Elevated, Concrete Buildings for Long-Term Management of Hazardous Wastes

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Large, permanent buildings that are constructed of prestressed concrete, can withstand hurricane-force wind loadings, and have extremely long lives can be used for long-term storage of hazardous wastes. The buildings protect against seepage of leachate into soils and ground waters, emissions of volatiles, and contact of wastes with precipitation. Materials stored within the buildings would be available when technology and economics make recycling feasible. Hazardous wastes would be stored almost 10 feet (3.05 m) above land surface in a building designed for sub-floor, walk-through inspections for leaks. The proposed buildings can be as large as 250 feet (76.2 m) on a side and 70 feet (21.3 m) high and can support 9,000 pounds (40,000 N) of waste loading per square foot (0.305 m) of floor area. Each building, which can be constructed at virtually any location, would hold enough hazardous wastes to provide millions of dollars of return from construction of each building.

INTRODUCTION

The Hazardous and Solid Waste Amendments of 1984 [*1*] to the Solid Waste Disposal Act [2] banned disposal of hazardous wastes to land unless such disposal were found to be protective of human health and the environment by the U.S. Environmental Protection Agency. The phrase ". . . protective of human health and the environment . . ." has resulted in substantial debate and disagreement over management of hazardous wastes. Safe management of hazardous wastes is requisite for a responsible industrialized society.

Large and small businesses, cities, states, and regions are all burdened to some extent by costs to manage hazardous wastes. Disposal is especially costly when hazardous wastes must be shipped great distances to landfills that are external to the area where the hazardous wastes were produced.

Proximity to an accessible, safe, well-managed hazardous-waste landfill can reduce costs of disposing hazardous wastes. Hydrogeologists and similar specialists recognize that there are few really "good" sites for hazardous-waste landfills. Good sites are generally found where there are excellent geologic conditions so that there is assurance of long-term containment of disposed wastes. Finding and evaluating a site is, in a litigious society, only a minor part of permitting a site for a hazardous-waste landfill.

Concerns regarding leaks and ultimate contamination of ground waters are warranted. Potential interactions of chemicals stored in landfills with synthetic liners and with geologic materials (for example, compacted soils) to produce leaks also concern investigators. Emissions of volatile compounds from materials stored in landfills and ultimate exposure of the proximate populace to the volatiles are recent concerns.

Regardless of the tremendous resistance to hazardous-waste landfills, such facilities are needed as the United States struggles to maintain its position in a competitive world. Though agreeing with objectives of recycling and waste minimization, professionals responsible for managing hazardous wastes recognize an immediate need for safe disposal of hazardous wastes until recycling and waste minimization can be implemented. Some professionals believe that there will not be new landfills for disposal of hazardous wastes without major changes in public attitudes. These professionals recognize the potential for shortfalls in capacities of facilities for treatment or disposal of hazardous wastes.

Above-ground, elevated permanent buildings are proposed for disposal of hazardous wastes. These buildings, which would be constructed of prestressed concrete, are economically and environmentally feasible. The buildings can provide protection against seepage of leachate into soils and ground waters, prevention of emissions of volatiles, and assurance of no contact of the wastes with precipitation. Materials stored within the buildings would be available when technology and economics make recycling feasible. Such buildings can be constructed at virtually any location and thereby provide for reasonable transportation distances and reduced costs. Such buildings will last for decades or centuries when maintained responsibly.

The greatest advantage in constructing and maintaining the buildings proposed herein is that hazardous wastes will be stored almost 10 feet (3.05 m) above the land surface and thereby preclude undetected leaks. Leaks will be readily detected because the building is designed for sub-floor, walk-through inspections. Such buildings, which can be as large as 250 feet (76.2 m) on a side, will hold enough hazardous wastes that millions of dollars of return can be realized on the investment in the construction of each building.

DESIGN CONSIDERATIONS

People generally do not trust what they cannot see. People particularly fear that components from accumulations of wastes will seep into the soil over which wastes are stored and flow onward to contaminate underground waters. Containment systems and monitoring systems around waste-disposal facilities represent considerable fractions of facility costs. Public concerns and costs make it desirable to prevent contact of wastes with the ground and to provide a demonstrable separation between the ground and wastes. One method of providing this separation is to store wastes on an upper floor in a reinforced concrete building so that an inspector can walk below the floor and inspect for any leakage.

The concept of above-ground storage of hazardous waste is not new. Lough, Gilbertson, and Riner [3] evaluated use of above ground facilities for storage of hazardous wastes for the Waste Management Board of Minnesota. They designed a facility for annual storage of 22,000 drums in a container building and 185,000 gallons in bulk-liquid tanks. The facility would require about 60 acres (243,000 square meters) for an assumed operating life of 10 years. Provisions were made in their design for offices and equipment, treatment of on-site wastewaters, water and sewer systems, and wells for the monitoring of groundwater. Assuming state ownership and no return on investment, the authors determined the price for storage of hazardous wastes at the facility to be about $1,100 per ton (907 kg).

Graybill [4] reported the potential for use of above-ground, on-site closures for containment of hazardous wastes. Such uses would incorporate civil-engineering concepts for design of above-ground, compacted, and formed shapes using solidified wastes. Waste sludges, for example, could be converted to materials having load-bearing capacities and soil-like consistencies that could be covered with compacted clay, topsoil, and grass which would protect the wastes from stormwater infiltration. A gravity-feed system for detection of leaks would be installed beneath solidified and compacted waste to warn of failure of the top liner. Because the structures would be above ground level, they provided easy access from the top or sides for remedial work.

Graybill also illustrated use of vaults in which wastes would be enclosed by liners at the top and bottom and be surrounded, in some instances, by reinforced concrete walls. Leachate collectors would be located beneath the wastes. Graybill illustrated a hillside adaptation of the vault concept. Costs ranged from $25 to $100 per cubic yard (0.765 cubic meters) depending on availability of on-site materials and characteristics of materials to be disposed.

Lough, Gilbertson, and Riner designed a facility specifically for storage of hazardous wastes for Minnesota. Graybill provided designs for construction of above-ground storage whereby wastes would become, in essence, a part of the structure. In contrast to their designs, the design proposed herein is for large concrete buildings that can be used to store hazardous wastes at virtually any location. The buildings are essentially secure, above-ground, inspectable, hazardous-waste landfills.

Experimental methods were not used for conceiving and designing a structure for disposal of hazardous wastes. Rather, the structure was designed after a set of building attributes appropriate for disposal of hazardous wastes were developed. The attributes were enumerated through consideration of the geotechnical difficulties in siting hazardous-waste landfills, public opposition to such landfills, risks involved in transporting hazardous wastes to distant landfills or incinerators, concerns over threats to underground waters, and concerns for emissions of volatiles from landfills.

From the above and related considerations, the authors selected specific attributes for the design of a system of modular, prestressed, concrete buildings that can be used for the continuing storage of hazardous wastes. The following attributes were selected for designing the building:

- Provide for storage of wastes on an elevated floor to provide for direct inspection for leaks and to separate wastes from soils
- Prevent leaks onto and into soil using a concrete slab that also spreads the loading of the building (onto the

supporting soils) so that geology and hydrology may be minimal concerns and thereby minimally restrict siting

- Provide for collection, analysis, treatment, and storage of any leachate—however miniscule—that might occur
- Provide for a structure of great strength that would withstand hurricane-force and reasonable tornadic-force wind loadings, contain large volumes of hazardous wastes, and have an extremely long life
- Provide a structure that could bear 150-pounds-per-cubic-foot (23,600 N/m^3) loadings through optimal spacing of exterior and interior support walls
- Provide for either bulk or containerized storage of hazardous wastes
- Provide for drains to accommodate rainfall from the roof of the structure
- Size the structure for volumetric equivalence to a very large pit (for example, 500 feet (152 m) by 500 feet (152 m) and as high as feasible) such as might be used in existing hazardous-waste landfills
- Provide for an almost air-tight structure through appropriate pouring and placement of concrete and through use of tight seams to join precast, concrete members
- Control miniscule leaks and production of volatiles by maintenance of slight negative pressure within the building with draft blowers followed by activated carbon filtration to collect volatile organics for return to the building.

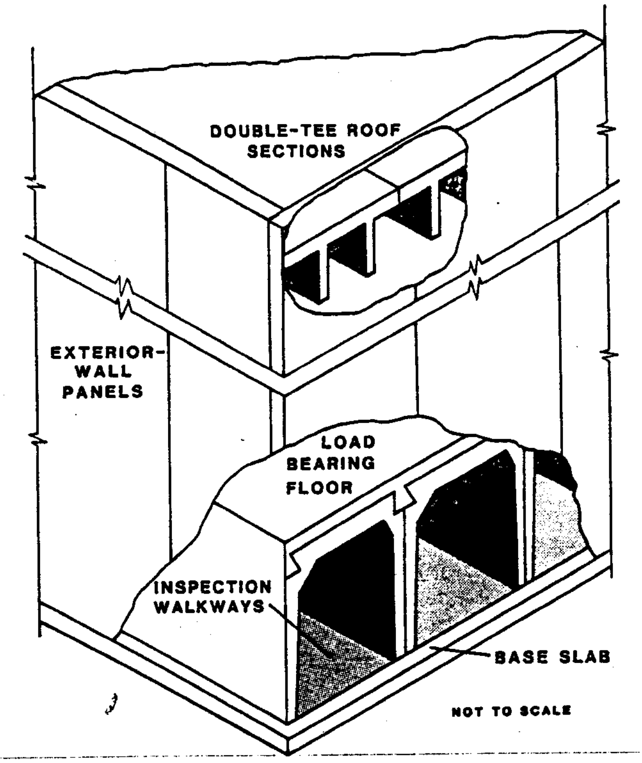

Figure 1. Sectional perspective of structure showing base slab, inspection walkways, and double-tee roof sections.

BUILDING DESIGN

The original concept was for a building that would be 500 feet (152 m) square. However, a maximal longitudinal dimension of 250 feet (76.2 m) was selected to accommodate thermal expansion and a maximal gross vertical dimension of 70 feet (21.3 m) was selected in response to the lateral loads exerted by 130-mile-per-hour (58.1-m/s), hurricane-force winds. Nominal, horizontal, module dimensions thus are 250 feet (76.2 m) square, and the 70-foot (21.3-m) overall height provides for a useful storage depth of 60 feet (18.3 m), the depth of the roofing system, and the depth necessary for walk-through inspection below the floor upon which the wastes are deposited. Further, the 250-foot-square (76.2-m-square) buildings can be constructed side to side and end to end thereby providing for a structure that is nominally 500 feet (152 m) square.

Figure 1 provides a cutaway, perspective view of the most salient features of the building. As can be seen, the structure provides for passages for walk-through inspections, a strong double-tee roof, interior support walls, an elevated floor for support and containment of hazardous wastes, and a poured-in-place, concrete slab that spreads the load of the building and contents on soils. The elevated construction and supporting concrete slab preclude undetected migration of leachate onto and into soils.

Figure 2 is a plan view of a single building (module) as it is related to a side by side and end to end configuration with three other modules that, for practical purposes, create a 500-foot-square (152-m-square) building. Also shown in this view are the planimetric relationships of the supporting walls of the walkways, the interior support walls, and the double-tee roof panels.

Figure 3 provides a cross-sectional view of the thickness, configuration, and orientation of the base slab, load-bearing floor, channel sections beneath the poured-in-place floor slab, and double-tee structural sections of the roof system. The floor upon which the wastes are placed is an 8-inch-thick (0.20-m-thick) slab that is poured in place with its surface sloped to floor drains, and the channel sections that support that floor are 8 inches (0.20 m) thick. The concrete floor could be sealed with epoxy or similar formulations or microsilica could be added to the concrete to maximize resistance to spilled chemicals. Trapped floor drains will allow visual inspection and easy sampling of any leachate from each drain and will be piped to a central point for appropriate treatment. Treat-

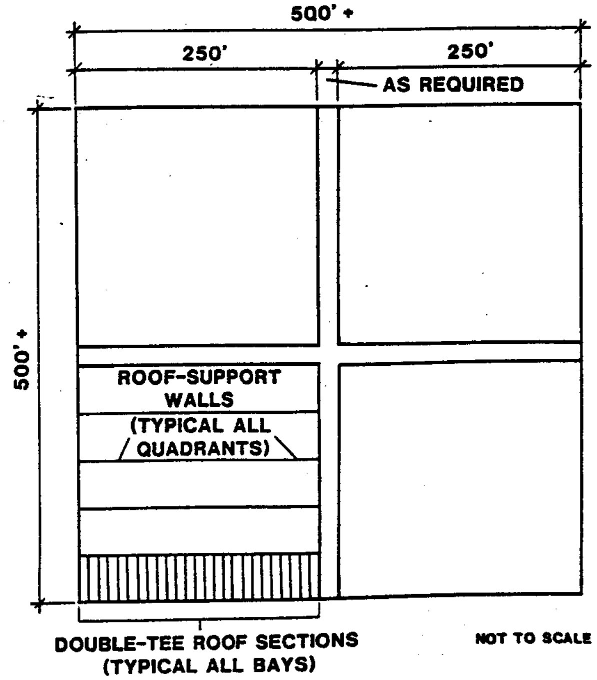

Figure 2. Roof framing plan for four adjacent buildings showing arrangements of roof panels and supporting walls.

ment of any leachate may include ion exchange, activated carbon sorption, and solidification for return to storage inside the building.

The foundation for the structure is a 12-inch thick (0.30-m-thick), post-tensioned, cast-in-place slab that is on grade. A continuous slab foundation will spread the structural loads onto consolidated soils or structural fills. In some locations, to satisfy specific building codes and on some foundation materials, additional enhancements of the foundation system such as piling support systems that are not a part of the system proposed herein may be necessary for the satisfactory performance of buildings like those herein proposed. The load- and floor-supporting, prestressed, channel sections and the exterior wall panels are placed and grouted onto the foundation slab.

A flat, membrane roof system with drains for storm runoff will be supported by prestressed, double-tee sections of nominal 50-foot (15.2-m) span. The double-tee sections will be supported by special prestressed panels that will be placed side by side to form load-bearing walls. Figure 4 provides a cross-sectional view of the size and configuration of the interior support walls. These walls and the roof double-tee sections serve as shear panels to furnish the reactions for prestressed, outside wall panels that are designed to sustain 130-mile-per-hour (58.1-m/s) wind loadings from hurricanes or tornadoes.

The walls, which would be 8 inches (0.20 m) thick, provide support for the roof while also providing for partitioning of wastes.

The subfloor, inspection walkways provide ample room for visual inspection of the floor that supports and contains the hazardous wastes. Support for the load-bearing, storage floor, which is designed to sustain a live loading of 150 pounds per cubic foot (23,600 N/m^3) of waste stored, is not a trivial structure. Precast channel sections were selected so that the legs of adjacent channels constitute load-bearing walls that support the storage floor, and the interior of the channels provide walk-through passageways for inspections.

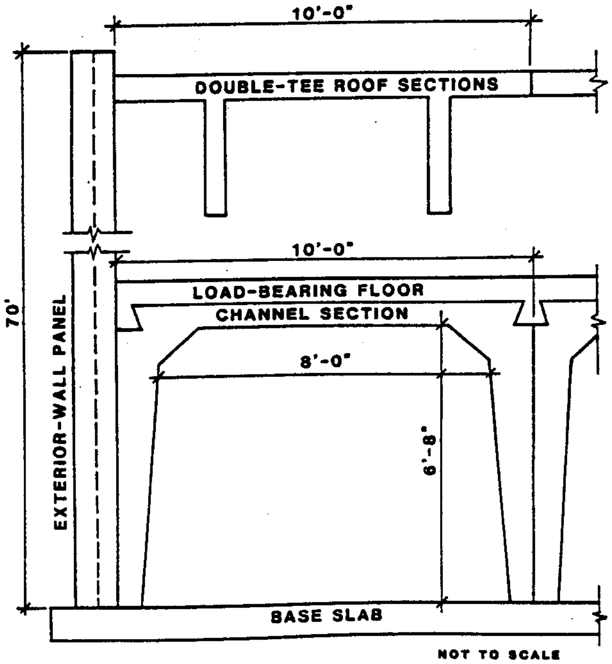

Figure 3. Elevation section showing base slab, floor-supporting channel sections, load bearing floor, and double-tee roof sections.

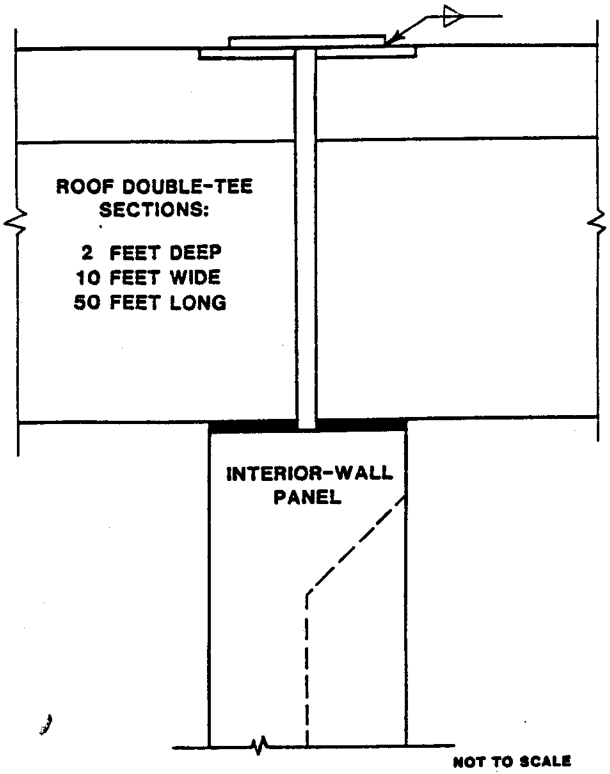

Figure 4. Detail section showing the bearing of roof double-tee sections upon the top of interior-wall panels.

DISCUSSION

Wastes that are stored in a building such as the one described above can be fixed or solidified to prevent migration of any appreciable amount of leachate. To further reduce the likelihood of migration, wastes would not be placed directly upon the poured-in-place concrete floor that will support them. Wastes would be deposited upon a layer of a porous material such as a geotextile or a pea gravel. Such a medium will allow flow of leachate to the trapped floor drains and piping for collection, inspection, analysis, treatment, and disposal. One possible treatment for leachate is solidification using some sorbent that would be returned to the building for storage.

Runoff will be piped from the roof away from any contact with the stored wastes. The roof, walls, and floor will combine to provide a tight system for confinement of wastes. Joints and seams are designed for maximizing the sealing of air within the structure and for adding structural strength to the building. As noted above, wastes could be stored in such a structure to a depth of about 60 feet (18.3 m). The design consideration that limits the depth of storage is the hurricane-wind loading on the exterior walls of the structure. The exterior wall panels are designed to withstand those external lateral loads but cannot withstand significant lateral loads from within the building. For this reason, wastes cannot be placed against the exterior walls unles they are in containers and stacked so that they will never exert appreciable lateral loads upon the exterior walls. Beyond this constraint, wastes generally could be deposited in bulk. Bulk waste can be placed directly against the load-bearing walls that support the double-tee sections of the roof. Placement against the opposite sides of a given wall must progress in a balanced manner so that large, unbalanced, lateral loadings will not be exerted against the interior walls.

The foundation slab provides for additional separation of disposed wastes from soils and groundwater. The slab further provides for a spreading of the load of the building and its contents so that geotechnical constraints are minimized. Geology and hydrology are less restrictive factors as compared to siting of hazardous-waste landfills. However, structures should not be built over sinkholes nor over highly compressible soils that would allow large differential settlements.

Security that can be provided with the storage of wastes in such a structure is economical, and its degree is both predictable and high. The strength of the structure and its foundation protect against natural forces. Provisions for leachate collection, treatment, and disposal; visual inspectability of the bottom of the containment systems; and provisions for collection and removal of runoff from the roof will prevent contamination of soils or ground water. The maintenance of sub-atmospheric pressure in the building and the treatment of discharged gas over activated carbon prevent atmospheric contamination. Physical security against vandalism and terrorism will be promoted by the neat physical boundaries of the facility and the susceptibility of such a system to effective video monitoring of building and fencing boundaries.

Disposal of wastes in perpetual-storage buildings of the sort that are described herein has many favorable attributes. The first attribute is that the facility will be profitable for those that provide such a service. For many, the varied assurances of safety of the system will be even more important than the attractive economics. The collection and removal of all storm water and the collection, monitoring, treatment, and satisfactory disposal of any leachate from the wastes preclude contamination of soils, groundwater, or surfacewater. The ability to walk beneath the stored material further guarantees that no water pollution will result from the storage of the waste.

Air pollution would be avoided by the system of durable and tight building components, the trapped floor drains, and maintenance of a slight negative pressure within the building. A blower can be used to maintain the building interior at a small negative pressure. Discharge from the blower would pass through an activated-carbon, sorption system to trap volatile organics. The sorbed organics could be incinerated or disposed inside the building. The air-handling system provides for removal of organic constituents from the air so that none escape and cause air pollution.

Control of volatiles and leachate reduce the likelihood of chemical reactions among the disposed wastes. Such reactions are further precluded if wastes are segregated within the compartments created by the walls that support the roof. The compartments can be specially equipped to accommodate wastes that might react with the concrete floor or other physical components within the structure. Compartmentalization of wastes also provides a means for maintaining an inventory of wastes for future recovery of raw materials. Such an inventory also would provide for research inspections to determine effects of wastes on containers, liners, or sorbents.

With a working storage depth of 60 feet (18.3 m), each square foot (0.305 m) of floor area can store about 2.2 cubic yards (1.68 m^3). At a ratio of 2 cubic yards (1.53 m^3) per square foot (0.305 m) of floor area, a 250-foot-square (76.2-m-square) module can be expected to store about an eighth of a million cubic yards (96,000 m^3) of waste. At a construction cost of about 90 dollars per square foot (0.305 m), that cost represents approximately 45 dollars per cubic yard (0.76 m^3) of stored waste. Currently, average cost for disposal of wastes in a hazardous-waste landfill is about 100 dollars per ton (907 kg). Although ratios for converting tons to cubic yards vary, a conservative estimate of one ton (907 kg) per cubic yard (0.765 m^3) can be used. This produces a gross profit of 55 dollars per ton (907 kg) of waste disposed in the proposed buildings. Thus, each 250-foot-square (76.2-m-square) building could provide for greater than six million dollars of income above the direct costs for construction of a building. Because disposal can be local, the transportation costs associated with other methods of disposal improve the attractiveness of the proposed method.

SUMMARY

The 250-foot-square (76.2-m-square) building proposed herein satisfies the required attributes deemed necessary by the authors for safe, long-term disposal of hazardous wastes. Each building constitutes a module that can be placed at the ends or sides of similar buildings to maximize storage capacity. Wastes can be stored on elevated floors to separate wastes from soils. Additional separation from soils is provided by the slab foundation, which spreads the loading of the building onto the supporting soils and reduces geotechnical and hydrogeologic constraints on siting. Leachate from the building can be collected, analyzed, and treated, and the residue can be retained in the building, if necessary. Undetected leaks of leachate are virtually impossible because of the inspection passages beneath the floor upon which wastes would be stored. The building is a structure of great structural integrity that can withstand hurricane-force winds, support 9,000 pounds (40,000 N) of waste loading per square foot (0.305 m) of floor area, and store either bulk or containerized wastes.

The structural redundances provided by the post-tensioned, foundation slab, the prestressed and grouted, floor-support channels, and the prestressed, load-bearing wall panels that will be laterally supported by wastes together provide a structural system that will be immune to the vast majority of natural damages.

The dependable, functional lives of the system components are extremely long. While an infinite period of utility can not be claimed for the components, they will be serviceable after the failure of many of the components of systems in which wastes are now being disposed. As the nation continues to use convenient raw materials, it may find that the contents of the proposed waste-disposal facilities will represent an economically attractive source of raw materials in the future.

The buildings provide an extremely secure system for waste disposal. The system is not fool-proof. A thoughtless operator could allow creation of an explosive mixture in the atmosphere of the building during the storage operations. A careful operator can just as predictably prevent such an occurrence through care in the storage operations and in the careful practice of ventilation during placement.

The building is practically air tight and provides for control of miniscule leaks of volatiles through use of a system to maintain a slight negative pressure and to capture volatile organics for incineration or storage in the building.

The building provides for an environmentally safe yet economically feasible method for disposal of hazardous wastes. Interpretation of gross economic estimates indicate that, at current average prices for disposal in hazardous-waste landfills, each building could provide a substantial profit to an operator.

A most significant use for the buildings proposed herein may be for disposal of ash from municipal, solid-waste incinerators. Such buildings could substitute for monofills, which are being considered for management of ash from municipal incinerators. Because geology need not so stringently control the location of the buildings as it does the locations of underground depositions, the buildings can be located for ease of use and convenience and safety of transportation of wastes. Each state can have a building. Each city can have a building. The buildings can be located to minimize exposure of the public to wastes. A building could reasonably be located in or adjacent to an industrial park. The exteriors of the structures are strong, constitute a well-defined boundary between the waste and the rest of the world, and can be treated architecturally to harmonize well with other industrial buildings. Consequently, the amounts of land needed for the buildings are not greatly in excess of the useful storage areas that they provide.

The accessibility and safety of such buildings provides for many alternatives for management of hazardous wastes. For example, wastes can be segregated and their locations recorded. Maintenance of such records provides for recovery of raw materials and for research regarding effects of wastes on liners, containers, or sorbents, or research on other aspects of managing hazardous wastes. Wastes within the buildings also could be recovered for incineration, recycling, or other treatment as capacity or technology develops. Schedules could be developed for use of available mobile incinerators or processes to destroy or treat certain wastes as such processes become available.

The adoption of the subject proposal is likely to require regulatory changes; almost every other anthropogenic or natural action does. If the modules are treated as units for extended storage of future raw materials, they may be perceived to be exempt from consideration under current law for the regulation of the disposal of wastes. Whether society decides that such facilities require regulation, the proposed system provides for the concerns of those whose interest is safety. A most likely concern for regulation may be that which considers the long-term continuity of the operators of such systems.

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LITERATURE CITED

1. U.S. Congress. *The Hazardous and Solid Waste Amendments of 1984.* 98th Cong., 2d sess., Public Law 98-616, Nov. 8, 1984, 98 Stat. 3221. Washington, D.C.: U.S. Government Printing Office.
2. U.S. Congress. *Solid Waste Disposal Act.* 89th Cong., 1st sess., Public Law 89-272, Oct. 20, 1965, 79 Stat. 997. Washington, D.C.: U.S. Government Printing Office.
3. Lough, C. J., M. A. Gilbertson, and S. D. Riner, "Above Ground Storage of Hazardous Waste," *Proc. of the National Conference on the Management of Uncontrolled Hazardous Waste Sites*, HMCRI, Washington, D.C., 228 (1982).
4. Graybill, L., "Evolution of Practical On Site Above Ground Closures," *Proc. of the National Conference on the Management of Uncontrolled Hazardous Waste Sites*, HMCRI, Washington, D.C. 275 (1983).

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SPECIAL ISSUE: FOURTH PENN WORKSHOP ON LITTER MANAGEMENT AND RECYCLING

Under the sponsorship of Industry Affairs of Anheuser-Busch Companies the Chair on Resource Management and Technology at the University of Pennsylvania organizes the Penn Workshop series on Litter Management and Recycling.

The purpose of workshops is to bring together a small number of interested individuals from industry, government, and academe to examine various litter measurement techniques, recycling activities, current control programs, and social-behavioral aspects of control. The objective of the Workshop is to develop an understanding of litter and recycling problems and opportunities. Attendance is by invitation.

The First Penn Workshop was convened in Philadelphia on April 22–24, 1985 and papers presented were published in the special issue of the Journal of Resource Management and Technology, Volume 14, Number 2, October 1985. Papers presented at the Second Penn Workshop were published in the special issue, Volume 15, Number 2, December 1986. Papers presented at the Third Penn Workshop were published in the special issue, Volume 16, Number 2, 1988. This issue contains papers presented at the Fourth Penn Workshop and includes a few papers from the Fourth International Conference on Urban Solid Waste Management and Secondary Materials which we deemed important.

We are grateful to Industry Affairs of Anheuser-Busch Companies, Inc. for their support in making these workshops possible.