and 5 both carry the gene. After further experimentation, Tan subsequently concluded that only chromosome 5 carries the structural gene; a genetic locus on chromosome 2 is involved in control of interferon production but is not the structural gene itself. Meanwhile, John Morser, working in Derrick Burke's laboratory at the University of Warwick in England, has obtained evidence that the gene for human fibroblast interferon is located on chromosome 9. Ruddle now says that the most recent results from his laboratory show that all three chromosomes carry a gene for fibroblast interferon. Geneticists consider it unusual for three separate chromosomes to carry exactly the same gene, although it would be less unusual if there were slight structural differences in the three genes.

Since there are three distinct types of interferon—leukocyte, fibroblast, and T or immune interferon—there is also the question of whether these are coded for by distinct structural genes. Alternatively, there may be only one interferon gene, with different cells having the capacity to produce different interferons by modifying either the mRNA or the protein whose sequences are specified by the common gene.

Sidney Pestka, of the Roche Institute of Molecular Biology, and Vilček have suggested that there are distinct structural genes, although they now concede that their experiment did not conclusively rule out the alternative possibility.

Pestka and Vilček prepared mRNA's from fibroblasts producing interferon and from an immature type of white blood cell that was producing leukocyte interferon. They injected the mRNA's separately into frog eggs. Eggs injected with the fibroblast messenger produced fibroblast interferon; eggs injected with the other messenger produced the leukocyte form.

The experiment rules out modification of the protein as the cause of the structural differences between the two types of interferon because the frog eggs would presumably produce the same alterations in the protein. But it does not rule out the possibility that the mRNA's underwent modification before they were isolated and injected into the eggs.

Modification of messengers is now thought to be an important feature of mammalian protein synthesis. But Pestka points out that they submitted their manuscript for publication in May 1977, just before the explosion of research on mammalian messenger processing documented the significance of the process. Thus, at the time, their conclusion that the mRNA's have different structures and are consequently the products of different structural genes for interferon seemed more clear-cut than it does now.

The original conclusion may still turn out to be correct, although Tamm points out that he and Sehgal have evidence suggesting that the mRNA for human fibroblast interferon is processed from a precursor roughly ten times larger than the final messenger, leaving a great deal of room for processing to produce alterations in the protein products.

The situation regarding the location of the genes needed for interferon's antiviral activity is somewhat clearer. At least one of them is located on chromosome 21, according to a number of investigators, including Tan and Ruddle. This chromosome may carry the gene for the interferon receptors known to be located on cell surfaces.

As interferon research now stands, the antiviral action of the agent is relatively well understood, but investigators are only beginning to tackle the mechanisms underlying its other effects. One important unanswered question concerns the relative roles of the three types of human interferons. They all act on viruses, cell reproduction, and the immune system, but their effects may vary in degree. Fibroblast interferon, for example, may not inhibit the division of a particular line of cells to the same extent that leukocyte interferon does.

Learning whether one interferon is more effective than another against a given tumor may help clinicians who are trying to determine whether the interferons will be useful agents for treating cancer. Interferon has not yet crossed the threshold to widespread clinical application, but the basic research now going on may give it a push in the right direction.—JEAN L. MARX

Burial Is Last Resort for Hazardous Wastes

Solidification may reduce leaching problem, but new rules, financial requirements may make disposal in landfills prohibitively expensive

Despite the many alternatives available for disposal of hazardous wastes, there are a great many materials that are too low in value to recycle, too difficult to degrade, too thick to inject into deep wells, and too contaminated with heavy metals and other nonflammable materials to incinerate. Some investigators consider these disposal methods to be volume reduction techniques because they leave a residue of hazardous materials. For most of these materials, the disposal option of last resort is burial in the ground. It's not the ideal solution, it's not necessarily even a good solution, but, realistically it's the only solution we now have. The problem then is to regulate landfills in such a manner that potential problems created by escape of toxic materials are minimized.

This is the last of four articles about the disposal of hazardous wastes.

The Environmental Protection Agency (EPA) has sponsored much research on the various facets of landfilling, such as engineering techniques, liners, covers, and gas generation. But if privately sponsored research is included, the greatest amount of effort has been devoted to the chemical solidification of wastes—the development of techniques to bind the wastes into a coherent mass before burial so that leaching of toxic materials by groundwater is minimized. Solidification is now used for only a very small percentage of hazardous wastes, but it promises to be one of the most important disposal techniques of the future. It also promises to be one of the most complex to evaluate. A recent survey by Robert B. Pojasek of Energy Resources Company Inc. of Cambridge found that at least 41 different companies and research

0036-8075/79/0622-1295$00.50/0

groups have developed proprietary processes for the solidification of wastes.*

Most of the processes for hazardous wastes are outgrowths of processes for solidification of low-level radioactive wastes; some processes, in fact, appear to be suitable for both. They can be broken down into four major categories: cement-based techniques; pozzolanic, or lime-based techniques; thermoplastic binders; and organic binders.

The cement-based or cementitious techniques are most common because they are generally the cheapest and easiest to use. They are effective primarily for inorganic wastes, and are particularly advantageous for wastes containing heavy metal ions. The high pH of the cement mixture tends to keep the metal ions in the form of insoluble hydroxide salts not unlike those found in the ores from which the metals were originally obtained. Many of the materials commonly present in wastes, such as asbestos, latex, metal filings, and plastic further strengthen the cement matrix, and proprietary additives are frequently used to further tie up troublesome contaminants. Organic materials in the wastes, however, generally weaken the cement.

Two of the better known cementitious processes are the Sealosafe process developed by Stablex Corporation, whose U.S. headquarters are in Radnor, Pennsylvania, and the Chemfix process, marketed by Chemfix Inc. of Kenner, Louisiana. Stablex operates two landfills in the English Midlands and one near London at which metal finishing and plating wastes from the automobile industry and some other materials are solidified before burial. The company hopes to open a 500,000-ton-per-year landfill in Groveland Township, northwest of Detroit, for disposal of wastes from automotive, chemical, and plating plants, but state and local officials are resisting because of fears that toxic substances might be leached from the solidified mass. Stablex says the cost of solidification by the Sealosafe process can vary from $5 to $500 per ton, depending on the nature of the waste.

The Chemfix process, in contrast, is most often used at the waste generator's facility for onsite fixation of sludge. A mixing unit and the additives are contained in a trailer that is driven to the plant. Sludges are pumped from holding lagoons, mixed with additives, and deposited in another holding lagoon or directly in a landfill and allowed to harden. In the first 7 years of commercial use of the process, the company says, more than 100 million gallons of wastes have been treated, including materials from the petrochemical, steel, electronics, and electric utility industries. The average cost of treatment is 3 to 4 cents per gallon.

The advantages and shortcomings of the cementitious techniques, like those of the other techniques, have been amply demonstrated in the nuclear waste industry, according to Douglas W. Thompson, Phillip G. Malone, and Larry W. Jones of the U.S. Army Engineer Waterways Experiment Station in Vicksburg, Mississippi, who have performed tests on many of the commercial processes. A major advantage is that wastes do not have to be dried before processing. The principal shortcoming is that low-strength cement-waste mixtures are often vulnerable to acidic leaching solutions. Other shortcomings include the need for expensive additives to treat many types of wastes and the added weight and bulk contributed by the cement. The cementitious solidified mass, like the products of other types of processes, is also vulnerable to freeze-thaw and wet-dry cycles in the environment. This should not be a problem, however, if the material is buried below the frost line.

The term "pozzolanic" comes from Pozzuoli, a city near Naples where volcanic silico-aluminate calcium ash has been mined since before the time of Christ. When mixed with lime and water, the ash forms a very hard material known as pozzolanic concrete. The most common materials used in place of the ash today are fly ash from electric power plants and cement kiln dust, which are themselves wastes. Proprietary additives are also used with the mixture to enhance strength and to limit the migration of contaminants.

As is the case for the cementitious processes, the additives for the pozzolanic processes are generally inexpensive and widely available, the equipment required for mixing is simple to operate, and the chemistry is relatively well known. The major shortcomings, Thompson says, are the increased weight and bulk, vulnerability to acidic leaching solutions, and difficulties associated with organic materials in the sludges.

The principal application of pozzolanic processes may be solidification of the sludges produced in removal of sulfur oxides from the exhaust gases of coal-fired power plants. Two companies that have processes for treatment of such wastes are Dravo Lime Company of Pittsburgh and IU Conversion Systems Inc. of Horsham, Pennsylvania. Dravo markets an additive called Calcilox that, when added to flue gas sludges, produces physically stable materials with the consistency of consolidated soils. The additive itself costs about $40 per ton, but its use with flue gas sludge, the company says, costs only about 40 cents per ton of coal burned. IU markets a process, called Poz-O-Tec, that converts flue gas sludge into a stable material that can be used in properly designed landfills, embankments, roads, parking lots, and the like. IU already has contracts with power plants that produce more than 22 million tons of sludge per year. Even so, such processes are still used for only a small portion of all flue gas sludges, since there are now no regulations requiring that they be stabilized.

Thermoplastic techniques use materials such as bitumen, asphalt, paraffin, and polyethylene that soften when heated, bind tightly to wastes, and solidify when cooled. Wastes must be dried before they are mixed with the hot thermoplastic material, and the resultant solid must frequently be placed in a steel drum or other container for structural support. These processes generally require relatively expensive equipment for heating and mixing the waste and the thermoplastic material; they also require skilled operators. Furthermore, since the binder accounts for one-third to one-half of the bulk of the finished product, the process is somewhat expensive.

A typical thermoplastic process is the volume reduction and solidification (VRS) process developed by the Werner & Pfleiderer Corporation of Waldwick, New Jersey. In the process, asphalt (or a similar binder) and wastes are passed through a specially designed heated screw extruder that mixes the two components thoroughly, then releases them into containers or a storage area for cooling. The VRS system, the company says, has been successfully tested in more than 2000 different applications in the chemical, plastics, food, and nuclear industries.

The principal advantage of the thermoplastic techniques is that the binders adhere exceptionally well to the incorporated wastes and are resistant to most aqueous solutions. The migration rates of contaminants are thus generally lower with thermoplastic processes than with any other technique. Among the shortcomings, Thompson says, are the flammability of thermoplastic materials, the need for great care in processing wastes that are volatile at low temperatures, and

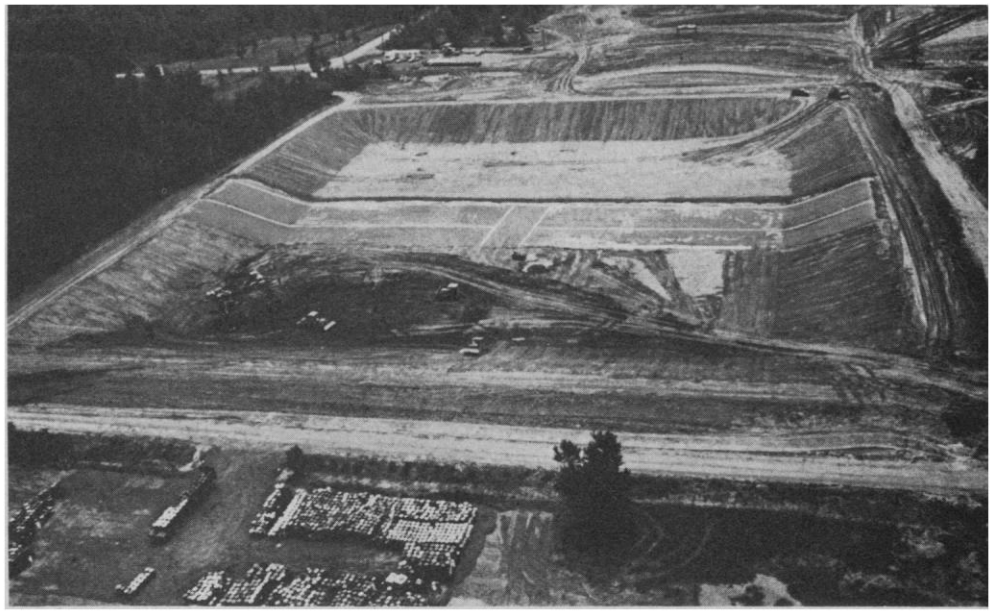
*For a review, see volumes 1 and 2 of the series *Toxic and Hazardous Waste Disposal*, edited by R. B. Pojasek, and published this year by Ann Arbor Science Publishers Inc.

the slow deterioration of the product that may be caused by organic solvents and some other organic materials. Thermoplastics thus seem to have promise primarily for extremely hazardous wastes, concentrated wastes, and radioactive wastes, where leaching or migration of the materials must be held to the absolute minimum.

The final class of processes involves organic polymers. In these processes, a small amount of monomer is mixed thoroughly with the wastes and a catalyst is added. As the polymer forms, typically, it does not combine chemically with the water, but forms a spongelike mass that traps solid particles while permitting much of the water to escape. The most common polymer technique is the urea-formaldehyde process, which was developed by the Teledyne Corporation of Louisville. Solidification with polyester resins has been studied by R. V. Subramanian and R. Mahalingam of Washington State University, and polyvinyl chloride has been studied by investigators at the Dow Chemical Company.

The primary advantages of the organic polymer techniques are that only small quantities of additives are required to solidify the wastes (often as low as 3 percent of the total weight), the techniques can be applied to either wet or dry sludges, and the finished waste-polymer mixture has a low density compared to the products of other solidification techniques. But if not enough resin is used, says Thompson, the polymer matrix does not trap all the wastes. The catalysts used in the urea-formaldehyde process, moreover, are strongly acidic; precipitated metal ions thus may redissolve and escape in water not trapped in the polymer matrix. Some organic polymers are biodegradable, and both urea-formaldehyde and polyesters are unstable in corrosive environments. Furthermore, the final product must generally be placed in a container before disposal.

Many of these problems can be overcome with a system developed by Hyman R. Lubowitz and his colleagues at TRW Systems in Redondo Beach, California. According to Robert Landreth of EPA, this system produces solids that show the least amount of leaching of any produced by other systems. Lubowitz uses polybutadiene as a binder to form wastes into cubes about 0.67 meter on edge. He then fuses onto the entire surface of the cube a layer of thermoplastic high-density polyethylene (HDPE) about 1 to 2 centimeters thick. HDPE is used to protect underground electrical cables and other equipment and has exceptional resistance to deterioration. Because the HDPE is fused onto the surface of the wastes with no seams, furthermore, it can withstand a great deal of stress, so that no other container is needed.



Lubowitz is also investigating a system for disposing of drums of chemicals—such as those that have been abandoned at various sites—in such a manner that they would not have to be opened and analyzed. The drums would be placed in a fiberglass cocoon big enough to accommodate warped or dented drums. A layer of HDPE would then be fused onto the surface. Tests at TRW have shown that such cocoons can withstand much more compression and stress than would be encountered in a disposal site and that they completely prevent leaching of the barrel's contents.

The principal disadvantages of the TRW system are the need for sophisticated and expensive equipment for the encapsulation process, and the cost. Lubowitz estimates that operation of a full-scale plant would cost about $91 per ton of dry waste; about 50 percent of that cost represents the purchase price of the resin, however, and Lubowitz thinks it should be possible to use a much less expensive grade of resin than that with which the experiments were conducted.

In general, say both Landreth and Thompson, solidification is a very good technique if it is used with proper constraints. The major problem with many of the processes is that they simply have not received enough testing under actual conditions in the field to determine their long-term resistance to deterioration and leaching, but such tests are now beginning at several locations. What has become clear so far, says Landreth, is that each process works on a different spectrum of materials. No company has a process that can handle everything, he says, but at least one process can be selected and tailored to handle anything. And if the solidified material is disposed of in a secure chemical landfill, then there should be virtually no problem with leaching.

The problem then is to make the landfill secure. Landfilling has long been the most common method for disposal of hazardous wastes because it has been inexpensive. Burial in a conventional sanitary landfill—which differs from a secured chemical landfill primarily in the degree of protection against leaching—costs between $3 and $8 per ton. Burial in an unsecured chemical landfill may have cost twice that much before the Resource Conservation and Recovery Act (RCRA) was passed. The costs were low because the technology was simple. Typically, a hole was dug in clay at a selected site, unconsolidated sludge and drums of chemicals were placed in it, and the hole was filled and covered with clay to keep out rain and other water. There are probably less than 30 commercial chemical landfills in operation around the country, but there is a large, unknown number of landfills at individual plant sites and probably tens of thousands that have already been closed. The vast majority of these are safe now and are likely to remain so in the future. The problem is the small number of sites that have inherent defects in construction or that are disturbed by man after their completion.

New regulations proposed by EPA under the provisions of RCRA are designed, in part, to assure safer construction of landfills. They would set specific standards for construction and operation of the site; they also would discourage use of landfills for liquid wastes, and would ban their use for certain volatile and flammable materials. More important, they would require monitoring of the completed landfill for an extended period to demonstrate that the site is sealed, and would establish standards for financial liability of the site's owner and operator for any incident resulting from the escape of the buried chemicals. Those regulations are not yet in force, but a good example of the type of operation that can be expected under them is the new landfill (illustrated in the accompanying photograph) operated at Model City, New York, by SCA Chemical Waste Services Inc. SCA's Peter Dunlap says this is the world's largest secured chemical landfill.

The landfill cell, 150 meters long and 150 meters wide, is excavated in dense clay and fitted with a liner of impervious, reinforced synthetics, which is then covered with a layer of about 1 meter of clay. Associated with the liner is a leachate collection system so that, in the rare event that water should enter the landfill, it could be pumped out and treated. The main landfill cell is divided by clay barriers into a number of subcells for specific types of hazardous wastes. Drums of PCB's and other chlorinated hydrocarbons might be kept in one subcell, for example, precipitated metal hydroxides in another, and organic sludges in a third. In this fashion, incompatible wastes are kept separated and the location of specific materials is known in case there should ever be a need to retrieve them. When it is filled with wastes, in about 12 to 18 months, the pit will be capped with another synthetic liner and a layer of clay, and another pit opened nearby.

SCA has six smaller landfills at the site that have already been closed. Surrounding and interspersed among them is a network of nearly 120 wells. Water from these is analyzed at regular intervals to ensure that there is no leakage from any of the sites. In accordance with the proposed EPA regulations, that monitoring is scheduled to be continued for at least 20 years after the last landfill at the site is closed. EPA's presumption is that if no leakage is detected during the operating life of the plant and for 20 years thereafter, the probability of a leak is small.

Several other companies operate similar landfills throughout the country, particularly in Texas, California, and Alabama. SCA itself has two smaller facilities at other sites and operated a third, the Earthline landfill at Wilsonville, Illinois, until it was shut down by a court order last year. The shutdown illustrates one of the major problems facing operators of landfills: citizen resistance. The court order closing Earthline was issued at the request of local citizen's groups who opposed the landfill; it was granted despite assurance to the court from both the federal EPA and the Illinois EPA that Earthline was necessary for disposal of wastes in that region, that it was operated responsibly, and that it posed no hazard to the community. That decision is being appealed to a higher court, but meanwhile, wastes that had been destined for Earthline are undoubtedly being buried in less secure facilities.

Dunlap contends that EPA should have presented a much more forceful argument to the court in favor of the landfill remaining open, and that it should take a much more active role in siting of future facilities. This view is echoed by some individuals within EPA and in the environmental community. Leslie Dachs of the Environmental Defense Fund, for example, concedes that a certain number of secure landfills will be required in the foreseeable future. He says that these should be organized on a regional basis and argues that EPA should take an active role to ensure that the best possible sites are chosen.

No company has a solidification process that can handle everything, but at least one process can be selected and tailored to handle anything.

EPA appears to be moving in that direction. One study now in progress for EPA is an analysis of the many cases in which permission to construct a landfill has been denied by courts and other agencies. If it can be determined what factors were most important in those decisions, EPA could be better prepared in future cases. EPA is also enlisting the help of such groups as the American Public Health Association, the Isaac Walton League, the League of Women Voters, the Environmental Action Foundation, the National Wildlife Federation, and the Technical Information Project to present programs of reassurance in communities where landfills might be located. It may also encourage state legislators to preempt local ordinances that might impede construction of landfills at appropriate sites.

The construction of SCA's Model City landfill cells has, in fact, been delayed by such ordinances. Ultimately, the New York State Supreme Court ruled that the state's Department of Environmental Conservation (DEC), which authorized the facility, has the power to preempt local laws. The court did, however, stipulate that SCA post a $100,000 bond to assure that the site would be restored to its natural condition if DEC did not issue an operating permit for the largest cell after its construction.

EPA's proposed regulations would, in effect, require posting of a much larger bond for all landfills. The proposals would require that anyone who operates a chemical landfill make a cash deposit large enough to guarantee that the site will be properly closed and monitored for 20 years. The rules would also require $5 million in insurance coverage for each site, half for "sudden and accidental occurrences" and half for "nonsudden and nonaccidental occurrences." This could be provided by a commercial policy or, more likely, through self-insurance.

If this regulation is enacted, industry sources argue, the cost will be enormous and it may very well doom the concept of onsite disposal of wastes. One example frequently cited by opponents of the proposal is the DuPont Company, which has about 88 plants in the United States. Assuming that the company disposes of hazardous wastes at only half of those sites, it would have to establish that it is self-insured for $220 million. This amount represents some 4.6 percent of the company's total equity, and such self-insurance would be very difficult for the company to achieve. "If DuPont doesn't have the resources to comply" with the proposed regulations, asks David Carroll of the Manufacturing Chemists Association, "how can anyone?"

As is so often the case, then, EPA is caught between a rock and a hard place—it must regulate the disposal of hazardous wastes, but it must do so without closing down American industry. The agency is now reviewing responses to its proposed RCRA regulations and may, in fact, modify some of them to make them a little more flexible. But no matter what changes are made, it seems clear that many small companies will be closing down their own disposal operations and shipping their wastes to commercial disposal firms. It is not clear what effect this will have on the chemical and allied industries, but the waste disposal industry, it would seem, should be prepared for a magnificent boom.

—THOMAS H. MAUGH II