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GREATER-CONFINEMENT DISPOSAL OF LOW-LEVEL RADIOACTIVE WASTES

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ABSTRACT

Low-level radioactive wastes include a broad spectrum of wastes that have different radionuclide concentrations, half-lives, and physical and chemical properties. Standard shallow-land burial practice can provide adequate protection of public health and safety for most low-level wastes, but 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. This paper presents an overview of the factors that must be considered in planning the application of methods proposed for providing greater confinement of low-level wastes.

INTRODUCTION

Low-level radioactive wastes include a broad spectrum of wastes that have different radionuclide concentrations, half-lives, and physical and chemical properties. These wastes range from 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 low-level wastes from both U.S. Department of Energy (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 wastes generated by DOE/defense and commercial activities, a Low-Level Waste Management Program was established within DOE to initiate and coordinate research and development activities for safe and cost-effective means for disposal of low-level wastes. The types of wastes that are being considered for GCD include: (1) wastes with high concentrations of short-lived radionuclides; (2) wastes with long-lived radionuclides; and (3) wastes co-contaminated with hazardous chemicals or chemicals that increase the mobility of radionuclides.

Wastes of the first type include some of the wastes generated by DOE and other government agencies as a result of defense activities, uranium-enrichment activities, 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. Wastes of the second type are largely those containing *naturally occurring radionuclides--e.g.*, mill tailings or raffinates, equipment, contaminated soils, and decommissioning rubble that remain at sites that were used for processing or storage of uranium and thorium ores and compounds.

The major reason that GCD is being considered for these types of 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 sites were to cease in the future. Possible reasons for cessation of control are loss of funds and catastrophic events.

The methods for greater confinement can be grouped according to modifications to the disposal cell or modifications to the wastes or 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 wastes and packaging are commonly referred to as improved waste form and high-integrity container (HIC), respectively.

PURPOSE

The purpose is to present an overview of the factors that must be considered in planning the application of methods proposed for providing greater confinement of low-level wastes, to present methods for evaluating existing and conceptual disposal units that would provide greater confinement of low-level wastes, and to review the characteristics of a limited set of designs that have emerged from these several efforts as the most promising for providing the confinement that may be required for these waste types.

APPROACH

The characteristics and expected volumes of wastes that might require greater confinement were derived from data bases that have been collected by DOE contractors. In general, these wastes could not be disposed by technologies referred to in 10 CFR 61 regulations. Greater confinement for even larger volumes than these is being requested by some citizen groups despite the fact that the characteristics of the wastes might permit less sophisticated and less costly disposal technologies. Current regulations on low-level wastes are purposefully not prescriptive with respect to technology; however, they do refer to SLB but not to any of the designs discussed here. Criteria expressed by the International Commission on Radiological Protection (9) are used in this work as minimum indications of the performance objectives that greater confinement must achieve. The possibility is explored of expressing performance assessment, i.e., analysis of the behavior of the technology and its compliance with performance objectives, in terms of risk analysis. The role of cost and benefit in selection of disposal technology by potential operators is also considered. Several design options were selected for this assessment, and these options are examined to identify the basic elements in each option that will support the performance objectives. The advantages and disadvantages associated with each option are also discussed.

PROBLEMS ENCOUNTERED

One problem encountered in this work was the brevity of information available for some disposal unit concepts, especially the engineered structures. The expected performance of some disposal unit alternatives was difficult to evaluate because of the incomplete state of development of some of the concepts. Regulations on low-level waste disposal such as 10 CFR 61 and DOE Order 5820.2 are not restricted to SLB; for example, the U.S. Nuclear Regulatory Commission (NRC) maintains that it could assess the licensability of alternative disposal units by the 10 CFR 61 guidelines. Nevertheless, these regulations--although only recently finalized--were developed before the even more recent surge of interest in alternatives to SLB.

Performance assessment of GCD by the methods of risk analysis and cost-benefit criteria could not be carried to the point of quantitative results because of the lack of parameters needed as input to the calculations.

RESULTS

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 the low-level wastes will be the primary index of whether they 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 will require management by GCD, but site-specific criteria may also require that wastes of concentrations lower than the limits of 10 CFR 61 be treated by GCD. For example, at the Savannah River Plant, 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 wastes in the United States that will require disposal is continually being improved by several waste inventory systems (11). The annual review by DOE (20) 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 low-level wastes may require this special treatment (7,20). In addition, a total of 2.3×10^7 m^3 (3×10^7 yd^3) of materials contaminated with long-lived, naturally occurring radionuclides 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 low-level wastes, 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 the National Environmental Policy Act of 1969.

Each GCD alternative carries with it certain waste-acceptance restrictions and thus imposes some restrictions on waste generators. Although the site-selection criteria for application of improved waste form or HIC may not differ from those for SLB, there will be additional criteria relative to the GCD techniques of deep trenches, engineered structures, augered holes, and hydrofracture--of which some criteria will be unique to each method.

Performance Assessment

The importance of assessing the technical performance of a disposal facility--before, during, and after its operational lifetime--is emphasized in 10 CFR 61 and DOE Order 5820.2, and it is likely that performance assessment of a GCD system will also be treated with 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 (9). The essence of these rules is that risk to both the general public and 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 (a) the expected technical performance that will permit achievement of these performance objectives, and (b) 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 (7).

Planners and waste generators anticipate that the cost of GCD will be greater than the cost of SLB. Based on some cost estimates for GCD designs that have been made (7), costs are expected to increase in the order SLB < deep trench or SLB with intruder barrier < augered shaft < concrete-walled trench < improved waste form. Costs are strongly dependent on site characteristics; hence, site-specific considerations could alter this order. Hydrofracture is too dependent on site-specific factors to permit inclusion in this ranking. If geologic conditions permit the use of hydrofracture, it is probably the most cost-effective disposal method for liquid waste and a comparable disposal method for solid wastes that can readily be formed into a slurry (e.g., ash from incinerated low-level wastes). 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 site (pathway analysis), and (2) qualitative comparison of the attributes of alternative disposal techniques. The results of calculating the concentrations of radionuclides at various distances in pathways leading from a disposal cell 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 cell, 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.

<u>Disposal Cell Design Alternatives</u>

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 low-level wastes. These concepts include augered shaft, deep trench, and engineered structures.

The augered shaft consists of a hole in the ground with a diameter of 3 to 4 m and a depth of 10 to 35 m, as exemplified by demonstrations at the Nevada Test Site (13) and the Savannah River Plant (14). Smaller, shallower boreholes have been used for waste disposal in the United States and other parts of the world. The advantages of the augered shaft 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 are acceptable to the typical diameters of the shafts.

The deep trench disposal unit is an excavation that is deeper than the normal

8-m depth of the SLB trench. The wastes are surrounded with soil material in the deep trench, as in SLB. The deep trench has not received much attention either in design or in use. One of the earliest references to the concept suggested that it would be quite similar to an SLB unit except twice the depth of a conventional SLB (10). 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, unless special shoring techniques are used, the wide opening required to excavate a deep trench will involve a relatively large area and may restrict emplacement techniques to unloading a waste-carrying vehicle at the bottom of the trench.

The engineered structure is a disposal cell 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 (2,8). These include the Canadian concrete-walled trench (5), the Savannah River Plant concrete-shored trench (14), the French tumulus (24), the NRC concrete-walled trench (21), and the concrete chamber of the University of Arizona (25). The main advantage of engineered structures is their potential barriers to infiltration and intrusion. Structures that are initially roofed will also provide protection from adverse 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 facilities that will be operated by state governments for disposal of low-level waste (23). 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 for Greater Confinement

The waste-emplacement 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 underground shale layers. This unique waste-emplacement configuration sets hydrofracture apart from the category of disposal cells 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 Oak Ridge National Laboratory (26). The advantages of hydrofracture include a high degree of isolation from the environment and from intruders, a small commitment of surface land area above the disposal zone, and a relative insensitivity 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. Also, if contamination of deep aquifers did occur, remedial action would not be feasible.

Improved Waste Forms for Greater Confinement

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 form. Improved waste forms are generally solid media into which primary waste forms are incorporated. Among the advantages of improved waste forms is the potential for their 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. 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 three types: cement, organic solids, and glass (6,15). Cement is the most commonly used solidification agent in management of radioactive low-level wastes. Additives such as organic polymers, silicates, and gypsum improve such properties as ability to incorporate oils, mechanical strength, and leach resistance; they introduce, however, some chemical-processing complications. Some organic solidification agents that have been investigated and used to varying degrees in actual practice are urea-formaldehyde, bitumen, epoxy resins, and vinyl ester-styrene. 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 (1).

High-Integrity Containers for Greater Confinement

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 (4). Designs of containers intended to meet criteria for HICs have been developed by several organizations (3,12,16,27). The favored materials of construction are polyethylene and concrete. Sizes vary from 55-gal drums 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.

Confinement of Low-Level, 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 the 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 wastes at West Chicago (22), Weldon Spring (18), Niagara Falls (19), and Cannonsburg, Pennsylvania (17). More recently, however, groups concerned with safe disposal of wastes are demanding that design elements similar to those of engineered structures be evaluated for confining these types of wastes, including man-made materials for drainage and resistance to water infiltration. The augered shaft technology might be applicable to this type of waste, but it might not satisfy the current preference of citizen action groups and state planners for above-grade emplacement of wastes.

Conclusions

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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