Table 5 — Comparison of some hazard reduction technologies [1]

	Disposal		Treatment		
	Landfills and impoundments	Injection wells	Incineration and other thermal destruction	Emerging high-temperature decomposition[a]	Chemical stabilization
Effectiveness: How well it contains or destroys hazardous characteristics	Low for volatiles, question for liquids; based on lab and field tests	High, based in theory, but limited field data available	High, based on field tests, except little data on specific constituents	Very high, commercial-scale tests	High for many metals, based on lab tests
Reliability issues:	Siting, construction, and operation Uncertainties: long-term integrity of cells and cover, liner life less than life of toxic waste	Site history and geology; well depth, construction and operation	Long experience with design Monitoring uncertainties with respect to high degree of DRE; surrogate measures, PICs, incinerability	Limited experience Mobile units; onsite treatment avoids hauling risks Operational simplicity	Some inorganics still soluble Uncertain leachate test, surrogate for weathering
Environmental media most affected:	Surface and ground water	Surface and ground water	Air	Air	None likely
Least compatible waste[b]	Linear reactive; highly toxic, mobile persistent, and bioaccumulative	Reactive; corrosive; highly toxic, mobile, and persistent	Highly toxic and refractory organics, high heavy metals concentration	Possibly none	Organics
Costs: Low, Mod. High	L–M	L	M–H (Coincin. = L)	M–H	M
Resource recovery: Potential	None	None	Energy and some acids	Energy and some metals	Possible building material

[a] Molten salt, high-temperature fluid wall, and plasma arc treatments.
[b] Waste for which this method may be less effective for reducing exposure, relative to other technologies. Waste listed does not necessarily denote common usage.

Table 6 — Comparison of thermal treatment technologies for hazard reduction [1]

Advantages of design features	Disadvantage of design features	Status for hazardous waste treatment
Currently available incinerator designs:		

Table 6 — Comparison of thermal treatment technologies for hazard reduction [1]

Advantages of design features	Disadvantage of design features	Status for hazardous waste treatment
Currently available incinerator designs:		
1. Liquid injection incineration: Can be designed to burn a wide range of pumpable waste. Often used in conjunction with other incinerator systems as a secondary afterburner for combustion of volatilized constituents. Hot refractory minimizes cool boundary layer at walls. HCl recovery possible.	Limited to destruction of pumpable waste (viscosity of less than 10000 SSI). Usually designed to burn specific waste streams. Smaller units sometimes have problems with clogging of injection nozzle.	Estimated that 219 liquid injection incinerators are in service, making this the most widely used incinerator design.
2. Rotary kilns: Can accommodate great variety of waste feeds: solids, sludges, liquids, some bulk waste contained in fibre drums. Rotation of combustion chamber enhances mixing of waste by exposing fresh surfaces for oxidation.	Rotary kilns are expensive. Economy of scale means regional locations, thus, waste must be hauled increasing spill risks.	Estimated that 42 rotary kilns are in service under interim status. Rotary kiln design is often centrepiece of integrated commercial treatment facilities. First non-interim RCRA permit for a rotary kiln incinerator (IT Corp.) is currently under review.
3. Cement kilns: Attractive for destruction of harder-to-burn waste, due to very high residence times, good mixing, and high temperatures. Alkaline environmental neutralizes chlorine.	Burning of chlorinated waste limited by operating requirements, and appears to increase particulate generation. Could require retrofitting of pollution control equipment and of instrumentation for monitoring to bring existing facilities to comparable level. Ash may be hazardous residual.	Cement kilns are currently in use for waste destruction, but exact number is unknown. National kiln capacity is estimated at 41.5 million tonnes/yr. Currently mostly non-halogenated solvents are burned.
4. Boilers (usually a liquid injection design): Energy value recovery, fuel conservation. Availability on sites of waste generators reduces spill risks during hauling.	Cool gas layer at walls result from heat removal. This contains design to high efficiency combustion within the flame zone. Nozzle maintenance and waste feed stability can be critical. Where HCl is recovered, high temperatures must be avoided. (High temperatures are good for DRE.) Metal parts corrode where halogenated waste are burned.	Boilers are currently used for waste disposal. Number of boiler facilities is unknown, quantity of wastes combusted has been roughtly estimated at between 17.3 to 20 million tonnes/yr.
Applications of currently available designs:		
5. Multiple hearth: Passage of waste onto progressively hotter hearths can provide for long residence times for sludges. Design provides good fuel efficiency. Able to handle wide variety of sludges.	Tiered hearths usually have some relatively cold spots which inhibit even and complete combustion. Opportunity for some gas to short circuit and escape without adequate residence time. Not suitable for waste streams which produce fusible ash when combusted. Units have high maintenance requirements due to moving parts in high-temperature zone.	Technology is available; widely used for coal and municipal waste combustion.

(2)

Table 6 — (*contd.*)

Advantages of design features	Disadvantage of design features	Status for hazardous waste treatment
6. Fluidized-bed incinerators:		
Turbulence of bed enhances uniform heat transfer and combustion of waste. Mass of bed is large relative to the mass of injected waste.	Limited capacity in service. Large economy of scale.	Estimated that nine fluidized-bed incinerators are in service. Catalytic bed may be developed.
7. At-sea incineration: shipboard (usually liquid injection incinerator):		
Minimum scrubbing of exhaust gases required by regulations on asssumption that ocean water provides sufficient neutralization and dilution. This could provide economic advantages over land-based incineration methods. Also, incineration occurs away from human populations. Shipboard incinerators have greater combustion rates; e.g., 10 tonnes/h.	Not suitable for wastes that are shock sensitive, capable of spontaneous combustion, or chemically or thermally unstable, due to the extra handling and hazard of shipboard environment. Potential for accidental release of waste held in storage (capacities vary from between 4000 to 8000 tonnes).	Limited burns of organochlorine and PCB were conducted at sea in mid-1970. PCB test burns conducted by Chemical Waste Management, Inc., in January 1982 are under review by EPA. New ships under construction by At Sea incineration, inc.
8. At-sea incineration: oil drilling platform-based:		
Same as above, except relative stability of platform reduces some of the complexity in designing to accommodate rolling motion of the ship.	Requires development of storage facilities. Potential for accidental release of waste held in storage.	Proposal incinerator currently under review by EPA.
9. Pyrolysis:		
Air pollution control need minimum: air-starved combustion avoids volatilization of any inorganic compounds. These and heavy metals go into insoluble solid char. Potentially high capacity.	Greater potential for PIC formation. For some waste produce a tar which is hard to dispose of. Potentially high fuel maintenance cost. Waste-specific designs only.	Commercially available but in limited use.
(*Emerging thermal treatment technologies:*)		
10. Molten salt:		
Molten salts act as catalysts and efficient heat transfer medium. Self-sustaining for some wastes. Reduces energy use and reduces maintenance costs. Units are compact; potentially portable. Minimal air pollution control needs; some combustion products, e.g., ash and acidic gases are retained in the melt.	Commercial-scale applications face potential problems with regeneration or disposal of ash-contaminated salt. Not suitable for high ash wastes. Chamber corrosion can be a problem. Avoiding reaction vessel corrosion may imply tradeoff with DRE.	Technology has been successful at pilot plant scale, and is commercially available.

(3)

11. High-temperature fluid wall: Waste is efficiently destroyed as it passes through cylinder and is exposed to radiant heat temperatures of about 4000°F. Cylinder is electrically heated; heat is transferred to waste through inert gas blanket, which protects cylinder wall. Mobile units possible.	To date, core diameters (3 in, 6 in, and 12 in) and cylinder length (72 in) limit throughput capacity. Scale-up may be difficult due to thermal stress on core. Potentially high costs for electrical heating.	Other applications tested; e.g., coal gasification, pyrolysis of metal-bearing refuse and hexachlorobenzene. Test burns on toxic gases in December 1982.
12. Plasma arc: Very high energy radiation (at 50 000°F) breaks chemical bonds directly, without series of chemical reactions. Extreme DREs possible, with no or little chance of PICs. Simple operation, very low energy costs, mobile units planned.	Limited throughput. High use of NaOH for scrubbers.	Limited US testing, but commercialization in July 1983 expected. No scale-up needed.
13. Wet oxidation: Applicable to aqueous waste too dilute for incineration and too toxic for biological treatment. Lower temperatures required, and energy released by some wastes can produce self-sustaining reaction. No air emissions.	Not applicable to highly chlorinated organics, and some wastes need further treatment.	Commercially used as pretreatment to biological wastewater treatment plant. Bench-scale studies with catalyst for nonchlorinated organics.
14. Supercritical water: Applicable to chlorinated aqueous waste which are too dilute to incinerate. Takes advantage of excellent solvent properties of water above critical point for organic compounds. Injected oxygen decomposes smaller organic molecules to CO_2 and water. No air emissions.	Probable high economy of scale. Energy needs may increase on scale-up.	Bench-scale success (99.99% DRE) for DDT, PCBs, and hexachlorobenzene.

(4)

(3) Techniques involving embedding wastes in thermoplastic materials such as bitumen, paraffin, or polyethylene;
(4) Solidification by addition of an organic polymer;
(5) Encapsulation of wastes in an inert coating;
(6) Treatment of the wastes to produce a cementitious product with major additions of other constituents; and
(7) Formation of glass by fusion of wastes with silica.

3.3 Physical, chemical and biological treatment processes

Many physical, chemical, and/or biological treatment processes can be used to eliminate or reduce the hazardous attributes of wastes. Several physical and chemical processes are listed in Table 4; Table 7 lists several biological treatment methods. All

Table 7 — Conventional bilogical treatment methods [1]

Treatment method	Aerobic (A) anaerobic (N)	Waste applications	Limitations
Activated sludge	A	Aliphatics, aromatics, petrochemicals, steelmaking, pulp and paper industries	Volatilization of toxics; sludge disposal and stabilization required
Aerated lagoons	A	Soluble organics, pulp and paper, petrochemicals	Low efficiency due to anaerobic zones, seasonal variations; requires sludge disposal
Trickling filters	A	Suspended solids, soluble organics	Sludge disposal required
Biocontactors	A	Soluble organics	Used as secondary treatment
Packed bed reactors	A	Nitrification and soluble organics	Used as secondary treatment
Stabilization ponds	A&N	Concentrated organic waste	Inefficient; long retention times, not applicable to aromatics; sludge removal and disposal required
Anaerobic digestion	N	Non-aromatic hydrocarbons; high-solids; methane generation	Long retention times required; inefficient on aromatics
Landfarming/spreading	A	Petrochemicals, refinery waste, sludge	Leaching and runoff occur; seasonal fluctutations; requires long retention times
Composting	A	Sludges	Volatilization of gases, leaching, runoff occur; long retention time; disposal of residuals

Aerobic — requires presence of oxygen for cell growth.
Anaerobic — requires absence of oxygen for cell growth.

(5)