should not be given.

Glossary of Terms

absorption
(1) The taking up of one substance into the body of another. (2) Selective concentration of dissolved solids from solution by diffusion into the interior of a solid material. See also **adsorption.**

accidental spills
Unplanned release of substances, either directly or indirectly, in such magnitude that substantial effects on receiving systems will be noted. Release is the result of accident, acts of nature, or operational malfunctions.

accrued depreciation
The estimated loss in service value of the utility plant accrued before the date of balance sheet.

accuracy
In physical measurements it is the degree of agreement between the quantity measured and the actual quantity. It should not be confused with **precision**, which denotes the reproducibility of the measurement.

acidity
The quantitative capacity of aqueous solutions to react with hydroxylions. It is measured by titration with a standard solution of a base to a specified end point. Usually expressed as milligrams of calcium carbonate per liter.

acid mine drainage
Water discharge, usually from coal mines, made acidic by biological oxidation and leaching of sulfur-containing minerals.

acid wastes
Wastes that contain appreciable acidity; they are characterized by low pH and an ability to react with hydroxylions.

activated sludge
Sludge withdrawn from a secondary clarifier following the activated sludge process; it consists mostly of biomass, with some inorganic settleable solids. Return sludge is recycled to the head of the process; waste (excess) sludge is removed for conditioning.

activated sludge process
A biological wastewater treatment process in which a mixture of wastewater and activated sludge is agitated and aerated. The activated sludge is subsequently separated from the treated wastewater (mixed liquor) by sedimentation and wasted or returned to the process as needed.

activated carbon
Adsorptive particles or granules usually obtained by heating carbonaceous material in the absence of air or in steam and possessing a high capacity to selectively remove trace and soluble components from solution.

adsorption
The adherence of a gas, liquid, or dissolved material on the surface of a solid. Should not be confused with absorption.

advanced waste treatment
Any physical chemical or biological treatment process used to accomplish a degree of treatment greater than that achieved by secondary wastewater treatment.

aerated pond
A natural or artificial wastewater treatment pond in which mechanical or diffused-air aeration is used to supplement the oxygen supply. See **oxidation pond.**

aeration
The bringing about of intimate contact between air and a liquid by one or more of the following methods: (a) spraying the liquid in the air, (b) bubbling air through the liquid, (c) agitating the liquid to **promote** surface absorption of air.

aeration tank
A tank in which wastewater or other liquid is aerated.

aerobic digestion
The breakdown of suspended and dissolved organic matter in the presence of oxygen. Usually associated with digestion of wastewater sludge.

aerobic lagoon
An oxygen-containing lagoon, often equipped with mechanical aerators, in which wastewater is partially stabilized by the metabolic activities of bacteria and algae. Small lagoons (less than 1/4 hectare and less than 1 meter deep) may remain aerobic without mechanical aeration.

alternating device
(1) A device in a wastewater treatment plant whereby wastewater may be delivered automatically or manually into different parallel treatment units in a cycle in accordance with a predetermined sequence. (2) A device in a pumping plant that will automatically divert flow to be pumped through two or more pumps in a cycle in accordance with a predetermined sequence.

alum
A common name, in the water and wastewater treatment field, for commercial-grade aluminum sulfate.

aluminum sulfate
A chemical formerly sometimes called **waterworks alum** in water and wastewater treatment, prepared by combining a mineral known as bauxite with sulfuric acid.

ambient
Generally refers to the prevailing dynamic environmental conditions in a given area.

amortization
Gradual reduction, redemption, or liquidation of the balance of an account according to a specified schedule of times and amounts. (2) Provision for the extinguishment of a debt by means of a sinking fund.

anaerobic
(1) A condition in which no free oxygen is available. (2) Requiring, or not destroyed by, the absence of air or free oxygen.

anaerobic waste treatment
Waste stabilization brought about through the action of microorganisms in the absence of air or elemental oxygen. Usually refers to waste **treatment** by methane fermentation.

analysis
The laboratory conduct of an examination of water, wastewater, or solids.

aquifer
A porous, water-bearing geologic formation. Generally restricted to materials capable of yielding an appreciable supply of water.

arid
(1) A term applied to regions where precipitation is so deficient in quantity, or occurs at such times, that agriculture is impracticable without irrigation. (2) In climatology, a term applied to climates which have rainfall insufficient to support vegetation.

artesian
Pertaining to groundwater, or things connected with groundwater (e.g., a well or underground basin), where the water is under pressure and will rise to a higher elevation if afforded an opportunity to do so.

assimilative capacity
The natural purification potential of a stream; its ability to receive wastewater and toxic materials without deleterious effects on the aquatic environment or on humans who consume the water.

audit
In the absence of any express limitation, an examination of the subject matter of the accounting in all its financial aspects, including, so far as the several classifications of accounts may be involved, the verification of assets, liabilities, receipts, disbursements, revenues, expenditures, reserves, and surplus in the detail necessary to permit certification of the statements rendered and of the accountability of the fiduciary parties.

automatic sampling
Collection of samples of prescribed volume over a defined time period by an apparatus designed to operate remotely without direct manual control. See also **composite sample.**

bacteria
A group of universally distributed, rigid, essentially unicellular microscopic organisms lacking chlorophyll. They perform a variety of

biological treatment processes including biological oxidation, sludge digestion, nitrification, and denitrification.

bacterial analysis
The examination of water and wastewater to determine the presence, number, and identity of bacteria; more commonly called bacterial examination.

bar screen
A screen composed of parallel bars, either vertical or inclined, placed in a waterway to catch debris. The screenings are raked from it either manually or automatically. Also called **bar rack, rack.**

basic data
Records of observations and measurements of physical facts, occurrences, and conditions, as they have occurred, excluding any material or information developed by means of computation or estimate. In the strictest sense, basic data include only the recorded notes of observations and measurements, although in general use it is taken to include computations or estimates necessary to present a clear statement of facts, occurrences, and conditions.

basin
(1) A natural or artificially created space or structure, either surface or underground, which has a shape and character of confining material that enable it to hold water. (2) The surface area within a given drainage system. (3) A small area in an irrigated field or plot surrounded by low earth ridges and designed to hold irrigation water. (4) An area upstream from a subsurface or surface obstruction to the flow of water.

bay
A recess or inlet in the shore of a sea or lake between two capes or headlands, not as large as a gulf but larger than a cove.

bed
The bottom of a watercourse or any body of water.

bed load
Sediment that moves by sliding, rolling, or skipping on or very near the stream bed; sediment that is moved by tractive or gravitational forces, or both, but at velocities less than that of adjacent flow.

belt screen
A continuous band or belt of wire mesh, bars, plates, or other screening medium which passes around upper and lower rollers and from which the material caught on the screen is usually removed by gravity, brushes, or other means. Also called **band screen.**

benthic
Relating to the bottom or bottom environment of a body of water.

benthos
The aggregate of organisms living on or at the bottom of a body of water.

biochemical oxygen demand
A measure of the quantity of oxygen utilized in the biochemical oxidation of organic matter in a specified time and at a specific temperature. It is not related to the oxygen requirements in chemical combustion, being determined entirely by the availability of the material as a biological food and by the amount of oxygen utilized by the microorganisms during oxidation. Abbreviated **BOD**.

biodegradation
The destruction of organic materials by microorganisms, soils, natural bodies of water or wastewater treatment systems.

biological filter
A bed of sand, gravel, broken stone, or other medium through which wastewater flows or trickles that depends on biological action for its effectiveness.

biological process
The process by which metabolic activities of bacteria and other microorganisms break down complex organic materials into simple, more stable substances. Self-purification of polluted streams, sludge digestion, and all the so-called secondary wastewater treatments depend on this process. Also called **biochemical process**.

biological wastewater treatment
Forms of wastewater treatment in which bacterial or biochemical action is intensified to stabilize, and oxidize the unstable organic matter present. Intermittent sand filters, trickling filters, and activated sludge processes and sludge digestion are examples.

biota
Fauna and flora, of a stream or other water body.

BOD
(1) Abbreviation for biochemical oxygen demand. The quantity of oxygen used in the biochemical oxidation of organic matter in a specified time, at a specified temperature, and under specified conditions. (2) A standard test used in assessing wastewater strength.

bond
(1) A written promise to pay a specified sum of money (called the face value) at a fixed time in the future (called the date of maturity). A bond carries interest at a fixed rate, payable periodically. The difference between a note and a bond is that the latter usually runs for a longer period of time and requires greater formality. (2) A warranty by an underwriting organization, such as an insurance company, guaranteeing honesty, performance, or payment by a contractor.

bonded debt
That portion of the indebtedness of an enterprise represented by outstanding bonds.

branch sewer
A sewer that receives wastewater from a relatively small area and discharges into a main sewer serving more than one branch-sewer area.

breakpoint chlorination
Addition of chlorine to water or wastewater until the chlorine demand has been satisfied and further additions result in a residual that is directly proportional to the amount added beyond the breakpoint.

broad irrigation
The irrigation of crops with wastewater. It differs from wastewater irrigation in that wastewater disposal is the primary object of broad irrigation and the raising of crops is incidental.

building sewer
In plumbing, the extension from the building drains to the public sewer or other place of disposal. Also called house connection.

bypass
An arrangement of pipes, conduits, gates, and valves by which the flow may be passed around a hydraulic structure appurtenance, or treatment process; a controlled diversion.

cage screen
A cage-shaped screen built of bars, rods, or mesh, arranged for lowering into water or wastewater and for raising when the cage is to be cleaned.

callable bond
A type of bond which permits the payment of the obligation before the stated maturity date by giving notice of redemption in a manner specified in the bond contract.

capital expenditures
Expenditures which result in the acquisition of, or the addition to, capital (or fixed) assets.

carbon
(1) A chemical element essential for growth. (2) A solid material used for absorption of pollutants.

carcinogen
A substance or agent producing or inciting cancer.

catch basin
A chamber or well, usually built at the curbline of a street, which admits surface water for discharge into a stormwater drain.

catchment area
(1) The intake area of an aquifer, and all areas that contribute surface water to the intake area. (2) In tropical island zones, a hard-surfaced area on which rain is collected and then conducted to a reservoir. (3) The area tributary to a lake, stream, sewer, or drain. Also called catchment basin.

Celsius scale
The international name for the centigrade scale of temperature, on which the freezing point and boiling point are 0^oC and 100^oC, respectively, at a barometric pressure of 760 mm hg.

center of gravity
(1) The point in a body through which the resultant of the parallel forces of gravity, acting on all particles of the body, passes, no matter in what position the body is held. (2) The point in a plane surface through which the resultant of a force uniformly applied over such a surface might be considered to act.

centigrade
A thermometer temperature scale in which 0 degrees marks the freezing point and 100 degrees the boiling point of water at 760 mm of mercury barometric pressure. Also called Celsius scale. To convert temperature on this scale to Fahrenheit, multiply by 9/5 and add 32.

centrifugal pump
A pump consisting of an impeller fixed on a rotating shaft and enclosed in a casing, and having an inlet and a discharge connection. The rotating impeller creates pressure in the liquid by the velocity derived from centrifugal force.

certification
A program to substantiate the capabilities of personnel by documentation of experience and learning in a defined area of endeavor.

cfs
The rate of flow of a material in cubic feet per second. Used for measurement of water, wastewater, or gas. One cfs equals 4.719×10^{-4} m3/s.

cgs system
A metric system of physical measurements in which the fundamental units of length, mass, and time are the centimeter, the gram, and the mean solar second.

chamber
Any space enclosed by walls, or a compartment; often prefixed by a descriptive word indicating its function, such as grit chamber, screen chamber, discharge chamber, flushing chamber.

chemical oxygen demand (COD)
A quantitative measure of the amount of oxygen required for the chemical oxidation of carbonaceous (organic) material in wastewater using inorganic dichromate or permanganate salts as oxidants in a two-hour test. Commonly abbreviated COD.

chemical treatment
Any water or wastewater treatment process involving the addition of chemicals to obtain a desired result such as precipitation, coagulation, flocculation, sludge conditioning, disinfection, or odor control.

chlorination
The application of chlorine or chlorine compounds to water or wastewater, generally for the purpose of disinfection, but frequently for chemical oxidation and odor control.

chlorination chamber
A detention basic provided primarily to secure the diffusion of chlorine through the liquid. Also called **chlorine contact chamber.**

chlorinator
Any metering device which is used to add chlorine to water or wastewater.

chlorine
An element ordinarily existing as a greenish-yellow gas about 2.5 times as heavy as air. The chemical symbol of chlorine is **Cl**, its atomic weight is 35.457, and its molecular weight is 70.914.

chlorine demand
The quantity of chlorine that would be consumed in a specified period by reaction with substances present in water, if the chlorine supply were not limited. The demand for any given water varies with both time of contact and temperature.

chlorine residual
The amount of chlorine in all forms remaining in water or wastewater after treatment to ensure disinfection for a period of time.

chlorine room
A separate room or building for housing chlorine and chlorination equipment, with arrangements for protecting personnel and plant equipment.

clarification
Any process or combination of processes, the primary purpose of which is to reduce the concentration of suspended matter in a liquid. Term formerly used as synonym of **settling or sedimentation.** In recent years latter terms preferable when describing settling process.

clarifier
Any large circular or rectangular sedimentation tank used to remove settleable solids in water or wastewater. A special type of clarifiers, called **upflow clarifiers**, use floatation rather than sedimentation to remove solids.

coagulant
A simple electrolyte, usually an inorganic salt containing a multivalent cation of iron, aluminum, or calcium, for example, FeC13, FeC12, A12(S04)3, CaO. Also, an inorganic acid or base which induces coagulation of suspended solids.

coagulation
The conversion of colloidal (<0.001 mm) and dispersed (0.001 to 0.1 mm) particles into small visible coagulated particles (0.1 to 1 mm) by the addition of a coagulant, which compresses the electrical double layer surrounding each suspended particle, decreases the magnitude of repulsive electrostatic interactions between particles, and thereby destabilizes the particles.

coagulation basin
A basin used for the coagulation of suspended or colloidal matter, with or without the addition of a coagulant, in which the liquid is mixed gently to induce agglomeration with a consequent increase in settling velocity of particulates.

coarse screen
A relative term, applicable to mesh or bar screen in which the openings are greater than 2.5 cm in least dimension, except in the case of racks.

collection system
In wastewater, a system of conduits, generally underground pipes, which receives and conveys sanitary wastewater and/or storm water. In water supply, a system of conduits or canals used to capture a water supply and convey it to a common point.

combined sewer
A sewer intended to receive both wastewater and storm or surface water.

combined wastewater
A mixture of surface runoff and other wastewater such as domestic or industrial wastewater.

common law
That body of law developed in England prior to the establishment of the United States. It refers principally to right and privileges and, while generally followed in the United States, has in some of its application been abrogated or modified, as in the case or riparian rights to water in some jurisdictions in the United States.

common sewer
A sewer in which all owners of abutting properties have equal rights.

complete treatment
In an imprecise and general sense, the processing of domestic and some industrial wastewaters by means of primary and secondary treatment. It may include other specialized types of treatment and disinfection. A high percentage removal of suspended, colloidal, and dissolved organic matter is implied.

composite sample
A combination of individual samples of water or wastewater taken at preselected intervals to minimize the effect of the variability of the individual sample. Individual subsamples may be of equal volume or may be proportional to the flow at time of sampling.

concentration tank
A settling tank of relatively short detention period in which sludge is concentrated by sedimentation or floatation before treatment, dewatering, or disposal.

construction grants
Financial aid for the construction of publicly owned wastewater treatment facilities or interceptor sewers under national or state legislation.

contact bed
(1) An artificial bed of coarse material providing extensive surface area for biological growth in a watertight basis. Wastewater exposure to the surface may be accomplished by cycling or by continuous flow through controlled inlet and outlet. (2) An early type of wastewater filter consisting of a bed of coarse broken stone or similar inert material placed in a watertight tank or basin which can be completely filled with wastewater and then emptied. Operation consists of fillings, allowing the contents to remain for a short time, draining, and then allowing the bed to rest. The cycle is then repeated. A precursor to the trickling filter.

contact chamber
Any large tank in which water or wastewater can be mixed with and allowed to react with a disinfectant, or other chemical agent.

controlled discharge
Regulation of effluent flow rates to correspond with flow variations in receiving waters, to maintain established water quality.

conventional treatment
Well-known or well-established wastewater treatment processes, excluding advanced or tertiary treatment; it generally consists of primary and secondary treatment.

cross connection
(1) A physical connection through which a supply of potable water could be contaminated or polluted. (2) A connection between a supervised potable water supply and an unsupervised supply of unknown potability.

debt service
The amount of money necessary annually; (a) to pay the interest on outstanding debt; (b) to pay the principal of maturing bonded debt not payable from a sinking fund; or (c) to provide a fund for the redemption of bonds payable from a sinking fund.

decomposition of wastewater
(1) The breakdown of organic matter in wastewater by bacterial action, either aerobic or anaerobic. (2) Chemical or biological transformation of organic or inorganic materials contained in wastewater.

deep-well injection
Discharge of wastewater through a properly designed well, either by gravity or pumping, into a previous geological stratum. Well depth may range from a few hundred to several thousand feet.

deferred charges
Expenditures not chargeable to the period in which made, but carried on the asset side of the balance sheet, pending amortization or other disposition. They include such items as discount on bond issues. Deferred charges usually involve expenses which are not to be spread over a relatively long period of time and which do not recur regularly in the operation of the enterprise. They are to be distinguished from other prepaid expenses which are usually spread over a short period of time and which recur more or less regularly in the operation of the enterprise.

deferred credits
Credit balances or items spread over subsequent accounting periods either as an addition to income or as a reduction of certain expenses. Payments made in advance represent an example of the latter.

degree of treatment
A measure of the removal effected by treatment processes with reference to solids, organic matter, BOD, bacteria, or any other specified parameter.

depreciation
As applied to depreciable utility plant, the loss in service value not restored by current maintenance, due to all the factors causing the ultimate retirement of the property. The causes of depreciation may be classified as follows: sudden physical damage, physical decrepitude, obsolescence, inadequacy, and supersession before elapse of useful life; for instance, removal necessitated by street improvements.

depreciation rate
The rate of percentage at which value or usefulness of a property is exhausted.

design criteria
(1) Engineering guidelines specifying construction details and materials.
(2) Objectives, results, or limits which must be met by a facility, structure, or process in performance of its intended functions. See also **design loadings.**

design loadings
Flow rates and constituent concentrations which determine the design of a process unit or facility necessary for proper operation.

dewatered sludge
The solid residue remaining after removal of water from a wet sludge by draining or filtering. Dewatering is distinguished from thickening in that dewatered sludge may be transported by solids handling procedures.

diffuser
A porous plate, tube, or other device through which air is forced and divided into minute bubbles for diffusion in liquids. Commonly made of carborundum, alundum, metal, or plastic materials.

digested sludge
Sludge digested under either aerobic or anaerobic conditions until the volatile content has been reduced to the point at which the solids are relatively nonputrescible and inoffensive.

digester
A tank or other vessel for the storage and anaerobic or aerobic decomposition of organic matter present in sludge.

digestion
(1) The biological decomposition of organic matter in sludge, resulting in partial liquefaction, mineralization, and volume reduction. (2) The process carried out in a digester. See also **sludge digestion.**

dilution
Disposal of wastewater or treated effluent by discharge to and dispersion in a receiving water with resulting reduction in concentrations of constituents, while accounting for background levels and natural assimilation processes.

disinfection
The killing of waterborne fecal and pathogenic bacteria and viruses in potable water supplies or wastewater effluents with a disinfectant; an operational term that must be defined within limits, such as achieving an effluent with no more than 200 colonies fecal coliform per 100 ml. (2) The killing of the larger portation of microorganisms, excluding bacterial spores, in or on a substance with the probability that all pathogenic forms are killed, inactivated, or otherwise rendered non-virulent.

dissolved oxygen
The oxygen dissolved in water, wastewater, or other liquid, usually expressed in milligrams per liter, or percent of saturation. Abbreviated **DO.**

domestic wastewater
Wastewater derived principally from dwellings, business buildings, institutions, and the like. It may or may not contain groundwater, surface water, or storm water.

drainage basin
(1) An area from which surface runoff is carried away by a single drainage system. Also called catchment area, watershed, drainage area. (2) The largest natural drainage area subdivision of a continent.

drainage district
(1) An organization created and operating under statutory enactment for the purpose of financing constructing and operating a drainage system. (2) The land or area within the boundaries of a drainage district, as delimited in the organizing statute.

drying beds
Confined, underdrained shallow layers of sand or gravel on which wet sludge is distributed for draining and air drying. Also applied to underdrained, shallow, dyked, earthen structures used for drying sludge.

ecology
The branch of biology dealing with the relationships between organisms and their environment.

economic depreciation
The loss in value resulting from external economic conditions affecting the character or degree of utilization.

ecosystem
The composite balance of all living organisms; plants, and their ambient environment -- air, water, and solid phases -- in a defined area.

effluent
(1) A liquid which flows out of a process or confined space. (2) Wastewater or other liquid, partially or completely treated, or in its natural state, flowing out of a reservoir, basins, treatment plant, or industrial treatment plant, or part thereof.

effluent quality
The physical, biological, and chemical characteristics of wastewater or other liquid flowing out of a basin, reservoir, pipe, or treatment plant.

effluent standard
Specification of the allowable concentration or mass of a constituent which may be discharged.

enclosed trickling filter
A trickling filter covered by a roof, sometimes domed.

enforcement
Administrative or legal procedures and actions to require compliance with legislation or associated rules, regulations, or limitations.

environment
A general description of the air, water, and land which support the life of an organism and receive its waste products.

environmental impact
Changes in the environment that result from specific actions or materials.

environmental protection agency
A national, state, or local unit of government established to consolidate programs dealing with air, water, solid waste, and other environmental concerns within one agency. The authority and scope of activity are determined by the legislation establishing the agency.

environmental quality
Characteristics of the environment that generally indicate its desirability for human activity.

equalization
In wastewater systems, the storage and controlled release of wastewaters to treatment processes at a controlled rate determined by the capacity of the

processes,or at a rate proportional to the flow in the receiving stream; used to smooth out variations in temperature and composition as well as flow.

extended aeration
A modification of the activated sludge process which provides for aerobic sludge digestion within the aeration system. The process includes the stabilization of organic matter under aerobic conditions and disposal of the gaseous end products into the air. Effluent contains finely divided suspended matter and soluble matter.

Fahrenheit
A temperature scale in which 32^{o} marks the freezing point and 212^{o} the boiling point of water at a 760 mm barometric pressure. To convert to a Fahrenheit temperature **centigrade (Celsius)**, subtract 32 and multiply by 5/9.

feedlot
A confined area where large numbers of cattle or other animals are grown or fattened for market.

feedlot wastes
Solid and liquid wastes from concentrated animal-feeding operations.

filtered wastewater
Wastewater that has passed through a mechanical filtering process but not through a trickling filter bed.

filter media
(1) Material through which water, wastewater, or other liquid is passed for the purpose of purification, treatment, or conditioning. (2) A cloth or metal material of some appropriate design used to intercept sludge solids in sludge filtration. (3) Particulate (sand, gravel, diatomaceous earth) or fibrous (cloth) material placed within a filter to collect suspended particles.

filter plant
In wastewater treatment units, the devices and structures required to provide trickling filtration.

filter rate
The rate of application of material to some process involving filtration; for example, application of wastewater sludge to a vacuum filter, wastewater flow to a trickling filter, water flow to a rapid sand filter.

final effluent
The effluent from the final treatment unit of a wastewater treatment plant.

final sedimentation
The separation of solids from wastewater in the last settling tank of a treatment plant.

final settling tank
A tank through which the effluent from a trickling filter or an aeration or

contact aeration tank is passed to remove the settleable solids. Also called final settling basin. See also **sedimentation basin.**

five-day BOD
That part of oxygen demand usually associated with biochemical oxidation of carbonaceous material within 5 days at 20°C. First stage biochemical oxygen demand.

fixed capital
The investment represented by fixed assets.

fixed charge
(1) The carrying and operating cost of any business or project which continues to occur whether or not the business operates or produces anything. (2) A charge that cannot be escaped, shifted, or altered, such as interest, rent, taxes, and amortization.

fixed liabilities
Liabilities which are to be paid one year or more after the date of a balance sheet.

flight sewer
A series of steps in a sewer to break up the velocity on a steep grade.

flocculation
In water and wastewater treatment, the agglomeration of a colloidal and finely divided suspended matter after coagulation by gentle stirring by either mechanical or hydraulic means. In biological wastewater treatment where coagulation is not used, agglomeration may be accomplished biologically.

fresh sludge
Sludge in which decomposition is little advanced.

gate chamber
A structure erected to house a valve or regulating device and provide access to the valve for maintenance and repair. If the chamber has a superstructure, it is termed a **gate house.**

gpcd
The rate of water, wastewater, or other flow measured in U.S. gallons per capita of served population per day.

gpm
The rate of water, wastewater, or other flow measured in U.S. gallons per minute.

grab sample
A sample taken at a given place and time. It may be representative of the flow. See also **composite sample.**

grinder
A device used to reduce the particle size of wastewater solids so that they may be returned to the wastewater flow or processed for later treatment.

grit
The heavy suspended mineral matter present in water or wastewater, such as sand, gravel, cinders. It is removed in a pre-treatment unit called a grit chamber to avoid abrasion and wearing of subsequent treatment devices.

hazardous waste
Any waste that is potentially damaging to environmental health because of toxicity, ignitability, corrosivity, chemical reactivity, or other reason.

heavy metals
Metals that can be precipitated by hydrogen sulfide in acid solution; for example, lead, silver, gold, mercury, bismuth and copper.

house connection
The pipe carrying the wastewater from the building to a common sewer. Also called building sewer, house sewer.

house drain
That part of the lowest horizontal piping of a drainage system which receives the discharge from soil, waste and other drainage pipes inside the walls of the building and conveys it to the **building sewer (house sewer)**, the pipe that begins five feet outside the inner face of the building wall. Also called **building drain.**

hydrogen-ion concentration
The concentration of hydrogen-ions in moles per liter of solution. Commonly expressed as the pH value, which is the logarithm of the reciprocal of the hydrogen-ion concentration.

impervious
Not allowing, or allowing only with great difficulty, the movement of water; impermeable.

impervious bed
A bed or stratum through which water will not move.

incineration
Combustion or controlled burning of volatile organic matter in sludge and solid waste which reduces the volume of the material while producing heat, dry inorganic ash, and gaseous emissions.

impoundment
A pond lake, tank, basin or other space, either natural or created in whole or part by the building of engineering structures, which is used for storage, regulation, and control of water.

indirect charges
Charges which are a part of a total charge, but not directly related to it; for example, overhead.

individual sewage disposal
A sewage disposal system located on a single premises and serving only that premises.

industrial reuse
The direct use or recycling of treated or untreated wastewater by industry.

industrial waste
Generally liquid solid or gaseous wastes originating from the manufacture of specific products. Such wastes are usually more concentrated, more variable in content and rate, and require more extensive or different treatment than municipal waste.

infiltration
(1) The flow or movement of water through the interstices or pores of a soil or other porous medium. (2) The quantity of groundwater that leaks into a pipe through joints, porous walls, or breaks. (3) The entrance of water from the ground into a gallery. (4) The absorption of liquid by the soil, either as it falls as precipitation or from a stream flowing over the surface.

inflow
In relation to sanitary sewers, the extraneous flow which enters a sanitary sewer from sources other than infiltration, such as roof leaders, basement drains, land drains, and manholes covers. See also **infiltration.**

influent
Water, wastewater, or other liquid flowing into a reservoir, basin, or treatment plant, or treatment process. See also **effluent.**

intercepting sewer
A sewer that receives dry-weather flow from a number of transverse sewers or outlets and frequently additional predetermined quantities of storm water (if from a combined system) and conducts such waters to a point for treatment or disposal.

intermediate treatment
(1) The removal of a high percentage of suspended solids and a substantial percentage of colloidal matter, but little dissolved matter. (2) Wastewater treatment similar to **secondary treatment** but generally not as complete, resulting in BOD removals of about 60 percent to 75 percent.

joint treatment
The combined treatment of municipal and industrial wastewaters.

kaolin
A special type of clay, usually high in aluminum content, sometimes used in water treatment.

lagoon
Any large holding or detention pond, usually with earthen dikes, used to contain wastewater while sedimentation and biological oxidation occur. See also **anaerobic lagoon.**

land application
The recycling treatment or disposal of wastewater or wastewater solids to the land under controlled conditions.

land disposal
Application of raw or treated wastewater sludges, or solid waste to soils and/or substrata without production of usable agricultural products. See also **land treatment.**

landfill
The disposal of solid wastes or sludges by placing on land, compacting and covering as appropriate with a thin layer of soil.

land treatment
Irrigation with partially treated wastewater on land; additional treatment is provided by soil, microorganisms, and crops which are grown to utilize nutrients. See also **land application, land disposal.**

lateral sewer
A sewer that discharges into a branch or other sewer and has no other common sewer tributary to it.

least-cost design
Facility design which complies with the intent of the specifications at the lowest possible cost.

lift pump
A pump used to elevate wastewater flow in a sewer to facilitate gravity flow in a portion of a collection system, before treatment, or afterwards, before effluent discharge.

line manhole
A manhole on a sewer at a point where no other sewers connect. It is often located at a point where the sewer changes direction, either in line or grade.

liquid disposal
Generally, any process for ultimate disposal of liquid wastes, as for example by discharge to ocean or other receiving water, **land application, deepwell injection.**

main sewer
(1) In larger systems, the principal sewer to which branch sewers and submains are tributary; also called **trunk sewer.** In small systems, a sewer to which one or more branch sewers are tributary. (2) In plumbing, the public sewer to which the house or building sewer is connected.

mechanical aeration
(1) The mixing, by mechanical means, of wastewater and activated sludge in the aeration tank of the activated sludge process to bring fresh surfaces of liquid into contact with the atmosphere. (2) The introduction of atmospheric oxygen into a liquid by a mechanical action of paddle, paddle wheel, spray, or turbine mechanisms.

mgd
Million gallons per day, a measure of flow, equivalent to 1.547 cfs; 681 gpm; 3785 cu m/d.

mg/l
Milligrams per liter, a measure of concentration, equivalent to the replacing ppm in the case of dilute solutions.

microbiology
Study of microscopic organisms of living matter and their processes.

mine water
Drainage water from surface or underground mines; when specified as acid mine drainage, refers to coal mine wastewater that is highly contaminated with sulfuric acid and dissolved iron produced by biological and chemical reactions with exposed iron pyrites.

mixing basin
A basin or tank in which agitation is applied to water, wastewater, or sludge to increase the dispersion rate of applied chemicals; also, tanks used for general mixing purposes.

monitoring
(1) Routine observation, sampling and testing of designated locations or parameters to determine efficiency of treatment or compliance with standards or requirements. (2) The procedure or operation of locating and measuring radioactive contamination by means of survey instruments that can detect and measure, as dose rate, ionizing radiations.

municipal waste
(1) The untreated wastewater entering a municipal treatment facility. (2) Generally, liquid and solid waste originating from a mixture of domestic (household) commercial, and industrial sources. See also **industrial waste, sanitary sewage.**

natural purification
Other body of water which result in the reduction of bacteria concentrations, satisfaction of the BOD, stabilization of organic constituents, replacement of depleted dissolved oxygen, and the return of the stream biota to normal. Also called **self-purification.**

navigable water
Any stream, lake, arm of the sea, or other natural body of water which is actually navigable and that, by itself or by its connection with other waters, is of sufficient capacity to float watercraft for the purposes of commerce, trade, transportation, or even pleasure for a period long enough to be of commercial value.

noise pollution
Introduction of undesirable sound into the environment at levels that can be detrimental to human activity.

non-point pollution
Man-made or man-induced alteration of the chemical, physical, biological, or radiological integrity of water, originating from any source other than a point source.

non-point source
Any source, other than a point source, which discharges pollutants into air or water.

nutrient
Any substance that is assimilated by organisms and promotes growth; generally applied to nitrogen and phosphorus in wastewater, but also to other essential and trace elements.

obsolescence
The decrease in the value of assets due to economic, social, technical, or legal changes. This is an element of depreciation.

ocean disposal
Ultimate disposal of solids, wastes or sludges by barging out to sea and dumping in deep water.

ocean outfall
Facilities for the discharge of storm drainage and/or wastewater into the ocean.

operating costs
Equipment, a treatment plant, or other facility or system to perform its intended function, excluding the initial cost of building or purchasing the equipment, plant, facility, or system. Depending on the context, it may or may not include such factors as labor, energy, chemicals, supplies, replacement parts, interest on borrowed money, insurance.

operating expenses
Expenses necessary for the daily running of an enterprise, rendering of service, and collection of revenue. It may include the daily costs of maintenance, labor, materials, chemicals, power and depreciation.

operation and maintenance (O & M)
Operation is the organized procedure for causing a piece of equipment, a treatment plant, or other facility or system to perform its intended function, but not including the initial building or installation of the unit. Maintenance is the organized procedure for keeping the equipment, plant, facility, or system in such condition that it is able to continually and reliably perform its intended function.

original cost
The actual cost of a property to the entity first devoting it to utility service.

outfall
(1) The point, location, or structure where wastewater or drainage discharges

from a sewer, drain, or other conduit. (2) The conduit leading to the ultimate disposal area. Also see **outfall sewer.**

outfall sewer
A sewer that receives wastewater from a collecting system or from a treatment plant and carries it to a point of final discharge. See also **outfall.**

overall reduction
The difference in the concentration of pollutants in the final effluent and that in the raw wastewater.

overhead
Those elements of indirect cost necessary to produce an article or perform a service but of such nature that the amount applied to each unit of product or service cannot be determined readily or accurately and is thus usually allocated on some arbitrary basis. Normally, overhead relates to those objects of expenditure which do not become an integral part of the finished product or service, such as rent, light, supplies, management, supervision.

oxidation ditch
A secondary wastewater treatment facility that uses an oval channel with a rotor placed across it to provide aeration and circulation. The screened wastewater in the ditch is aerated by the rotor and circulated at about 0.3 to 0.6 m/sec. See also **secondary treatment.**

oxidation lagoon
A type of oxidation pond.

oxidation pond
A relatively shallow body of wastewater contained in an earthen basin of controlled shape, in which biological oxidation of organic matter is effected by natural or artificially accelerated transfer of oxygen.

package wastewater plants
Prefabricated structures that perform one or more wastewater treatment processes.

parts per million (ppm)
The number of weight or volume units of a minor constituent present with each one million units of a solution or mixture. The more specific term **milligrams per liter is (mg/l) preferred.**

peak demand
The maximum momentary load placed on a water or wastewater plant or pumping station or on an electric generating plant or system. This is usually the maximum average load in one hour or less, but may be specified as instantaneous or with some other short time period.

peak flow
Maximum flow.

percentage reduction
The ration of material removed from water or wastewater by treatment to the material originally present, expressed as a percentage.

pH
See hydrogen-ion concentration.

pilot-plant studies
Evaluation, on a scale larger than laboratory-scale but smaller than full-scale, of the amenability of wastewater to treatment with particular operations or processes.

pipe
A closed conduit that diverts or conducts water or wastewater from one location to another.

pit privy
A privy placed directly over an excavation in the ground.

plain sedimentation
The sedimentation of suspended matter in a liquid, unaided by chemicals or other special means and without provision for the decomposition of deposited solids in contact with the wastewater.

plant-scale studies
Full-scale evaluation of whether or not a particular wastewater is amenable to treatment with particular operations or processes.

point source
Any discernable, confined, or discrete conveyance from which pollutants are or may be discharged, including, but not limited to, any pipe, ditch, channel, tunnel, conduit, well, container, rolling stack, concentrated animal feeding operation, or vessel or other floating craft.

pollution
(1) Specific impairment of water quality by agricultural, domestic, or industrial wastes (including thermal and atomic wastes) to a degree that has an adverse effect upon any beneficial use of water. (2) The addition to a natural body of water of any material which diminishes the optimal economic use of the water body by the population which it serves and has an adverse effect on the surrounding environment.

population equivalent
The estimated population which would contribute a given amount of a specific waste parameter (BOD_5, suspended solids, flow); usually applied to industrial waste. Domestic wastewater contains material that consumes, on the average, 0.17 lb (0.08 kg) of oxygen per capita per day, as measured by the standard BOD test. For example, if an industry discharges 1,000 pounds (454 kg) of BOD per day, its waste is equivalent to the domestic wastewater from 6,000 persons (1,000/0.7 = approx. 6,000).

preliminary treatment
(1) The conditioning of a waste at its source before discharge into a sewer system, to remove or to neutralize substances injurious to sewers and subsequent treatment processes or to effect a partial reduction in load on the treatment process. (2) Unit operations, such as screening, comminution, and grit removal, that prepare the wastewater for subsequent major treatment.

pre-treatment
(1) Any water or wastewater treatment process that precedes primary treatment; may include aeration, equalization, pH adjustment, grit removal, grease removal, screening, skimming, and comminution.

primary treatment
(1) The first major treatment in a wastewater treatment facility, usually sedimentation but not biological oxidation. (2) The removal of a substantial amount of suspended matter but little or no colloidal and dissolved matter. (3) Wastewater treatment processes usually consisting of clarification with or without chemical treatment to accomplish solid-liquid separation. See also **secondary treatment, tertiary treatment.**

product substitution
The replacement of any product intended for an intermediate or final use with another product intended and suitable for the same intermediate or final use.

rate base
The investment or established valuation on which a public utility is entitled to a fair return and on which rates may be based.

raw sludge
Settled sludge promptly removed from sedimentation tanks before decomposition has much advanced. Frequently referred to as **undigested sludge.**

receiving water
A river, lake, ocean or other watercourse into which wastewater or treated effluent is discharged.

receiving waters
Waters into which point or non-point sources discharge.

re-circulation
(1) In the wastewater field, the re-filtration of all or a portion of the effluent in a trickling filter to maintain a uniform high rate through the filter. Return of a portion of the effluent to maintain minimum flow is sometimes called recycling. (2) The return of effluent to the incoming flow. (3) The return of the effluent from a process, factory, or operation to the incoming flow to reduce the water intake. The incoming flow is called **makeup water.**

reclaimed
A material is reclaimed if it is processed to recover a usable product or if it is regenerated. Examples are recovery of lead values for spent batteries and regeneration of spent solvents.

recycled
A material is recycled if it is used, reused, or reclaimed.

reduction in toxicity
The reduction or elimination of the toxicity of a hazardous waste by (1) altering the toxic constituents of the waste to less toxic or non-toxic forms or (2) lowering the concentration of toxic constituents in the waste by means other than dilution.

replacement
Installation of new or alternate equipment in place of existing equipment for a variety of reasons such as obsolescence, total disrepair, improvement, or modification.

retention ponds
Basins, usually enclosed by artificial dikes, that are utilized for wastewater treatment and/or storage.

returned sludge
Settled activated sludge returned to mix with incoming raw or primary settled wastewater. More commonly called **returned activated sludge.**

reuse
Application of appropriately treated wastewater to a constructive purpose. See also **recycle.**

river basin
The area drained by a river and its tributaries. See also **drainage basin.**

rotary distributor
A movable distributor made up of horizontal arms that extend to the edge of the circular trickling filter bed, revolve about a central post, and distribute liquid over the bed through orifices in the arms. The jet action of the discharging liquid normally supplies the motive power.

sanitary sewage
Home wastewater that contains human wastes; the major fraction of municipal wastewater. See also **sewage, stormwater.**

screen
A device with openings, generally of uniform size, used to retain or remove suspended or floating solids in flowing water or wastewater and to prevent them from entering an intake or passing a given point in a conduit. The screening element may consist of parallel bars, rods, wires, grating wire mesh, or perforated plate, and the opening may be of any shape, although they are usually circular or rectangular.

screening grinder
A device for grinding shredding, or macerating material removal from wastewater by screens.

secondary settling tank
A settling tank following secondary treatment designed to remove by gravity part of the suspended matter. Also called **secondary clarifiers.** See also **sedimentation basic.**

secondary treatment
(1) Generally, a level of treatment that produces removal efficiencies for BOD and SS of 85%. (2) Sometimes used interchangeably with concept of biological wastewater treatment, particularly the **activated sludge process.** Commonly applied to treatment that consists chiefly of clarification followed by a **biological process,** with separate sludge collection and handling.

sedimentation
(1) The process of subsidence and decomposition of suspended matter carried by water, wastewater, or other liquids, by gravity. It is usually accomplished by reducing the velocity of the liquid below the point at which it can transport the suspended material. Also called settling. May be enhanced by coagulation and flocculation. (2) Solid-liquid separation resulting from the application of an external force usually settling in a clarifier under the force of gravity. It can be variously classed as **discrete, flocculent, hindered and zone sedimentation.**

sedimentation basin
A basin or tank in which water or wastewater containing settleable solids is retained to remove by gravity a part of the suspended matter. Also called **sedimentation tank, settling basin, settling tank.**

settling basin
A basin or tank in which water or wastewater containing settleable solids is retained to remove by gravity a part of the suspended matter. Also called sedimentation basin, sedimentation tank, settling tank.

sewage
Household and commercial wastewater that contains human waste. Distinguished from industrial wastewater. See also **wastewater.**

sewerage
A complete system of piping, pumps, basins, tanks, unit processes, and appurtenances for the collection, transporting, treating, and discharging of wastewater. Term is declining in use. See also **sewer system, wastewater facilities.**

sludge
(1) The accumulated solids separated from liquids, such as water or wastewater, during processing. (2) Organic deposits on bottoms of streams or other bodies of water. (3) The removed material resulting from chemical treatment coagulation, flocculation, sedimentation, floatation, and/or biological oxidation of water or wastewater. (4) Any solid material containing large amounts of entrained water collected during water or wastewater treatment. See also **activated sludge.**

sludge digestion
The process by which organic or volatile matter in sludge is gasified, liquefied, mineralized, or converted into more stable organic matter through the activities of either anaerobic or aerobic organisms.

sludge lagoon
A basin used for the storage, digestion, or dewatering of sludge.

sludge treatment
The processing of wastewater sludges to render them innocuous. This may be done by aerobic or anaerobic digestion followed by drying on sand beds, filtering and incineration or filtering and drying or wet air oxidation.

source control
Any activity classified under source reduction with the notable exception of product substitution.

source reduction
Any activity that reduces or eliminates the generation of a hazardous waste within a process.

stabilization pond
A type of oxidation pond in which biological oxidation of organic matter is effected by natural or artificially accelerated transfer of oxygen to the water from air.

storm water
Surface water from rain, snow, or ice melting and running off from the surface of a drainage area. It is normally collected in sewers separate from the sanitary sewers, and receives minimal, if any, treatment prior to discharge to a receiving water. When collected in a combined sewer system, the resulting mixture of sewage and stormwater is called **combined wastewater.**

stream standards
A set of criteria defining the desired physical, chemical, and biological conditions of a stream; usually established by government regulation.

subsurface irrigation
(1) Irrigation by means of underground porous tile or its equivalent. (2) The process of wastewater treatment and disposal in which wastewater or effluent is applied to land by distribution beneath the surface through open-jointed pipes or drains.

suspended solids (SS)
(1) Insoluble solids that either float on the surface of, or are in suspension in, water, wastewater, or other liquids. (2) Solid organic or inorgaic particles (colloidal, dispersed, coagulated, or flocculated) physically held in suspension by agitation or flow. (3) The quantity of material removed from wastewater in a laboratory test, as prescribed in "Standard Methods for the Examination of Water and Wastewater" and referred to as non-filterable residue.

tertiary treatment
The treatment of wastewater beyond the secondary or biological stage. Term normally implies the removal of nutrients, such as phosphorus and nitrogen and of a high percentage of suspended solids. Term now being replaced by preferable term, advanced waste treatment. See also **advanced waste treatment.**

thermal pollution
Discharge of heated effluents at temperatures that can be determined to aquatic life.

toxic wastes
Wastes which, when they come in contact with a biological entity, cause an adverse response.

treatment
(As part of waste minimization) -- any activity or series of activities that results in reduction of the volume and/or toxicity of hazardous waste without attendant generation of a valuable material that is subsequently employed in the manufacture of a commercial product (an example is an incinerator for disposal of spent chlorinated solvent with scrubbing and neutralization of hydrogen chloride from the flue gas).

treatment plant
The central portion of water or wastewater facilities, which contain various treatment processes exclusive of collection or distribution of water or wastewater.

trickling filter
A very coarse filter used to provide secondary treatment of wastewater. A film of aerobic microorganisms on the filter media metabolizes the organic material in the wastewater trickling downward to underdrains, biofilm that sloughs off is subsequently removed by sedimentation.

trunk sewer
A sewer that receives many tributary branches and serves a large territory. See also **main sewer.**

underdrain
A drain that carries away groundwater or the drainage from prepared beds to which water or wastewater has been applied.

undigested sludge
Settled sludge promptly removed from sedimentation tanks before decomposition has much advanced. Also called raw sludge.

user charge
Charge made to users of water and wastewater systems for services supplied.

volatile suspended solids
The fraction of suspended solids, including organic matter and volatile inorganic salts, which will ignite and burn when placed in an electric muffle furnace at 550 C for 60 minutes. Commonly abbreviated **VSS.**

waste activated sludge
Solids removed from the activated sludge process to prevent an excessive build-up in the system.

waste disposal plant
(1) A plant equipped for treatment and disposal of waste. (2) An arrangement of devices and structure for treating wastewater, industrial wastes, and sludge.

waste minimization
The reduction, to the extent feasible, of hazardous waste that is generated or subsequently treated, stored, or disposed of. It includes any source reduction or recycling activity undertaken by a generator that results in either (1) the reduction of total volume or quantity of hazardous waste, or (2) the reduction of toxicity of hazardous waste, or both, so the goal of minimizing present and future threats to human health and the environment.

waste treatment
(1) A series of chemical, physical, or biological processes to remove dissolved and suspended solids from wastewater before discharge. (2) Any process to which wastewater or industrial waste is subject to make it suitable for subsequent use or acceptable for discharge to the environment. (3) In a broader sense, encompasses the treatment and disposal of solid waste as well as wastewater.

wastewater
The spent or used water of a community or industry which contains dissolved and suspended matter.

wastewater charge
A service charge made for providing wastewater collection and/or treatment service. A specific charge, in contrast to and ad valorem tax.

wastewater facilities
The structures, equipment, and processes required to collect, convey, and treat domestic and industrial wastes and dispose of the effluent and sludge.

wastewater lagoon
An impoundment into which wastewater is discharged at a rate low enough to permit oxidation to occur, so that no substantial nuisance develops.

wastewater management
The collection and treatment of wastewater, including such ancillary matters as administration and financing, engineering planning and design, operation and maintenance, and monitoring and evaluation of overall performance.

water standards
Definitions of water quality established as a basis of control for various water-use classifications.

water use
A system of classifying utilization of waters in natural watercourses for

such purposes as potable water supply, recreation and bathing, fish culture, industrial processes, waste assimilation, transportation, and power production.

weir
(1) A diversion dam. (2) A device that has a crest and some side containment of known geometric shape, such as a V, trapezoid, or rectangle, and is used to measure flow of liquid. The liquid surface is exposed to the atmosphere. Flow is related to upstream height of water above the crest, to position of crest with respect to downstream water surface, and to geometry of the weir opening.

wwtp
Wastewater treatment plant.

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