CONF-850314--10

GREATER CONFINEMENT DISPOSAL OF RADIOACTIVE WASTES

by

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CONF-850314--10

DE85 007941

ABSTRACT

Low-level radioactive waste (LLW) includes a broad spectrum of different radionuclide concentrations, half-lives, and hazards. Standard shallow-land burial practice can provide adequate protection of public health and safety for most LLW. A small volume fraction (~1%) containing most of the activity inventory (~90%) requires specific measures known as "greater-confinement disposal" (GCD). Different site characteristics and different waste characteristics--such as high radionuclide concentrations, long radionuclide half-lives, high radionuclide mobility, and physical or chemical characteristics that present exceptional hazards--lead to different GCD facility design requirements. Facility design alternatives considered for GCD include the augered shaft, deep trench, engineered structure, hydrofracture, improved waste form, and high-integrity container. Selection of an appropriate design must also consider the interplay between basic risk limits for protection of public health and safety, performance characteristics and objectives, costs, waste-acceptance criteria, waste characteristics, and site characteristics.

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INTRODUCTION

Non-high-level radioactive wastes include a broad spectrum of wastes that have different radionuclide concentrations, half-lives, and hazard potentials. These wastes range from low-level wastes (LLW) to wastes containing naturally occurring radionuclides to mixed wastes containing both radioactive and chemical contaminants. Standard shallow-land burial (SLB) and other near-surface stabilization methods are most commonly used for disposal of these wastes. In a typical SLB facility, the waste is buried in shallow trenches, about 8 meters in depth. Wastes containing long-lived, naturally occurring radioisotopes have, in many cases, been temporarily stabilized by simple means such as confinement in pits or covering with soil.

A small fraction of LLW from both DOE and commercial sources contains radionuclides in sufficiently high concentrations or with sufficiently long half-lives to require greater-confinement disposal (GCD), defined as "a technique for disposal of waste that uses natural and/or engineered barriers which provide a degree of isolation greater than that of shallow land burial but possibly less than that of a geologic repository" (DOE Order 5820.2).

In anticipation of the need for new land disposal facilities to better accommodate low-level radioactive waste (LLW) generated by DOE/defense and commercial activities, a Low-Level Waste Management Program was established within the U.S. Department of Energy in September 1978 to initiate and coordinate research and development activities for safe and cost-effective means for disposal of low-level waste. The types of wastes that are being considered for greater-confinement disposal include: (1) low-level wastes whose radioactivity consists mainly of short-lived radionuclides--e.g., some of the wastes generated by DOE and other government agencies as a result of defense activities, uranium-enrichment operations, and research and development activities as well as some of the wastes generated in commercial activities such as nuclear power production, manufacturing, medical applications, and research, (2) wastes containing naturally occurring radionuclides--e.g., the mill tailings or the raffinates, equipment, contaminated soils, and decommissioning rubble residing at sites that have been used for processing or storage of uranium and thorium ores and compounds, and (3) wastes co-contaminated with chemicals--e.g., those wastes containing hazardous chemicals or chemicals that increase the mobility of the radionuclides.

The major reason that greater-confinement disposal is being considered for these wastes is the potentially unacceptable risks associated with releases to the environment and with human intrusion into the wastes if government control of the disposal site ceases in the future. The reasons for cessation of control can range from loss of funds to catastrophic events.

The methods for greater confinement can be grouped according to modifications to the disposal cell or modifications to the waste or its packaging. (The term "cell" is a general term indicating an individual hole, trench, shaft, or structure in which wastes are emplaced for disposal.) Modifications to the disposal cell include: augered shaft, deep trench, and engineered structure. The special disposal technique of hydrofracture is also being considered as an example of greater confinement. Modifications to the waste and packaging are commonly referred to as improved waste form and the high-integrity container (HIC).

This paper presents an overview of the factors that must be considered in planning the application of the methods proposed for providing greater confinement.

WASTE CHARACTERISTICS

The expected characteristics of wastes--especially their radiological, chemical, and physical properties--will be the most important determinants not only of whether GCD is required but also of which GCD technique will be applicable for a given disposal site. The concentration of radionuclides in LLW will be the primary index of whether it must be managed by GCD techniques. For commercial wastes, it is expected that any wastes exceeding the Class C radioactivity concentrations defined by 10 CFR 61 would require management by GCD, but site-specific criteria may require that wastes of concentrations lower than the limits of 10 CFR 61 be treated by GCD. For example, at the Savannah River Plant (SRP), some wastes that do not exceed concentrations corresponding to the limits of Classes C, B, or even A are managed by GCD techniques.

Our knowledge of the characteristics, volumes, and properties of the wastes in the United States that will require disposal is continually being improved by several waste inventory systems (Notz 1982). The annual review by DOE (U.S. Dept. Energy 1984c) also presents information on U.S. waste inventories that will aid decisions on which wastes are likely to require GCD. Current estimates indicate that about 1% or 1,600 m^3/yr (2,100 yd^3/yr) of all LLW may require this special treatment (Gilbert and Luner 1984; U.S. Dept.

Energy 1984c). In addition, a total of 2.3×10^7 m^3 (3×10^7 yd^3) of materials contaminated with long-lived, naturally occurring radioistopes awaits permanent disposal.

REGULATIONS

Regulations specifically for management of GCD wastes have not been expressed in detail, but general guidelines are given in DOE Order 5820.2, 10 CFR 61 (NRC), and the criteria, rules, and laws being developed in the formation of state compacts. The policies of DOE Order 5820.2, Chapter III, that apply to wastes generated at DOE-controlled sites give general guidelines for the waste-acceptance criteria that must be developed by each DOE disposal site. The criteria of 10 CFR 61, which apply to commercial wastes, indicate the limits above which wastes require greater confinement than conventional SLB. Although the regulation of GCD has not been explicitly defined, at least the concentrations of radionuclides at the site boundaries of a facility are defined by the concentration limits of 10 CFR 20; DOE Order 5480.1A, Chapter XI; and the drinking water limits of 40 CFR 141. These represent goals for performance of GCD techniques. The 10 CFR 61 regulations indicate that more specific guidance for alternatives to near-surface disposal of LLW, e.g., 10 CFR 61.50(b) on site selection, will be developed. In addition to these regulations and criteria, plans for design and construction of a GCD facility may require an environmental evaluation in compliance with NEPA.

Each GCD alternative carries with it some waste-acceptance restrictions and thus imposes some restrictions on waste generators. Although the criteria for site selection for the application of HIC or improved waste form need not differ from those for SLB, the criteria for siting deep trench, engineered structures, augered holes, mined cavities, and hydrofracture will have additional criteria, some that are unique to each method.

PERFORMANCE ASSESSMENT

The importance of assessment of the technical performance of the disposal facility--before, during, and after the operational lifetime--are emphasized in 10 CFR 61 and DOE Order 5820.2. Performance assessment of a GCD system will likely be treated with equal importance. The performance of a disposal facility is customarily assessed against performance objectives. Although federal regulations (10 CFR 61, 10 CFR 20, and DOE Order 5480.1A) imply performance objectives and although each regional compact is expected to express its own set of objectives, the clearest current statement of performance objectives is presented in the basic rules of the International Commission on Radiological Protection (1977). The essence of these rules is that (1) risk to the public should be limited, and (2) risk to occupational workers should be limited. The basic dose limits are 500 mrem/yr for short-term exposure and 100 mrem/yr for lifetime exposure. The occupational limits are greater by a factor of 10. Decisions among design alternatives should be based on expected technical performance that will permit achievement of these performance objectives and also on the cost of achieving a given level of technical performance. Thus, ideally, the choice of disposal techniques should be made on the basis of benefit-cost-risk (BCR) analysis. The application of this type of assessment to GCD techniques has been described by Gilbert and Luner (1984).

Planners and waste generators anticipate that the cost of GCD will be greater than the cost of SLB. Some cost estimates for GCD designs have been made (Gilbert and Luner 1984). Although reliable values for some costs are unavailable, differences can be recognized in addition to an approximate order of total costs. Thus, costs are expected to increase in the order SLB < SLB with HIC < deep trench < augered shaft < engineered structure < improved waste form. If the alternatives could be compared on the same basis, then the cost of hydrofracture might fall between that of engineered structures and improved waste forms. As a general rule, cost comparisons for this set of technologies are made difficult by differences in geological requirements. The cost categories in which GCD is expected to differ significantly from SLB are labor, materials, post-operational stabilization, and purchase and replacement of equipment.

Although a BCR analysis can be mathematically expressed, the lack of parameters with which to obtain quantitative results has led to the proposal to make decisions among GCD alternatives by a two-part assessment method: (1) quantitative estimation of risk associated with a disposal method by modeling the migration of radionuclides from the disposal situation (pathway analysis), and (2) qualitative comparison of the attributes of alternative disposal techniques. The results of calculating the concentration of radionuclides at various distances in pathways leading from a disposal unit can be used to compare the risks associated with alternative designs. The qualitative comparison of technical performance can be based on an evaluation of the contribution to realizing the performance objectives that would be made by performance attributes such as the characteristics of the waste form, container, design of the disposal unit, emplacement procedures, and emplacement equipment. The assessment can be carried into further detail by determining which designs provide the even more basic elements that are ultimately responsible for those performance attributes: intrusion resistance, compressive strength, corrosion resistance, radiation stability, drainage control, infiltration resistance, leach resistance, biodegradation resistance, ion-exchange capacity, thermal stability, distance from surface, distance from hydrologic movement, permeation resistance, distance from radiation sources, minimum time of exposure to radiation sources, shielding, structural stability, and chemical inertness.

DISPOSAL CELL DESIGN ALTERNATIVES

A few disposal cell concepts have been considered to be practicable by several evaluations. These concepts are being catalogued in an overview of GCD, currently in preparation, that will be published as one of the DOE handbooks on management of LLW. These concepts include augered shaft, deep trench, and engineered structure.

Augered Shaft

Although relatively small, shallow boreholes have been used for waste disposal in the United States and other parts of the world, the augered shaft concept considered here is exemplified by the demonstrations at the Nevada Test Site (Reynolds Electr. Eng. Co. 1983) and at the Savannah River Plant (Towler et al. 1983). Advantages of the augered shaft, a hole in the ground with a diameter of 3 to 4 m and a depth of 10 to 35 m, include a geometry that shields operators from emplaced radioactivity; compatibility with remote-handling techniques; remoteness from plant and animal intrusion; easy closure, both temporary and final; and low susceptibility to erosion. A disadvantage of the augered shaft is the limited size of the waste items that would be acceptable to the typical diameters of the shafts.

Deep Trench

The deep trench disposal unit is an excavation that is deeper than the normal 8-m depth of the SLB trench; in it, the wastes would be surrounded, as in SLB, with soil material. The deep trench has not received much attention either in design or in use. One of the earliest references to the concept (Macbeth et al. 1979) suggested that it would be quite similar to an SLB unit except twice the depth of a conventional SLB. In addition to the advantage of placing wastes beyond the depth of penetration of roots and animals, the deep trench offers simplicity, flexibility in acceptance of waste types, and little vulnerability to erosion. The deep trench, however, requires a site that has an unusually thick layer of soil and unconsolidated materials over the water table. Furthermore, the wide opening required to excavate a deep trench, unless special shoring techniques are used, will involve a relatively large area and may restrict emplacement techniques to unloading a waste-carrying vehicle at the bottom of the trench.

Engineered Structure

The engineered structure is typically a disposal unit in which one of the most important barriers to intrusion and release of radionuclides is a chamber typically built of concrete. A large variety of designs have been described, involving placement of wastes both above and below grade level. These include the Canadian concrete-walled trench (Feraday 1982), the SRP concrete-shored trench (Towler et al. 1983), the French tumulus (Van Kote 1982), the NRC concrete-walled trench (U.S. Nucl. Reg. Comm. 1981), and the concrete chamber of the University of Arizona (Wacks 1981). The main advantages of engineered structures are their potential barriers to infiltration and intrusion. Structures that are initially roofed will also provide protection from the weather during emplacement operations. However, because concrete is prone to eventual cracking, the engineered structure eliminates neither infiltration of water nor release of leachate over the long term. Recently, a preference for engineered, above-grade disposal units has been expressed in planning of facilities that will be operated by state governments for disposal of low-level waste (U.S. Nucl. Reg. Comm. 1984). Above-grade structures have received considerable attention because they are perceived to offer advantages for protection from groundwater and also for ease of surveillance, maintenance, and remedial action.

HYDROFRACTURE

The configuration of the hydrofracture alternative consists of a stack, several hundred meters in diameter, of thin sheets of grout incorporating the wastes; the grout sheets are interleaved between shale layers, underground. This unique waste-emplacement configuration does not permit hydrofracture to be categorized as a disposal cell such as those discussed in the foregoing sections. Disposal by hydrofracture (mixing wastes in liquid or slurry form with cement and injecting the mixture into horizontal fractures in rock formations located several hundreds of meters below the earth's surface) has been practiced successfully over a period of many years at ORNL (Weeren et al. 1982). The advantages of hydrofracture include a high degree of isolation from the environment and from intruders; it makes little claim on surface land above the disposal zone, and is relatively insensitive to weather during emplacement and to erosion after emplacement. The disadvantages of hydrofracture include applicability only to wastes in liquid or slurry forms or to wastes that can be converted to such forms, the possible stimulation of minor seismic effects, and the requirement that the disposal site have special geologic characteristics.

IMPROVED WASTE FORMS

Whereas the GCD technologies described in the foregoing sections have emphasized confinement by geologic media, the concept of improved waste form emphasizes the capability of confinement derived from the physical and chemical properties of the waste forms. Among the advantages of use of improved waste forms is their potential for use in an ordinary SLB trench to provide GCD. Also, they provide some attenuation of penetrating radiation, are independent of site characteristics, permit retrievability in case of need for remedial actions, limit dispersion in case of accidents, and reduce migration of radionuclides caused by leaching. Improved waste forms are generally solid media into which primary waste forms are incorporated. Among the disadvantages of improved waste forms is the involvement with chemical processing equipment, with the attendant needs for maintenance, decommissioning of contaminated equipment, and costs. Some solidification agents are unable to completely incorporate all waste forms, particularly oils and organic liquids. The solidification agents used to produce improved waste forms can be grouped into four types: cement, organic solids, synthetic minerals, and glass (Fuhrmann et al. 1981; Tucker et al. 1983). Cement is the most commonly used solidification agent in management of radioactive LLW. Additives such as organic polymers, silicates, and gypsum improve the mechanical properties and leach resistance of cement, but add some chemical-processing complications. Several organic solidification agents have been investigated and used to varying degrees in actual practice: urea-formaldehyde, once widely used, has now been rejected, mainly because of its release of contaminated water; bitumen, used frequently in Europe, but infrequently in the United States, still seems acceptable for some applications; epoxy resins are offered in commercial waste-solidification systems; and a vinyl ester-styrene process is available in another commercial solidification system. Although glass waste forms have been developed mainly with the intention of application to high-level waste, their application to other wastes also seems feasible according to a recent evaluation (Armstrong and Klinger 1984).

HIGH-INTEGRITY CONTAINERS

Another GCD technique that relies on factors other than those of geologic media to provide confinement is the high-integrity container (HIC). Its confinement capabilities are based on its design and on the physical and chemical properties of the material from which it is fabricated. A high-integrity container is a vessel that is intended to provide structural stability and containment of radionuclides for a long period; characteristics of the HIC have been more specifically defined in criteria formulated by regulatory bodies such as the NRC and the state of South Carolina (Ensminger and Kaplan 1983--App. B). Designs of containers intended to meet criteria for

HICs have been developed by several organizations. The favored materials of construction are polyethylene and concrete. Sizes vary from 55-gal cans to large units that can be handled only by powered cranes. In many cases, emplacement of an HIC in an ordinary SLB trench should provide the security required for GCD without the cost or trouble of constructing any more sophisticated disposal unit. Probably the most serious disadvantage of the HIC is its inability to accept large items, e.g., those that may occur occasionally as a result of decommissioning activities such as vehicles, cranes, processing equipment, and rubble from the demolition of buildings.

LONG-LIVED WASTES

Because the radioactive constituents of long-lived wastes--raffinates, tailings, rubble, and contaminated soil material--are mostly isotopes of uranium and thorium with their daughters, a major concern is control of radon release. Thus, a diffusion barrier that slows the escape of radon to permit most of it to decay before reaching the atmosphere--consisting of a medium of low permeability, e.g., clay--is common to most designs of disposal units for this type of waste. Such a barrier can do triple duty if it also has the capacities to slow the migration of ionic radionuclides, as some clays do, and to resist the infiltration of water. Designs for these disposal units place the wastes either above or below the earth's surface. Design criteria for such disposal units include multilayered caps of natural materials that provide--with little maintenance--drainage, physical stability, erosion resistance, and intrusion resistance. Examples of the latest designs for such units are given in plans for handling residues at West Chicago (U.S. Nucl. Reg. Comm. 1983), Weldon Spring (U.S. Dept. Energy 1984a), Niagara Falls

(U.S. Dept. Energy 1984b), and Cannonsburg, Pennsylvania (U.S. Dept. Energy 1983). More recently, however, groups concerned with safe disposal of wastes are demanding that design elements similar to those of engineered structures, including man-made materials for drainage and resistance to water infiltration, be evaluated for these types of wastes. For greater confinement of this type of waste, the augered shaft technology might be useful. This type of disposal unit, however, would not satisfy the citizen action groups and state planners who are expressing preferences for above-grade disposal of wastes.

CONCLUSION

The need for disposal technology offering greater confinement than SLB arises not only from the existence of wastes exceeding the regulatory limits for SLB, but also from individual policies of organizations and demands of concerned citizens. The number and variety of technologies judged capable of providing greater confinement than SLB have been expanded. Several of them that have been perceived to be technically feasible and applicable to the types of wastes for which greater confinement is being demanded have been briefly described and evaluated here. Applicability of any one of these techniques to an individual disposal problem will depend on the characteristics of the wastes and the disposal site. It is expected that not only the selection of the technology to be applied but also the need for GCD will have to be established on a case-specific basis.

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