

## PLANNING FOR GREATER-CONFINEMENT DISPOSAL

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## ABSTRACT

This contribution is a progress report for preparation of a document that will summarize procedures and technical information needed to plan for and implement greater-confinement disposal (GCD) of low-level radioactive waste. Selection of a site and a facility design (Phase I), and construction, operation, and extended care (Phase II) will be covered in the document. This progress report is limited to Phase I. Phase I includes determination of the need for GCD, design alternatives, and selection of a site and facility design. Alternative designs considered are augered shafts, deep trenches, engineered structures, high-integrity containers, hydrofracture, and improved waste form. Design considerations and specifications, performance elements, cost elements, and comparative advantages and disadvantages of the different designs are covered. Procedures are discussed for establishing overall performance objectives and waste-acceptance criteria, and for comparative assessment of the performance and cost of the different alternatives.

## INTRODUCTION

The following contribution is a progress report for preparation of a planning document for greater-confinement disposal (GCD). Most low-level radioactive waste (LLW) can be safely disposed by shallow-land burial (SLB), i.e., disposal in trenches typically about 8 m in depth. Disposal by means providing greater confinement may be required for a small volume-fraction of the LLW containing radionuclides in sufficiently high concentrations, or with sufficiently long half-lives, or mixed with other hazardous materials that cannot be neutralized or removed. This document is intended to present planning procedures and technical information for developing disposal of such waste, commonly referred to as "GCD waste". The primary intended audience is government officials (federal and state) and contractors responsible for disposal of DOE/defense or commercial LLW.

The scope is limited to the GCD component of LLW. LLW is defined, by exclusion, as any gaseous, liquid, or solid radioactive waste not classified as high-level waste, transuranic waste, spent nuclear fuel, or mill tailings. The focus is on procedures and facility designs that have reached, or are approaching, a stage where there is sufficient basis to justify use for an operating facility. Ideas that have been proposed or treated in conceptual studies, but not proven by demonstration projects or use in operating facilities, will be covered only by reference.

**MASTER**

Transportation of waste from generators to a disposal site is not covered in the document. The costs and risks of transportation, and the variables that affect them, should be taken into account in siting a GCD facility. Packaging requirements for transportation can also affect facility design. Hence, transportation is an important consideration in planning for GCD. It is expected that these aspects of GCD planning will be covered in a separate document of the Low-Level Waste Management Program (LLWMP) Handbook Series.

## PLANNING CONSIDERATIONS

### Planning Objectives

The GCD planning objectives are to reduce the risk to the general public and to the work force (individually and collectively) to levels that are as low as reasonably achievable (ALARA) and to comply with applicable federal and state laws and regulations and DOE Orders in a cost-effective manner. Planning for site selection, facility design, operating policies and procedures, and closure and extended care is needed to accomplish these objectives. This planning may be broken down into two phases. Phase I covers activities that culminate in the selection of a GCD disposal site and facility design. Phase II follows the siting and basic design decisions and covers construction, operation, closure, and extended care. This progress report covers only the Phase I.

### Determination of Need

A need for GCD will develop when the characteristics of a waste stream exceed the waste-acceptance criteria for the available SLB facilities. It may be assumed that waste-acceptance criteria and incoming waste stream characteristics at existing SLB facilities are sufficiently well known to enable a determination of the need for GCD. In situations where a new LLW disposal facility is developed, the question of whether or not to provide for GCD will arise. Unless the available information clearly indicates that all of the LLW streams for which the new facility is needed will meet the waste-acceptance criteria for SLB without GCD, then the planning effort for the new LLW facility should include provisions for GCD. It is expected that information sufficient to preclude the need for GCD will usually be lacking; hence, it is considered advisable to include the development of GCD capabilities in any planning for a new LLW disposal facility.

A GCD facility may either be separate or co-located with an SLB facility (existing or new). The base case considered in this document will be a co-located GCD facility, but the planning procedures are also applicable, with appropriate modifications, to a stand-alone facility.

## WASTE CHARACTERIZATION

In planning for GCD, one must know the characteristics of the waste. The specific radiological, physical, and chemical properties of the waste that will determine the containment requirements are as follows:

### Radiological

Radionuclide concentrations  
Radionuclide half-lives  
Radiotoxicity  
Surface activity  
External  $\gamma$ -radiation level

### Chemical

Leachability  
Chemical toxicity  
Reactivity

### Physical

Stability  
Waste Form

Information on waste characteristics should be provided by waste generators or inferred from the type of waste source. Different source streams typically contain different nuclides and have characteristic physical and chemical properties.

The data on radiological properties should include the concentrations and half-lives of the radionuclides in the waste, the surface activity, and the  $\gamma$ -exposure rate of the packages. The primary data used for specifying GCD threshold characteristics ("trigger values") are radionuclide concentrations. Threshold concentrations are set on the basis of half-lives, radiotoxicity, and limiting SLB containment capabilities (which depend on leachability, reactivity, stability, and waste form). Concentrations of co-contaminants must also be specified because chemical toxicity is important. Surface  $\gamma$ -exposure rates and external activity of the packages should be such that occupational exposures are within acceptable limits. The criticality safety requirements should also be considered.

Chemical characteristics of waste can affect the hazard by influencing the release rate of radionuclides into the environment or by introducing an additional hazard from chemical toxicity. Both effects need to be considered. An important chemical property is leachability of the radionuclides. If containment does not prevent water infiltration, the rate of release of radionuclides and the groundwater concentrations will be controlled by the leach rate. Leachability can be reduced by modifying the waste form. The content of chelating or complexing agents should be limited. DOE and NRC regulations require that the waste must not be capable of generating gases, vapors, or liquids that could jeopardize site performance or be harmful to persons handling the waste. Regulations also prohibit wastes that are explosive, flammable, pyrophoric, corrosive, or reactive.

A critical physical characteristic of the waste-disposal system is stability. Structural degradation of the waste must be prevented to avoid collapse or slumping of the site with subsequent water infiltration. Stability is also a factor in limiting exposure to an inadvertent intruder. The factors that need to be considered are chemical reactions, biodegradation, radiation effects, temperature changes, and the ability of the waste to maintain its physical dimensions and consistency under compressive load. The length of time over which the structural stability should be maintained will depend on the radiological properties of the waste. In some cases, the original waste form is stable enough to meet the long-term performance criteria. In many other cases, structural stability can be attained by appropriate conditioning or packaging.

Generic guidelines for threshold and limiting characteristics for GCD waste can be given on the basis of data for waste characteristics and parameters that characterize a typical site and a typical design for a GCD alternative (1,2); however, there can be wide variations in the containment capabilities of different sites and designs. Threshold and limiting values of waste characteristics for GCD should, therefore, be based on a site- and design-specific analysis.

## REGULATORY REQUIREMENTS

Regulations that must be taken into account in assessing the need for GCD include DOE Orders 5820.2, 5480.1A, and 5480.2; NRC regulations in 10 CFR 61, 10 CFR 20; EPA regulations in 40 CFR 141; and a DOE/EPA Memorandum of Understanding on radioactive mixed waste. DOE Order 5820.2, Chapter III, establishes policies and guidelines for managing low-level DOE/defense waste. DOE Order 5480.1A, Chapter XI, sets forth requirements for the environmental protection, safety, and health protection program for DOE operations. DOE Order 5480.2, Chapter II, provides guidance for managing radioactive mixed waste at DOE facilities operated under authority of the Atomic Energy Act of 1954, as amended. 10 CFR 61 outlines the procedures, criteria, and standards established by NRC for the disposal of commercial radioactive waste by near-surface disposal. 10 CFR 20 covers NRC standards for protection against radiation, including regulations pertinent to disposal of radioactive wastes by individual licensees. 40 CFR 141 gives national interim primary drinking water regulations. The Memorandum of Understanding on mixed waste delineates the areas of responsibility of DOE and EPA concerning mixed waste management. A more comprehensive list of relevant regulations may be found in DOE Order 5480.4. The intent of the regulations may be summarized in terms of risk limits from which performance objectives and performance elements may be derived.

## PERFORMANCE OBJECTIVES

### Basic Performance Objectives

The basic performance objectives may be summarized in terms of risk: to reduce the collective risk to the general public and work force to levels that are as low as reasonably achievable and, more specifically, to ensure that the risk to an individual member of the general public does not exceed  $10^{-5}$  fatalities per year and the risk to an individual worker does not exceed a level of  $10^{-4}$  fatalities per year. These are the risk limits currently recommended by the International Commission on Radiation Protection (ICRP).

Applicable radiation protection standards are generally consistent with these risk limits and, in some cases, may be derived directly from them. By stating the basic performance objectives in terms of basic risk limits, one may derive a coherent and consistent set of more specific performance objectives for use in planning. Adjustments of numerical values of parameters used to control risk (e.g., radionuclide concentrations in the air and water, and individual dose limits) may be necessary in order to accommodate specific regulatory requirements, but this does not alter the conceptual

structure used to state basic performance objectives and to derive more specific performance objectives.

DOE radiation protection standards (DOE Order 5480.1A) are currently in the process of revision to make them more consistent with ICRP recommendations. ICRP recommendations may be expected to exert a significant influence on forthcoming NRC and EPA regulations. It is also anticipated that updated recommendations of the National Council on Radiation Protection and Measurements regarding risk and radiation protection standards, which are under development and have reached the stage of preliminary review, will be generally consistent with current ICRP recommendations.

The performance objectives for GCD, and also the GCD threshold and limiting waste-acceptance criteria, are determined by the basic risk limits specified above. The relationships between risk, facility containment capabilities, and radionuclide concentrations are given below. These relationships may be used to establish performance objectives and waste-acceptance criteria in terms of site and GCD facility design parameters.

### Derived Performance Objectives

The relation between the risk to an individual and the hazard presented by radioactive waste may be expressed as a sum of products of transfer and conversion factors for the various pathways and pathway segments by which radionuclides in the waste can migrate to a point of human exposure where they can irradiate an individual or be ingested or inhaled. The pathway sum may be expressed as the formal product:

$$R = (R/E) \times (E/S) \times S \quad (1)$$

where R is the risk (expressed as the annual probability of death due to exposure to radionuclides from the waste), R/E is the risk from unit exposure (where the exposure may be expressed as the concentrations of radionuclides in the air, water, ground, or food at the point of exposure), E/S is the exposure from a unit concentration of radionuclides in the waste, and S is the concentration of radionuclides. (It should be emphasized that Equation 1 is a formal product introduced to simplify the discussion. For quantitative analyses, a sum of products--summed over different pathways and radionuclides--must be used.)

The factor R/E may be calculated from the risk factors (the risk of death from a unit dose of radioactivity or toxic chemical) and the dose conversion factors (which give the relation between the amount inhaled or ingested, or external radiation level, and the dose to critical organs of the body). It is a common factor for all sites and all facility designs. The factor E/S characterizes the containment capability of a site and design, and may be used to characterize the overall performance of the disposal facility and specify derived performance objectives. It may be assumed to be approximately independent of the radionuclide concentrations, but will depend on other waste characteristics (e.g., various parameters, different for each chemical species, that specify properties controlling the release, migration rates, and dilution of the radionuclides).

The E/S would be null (E/S = 0) if containment were perfect. The overall containment factor would be unity (E/S = 1) if the disposal facility provided no containment and no dispersion of the radionuclides occurred (a situation equivalent to direct exposure of an individual to the waste inside a container--noting that one must, in application, distinguish between factors for ingestion, inhalation, or external radiation).

If a risk limit (RL) and the maximum concentration (SM) of radionuclides are given, the performance objective for a GCD facility may be expressed in the form:

$$F = E/S = \frac{RL}{(R/E) \times SM} \quad (2)$$

where F is the overall containment factor, defined to be equal to the source-to-exposure transfer factor E/S.

If, on the other hand, the performance of a site and design is known, and specified in terms of the overall containment factor, then the waste-acceptance criteria may be stated as:

$$ST = \frac{RL}{(R/E) \times FSLB} \quad (3)$$

$$SL = \frac{RL}{(R/E) \times FGCD} \quad (4)$$

where ST is the threshold concentration, the maximum concentration acceptable at an SLB facility, which is determined by the SLB containment factor, FSLB; and SL is the limiting concentration for waste that can be accepted in the GCD facility, which is determined by the containment factor for the GCD facility, FGCD.

One can obtain generic estimates of the containment factors for use in developing generic guidelines for GCD waste-acceptance criteria; however, they are of limited use because of the strong site- and design-specific dependence of the factors. A site- and design-specific pathway analysis for each GCD facility will be needed to establish appropriate waste-acceptance criteria.

The overall containment factor F can be expressed as a product:

$$F = FW \times FC \times FE \times FD \times FNE \quad (5)$$

that is useful for comparing facility designs. The individual factors in the product are related to different features of a GCD operation as follows:

<u>Containment Factor</u>	<u>Controlling Process</u>
FW: Waste form	} Waste processing and packaging
FC: Waste container	

FE: Engineered features	}	Facility design
FD: Depth of placement		
FNE: Natural environment		Site location

It is important to note that the individual containment factors will be time-dependent. The factors FW, FC, and FE will increase with time due to degradation of the waste form, container, and engineered structure, respectively. FD will increase from an initial null value (for times too short for the radionuclides to reach an access point) and will remain at a value determined by the dilution of radionuclides at an access location that would occur under steady-state conditions as a consequence of the greater disposal depth. The factor FNE characterizes containment by the natural environment outside the disposal site boundary and is determined by the choice of site. Under assumed steady-state conditions, it can be treated as a time-independent quantity, except for the groundwater pathway for which the time dependence should be explicitly calculated for each site.

An important performance objective is to ensure that the rate of increase of the containment factor does not exceed the rate of reduction of the source term by radioactive decay or controlled dispersion.

The containment factor may be used as a measure of performance for management of public risk. For occupational risk, a different analysis is needed, which depends on operational procedures and can be controlled by these procedures. Derived performance objectives for occupational risk will be considered in Phase II of the project.

## DESIGN ALTERNATIVES

A number of technological alternatives, ranging from undeveloped concepts to demonstrated technologies, have been suggested for GCD. The GCD document will be limited to a set of alternatives that are in a relatively advanced state of development. Six alternatives are recommended and described: (1) augered shaft, (2) deep trench, (3) engineered structure, (4) hydrofracture, (5) improved waste form, and (6) high-integrity container.

### Augered Shaft

The augered shaft for GCD is a hole in the earth, with a large ratio of length to diameter, of sufficient depth to provide a location for waste that is remote from the penetrations of roots, animals, and human intruders. Although the term "augered shaft" is adopted from the use of readily available equipment that is probably the most convenient method for making this type of excavation--the drill or auger--it is intended to apply to any hole of this general description and constructed by any means.

The characteristics of two demonstration projects, one at the Savannah River Plant (SRP) and the other at the Nevada Test Site (NTS), can be used to illustrate the concept further. The SRP shaft (3) sunk to a depth of 15 m (50 ft), has a diameter of about 2.7 m (9 ft) and a waste layer of

about 6 m (20 ft) thickness to provide a disposal volume of about 45 m<sup>3</sup> (1600 ft<sup>3</sup>). Waste is emplaced into a fiberglass liner, which is backfilled with soil and capped with clay. The NTS shaft (4), sunk to a depth of 37 m (120 ft), has a diameter of 3 m (10 ft) and a waste layer of 12 m (40 ft) thickness to provide a disposal volume of about 90 m<sup>3</sup> (3100 ft<sup>3</sup>). The NTS shaft has no liner and is backfilled with regolith.

### Deep Trench

The deep trench differs from the ordinary SLB trench only in having twice the depth and thus about twice the thickness of cover over the waste (5). Accordingly, the bottom of the trench would be at about 16 m (50 ft) in depth. The deep trench is assumed to provide the same disposal volume as the reference SLB unit, about  $3.8 \times 10^4$  m<sup>3</sup> ( $1.3 \times 10^6$  ft<sup>3</sup>). One of the concerns for the deep trench is the stability of the walls during the emplacement period. If shoring is not used to keep the walls of the unusually deep cavity from crumbling, then the walls must have a gentle slope, determined from a slope-stability analysis of the soil, with the result that a large area is required for the open trench. The unusually large width of the deep, unshored trench may impose some special requirements on equipment and procedures if waste is to be emplaced from the edges by crane.

If necessary, the walls of the deep trench may be lined--either with clay to retard the migration of radionuclides, or with plastic sheeting to reduce seepage into the trench. The floor of the deep trench has a small end-to-end slope and a small side-to-side slope, a layer of sand or gravel for drainage, and a French drain along the lower side to conduct any seepage to a sump. Polyethylene pipes, standing upright in the French drain, permit monitoring after closure. The deep trench is capped by a 1-m thick layer of clay over the backfill, and an outermost layer of topsoil covered with vegetation. Because of the depth of the trench, no special intrusion barriers are considered necessary.

### Engineered Structure

The engineered structure is a disposal unit in which the most important barrier to intrusion and migration of waste components is a chamber with a volume of several hundred to several thousand cubic meters, built of some engineering construction material--usually concrete. The general performance requirements are long-term stability of the structure and low permeability. Drainage, to preserve waste containers and the stability of the structure, is an important element of the design of the engineered structure. Thus, most designs include both external and internal drainage systems. Because of the variety of designs, the description of a reference concept would not be useful. Instead, several examples will be described: the Canadian concept, the French tumulus, and the shored trench of SRP:

The Canadian concept (6) consists of a rectangular trench with walls of reinforced concrete. The floor is a layer of gravel over a layer of a bentonite-sand mixture. The emplaced waste is capped with a layer of compacted clay, then an arched concrete cover, and finally, a layer of topsoil.

The French tumulus (7) consists of a below-grade, rectangular, compartmented structure of concrete floors and walls. The waste-filled compartments are backfilled with grout and covered with a layer of asphalt whose surface is at grade level. This layer serves as the floor for an above-grade structure whose walls are built of stacked concrete cylinders. The waste-filled, above-grade structure is backfilled with gravel and capped with clay and soil.

The SRP engineered structure (3) is formed by excavating a trench with a depth of 3 m (10 ft) and boundaries of 15-30 m (50-100 ft) by 60-150 m (200-500 ft). Shoring walls of concrete, 0.5- to 1.5-m (1.5- to 2-ft) thick, are then inserted into the ground--outlining the trench--to support the earth while a second trench, within the first, is excavated to an additional depth of 6 m (20 ft). Waste is emplaced into this deeper trench onto compacted earth or a concrete floor which is sloped, for drainage collection, to a sump.

### Hydrofracture

Hydrofracture is a method for disposing of waste by mixing the waste with a grout and injecting the resulting slurry into horizontal fractures previously induced into rocks at depths up to 1000 m (3300 ft) below the surface (8). Injections at several levels in the same well result in a stack of relatively thin sheets of solidified grout, separated by vertical distances of about 3 m (10 ft) and fixed into the host rock. Each grout sheet is typically 1-cm (0.4-in.) thick and several hundred meters (up to 1000-ft) wide. The hydrofracture alternative provides containment by three mechanisms: physical containment by the rock formation, fixation by the grout, and retention of any radionuclides leached from the grout by the capacities of the lithology for ion exchange.

The technique has been practiced at ORNL for over 30 years. During an injection at ORNL, waste solution is pumped to a mixer where it is mixed with cement and other additives. The resulting grout is pumped 200-300 m (700-1000 ft) down the injection well and out into the shale formation at a pressure of about 20 MPa (3000 psi). The grout injection rate is typically about 1000 liters/min (250 gal/min); an injection requires about 8 to 10 h to complete.

Although the hydrofracture process was developed to dispose of a special type of waste solution at a specific site, experience suggests that other waste forms could be disposed by this technique at other sites underlain by the type of rock formation, e.g., typically shale, in which horizontally oriented fractures can be induced.

### Improved Waste Form

Several processes for incorporating LLW into monolithic forms have been practiced widely for many years. Some of these processes also provide volume reduction; others present a disadvantageous volume increase. The main reasons for converting wastes to solid monolithic forms are to prevent dispersibility in case of accidents in handling and transportation and also to reduce the leachability of radionuclides in contact with hydrologic seepage. Since none of the solidification processes have been entirely

satisfactory, either because of incomplete solidification or because the properties of the resulting solids do not meet waste-form criteria, development of techniques for the solidification of LLW is still ongoing. Because of the shortcomings of current techniques, descriptions of some of the new techniques under development that may provide better results in the future and evaluations and development work carried out in other DOE programs will be included (9-11). Descriptions will include the most commonly used solidification agents: cement and its many modifications, urea formaldehyde, and bitumen. Other solidification agents that will be briefly described and referred to include polyethylene, polyester resins, epoxy resin, synthetic minerals, glass, polymer-modified gypsum cement (Envirostone), polymer-impregnated concrete, and sulfur cement.

### High-Integrity Containers

Design criteria for high-integrity containers (HIC) are aimed at achieving structural stability and containment of radionuclides over a long period. Use of the HIC has not been frequent, and the general specifications have been translated into the design and manufacture of only a few models. The HIC concepts will be illustrated by guidelines that have been suggested and also by some specific designs that have been described (12-14). Some guidelines for HIC design have focused on handling wastes of specific origin, e.g., spent resins from reactors or the EPICOR-II filter liners from the TMI-2 cleanup. Other guidelines have focused on handling wastes of general LLW types. To meet these guidelines, HICs constructed of concrete and of polyethylene have been proposed.

### SITE SELECTION

Selection of a site for GCD would be guided by a set of criteria describing characteristics that a site must possess if the intended disposal technique is to be successfully carried out there. The criteria for siting a GCD facility would be analogous to the requirements listed in 10 CFR 61.50(a), disposal site suitability for near-surface disposal. Section 10 CFR 50(b) is reserved for requirements addressed to land disposal other than near-surface. It is assumed that the requirements that will appear in this section will apply to GCD, but they have not yet been formulated. Pending the publication of these rules, siting criteria for GCD can only be anticipated. It is assumed that plans for siting a GCD facility might follow those addressed to near-surface disposal, which seem to be sufficiently general that they would apply as minimum requirements, together with additional rules that would be specifically required for each GCD technique. Characteristics that each technique would require of a site may be summarized as follows.

For the augered shaft, the site must have soil that can be augered, is self-supporting, has no karstic or cavernous features, and has a deep cover of soil over the water table.

For the deep trench, the siting criteria should be similar to those for the conventional SLB trench given in 10 CFR 61.50(a), with the added requirement of a deep cover of soil over the water table.

For the engineered structures the siting criteria for 10 CFR 61.50(a) are also appropriate, in addition to requirements that the geologic medium must not place destructive mechanical stresses on the structure, must support the intended loads, and must be chemically inert to the structure.

For hydrofracture, a number of special requirements must be met, mainly by the rock formation that is to serve as host to the injected grout. Among the many requirements are suitable depth; fracturing at small angles to the horizon; inertness to the wastes; low permeability; absence of natural, vertically oriented faults; and isolation from groundwater movement.

For use of improved waste forms and high-integrity containers, no special site requirements are necessary.

## DESIGN SELECTION

### Performance Elements

A performance element is any characteristic of a disposal concept that has a significant effect on performance. Each disposal technique incorporates several performance elements. The planning of a GCD facility should include a review of the performance objectives and technical criteria that must be observed. Performance elements should be evaluated for their contribution to these objectives and criteria and should include:

Depth	Emplacement access
Cover thickness	Lithologic ion exchange
Cover material	Compartmentalization and layering
Fill or grout material	Corrosion resistance
Wall thickness and material	Strength of materials
Drainage	Shielding
Leach resistance	Thermal and radiation stability

### Cost Elements

An important factor in the choice of a GCD design is the cost for construction/operation of such a facility. Because the costs are case-specific, no attempt is made to develop total costs for GCD alternatives. Instead, cost elements that differ from conventional SLB are identified. The cost elements for a conventional SLB are as follows:

#### Development

Direct: Licensing, land, buildings, site security, environmental monitoring, equipment

Indirect: Administration, general supply

#### Operational

Pre-Tax: Labor, fringe, overhead, environmental monitoring, inspections, materials and supplies

After-Tax: Equipment replacement, license renewals, closure approval

### Postoperational

Closure/Stabilization: Building removal, stabilization, labor, fringe, overhead, environmental monitoring, materials and supplies

Extended Care: Labor, fringe, overhead, environmental monitoring, materials and supplies

Cost elements for the augered shaft, engineered structure, and hydrofracture alternatives that differ from conventional SLB consist of the following subset of SLB cost elements:

#### Development

Equipment

#### Operational

Labor, materials, equipment replacement

#### Postoperational

Stabilization

Work is under way to obtain the unit costs for these cost elements.

### COMPARISON OF ALTERNATIVES

A rigorous comparison of GCD alternatives would require a comparative benefit-cost-risk (BCR) analysis. In such an analysis, the total risk (occupational and general public) must be calculated and converted to a dollar value by means of an appropriate trade-off factor:

$$\text{Risk(\$)} = [\text{Trade-off Factor}(\$/\text{fatality})] \times [\text{Risk}(\text{fatalities})]$$

The converted risk and costs may be used to determine a ranking factor:

$$\text{Ranking Factor} = \text{Cost(\$)} + \text{Risk(\$)}$$

This quantity is the negative of the net present value (NPV) used in BCR analysis. The benefits do not enter because they are assumed to have accrued in the activities that generated the waste, and are the same for all alternatives. This ranking factor could, in principle, be used to rank alternatives and select a preferred alternative. In practice, this BCR approach is of limited use. On the basis of a generic analysis of GCD alternatives (15), it was found that the cost is a dominant factor for any reasonable choice of the cost/risk trade-off factor and that risk estimates are very uncertain. The uncertainty could be reduced by using site- and design-specific pathway analyses for estimating risk; however, the uncertainty in even the best state-of-the-art site-specific pathway analyses can be expected to be a factor of 10 or larger (16). Thus, comparative BCR analysis can be expected to reduce to a comparison of cost alone.

An alternative procedure that can be used to screen the facility designs and identify a preferred design for detailed study is, therefore, needed. The proposed approach starts with identification of a list of "design factors" that determine the overall performance of the GCD facility. Advantages or disadvantages of each design for each factor are then ascertained and used to develop a comparison tableau. The following list may be used for this purpose:

- Support of performance objectives/technical criteria
- Cost
- Materials-handling needs
- Complexity
- State of technological development
- Maintenance requirements
- Decontamination and decommissioning requirements
- Environmental effects
- Reliability
- Flexibility in acceptance of waste forms
- Vulnerability to weather
- Ability to handle high radiation levels
- Flexibility in siting requirements
- Ease of performance assessment
- Compatibility with low-volume rate
- Need and ease of remedial action

The tableau would consist of a matrix of entries for each of the six major design alternatives and each factor. The entries would be + (a clear advantage), 0 (no clear advantage or disadvantage), or - (a clear disadvantage). The tableau will depend on the site and on the waste characteristics. This approach can be used to identify a preferred variant of a major design alternative as well as a major alternative--e.g., to select a solidification agent or processing technique for an improved waste form.

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