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PLANNING FOR GREATER-CONFINEMENT DISPOSAL

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ABSTRACT

A report that provides guidance for planning for greater-confinement disposal (GCD) of low-level radioactive waste is being prepared. The report addresses procedures for selecting a GCD technology and provides information for implementing these procedures. The focus is on GCD; planning aspects common to GCD and shallow-land burial are covered by reference. Planning procedure topics covered include regulatory requirements, waste characterization, benefit-cost-risk assessment and pathway analysis methodologies, determination of need, waste-acceptance criteria, performance objectives, and comparative assessment of attributes that support these objectives. The major technologies covered include augered shafts, deep trenches, engineered structures, hydrofracture, improved waste forms, and high-integrity containers. Descriptive information is provided, and attributes that are relevant for risk assessment and operational requirements are given.

OBJECTIVE, SCOPE, AND ORGANIZATION

A document on planning for greater-confinement disposal (GCD), one of a series of handbooks sponsored by the National Low-Level Water Management Program, is in preparation. Peer review of a working draft has just been completed, and a final version will be issued early next fiscal year. The objective of the document is to provide procedures and technical information needed to plan for and develop a greater-confinement disposal (GCD) facility for low-level radioactive waste (LLW).

The focus of the document is on LLW that requires GCD because of high activity concentrations or long half-lives of the radionuclides present in the waste. It is intended to address the planning problems of developing a GCD facility: selecting a suitable site, selecting a suitable method of waste confinement and facility design, and anticipating the operating problems and problems of closure and extended care. The document does not endorse a particular GCD technology, nor is it intended to provide answers to specific questions or problems; rather, it is intended as an overview of the GCD technologies available and as a planning guide for selecting and implementing the GCD technology best suited for a specific situation. The choice of a GCD technology in a specific situation will depend on the waste stream, characteristics of available sites, institutional requirements, and other variables. The problems of mixed waste (defined as radioactive waste containing hazardous biological or chemical material in concentrations sufficient to present a significant hazard) and of transportation of waste from a generator to a disposal site are outside the scope of the document.

The document is organized into two parts corresponding to two planning phases. Phase I planning covers two major topics: (a) planning procedures for selecting a suitable site and facility design, and (b) relevant technical information for implementing the planning procedures. Phase II planning covers operation, closure, and extended care for a selected site and design. The overall planning sequence for both phases is shown diagramatically in Figure 1.

PLANNING PROCEDURES

Basis for Determining Need and Selecting an Alternative

The performance objective that guides all of the planning effort is to limit the risk of adverse health effects--more specifically, to limit the radiation dose to the general public from release of radionuclides into the environment or intrusion into the waste and to limit the occupational dose during emplacement operations, closure, and extended care. The performance objectives provide the basis for resolving the two major Phase I issues: establishing the need for GCD and selecting an alternative for implementation.

The need for GCD can be established prior to a detailed analysis if, on the basis of information available at the outset, it can be established that SLB cannot meet regulatory requirements for radiation protection. If this cannot be clearly established, then SLB is included among the alternatives considered for detailed analysis, and a final answer to the need for GCD is obtained at the end of the selection process. Six alternatives for GCD that merit consideration in the selection process are described in the section, "GCD Alternatives". The alternatives considered are limited to those which, on the basis of preliminary information, can be expected to be in compliance with regulatory requirements for the candidate waste streams. Regulatory requirements are also considered.

The criterion used to select an alternative for implementation is that the total short-term and long-term risks associated with disposal of the waste should be as low as reasonably achievable (ALARA). A comparative benefit-cost-risk (BCR) assessment of the different alternatives must be carried out in order to rank the alternatives and identify a preferred alternative according to this assessment.

In a comparative BCR assessment, the alternatives are ranked according to the net present value (NPV) for each alternative, defined as the benefits less costs and risks: NPV = B - C - R. The benefits accrue in actions that generate the waste; hence, the comparison of GCD alternatives reduces to a comparison of costs plus risks. Discounting procedures for including long-term costs and risks and introducing a time horizon that takes into account the large uncertainties in long-term predictions are discussed.

In a traditional cost-risk analysis, it is necessary to establish trade-offs between the costs and the various risk components in order to define a single quantity, analogous to the NPV, that can be used for comparing different alternatives. There is no concensus on these trade-off

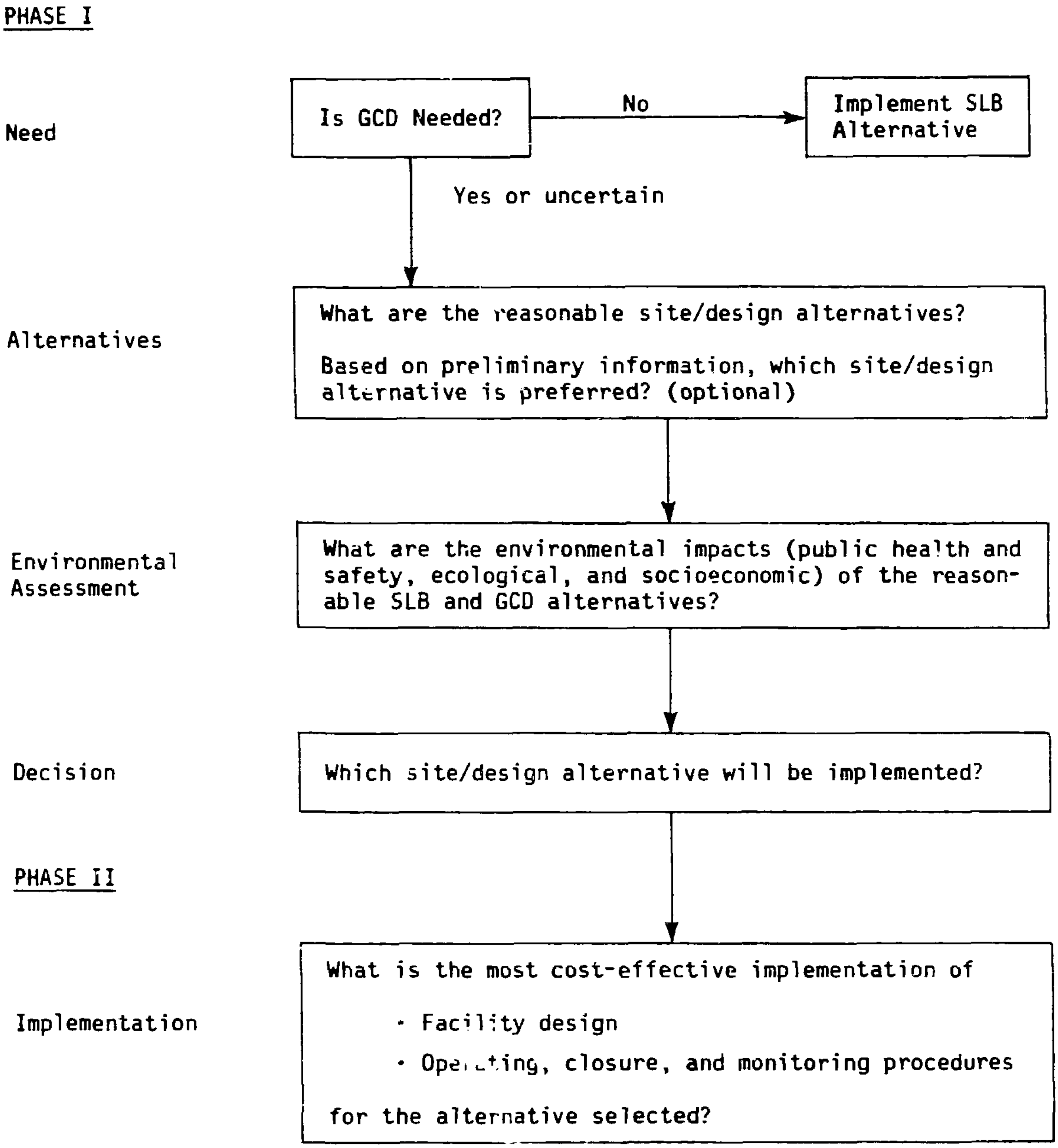

Figure 1. Overall Planning Sequence.

factors, and they may vary from one situation to another. Specifying a trade-off between costs and risk is equivalent to assigning a dollar value to a fatality, although this may not be apparent (and may be more acceptable politically) if the trade-off is expressed as the cost per person-rem averted. In view of the lack of concensus and the sensitivity of the trade-off to case-specific conditions, the purpose of the planning procedure is to provide a separate assessment of the different costs and risks involved and to present the results of the cost-risk assessment in a tabular form. The items that would be included in the table would include the cost, the population dose, the dose to a member of the critical population group (or maximally exposed individual)--both onsite and offsite, the occupational dose (and risk), and the groundwater contamination. These quantities would be determined for each of the reasonable alternatives. All costs and risks would be for a unit quantity of a specified mix of waste streams for a specified scale of operations. This information, summarized on a single sheet, would be the basic data on which the choice of a particular GCD technology for a particular situation and site would be based. Although some guidance on weighting factors is provided, the choice of weighting factors for using the data in making the final selection of a GCD technology is left to the individual responsible for the final decision.

Cost Estimates

The cost estimates may be developed by standard procedures for estimating costs for engineering projects. The selection of GCD alternatives must be based on case-specific estimates because generic estimates are too uncertain to discriminate between GCD alternatives (due to regional cost differences for materials and services and dependence of costs on case-specific design details). Cost elements specific to GCD that must be taken into account in making cost estimates are provided; however, no cost figures are given in the report because they would be necessarily generic or exemplary, and subject to misinterpretation and misuse.

Risk Analysis

Much of the planning effort for GCD centers on risk estimation and assessment. The key quantities for establishing the need for GCD and identifying a disposal alternative for implementation are the waste hazard (H), the risk (R) associated with disposal of the waste, and the risk/hazard relation (R/H).

The risk from waste disposal consists of all adverse effects, primarily health effects from exposure to radioactivity, that are incurred during and after disposal of the waste. A concensus on a single quantity that could be used as a summary measure of the total risk is lacking; hence, the comparative risk assessment of different disposal technologies is based on an appropriate measure of those risks that are of greatest regulatory and public concern. The two risks of greatest regulatory concern are (1) the radiation dose to a critical population group (commonly interpreted as individuals who establish residence on the site at some time in the distant future), and (2) the occupational risk. The collective dose to the surrounding population is also of concern and is used in the comparative cost-risk analysis. For the purpose of the following discussion, the risk may be interpreted as the effective committed dose equivalent to an average member of a critical population group.

The waste hazard is the risk that would be be incurred if the waste was not confined. There are many factors that determine the hazard of a waste--including the radiotoxicity of the radionuclides present, the chemical and physical form, and the activity concentrations (expressed, for example, in Ci/m^3) of the radionuclides present. Waste-acceptance criteria, which are based on waste hazard, are commonly given by specifying the allowable chemical and physical characteristics and limits on the concentrations of specific radionuclides. In the following discussion, the waste hazard may be interpreted as the activity concentration of radionuclides in the waste.

For any disposal technology implemented at a specific site, there will be a characteristic relation R = f(H) between the waste hazard and the risk incurred from disposal by that technology. In general, the risk will increase with the hazard. For the purpose of explaining the risk assessment methodology, it may be assumed that the relation is linear. With this idealization, the risk-hazard relationship of a disposal technology implemented at a specific site will be represented by a straight line. The slope, R/H, of this line is the key quantity for characterizing the degree of confinement and comparing the risks of different disposal technologies at a given site. If H_0 is the hazard of a particular waste stream and $(R/H)_{DT}$ is the risk/hazard ratio for a particular disposal technology implemented at a specific site, then the risk from disposal of the waste stream at the site with the specified disposal technology is $R_0 = (R/H)_{DT} \times H_0$. The R/H ratio will decrease with increasing confinement, with a resulting decrease in the risk for disposal of a waste stream with a given hazard. These relationships are shown schematically in Figure 2. The lines representing the characteristic R/H relation for a particular GCD disposal facility and an SLB disposal facility at a specified site are represented by bands rather than lines in order to indicate the uncertainty in the determination of the risk/hazard relationship.

There will be a maximum acceptable risk for waste disposal, established by regulation. (A risk limit is in practice, specified as a basic radiation dose limit.) This limiting risk is indicated by the upper line in Figure 2. The intersection of this line with the R/H line determines the waste-acceptance criteria for the most hazardous waste that can be accepted at a site. The point D corresponds to the most hazardous waste that would be acceptable if the GCD technology characterized by the R/H line were implemented; the point C corresponds to the most hazardous waste that could be accepted if an SLB technology were implemented. For risks below some threshold value (commonly referred to as a risk that is "below regulatory concern"), it becomes unnecessary, and generally uneconomic, to provide the same confinement needed for more hazardous wastes. The threshold risk is represented by the line labeled "threshold risk" in Figure 2. The intersection of the R/H line with the threshold risk line determines a waste hazard value threshold criterion) for which it is appropriate to use less costly disposal technologies that generally provide less confinement. The threshold criteria for the SLB and GCD facilities correspond to the points A and C, respectively, on the abscissa in Figure 2.

If, in a given situation, the hazards for all waste streams requiring disposal lie below the point C, GCD is unnecessary. For waste streams in the interval between C and D, a GCD facility is necessary; for waste streams

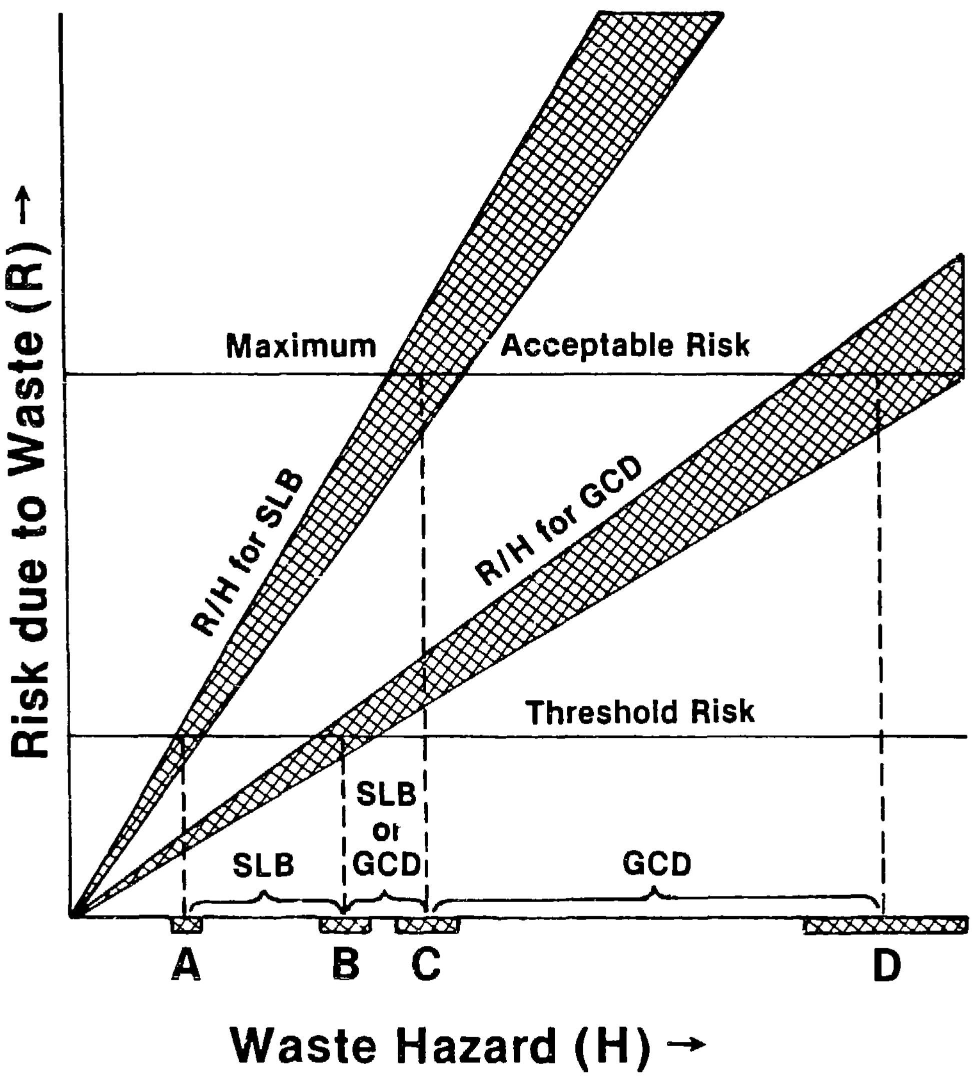

Figure 2. Risk-Hazard Relationships for Disposal of Low-Level Radioactive Waste.

in the interval between B and D, GCD is appropriate. (Institutional and political considerations could lead to use of GCD for waste streams below the point B.) If the waste hazard exceeds the point D, a technology providing greater confinement than the GCD technology corresponding to the R/H factor shown in Figure 2 would be needed.

The risk analysis needed for GCD planning consists of procedures for determining the R/H ratios and their dependence on the various attributes of a particular technology. A quantitative determination of the R/H ratio may not be feasible or necessary in many circumstances. If it can be established that modifying a particular design attribute in a specified way can increase or decrease the R/H ratio, then a comparative risk assessment can be carried out even if the quantitative relation between the modification of the attribute and the effect of this modification on the R/H ratio cannot be determined.

In application, the determination of the R/H ratio reduces to a determination of the ratio of the radiation dose (D) to an individual (or population) to the concentration (S) of the radionuclides in a waste stream. This relation is commonly referred to as the dose/source (D/S) ratio.

Waste Characterization

The primary waste characteristics include radiological, physical, and chemical characteristics. Radionuclide activity concentrations are the key quantities for specifying waste-acceptance criteria. Other waste characteristics are important because the D/S ratios may depend on them; they are used to establish different waste categories to which different concentration limits apply. Waste categories in current use are discussed in the report.

The two waste characteristics of greatest concern for selecting a GCD alternative are the initial activity concentrations and the half-lives of the radionuclides. The type of facility needed for confining short-lived and long-lived radionuclides can be quite different. Short-lived radionuclides can have very high initial activity concentrations that require greater confinement, but loss of containment effectiveness beyond a few hundred years is usually acceptable. For long-lived radionuclides, the duration of effective containment becomes a matter of primary concern. Waste streams consisting of mixtures of short-lived and long-lived radionuclides present the greatest problem, and may require a different approach that combines both greater initial confinement and more lasting confinement. It is helpful for planning to be able to visualize the activity concentration as a function of time in order to assess both the initial hazard and the duration of the hazard. Activity/time plots, as shown in Figure 3, are useful for this purpose. Activity/time plots for a number of commercial and DOE/defense waste streams are given in the report.

Pathway Anaysis

A pathway analysis of the mechanisms by which radionuclides can migrate along different pathways from the waste to a point of human exposure is needed to estimate the risk for different disposal sites and facility designs. The pathway analysis is used to calculate a dose/source factor, $(D/S)_i$, for each radionuclide (i). A given disposal alternative is characterized by the

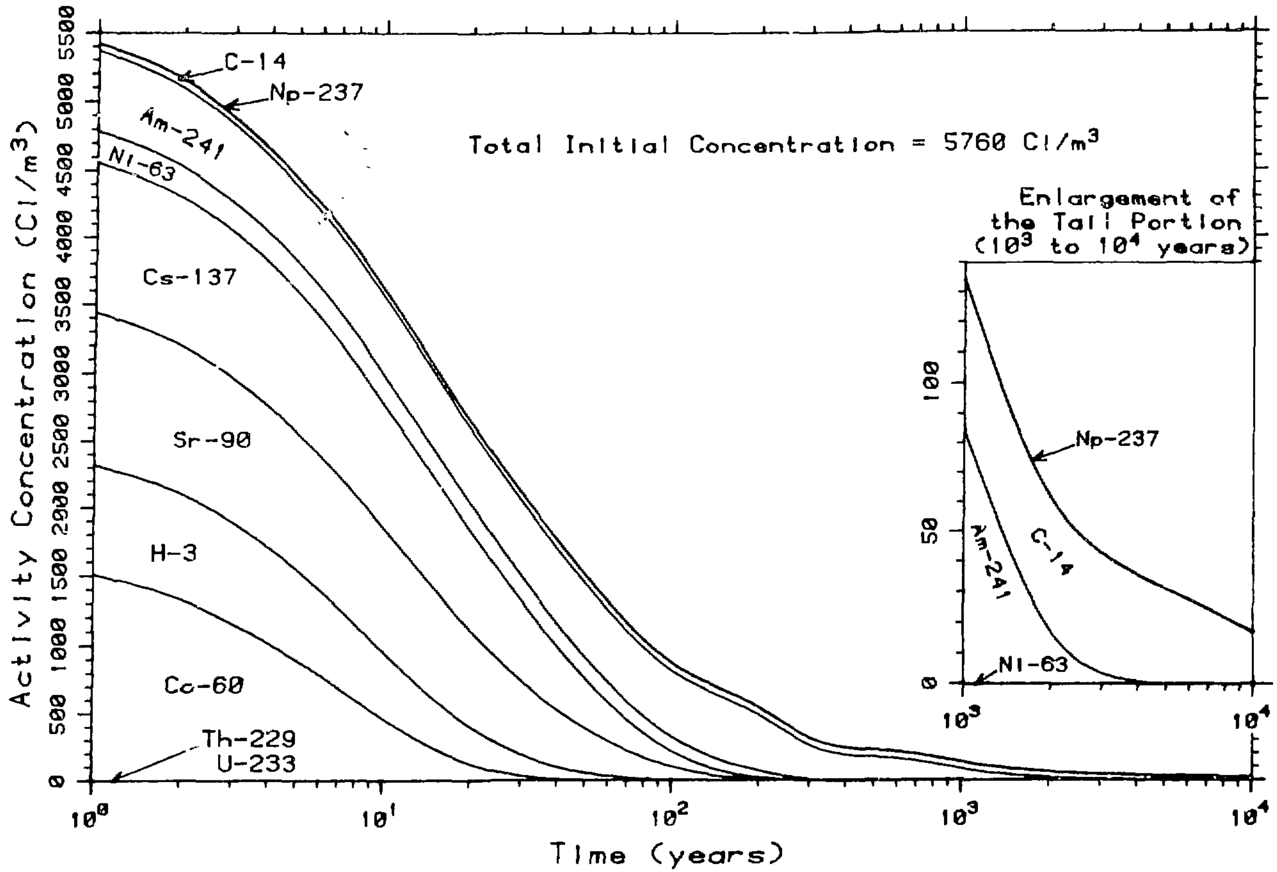

Figure 3. Radionuclide Composition as a Function of Time for Industrial Sealed Sources Waste (N-SOURCES)

ratios $(D/S)_i$, and a given waste stream is characterized by the radionuclide concentrations S_i. The radiation dose for a given disposal alternative and waste stream may be calculated by means of the formula:

$$D = \sum_i (D/S)_i \times S_i. \qquad (1)$$

In the pathway analysis, the D/S ratio for each pathway and each radionuclide is expressed as a product, $D/S = F_D(P_D) \times F_I(P_I) \times F_E(P_E) \times F_C(P_C)$, of a dose conversion factor (F_D), an intake or shielding factor (F_I), an environmental transport factor (F_E), and a containment factor (F_C). P_D, P_I, P_E, and P_C are sets of parameters that characterize biological processes and the facility, site, and waste. The dose conversion factors and intake or shielding factors are common to all alternatives, the environmental transport factors are characteristic properties of a site, and the containment factors are characteristic properties of the facility design (but also depend on nonradiological waste characteristics).

In a comparison of alternative sites, all factors except the site-dependent factors are combined into a single weighting factor, $W_E = F_D(P_D) \times F_I(P_I) \times F_C(P_C)$, for each pathway and radionuclide. The D/S ratios for alternative sites are then calculated by the formula, $(D/S)_i = \Sigma_k W_{E,ik} \times F_{E,ik}$, using the common set of environmental weighting factors ($W_{E,ik}$) for each radionuclide (i) and each pathway (k) and the environmental transport factors ($F_{E,ik}$) calculated for each site. The sites may then be compared by comparing dose estimates for a given waste stream, calculated by using Equation 1.

Alternative facility designs may be compared in a corresponding manner by calculating a common weighting factor $W_C = F_D(P_D) \times F_I(P_I) \times F_E(P_E)$, calculating D/S ratios for each design by the formula $(D/S)_i = \Sigma_k W_{C,ik} \times F_{C,ik}$, and comparing the dose estimates for a specified waste stream using Equation 1.

Each containment factor may be resolved into a product, $F_C = F_{CW} \times F_{CC} \times F_{CE} \times F_{CD}$, where the individual subfactors correspond to confinement barriers provided by the waste form (F_{CW}), waste container (F_{CC}), engineered features of the disposal cell (F_{CE}), and depth of placement (F_{CD}). The relationship between these factors and the transfer coefficients that specify the rate of migration through barriers is discussed in the report.

Methods and data for calculating the dose conversion factors, intake or shielding factors, environmental transport factors, and containment factors for depth of placement are available from the literature. Containment factors that characterize the short-term effectiveness of waste forms, waste containers, or engineered structures can be inferred from engineering specifications. Methods and data for inferring the long-term effectiveness of these barriers--i.e., the long-term time dependence of the containment factors--are lacking; hence, estimates of long-term performance must rely largely on engineering judgment.

The need for GCD can be established by calculating the D/S factors for an SLB facility and using these factors in Equation 1 to calculate the annual individual dose for a critical population group for a candidate waste stream. If this estimated annual effective dose equivalent exceeds 100 mrem/yr, then SLB is unacceptable and GCD is mandatory. If the estimated annual effective dose equivalent is less than 100 mrem/yr, GCD may still be the most appropriate alternative but the selection should be based on a comparison of risk and cost rather than on risk alone.

A risk analysis for establishing compliance with regulatory limits for the dose to an individual or for ranking alternatives with respect to public risk alone is based on the risk to a member of a critical population group, assumed to be an individual who lives in a residence built on the site after institutional controls have lapsed. In order to rank sites with respect to both cost and risk, the costs and risks must be aggregated. This requires a determination of the collective dose to the exposed population. Equation 1 may be used for this purpose if: (1) the offsite pathways not included in calculating the onsite dose are added, (2) the dependence on the location at which exposure occurs is taken into account, and (3) the individual dose estimates are summed over the entire exposed population. The occupational dose should also be included in an assessment based on the aggregated total of costs and risks.

Site Selection

The procedures for site selection are essentially the same for an SLB facility or a GCD facility. The differences arise in the need to choose a site with characteristics that are compatible with the special requirements for some GCD technologies. The site requirements for the GCD alternatives of improved waste form and high-integrity container are the same as those for SLB. Changes from SLB requirements for an engineered structure are minor, and they are related to the engineering specifications for supporting the engineered structure. The augered shaft and deep trench alternatives, especially the former, require greater depth to the water table and soil characteristics that allow steep or vertical unsupported slopes during construction. Hydrofracture places the most stringent siting requirements; it can be used only when strata are present that are suitable for formation of horizontal grout sheets by injection at an appropriate depth.

Summary of Planning Procedures for Selecting a Site and Facility Design

The steps in the planning procedures for selecting a site and facility design for GCD are summarized in Table 1.

TABLE 1. PLANNING STEPS FOR SYSTEMATIC SELECTION OF A GCD ALTERNATIVE

- Identify reasonable alternatives
- Screen reasonable alternatives to identify sites and facility designs for detailed study
- Identify exposure pathways and scenarios
- Identify cost elements, risk parameters, and facility attributes
- Develop a data base for cost elements and risk parameters for all alternatives selected for detailed study
- Determine costs for alternatives
- Evaluate
  - Dose conversion and intake factors
  - Environmental transport factors for different sites
  - Containment factors for different facility designs
- Assess risks and environmental impacts of alternative sites (using generic containment factors)
- Select a preferred site
- Evaluate costs and risks for SLB and GCD alternatives (using environmental transport factors for preferred site)
  - Determine concentration limits for disposal by SLB from regulatory dose limits
  - Make a definitive determination of need for GCD (if preliminary assessment did not lead to an unambiguous decision)
- Evaluate uncertainties in costs and risks
- Identify a preferred GCD candidate alternative (or alternatives) on the basis of aggregated costs and risks
- Select a preferred GCD alternative from preferred candidate alternatives on the basis of attribute analysis if the cost-risk analysis does not lead to unambiguous selection of an alternative

GCD ALTERNATIVES

Although an indefinite number of technologies might be shown to fit the definition of GCD, this work focuses on the six most cost-effective alternatives identified in an earlier study[1]: (1) augered shaft, (2) deep trench, (3) engineered structure, (4) hydrofracture, (5) improved waste form, and (6) high-integrity container. These alternative technologies are described below by examples that include materials of construction, spatial arrangement, and typical dimensions. Advantages and disadvantages associated with each of the technologies are also briefly discussed. The choice of six alternatives for consideration in this report is not intended to limit the range of alternatives that might be considered in a specific case; they were chosen as examples of the range of alternatives that merit consideration.

The augered shaft, exemplified by demonstrations at the Nevada Test Site[2] and the Savannah River Plant,[3] consists of a hole in the ground with a diameter of about 3 m and a depth of 10 to 35 m. Advantages of the augered shaft include a geometry that shields operators from emplaced radioactivity, compatibility with remote-handling techniques, sufficient depth to preclude plant and animal intrusion, easy closure, and low susceptibility to erosion. A disadvantage is the limit required by typical shaft diameters on the size of waste items.

The reference deep trench holds the same volume of wastes as the SLB trench, but at a depth of 16 m--twice that of the SLB case.[4] The wastes would normally be surrounded with soil, as in the SLB trench. The deep trench places wastes beyond the depth of penetration of intruding roots and animals and offers simplicity, flexibility in acceptance of waste types, and little vulnerability to erosion. It requires, however, a thick layer of soil and unconsolidated materials over the water table. Unless shoring techniques are used, the wide opening required to excavate a deep trench requires a large area commitment and may cause difficulties for emplacement of wastes from its top edge.

The engineered structure is typically a chamber built of concrete.[3,5-7] Several concepts, intended for placement either above or below grade level, have been described. The main advantage of the engineered structure is the barrier it would present to infiltration and intrusion. Because concrete is prone to eventual cracking, however, the engineered structure eliminates neither infiltration of water nor release of leachate over the long term. Above-grade placement of engineered structures has received much attention because it is perceived to offer protection from groundwater and ease of surveillance, maintenance, and remedial actions.

In disposal by hydrofracture, a grout slurry containing the waste to be disposed is injected into fractures in deep-lying shale formations.[8] This method has been practiced successfully over a period of many years at Oak Ridge National Laboratory. The advantages include a high degree of isolation from the environment and from intruders, little commitment of surface land, and low sensitivity to weather during emplacement and to erosion after emplacement. Disadvantages include applicability only to wastes in liquid or slurry form or to wastes that can be converted to such forms, the possible stimulation of minor seismic effects, a requirement for special geologic characteristics, and the impossibility of any remedial action.

Improved waste forms are generally created by using some binding agent to incorporate primary waste forms of miscellaneous sizes, shapes, and physico-chemical properties into solid blocks.[9] The binding agents used to produce improved waste forms are of three types: cement, organic solids, and glass. An advantage 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, and limit both dispersion and leaching. Disadvantages include the involvement with chemical processing equipment that is usually necessary and an inability, in many cases, to completely incorporate all waste forms--particularly oils.

The high-integrity container (HIC) is a vessel that is intended, according to criteria for HIC design that have been defined by the NRC and the state of South Carolina, to provide structural stability and containment of radionuclides for 300 years. Prototypes fabricated by various organizations are of polyethylene, steel, and concrete with sizes ranging from 55-gal drums to large units that can be handled only by powered cranes. The HIC, like improved waste forms, offers the advantage of achieving GCD within the SLB trench. A disadvantage is its inability to accept unusually large items.

ATTRIBUTE ASSESSMENT

Risk assessment is based on known quantitative relationships between the risk and numerical-valued parameters. A quantitative formulation is most feasible when the risk-determining attributes are characterized by descriptive text rather than by numerical-valued parameters or when the quantitative risk-parameter relationships are not known. A comparative assessment that enables a ranking of the alternatives with respect to risk can still be carried out in these circumstances by using a qualitative or semiquantitative variant of risk analysis referred to as "attribute analysis".

Attribute analysis is used at two stages of the planning. One is for a preliminary ranking of the alternatives for the purpose of selecting a limited number of the most promising alternatives for a quantitative risk analysis. The other is to resolve ambiguities in a quantitative risk analysis. If the difference in the risk estimates for two alternatives is comparable to the uncertainty and if the cost difference is not sufficient to justify selection of one over the other, then attribute analysis may be used to take into account unquantifiable attributes not included in the risk analysis for making a final selection. The use of quantitative risk analysis and qualitative attribute analysis, together, provide a more reliable and cost-effective means for selecting a GCD alternative than use of either method alone. Quantitative risk analysis can be used for either an absolute or comparative assessment of the risks of GCD alternatives. Attribute analysis can be used only for comparative assessments. The planning time and expense is considerably greater for a quantitative risk analysis of an alternative than for an attribute analysis; thus, it is desirable to limit the number of alternatives for which a quantitative risk analysis is carried out.

The relationship between risk analysis and attribute analysis is discussed in the reports. The risk from disposal of waste in a GCD facility can, in principle, be expressed as a function of all system design elements or of all attributes (including those that are defined by description rather than numerical-valued parameters because of their complexity). (An attribute is an inherent characteristic, quality, or property of a GCD alternative; a system design element is a specific property, usually a physical quantity, used in preparing specifications for a disposal system. The attributes will be functions of the system design elements; the risk can, in principle, be expressed as a function of either the attributes or the system design elements.) The functional relationship between the risk and the attributes (or system design elements) can be approximated by a linear relation of the form $R = \Sigma_j W_j \times a_j$, where a_j are parameters or descriptive categories (referred to as descriptors) that specify the attributes. In risk analysis, the attributes must be numerical-valued parameters, and the coefficients W_j--which may be regarded as weighting factors for the attributes--must be calculable. In attribute analysis, the weighting factors are assigned on the basis of expert judgment and the attributes may be specified either by parameters or descriptors. Quantitative risk analysis is usually based on the relation between risk and system design elements; attribute analysis is based on the relation between risk and attributes because judgmental assignment of attribute weights is more credible than judgmental assignment of design element weights, and examination of the attributes provides a more systematic means for taking into account all qualities and properties that can affect the risk. In some circumstances, the only credible judgment that can be made regarding attribute weights is the signature--i.e., whether increasing a given attribute will increase or decrease the risk.

Attribute analysis consists of three steps: (1) identifying a set of attributes--called performance attributes--that are important for realizing the performance objectives identified above; (2) ranking the GCD alternatives with respect to each performance attribute; and (3) aggregating the individual attribute rankings in order to obtain an overall ranking of the GCD alternatives with respect to attributes.

In order to facilitate identification of all relevant attributes, a categorization into site attributes, GCD attributes (waste form, packaging, and facility design), and operational attributes is introduced; and the important attributes for each category are identified. A list of performance attributes is given in Table 2.

Various methods can be used for ranking sites with respect to attributes. A common method is a pairwise ranking with respect to each attribute. Weights must then be assigned to the different attributes in order to obtain a pairwise ranking of the alternatives and to obtain an ordered ranking of all alternatives. Another procedure is to rate each alternative with respect to each attribute on a ranking scale (e.g., a scale of 1 to 10), assign a weight to each attribute, and then rank the alternatives with respect to scores obtained by summing the product of the attribute ratings and weights for each alternative. The simplest procedure, useful for screening, would be to use a three-point ranking scale for rating a site with respect to an attribute. The assignment of attribute ratings and weights should be based on the collective judgment of a panel of experts, which should include

TABLE 2. PERFORMANCE ATTRIBUTES

SITE ATTRIBUTES

- Climate
- Demographic setting
- Economic value (present and future)
- Erosion resistance
- Hydrogeologic complexity
- Natural drainage and flooding potential
- Radionuclide migration resistance
- Topography
- Water infiltration resistance

GCD ATTRIBUTES (WASTE FORM, PACKAGING, AND FACILITY DESIGN)

Attributes Relevant for Public Risk

- Biodegradation resistance
- Compressive strength
- Chemical inertness
- Distance to groundwater
- Drainage control
- Infiltration resistance
- Intrusion resistance
- Ion-exchange capacity
- Leach resistance
- Radiation stability
- Structural stability
- Thermal stability

GCD ATTRIBUTES (Continued)

Attributes Relevant for Occupational Risk

- Limitation of stress on container
- Strength of container
- Worker exposure

OPERATIONAL ATTRIBUTES

Pre-Closure

- Ability to handle high radiation levels
- Compatibility of low-volume rate
- Complexity
- Ease of performance assessment
- Flexibility in siting requirements
- Flexibility in waste-form acceptance
- Maintenance requirements
- Materials-handling needs
- Reliability
- State of technological development
- Vulnerability of emplacement operations to weather

Closure and Post-Closure

- Ease of carrying out decontamination and decommissioning
- Ease of surveillance and monitoring
- Need and ease of carrying out remedial action

administrators or staff who are well-informed and can objectively assess public concerns. A process known as the Delphi Method, which is an iterative procedure for arriving at a panel concensus, is useful for this purpose.[10]

PLANNING FOR OPERATION, CLOSURE, AND EXTENDED CARE

Some operations that would be carried out at a GCD facility are similar to those carried out at any disposal facility for low-level waste, whereas others would be unique and specific to the type of GCD technique that is practiced. The latter type has been given attention in this document. Each of the six GCD techniques considered is examined for the unique operations that are required for implementation of that technique by the operator of the disposal facility. The operations and supporting equipment considered include construction of facility and disposal cells, waste receipt and inspection, equipment maintenance, waste emplacement, monitoring, record-keeping, radiation and industrial safety, quality assurance, disposal cell closure, site closure, and post-closure activities. Diagrams are provided that represent the sets of generic operations that would be carried out at any waste disposal facility and for each of the GCD technologies considered.

The operations of waste receipt and inspection are governed by waste-acceptance criteria that must be developed at each facility to suit the GCD technique and site characteristics. Even though the GCD facility is designed to provide a superior degree of containment, it will impose restrictions on waste form, radionuclide concentrations, and packaging. Waste-acceptance criteria must also provide a system for establishing the destination for a given waste, i.e., whether disposal by SLB or GCD is appropriate. As for any disposal facility, the primary goal of waste-acceptance criteria at the GCD facility will be to limit the health risks to the general public and to operating personnel, in conformance with DOE ALARA policy. Because, it is not practicable to base waste-acceptance criteria on quantitative relationships between risk and radionuclide concentrations, these criteria will have to be based on more qualitative judgments--including public concerns, costs, technical feasibility, and site-specific factors. In receiving operations, wastes will be expected to arrive separated from SLB wastes and to be subjected to visual inspection, to surveys for both penetrating radiation and surface contamination, to weighing, and to verification of the descriptions given in the shipping manifest. A major consideration for GCD wastes, not only in receipt and inspection but also in subsequent handling, is that they may have high radionuclide concentrations and therefore present increased hazard in the event of loss of integrity of containment or shielding.

Each GCD technique has some requirements for special disposal procedures and operational equipment that are not employed in the traditional SLB technology. Major examples are: (1) earth augers in excavation for augered shafts; (2) draglines rather than dozers or backhoes in excavation for deep trenches; (3) equipment and supplies characteristic of reinforced-concrete construction for engineered structures; (4) equipment essential to construction, operation, and maintenance of injection wells for hydrofracture; (5) chemical-processing equipment for improved waste forms; and (6) container-fabrication facilities, although not at the disposal site, for high-integrity containers.

From the definition of GCD as a type of containment whose quality must exceed those provided by SLB, it is inferred that quality assurance techniques must be used as to control the quality of the various elements on which that containment depends: disposal cell design, equipment, operations, and fabrication of waste forms and packaging. Quality assurance in nuclear projects is commonly ba d on the set of 18 requirements expressed jointly by the American National Standards Institute and the American Society of Mechanical Engineers. Actions required of the GCD operator to ensure that operations in carrying out any of the six GCD techniques considered here conform to each of the 18 quality assurance requirements are reviewed. Those requirements, which are mainly management-control strategies, would be practiced at the GCD facility in the same way as at any other waste disposal facility. Carrying out some of the quality assurance requirements, however, will require activities unique to each GCD technique.

Although the closure of each different type of disposal cell has some singular characteristics because of design, the task of site closure--making it ready for long-term, minimum-maintenance containment--is expected to be much the same for most GCD facilities as for an SLB facility. The exceptions are deep augered shaft and hydrofracturing, which would not involve the same type of surface-maintenance problems as a grid of disposal cells located on the surface or slightly below it.

Post-closure operations at a GCD facility are expected to be the same as those suggested for an SLB facility: a 5-year period of relatively active maintenance, surveillance, and monitoring, followed by a longer period of institutional care in which these activities would be carried out on a less-intense schedule.

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