Chapter 6

Cleanup Technologies

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INTRODUCTION

In the Superfund program so far cleanup of uncontrolled sites has generally meant that hazardous wastes are confined on the site or disposed of elsewhere. Containment strategies have been adapted from construction engineering techniques and little thought given to the development and application of innovative technologies to deal with the unique problems encountered. With increasing evidence that containment is not effective in the long term and may result in the need to repeat site remedial action at the same site or on the same waste and as the dimensions of groundwater problems at these sites become clearer, technologies which aim at *destroying* the toxic component of hazardous wastes are now being developed by the private sector, However, the adoption of new treatment technologies by the Superfund program faces institutional, regulatory, and financial barriers.

This chapter is divided into four sections. The first section is an overview of the problems encountered at Superfund sites and an introduction to the applicable technologies. Next, the barriers to the adoption of improved technology are discussed. In the third section, conventional and innovative technical options are summarized and analyses of the effectiveness and applicability of both types is provided. The final section reviews the current status of Federal, State, and private sector support for Superfund technology research, development, and demonstration (RD&D).

THE PROBLEM

The selection of the preferred technology or set of technologies for cleanup at a Superfund site depends on the characteristics of the site, the composition and distribution of hazardous materials, the technical characteristics of the technologies, the costs of the technologies, the nature of the selection process mandated by regulation, and other institutional factors. Ultimately, the selection of technologies for remedial action is accomplished by examining the cost effectiveness of a technology or a set o 1' technologies vis-a-vis the alter natives.[1]

The feasibility' of any given technology for a site cleanup is decided early in the decision process. Once a Superfund site has been identified and remedial action proceeds, current practices call for the following basic steps:

1. problem definition (Remedial Investigation);
2. selection of alternatives (Feasibility Study);
3. engineering design;
4. construction;
5. startup, trouble shooting, and cleanup: and
6. long-term operation and maintenance, if necessary,

A Remedial Investigation (RI) and Feasibility Study (FS) are required for all Superfund financed and enforcement-lead remedial actions. The RI focuses on data collection and site characterization; the FS on data analysis and evaluation. Despite the dependence of the FS on results from the RI, EPA conducts the two concurrently rather than sequentially.

[1] A discussion of cost effectiveness and institutional factors that affect the decision process appears in the following section, "Barriers to the Adoption of Improved Technology."

Site Conditions and Wastes

As part of its data collection, the RI catalogs the site's conditions and its wastes, Site factors that affect technology applicability include its geologic, topographic, hydrologic, and meteorologic characteristics. Waste characteristics pertain to the chemical and physical state of the waste and to the media where it is found. Hazardous wastes may have been placed in "surface impoundments, " such as settling ponds or lagoons that can contain liquid wastes and sediments; may be found in drums; and/or may have been landfilled (buried). Other Superfund sites have been created by the application of pesticides (e.g., dioxin) to large land areas. Contaminated environmental media at Superfund sites include air, soils, water (surface or groundwater), and biota.

While there is an extraordinary degree of variability among uncontrolled sites, most wastes found at sites can be broken down into five distinct classes for consideration of applicable technologies:

- slightly contaminated solids and soils,
- contaminated groundwater,
- concentrated liquid wastes,
- concentrated organic sludges and solids, and
- concentrated inorganic sludges and solids.

Organic materials of concern are hydrocarbons (compounds of carbon and hydrogen) or compounds containing carbon, hydrogen, and other elements, The latter include solvents, PCBs, pesticides (e.g., dioxin and DDT), and halogenated compounds (primarily those with chlorine). Inorganic materials of primary concern include heavy metals (e.g., cadmium, chromium, mercury, copper, zinc), cyanide, ammonia, and nitrates.[2] Because mixed wastes, plus variable concentrations of wastes, must be dealt with, Superfund cleanup technologies must operate in a different environment than those processes that treat the more consistent waste streams generated at industrial plants.

Technology Evaluation

As the FS evaluates alternative remedial actions, various types of technologies are introduced as possible solutions to site problems. After an initial screening of technologies, obviously infeasible or inappropriate alternatives are eliminated, The remaining technologies are then subjected to complete technical, cost, institution, public health, and environmental analyses to provide a "cost-effectiveness" evaluation. The cost-effectiveness measure attempts to weigh the costs of various options versus the effectiveness of the cleanup achieved. This evaluation limits the number of technologies suitable for consideration and forms the basis of an engineering design study for the cleanup procedure. However, without cleanup goals, alternatives cannot be properly evaluated. This leads to cost-benefit analysis where both effectiveness and cost vary. It is possible, therefore, to choose a relatively low-cost option whose level of effectiveness may equate to some arbitrary level of protection.

The basic generic technological approaches at any Superfund site are:

1. *in situ treatment* of soils or groundwater containing hazardous waste;
2. *excavation* of the hazardous waste solids, liquids, and/or sludges *for disposal, storage, or treatment* offsite (removals) or onsite; and
3. *pathway control* through encapsulation and/or containment, or by ground or surface water diversion, a

Nontechnical alternatives to cleanup that also are relevant to site (risk) management include mitigating exposures by providing an

[2] A recent EPA study shows that, of the 2 5 most frequent substances found at Superfund sites, 11 are chlorinated solvents, 7 are heavy metals, 5 are aromatic solvents, and 1 is cyanide. (Reported in the Hazardous Materials Control Research Institute's *Focus* newsletter, February 1985.)

[3] Trade-offs occur when hazardous wastes are transported offsite. While transportation adds a cost that can be substantial, for low volumes of a particular hazardous waste it may be less expensive to treat in regionally located facilities. Transportation off site adds a health and environmental risk. Onsite treatment may be restricted due to the availability and cost of necessary infrastructure, such as power and water sources.

alternate water supply, restricting land use, and evacuating people.

Remedial technologies are often broken down into two broad categories: containment *and treatment*. Table 6-1 compares containment and treatment technologies, both conventional and innovative, in terms of their effectiveness, reliability, environmental media affected by their use, least compatible waste, and estimated cost. The primary functions of containment technologies are: 1) to arrest or prevent the movement of contaminants from a source (e. g., overflow of a holding pond); 2) to limit the extent of already contaminated groundwater plume or soil mass; or 3) to immobilize the contaminants to prevent or reduce exposure to humans or the environment, The functions of treatment technologies are: 1) to detoxify contaminants by changing or destroying the chemical characteristic(s) that render them hazardous, or 2) to separate those hazardous materials from the environmental media that serve as routes of exposure.

Since containment technologies do not render harmless that which is the *source* of the problem, Superfund sites subjected to containment may have to be monitored indefinitely, or at least for as long as containment is used, to assure continual protection. Landfills under Subtitle C of the Resource Conservation and Recovery Act (RCRA) are containment technologies. Treatment processes, while they have been shown to destroy extremely high percentages of hazardous constituents, inevitably produce a residue that must be dealt with. Processes such as incineration, for instance, produce ash that may or may not be considered a hazardous waste and air emissions that may have to be controlled, Physical separation techniques produce an output stream that retains the hazardous properties of the original waste, frequently in a more concentrated, manageable form. These residues require proper disposal (and perhaps additional treatment) to achieve overall objectives. If the subsequent treatment and disposal are not properly managed, the original hazards may be shifted to other environmental media or locations and to new exposed populations. Such a shift is always the case when hazardous wastes are simply removed from Superfund sites for containment (land disposal) elsewhere.

Both containment and treatment technologies range greatly in potential applicability and expected effectiveness. *Most containment technologies depend primarily on site factors*. On the other hand, *most treatment technologies are dependent on waste properties*, both in terms of class (organic or inorganic) and also physical state. In general, containment systems have low capital costs but long-term operating and maintenance (O&M) costs which can be substantial if measured over their lifetime. The reverse is generally true for treatment technologies: high capital costs with short-term O&M costs. The result is that if *all* costs are accounted for over the long term, then treatment technologies can offer lower overall costs, Offsite application of either type of technology adds cost to cleanup activity and introduces risks from the transportation of hazardous wastes.

Containment systems generally fall into four types. The first, based on hydrologic principles, uses wells and pumping to control the outward flow from, or the potential contact of, groundwater with, a source of contamination. Alternatively, some sort of physical barrier, such as a grout curtain or slurry wall, can be installed to prevent groundwater from moving into or out of the contaminated mass of soil or aquifer. The third type comprises conventional interception and drainage systems. The fourth set of technologies isolates the wastes in containers or highly impermeable matrices. These techniques are often employed in combination to increase effectiveness,

Treatment technologies employ many types of processes. *Organic* chemicals can be broken down by biological, chemical, or thermal methods, or toxic organics can be separated from nontoxic materials by physical methods. Detoxification of *inorganic* species, such as arsenic or cadmium, is more difficult. Toxicity often resides in the element itself. Treatment technologies act on inorganic species by immobilization and separation, or in a few cases,

Table 6-1 .—Generic Technology Comparison

	Containment	Treatment			
	Landfills ‘and impoundments	Conventional incineration	Emerging thermal/ chemical destruction	Physical/chemical separation methods	Biotechnology
Effectiveness: How well it contains or destroys hazardous characteristics	Low for volatiles, questionable for liquids; based on field tests, preliminary use data	High, based on field tests, except little data on specific constituents	Very high. commercial-scale tests	High, based on conventional uses	High, when combined with pre/post treatment
Reliability issues	Siting, construction and operation Uncertainties: long-term cover, liner life less than life of toxic waste	Long experience with design Monitoring uncertainties with respect to high degree of DRE, surrogate measures, PICs, incinerability	Limited experience Residues, PICs Mobile units; on-site treatment avoids hauling risks Operational simplicity	None, due to long experience	Completeness of in situ process
Environmental media most affected by use of technology	Surface and ground water	Air	Air	Depends on waste management	None likely; except groundwater, if in situ
Least compatible waste[a]	Linear reactive; highly toxic, mobile, persistent, and bioaccumulative	Highly toxic and refractory organics, high heavy metals concentration	Metals	Possibly none. Each process highly waste specific	Mixtures
costs: (low, medium, high)	L – M	M — H	M – H	L — M	L – M

[a]Waste for which this method may be less effective for reducing exposure relative to other technologies Wastes listed do not necessarily denote common usage

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by converting the element to a nontoxic or less toxic compound. As with toxic treatment residues, unless a separated material can be recycled for reuse, landfilling will be the ultimate means of disposal.

Unless a Superfund site is found to contain a single source of a hazardous waste and in a single form, a combination of technologies will most likely have to be applied. A number of containment techniques are often combined—for instance, groundwater barriers with pumping and treatment of leachate. Treatment technologies may have to be applied in combination to permanently destroy hazardous wastes, or with some form of containment to prevent the contamination from spreading during the period required for treatment. In the Superfund program, the choice of technologies has been primarily containment methods applied on a site or off'. In a 1984 study that evaluated 395 Superfund sites,[4] destruction technology (incineration) was employed for 1 percent of the sites. The balance of responses were combinations of onsite containment technologies or offsite removals of the hazardous wastes.

[4]U.S. Environmental Protection Agency, *Summary Report: Remedial Response at Hazardous Waste Sites,* EPA-54012 -84-O02a (Cincinnati, OH: Office of Research and Development, March 1984).

BARRIERS TO THE ADOPTION OF IMPROVED TECHNOLOGY

The selection of technology rests on a cost-effectiveness measure previously discussed. To be among the alternatives whose cost and effectiveness are evaluated, a technology must be known to the contractors who prepare the FS and it must have been judged viable through research, development, and demonstration (RD&D). Once included in the evaluation process, a technology must be treated equitably relative to other technologies. But the current Superfund selection system inhibits the development and consideration of innovative technologies for permanent remedies in a number of ways. These barriers can be broken down into four categories:[5]

- policy and market uncertainties,
- RD&D financing,
- institutional practices and regulatory impacts, and
- a status quo/existing tech nology bias.

[5]As developed by a workshop held by OTA in Washington, DC, in November 1984 entitled "The U-se of Innovative Technologies for Superfund Remedial Action. " Attending were representatives of technology developers, State agencies, an EPA Superfund contractor, and industrial firms who conduct voluntary cleanups.

Policy Uncertainties Create Market Uncertainties

Superfund, along with the Federal-State RCRA program, industrial generators of hazardous wastes, and the current commercial waste management industry, determine the market for hazardous waste treatment technology. The market is driven by regulations imposed by the Federal Government under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), RCRA, and the Toxic Substances Control Act (TSCA) and those imposed by individual States. Regulations determine which materials are classified as hazardous wastes, whether and the extent to which such materials must be controlled, and how they are controlled. Technologies evolve because of and based on these regulations, Institutional practice has determined how the market views innovative, developmental technologies. They must compete with the dominant, historically used solutions (land disposal and incineration techniques).

Continuing to view Superfund as a short-term program results in weak market support for long-term development of innovative technology. Uncertainties over the ultimate size and type of the Superfund program (how many sites undergo remedial action, the level of cleanup desired, the type of solutions selected) create market uncertainties. Technology developed to treat newly generated hazardous wastes may be inadequate and/or inappropriate for cleanups.

According to the president of one technology firm, the Superfund program is full of uncertainties, elusive, going through a shakedown process, a market characterized as one of "indeterminate clients."[6] Such uncertainties affect the availability of funds to conduct R&D programs and corporate decisions to enter the market or continue involvement with technology development. Another view expressed is that there may be no clear market for treatment options until the destruction of hazardous wastes is the *prime* Superfund goal.[7]

Uncertainties also result from technology marching ahead of the regulatory process. The only standards available to judge Superfund technologies are those for incineration and land disposal. Without regulation or guidance for other technologies, there are no operating standards to incorporate into the design of a new technology. Thus, there is no clear-cut, objective way to judge the effectiveness of new technologies, or to compare them with the traditional technologies. For biotechnology, rules for the release of genetically engineered organisms are not yet set. How much effort should a private firm risk developing an in situ biological process for destroying hazardous wastes when the technology may be regulated out of use? Another unknown that industry faces are patent rules for both micro-organisms and the process technology necessary to use the bugs.

The continuing lack of cleanup standards for Superfund sites, a definition of "how clean is clean," gives the impression that new cleanup technologies are not necessary to safeguard public health and the environment. Technology development that does push ahead suffers from uncertainties over whether levels eventually will be set too high to meet or too low to justify the cost of the process.

Access to RD&D Financing

Without adequate R&D and demonstration funding, no technology will reach the stage where it can demonstrate an acceptable level of reliability and effectiveness under field conditions. This critical and expensive demonstration period is preceded by laboratory and pilot stages that often must be funded without guarantee that a commercial product will result.

The degree of market uncertainty will determine when and at what levels the private sector will support the RD&D process. The private sector funds RD&D either by committing internal funds (primarily in the case of large firms) or through the use of venture capital and limited partnerships (in the case of entrepreneurial firms) but they will do so only on a limited basis and only if a clear, sustainable market for the end results can be identified. One large firm, J. M. Huber Corp., has spent $6 million so far in RD&D of its Advanced Electric Reactor. Now, at the point of committing additional funds to attempt to commercialize their technology, several criteria must be met, including an appropriate market size for their product, an estimate about when that market will be available, and a sense that the risks of entering the market are manageable. Another, small firm sought funding for 9 months before it secured $2 million to produce a demonstration unit. Part of the necessary money came from several foreign firms seeking treatment technologies because they are subject to regulations prohibiting landfilling of hazardous wastes.

Ultimately, it is up to the public to decide how much it is willing to pay for the best possible cleanup of hazardous wastes. Support for RD&D of innovative technologies offers a real possibility to lower those costs. Direct support by the Federal Government, however, has been very limited, in terms of level of funding, ac-

[6]Lowell Bowie, president of RoTech Inc., OTA Workshop, November 1984.
[7]Michael Modell, president of MODAR Inc., OTA Workshop, November 1984.

cess to funds, or relevant programs. B State funding is, for the most part, constrained by budgets that must consider immediate cleanup costs before engaging in long-term R&D funding, Some market risk could be mitigated by indirect support, such as tax incentives.

Institutional Practices and Regulatory Impacts

It is often difficult to separate institutional practices and regulatory impacts. In terms of Superfund technology, these factors combine to increase the financial burden on technology firms seeking operating permits and increase the uncertainties over permitting for testing purposes. Testing standards are not available and valid testing materials are difficult to acquire. A bottleneck exists, make recognized testing standards unavailable and access to testing materials from sites difficult, and create a bottleneck under RCRA hazardous waste delisting procedures. The problems culminate when a technology is at the stage of actually demonstrating its effectiveness. They can raise the cost of (or bar) such demonstrations and result in inconsistencies in the information available on new technologies. There is no established procedure for collecting and disseminating the information that is generated.

Authentication

Permitting requirements under the RCRA program for processes in the RD&D stages are expensive and time-consuming. Procedural duplication between Federal and State agencies and differences between the various States, and even between EPA Regions, multiply time and expenses. A 1- to 2-year processing period is not uncommon and one firm has calculated that it has spent $1 million so far in permitting procedures.

Because landfill and incineration technologies are defined under RCRA, these technologies are given de facto established technology status even though not much data has been collected about their performance as Superfund technologies. On the other hand, new technologies are required to present recognized testing results to demonstrate comparable reliability and effectiveness. A *protocol,* a detailed, technology and application specific testing procedure, must be followed. Protocols, however, by their very nature are not available for innovative technologies, and cannot be written without first acquiring testing information. The following examples of what two different firms had to undergo in order to *prove* their technology illustrate these points.

A permit for a 3-month demonstration project was applied for by MODAR Inc., a small R&D firm, through Region 2 of the Environmental Protection Agency (EPA) in August 1983. Permission was finally granted by October 1984, over a year later. Two parallel permitting processes were necessary, one under RCRA and the other under TSCA since one of the wastes that MODAR intended to test was PCBs. (RCRA permits protect against adverse affects of hazardous wastes; TSCA regulates specific wastes.) Under RCRA law at the time, there was no provision for R&D permitting as opposed to operations permitting unless the system classified as an incinerator. MODAR's unit is not an incinerator, but they had to convince EPA of that fact. Eventually it was classified as a "new chemical physical process" for which tests would be needed to develop a protocol. In this instance, EPA decided that the 3-month demonstration testing would be considered the required tests and gave MODAR a release to conduct those tests. For TSCA purposes, MODAR developed a set of tests for their unit equivalent to those established for incineration and was given a permit. Meanwhile, the State of New York conducted its own investigation and issued a permit after EPA did so. The end result is a permit/release valid for 3 months demonstration testing at one site in New York, Testing anywhere else, or beyond the 3-month period, will require MODAR to apply for a new permit.[9]

[8]See the discussion of RD&D support for technology in the last section of this chapter.

[9]Michael Model], personal communication, December 1984,

Lopat Enterprises has produced a sealant or encapsulant which they state is applicable to PCB contaminated structures, After trying unsuccessful y on their own to reach someone within EPA who could make a decision about evaluating the sealant, they secured assistance from congressional staff in setting up meetings with appropriate EPA officials, The writing of a protocol was agreed on but testing did not occur due to EPA's lack of funds, Lopat, meanwhile, was testing their product at their own expense. They were told, however, that running tests on their own in a recognized laboratory would not be valid because the government had to run parallel tests. At one point, when EPA was well aware that Lopat's process was a chemical one, they provided a protocol covering processes that incinerate PCBs.[10]

Often no response is forthcoming. Deluged with requests for authentification of many black box processes, EPA is forced, in the absence of established procedures and adequate staff, to essentially ignore the information it receives regardless of the possible merit of a technology. One particular incident involved the participation of the Mayor of Verona, Missouri, who repeatedly asked the regional EPA office, EPA in Washington, and the State agency for a hearing on a chemical process designed to detoxify dioxin-contaminated soils, The Mayor saw it as a possible alternative to expensive and controversial incineration techniques which were being imposed on her community. Over a period of months, meetings were agreed to and then canceled. No action was ever taken.[11]

Testing Material

Testing that will result in applicable and valid data requires the use of *real* material rather than synthetically produced wastes. Material can be supplied from the outflow of an industrial process or can be samples from Superfund sites, Firms encounter costly delays and other problems in the acquisition and transport of such material that can strain their resources. Transporting relatively small quantities of hazardous waste requires the transportation system and receiver to follow the same rules and procedures as those for regular hazardous waste shipments. Under these circumstances it can be difficult to locate an experienced carrier who is willing to handle an LTC (less than carload) shipment. If the material is acquired, the receiver becomes subject to uncertain liabilities.

Regulations

This section about policy uncertainties has shown how the lack of regulations or uncertainty about new regulations can negatively affect technology development. Existing regulations also affect technology adoption because of: 1) duplication in permitting requirements between Federal, State, and local agencies; 2) differences between various States and EPA regions and; 3) the preemption of sister regulations, such as those covering landfill and incineration practices under RCRA.

Simply figuring out which regulations apply in any given case can be frustrating. Experts attending an OTA workshop in November 1984 could not agree among themselves, even after extended discussion, about the applicability of various regulations. In fact, the only agreement they reached was that sorting out conflicting regulations and determining applicability were a major problem for technology developers who are trying to demonstrate their processes. There appears to be no one place to consult to obtain definitive information,

One option available under Superfund remedial actions is to use mobile or transportable treatment systems, but the regulatory climate does not yet support this option. Under RCRA, once a permit is granted it only covers the operation of a treatment technology on a particular substance at a particular site. Moving the system requires engaging once more in the permit process, The *availability of class rather than site permits would alleviate a considerable burden on treatment technologies.*

[10] U.S. Congress, House of Representatives, Committee on Small Business, hearings Oct. 27, 1983. From the statement of Louis Flax, president of Lopat Enterprises Inc., p. 49.

[11] Jane Johnson, Mayor of Verona, MO, personal communication, September 1984.

Any residue from a hazardous waste treatment process is considered hazardous waste itself unless the residue receives a delisting, i.e., is removed from regulation. This is one of the most important steps in determining the acceptability of a new process as it can provide information about the completeness of the destruction and assure that no new hazardous products are created. Under current EPA practices, however, delisting is a costly and lengthy procedure which can take over a year. Two components appear to adversely affect the procedure: 1) lack of sufficient EPA staffing, and 2) the analytical burden on the technology developer to provide a negative finding (i.e., that the residue is in no way hazardous).

The Status Quo/Existing Technology Bias Syndrome

Both the regulations under the National Contingency Plan (NCP) that deal with remedial action (Section 300.68 of CFR 40) and EPA's "Guidance on the Preparation of Feasibility Studies" encourage a bias toward containment and, to a lesser extent, incineration technologies. It is against these so-called established technologies that all others are measured, even though the presumption that such technologies have proven their effectiveness for cleanups generally is not correct. A predilection for short-term costing and a reluctance to reach beyond comfortable, traditional technology favors the status quo.

For instance, the user of the Feasibility Guide is advised to adhere to the guidance document in order to guard against legal challenges to enforcement actions,[12] Since established technologies are emphasized, innovative ideas seem to be viewed as detrimental to the overall process of remedial action. In another example, in the first step of the FS the Guide advises that "technologies which are unreliable, offer inferior performance, or are not *demonstrated* (emphasis added) processes should be eliminated from further consideration."[13] No provisions are offered for obtaining recognized information that may constitute *demonstration,*

The lack of demonstration data prevents a new technology from being considered in the RI/FS process and ultimately used for remedial action. Both the high cost of demonstration projects and the lack of EPA procedures and support for the evaluation of technologies are obstacles that a new technology must overcome to be adopted. (See the section, "Support of Cleanup Technology RD&D, " in this chapter.)

The primary criterion for selecting technologies at cleanup sites, as reflected in the NCP and in most equivalent State documents, is cost effectiveness; that is, the "lowest cost alternative that is technologically feasible and reliable and which effectively mitigates and minimized damage to and provides adequate protection of public health, welfare, or the environmerit, ' '[14] In the Federal decisionmaking process, this criterion is qualified by the fund-balancing provisions of the NCP. These provisions require that prospective costs at a given site be balanced against the overall needs for all sites to be cleaned up. In essence, even the most cost-effective alternative at a site may be ruled out if the total cost is out of line with needs at other sites.

The *effectiveness* portion of the cost-effectiveness criterion is based on technical factors (performance, reliability, implementability), public health (level of cleanup/isolation achievable, reduction of impacts], institutional factors (permitting requirements, community impacts), and environmental factors (beneficial and adverse effects] factors.[15] *Costs* considered include capital costs, operation and maintenance costs, and/or a present value calculation combining both capital and O&M costs.[16]

If these factors and their components are not uniformly applied to both containment and treatment technologies, the options will not be judged fairly. Containment technologies, for instance, despite increasing evidence to the contrary, are considered to be more reliable than

[12] U.S. Environmental Protection Agency, "Guidance on the Preparation of Feasibility Studies," final draft, Nov 15, 1983, pp 1-6

[13] Ibid , pp 2-12

[14] Ibid., p i\,

[15] Ibid, chapter 8.

[16] Ibid.

treatment technologies. Moreover, permitting requirements for treatment technologies tend to be more burdensome than for containment technologies.

The cost elements applied to containment versus treatment are quite different. For treatment systems, estimates are generally quite straightforward, Project life is usually short; a few years is common. Assuming proper design and that the system will operate as projected, all the cost elements can be estimated quite accurately. (Decommissioning costs have been less consistently included and are more difficult to estimate,) No long-term costs are involved because the project is expected to end with an acceptable level of residual contamination.

The situation for containment is quite different. Since the hazards remain in place indefinitely, any future costs associated with maintaining the original level of protection, such as monitoring, major repairs, and future cleanups, should be included. When removal for redisposal is considered and only the immediate costs for commercial land disposal are included in the cost projection, the analysis is not realistic, O&M costs for onsite containment, moreover, are usually considered only for a relatively short time, often 20 to 30 years. Since no long-term performance data is available for containment systems for hazardous waste applications, O&M uncertainties are likely to be high. Discounting or computing the costs on a present value basis, with conventional discount rates (currently around 10 percent), effectively ignores costs beyond a 30-year period, even though many contained hazardous wastes are likely to remain toxic and will need to be controlled well beyond that period.

One factor that has influenced the choice of technology is related to the cost-sharing provisions of CERCLA. For State and Federal lead sites, the Federal Government generally pays 90 percent of the capital costs and costs for the first year's operation. Subsequent O&M costs, on the other hand, are entirely the State's responsibility. The consequences are fairly straightforward: the Federal Government favors technologies with low capital costs and States argue for low and/or short-term O&M costs,

National cleanup goals do not exist to compare and evaluate technology performance, Without cleanup standards, choices must be made as to what environmental standards apply (if any) to any given situation, If, for instance, effluent limitations rather than water quality standards are chosen for a groundwater treatment system, capital and O&M costs can change. This will alter the apparent cost-effectiveness of the solution and its potential for selection, If RCRA or equivalent State permits are deemed to be required for operations at cleanup sites, technologies considered difficult to permit will be discriminated against, as obtaining a permit adds time, cost, and uncertainty to the process.

The budget process in most States creates a bias against alternatives that have costs spread out over a number of years. Most States can only budget year-by-year and many have no authority to operate cleanup projects through trust funds or bond proceeds.

EPA and most State agencies rely heavily on contractors to carry out the RI/FS process, Because of public and political concerns, there is tremendous pressure to move through the site study phases quickly. The time pressures can inhibit thoughtful and careful examination of all alternatives. This is of particular significance now because few sites have yet moved beyond the study phase. Consulting firms are conservative, concerned about liability, and are under considerable pressure to produce sound and reliable solutions and to control their costs. These conditions have made it hard for innovative or developing technologies to receive serious consideration thus far in the Superfund program,

THE TECHNICAL OPTIONS

Technical solutions to the problems of Superfund sites are either long-term containment systems or relatively expeditious treatment remedies. These technologies are discussed in some detail in the following sections on conventional containment and treatment. A review of emerging innovative treatment methods follows. Another option is presented first: techniques for temporary storage. These are most appropriate for use in initial responses to reduce immediate threats to public health and the environment under a two-part Superfund strategy.

Temporary Storage

Increasing attention is being given to the above ground storage of cleanup wastes (see chapters 1, 2, and 3). A variety of technologies exist to carry out storage safely and cost effectively. There are three approaches: 1) when amounts are small, containerization as used in transportation and traditional chemical storage; 2) when amounts are large, bulk storage in tanks, vaults, and other structures; and 3) when amounts are large, new forms of above ground encapsulation technology. The first two options are likely to be combined at some Superfund sites.

In general, it should be possible to safely store cleanup wastes for anywhere from 5 to 20 years, When onsite storage is difficult because of limited space or unsuitable geologic or climatic conditions (e.g., earthquake fault zones or flood plains), offsite storage can be considered. It may be necessary to examine the possibility of building regional storage facilities to deal with Superfund wastes. Most importantly, above ground storage offers the intrinsic advantage, compared to traditional burial and land disposal, of ready accessibility and relatively easy visual inspection to detect leakage and damage to containers and structures, Moreover, many types of instruments and monitoring devices are available to provide safeguards, including those to deal with the chance of fire and explosion.

Recent advances in materials have improved containers. High-strength, corrosion-resistant materials are now readily available for the most hazardous materials; often these containers can be cleaned and reused. Containers can be placed in various types of structures to reduce the effect of weather, For example, they can be stacked on concrete slabs in shelters with roofs but not necessarily walls. Containers, such as drums, can also be encapsulated with polyethylene to mitigate the effects of leakage. If the amount of cleanup waste is relatively small, use of containers and onsite storage is feasible.

Tanks, vaults, and more complete buildings are also used for conventional storage in the chemical and petroleum industries. This is attractive for bulk materials that are not highly hazardous or corrosive, and materials that can be moved easily in large amounts, such as liquids and soil. If the amounts of cleanup waste are very large, it may be too costly to store onsite, and a regional storage facility may be needed.

A recent proposal in Minnesota combines containers and bulk storage and illustrates what might be conceived of for regional storage facilities for Superfund wastes. The concept was developed for "long-term monitorable and retrievable storage facility for hazardous wastes . , . The facility was designed to store 22,000 drums in a container building and 185,000 gallons in bulk-liquid tanks each year. Assuming an operating life of ten years, the facility would require an area of 60 acres. "[17] The study dealt with every conceivable type of environmental safeguard and was probably over designed, resulting in relatively high costs, particularly for construction of buildings to house drums. The initial investment was estimated at $10.6 million; annual O&M costs varied from $1 million to $2 million over the lifetime of the

[17]C. l. Lough, et al., "Above Ground Storage of Hazardous Waste, " *Management of Uncontrolled Hazardous Waste Sites* (Silver Spring, MD: Hazardous Materials Control Research Institute, 1982).

facility. More recent work, such as in Missouri, has focused on the use of less costly structures while affording environmental protection.

There have also been several recent proposals for new types of above ground storage aimed especially at the hazardous waste market, In one of these, wastes are chemically treated to solidify and stabilize them; they are then formed into an onsite mound on top of various engineered materials, The mound is covered to prevent water intrusion, Again, various safeguards are used to collect and monitor water. The author notes that the method "provides easy access for future manipulation of the waste for resource recovery and new treatment technology."[18] It is also claimed that exhumation and solidification rates of about 1,000 to 3,000 tons per day are possible. Some cost data are provided that indicate savings over more traditional offsite removal and redisposal. One project involving PCB sludge was estimated to cost $70 to $80 per cubic yard to evaluate and execute. O&M costs to monitor groundwater were not provided,

A case has also been made for what is called an above ground "hillfill" that provides ease of collecting leachate and protection against contaminating groundwater.[19] Most of the problems with conventional landfills are reduced or eliminated by this approach, which still allows removal of the wastes later for treatment.

Conventional Technologies[20]

Since *containment* methods have been the technology of choice for Superfund remedial action, they constitute the bulk of applicable conventional technologies. Existing methods of *treatment,* such as incineration, are also conventional in the sense that forms of the techniques have been used in many industries for many years and are relatively easy to adapt to Superfund problems. These conventional containment and treatment technologies are examined below. Containment technologies use construction engineering techniques that have long records of successful use *in that application*. However, because relatively few remedial actions have actually taken place and because no long-term record of performance at Superfund sites exists, there is little data available to support the view that containment technologies are reliable or proven for use with hazardous wastes, In fact, the evidence appears to be pointing in the opposite direction (see chapter 5). Existing treatment technologies, so far limited in use for Superfund cleanups, constitute the basis for most emerging technologies.

Table 6-2 compares the estimated costs of applying a number of conventional technologies at Superfund sites.

Conventional Containment

Hazardous waste—regardless of whether disposed of in the ground, in barrels or drums, in impoundments, or in landfills—eventually leaks to some extent. The threat that this leakage (or migration) presents is related to the level of contamination (exposure) at points of concern. Migration primarily occurs when ground or surface water or air comes in contact with the hazardous waste. Thus the objective of containment is to seal the hazardous waste as well as possible and reduce the possibility of an inflow of migration media or outflow of contamination. In addition, any leachate formed by contact of the hazardous waste with water must be collected and treated, This system of control requires that a number of technologies be combined to produce the lowest possible probability of failure.

The following is a summary of these containment technology components, how they are used and function. Their applicability depends almost entirely on site factors (e.g., topography, erosion potential, surface and groundwater water flow patterns, and expected rainfall) and is primarily independent of waste specific fac-

[18] L. Graybill, "Evolution of Practical On Site Above Ground Closures," *Management of Uncontrolled Hazardous Waste Sites* (Silver Spring, MD: Hazardous Materials Control Research Institute, 1983).

[19] K. W. Brown and D.C. Anderson, "The Case for Aboveground Landfills," *Pollution Engineering*, November 1983.

[20] This section is based primarily on A. D. Little, "Evaluation of Available Cleanup Technologies for Uncontrolled Waste Sites," contractor report prepared for the Office of Technology Assessment November 1984.

Table 6-2.—Estimated Costs of Conventional Technologies

	Capital costs: based on a hypothetical site[a]	Operation and maintenance costs
Containment t:		
Ground water barriers.		
Slurry walls	$250.000	
Grout curtain	$1,25 million	
Piling . , ...	$800,000	
Vibrated beam	$250,000	
	2,400 ft long, 20 ft deep barrier	
Groundwater pumping	$55,000 to $65,000 18 PVC well points, 15 ft apart Pumped at 25 gpm with 18 pumps 1,250 ft piping, wellheads to treatment	Due to the lack of operational experience using these technologies at remedial sites, there is little data available on which to base estimates of operation and maintenance costs.
Subsurface drains	$15,000 to $20,000 200 ft long drain, 20 ft deep using 12" PVC pipe; backfilled with 5 ft clay	Operation and maintenance costs for containment technologies include site costs such as: 1) the running of any necessary equipment (i.e., pumps); 2) site monitoring (particularly for groundwater migration); 3) inspection of the systems; and 4) any necessary repairs and possible replacement.
Runon/runoff controls	$1,000 500 ft dike, up slope	Repairs and replacement constitute the most expensive items. Several years after construction, repairs might cost 50 percent of the original cost; replacement, over 100 percent (due to inflation and worsening conditions).
Surface seals/caps:		
Materials available onsite	$32,000	Uncertain: depends on life of system relative to lifetime of toxic wastes.
Using off site materials	$150,000	
Synthetic cap (top layer) sub-base materials available onsite	**$50,000**	
	Cap over source area consisting of sand (6 in), clay (**2** ft), sand/gravel (1 ft), and top soil/vegetation (2 ft)	
Onsite treatment:		
Solidification and stabilization	**$5,000** to $10,000 60 cubic yards of sludge in lagoon excavated and mixed with kiln dust; then replaced	

Groundwater treatment;	Based on treating 450 gallons per minute	Costs per year[b]	Costs per 1,000 gallons treated[b]
Biological treatment activated sludge	$3.1 million	$940,000	$4.14
Chemical treatment neutralization and precipitation	**$650,000**	**$233,000**	**$1.03**
Physical treatment			
carbon absorption . , .	$7.5 million	$3.8 million	$16.75'
ion exchange . . .	$2.25 million	$1.2 million	$5.13
air stripping . . .	$360.000	$153,000[d]	$0.67[d]

NOTES

[a]This example site is 200 ft by 200 ft and has three sources of contamination — a drum recycling area, a metals recovery operation, and a lagoon filled with sludge (4 ft. 20 ft, 20 ft) As a result of leakage and spills from these sources, groundwater has been contaminated with organic solvents and heavy metals A 200 ft wide plume of contamination extends 81X ft of fsite, and is only 2,500 ft from a nearby well field The water table is 5 ft below the ground surface Bedrock is sound and unfractured and begins 20 ft below the site Groundwater travels at O 001 cm/second, and a groundwater treatment rate 450 gpm is expected

[b]Both O&M and capital recovery costs are included O&M costs are incurred Until treatment has been completed

[c]Carbon regeneration not included

[d]vapor treatment not included

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tors. Table 6-3 presents the advantages, disadvantages, and limitations of their use.

Groundwater Barriers.—Groundwater barriers are designed to prevent the offsite migration of contaminated groundwater by physically restricting horizontal groundwater flow. Groundwater barriers have become one of the principal options to contain plumes of contamination at cleanup sites threatening aquifers, They can be used alone, but often are employed in combination with capping or groundwater pumping, All methods, except block displacement, are derived from general construction practices. Experience under conditions at cleanup sites, however, is as yet limited, and little data are available to show the long-term effects of wastes in contact with the barrier. Considerable research evidence for adverse impact of wastes on barrier materials does exist.[21]

Except for the block displacement technique, barriers must be keyed in or attached to a low-permeability layer, such as bedrock or clay, beneath the site that will restrict vertical or downward migration of contaminants. Barriers, then, are limited to sites where bedrock is not extensively fractured or is not too far below the surface, The extent of fracture in bedrock is difficult to predict,

None of these techniques provides a completely impermeable barrier, even if constructed ideally. Rather, they reduce groundwater flow through the contained region to on the order of 10-* centimeters per second (77 gallons of groundwater per year would pass through a barrier 10 feet deep by 100 feet long), Thus, an anciliary pumping or drainage system is used to contain the leakage or dewater the zone near the barrier. Caps over the site are used to reduce the amount of water that can enter the contained area. Such systems must function indefinitely or as long as a medium for movement of the contaminant is present.

The major types of groundwater barriers are:

- *Slurry walls:* fixed underground physical barriers formed by pumping slurry (e.g., a cement-bentonite mixture) into a trench and either allowing the slurry to set or backfilling with a suitable engineered material, Use of a vibrating beam technique, a relatively new procedure, avoids the need to dig a trench prior to filling with slurry.
- *Grout curtains:* fixed underground physical barriers formed by injecting a grout (either particulate such as portland cement or chemical such as sodium silicate) into the ground through well points.
- *Pilings:* fixed underground physical barriers constructed by driving webbed sections of sheet piling (typically steel) into the ground. Each section is connected with interlocking socket or bowl and ball joints that fill with fine-medium grain soil particles. This serves as a seal to restrict groundwater flow through the barrier.
- Block *displacement* allows for the placing of a fixed underground physical barrier beneath a large mass of earth, This developmental technique was field tested by EPA in 1982.[22] Unexpected geologic details of the site interfered with accomplishment of the barrier placement according to the design plan.

Groundwater Pumping.—Groundwater pumping involves the use of a series of wells to remove groundwater for treatment or to contain a plume. Techniques are well developed, depend on standard technology, and offer high design flexibility (number of wells, location, depth, and pumping rate) to meet a wide variety of site-specific requirements. Uncertainties with groundwater information and modeling, especially in complicated flow regimes and for deep well systems, mean that the effectiveness of the system must be verified in the field. Modifications that might be required can reduce the cost effectiveness of the system. (See chapter 5 for

[21] See, for instance, "Barrier-Leachate Compatibility: Permeability of Cement/Asphalt Emulsions and Contaminant Resistant Bentonite/Soil Mixtures to Organic Solvents" by David C. Anderson, Alicia Gill, and Wayne Grawley. Paper presented at 5th National Conference on Management of Uncontrolled Hazardous Waste Sites, Washington, DC, November 1984 (Silver Spring, MD: Hazardous Materials Control Research Institute, 1984).

[22] Ronald D, Hill, U.S. Environmental Protection Agency, "Promising Site Cleanup Technology, " paper presented at *Superfund Update: Cleanup Lessions Learned*, Schaumburg, IL, Oct. 11-12, 1983.

Table 6-3.—Containment Technologies—Summary

Advantages	Disadvantages	Limitations
Groundwater barriers:		
• *Slurry wall*		
Most versatile, best understood barrier technology. Can be inexpensive compared to other barrier techniques. Low O&M	Requires excavation. Requires site area to mix backfill. Difficult to verify continuity of slurry or backfill. Difficult to key to bedrock.	Must tie to impervious zone. Not 100°/0 impermeable. Long-term effects of some chemicals on permeability uncertain.
• *Grout curtain*,		
Minimal site disturbance, No excavation required, Low O&M.	Chemicals in the grout may cause site safety or environmental problems. Difficult to verify continuity of wall. Limited applicability. Expensive compared to other barriers. Difficult to key to bedrock.	Less than 20°/0 soil can pass No. 200 sieve. Must tie to impervious zone. Not 100°/0 impermeable. Long-term effects of some chemicals on permeability uncertain,
• *Vibrated beam*		
Special slurries improve chemical compatibility. No excavation required, Low O&M.	Very sensitive to construction quality. Difficult to verify continuity of wall. Difficult to key to bedrock. Relatively new technology.	No obstructions in soil. Must tie to impervious zone Access for large crane needed. Not 100°/0 impermeable. Long-term effects of chemicals on permeability uncertain.
• *Sheet pile*		
No excavation required Low O&M.	Expensive. Difficult to key to bedrock. Continuity of wall at joints difficult to verify.	Soils must be loosely packed, Limited to about 50 ft. Must tie to impervious zone. Not 100°/0 impermeable. Some chemicals may attack piling material.
• *Block displacement t*		
No underlying impervious zone needed,	Technology under development. Continuity is difficult to verify.	Site conditions must conform to complex design requirements.
Groundwater pumping:		
• *Well points*		
Proven and well understood, Can function for very long periods. High design flexibility, High reliability, Useful in many situations. Effectiveness can be verified	Design may require expensive modeling. Long-term O&M required. Performance sensitive to design. Collected liquid must be treated or disposed of.	Useful up to 10 meters. Will not affect contaminants in unsaturated zone or contaminants that do not flow. Site conditions may complicate use and performance.
• *Deep we// systems*		
Same as well points.	Same **as well** points	Same as well points; except useful to any depth.
Subsurface drains:		
Proven and well understood, Low O&M. Superior to wells under certain conditions. Less sensitive to design than wells. Conceptually simple.	Less flexibility than wells. Susceptible to clogging. Excavation required. Collected liquid must be treated or disposed of.	Difficult to install beneath waste site. More cost effective in shallow applications.
Runon/runoff controls:		
Proven and well understood, Inexpensive. Effectiveness desirable. Only conceptual design required.	Periodic inspection and maintenance required.	May not be able to handle abnormal storms.
Surface seal/caps:		
Inexpensive compared to excavation and removal. May be used as an interim measure where surface infiltration is a problem,	Periodic inspection and maintenance required.	Difficult for very large sites, or if obstructions are present. Subject to potential failure without proper design, installation, and maintenance.

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Table 6-3.—Containment Technologies—Summary -Continued

Advantages	Disadvantages	Limitations
Solidification and stabilization:		
Improves containment performance.	**Extensive testing may be required.**	**Long-term integrity uncertain.**
High short-term effectiveness possible.	**Many** processes developmental.	Not useful for many organics.
Waste material (e.g., fly ash, kiln dust) can be used as pozzolan.		
Encapsulation:		
Improves effectiveness of land disposal.	Developmental.	Long-term integrity uncertain.
		Requires solidification of bulk wastes.

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a discussion of problems related to understanding groundwater and containment movement.)

As soon as a pumping system is shut down, groundwater flow patterns are likely to return to their pre-pumping condition. Therefore, *pumping systems have to be operated for long periods of time* unless *the source of contamination is eliminated or degraded through treatment.* If, during this time, other wells are used to draw water from the same groundwater system, flow patterns may change.

Subsurface Drains .—Subsurface drains can be installed to collect leachate as well as lower the water table for site dewaterin. They are built by placing tile or perforated pipe in a trench, surrounding it with gravel (or similar material), and backfilling with topsoil or clay.

The use of subsurface drains is a very old technology, well proven in applications other than for hazardous waste environments. While overall costs will vary depending on site-specific conditions, the drains are relatively inexpensive to install and have low O&M costs.

Drains are not as versatile as wells and are more sensitive to design errors. They compete with wells where soils are heterogeneous or exhibit low hydraulic conductivity, or where the plume of contamination is very large. They may be preferred to wells where there is a contaminant layer floating on the groundwater or where the contaminants are viscous.

placing drains in highly contaminated soils can require special construction techniques. They are susceptible to clogging and their performance can be affected by variations in groundwater flow and level, important problems, considering the long lifetimes of many hazardous substances.

Runon/Runoff Controls.—Surface water control technologies are designed to prevent contaminated surface water from leaving a site and uncontaminated water from entering a contaminated area. They are almost always employed in conjunction with other technologies (e. g., surface seals or excavation and removal), Conventional and inexpensive techniques include dikes, terraces, channels, chutes, downpipes, grading, and revegetation. Contaminated runoff, if it occurs, requires treatment prior to discharge.

Surface Seals/Caps.—Surface seals are low-permeability barriers placed over a site to reduce surface water infiltration, prevent contact with contaminated materials, and control fugitive emissions (gases and odors) at cleanup sites. Various materials are used including soils and clays; mixtures (e. g., asphalt and concrete, soil and cement); and polymeric membranes. Soil and vegetation generally cover these materials.

Surface seals are versatile and can be designed for most sites, although they may be difficult to install at large sites, sites with surface obstructions, sites with extremely irregular topography, or sites with inadequate subbase stability, which leads to subsidence or settling. They require very careful installation, as well as continued inspection and maintenance to ensure their integrity over time. Vents may be required to prevent gas buildup from cracking the cap. Over the long term, there are concerns about increased permeability resulting from puncturing by roots, animals, and activities on the surface. Under some conditions, contact with waste or leachate also causes problems.

Solidification and Stabilization.—Solidification, stabilization, and chemical fixation technologies reduce the potential for leachate production by binding waste in a solid matrix via a physical and/or chemical process. Wastes are mixed with a binding agent and subsequently cured to a solid form. The stabilized waste then usually is capped, contained, or land disposed to prevent contact with water,

Applicability of the technique is affected by both waste and site characteristics, Prime candidates for fixation by state-of-the-art processes are inorganic materials in aqueous solution or suspension and those containing large amounts of heavy metals or inorganic solids. Organic wastes and waste streams containing organic constituents (one of the major problems at Superfund sites) are less amenable to fixation. Site-specific factors determine the feasibility of mixing the waste with a fixative, and whether the mixing can occur in situ or after excavation of the waste. In some cases significant volume increases raise problems for onsite use,

While in situ and onsite solidification and stabilization technologies offer promise in decreasing leaching at cleanup sites (in combination with caps and barriers), reliability over time is uncertain due to the lack of monitoring data. Questions remain as to the long-term integrity of the resultant matrices. Freeze-thaw cycles can cause cracking in the wastes above the frost line. For in situ use, nonuniform conditions at a site and operational difficulties can create pockets of incomplete immobilization,

Encapsulation .—Encapsulation is a process where wastes are enclosed in a stable water-resistant material. The process may be applied to wastes in containers or to wastes that have been bound into a matrix of sufficient strength to hold together while the covering is applied. Once encapsulated, wastes must be placed in a landfill.

As long as the covering is intact, the potential for leaking is very low. However, no data are available on the long-term stability and integrity of the covering materials.

Conventional Treatment

Treatment technologies can be broken down into four major types: physical, chemical, biological, and thermal. All tend to be waste-specific, some more so than others. This section explains each type in general and looks at specific conventional treatment technologies. Table 6-4 summarizes these technologies and their advantages and disadvantages.

Few have been applied at Superfund sites. Largely, these technologies are standard processes that are used to treat industrial hazardous waste streams and might be adaptable to Superfund wastes, perhaps using specially constructed onsite facilities, The complexities and variability of wastes at Superfund sites as compared to the outflow of a given industrial process, however, may reduce the applicability and efficiency of most of these techniques. Thus, multiple treatment may be necessary.

Physical Treatment.—Physical treatment processes do not destroy contaminants. They change the hazardous constituents to a more convenient form through concentration and/or phase change. Ideally two output streams are produced. One is a concentrated volume of hazardous material that must undergo additional treatment or be placed in a landfill and the second is a nonhazardous liquid or solid material.

Physical treatment systems are used widely for conventional wastewater treatment, and methods are available to treat many types of wastes over a wide range of conditions. Nevertheless, the combinations of wastes found at cleanup sites may limit the degree of separation that can be achieved.

Some of the more widely used processes include carbon adsorption, flocculation, sedimentation, filtration, flotation, stripping, ion exchange, and reverse osmosis. Many are used in combination with other treatment processes. Some of the systems that remove inorganic

Table 6-4.—Treatment Technologies—Summary

Advantages	Disadvantages	Limitations
DESTRUCTION/DETOXIFICATION PROCESSES:		
Biological treatment:		
● *Conventional*		
Applicable to many organic waste streams. High total organic removal. Inexpensive. Well understood and widely used in other applications.	May produce a hazardous sludge which must be managed. May require pre-treatment prior to discharge.	Micro-organisms sensitive to oxygen levels, temperature, toxic loading, inlet flow. Some organic contaminants are difficult to treat. Flow and composition variations can reduce efficiency. Aeration difficult to depths > 2 ft.
• *In-situ biodegradation*		
Destroys waste in place.	Limited experience. Extensive testing may be required. Containment also required.	Many common organic species not easily biodegraded. Needs proper combination of wastes and hydrogeological characteristics. Obtaining proper mix of contaminants, organisms, and nutrients. Organisms may plug pores.
Chemical treatment:		
● *Wet air oxidation*		
Good for wastes too dilute for incineration or too concentrated or toxic for biological treatment.	Oxidation not as complete as thermal oxidation or incineration. May produce new hazardous species. Extensive testing is required. High capital investment. High level of operator skills required. May require post-treatment.	Poor destruction of chlorinated organics. Moderate efficiencies of destruction *(40-90 "/0),*
● *Chlorination for cyanide*		
Essentially complete destruction. Well understood and widely used in other applications.	Specialized for cyanide.	Interfering waste constituents may limit applicability or effectiveness.
● *Ozonation*		
Can destroy refractory organics. Liquids, solids, mixes can be treated.	Oxidation not as complete as thermal oxidation or incineration. May produce new hazardous species. Extensive testing is required. High capital investment; high O&M.	Not well understood.
. *Reduction for chromium*		
High destruction. Well understood and widely used in other applications.	Specialized for chromium.	Interfering waste constituents may limit applicability or effectiveness.
Ž*Permeable treatment beds*		
Limited excavation required. Inexpensive,	Developmental. Periodic replacement of treatment media required. Spent treatment medium must be disposed of.	Best for shallow plumes. Many reactants treat a limited family of wastes. Effectiveness influenced by groundwater flow variations.
● *Chemical injection*		
Excavation not required. No pumping required.	Developmental. Extensive testing required.	Best for **shallow plumes.** Need fairly homogeneous waste composition.
incineration:		
● *Conventional incineration*		
Destroys organic wastes (99.99 + "/0).	Disposal of residue required. Test burn may be required. Skilled operators required. Expensive.	

Table 6-4.—Treatment Technologies—Summary -Continued

Advantages	Disadvantages	Limitations
• *Onsite*		
Destroys organic wastes (99.99 + %). Transportation of wastes not required.	Disposal of residue required. Onsite feedstock preparation required. Test burn may be required, Skilled operators required. Expensive.	Mobile units have low feed rate.
• *Thermal oxidation for gases*		
Proven technology. High destruction efficiencies. Applicable to most organic streams.	May require auxiliary fuel. O&M cost can be high.	
SEPARATION/TRANSFER PROCESSES:		
Chemical:		
• *Neutralization/precipitation*		
Wide range or applications. Well understood and widely used in other applications. Inexpensive.	Hazardous sludge produced.	Completing agents reduce effectiveness.
• */on exchange*		
Can recover metals at high efficiency.	Generates sludge for disposal. Pre-treatment to remove suspended solids may be required. Expensive.	Resin fouling. Removes some constituents but not others.
Physical treatment:		
. *Carbon absorption for aqueous streams*		
Well understood and demonstrated. Applicable to many organics that do not respond to biological treatment. High degree of flexibility in operation and design. High degree of effectiveness.	Regeneration or disposal of spent carbon required. Pre-treatment may be required for suspended solids, oil, grease. High O&M cost.	Many inorganic, some organics are poorly absorbed.
. *Carbon absorption for gases*		
Widely used, well understood. High removal efficiencies.	High capital and O&M costs.	More effective for low molecular weight, polar species. Disposal or regeneration of spent carbon required.
. *Flocculation, sedimentation and filtration*		
Low cost. Well understood.	Generates sludge for disposal.	
. *Stripping*		
Well understood and demonstrated.	Air controls may be required.	Applicable only to relatively volatile organic contaminants.
• *Flotation*		
Well understood and demonstrated. Inexpensive.	Generates sludge for disposal.	—
. *Reverse osmosis*		
High removal potential.	Generates sludge for disposal. Pre-treatment to remove suspended solids or adjust pH may be required. Expensive.	Variability in waste flow and composition effects performance.

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will produce a sludge or solid (e.g., heavy metals) that must be sent to a landfill for disposal. Reverse osmosis and ion exchange produce a dilute aqueous stream containing the toxic substances that have been removed. Stripping transfers volatile compounds to a gas stream where they may be destroyed by thermal oxidation, treated by other techniques, or emitted into the atmosphere. These systems range in cost from quite low (sedimentation, filtration) to quite high (ion exchange, reverse osmosis). Operating costs for carbon adsorption are generally high and depend on the concentration of the contaminant stream.

Under *carbon adsorption* waste streams are passed through beds of activated carbon particles, Organic compounds and some inorganic species in the waste stream become bound to the surface of the particles and can subsequently be removed along with the carbon adsorbent, But treatment and disposal of spent adsorbent poses a significant secondary problem. The adsorbent can be regenerated, in which case the contaminants and carbon are separated and the contaminants must undergo subsequent treatment, or the adsorbent including contaminants must be destroyed or landfilled.

Carbon adsorption is a highly effective, well demonstrated technique for removing organic compounds, and to a lesser degree metals, from aqueous waste streams. It is a widely used technique for removing organic contaminants from gas streams. It also can treat many organic species that do not respond well to biological treatment. Streams with high organic concentrations can be treated but the cost may become excessive due to high carbon use and other O&M costs. In such cases, combining carbon adsorption as a finishing step with a cheaper process such as biological treatment may be more cost effective. Pre-treatment stages may be needed to remove suspended solids, oil, and grease, all of which would rapidly plug and deactivate the carbon bed.

Flocculation, sedimentation, and filtration are used to remove suspended solids from a waste stream. Flocculation is a process in which small particles are brought together in larger aggregates. The larger particles can then be filtered out of the waste stream. Sedimentation removes suspended solids by permitting the particles to settle to the bottom of a vessel through the action of gravity. Filtration separates the solids from the liquids by forcing the fluid through a porous medium. Filtration can also be used to dewater sludges.

Stripping removes volatile contaminants from an aqueous waste stream by passing air or steam through the wastes, Contaminants are transferred to the air stream, or, in the case of the steam process, to a distillate.

Dissolved air flotation removes insoluble hazardous components present as suspended fine particles or globules of oils and greases from an aqueous phase. After being saturated with air at high pressure and being removed to tanks under atmospheric pressure, bubbles form in the aqueous mixture, The bubbles containing the fine particles and globules rise to the surface and can be skimmed off.

In *ion exchange,* unwanted ionic species, principally inorganic, are exchanged with innocuous ions on a resin. The process results in a sludge that requires management.

Reverse osmosis removes contaminants from aqueous wastes by passing the waste streams at high pressure (usually in the range of 200 to 400 psi) past a semipermeable membrane. Clean water passes out through the membrane, leaving behind a concentrated waste stream for further treatment, Typical membranes are impermeable to most inorganic species and some organic compounds,

Chemical Treatment.—In chemical treatment, hazardous constituents are altered by chemical reactions, In the process, hazardous constituents may be either destroyed or the resultant product or products may still be hazardous, although in a more convenient form for further processing or disposal. Since chemical reactions involve specific reactants under specific conditions, these processes are usually used when only one substance is involved (or a few substances similar in chemical character).

When chemical treatment is applied to a mixed composition waste, there can be problems because the treatment chemical might be consumed by side reactions, the intended chemical reactions might be blocked by impurity interference, or unexpected end products might add new hazards.[23]

Neutralization and precipitation are widely used in industry to remove inorganic and some organic compounds from aqueous streams. They are important options for separating out heavy metals in hazardous wastes, Neutralization may be used alone or in combination with other techniques. Precipitation is always used with follow-up steps to remove the insoluble matter produced. Both are often used as parts of larger treatment programs. Neutralization adjusts the pH of acidic or basic liquid wastes, soils, or other contaminated materials. It may be used alone to reduce the corrosivity of wastes or to adjust the pH to a range where metals are immobilized (remain in insoluble form). Precipitation is used, often in combination with neutralization, to reduce the concentration of metals, and in rarer cases organics such as phthalates, to low levels in an aqueous stream. The major problem with both processes is that they create hazardous sludges that must be subsequently disposed of in a secure manner.

Other chemical processes can be used to treat contaminated hazardous liquids. Both wet air oxidation and chemical oxidation can be applied to broad families of organic wastes. Other processes apply to specific waste types. While there has been little or no experience with these technologies at Superfund sites, all have been used at regulated hazardous waste treatment facilities or in conventional industrial waste treatment, The variable nature of contaminant streams at cleanup sites may limit performance relative to conventional applications.

Wet air oxidation involves a combustion reaction occurring in the liquid phase through addition of air or oxygen at high pressure (greater than 350 psi) and elevated temperature (greater than 1700 C]. The products of the reaction are steam, N_2, CO_2 and an oxidized liquid stream. In *chemical oxidation,* an oxidant (e.g., ozone, perchloric acid, or permanganate) is mixed with the waste and reacts with those oxidizable species present. Neither process breaks down organic molecules as completely as thermal destruction or incineration, and new hazardous species may be produced in the process of destroying those in the wastes. Both require extensive testing to determine their efficiency and the properties of their effluents. Both are expensive to operate and require major capital investments,

Toxic hexavalent chromium ion (Cr VI) can be reduced to the less toxic trivalent chromium ion (Cr 111) by adding a reducing agent under highly acidic conditions. The reduction process is followed by Cr III removal through precipitation as the insoluble hydroxide. *Alkaline chlorination* is used to remove cyanide from alkaline cyanide-containing waste by oxidation in stages,

Biological Treatment.—Biological treatment uses micro-organisms to degrade (biodegradation) or remove (bioadsorption) contaminants from a waste stream. It has seen widespread application for many years for treating wastewaters, both hazardous and nonhazardous, in closed systems such as sewage treatment plants. It is a generally inexpensive method of treatment for groundwater, surface water, or impounded liquids containing a low concentration of organics. Although systems can be designed to achieve fairly high levels of overall removal, the effectiveness for specific hazardous organic species can be quite low. For this reason, some sort of post- or pre-treatment, such as carbon adsorption, may be required.

Conventional biological treatment processes include *activated sludge, aerobic stabilization ponds (surface impoundments), rotating biological disks, and trickling filters,* All of these techniques produce a sludge containing the remains of the organisms, unreacted organic matter, and the insoluble inorganic constituents. Metal removal occurs by processes that attach the metal cations to the sludge. Some organic compounds, such as PCBs and poly - nuclear aromatic compounds, may become ad-

[23] Jay A. Mackie, et al., "Hazardous-Waste Management: The Alternatives," *Chemical Engineering,* Aug. 6, 1984, p. 57.

sorbed to the sludge and exhibit some removal although not by biological activity, The sludge may be considered hazardous and require additional treatment if residual toxic contaminants are present. The performance of biological systems can vary substantially from unit to unit depending on the individual compounds treated. Variations are due to the basic composition of the micro-organisms present, the degree to which the mix has become acclimated to the wastes, the presence of interfering or toxic (to the organisms) contaminants, flow and concentration variations, and other factors.

Biological treatment systems are very sensitive to changes in temperature, oxygen content, and to toxic loading of contaminants. Sensitivity to changes in inlet composition is a particular problem in adapting these techniques for use at cleanup sites. Achieving low enough residual levels of contaminants can be a problem under some conditions.

Biodegradation is discussed in the "Innovative Technologies" section.

Thermal Treatment.—Thermal treatment processes use high temperature as the principal mechanism, either to drive a chemical reaction or to simply break chemical bonds and thus destroy the hazardous nature of a substance. During incineration, the conventional method of thermal treatment, organic materials are burned (i.e., oxidized) at very high temperatures. Common types of incinerators applicable to hazardous wastes include rotary kilns, multiple hearth, fluidized bed, and liquid injection and are discussed below.[24] New forms of *thermal destruction* processes are discussed under "Innovative Technologies. "

The end products of complete incineration depend on the input materials but will generally include CO_2, H_2O, SO_2, NO_x, HCl gases, and ash. Emission control equipment (scrubbers, electrostatic precipitators) for particulate, SO_2, NO_x, and products of incomplete combustion (PICs) are needed to control emission of hazardous air pollutants, Incineration is effective for essentially all organic contaminants, particularly if they are present as liquids. Sludges and contaminated soils require special incinerators, usually rotary kiln types that properly mix the reactants and provide even heat transfer.

Incineration can be employed on or off a Superfund site, Although commercially available techniques could be adapted for onsite incineration, the technology has not been used at cleanup sites. Limited quantities of wastes and contaminated soils have been transported to offsite incinerators, As with the onsite/offsite applications of any technology, trade-offs will occur. Onsite units could be semi-permanent, constructed onsite, or mobile units brought to the site as component units and assembled onsite. Offsite units could be regionally located, permanent facilities that might offer economies of scale. However, they would require that hazardous wastes be transported, an expensive and potentially risky operation. Onsite incinerators require substantial supporting activities, such as electric power, and must be permitted by Federal, State and, often, local governments for each site at which they are used. (See the "Barriers to Adoption of Improved Technology" section in this chapter.)

The secondary effects of incineration include residue disposal, possible exposure to unburned contaminants or toxic products of combustion in the stack gases, scrubber sludge disposal, and scrubber effluent discharge, Removing wastes to an offsite incinerator changes the population affected by exposure to these secondary effects. Incinerating contaminated soil would produce large amounts of residues. Until the issue of *delisting* is handled efficiently, residues would be deemed hazardous and would have to be placed in a RCRA-permitted landfill.

Rotary kilns can handle a wide variety of burnable waste feeds—solids and sludge, as well as free liquids and gases, A rotating cylinder tumbles and uncovers the waste, assuring uniform heat transfer. The cylinders range in size and the kilns operate between temper-

[24] More complete information can be found in U.S. Congress, Office of Technology Assessment, *Technologies and Management Strategies for Hazardous Waste Control, OTA-* M-196 (Washington, DC: U.S. Government Printing Office, March 1983),

atures of approximately 1,5000 and 3,0000 F, depending on the position along the kiln.

Multiple hearth incinerators use a vertical cylinder with multiple horizontal cross-sectional floors or levels where waste cascades from the top floor to the next and so on, steadily moving downward as the wastes are burned, This action provides for long residence times. While such incinerators are able to handle a wide variety of sludges, they are not well suited for most hazardous waste for two reasons, First, they exhibit relatively cold spots wherein complete combustion will not occur producing a very uneven burn, Second, because wastes are introduced relatively close to the top of the furnace, where hot exhaust gases also exit, there is the potential for volatile waste components near the top of the incinerator to escape to the atmosphere without being destroyed.

Fluidized bed combusters are a relatively new design being applied in many areas. They achieve rapid and thorough heat transfer to the injected fuel and waste, and combustion occurs rapidly. Air forced up through a perforated plate maintains a turbulent motion in a bed of very hot inert granules, which provide for direct conduction heat transfer to the injected waste. The bed itself acts as a scrubber for certain gases and particulate. The units tend to be compact and are simple to operate relative to incinerators but have low throughput capacity. Other disadvantages are a limited range of applicable wastes and difficulties in handling the ash and residues. (The "Innovative Technologies" section has information on adaptions of this conventional technique,)

With *liquid injection* incineration, freely flowing wastes are atomized by passage through a carefully designed nozzle. It is important that the droplets are small enough to allow the waste to completely vaporize and go through ail the subsequent stages of combustion while they reside in the high-temperature zones of the incinerator. Injection incinerator designs tend to be waste-specific, especially nozzle design, but can be designed to burn a wide range of pumpable waste.

Groundwater Treatment.—The contamination of groundwater is a common occurrence at Superfund sites and may be the major and most intransigent problem. Treatment often incorporates a combination of the above technologies, is costly, and there is no guarantee that complete renovation of aquifers can ever be accomplished.

While some innovative techniques pursue in situ biological or chemical treatment of groundwater, the current practice is to first contain a plume of contamination to avoid further migration and then pump the contaminated water from the ground and through a treatment facility located onsite. Treated water can be reinjected into the ground to enhance and speed up the flushing of the contaminants from the system or pumped down gradient (i.e., returned to the aquifer or a stream or river).

Some discussion of how technology has been applied at Superfund sites to treat groundwater and its effectiveness can be found in chapter 5. For a more complete discussion of groundwater treatment options, see OTA's report, *Protecting the Nation Groundwater From Contamination*.[25]

Innovative Technologies

Innovative technologies are varied but can be broadly classified into containment and treatment categories. The concentration in this section, however, is on new treatment technologies[26] that offer the possibility to destroy hazardous wastes and eliminate the need to tie up resources in long-term operation and maintenance of containment facilities. Not all innovative treatment technologies destroy contaminants, however. Some improve on physical separation methods and, as such, can provide important pre-treatment steps. Others, such as

[25] U.S. Congress, Office of Technology Assessment, *Protecting the Nation Groundwater From Contamination*, OTA-O-233 (Washington, DC: U.S. Government Printing Office, October 1984),

[26] Most of these technologies are not breakthroughs in basic science but rather are innovative in adopting existing processes for the management of hazardous waste.

vitrification, decompose and entrap hazardous wastes.

The nature of innovation makes it more difficult to classify developing treatment methods as strictly physical, chemical, biological, or thermal processes, In fact, procedures for qualifying new technologies on the basis of preexisting classifications can inhibit their adoption, New methods of analysis will have to be considered to properly evaluate the effectiveness and reliability of innovative technologies,

Because the procedure for testing incineration technologies (the most common conventional destruction technique) has been defined under RCRA and performance standards adopted, the recognized bottom line for any hazardous waste reduction/destruction technology has become the Destruction and Removal Efficiency (DRE)[27] rating. This system forces all technologies to a level of 99.99 percent ("four nines") removal for organic hazardous wastes and 99.9999 ("six nines") for PCBs (regulated under TSCA). The blanket use of this rating ignores the question of whether these degrees of thoroughness are an appropriate level of hazard reduction for the public *and the* environment for *all* hazardous wastes found in *all* media and whether the public ought to pay that cost in all cases, However, until national cleanup goals are established and/or additional ways of measuring technology effectiveness are adopted, DREs will remain the prime criterion for technology evaluation.

Comparing technologies by their DREs must take into account that the type and concentration of the input material can affect the outcome for each technology. Often it will be less expensive to attain desired removal rates by combining techniques that individually offer relatively low removal rates. Other methods of regulating technologies include "design and operation" standards (such as applied to landfill techniques under RCRA) and environmental standards (comparable to National Primary and Secondary Air Quality Standards). With regard to the latter, it should be noted that even *high DREs do not necessarily signify acceptably low levels of toxic air emissions in terms of the quantity released over time.*

Technology Comparisons

Of the many technologies that are now being conceived, researched, and developed, OTA has selected some examples of alternatives to common Superfund practices that appear to offer the potential for improved reliability and cost effectiveness.

Much of the analysis of innovative technologies and their applicability to Superfund must be based on judgement due to a lack of Superfund performance data.[28] Comparisons among the technologies is difficult because of a lack of standardization in the available information. While only one of the technologies presented below has been applied at an uncontrolled site; some have been used to treat industrial hazardous waste streams.

All have undergone a variety of tests, but only a few of the technologies have actually been tested on a Superfund site or on a large scale with Superfund waste (i. e., have been demonstrated), Instead, the material used for testing has ranged from pure hazardous waste compounds to synthetically produced wastes to sample Superfund wastes, in varying concentrations. Testing has been conducted at different levels (e.g., laboratory, bench, and pilot-scale) since the technologies exist at these different levels of development,

[27] The DRE is calculated by the following mass balance formula:

$$DRE = (1-W_{out}/W_{in}) \times 100 \text{ percent}$$

where:

W_{in} . the mass feed rate of 1 principal organic hazardous constituent (POHC) in the waste stream going into the incinerator.

W_{out} = the mass emission rate of the same POHC in the exhaust prior to release to the atmosphere.

Incinerators are also regulated by the amount of hydrogen chloride and particulate emitted. See U.S. Congress, Office of Technology Assessment, Technologies *and Management Strategies for Hazardous Waste Control, OTA-M-196,* p. 159 (Washington, DC: U.S. Government Printing Office, March 1983) for more detailed information.

[28] An assumption is often made that such data exists for conventional technologies and that, therefore, their reliability and effectiveness is better known. In fact, conventional technologies are only conventional in the sense that the techniques have been proved in conventional applications; i.e., applications other than Superfund remedial action.

There are no standardized estimates of capital and operating costs for each technology. Costing is often based on the results of tests specific to a certain type and concentration of hazardous waste and is not necessarily transferrable to the treatment of other types and concentration of hazardous wastes. For example, as a waste stream becomes more dilute (i.e., the water content of an aqueous waste stream increases), incineration techniques become increasingly expensive due to the need to raise the water in the waste stream to treatable temperature, Therefore, while a technique maybe technically capable of treating a variety of waste streams, it may be *inefficient* to do so.

Physical, chemical, biological, and thermal treatment processes have been described earlier under "Conventional Technologies. " For innovative technologies, thermal and biological categories require further descriptions.

Thermal Destruction.–High temperatures (800° to 3,0000 F) are used to break down organic compounds into simpler, less or nontoxic forms under either oxidation or pyrolysis. Two important questions to ask are how completely the process will destroy the input hazardous wastes and what products are created out of the destruction of hazardous wastes.

During *incineration,* combustion occurs in the presence of excess oxygen (more oxygen than theoretically needed for a reaction to occur). In general, complete incineration produces water, carbon dioxide, ash, and acids and oxides that depend on the input material. *Pyrolysis* occurs in an oxygen deficient atmosphere, and pyrolysis facilities consist of two stages: a pyrolyzing chamber and a fume incinerator. The latter, which operates at 1,800° to 3,0000 F, combusts the volatilized organics and carbon monoxide produced in the pyrolyzing chamber. This two-stage system avoids the volatilization of inorganic components (i.e., the production of hydrogen chloride, for instance, which can corrode the system) and forms inorganic, including any heavy metals, into an insoluble solid char residue. Thus, the air emissions and residues from incineration and pyrolysis are different and depend on the point at which they are removed from the system or released to the atmosphere. Ash and char residues can contain salts, metals, and traces of other noncombustibles that must be properly handled. Incineration systems must be fitted with devices to control the release of acid gases and particulate. And these collected materials must be treated or landfilled.

No system is perfect or operates at maximum efficiency at all times. Inevitably, PICs are produced along with the expected products. A recent Science Advisory Board report[29] reviewed the environmental impacts of the incineration of liquid hazardous wastes and evaluated the overall adequacy of existing scientific data. Among their findings were:

- the adoption of the concept of destruction efficiencies emphasizes the elimination of several preselected compounds in the waste and does not fully address either partial oxidation or chemical recombination, which may create new toxic compounds in the incineration process;
- research on the performance of incinerators has been conducted only under optimal burn conditions, ignoring upset conditions that occur; and
- the existing analytical data for emissions from hazardous waste incinerators have serious limitations and toxicology information on emissions is inadequate.

While basic research still needs to be conducted on the processes of combustion, the emerging thermal processes offer improvements over traditional means of incineration. Improvements show in the ways they maintain adequate *temperatures* for the required reactions to occur, provide for adequate *turbulence* (mixing) of waste feed and fuel with oxygen for even and complete combustion, and allow for adequate residence *times* in high-temperature zones so that waste materials can volatilize and the gases completely react. In addition, new thermal processes may be superior

29 U. s. Environmental Protection Agency, Science Advisory Board, Environmental Effects, Transport and Fate Committee, "Draft Report on Incineration of Hazardous Liquid Waste," December 1984.

to traditional incineration because of reduced air emissions and improved quality control during processing.

The thermal processes described below may be unique because of their heat transfer mechanism (e. g., fluidized bed, supercritical water). Improvement in the transfer of heat can increase the probability of reaction and decrease the reaction time (and cost) of a process. They also offer different mechanisms for breaking the bonds of compounds. The plasma arc, for instance, uses the bombardment of very high energy free electrons.

Vitrification.–This special form of thermal treatment involves the melting of soil and wastes by passing an intense electric current through the mixture. The high temperature fuses the materials and binds them into a glassy, solid matrix after cooling.

In situ vitrification has been successfully tested in laboratory and pilot-scale tests for soils contaminated with radioactive wastes, but no data is available for applications to hazardous wastes. The process should be compatible with nonvolatile inorganic wastes/soil mixtures in general, but probably not with soils containing organic contaminants. It may not be applicable to saturated soils and is limited by the amount of water present. Little data exist on long-term resistance to leaching.

Vitrification may have limited applications because variable site conditions and the presence of complex mixes of contaminants severely lessen its reliability. If found to be practical, however, it could be used to treat wastes in situ and provide a more permanent containment solution than the use of barriers.

Biodegradation.–These techniques involve the use of naturally occurring or synthetically generated bacteria to break down chemicals via ingestion and respiration. They include either applying the organisms to aerated soils in situ or after excavation and deposition in surface impoundments, ponds, or treatment facilities where the wastes can be mechanically aerated, More recently, several concepts have been developed where the biodegradation occurs within the saturated, contaminated soil/groundwater system. Here, nutrients and oxygen are injected directly into the groundwater. Oxygen is added by pumping air into the ground through well points located below the water table. Some systems rely on indigenous micro-organisms; others inject additional micro-organisms together with nutrients. All pump and recirculate groundwater, since it takes more than one pass to obtain high removal efficiencies.

While biological treatment of wastewater is not a new concept, its application to solid waste and contaminated soils, especially in situ, is.[30] Various natural and chemical processes will affect the efficiency of biotechnology used in open systems. The effectiveness of the technology will be influenced by environmental conditions such as temperature, type of soil, type of naturally occurring micro-organisms, and the amount of air and water within the soil matrix.[31]

A biotechnology system to degrade hazardous waste consists of micro-organisms (selected mutants of natural strains already present in the contaminated matrix or genetically engineered organisms) and a *process technology*. The process technology makes possible the use of the organisms in highly variable, real world conditions, So far, much of the research interest and funding has been directed toward the micro-organisms with only limited funding to develop the technology.[32]

Before *genetically* engineered organisms can be used effectively in Superfund applications, especially in situ, certain problems require solutions :[33]

- Foreign organisms injected into a particular system will likely create problems of

[30] Wastewater treatment facilities are closed systems where the proper environment can be maintained for optimal performance results.

[31] S. W. Pirages, et al., "Biotechnology in Hazardous Waste Management: Major Issues, " paper presented at symposium *Impact of Applied Genetics in Pollutions Control,* University of Notre Dame, May 1982.

[32] Stanley Sojka, Manager, Environmental Technology, Occidental Chemical Corporation, personal communication, December 1984.

[33] M. A. Alexander, '<Ecological Constraints on Genetic Engineering: Genetically Engineered Organisms in the Real World, " paper presented at *Genetic Control of Environmental Pollutants,* University of Washington, Seattle, 1983.

s urvival for either the indigenous or foreign organisms.

- Laboratory results cannot be directly extrapolated to full scale because of differing conditions under which micro-organisms operate.
- Soil particles present a physical barrier to the movement of micro-organisms as water is required for movement between particles. Lack of proper conditions would give uneven degradation.
- The effect of possible abiotic stresses (e.g., unsuitable temperatures and pH levels) on micro-organisms released into the environment are unknown. Toxic elements within the environment might reduce, or eliminate, a microorganism's ability to degrade chemicals of concern. In addition, possible predators could be a critical factor to the effective use of laboratory-bred organisms,

An additional point is that little work has been done using organisms to treat complex waste mixes.

An advantage to using genetically engineered organisms at a Superfund site is that once the wastes have been degraded, the organisms should die, This is because the carbon source for growth and reproduction of the microorganism has been depleted or is unavailable to the organism.

Illustrations of Innovative Technologies

The following section describes **26** innovative technologies. Using available information, OTA has attempted to discuss: the principles on which each technology is based and the process itself; whether it destroys or contains hazardous waste; the expected products, air emissions and residues; the applicable wastes; economic costs and uncertainties; and the current stage of development and the level of testing, These technologies illustrate the scope of activity underway in cleanup technologies; OTA does not recommend or endorse any of them. Many more innovations are also likely to exist now, and yet more can be expected in the future,

Table 6-5 provides a technical summary of the 26 technologies showing their development stage, an estimate of how well each removes or destroys hazardous wastes, and the relative cost of their use. Table 6-6 summarizes their applicability to Superfund sites and table **6-7** their technical advantages and disadvantages. *A preferred technology would effectively treat a variety of hazardous wastes under a variety of physical conditions, be transportable so as to be useful for onsite treatment, transfer little health or environmental risk through air emissions and residue, and would not require extensive post-treatment facilities.* Many of the technical disadvantages and uncertainties of these emerging technologies might be resolved through demonstration testing.

1. **GARD Division, Catalytic Dehalogenation.—In the** presence of a catalyst, halogenated compounds (organic compounds that include a halogen such as chlorine, bromine, or fluorine) react with hydrogen to form an acid and a hydrocarbon. In this system, organic material is detoxified by reacting with hydrogen to form nontoxic materials.

GARD, a division of Chamberlain Manufacturing, has developed a treatment system using a platinum-based reforming catalyst supported on gamma alumina. The system begins with a storage unit that holds the hazardous waste material. The material is pumped from the tank to a preheater. When it reaches the proper temperature, it is sent to the catalytic reactor where it reacts with hydrogen. For a chlorinated compound, the reaction yields hydrochloric acid and a hydrocarbon. During the processing, most solvents remain intact and can be recovered, After leaving the reactor, the products are cooled and sent to a vapor-liquid separation stage. The dehalogenated hydrocarbon and acid are sent through a scrubber and on to another storage tank.

A second conversion stage can be added to the system as a polishing stage to remove a second halogen if necessary, and a provision for product recycle can be added to the reactor for cases when one pass is insufficient. The second conversion stage could be used to remove oxygen from some materials to enhance their fuel value.

GARD's process is probably best suited for treating liquids with low concentrations of halogenated compounds (e. g., Silvex herbicide), but it is also capable of treating liquids that are pure halogenated compounds and solids (e. g., contaminated soils), Liquid wastes can be treated directly with no pre-

Table 6"5.—Innovative Technology Summary

Company	Project development stage	Removal/ destruction capability	Relative estimated costs	
			Capital	Treatment
Gard	pilot	medium	low	*low*
Zerpol	pilot	?	7	?
Bend Research	pilot	medium	low	*low*
DeVoe-Holbein	pilot	medium	low	low
MODAR	pilot	high	medium	medium-high
Zimpro	full	low-medium	medium	low
Methods Eng.	pilot	?	medium	low
IT Corp.	bench	low-medium	?	medium-high
Huber..	pilot	high	high	medium-high
Thagard ...,	pilot	high	?	7
Pyrolysis	pilot	high	medium	high
Westinghouse.	pilot	high	high	high
Lockheed.	bench	medium-high	?	7
RoTech	pilot	high	medium	low-medium
Midland-Ross	full	?	high	medium
Waste-Tech	pilot	medium	medium	?
GA Tech.	pilot	medium-high	medium	7
Rockwell	pilot	high	medium	high
Sandpiper	pilot	7	medium	medium
Detox	pilot	medium	?	low
GDS	full	medium	low	low
SBR Tech	pilot	medium	7	?
University of Gottingen	research	high	?	7
Battelle Pacific.	pilot		7	low
Lopat-K20	pilot/full	high	low	low
NMT-Fujibeton	pilot/full	_high	low	low

NOTES
na not applicable
? = not available
KEYS
Removal/destruction capability (systems not necessarily tested on comparable waste)
Low = less than 90 percent
Medium = 90 to 9999 percent
High – 9999 percent and greater
Capital costs (based on full-scale system where possible)
Low – less than $1 million
Medium - $1 million to $5 million
High = more than $5 million
Treatment costs (not all systems evaluated using same operating costs components)
Low - less than $100/ton or $0.01/gallon
Medium = $100 to $500/ton or $0.01 to $1/gallon
High greater than $500/ton or $1/gallon

SOURCE: Office of Technology Assessment

treatment, except for filtering to catch solids. Solid waste must be dissolved in hydrocarbon solvents first. Since the solvent is unaffected by the process, however, it can be used repeatedly,

A bench-scale single pass reactor has been built for testing. GARD has considered building a pilot-scale system for further testing but is seeking financial assistance (private or public sector) before continuing the research. Test results are available for Silvex and PCBs, With a single pass, Silvex was dechlorinated by nearly **80** percent; with two passes, greater than 99 percent. Dechlorination of 93 percent in a single pass was achieved with material containing approximately **2,000** ppm PCBs, but only 30 percent for material containing slightly more than 17,000 ppm PCBs.

GARD has estimated costs based on the treatment of 1 million gallons of Silvex, assuming a feed rate of 50 gallons per minute. Capital costs would be $110,000 for **a** skid-mounted system and site hookups (e. g., electricity). Operating costs would be $99 per 1,000 gallons of Silvex treated and include cost of the hydrogen, pumping power, heating and cooling water without heat recovery, and labor. [GARD is located in Niles, IL; (312) 647-9000.][34]

[34]Each of the 26 technologies is listed by the firm developing the technology and the firm's name for its product. In addition, each firm's location and telephone number are provided so that the reader who wants more information may contact the developer directly.

Table 6-6.—Innovative Technology Applicability to Superfund Sites

Company	In situ[a]	System applicability: Onsite[a]	Offsite[a]	Mobile(M) Transportable(T) Permanent(P)	Primary waste applicability[b]: Class	Form	Air emissions and/or residues generated[c]	Post-treatment required[d]	Applicable systems standards
GARD	N	Y	Y	M,T	O	L,SL	L	P	P
Zerpol	N	Y	N	T	I	GW,L	L	P	P
Bend Research	N	Y	P	M,T	I	GW,L	s	Y	P,DO
DeVoe-Holbein	N	Y	N	M,T	I	GW,L	S,L	Y	DO,P
MODAR	N	Y	Y	P,T	o	GW,L	L	N	P
Zimpro	N	P	Y	P,T	o	GW,L	L,S	P	P,DO
Methods Egg.	N	P	Y	P	o	GW,L	L	N	P
IT Corp.	N	P	Y	P	o	L	L,A	P	P
Huber	N	Y	Y	T	o	S,L	A	N	P
Thagard	N	Y	Y	T	o	S,SL	A	N	P
Pyrolysis	N	Y	N	M,T	o	L	A,S	N	P
Westinghouse	N	Y	N	M,T	o	L	A,S	N	P
Lockheed	N	P	Y	P	o	L	s	N	P,DO
Ro Tech	N	Y	Y	M,T	o	S,SL,L,S	s	N	P
Midland-Ross	N	P[f]	Y	P,T	o	SL,L	L,S	N,P	DO,P
Waste-Tech.	N	P[f]	Y	P	o	SL,L,S	A	N	P
GA Tech.	N	Y	Y	M,T	o	S,SL,L	s	N	P
Rockwell	N	N	Y	P	o	L,SL	s	N	DO
Sandpiper	N	Y	Y	M,T,P	o	L,S,SL	L	P	P,DO
Detox	Y	Y	N	T	o	GW,S,SL	A,S,L	P	P,DO,E
GDS	P	Y	N	T	o	GW,L	none	N	P,E
SBR Tech.	N	‘t	Y	P,T	o	GW,L	S	P	P
University of Gottingen	P	P	P	T	O	SL,L	7	P	?
Battelle Pacific	Y	P	N	T	o	S,SL	A	N	E(g),DO
Lopat	Y	Y	Y	T	O/I	S,SL,L	s	P	P,E(g)
New Materials	Y	Y	Y	T	O/I	S,SL,L	s	P	P,E(g)

[a]Y = yes N . no P = perhaps with further testing
[b]*Class*
O – organics
I – inorganics
Form
GW – groundwater (dilute aqueous)
S = soils/solids (low concentrated)
L liquids (concentrated)
SL - sludges/solids (concentrated)
Pretreatment pretesting mav be required
[c]S solid L = liquid A air emissions Shown as dominant form since most processes result in some of each
[d]Y yes N no P possibly Post-treatment needs can vary i.e., products depend on treated hazardous waste In general thermal processes do not treat heavy metals therefore residues may have to be tested for trace amounts prior to landfill Also products of Incomplete combustion may be hazardous knowledge base is weak
[e]If utilized on Superfund wastes a technology Will probably require regulation Three types are considered p performance (analogous to RCRA Subpart O incinerator regulations e.g 99.99 percent DRE for primary organic hazardous components) DO design/operation (similar to RCRA landfill standards) and E environmental standards (comparable to National Primary and Secondary Air Quality Standards) The most applicable approach is given first
[f]For large sites: i e high volume of waste to b@ treated
[g]For subsequent leaching from a treated area

SOURCE Off Ice of Technology Assessment

Table 6-7.—Innovative Technology Advantages and Disadvantages

Company: Technology	Advantages	Disadvantages/uncertainties
GARD: **Catalytic dehalogenation**	Little pre-treatment for liquids Fuel recovery potential Good portability Conventional equipment	Wastes must be in liquid phase Development at small pilot stage
Zerpol: Zero Technology	Salt recovery possible Highly treated liquid discharges Highly concentrated residues Leads to metals recovery	Has not undergone relevant testing Applicable to concentrated wastestreams Pretesting required to fix wastestream applicability—highly selective applicability y
Bend Research: Coupled transport for sludge reclamation	Potential for metals recovery Requires little ion exchange agent High copper, chromium, zinc applicability	**Only** tested at small scale High exchange membrane costs Sludge requires residue disposal
DeVoe-Holbein: **Metal extraction**	Selective exchange leads easily to **metal recovery** **High metal capture efficiencies**	Clean, dilute liquid wastes required Considerable pre-treatment required
MODAR: Supercritical water oxidation	**High DREs for wide range of organics** **Operates in self-sustained** mode on low organic content wastes Applicable to large volumes of wastes	Requires demonstration testing Relatively high capital costs High pressure/temperatures process[a]
Zirnpro: Wet **air oxidation**	Wide previous experience on variety of nonhazardous wastes Low energy requirement v. incineration	Destruction dependent on residence time Higher capital investment than for incineration Elevated temperature/pressure process[a]
Methods *Eng.:* Submerged reactor	Potential onsite application Operates in self-sustained mode on low-organic content wastes Applicable to large volumes of waste	Requires demonstration testing Relatively high capital costs High pressure/temperature process[a]
IT Corp.: **Catalyzed wet ox id at** ion	Can be operated to produce no aqueous residue Low-volume residue for further disposal	Destruction dependent on rates of oxidation of compound in reactor—longer rates will dominate processing time for waste Elevated temperature/pressure process[a]
Huber: Advanced Electric Reactor	Very high reaction temperatures/absence of oxygen limits unwanted product formation High destruction efficiencies for organics Applicable to large sites Demonstration tested	High energy use
Thagard: Fluid wall reactor	Very high combustion temperatures PIC formation considered low[b] High destruction efficiencies for organics Applicable to large sites	High energy use
Pyrolysis:		
Plasma arc	High operating temperatures result in high organic destruction efficiencies Mobile system possible	Cost estimates incomplete
Westinghouse: **Plasma arc**	High operating temperatures result in high organic destruction efficiencies	**Small-scale testing** to date Cost estimates incomplete
Lockheed.' Microwave plasma	High destruction efficiencies for chlorinated compounds Can process gases and liquids	High degree of pretreatment required Bench-scale tests convince developer to drop project
RoTech: Cascading Rotary Incineration System	Small commercial-scale operation on actual wastes Cascading solids have very high contact with combustibles No afterburner required No refractory maintenance	Testing required on mixed wastes, metals emissions Need pre-treatment for waste size uniformity Destruction efficiency difficult to assess
Mid/and-Ross: Rotary pyrolytic incineration	Fuel recovery possible Application shown on actual wastes Metals retained on residual char Low or no NO, emissions	Not applicable to aqueous wastes Tested on a narrow range of wastes

Table 6“7.—Innovative Technology Advantages and Disadvantages—Continued

Company: Technology	Advantages	Disadvantages/uncertainties
Waste-Tech: Fluidized bed Incineration	Expect metals attenuation in bed Good combustion turbulence and waste contact Capital costs compare to rotary kiln Destruction efficiencies high	Waste character and particle size should be uniform Need further metals emission testing and waste tests
GA Tech: Circulating bed combustor	Higher turbulence than typical fluidized bed Expect metals retention in bed Shown on variety of wastes High destruction efficiencies Little/no gas discharge treatment required Low-temperature operation—expect low NO_x emissions	Need further metals emission testing Waste feed pre-treatment for character/size uniformity required Need fuller testing on mixed wastes
Rockwell: Molten salt incineration	Little air emission of toxics Metals retained in melt Very high destruction efficiency for organics	Works best on low ash content wastes: requires melt-ash removal system Small-scale test thus far
Sandpiper: SEGAS process	Energy recovery possible Compact mobile system	Costs/testing for waste application incomplete
Detox: In situ biological treatment	Tested at actual site on mixed wastes Demonstrated lower costs than some chemical/thermal processes Anaerobic capability Tested in a soil matrix Little pre-treatment	Longer treatment times than chemical/thermal Intermediate compounds not defined
GDS: Biological degradation	Proven cleanup technology	Applicability dependent on site characteristics In situ phase contribution uncertain
SBR Technologies: Sequencing Batch Reactor	Each cycle is monitored by computer system High throughput possible	Production of sludge can reduce efficiency of operation
University of Gotfingen: Biological degradation	Promising research approach	Intermediates are formed Needs process technology
Battelle Pacific: In situ vitrification	No removal costs Very low leachability Application in past to radioactive wastes successful Good control for metals	High energy use Small site applicability For organics—requires off gas treatment High soil moisture increases costs
Lopat: Chemical treatment	Low cost, safe chemical, easy to apply to wastes and contaminated surfaces Effective on organic and inorganic materials	Duration of effectiveness uncertain For soils and wastes other additions such **as** cement, increase volume
New Materials: Chemical treatment	Low cost, **safe** chemical, easy to apply to wastes and contaminated surfaces Effective on organic and inorganic materials Proven technology	Long-term (greater than 10 years) effectiveness uncertain

[a]High temperature h..h..~~ systems have inherent risk of process catastrophe Redundant safeguards required
[b]PIC—Product of Incomplete Combustion

SOURCE Off Ice of Technology Assessment

2. **Zerpol Corp., Zero Technology .—This** pollution control system developed for the metals finishing industry is a unique collection of conventional processes. The system recently has been extended to other industries, such as textile manufacturers, chemical manufacturers, petroleum refiners, paper mills, and pharmaceuticals. It could provide a chemical method of removing organics, heavy metals and inorganic, including cyanides, from contaminated groundwater. There is no liquid discharge from the system.

For wastewater from a metal finishing plant, proprietary chemicals sequentially reduce chromates, oxidize cyanides and adjust the pH to 9 to 9.2 (an alkaline solution). The primary objective is to reduce the cyanide levels in the solution and precipitate out heavy metals without the use of flocculating and settling agents. The resultant liquid contains dissolved salts that must eventually be removed by a distillation process. The distilled water is then recycled back through the system.

Residues from the process include heavy metals and a concentrated salt solution that is dried by evaporation, producing a small amount of solids, No test data is available on hazardous waste removal levels, nor is any information regarding capital and operating costs, [Hatfield, PA; (212) 368-0501]

3. **Bend Research, Coupled Transport for Sludge Reclamation.**—This coupled transport system is an adaption of ion exchange technology in which an immobilized, liquid membrane process allows certain metals to be selectively extracted from a solution containing various other metals. This system offers several advantages over other ion exchange processes. It requires only small amounts of agent, thereby lowering costs, and feed pre-treatment, especially the removal of suspended solids, is expected to be minimal.

An inert, microporous support is impregnated with a water-miscible liquid ion exchange resin. (This agent is held in the pore of the support material by capillary forces.) When the membrane contacts an aqueous solution containing metal ions, the membrane exchanges ions of like charge, thereby extracting the metal ions from solution, The process includes acid leaching of sludge as a first step, followed by the exchange in which the metal is deposited on one side of the membrane. An electrolytic extraction of the exchange-concentrated solution is the final step,

Bend has developed three membranes so far, for copper, chromium, and zinc recovery. If the process can be made to work on a wider base of metals, the potential for treating hazardous wastes might be high. As this is a physical separation process, the products are a metal and a sludge residue. Given that the metal is a hazardous waste component of the initial sludge, that product would have to receive further treatment or disposal, if it is not recycled.

The process has received only laboratory-scale testing. In those tests, copper purity in a sample was over 99,9 percent. Future work is required to demonstrate nickel recovery and to increase copper flux in the ion exchange unit, chromium oxidation efficiency, and the number of potentially exchangeable metals.

Costs have been estimated for a plant capable of treating 27,000 grams (60 pounds) per hour of sludge. Post-treatment of the metal residue and sludge disposal is not included. Capital costs would be $118,700 and operating costs, $85,700 per year, with payback within 4 years. At this level of operation, resale of the metal values are said to result in income of $148,000, but this would depend on metal market conditions. [Bend, OR; (503)382-4100]

4. **Devoe-Holbein, Inc., Metal Extraction.—This technology** offers a method to extract metal from relatively clean waste streams using synthetically produced compositions. Ion exchange then regenerates the compounds by separating out the metals. The extraction compositions are patterned after the natural metal extraction capability of living cells.

Each of the 30 compositions developed by Devoe-Holbein extracts a different metal. Both the composition and the extracted metal can be recovered and reused, reducing the cost of the process. The technology might be used either as an independent waste treatment or in conjunction with other processes as a pre-treatment step,

The process is mainly applicable for treating dilute wastes such as those produced by metal finishing operations (i. e., electroplating). It is highly selective of the metal in question. Once metals considered to be hazardous have been extracted, they must be reused or receive further management,

The measure of success for the process is the percent of metal captured from the solution being treated. Synthetic compositions have been shown to capture nearly 100 percent of the metals in both aqueous solutions and industrial wastes in pilot-scale tests: 99.96 percent of copper in solution, 99,91 and 99.98 percent of zinc chloride and zinc phosphate from electroplating rinse solution, 99.99 and 99.97 percent of cobalt and zinc from a petrochemical effluent, Large-scale testing is planned.

Estimated capital and operating costs have been made for a representative plant treating 10 gallons per minute of waste and removing zinc. Capital investment for this relatively small plant would be $15,000. Stated operating costs of $6,100 to $6,600 per year (at 8 hours per day and 220 days per year) work out to less than a penny per gallon of waste, but Devoe-Holbein has not included labor costs. [Quebec, Canada; [514)636-6042]

5. MODAR Inc., Supercritical Water Oxidation.—Supercritical water is used by MODAR to destroy organic materials by oxidation. Above its critical temperature [374° C) and pressure [210 atm or 0.3 g/cm^3), the properties of water are quite different from that of the normal liquid or atmospheric steam. For example, organic substances are completely soluble in water under some supercritical conditions, while salts are almost insoluble under other supercritical conditions. The volubility of organics, coupled with low hydrogen bonding properties in supercritical water, facilitates the destruction of organics and formation of inorganic acids (from the halogens and possible metal elements present), plus carbon dioxide and water. The acids can be precipitated out as salts by adding a base to the feed,

The MODAR system is a multi-stage process. First, the waste in the form of an aqueous solution or a slurry is delivered to the oxidizer inlet, where it is pressurized and heated to supercritical conditions by direct mixing with recycled reactor effluent. Oxygen is then supplied in the form of compressed air and the inlet mixture is a homogeneous phase of air, organics, and supercritical water. The organics are oxidized in a controlled but rapid reaction (residence time of 5 seconds), The effluent is fed to a cyclone where the inorganic salts that are originally present in the feed, or which form in the combustion reactions, precipitate out and are separated from the effluent. The fluid effluent (some of which is recycled through the system as a preheater) is then a mixture of water, nitrogen, and carbon dioxide. Once cooled to subcritical temperature, the mixture forms two phases and enters a high pressure liquid-vapor separator. Practically all of the N_2 and most of the CO_2 leaves with the gas stream; the liquid consists of water, inorganic salts, and an appreciable amount of dissolved CO_2. The liquid is depressurized and fed to a low-pressure separator. The vapor stream is vented. At two points in the system, energy can be generated.

The MODAR process can be applied to organic wastes with a wide range of concentrations; solids must be slurried prior to treatment. Economically, it is currently particularly well suited for aqueous wastes containing 1 to 20 percent weight organics. For lower concentrated wastes, fuel value must be added; for higher concentrations, water.

Originally designed to detoxify industrial aqueous organic waste streams, the firm is now offering the process for use at Superfund sites. A demonstration, skid-mounted pilot-scale system is available for testing.

A continuous flow, bench-scale system with an organic throughput of 1 gallon per day was used to collect the test results. Feed mixtures of various organic hazardous wastes were used, containing from 1 to 20 percent chlorine. Liquid effluents were analyzed for total organic carbon (TOC) and pH. Gaseous effluents were analyzed for low molecular weight hydrocarbons and permanent gases. In general, organic carbon is reduced to less than 1 ppm (DREs of 99,99 to 99.9999 percent); organic chloride DREs are also 99,99 to 99.9999 percent.

The system has low operating costs but relatively high capital costs. Operating costs are kept low because the system recycles its superheated effluent to heat incoming wastes. Consequently, the system requires almost no fuel once operation has begun. The incoming slurry must contain at least 2 percent combustible organic matter to maintain self-sufficiency (compared with a typical incinerator's feed of about 30 percent), Excess heat generated by the system can be used to drive a turbine to generate electricity (an option that might only be feasible for a centrally located plant rather than a transportable system used for Superfund sites).

Disposal costs have been projected by MODAR for a representative plant processing 10 tons of organic waste per day; it would require a capital investment of nearly $5 million with treatment costs of $1.50 per gallon for organic liquid and solid wastes and $0.15 for dilute aqueous wastes. [Natick, MA; (617)655-7741]

6. Zimpro, Wet Air Oxidation.–The basic principles of air oxidation are covered above under "Conventional Treatment Technologies. " The use of water ("wet") as a reaction medium allows for reactions to take place at relatively low temperatures, 175° to 3250 C (347° to 617° F). It also modifies the reaction rates that remove excess heat by evaporation and provides an excellent heat transfer medium. This allows the process to be self-sustaining thermally with relatively low organic feed concentrations (i.e., feeds with low fuel value). The process pressure is usually between 300 and 3,000 psi to prevent excessive evaporation of the liquid phase in the reactor,

Zimpro has been using wet oxidation for the treatment of industrial wastes for over 30 years, and they are now adapting the process for the treatment of hazardous waste, The degree of oxidation achieved (i. e., degree of destruction) depends on temperature and residence time in the reactor and oxidation conditions are waste-specific, Zimpro feels that wet oxidation can be valuable for the treatment of dilute organic hazardous waste streams because it is far more efficient (in terms of energy consumption) than incineration.

Air pollution problems are nearly eliminated because most harmful contaminants produced remain in the aqueous phase and do not burn off as gases. The only gases discharged from the process are spent air and a small amount of carbon dioxide. Any harmful liquids produced may have to be treated.

Bench-scale tests have been conducted with pure hazardous organic compounds and DREs ranged from 2.0 to 99.997 percent. The poorest performers were Kepone (31 percent), Arochlor 1254 (2 and 63 percent), and 1,2, -dichlorobenzene (32 and 69 percent). Otherwise, DREs were at least 82 percent and averaged over 99 percent. Testing and treatment of industrial hazardous waste streams show that most compounds are easily oxidized by the wet air process but that halogenated aromatic compounds (e.g., chlorobenzene and PCBs) are resistant.

The capital investment for wet air oxidation is considerably higher than that for conventional incineration, but there is the potential for lower operating costs. A small plant processing about 4 tons per day would require a capital investment between $1.9 million and $3.0 million, Zimpro expects wet air oxidation to save a great deal in operating costs because power requirement are low. Total operating costs are expected to vary depending on plant capacity; estimates of $30 per ton (at 100 tons processed per day) and $150 per ton (at 10 tons per day) have been made. [Rothschild, WI; (715) 355-3523]

7. Methods Engineering, Inc., Burleson/Kennedy Submerged Reactor.—The Burleson/Kennedy reactor uses a deep well to form a reaction chamber for the combustion of waste in water. The deep well promotes the conditions (pressure and temperature) necessary for supercritical water, which is used as a process medium (see MODAR, above).

The ideal structure for the submerged reactor is an abandoned oil well at least 6,400 feet deep with a cement casing to retard heat loss. Water, pressurized oxygen, and the hazardous waste to be treated must be pumped into the well, The bottom of the well serves as the reaction vessel. An electrical current input near the bottom of the well heats the fluid for the reaction.

Aqueous organic hazardous wastes would be the most appropriate use of this system. The products of the process are carbon dioxide, water, and various soluble and insoluble solid salts, Depending on the input waste, some of the salts may contain heavy metals that will need to be separated out for proper handling.

Information is not available on testing results. Capital and operating costs were estimated in mid-1984. The initial capital outlay would be $1.2 million, and the system is expected to be capable of processing 480 million gallons of wastewater per year at a cost of $0.0014 per gallon, [Angleton, TX; (409)849-7033]

8. IT Corp., Catalyzed Wet Oxidation.—In conventional wet air oxidation, heat and pressure drive the dissolution of oxygen from air and its reaction with dissolved organics in an aqueous solution. In this catalyst system, the transfer of oxygen to the dissolved state is speeded. With enhanced oxygen transfer, it is possible to oxidize organics at lower temperatures (165° to 200° C versus 250° to 3250 C for conventional systems) and at lower pressures. The catalyst consists of bromide, nitrate, and manganese ions in acidic solution.

In its simplest form, the reactor contains a continuously stirred catalyst solution. Air and waste are continuously pumped into the reactor. Products formed that leave the reactor are CO_2, N_2, water vapor, and depending on the input, volatile organics and inorganic solids. Water is condensed and returned to the reactor, if necessary, as are condensable organics. Any inorganic salts or acids that may form have to be removed by treatment (e. g., filtration or distillation) of the catalyst solution in a closed loop stream. The vent gases are low in volume and can, if necessary, be treated by conventional techniques such as adsorption or scrubbing, Nonvolatile organics remain in the reactor until destroyed and there is no aqueous bottoms product.

This system is best suited for the treatment of liquid organics, and bench-scale tests have been conducted by IT Corp. Results show that organic reduction varied depending on the compound tested, temperature, and residence time. Further R&D awaits more funding. The initial research was internally funded by IT, supplemented by EPA funds.

Preliminary treatment costs have been estimated so far and range from $0.12 to $1.04 per pound of compound. Actual costs will vary markedly depending on what compound is sent through the system. Slow destruction rate compounds would cost much more to treat than fast destruction rate compounds. In addition, treatment costs are influenced to a lesser degree by factors such as the air compressor, condenser size, cooling water requirements, neutralization or scrubbing requirements, and catalyst loss. [Knoxville, TN; (615)690-321 1]

9. J.M. Huber Corp., Advanced Electric Reactor.—The Advanced Electric Reactor (AER) rapidly heats materials to temperatures in the range of 4,0000 F (2,2000° C) using intense thermal radiation in the near infrared region. The reactants are isolated from the reactor core walls by means of a gaseous blanket formed by flowing nitrogen radially inward through the porous core walls (thus, its common name of "fluid wall reactor"). Solid waste is introduced at the top of the reactor through a metered screw feeder, and nitrogen is forced through the walls of the reactor.

After leaving the reactor, where pyrolysis occurs at temperatures of about 4,0000 F, the product gas and waste solids pass through two post-reactor treatment zones. The first is an insulated vessel to provide additional high temperature (in excess of 2,000° F) and residence time (5 to 10 seconds), The second is water cooled to reduce the gas temperature to less than 1,000° F prior to downstream particulate cleanup. Solids exiting these zones are collected in a sealed bin. Additional solids in the product gas are removed by a cyclone and routed back to the solids bin, The product gas then enters a bag house for fine particulate removal followed by an aqueous caustic scrubber for chlorine removal. Any residual organics and chlorine are removed by passing the product gas through activated carbon beds just upstream of the emission stack. The organic, particulate, and chlorine-free product gas composed almost entirely of nitrogen is then emitted to the atmosphere through the process stack.

The AER runs entirely on electrical power and requires 800 to 1,200 kWh per ton for treating contaminated soils and 1,500 to 2,000 kWh per ton for the complete dissociation of liquids. Gaseous, liquid, or solid wastes can be treated. Pre-treatment of solids and liquids may be required to ensure that feed particle size is small enough for the reaction to proceed to completion within the residence time, The system is suited for the treatment of low Btu content hazardous materials (i. e., contaminated soils, pure PCBs, and other heavily halogenated hydrocarbons) and extremely hazardous materials [e.g., dioxins and nerve gases).

The principal products of soil-borne PCB destruction using the Huber process are H_2, Cl_2, HCl, elemental carbon, and a granular, free-flowing, solid material. Typical products of incineration, such as carbon monoxide, carbon dioxide, and oxides of nitrogen, are not formed in significant concentrations.

Huber has built and maintains two fully equipped reactors as part of its over $6 million 17 RD&D program. The smaller reactor unit (0.6 pounds per minute of contaminated soil feed capacity) is installed in a covered truck trailer for mobility. It is used for proof-of-concept experiments and onsite demonstrations. The larger, pilot/commercial-scale reactor with a capacity of up to 50 pounds per minute or 10,000 tons per hour is used solely for research purposes. Although the larger unit has been permitted by EPA Region VI to commercially treat PCB-contaminated soils, corporate policy restricts its use to RD&D.

To date, four test programs have been conducted to demonstrate the effectiveness of the AER for treating soils contaminated with hazardous wastes. Tests were conducted in September 1983 on PCBs and certification was received from EPA Region VI in May 1984 under TSCA. A second series of tests were conducted in May 1984 with carbon tetrachloride in applying for a broad RCRA permit (expected in 1985). In October 1984, a test series was initiated on soils spiked with octachlorodibenzo-p-dioxin (a thermodynamically more stable surrogate for the acutely toxic 2,3,7,8 tetrachlorodibenzo-p-dioxin isomer). In November 1984, at Times Beach, Missouri, the mobile reactor was tested on soil contaminated with 2,3,7,8 TCDD and other dioxins.

Results from various test programs have provided typical gas phase DREs of 99.99999+ percent. In all cases, DREs were at least 99.9999 percent. Treated soil concentrations have always been equal or less than 1 ppb of the contaminant in question (PCB, CCl_2, dioxin) and usually nondetectable. Further, no chlorinated products of incomplete pyrolysis have been observed.

Operating costs depend on the size of the waste site and the soil pre-treatment requirements, which could include drying and sizing. For a large site (containing more than 10,000 tons of materials), the cost is estimated to be between $300 and $600 per ton, But costs could be as high as $1,000 per ton. Capital costs to build a large reactor are estimated at $10 million. [Borger, TX; (806)274-6331]

10. Thagard Research, High Temperature Fluid Wall Reactor .—This High Temperature Fluid Wall [HTFW] process is based on the same principles as the Huber's AER. The reactor was orginally developed for the continuous dissociation of methane into carbon fines and hydrogen. To accomplish this, temperatures in excess of 1,700° C (3,0920 F) and a mechanism to prevent precipitate formation on the reactor walls were required. To meet both requirements at the same time, the reacting steam is kept out of physical contact with the reactor wall by means of a gaseous blanket. Energy for the reaction is supplied by carbon resistance heaters that bring the carbon core of the reactor to incandescence. Heat transfer occurs through radiative coupling from the core to the stream.

The destruction process is driven by pyrolysis conditions in the reactor, In addition, some materials (e. g., soils) will vitrify under the high temperatures. The system has a wide application to many hazardous wastes as long as they can be fed into the reactor in a pulverized form. This may require pre-treatment.

Two sets of testing have been done on a pilot-scale unit. Thagard views one set to be correct and the other incorrect due to errors in testing (contamination occurred), DREs for the former test were dichloromethane (99,9999+ percent), carbon tetrachloride (99.9+ percent), dichlorodifluoromethane freon 12 (84.99 percent), trichloroethane (99.99 + percent), and hexachlorobenzene (percentage not reported). In the latter tests, the most significant difference showed in dichloromethane, with much lower DREs,

Extensive cost estimates (capital and operating) prepared by Thagard have compared its treatment process with the cost of landfills. They concluded that if wastes must be moved at least 100 miles at a cost of $65 per ton, the HTFW reactor can be substituted as long as at least 100 tons per day are being processed. [Costa Mesa, CA; (714)556-4470]

11. Pyrolysis Systems, Inc., Plasma Arc Technology.– The principle of plasma pyrolysis involves breaking the bonds between organic constituents. Once the compounds are atomized, they reform into other compounds under controlled conditions that attempt to prevent the formation of hazardous materials.

Waste fluids are injected into a plasma arc zone of a reactor vessel where temperatures ranging from 15,0000 to 50,0000 C exist in a gaseous cloud of charged particles between electrodes. The organic molecules react with the plasma species and are destroyed within microseconds. These elements are subsequently released into another vessel where they recombine into stable forms such as hydrogen gas and methane.

The new compounds created are predictable. Using a computer model, the appropriate operating conditions can also be predicted prior to destruction. Undesirable products can be reduced by altering the character of the feedstock or modifying the operating conditions.

At the product gas outlet from the reaction chamber, water is injected along with liquid caustic soda to quench the product gas, neutralize acidic products, and trap particulate, Saltwater and particulate are pumped and sampled before the discharge is approved.

Product gas, mainly of hydrogen and carbon monoxide, flows to a flare stock where it is electrically ignited and burns between 2,0000 and 3,0000 C. The flare prevents the release of methane gas to the environment, Chlorinated wastes produce a hydrogen byproduct that is converted to salt in a caustic scrubber. An activated carbon filter blocks the release of toxic material in the event of a power failure.

The system has been designed to be mobile. All of the equipment is to be contained in a 45-foot trailer. It includes a 500-kilowatt plasma device located at one end of a stainless steel reaction chamber with a graphite core,

The technology has been developed with financial assistance (up to $1.5 million) from EPA and the State of New York to treat the organic leachate from the Love Canal site. Pilot-scale testing (1 gallon per minute) on organic sludges is to begin in 1985 in Canada. These tests will provide data for the permit to place the unit on the Superfund site in New York for demonstration testing. Previous laboratory-scale tests of askarel fluids with contents up to 58 percent chlorine have produced DREs in excess of 99.9999999 percent. Handling contaminated soils for treatment would involve melting down the inorganic components and gasifying the organic components,

Full-scale operating costs have not been estimated by Pyrolysis Systems yet, Estimates made in 1983 for the prototype model showed operating costs of about $0.30 per pound of waste at a treatment rate of 1 gallon per minute and that capital costs would be $2 million to $2.5 million for a full-scale unit with an input feed of 50 gallons per minute. Labor costs have not been estimated, but it is known that three operators would be required to run the system. [Welland, Ontario, Canada; (416)735-2401]

12. Westinghouse Electric Corp., Plasma Arc Technol-Ogy.—Plasma arc technology has been described above under Pyrolysis Systems, Inc. Westinghouse has been a major developer of the torch systems incorporated in plasma arc furnaces and has developed a bench-scale reactor to test surrogate hazardous waste fluids, The surrogate material chosen for testing was 31 percent by weight hexachlorobenzene in a slurry made up of water (26 percent), alcohol (as an emulsifier), and kerosene (3 I percent). The researcher felt that the results for this surrogate would be similar to those of PCBs, (PCBs were not chosen because EPA approval is required to test with PCBs.] The results demonstrated the ability of the plasma technology to destroy hexachlorobenzene, dibenzofuran, and dibenzodioxin. In three tests the treatment product, analyzed by both a mass spectrometer and a gas chromatography, showed 0.13, 0.3, and 0.5 ppm of hexachlorobenzene. The latter substances were not detected at a 1 ppm resolution,

The company has recently begun an intensive 10-month testing program that they expect will answer any remaining questions about the new technology on a larger scale.

Preliminary cost estimates were made for a fixed plant treating 700,000 gallons of PCB liquids per year (assuming 7,000 hours of operation a year). Capitol cost was set at nearly $5.9 million, with total operating costs for one year at $2.8 million. These costs are now under revision, [Madison, PA; (412) 722-5000]

13. **Lockhead Missles & Space Co., Inc., Microwave Plasma Detoxification.—In** a microwave reactor, a plasma is generated by electrons subjected to microwaves. When used to decompose organic materials, a large number of complex reactions take place. Free radicals and atoms are produced from collisions of free elections with organic molecules. These species then react further to form secondary products.

The reactor effluent consists mainly of carbon dioxide and steam, with minor amounts of chlorine, hydrochloric acid vapors, and nitrogen oxides depending on the molecular structure of the material being destroyed. The hot gaseous plasma effluent is cooled, discharged through a caustic scrubber to remove acid products, and vented to the atmosphere.

Lockheed initiated a research program on applying this process to hazardous waste detoxification in 1975, By 1980 a bench-scale reactor (rated at 15 kilowatts) had been developed to a stage where both gases and volatile liquids could be fed into the system. The feed rate was 10 to 20 pounds per hour, and reaction time was on the order of 10 milliseconds.

Simulated wastes were used for testing the bench-scale reactor. For vinyl bromide, DREs ranged from 99.98 to 99.9998 percent and carbon tetrachloride, 99.72 to 99.94. For tests of aniline, toulene and 1,1,1-trichloroethane, results averaged 99.99 percent.

Lockheed has not compiled cost data for this project, which was primarily funded by outside sources (EPA and a Canadian firm). It seems, however, to be an expensive way of destroying hazardous wastes. In 1980, EPA withdrew funding and Lockheed abandoned the research before any demonstration took place, Technical and political issues also contributed to the project's termination. Included among the technical problems were feed rates too slow to be commercially viable, difficulties in proving DREs of six nines, and corrosion by HCl on the vaccum pump requiring an internal scrubbing system, Politically, Lockheed faced problems in acquiring permission from the local community to test real wastes. [Palo Alto, CA; (415)424-2593]

14. **RoTech Inc. (formerly Pedco), Cascading Rotary Incineration** System .—The RoTech technology is an incinerator whose cylindrical reactor unit rotates at 10 to 20 revolutions per minute (rpm), A conventional rotary kiln incinerator usually rotates at I to 3 rpm. This motion produces a cascading motion of the solids in the reactor (ash, unburned solids, and limestone residue) through the combustion gases, The high turbulence and solids-gas contact results in maximized heat transfer and optimal combustion kinetics.

The intimate contact between solids and gases also provides the opportunity to neutralize acid gases (e.g., HCl) by adding limestone to the combustion zone. The high combustion efficiency and acid gas removal eliminates the need for afterburners and acid scrubbers. Particulate are removed with baghouse filters.

The system includes air preheating and solid reheating by countercurrent flow with combustion gases. Combustion takes place between 1,2000 and 1,500° F (640° and 807° C).

RoTech's system could be applied to a wide range of organic wastes: solids (pre-treated if necessary for size consistency), gases, solid-laden gases, sludges, and liquids. Low heat value wastes (sewage sludge at 1,650 Btu per pound, for instance) can be incinerated without auxiliary fuel.

Combustion gas products include carbon dioxide, oxygen, and water. As mentioned above, acid gases produced from halogen compounds are reacted with limestone to produce salts. These solids, along with inert ash, are periodically removed from the furnace. Additional pollution control needs will be evaluated as testing proceeds,

At present, a pilot or small commercial size unit is operatin g on industrial and other wastes and has been tested on a sludge/emulsion, an acrylic emulsion, and a chlorinated aromatic waste. The DREs are expected to be high, better than 99.99 percent, but the data are not yet available. The technology is ready for full-scale application, and several units with 100 ton-per-day capacity are under design.

The installed cost for a system at the 35 million Btu per hour capacity level is estimated to be about $2,5 million; a 10 million Btu per hour unit is estimated to cost $1.5 million. Treatment costs are estimated to range from $70 to $150 per ton. [Cincinnati, OH; (513)782-4519]

15. **Midland-Ross Corp., Rotary Pyrolytic Incineration.—** The main objective of this system is to convert waste material from a disposal problem to a gaseous fuel source using pyrolysis. (Pyrolysis produces a product stream that contains a high-energy content by virtue of its hydrocarbon concentration.)

The treatment process begins with dried sludge being deposited onto a preheated, rotating hearth. When the sludge comes into contact with the hearth, its viscosity decreases and the material spreads out in a uniform, thin layer. Due to the absence of air, the material is pyrolyzed on the hearth. Volatile products are exhausted through a flue and the inert char materials that are left, mostly carbon and ash, are removed. The generated gases are combusted in a reactor at approximately 2,800° F in the presence of oxygen.

The prime candidate hazardous wastes for this system are organic sludges. Products of the process are a char and gas effluent from the energy conversion unit. The char is collected to prevent leakage to the atmosphere and must be shipped to a landfill.

Three types of wastes have been tested using this process: API waste, styrene waste, and rubber plant waste. All three are organic wastes containing various metals in amounts ranging from 0.1 to 1,000 ppm. Testing results have not been made available,

Preliminary economic estimates have been made for the processing of API and rubber wastes (styrene waste was not included because of poor test results). The estimates were made for a system that included waste storage, a feed system, the pyrolyzer, fume incinerator, and heat recovery. No costs were included for air pollution control, which could be necessary. The total estimated operating costs for the API waste is $894 per metric ton for a $440,000 system capable of processing 300 metric tons per year. For rubber waste, three systems were considered. At 1,000 metric tons per year, capital costs were estimated at $670,000 and operating costs, $526 per metric ton; at 2,000 metric tons, $920,000 and $296 per metric ton; and at 6,000 metric tons per year, $150 million and $117 per metric ton. [Toledo, OH; (419)537-6242]

16. **Waste-Tech Services, Fluidized Bed Incineration.—** The fluidized bed concept was described earlier under "Conventional Treatment Technologies. " Waste-Tech has extensive experience in such standard systems, having provided 45 commercial fluidized bed incinerators for nonhazardous waste disposal, They are now building two similar incinerators for hazardous waste treatment.

Solids, sludges, slurries, and liquids can all be treated with this system, although it is not very economical to treat liquids with a fluidized bed, Products of the incineration process are flue gases and ash, The contents of both are dependent on the input hazardous waste.

The ash generated is sent through a cyclone to remove particulate matter. Gases are then sent through a scrubber to remove the remainder of the particulate matter, A caustic neutralized wet scrub system can be used to remove HCl from the exhaust gases before release to the atmosphere. All noncombustible, inorganic wastes larger than the bed material are removed from the incinerator by a screening and recycling system. This material and particulate removed from ash and gases would have to be separately treated for any hazardous waste components.

Waste-Tech has tested chemical compounds as well as actual wastes in their pilot incinerator, Included have been fuel oil, carbon tetrachloride, tetrachlorophenol, pentachlorophenol, and phenol at concentrations ranging from 0.5 to 40,8 percent by weight. All of the components tested had DREs of at least 99.99 percent except for tetrachlorophenol (99.97 percent). Waste-Tech claims to have destroyed tetrachlorophenol up to 99.99 percent in subsequent experiments by raising the system temperature. Pilot-scale testing has also shown that DREs are inversely related to the feed rate.

The company estimates capital costs to be between $790,000 and $1.35 million depending on the size of the incinerator required (a site-specific factor). The smallest unit could treat about 2,500 tons of waste per year; the largest, 10,000 tons per year, The estimated operating costs for relatively small units range from $0.18 to $0.21 per pound of treated material, based on non-hazardous waste and include costs for labor, utilities, consumable, depreciation, cost of money, and permitting, [Idaho Falls, ID; (208)522-0850]

17. G. **A. Technologies, Circulating Bed Combustor.—** This circulating bed combustor is designed to be an improvement over conventional fluidized beds (see "Conventional Treatment Technologies"). It operates at higher velocities and with less and finer

sorbents than conventional systems, allowing for a unit that is more compact and easier to feed. The unit also produces lower emissions and an offgas scrubber is not necessary.

The key to the high efficiency (in terms of destructive power) of the circulating bed combustor is high turbulence, a large combustion zone with uniform and relatively low (less than 8500 C, or 1,5620 F) temperatures, and longer residence times.

This technology can destroy all types of halogenated hydrocarbons, including PCBs and other aromatics. It is capable of treating solids, sludges, slurries, and liquids containing such compounds as chlorobenzenes, acetonitrile, carbon tetrachloride, trichloroethane, sodium fluoride, tributyl phosphate, aniline, malathion, sodium silicates, and lead oxide. Wastes , however, must be homogeneous in composition when fed to the combustor.

Due to the relatively low operating temperature of the system, acid gases can be treated with lime scrubbing within the combustor, resulting in the release of lime salts. The low combustor temperatures, coupled with good mixing in the combustor, prevent extensive formation of NO_x.

More than 7,500 hours of testing have been completed using four pilot-scale combustors. The variety of wastes tested have included spent carboneous cathodes from primary metal plants, halogenated hydrocarbon solvents, phosphate bearing wastes from polymer production, and radioactive waste carbon from metals production. All tests showed efficient destruction of hazardous chemicals, low emissions of air pollutants (NO_x levels were 120 ppm or less), high combustion efficiency, and significant volume reduction. DREs exceed 99.99 percent for oily water sludge, chlorinated organic sludge, aluminum potlinings and PC B-contaminated soil. Chemical plant wastes showed DREs of greater than 99.9 percent.

The capital investment for a 25 million Btu per hour sludge incinerator, including a process steam generator, has been estimated at $2 million plus or minus 30 percent. A smaller, 6 million Btu per hour, incinerator is estimated at $1 million to $1.5 million plus or minus 25 percent. Operating costs vary widely depending on the wastes being destroyed. [San Diego, CA; (619)455-3045]

18. Rockwell International, Molten Salt Incineration.— Molten salt incineration is a method of burning organic material while simultaneously scrubbing the objectionable byproducts from the effluent gas stream. Materials to be burned are mixed with air and injected under the surface of a pool of molten sodium carbonate. The melt is maintained at temperatures on the order of 9000 C, causing the hydrocarbons of the organic matter to be immediately oxidized to carbon dioxide and water.

Rockwell's units are capable of being fed either crushed and sized solid material or liquid fuels. The pulverized solids, mixed with air being used for combustion, are injected into a stainless steel reaction vessel. The feed mixture passes through 6 inches of salt (in a bench-scale unit). Periodically, the inorganic materials that build up in the molten salt must be removed so that the bed can retain its ability to absorb acidic gases. Exhaust gases (carbon dioxide and water vapor] can be directed through a scrubber and/or baghouse, if necessary, to remove particulate before being released to the atmosphere.

The ultimate products of the molten salt process are carbon dioxide, water, various inorganic salts, and ash. The ash and any inorganic materials containing metals may be considered hazardous.

Although molten salt technology has been used by several companies to incinerate wastes, only Rockwell's system has been used to incinerate hazardous liquid or solid wastes. The company currently operates three sizes of units: bench-scale (feed rate of 2 pounds per hour), pilot-scale (up to 250 pounds per hour), and a production unit that is operated as a coal gasifier and has not been designed for hazardous wastes.

The bench-scale unit has been tested and shown to effectively destroy organic chemicals and wastes (DREs have exceeded 99.99 percent). No hazardous waste streams have been incinerated in the larger unit but since its bed depth is proportionally larger, it is reasonable to expect that its destruction efficiencies would be at least as great as in the bench-scale unit.

Cost estimates are not available for Rockwell's incineration system. [Conoga Park, CA; [818) 700-4887]

19. A. L. Sandpiper Corp., SEGAS Process.–SEGAS, or Sequential Gasification, converts incinerable solids, sludges, and liquid waste to a medium heat-value fuel gas. The process was developed in the 1970s to convert petroleum into more volatile products. Sandpiper is now testing the system for use on hazardous wastes typical of Superfund sites.

The basis of the SEGAS process is a pressure vessel operating at 1,2270 C [2,241 °F) and 200 psi. The reactants, the wastes, and superheated steam are continuously fed into a proprietary fluid bed reactor. Wastes are thermally decomposed, releasing hydrogen and carbon. The steam reacts with the deposited carbon to form carbon monoxide and additional hydrogen. This mixture of hydrogen and carbon monoxide—synthesis gas—is a fuel gas and basic raw material of the petrochemical industry. Chlorine and sulfur in the waste feed material react with the hydrogen within the reactor to form hydrogen chloride gas or hydrogen sulfide gas and are removed by conventional scrubbing technology. Solid residues will vary depending on the feedstream and scrubbing technology and must be landfilled if not delisted.

The process differs from conventional incineration in that it does not burn the waste and, therefore, no air of combustion is required in the system. The absence of air eliminates the necessity to contain, heat, cool, scrub, and discharge large volumes of nitrogen. The reactor and scrubbing system are substantially smaller than for conventional incineration of comparable waste streams.

Results of testing hazardous wastes are not yet available but Sandpiper claims that extensive testing of the technology has been conducted on a variety of heavy petroleum products and has demonstrated process efficiency. Separate testing of the fluid bed reactor showed high DRE capabilities. Integration of the reactor with the SEGAS process will occur in a 60 gallon per hour demonstration unit expected to be available by June 1985.

Sandpiper has designed a stationary or mobile unit (on a 40-foot trailer) to treat 600 gallons of waste per hour, They have projected capital costs for a stationary unit of $2.3 million and $2.2 million for the mobile unit. Operating costs will vary depending on the specific waste being processed. Sandpiper estimates that it will cost $0.03 per pound to process lower heat value, refractory materials (e.g., heavily chlorinated hydrocarbons). Costs do not include any offset from the sale of synthesis gas. [Columbus, OH; (614)486-0405]

20. **Detox Industries, Inc. (DTI), In Situ Biological Treatment.—This** is an assisted microbiological degradation process for the destruction of organic compounds. It will work either aerobically or anaerobically. In anaerobic conditions, an oxygenating agent is added. Chlorinated organics serve as the carbon source for the organisms and the process is more efficient in destroying toxic compounds if the carbon source is limited to the compounds of interest.

DTI developed its degrading microbe culture by selective adaption of known bacteria in the presence of various concentrations of PCBs. The organisms were conditioned to use PCBs as the sole carbon source. The biodegradation of 14,000 cubic yards of soil contaminated with pentachlorophenol has been completed, and PCBs (Arochlor 1260) have been treated in a 25,000 gallon tank. Treatment applied to several hundred thousand cubic yards of material can be expected to take months to complete.

The first step is to determine the parameters of the material to be treated. Contaminant concentrations, acidity, density, volubility, temperature, oxygen, and moisture content are important variables. Then a design is developed to most effectively stimulate growth and biodegradation. The process uses naturally occurring microbes, but is proprietary. To be effective, proper mixing of and contact between the microbes, waste constituents, and nutrient supply, along with control of environmental factors, must be maintained.

The process has been tested on PCBs and can be designed to be applied in situ to detoxify soils, sludge, lagoon contents, or can be designed to operate as a treatment process on or offsite. Degradation results in carbon dioxide, water, and cell protoplasm (new cells). After degradation is complete, the micro-organisms used in DTI's process die off and the original culture, or mix, of organisms becomes dominant again.

Demonstrations with DTI's process have used concentrations ranging from 46 to 2,000 ppm of PCBs and have achieved destruction efficiencies greater than 99 percent, Further work will fix the efficiencies more accurately and extend the range of chemicals.

Costs are highly site-specific, DTI has estimated that costs will range between $60 and $120 per cubic yard (about 1 ton) of material to be treated, depending on the initial concentration of contaminant and the matrix within which it is contained. [Houston, TX; (713)240-0892]

21. **Groundwater Decontamination Systems, Inc., Biological Degradation .—The GDS system takes** place onsite and aims to eliminate hydrocarbon and halogenated hydrocarbon contaminants from groundwater and soil through accelerated biodegradation by micro-organisms existing in the contaminated soil. It was developed by Biocraft Laboratories in New Jersey as a remedial technique for cleanup of their own property under a consent order and is now being marketed for use at other locations.

It is essentially a flushing and treating operation that must be specifically designed for the characteristics of each site and its contaminants, A pumping system is installed to remove contaminated groundwater from the site, The water is cycled through an activating tank, where the micro-organisms found in the water are enriched with compounds of phosphates and ammonia. From the activating tanks, the water is transferred to settling tanks and the treated water, rich in oxygen, nutrients, and micro-organisms is reinfected into the ground upgradient from the intake system. This permits biodegradation to occur in situ as well as in the tanks, The groundwater and soils are aerated through air injection wells to further increase the rate of biodegradation.

At the original site, groundwater was contaminated by leaking underground storage tanks, The contamination covered a surface area of 360 feet by 90 feet and extended below the surface to a depth of 10 feet. Biodegradation treatment was considered the most cost effective choice when compared with carbon absorption (too expensive) and ozone treatment (too ineffective), Measurements of the effluent indicate that removal of most of the contaminants to the desired level has occurred. Average removal efficiency for the system was greater than 98 percent for isopropyl alcohol, greater than 97 percent for butyl alcohol, greater than 88 percent for acetone, and greater than 64 percent for dimethyl aniline during the first 16 months of operation. In the following 7 months the acetone removal was increased to greater than 97 percent and dimethyl aniline to greater than 93 percent.

GDS claims that conventional methods might have taken 15 to 20 years cleanup time whereas their system will be completed in less than the 5 years originally estimated, and at a lower cost. At the New Jersey site, 12,000 gallons of groundwater are being treated daily at a cost of less than $0.02 per gallon. Total cost of the project has been placed at $859,000 including the original R&D costs of $453,000. [Waldwick, NJ; (201)796-6938]

22. SBR Technologies, Sequencing Batch Reactor.—The Sequencing Batch Reactor (SBR) has been under development by Professor R. L, Irvine of Notre Dame University over the past 15 years. Although initially intended for municipal wastewater treatment, the technology recently has been shown to be applicable to treat contaminated groundwater and hazardous waste leachates.

The SBR has several virtues that overcome the traditional disadvantages of biological treatment. For example, the SBR has been shown to be relatively insensitive to changing feed characteristics, including loading rates. It is not as susceptible to shock loadings; it selects for the proper micro-organism in a mixed population; and it combines all treatment functions in only one tank, a definite economic advantage,

The reactor does in time what traditional biological process technology does in space with sequential tanks. There are five periods in its operation: fill, react, settle, draw, and idle. During fill, wastewater is charged to the reactor, and during react the biological processes started in fill are continued, Aerobic, anoxic, or anaerobic conditions can be created during the fill and react periods. During settle, the micro-organisms are allowed to settle to the bottom of the tank, and during draw the supernatant treated water is removed. Idle is a short time where the reactor is awaiting the next batch of feed. The five time periods can be adjusted for optimum removal efficiencies for varying types of wastes.

Two full-scale demonstration SBR plants exist: one in Indiana treating municipal waste and a 250,000 gallon per day facility at the Cecos site in Niagara Falls treating hazardous waste. The project at Cecos is cofunded under a demonstration contract with the New York State Energy Research and Development Authority and in part by Jet-Tech., manufacturer of SBR's aeration and decant system, A computer controls all phases of the treatment process, Laboratory studies show that the SBR can achieve 70 to 80 percent removal of organic materials and 98 percent removal of phenol, A carbon adsorption system has been added as a secondary treatment method to achieve higher removal levels.

This may be quite a cost-effective approach to the destruction of hazardous leachates, especially when coupled with some form of carbon treatment. Production of biomass or sludge is a potential disadvantage; however, natural decomposition seems to circumvent the need for frequent sludge removal. [Mishawaka, IN; (219)236-5874]

23. **University of Gottingen, West Germany, Biological Degradation of Chlorophenols.—West** German researchers have developed several bacterial strains that are capable of degrading chlorophenols. The process has been tested on synthetic sewage containing phenol, acetone, and alkanols plus 4-chlorophenol or a mixture of isomeric chlorophenols. One particular bacterial strain completely degraded the chlorophenols in the synthetic mix. The release of chloride and a low content of dissolved organic carbon in the cell-free effluents indicated total degradation of the organic carbon. During adaptation to high loads of chlorophenols, hybrid strains were detected that were determined to be even more competitive than the original strain for the degradation of chlorophenol.

The research has also shown, however, that the presence of additional organisms capable of degrading the phenol, acetone, and alkanols in the mix caused incomplete degradation of the chlorophenols. Thus, the approach, while considered well defined, is valid only for one organism at a time.

24. Battelle Pacific Northwest Laboratories, In Situ Vitrification.—In situ vitrification classifies contaminated soils in place while the organic waste constituents contained within are pyrolyzed, The gases from the process combust when they rise above the soil and contact the air.

The area to be treated is heated (between 1,100° and 1,600° C) electrically, melting the soil, As the soil is heated, the molten zone grows outward and downward approaching temperatures of 2,0000 C. The high temperatures and long residence times result in essentially complete combustion and destruction of the organic components. An offgas hood is placed over the soil to catch small amounts of hazardous elements, The effluents are directed to an offgas treatment system in a mobile semitrailer. The effectiveness of the gas capture system is not proven,

Cooling takes several months and depends on the size of the mass produced. After cooling, the vitreous mass may be covered with clean fill. The mass is a containment system that could be enhanced by the addition of engineered barriers,

This process was originally designed for radioactive wastes. Tests have been conducted on various metals (e. g., cobalt, cadmium, lead) as well as carbon tetrachloride, tributyl phosphate, bibutyl butylphosphate, wood, plastics, and other organic compounds. Bench- and pilot-scale tests have been conducted on soils contaminated with metals and organic wastes. While organic materials will be destroyed by the process, metals are encapsulated, The cost of the process increases as the liquid content of the waste increases.

All residues are contained within the vitreous mass that remains in the ground. Air emissions are controlled by the offgas system, which includes a scrubber, a water separator and condenser, and particulate air filters,

Battelle has estimated costs and the major variables are soil moisture and cost of electric power. In five different scenarios, costs ranged from $4,60 to $6.30 per cubic foot ($161 to $224 per cubic meter) of soil vitrified, (Soil was vitrified to a depth of 5 meters in each case.) Calculations included site preparation, annual equipment charges, operational costs (labor), and consumable supplies such as electrical power and electrodes. [Richland, WA; (509)375-2927]

25. Lopat Enterprises, K-20 Chemical Treatment.—The patented agent K-20 was developed to seal surfaces against water intrusion. It was found to be a fire retardant and to have the ability to encapsulate a number of toxic chemicals, K-20 is a mixture of potassium silicates and other materials, is said to be safe and nontoxic, can be varied to meet different objectives, and can be used in conjunction with cement and other inorganic agents. Unlike conventional chemical fixation and stabilization products, K-20 appears to be effective on organic as well as inorganic toxic materials,

The product is applied to surfaces after being mixed with a catalyst, Little technical expertise is required to apply it once an effective formulation has been developed for a particular application. The product can penetrate porous materials of any sort to considerable depths.

K-20 has been used commercially to a limited extent on building surfaces contaminated with either PCB or chlordane. In both cases, readings on contaminated surfaces and in the air after application of K-20 have been brought down to the nondetectable level. Lopat Enterprises is pursuing studies to determine exactly how K-20 works on organic toxic chemicals. Questions have been raised about how long the chemical encapsulation will be effective. The company maintains that the base silicates it uses have been used for other purposes for many years and that its product should be effective for at least 50 years. The product has also been used effectively on buildings with asbestos contamination. In this case, microscopic evidence shows that K-20 penetrates deeply and coats asbestos fibers so that they are not friable or suspendable in air,

The company also has laboratory test results on contaminated soil. When mixed with portland cement and soil with a lead content of 200 ppm, K-20 reduced the measured lead level to 0.1 ppm according to EPA's EP Toxicity test. The product was recently tested on dioxin-contaminated soil from Missouri. For a sample of soil containing 174 ppb of dioxin, treatment with K-20 at levels of 5, 10, and 20 percent by weight resulted in a finding of less than 1 ppb, the limit of detection. Proponents say that contaminated soil could easily be treated in situ or in other ways. After treatment, the soil is an inert, friable material.

Research is also planned for introducing K-20 into materials used for below ground barriers for groundwater, such as slurry walls, to reduce attack or penetration by organic toxic chemicals. There is also potential for the product to be used with liquids in uncontrolled surface impoundments to form solid harmless materials.

Although precise cost data is not available, costs appear quite low. Cost depends on how much of the product is necessary, and that depends on a number of factors such as the nature of the contaminated material, the contaminants, and the need for additional agents such as cement. For treatment of contaminated soils, some equipment would be necessary to achieve thorough mixing of K-20 and soil.

The company is a small business that has faced difficulties obtaining funds for RD&D. Thus far all its work has been self-supported. [Wanamassa, NJ; (201)922-6600]

26. New Materials **Technology Corp., Fujibeton Encapsulation.**—Fujibeton is an inorganic polymer that has been shown to chemically bond with and physically encapsulate both inorganic and organic toxic compounds. It has been used in large hazardous waste treatment projects in Japan. The product was developed by Fujimasu Synthetic Chemical Laboratories in Tokyo, and New Materials Technology Corp. is its exclusive manufacturer and distributor in the United States. The technology's supporters claim over 10 years of successful application in Japan.

Fujibeton is an advanced form of cement, [Concrete, which results from the reaction of water, cement, and aggregate is a relatively primitive example of an inorganic polymer.) It is able to improve the bonding properties and cross-linking abilities of silicate macromolecules. The result is to greatly reduce the release of hazardous chemicals from the treated materials. The combination of compounds and the nature of the bonding mechanism of the process are proprietary.

New Materials Technology foresees several applications in the hazardous waste area for their product. For remedial action, its prime use would be to treat and immobilize hazardous wastes in solid, sludge, and liquid forms. Liquid wastes must be first mixed with an absorbent, such as fly ash. The solidified end product can be reduced to a granular form without substantially reducing its effectiveness. Treatment can take place onsite with simple equipment (e. g., a concrete mixer).

An example of a successful application in Japan was the treatment and stabilization of PCB-contaminated sludges and sediments found in the harbor of Takasago West Port, Prior to treatment the sludge contained 450 milligrams per kilograms (mg/kg) of PCB plus 91 mg/kg of lead and 0.02 mg/kg of mercury. Leachable concentrations after treatment were 0,003 milligrams per liter (mg/1) of PCB, 0.01 mg/1 of lead and 0.0005 mg/l of mercury,

Two remedial action projects are planned for 1985 in Japan using Fujibeton. Up to 763,000 cubic yards of contaminated material will be dredged from the bottom of Waka River which has been polluted over a long period of time with *a* whole range of industrial wastes. After treatment, the stabilized material will be used as a landfill for a new industrial site for Sumitomo Heavy Industries. At Lake Biwa, the largest inland lake in Japan, 25.5 million cubic yards of contaminated sediments will be treated in place to improve the water quality to an acceptable drinking level, The lake serves as the main source of water for the Osaka-Kyoto area with a population of 13 million.

Several tests have been conducted on the effect of applying Fujibeton to a variety of hazardous wastes, both organics and metals. In one University of Arizona test, an electroplating sludge was treated; and the resultant material underwent the standard EPA EP Toxicity test. For all metals present, the extractable metal concentrations from the treated/stabilized material were one to two order of magnitude below the maximum allowable. For instance, lead ranging from 360 to 690 ppm was reduced to 0,5 to 0,36 ppm; chromium, from 37 to 100 ppm to 0.8 to 0.35 ppm; and cadmium, from 1.7 to 2,9 ppm to an undetectable level. Similar results occurred when material from a toxic waste dump at Bridgeport, New Jersey, was tested. In addition, in the latter case the organics orginally present were not detectable in leach tests on the treated samples. Comparative leach testing against conventional technologies (cement/soluble silicate and portland cement) have shown Fujibeton to be superior.

There are no capital costs associated with the use of this encapsulation technology, Material costs for the treatment of contaminated soils vary depending on the amount of Fujebiton required (5 to 15 percent) per pound of soil and the overall size of the project. The amount required varies depending on the level and type of contamination, and the unit cost ($0.15 to $0.25 per pound) decreases as the project size increases, For instance, a project treating 50,000 tons of soil and consuming 10 million of pounds of Fujebiton (at 10 percent per pound of soil) would cost from $30 to $50 per ton of soil. The treatment process would consist of three steps: 1] excavation of the soils, 2) mixture with Fujibeton, and 3] cure and subsequent disposal as nonhazardous fill back into the original excavation. [Wichita, KS; (316] 683-8986]

SUPPORT OF CLEANUP TECHNOLOGY RD&D

Introduction

Research and development can lead to better ways of tackling Superfund remedial action problems. Compared to existing cleanup options, R&D can improve the range of applicability, the effectiveness, and the reliability of technology and also reduce costs. Hazardous waste problems at any one Superfund site can range from one to many, and a technology may be *applicable* to only a specific waste and form, A technology is *effective* when it achieves remedial action objectives and is *reliable* if it is effective under operating conditions and has the ability to maintain its effectiveness over the long term.

The design and development of innovative technologies are conducted within the private sector with little assistance from the Federal Government. The Federal Government funds Superfund-related R&D programs in EPA and in the Department of Defense (under its Installation Restoration program). Within EPA the amount of funds for the support of Superfund technologies has been relatively small and narrowly focused. For example, while over 50 percent of EPA's total R&D budget has been spent on contracts and grants during the last 5 years, only a fraction of the total (4 percent in fiscal year 1985) has been dedicated to the Superfund program and only a portion of that to cleanup technologies.[35] Most of the research contracts awarded by EPA under Superfund seem to complement internal activities rather than provide for the influx of new ideas.

In what may prove to be a more relevant link between research and technology, the National Science Foundation (NSF) in October 1984 provided seed money for an Industry/University Cooperative Center in New Jersey that will concentrate on hazardous and toxic waste research.

[35] According to a summary sheet prepared by the Congressional Research Service in October 1984, a total of $307 million was appropriated for R&D at EPA for fiscal year 1985; $202 million is for grants and contracts, $9 million of which is for Superfund.

EPA Technology Research and Development

Because Superfund has been considered a short-term program, EPA has not followed the normal research and development process of concept development, laboratory evaluation, pilot testing, and field demonstration. Instead, the program has been one of:

> . . . technology assessment to determine cost and effectiveness, adaptation of technologies to the uncontrolled waste site problem, field evaluation of technologies that show promise, development of guidance material for the EPA Office of Emergency and Remedial Response (OERR), technical assistance to OERR and EPA Regional Offices.[36]

Short-term thinking and an original interpretation by EPA that CERCLA excluded expenditures for basic research has concentrated activity on applied research, such as adapting existing construction engineering technologies to improve disposal practices and evaluating containment and incineration technologies, This policy, compounded by an initial belief that existing technologies could indeed solve Superfund problems (i.e., innovation was not *required)* has resulted in little if any emphasis on basic research and innovative approaches.

There are some signs that this attitude is beginning to change within the EPA R&D system, but only evidence of a shift in funding levels in the next few years will confirm a real shift in commitment. In 1985, new emphasis will be placed on innovative approaches, such as in situ technologies and onsite treatment.[37] According to a recent report, EPA is now beginning to look at the prevalant wastes found

[36] Ronald D. Hill, U.S. Environmental Protection Agency, "Promising Site Cleanup Technology," paper presented at *Superfund Update: Cleanup Lessons Learned,* Schaumburg, IL, Oct. *11-12, 1983*. Similar statements were made in 1984 at EPA's *Tenth Annual Research Symposium: Land Disposal of Hazardous Waste.*

[37] Ronald Hill, *director,* Land Pollution Control Division, Office of Research and Development, U.S. Environmental Protection Agency, personal communication, Dec. 14, 1984.

at Superfund sites and to attempt to match them with the best treatment technology.[38]

R&D Funding

The total EPA R&D budget during each of the Superfund program's first 5 years is shown in table 6-8, with a comparison of the amounts dedicated to Superfund and Hazardous Waste activities.[39] Over the 5-year period, only about $50 million has been spent on Superfund R&D, a small fraction of the $1.6 billion Superfund program.

The R&D amounts for the Superfund program are modest when compared with the total EPA R&D budget and with what many observers think is required to adequately support the development and assessment of technology to handle Superfund problems.'" The *Superfund R&D budget for fiscal year 1985 represents about 4 percent of the EPA R&D budget, while the Superfund program represents 35 percent of the total EPA Operating Budget request.*[41]

The R&D funds are budgeted under the Office of Research and Development (ORD) and within ORD divided as shown in table 6-9. At most, about half these funds are related to R&D in cleanup technologies. The EPA budget, as shown in table 6-8, also allocates R&D funds under hazardous waste (13 percent of R&D in fiscal year 1985) for RCRA-related activities, Some of this R&D, as well as that conducted under other programs is relevant to Superfund program needs. But only the funds committed under Superfund consider remedial action technology per se and are dedicated to solving Superfund's special problems.

R&D Activities

Superfund and RCRA R&D within ORD were reorganized in late 1984 to more closely link the activities of the two programs. R&D objectives that deal with technology are primarily the concern of the ORD's Office of Environmental Engineering Technology and its Hazardous Waste Engineering Research Laboratory (HWERL), HWERL'sS Land Pollution Control Division (through its Containment Branch and Releases Control Branch) and the Alternate Technologies Division deal with Superfund-related technology investigations. The Containment Branch is responsible for research in the area of remedial action (also for RCRA); the Releases Control Branch for emergency removals. The Alternate Technologies Division now conducts research in incineration, chemical and biological technologies, primarily those applicable under RCRA.

The Releases Control Branch work is divided into three areas. The goal of the *personnel health and safety* program is to develop protective equipment and procedures for personnel working in known or suspected dangerous environments. Efforts under *removal technol-*

Table 6-8.— EPA R&D Budget (millions of dollars)

Fiscal year	Superfund	Hazardous Waste	Overall[a]
1981 . . . . . , . . .	4.7	21,9	303.0
1982 . . . . , .	13,8	29.2	314.6
1983. , ...	6.9	33.4	228.5
1984[b]	9.0	33.5	250.0
1985[b]	12.7	40.7	306.0

[a]Includes funds for Superfund and Hazardous Waste plus Air, Water Qual W, Drinking Water, Pesticides Radiation Toxic Substances Energy, Interdisciplinary, and Management categories
[b]Estimated

SOURCE U S Environmental Protection Agency, Off Ice of the Comptroller, December 1984

[38]Theresa Hitchens, "Public Push for Alternatives to Land Disposal Years Ahead of Research, " *Inside E. P. A.*, Feb. 15, 1985, pp. 12-13.

[39]EPA b...ks down its R&D budget into 11 *media* categories: air, water quality, drinking water, hazardous waste, pesticides, radiation, interdisciplinary, toxics, energy, management, and Superfund. Each of these media are subsequently broken down into various *program elements* and program elements into *objectives*.

'According to an internal EPA memo dated Dec. 3, 1980, from Alvin R. Morris, director, Superfund Task Force, projected Superfund program costs are dependent on the number of NPL sites. Under this scheme, Superfund R&D should total $115.5 million for 1,000 sites, $152.4 million for 1,400,$1893 million for 1,800, and $226.1 million for 2,200 sites. As of late 1984, NPL sites totaled 538. This would argue for a Superfund R&D budget of about $90 million.

[41]U.S. Environmental Protection Agency, *Summary of the 1985 Budget* (Washington, DC: Office of the Comptroller, January 1984).

Table 6-9.—Superfund R&D Budget (millions of dollars)

ORD Office	FY84	FY85	Primary objectives
Environmental Engineering Technology	3,7	6.3	Control technology, technical support
Monitoring Systems and Quality Assurance	3,7	4.9	Site assessment, quality assurance
Health and Environmental Assessment	1.0	1.3	Site assessment, technical support
Environmental Processes and Effect Research	0.5	0.2	Site assessment
Total[a]	8.9	12,6	

[a]Figures may not add to totals due to rounding

SOURCE U S Environmental Protection Agency, Office of Research & Development, December 1984

ogy center on demonstrating equipment for hazardous spill control. Under this program a mobile incinerator, carbon regenerator, and soils washer equipment are being modified, adapted, and field tested. The *chemical countermeasures* program is concerned with the use of chemicals and other additives that are intentionally introduced into the open environment for the purpose of controlling hazardous contaminants,

The activity of the Containment Branch includes: 1) the survey and assessment of current technologies, 2) field demonstration and verification of techniques, and 3) site design analysis. The first activity is a followup to remedial actions that have occurred, reviewing and evaluating techniques that have been applied at Superfund sites, Techniques identified as having "potential for being cost effective" or those being installed as part of a remedial action are given field testing and evaluation. For example, the block displacement method of isolating hazardous wastes has been field tested and a particular slurry trench installed at a New Hampshire site has been given field evaluation. The third category, which involves the publication of technical handbooks to guide those handling site design analysis, is an outgrowth of the data collected and analyzed in the first two areas of activity.

Specific projects under both branches can be broadly classified as either pertaining to treatment or containment technologies and include:

- *Treatment.* Development of: 1) a mobile soils washing system that can be used to treat excavated soils onsite, 2) mobile and modular incineration systems for field use to destroy hazardous organic substances collected from cleanup operations at spills or at uncontrolled hazardous waste sites, and 3) a trailer-mounted system for the onsite regeneration of spent granular, activated carbon from carbon adsorption systems. In addition, bench-scale testing of a number of leachate treatment processes will be conducted and the Chemical Countermeasures Program mentioned above is underway.
- *Containment.* Evaluation of installed slurry systems and low-permeability covers, pilot-scale tests of injection grouting, assessment of the feasibility of retrofitting membrane liner systems to existing surface impoundments, development of the criteria for evaluating the use of permeable materials as hazardous waste control mechanisms. Development and evaluation of a prototype full-scale process and equipment for encapsulating corroding 55-gallon drums of hazardous waste. The investigation of asphalt encapsulation techniques to improve the leachate quality and act to reduce the hazardous nature of some sludges.

The Alternative Technologies Division now incorporates activities evaluating fixed incineration systems that were ongoing under the previous Industrial Environmental Research Laboratory. The division is funded ($8.8 million in contract funds in fiscal year 1985)[42] from the RCRA R&D budget and consists of two branches: the Thermal Destruction Branch, which will continue with the above incineration program, and a Chemical and Biological Technology Branch. The division's primary emphasis is ap-

[42]Clyde Dial, director, Alternative Technologies Division of the Office of Research and Development, U.S. Environmental Protection Agency, personal communication, Dec. 13, 1984.

plied research on industrial hazardous waste streams although some fundamental research is conducted in such areas as combustion (e. g., minimization of PIC formation) and genetic engineering, Although this division is RCRA-oriented, many of its activities could have applicability to Superfund, The group has cooperated with various States that wish to evaluate innovative technologies. In a project completed with the State of California, EPA paid for the sampling and analysis of molten salt, fluid wall, and wet oxidation processes. *Emphasis on this type of program could help generate standardized data collection to be used for the development of protocols for testing of new technologies.*

Grants and Contracts

One of the major ways that technology transfer occurs between the private sector and EPA is through the grants and contracts awarded by EPA, That portion of the R&D budget totals $201.8 million for fiscal year 1985 (66 percent of the overall R&D budget). The funds are spent under a grants program, a centers program, and by contracts let through the laboratories of ORD. Due to the Small Business Innovative Development Act of 1982[43] at least 1 percent of these funds must be spent to support small business R&D.

The agency's Small Business Innovative Research (SBIR) program was set up within ORD in November 1982. Once a year, it solicits bids on a dozen or so topics considered to be of interest to EPA, Twelve topics were listed in the 1984 offering, a number of which are directly related to Superfund cleanup technology R&D. Included were improved stability of containment mechanisms; organic waste/containment liner compatibility; biotechnology applications for hazardous waste control; advanced thermal, chemical, and physical methods for hazardous waste destruction; methods for soil and aquifer decontamination; and innovative volatile organic compound control methods. To participate, a firm must first apply for a Phase I contract to show the scientific and technical merit and feasibility of its idea. Following successful completion of Phase I, a firm can apply for a Phase II contract to further develop the proposed idea. In the first year of the program (fiscal year 1983), 10 Phase I projects were funded for a total of $248,000. Ten Phase I and five Phase II projects (at about $100,000 each) were funded in fiscal year 1984 at a total cost of $856,000. In fiscal year 1985, the SBIR program expects to spend $1.9 million. Six to eight Phase II projects will be funded at about $150,000 each, along with Phase I projects at about $48,000 each.

The SBIR program is considered by the private sector to be the prime source of financial assistance for R&D in Superfund-related innovative technologies, but it has its drawbacks, First, due to SBIR's once-a-year funding cycle, a firm must wait a full year to obtain follow-on (Phase II) funding. An option that would be more conducive to the private sector business climate would be to allow Phase II funding to proceed directly following the completion and evaluation of a Phase I project. Second, the size of the awards may not be consistent with private sector costs of R&D.

Most of EPA's basic research is funded under its grants program in ORD which has a 1985 budget of $12.2 million, The monies can be used by nonprofit entities only. General guidelines are provided in an annual proposals list covering five program areas: environmental health, environmental biology, environmental engineering, and physical/chemical measurement of air and water. Due to the initial decision by EPA that Superfund monies cannot be expended for basic research, grants are not awarded for research specifically related to Superfund. Undoubtedly some of the research will eventually benefit Superfund but it is difficult to measure how much. (Possibly about 10 percent of the work funded under the environmental engineering category will eventually benefit Superfund.)[44]

[43] Public Law 97-219, July 1982.

[44] Clarise Gaylord, director, Grants Office of the Office of Exploratory Research of the Office of Research and Development, U.S. Environmental Protection Agency, personal communication, December 1984.

The centers program was set up within ORD in 1979 in response to criticisms regarding EPA's concentration on short-term research. EPA developed eight themes needing support in fundamental research, and eight centers based on these themes have now been funded through cooperative agreements at various universities. Each center receives about $500,000 per year from EPA (out of ORD's R&D budget) and is expected to supplement its income from other public and private sector sources. The results of the research conducted by the centers are disseminated through peer review journals and publications.

Three of the centers conduct research that may have a bearing on Superfund needs: the Hazardous Waste Center at Louisiana State University, the Center for Advanced Environmental Control Technology at the University of Illinois at Urbana, and the Industrial Hazardous Waste Elimination Center at the Illinois Institute of Technology in Chicago. Of the three, the Hazardous Waste Center is most germaine to Superfund technology needs. Its research focuses on ultimate disposal and landfill techniques and destruction technology.

At Tufts University in Massachusetts, EPA has funded at the specific request of Congress the Center for Environmental Management, So far, $3 million have been appropriated for the Center; $2 million in the fiscal year 1983 supplemental appropriations bill for EPA and $1 million in the fiscal year 1984 supplemental appropriations. This program is outside of the Centers Program, and its grant money does not come from ORD's R&D budget, This "national research, education, and policy center" is applying a multidisciplinary research approach to link environmental research, technology, and public policy issues.[45] The chairman of EPA's internal Hazardous Waste Committee oversees the Center's research program, and efforts are made both by EPA and the Center to coordinate its research with that ongoing within EPA and with the activities of the centers program.[46]

[45] Anthony Cortese, director, Center for Environmental Management, persona] communication, December 1984.

[46] Mathew Bills, EPA program manager for the Center fOr Environmental Management, personal communication, December 1984,

Of the first $2 million appropriated, six research projects were funded by the Center for $330,000. (The balance of the funds were spent on planning and setting up the Center.) One of these projects, investigating a new method for groundwater monitoring using laser fluorescence fiber optics, is relevant to the Superfund program. A proposal will be made by the Center in 1985 to use the remaining $1 million appropriation to set up a comprehensive research project dealing with an actual Superfund site, An investigation of innovative cleanup techniques and followup assessment of their effectiveness is expected to be part of this project.[47] This prospect has the potential to make a substantial contribution to the Superfund program,

Support for the Private Sector

Outside contracting by the EPA laboratories and program offices could be a source of support for private sector R&D efforts. The established contract procedures, however, apparently inhibit participation because they do not offer a mechanism for handling unsolicited *proposals* from the private sector, Thus, if a firm is seeking financial assistance for R&Don its particular technology, it must be able to mesh its requirements with those established by an EPA Request For Proposal.

From EPA's point of view, funding an unsolicited proposal constitutes single source procurement and EPA is loath to being viewed as supporting any particular firm or technology over another, This appears to be a critical barrier to the adoption of innovative technologies, EPA is the *buyer* of technologies under Superfund; yet if a technology has not been evaluated by them and testing methods declared acceptable, it will be eliminated from consideration during the FS process of evaluating a Superfund site, (The situation may not be much different for cleanups financed in other ways.) *Removing this barrier will require an active demonstration projects policy on the part of EPA.* Lately, EPA has made attempts to correct this situation and to devise ways to handle the large volume of unsolicited proposals that it receives.

[47] Cortese, personal communication, op. cit.

However, the amounts dedicated have been relatively minor and the decision process is slow,[48]

According to one EPA official,[49] demonstration projects to test commercially developed, new technologies under actual Superfund site conditions are hampered for three basic reasons: 1) EPA's existing R&D funding levels are not sufficient to cover the costs; 2) demonstration projects have required RCRA permits that are not obtainable without testing data the demonstration is intended to provide; so and 3) demonstrations conducted on Superfund sites can run against public sentiment, which wants cleanup activity to proceed quickly.[51]

The Land Pollution Control Division initiated a demonstration program in 1984 ($150,000 was offered for two solicitations), and starting in 1985 it will begin an annual program, In 1985, with a maximum budget of $750,000, three to ten projects will be selected and testing will be conducted to develop protocols. A set of demonstration projects are planned for 1985 and the next 5 years by the Releases Control Branch, They are seeking technologies for use in removal actions where short-term response and mobility are key criteria. The initial year's effort has a maximum budget of $250,000; the following years will be funded at about $400,000 per year. Not all of the monies will necessarily be spent, however. Actual spending levels will be determined by the quality and appropriateness of the solicitations.[52]

The programs will be run on a cost sharing basis with the selected technology firms. Each firm is expected to provide the complete hardware (late pilot or full scale), pay for the operation of tests, and obtain the necessary permits. EPA will help design the testing programs, provide quality assurance and quality control, and offer an independent evaluation of the results. Because of the potential high cost of this program to firms, only those firms with substantial financial resources will be able to participate. Accordingly, these demonstration programs are designed not to provide financial assistance, but to give firms access to appropriate testing materials and to result in recognized testing results that will enable them to market their technology.

In comparison to the above-mentioned funding levels for demonstration projects and indicative of the *real* **costs** involved, EPA is planning to spend approximately $3 million ($2 million from the Superfund budget and $1 million from R&D) in 1985 to run test burns at the Times Beach area in Missouri on its *own* mobile incinerators' Technology firms have told OTA that demonstration costs can range from several hundred thousand to a million dollars for one test burn.

Department of Defense

The Department of Defense has been given the authority to conduct all hazardous waste cleanups on military bases, and the Installation Restoration (IR) program has been set up to parallel EPA's Superfund program, Although the program has been in existence for about 7 years, only in the last 2 years has it received emphasis within DOD.

Under this program, the U.S. Air Force is taking the lead in R&D activity with a $12.1 million budget in fiscal year 1985 (an increase of **$10.8** million over 1984). Included are projects

[48]The Alternate Technology Division, for instance, soli Cited bids for "ideas" in 1983. out of 27 proposals received, 2 projects were selected and funded in the fall of 1984. The total budget for the program is $300,000 for processes considered to be at the demonstration stage. *One* demonstration project can easily cost a firm $500,000 or more.

[49]Hill, personal (communication, op.cit.

[50]Provisions in the RCRA legislation passed by the 98th Congress may reduce this barrier. Under Subtitle B, EPA is authorized to issue special RD&D permits for any hazardous waste treatment facility which proposes to use an innovative and experimental hazardous waste treatment technology or process for which permit standards have not been promulgated. One technology firm commented to OTA that, while they were extremely pleased to see this provision, they were worried that the vagueness of the wording would cause EPA to be extremely cautious in using it.

[51]To avoid this potential problem, two Land Pollution Control Division demonstration projects will proceed in 1985 in cooperation wit h the U. S Air Fore e on Federal la rids. I n Texas a microbial process will be tested on contaminated soils: and i n Wisconsin, EPA's mobile soils washer,

[52]Mary Stinson, EPA project officer, persona] communication, Dec. 13, 1984.

[5344] EPA to Conduct Dioxin Test Burns in Missouri," *Hazardous Wastes Report,* Jan, 7, 1985.

to develop technologies to clean contaminated groundwater. The U.S. Army will spend $2.7 million in fiscal year 1985 to develop treatment technologies for contaminated soil/sediment, water, and buildings; containment systems; and methods to recover energy and materials from hazardous waste. This program is projected into the 21st century.

National Science Foundation

NSF awarded a 5-year grant of $350,000 in October 1984 to set up the Industry/University Cooperative Research Center for Hazardous and Toxic Waste at the New Jersey Institute of Technology in Newark. In addition to NSF, the Center is sponsored by private industry (a dozen or so companies have paid an annual fee of $30,000 each) and academic institutions. It has also received a grant of $1.2 million from the State of New Jersey.

The goal of the Center is to help bridge the gap between governmental requirements and the needs of industry. Its research goal is to advance the state of engineering management of hazardous and toxic waste. According to its director, the Center has an annual budget of $2 million and has already solicited bids under specific research topics.[54] Included are a number of research projects relevant to Superfund technologies, such as the incineration, biological/chemical, and physical treatment of hazardous wastes. Many of the projects are planned to proceed to the pilot stage.

State Efforts

Efforts by individual States to assist in RD&D for Superfund technology are hampered by a lack of funding and a need to be able to prove that any monies spent are directly applicable to specific State problems. Their first priority is cleanup itself, and often funding for this purpose alone is difficult to appropriate. However, some States do offer support to RD&D and a few examples are presented below.

As the result of a comprehensive study of hazardous waste management in Illinois, in 1984 the State created a Hazardous Waste Center within the Illinois Department of Energy and Resources. It will be supported by the State hazardous waste tax and general revenue funds. The Center, which is to take a broad view of the hazardous waste problem from generation to cleanup needs, will focus on technology-based applied research and technology transfer.[55] The State of Pennsylvania has a similar program,

Missouri has turned part of its Times Beach dioxin-contaminated area into a research facility, The objectives are: 1) to identify those technologies that have potential to detoxify dioxin-contaminated material; and 2) to compare different, successful technologies for their ability to solve the State's extensive problem with dioxin-contaminated soils. Plots of contaminated soils are made available to firms to test their techniques, and some of the infrastructure (e. g., water and power connections) is provided. The cost for leasing a plot is a one-time fee of $16,500 and is meant to cover the cost of the State's sampling and analysis program,

New York has underway a project to assist in the development and demonstration of a plasma arc technology for use at Love Canal to treat organic sludges. The project is now budgeted at $1.5 million and while EPA is contributing to the cost, the State's share is over 50 percent.

Private Sector

As the previous "Innovative Technology" section shows, a wealth of new technology ideas is being generated by the private sector. Two fundamental problems are faced by this group, however, in moving these technologies along the long path toward commercialization: 1) an initial difficulty in obtaining seed money to continue the R&D process beyond the first few tentative steps; and 2) overcoming the barriers to the adoption of these technologies, primarily through the ability to demonstrate their worth, These, and other barriers have been discussed above and in a previous section of this chapter,

[54] John W. Liskowitz, personal communication, Dec. 12, 1984.

[55] James Patterson, Chairman, Pritzker Department of Environmental Engineering, Illinois Institute of Technology, personal communication, Dec. 18, 1984.