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Fissile Material Disposition Program

Deep Borehole Disposal Facility PEIS Data Input Report for Immobilized Disposal

Immobilized Disposal of Plutonium in Coated Ceramic Pellets in Grout Without Canisters

Version 3.0

January 15, 1996

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PREFACE

The Department of Energy (DOE) is examining options for disposing of excess weapons-usable nuclear materials (principally plutonium and highly enriched uranium) in a form or condition that is substantially and inherently more difficult to recover and reuse in weapons production. The potential environmental impacts of facilities designed to implement disposition alternatives will be described in the *Storage and Disposition of Weapons-Usable Fissile Material Programmatic Environmental Impact Statement* (PEIS).

The PEIS will examine the environmental, safety, and health impacts of implementing each disposition alternative on land use, facility operations, and site infrastructure; air quality and noise; water, geology, and soils; biotic, cultural, and paleontological resources; socioeconomics; human health; normal operations and facility accidents; waste management; and transportation. This data report is prepared to assist in estimating the environmental effects associated with the construction and operation of a Deep Borehole Disposal Facility, an alternative under consideration for inclusion in the PEIS.

The facility projects under consideration are, for the most part, not site specific. This report therefore concentrates on environmental, safety, and health impacts at a generic site appropriate for siting a Deep Borehole Disposal Facility.

The preparation of a Programmatic Environmental Impact Statement is a requirement of the National Environmental Policy Act (NEPA). This report presents the data and supporting information necessary for the preparation of a PEIS for Immobilized Disposal of Plutonium in a Deep Borehole. The data consists of summaries of the facility design issues and concepts; descriptions of the facility structures, their layout, and the required support services; descriptions and quantities of the environmental emissions, effluents, and wastes generated by the facility; and its resource and employment needs. The data covers the construction, operation, closure, and post-closure performance phases of the facility. In addition to the conceptual design and the PEIS data for the facility, the report also addresses the Research, Development, Testing, and Risk Assessment activities that are required to support the engineering design and site selection for an actual facility.

The design presented in this report is a preliminary conceptual design for a new Deep Borehole Disposal Facility for Immobilized Disposal of Surplus Fissile Materials that, if built, would fully comply with applicable existing environmental, safety, and health laws, regulations, and orders. However, this design is only conceptual and is not intended to serve as a basis for setting up new engineering design and safety standards. These standards can be established only after significant additional work. The Deep Borehole Disposal Facility accepts surplus fissile materials as plutonium-loaded ceramic-coated ceramic pellets for permanent disposal in deep stable geologic formations. The disassembly and conversion of the original feed materials and the immobilization of the plutonium in this disposal form are assumed to be performed at a separate Disassembly, Conversion, and Immobilization Facility at a different site. A *Deep Borehole Disposal Facility PEIS Data Input Report for Direct Disposal* (Wijesinghe et al., 15 January, 1996) similar to this report has been prepared for direct disposal of plutonium in a Deep Borehole Disposal Facility.

1.1.1 Overview of Deep Borehole Disposal Facility Design Concept

In the deep borehole concept for geologic disposal of surplus fissile materials, the material will be emplaced in the lower part of one or more deep boreholes drilled in tectonically, hydrologically, thermally, and geochemically stable rock formations (see Figure 1.1.1-1). Deep, Precambrian crystalline plutonic/metamorphic rock formations appear to have the most favorable characteristic for deep borehole disposal of fissile materials. The depths considered for the "emplacement zone" (2–4 km) in the deep boreholes are several thousands of meters greater than those of mined geologic repositories. The plutonium-loaded ceramic pellets, containing 1% plutonium by weight, are mixed with an equal volume of plutonium-free ceramic pellets and a specially formulated sealing grout, and the mixture is emplaced in the emplacement zone of the borehole without any canisters. The plutonium-free ceramic pellets serve as an inexpensive filler material and reduce the effective plutonium loading of the pellets to 0.5%. The volume fraction of the ceramic pellet aggregate in the pellet–grout mixture is selected to be close to the maximum packing fraction for spherical pellets to prevent further increase or segregation of pellets through settling. The ceramic material is assumed to be a tailored material containing the phases zirconolite ($CaZrTi_2O_7$) and perovskite ($CaTiO_3$) in appropriate proportions and to be approximately 4.0 g/cm^3 in density. A total of 1,250 t of Pu-loaded pellets containing 12.5 t of Pu is emplaced in a single borehole. Thus, the full 50 t of plutonium available for disposal is disposed in four deep boreholes. Once the emplacement zone of the borehole is filled with emplaced material, the "isolation zone," extending from the top of the emplacement zone to the ground surface, is filled and sealed with appropriate materials.

1.1.1.1 Proliferation Resistance

The high resistance to fissile material recovery offered by emplacement in the deep borehole in the present design arises from two sources. First, because of the great depth and the resulting difficulty of gaining access (see National Academy of Sciences, *Management and Disposition of Excess Weapons Plutonium,* 1994), the deep borehole design offers a very high degree of security against recovery by all except the host government in possession of the disposal site. Recovery by even the host government would be a difficult, expensive, hazardous, time-consuming, and easily detectable under taking. Thus, it is essentially a method for permanent disposal of the fissile material without the intent of later retrieval. The immobilized ceramic pellet disposal form used in this design confers a second layer of proliferation resistance because it increases the difficulty of processing any mined-out material into weapons-usable fissile material. Additional layers of defense against proliferation can be embedded in the ceramic pellet disposal form by including optional chemicals that inhibit chemical separation, increase neutron absorption, or increase the difficulty of separation of the fissile isotopes. The degree of physical dilution and the difficulty of chemical separation increase the proliferation resistance provided by the ceramic disposal form.

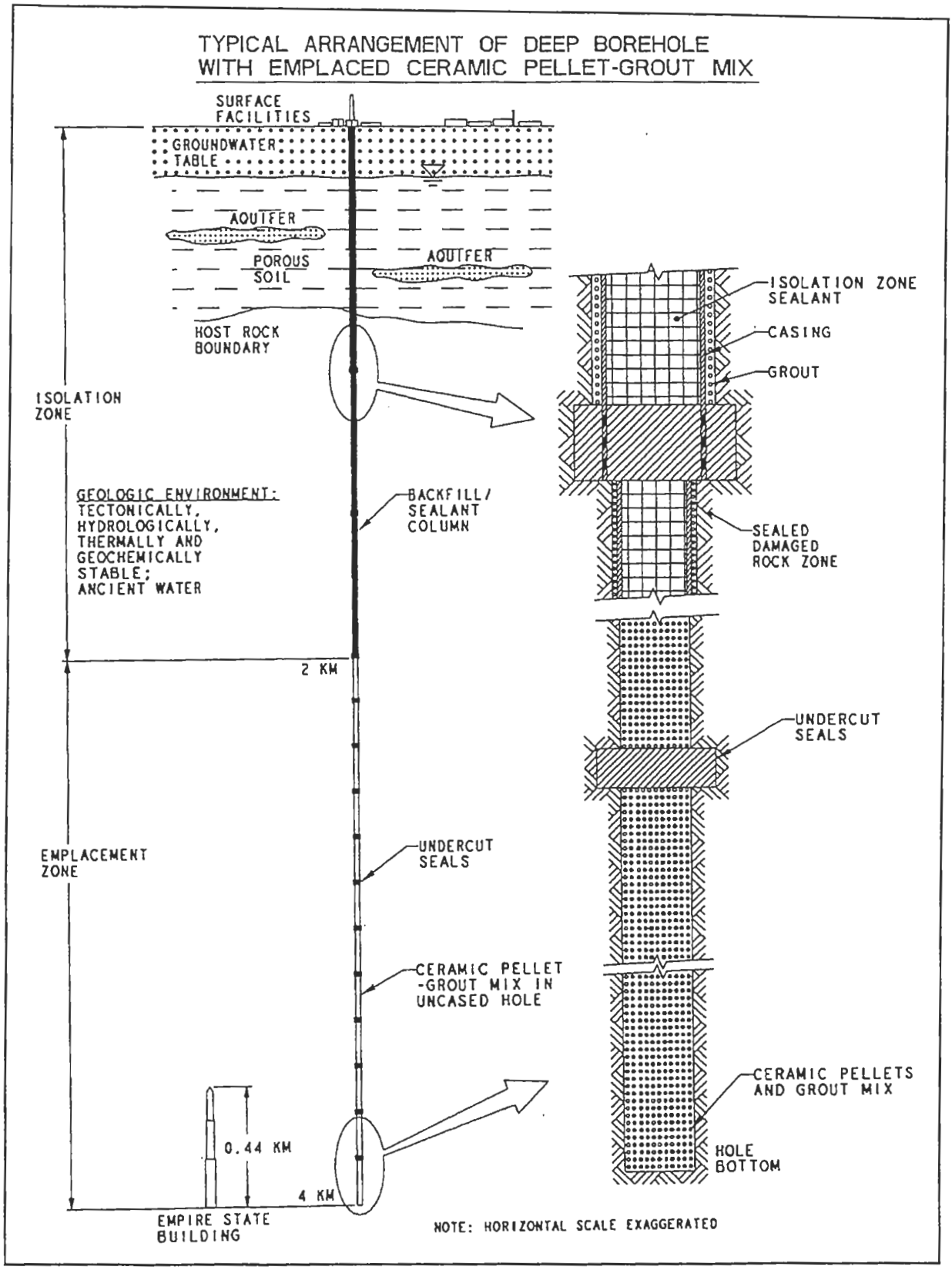


Figure 1.1.1-1. The Deep Borehole Disposal Concept for Immobilized Disposal of Coated Ceramic Pellets in Grout.

to radioactive decay). As a result, heat generation by the disposal form is not large enough to disturb the stagnant fluid regime at depth. However, sealing material degradation, enhanced dissolution of the disposal form by oxidants produced by water radiolysis, and gas generation due to degradation of materials must be considered. For example, plutonium emits alpha radiation, which is known to cause transformation of bentonitic sealing materials to amorphous silicious masses. These factors are particularly important to the durability of engineered barriers.

The Natural Transport Barriers

Irrespective of whether the contaminant is transported by advection with the flowing brine and/or by molecular diffusion, the contaminant will interact physico-chemically with the surrounding rock with the result that a portion of it will be sorbed on to the rock surface. Sorption of the contaminant by the rock reduces the effective speed with which the contaminant moves through and disperses within the rock by both advection and molecular diffusion. The greater the sorption by the rock the slower is the movement of the contaminant away from the source. Consequently, the geosphere itself serves as a "natural transport barrier" that helps to retard the escape of the contaminants from the borehole and their subsequent movement towards the biosphere. Plutonium, in particular, is highly sorbed, and its movement retarded, by most rock types; the unretarded transport time is increased by a factor of 50–10,000. For example, neglecting the dissolution rate limitation on plutonium mobilization, if the brine at an average depth of 3 km flows towards the surface at a uniform velocity of 1 cm/yr, and the retardation factor is uniform and is equal to 1000, the travel time to the surface for plutonium dissolved in brine at that depth would increase from 300,000 yr to 300 million yr.

At great depths in tectonically, thermally, hydraulically, and geochemically stable rock formations, the brine flow velocities are expected to be very small. This is advantageous because it reduces the corrosion and degradation of emplacement canisters and borehole seals, the rate of release of fissile materials to ground water through dissolution, and the rate of convective transport of dissolved contaminants through the surrounding geosphere towards the biosphere. Usually, candidate host rock types are expected to have few fractures at depth, and the apertures and hydraulic conductivities of the fractures that do exist are expected to be much smaller than at shallow depths. However, this is an area of controversy, because although the porosity and permeability of intact plutonic/metamorphic rocks are expected to be very small at great depths because of flow and healing under large compressive in situ stresses, there is also evidence that great depth does not guarantee that the fractures and faults will be closed.

More importantly, in normally pressurized host rock media at large depths, there is likely to be negligible net driving pressure to cause fluid flow, as indicated by the presence of ancient connate waters in granitic rocks at great depths. One force that potentially could initiate fluid circulation at depth is the buoyancy pressure force caused by the increase of temperature with depth. However, effective fluid density is a function not only of temperature but also of the concentration of salt in solution. In normally pressurized areas with normal geothermal gradients (15–25°C/km), it can be shown that the presence of moderate salinity gradients (e.g., 2% per km) would prevent hydrothermohaline instabilities from developing into fluid circulation loops for even relatively large fracture permeabilities. The stability of this stagnant fluid regime, however, can be disturbed in a number of ways. These include, for example, the introduction of large heat sources (e.g., heat of radioactive decay from HLW or criticality-induced heating and steam generation), formation of pressurized fluid zones by earthquake-generated rock mass displacements, and the linking-up of highly permeable existing fault zones by further faulting. Therefore, to exploit the absence of fluid flow and convective transport, criteria for the selection of a site for a deep borehole disposal facility must include the following: (1) seismic stability, (2) low geothermal gradient, (3) high salinity gradient, (4) low density of fracturing, (5) the absence of nearby active fault zones, and (6) the presence of very old, undisturbed connate water.

1.1.1.3 Pre-Closure Safety

The environmental, safety, and health impacts of the transporting, processing, emplacing, borehole sealing, decontaminating, and decommissioning activities that precede the closure of the deep borehole facility are important issues that affect the decision to choose a disposition alternative. However, compared with the difficulties and uncertainties involved in ensuring post-closure safety over an indefinitely long performance period, the risks of pre-closure safety are controllable aspects of the deep borehole facility design whose risks can be reduced to acceptable levels by adopting appropriate facility design safety margins and administrative procedures. Accordingly, Pre-Closure Safety is an important but secondary issue in deep borehole facility design.

The design of the Deep Borehole Facility will include the basic controls for assuring nuclear criticality safety in the Surface Processing Facility and the Emplacing–

Borehole Sealing Facility, during on-site transportation of disposal form between the site perimeter and the Surface Processing Facility, and during transportation of processed disposal form from the Surface Processing Facility to the Emplacing–Borehole Sealing Facility. The process designs will satisfy the double contingency principle, that is, "process designs shall incorporate sufficient safety factors so that at least two unlikely, independent, and concurrent changes in process conditions must occur before a criticality accident is possible" (DOE Order 5480.24). Basic control methods for the prevention of nuclear criticality include the following:

1. Provision of safe geometry (preferred).
2. Engineered density and/or mass limitation.
3. Provision of fixed neutron absorbers.
4. Provision of soluble neutron absorbers.
5. Use of administrative controls.

Although geometric controls are used extensively wherever practical, there are cases where geometric control alone cannot practically provide assurance of criticality safety. In these cases, engineered controls can be used to control neutron moderation, neutron absorbing poisons, and the mass and concentration/density of the materials.

Criticality Safety of Initial Emplacement Configuration and Emplacement Accidents

In canistered design concepts, the initial criticality of the plutonium in the emplacement configuration at emplacement time can be controlled by appropriate choice of the plutonium concentration in the disposal form, the design dimensions, spacing, and arrangement of the disposal form within the emplacement canister, the spacing between the emplacement canisters, and the composition dependent nuclear properties of the materials used in the design. In the present uncanistered design concept, downhole criticality is controlled by adjusting the plutonium loading and concentrations of neutron-absorbing additives in the disposal form for criticality safety in different pellet packing configurations, with emphasis on the close-packed arrangement of the pellets. The criticality analyses used for designing the emplacement configuration must account for not only the presence of the fissile material, but also the moderation, reflection, and absorption nuclear properties of the different materials. The materials that must be considered in the analyses include the sealant materials within the emplacement canister, the canister material, the sealants/concretes between the canister and the borehole wall, and the properties of some portion of the host rock itself. In particular, it is necessary to consider the moderating effects of hydrogen in the bound water in the concrete/grouts and in the brine invading the interstitial pore space of all materials external to the emplacement canister.

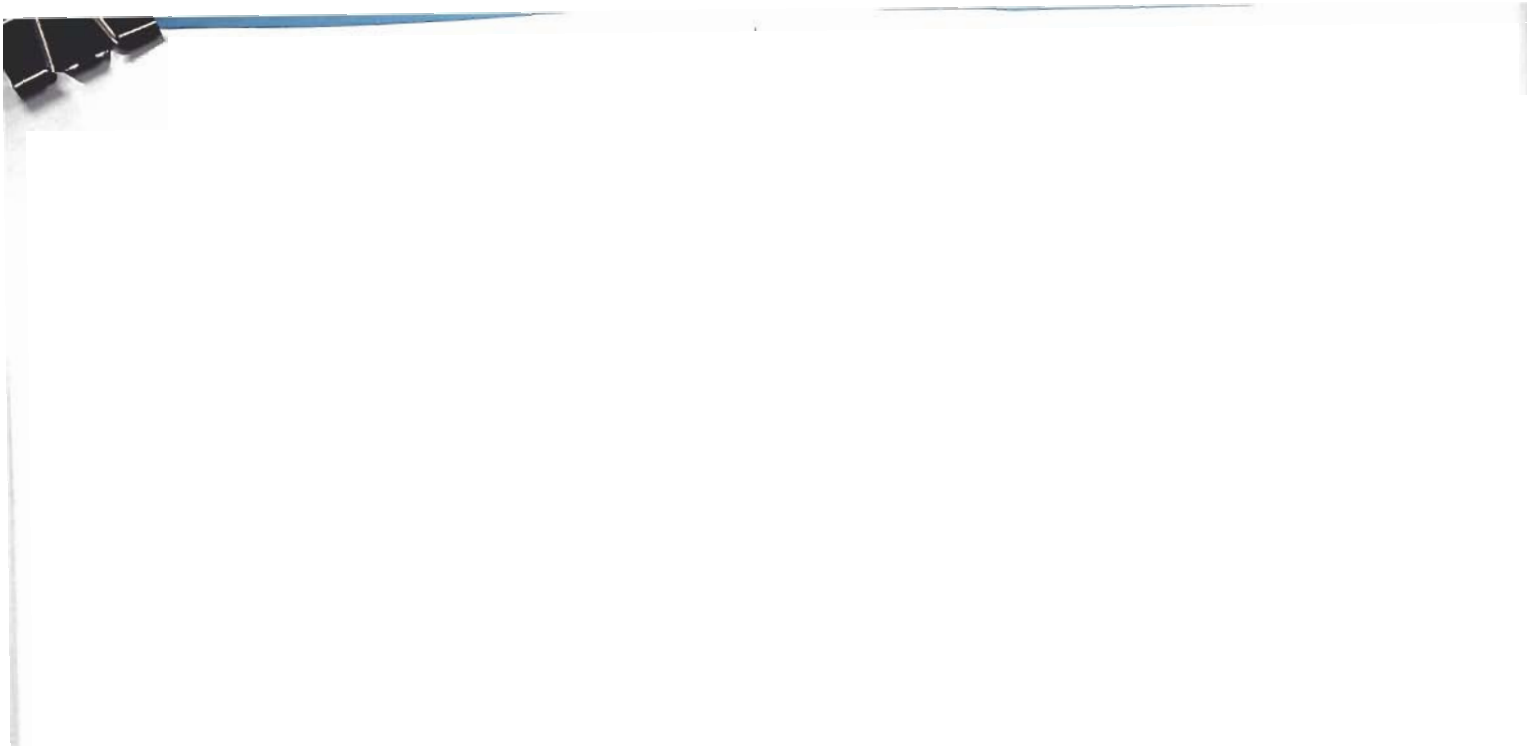
A considerable effort has been devoted in the present design to ensuring criticality safety of the initial emplacement configuration. Some effort has been expended on analyzing the criticality safety of accidents during the emplacement process. These results, which are briefly outlined in Section 2.2.6.3, indicate that the design has a large margin of criticality safety in the initial emplacement configuration.

1.1.1.4 Post-Closure Criticality Safety

Depending upon the circumstances, criticality of the plutonium disposed in the subsurface may become an issue after a long period of time. In contrast to nuclear waste disposal, criticality rather than the heat generation rate, will be the primary determinant of the plutonium loading in the emplaced disposal form. Among the issues that need to be addressed are: (1) the impact on criticality safety of moderation by the hydrogen in brine that will permeate the borehole and the disposal form, (2) criticality due to dissolution, transport, and precipitation/sorption scenarios, (3) criticality under earthquake disrupted emplacement geometries, (4) the consequences of post-closure criticality on borehole sealing, (5) fluid circulation in the geosphere due to criticality induced heat generation, (6) production and possible transport of fission product contaminants to the biosphere, and (7) the venting of the borehole due to complete failure of containment during a criticality event. Also, (8) the addition of neutron absorbers poisons (e.g., gadolinium, hafnium, europium, samarium, boron) as insurance against criticality and as a means of increasing plutonium loading in the disposal form without inducing criticality must be investigated. If neutron poisons are added to the disposal form for these purposes, then another issue that needs to be assessed is (9) the effect of separation of the neutron poison from the plutonium it is designed to control during disposal form dissolution, neutron poison release, and sorptive transport.

Long-Term Criticality Safety of Undisrupted Configurations

In addition to the considerations addressed in Section 1.1.1.3 regarding criticality safety at the time of initial emplacement, additional short-term, intermediate-term, and long-term scenarios will have to be considered to evaluate criticality safety under normal operating and natural event–induced accident conditions. Long-term criticality evaluations are necessary because both ^{239}Pu and its alpha-decay product ^{235}U are fissile and very long lived



The Implementation Schedule for the Immobilized Deep Borehole Disposition Alternative shown in Figure 1.2.2-1 shows the schedules for the Licensing & Permitting, Research & Development, Design & Construction, Operation, Closure (D&D), and Post-Closure Monitoring activities. The estimated start date is September 1, 1996. Further discussion of individual activities are presented in the following subsections.

1.2.2.1 R&D Effort

A comprehensive five-year R&D effort has been planned to support the facility design, site characterization and site selection, licensing, emplacement, and closure phases of the Deep Borehole Disposal option for the disposition of the immobilized plutonium. The areas requiring research and development are as follows:

1. Site characterization, including vertical and horizontal flow rates of brine; geochemical composition, pH, and Eh of brines at depth; temperature and salinity gradients; compositional, chemical, hydrological, thermal, and mechanical properties of host rock at depth; characterization of fracture distribution and properties; borehole logging, surface seismic and cross-borehole acoustic/electrical tomographic imaging for definition of geologic structure and rock properties; cross-borehole pressure and tracer tests for hydrologic characterization; tectonic and seismic stability of the geologic formation.

2. Field technologies, including drilling methods; borehole accuracy, deformation, and stability; sealing technologies for undercut emplacement zone seals, isolation zone sealing and sealing fractures; mixing of the Pu disposal form with grout; emplacement methodology for the pellet–grout mixture; surface and subsurface handling of Pu-loaded ceramic pellets; quality assurance for subsurface operations.

3. Downhole materials performance, including disposal form dissolution and leaching at deep borehole conditions; solubility of Pu in brine at depth; transport properties of Pu in host rock and the pathway to biosphere; durability, selection, and performance of grouting/sealing materials; effects of radiolysis on downhole materials; criticality related properties of disposal forms, grouts, brines, and host rock.

4. Post-closure phase performance assessments, including mechanisms for initiation of fluid flow; transport of Pu and daughter products in the borehole and host rock and along pathways towards the biosphere; Pu release rate from the disposal form; Pu reconcentration mechanisms and evaluation of long-term criticality risk; borehole integrity; grout durability and performance; ES&H, criticality, and proliferation risk assessments; natural analog studies of naturally occurring geologic reactors to support long-term performance predictions; integrated systems level performance; cost analyses for design optimization.

These research and development needs would be addressed in a five-year plan, geared to the following:

1. *Acquiring the required field data* on the conditions at large subsurface depths through an experimental site characterization program at a typical site.

2. *Extending and specializing existing performance analysis models or developing new models* for coupled fluid flow, reactive fissile material transport, disposal form dissolution and fissile material release, downhole short- and long-term criticality assessments, geomechanical analyses, ES&H and proliferation risk assessments, and cost analysis to the deep borehole application.

3. *Acquiring unavailable data* required by the above predictive models through laboratory and field experiments that simulate downhole conditions.

4. *Developing the required engineering and operations technologies* required to safely and efficiently implement the site characterization, drilling, emplacing, borehole sealing, and remote monitoring activities associated with construction, operation, and post-closure performance of a Deep Borehole Disposal Facility.

5. *Performing the long term performance, risk, and cost assessments* required to support the facility design and licensing activities.

6. *Demonstrating the developed drilling, emplacement, and sealing technologies* through a pilot large diameter deep borehole field demonstration.

This R&D Program would begin at the start of the deep borehole disposition program in September 1996 and would continue for five years until September 2001, as shown in the Implementation Schedule in Figure 1.2.2-1.

1.2.2.2 Permitting and Licensing Schedule

The establishment of a regulatory basis for the disposal of excess special nuclear material is necessary prior to obtaining permits and licenses for the deep borehole project. The regulatory basis may requires 4 yr to synthesize the regulations, give public notice, and conduct all the public hearings that are part of the process. It is expected to begin at the start of the deep borehole disposition program in September 1996 and to continue until September 2000.

From the time that the regulations are established, the permitting and licensing schedule will require an additional 5 yr to certify the site. This includes the production of a site specific Environmental Impact Statement (EIS), the holding of public hearings and certifying that the site will meet the design and performance criteria necessary to meet the regulations and satisfy the mitigations given in the EIS. The Site Selection and Characterization in support of this activity will begin in September 1996 at the beginning of the deep borehole disposition program and will culminate with DOE's filing of the deep borehole disposal facility license application in December 2005. This will be followed by the license review and approval process that includes review by the Nuclear Regulatory Commission (NRC), public hearings and decision making by the Atomic Safety Licensing Board (ASLB) culminating in the NRC issuing a license to construct and operate the facility in March 2010.

1.2.2.3 Construction, Operation, Closure, and Post-Closure Schedules

The Implementation Schedule to deploy, operate, and decommission the borehole disposal facility is presented in Figure 1.2.2-1. As indicated in this schedule, conceptual design of the deep borehole disposal facility begins at the start of the deep borehole disposition program in September 1996 and continues until April 2001. The conceptual design is required for the preparation of the EIS by the DOE. Title I design begins at the same time as the preparation of the site specific EIS. Title I & II (preliminary and detailed design) is estimated to require approximately 3.75 yr to complete. This will allow construction to start in December 2004. The construction is estimated to require about 4 yr leading to start of operations of the facility in September 2009.

After initial preparation and drilling, emplacement operations are assumed to start in April 2010, continue for 10 yr, and be complete by April 2020. Decontamination and decommissioning of the facility is estimated to require approximately 3 yr resulting in an overall program completion date of September 2022.

The emplacement operations for this option could be accelerated and completed in 3 yr if the Pu final form material could be all shipped to the borehole site within that period. This will accelerate the overall program completion date to June 2016.

1.2.3 Compliance

1.2.3.1 Rules, Regulations, Codes, and Guidelines

The regulations that cover the requirements that must be met for the disposal of Surplus Nuclear Materials in a Deep Borehole Disposal Facility address a wide variety of issues. These issues include transportation, operation of the Surface Processing Facility, emplacement and sealing of the boreholes, closure of the facility, post-closure performance, and possibly post-closure monitoring.

Existing regulations that could apply to the development of regulations for a Deep Borehole Disposal Facility are summarized in Figure 1.2.3.1-1. The off-site transportation of excess nuclear material will be covered by 49 CFR 173.7 for U.S. Government material, with 49 CFR 173, Subpart I, for radioactive materials. The packaging will be certified to be in conformance with 10 CFR 71. The transportation of the material will conform to the IAEA Safety Series No. 6 and to the additional requirements for the shipment of plutonium given in 10 CFR 71. The Safeguards and Security for offsite shipments must conform to 10 CFR 73.26.

The on-site activities must conform to the procedure rules given in 10 CFR 820. The nuclear safety management at the site will conform to the use in the proposed 10 CFR 830 regulation. The occupational radiation protection will conform to 10 CFR 835. The quality assurance program will be similar to 10 CFR 60 Subpart G, which will form the basis for the QA program for the facility.

1.2.3.2 Safeguards and Security

Safeguards and security protection for the disposition of excess special nuclear material are assumed to conform to the applicable sections of DOE 5630 series orders or their appropriate future alternatives.

1.2.3.3 Environmental, Safety, and Health (ES&H)

The various areas of ES&H that are of significant concern for the deep borehole facility include the contamination of water by the processing of the excess plutonium as well as exceeding the allowable concentration of

The Borehole Array Area contains the deep boreholes in which the coated ceramic pellets will be mixed with grout and emplaced without canisters. The deep boreholes are drilled by a relocatable drilling facility that moves from one drill site to another as the boreholes are drilled in sequence. The boreholes are typically 4 km in depth and decrease in diameter with depth in a stepwise fashion. The Drilling Facility drills the boreholes and seals permeable zones, fractures, and near-field drilling-induced damage zones in the rock formations as they are encountered. It also installs several well casings of decreasing diameter with depth and cements the spaces between the casing and the borehole wall with cement grout. The lower 2 km of the boreholes, comprising the emplacement zone, will be located in competent host rock and will not be cased.

A separate relocatable Emplacing–Borehole Sealing Facility will emplace ceramic pellets as a concrete mix in the boreholes in the sequence in which the boreholes are drilled. The duration of emplacement operations will depend on the schedule of delivery of disposal form feed material to deep borehole facility. An accelerated delivery schedule may require additional Drilling and Emplacing–Borehole Sealing Facilities.

2.1.2 Deep Borehole Disposal Facility Plot Plan

Figure 2.1.2-1 shows a general plot plan for the Deep Borehole Disposal Facility. Detailed descriptions of individual buildings are provided in Section 2.1.3. The size, number, and arrangement of facility buildings is conceptual, and the plot plan conveys general layout information only.

The Site Plan of the Deep Borehole Disposal Facility given in Figure 2.1.2-2 shows in detail the layout of the facility in both the Main Facility and Borehole Array Areas. It also shows the access routes for off-site transportation and the two on-site transportation routes for trucks bearing plutonium. Figure 3.1.7-1 shows the Security Boundaries and Buffer Zone Surrounding the Facility. It also shows the 4 boreholes required by this design and the spacing between the boreholes in the array.

For the purpose of preparing this document no site-specific data can be given for an actual site because no specific site has been selected. Instead, the data provided is for a generic example site. The generic site description is given in Section 3, together with a generic site area map (Figure 3.1.1-1), a hydrogeologic cross section of the subsurface at the site (Figure 3.1.5-1), and a generic site plan (Figure 3.1.7-1). The general features of the facility site are a Main Facility comprising a Surface Processing Facility, administration buildings, and other support facilities in the southern part, and a Borehole Array area with the Drilling and Emplacing–Borehole Sealing Facilities located in the northern part of the site. The surface processing and waste treatment areas in the southeast quarter of the facility are located as far as possible from the administration and personnel services areas located in the southwest quarter. The railway and truck road connections are from the southeast with ready access to the plutonium receiving area of the Surface Processing Facility, the warehouses and the drilling materials laydown area; passenger traffic access is from the southwest of the site. The roads have been routed to provide unrestricted access to truck traffic plying between the Surface Processing Facility, the drilling materials laydown area, and the Borehole Array while avoiding the administration and personnel services areas with passenger traffic.

The Site Map in Figure 3.1.7-1 also shows security boundaries: the Protected Areas (PA), the Limited Areas (LA), and the Property Protection Areas (PPA) of the Deep Borehole Disposal Facility. The Surface Processing Facility in which plutonium is received and stored and the Emplacing–Borehole Sealing Facility to which the ceramic pellets are brought from the Surface Processing Facility are within separate Protected Areas (PA). Each PA is secured with a double fence and intruder detection systems. The PA and operations involving classified materials are contained within the Limited Area (LA). The (PPA) bounded by the Site Perimeter Fence surrounds the LA and includes a 1.6-km-wide (1-mile) buffer zone surrounding the facility. The passenger vehicle parking and passenger services (e.g., cafeteria, training) facilities are located outside the LA but within the PPA. Access to the site is controlled at the guardhouses located at both the Site Perimeter Fence and at the Security Fence surrounding the LA and PA areas of the Main Facility. Passenger traffic to the Main Facility is controlled at the east gates while rail and truck traffic are controlled at the west gates. Access to the Borehole Array, which is located entirely within the LA, is only permitted to traffic arriving from the Main Facility area. Access to the Surface Processing Facility and the Emplacing–Borehole Sealing Facility is controlled at guardhouses located at the Protected Area (PA) perimeter fences surrounding these two facilities.

A Ventilation Exhaust Stack discharges ventilation air from the Receiving and Processing Building comprising the Surface Processing Facility and from the Process Waste Treatment System in the Waste Treatment Building. Other sources of airborne emissions at the site are the Boiler Stack at the Support Utilities Building and the HVAC exhaust outlets from the non–process support buildings. All non-process liquid effluents from the site are treated in the Sanitary and Utility Waste Treatment Systems in the Waste Treatment Building.

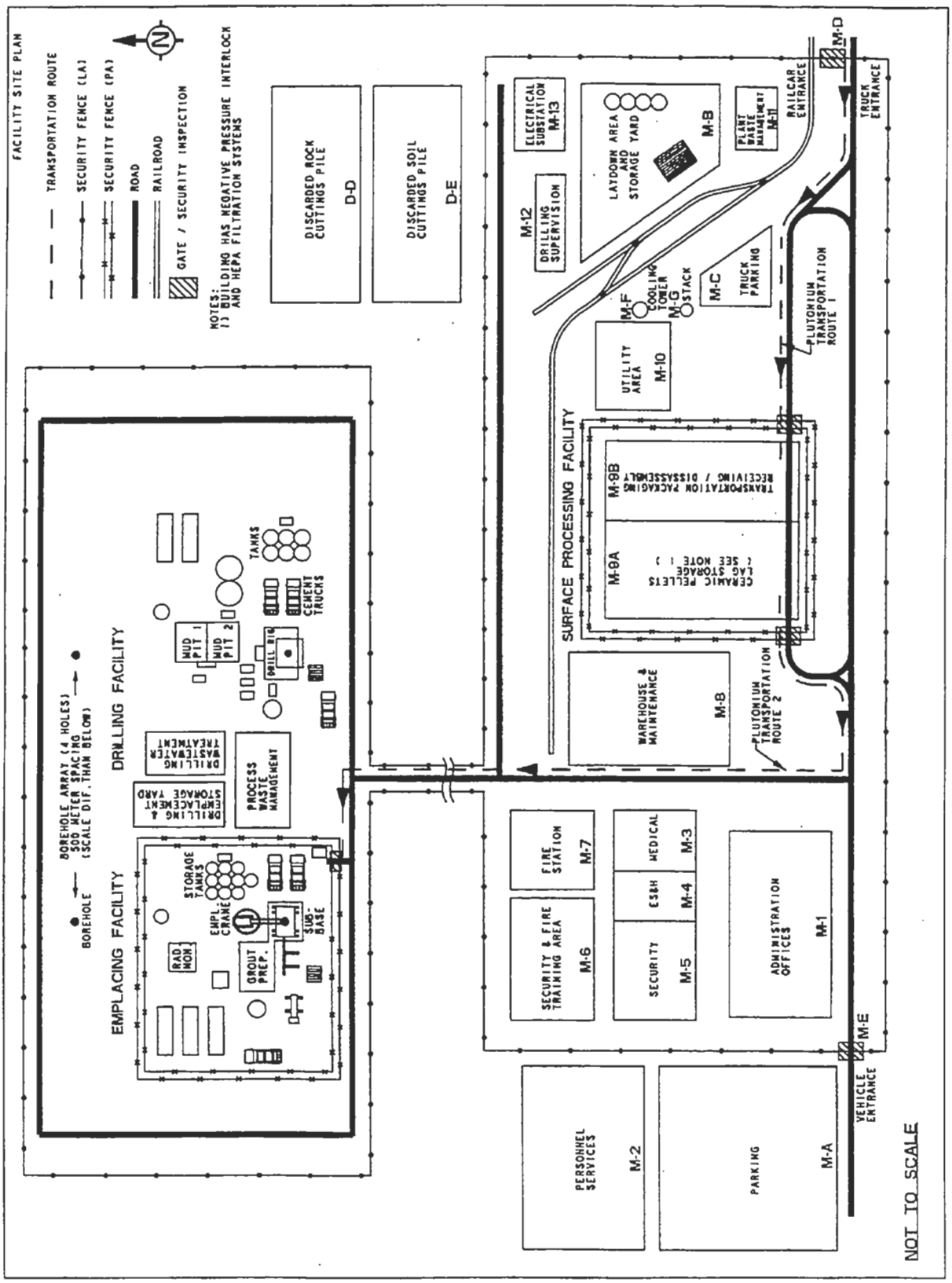


Figure 2.1.2-2. Deep Borehole Disposal Facility Site Plan Detail and Plutonium Transportation Routes.

Table 2.1.3-1. Deep Borehole Disposal Facility Data (Continued).

Building Name	Building Code	Footprint (m^2)	Number of Levels	Special SNM Materials	Construction Type
Drilling Facilities		46,450			
Drill Rig	D-1	1,858	1	None	Steel Frame
Drilling Shift Office Trailers	D-2	1,858	1	None	Trailer
Cement Trucks	D-3	139	1	None	Vehicles
Cement & Water Storage Tanks	D-4	465	1	None	Steel Tanks
Compressor Station	D-5	47	1	None	Concrete Pad
Potable Water Tank	D-6	47	1	None	Stainless Steel
Drilling Fluid Tanks	D-7	465	1	None	Steel
Treated Water Storage	D-8	3,716	1	None	Steel, concrete
Generator Truck	D-9	70	1	None	Vehicle
Drilling & Emplacing Storage Yard	D-A	929	1	None	Concrete
Drilling Wastewater Treatment	D-B	186	1	None	Steel Frame
Drilling Mud Pits	D-C	7,432	1	None	Earth
Mud & Water Pumps	D-D	47	1	None	Concrete Pads
Pipe Storage	D-E	186	1	None	Packed Earth
Emplacing Facilities		46,450			
Emplacing Crane	E-1	1,858	1	None	Steel Frame
Radiation Monitoring	E-4	93	1	None	Light Steel Frame
Containment Structure	E-5	279	1	SNM Waste	Heavy Steel Enclosure
Emplacing Sub-Base	E-6	186	1	SNM Waste	Steel Frame
Emplacing Shift Office Trailers	E-7	1,858	1	None	Trailer
Storage Tanks	E-8	186	1	SNM Waste	Steel
Compressor Station	E-9	47	1	SNM Waste	Concrete Pad
Generator Truck	E-10	70	1	SNM Waste	Earth
Cement Trucks	E-11	139	1	SNM Waste	Earth
Potable Water Tank	E-12	47	1	SNM Waste	Steel
Pipe Handling Crane	E-13	139	1	SNM Waste	Packed Earth
Process Water Storage	E-14	93	1	SNM Waste	Steel Tank
Waste Monitoring & Testing Station	E-15	47	1	SNM Waste	Light Steel Frame
Entrance Security Portal	E-16	9.3	1	None	Masonry

2.1.3.1 *Receiving and Processing*

A Surface Processing Facility for receiving the coated ceramic pellet disposal form from an off-site immobilization facility, inspecting and accounting for received material, and storing the received Pu-loaded pellets is provided in the Main Facility Area. The plot plan of this Receiving Sub-Facility is given in Figure 2.1.3.1-1. In addition to this receiving sub-facility, a processing facility is required to mix the ceramic pellets with the grout in the Emplacing–Borehole Sealing Facility Area. The plot plan of this Ceramic Pellet–Grout Mix Preparation Emplacing Sub-Facility that is located in the Borehole Array Area is given in Figure 2.1.3.1-2.

2.1.3.2 *Waste Management*

A Process Waste Management Facility is provided for treating the Process Radwastes and Process Wastewater in the Borehole Array Area. These wastes are generated by the borehole disposal operations. In addition, a Plant Waste Management Facility is provided in the Main Facility Area to handle Utility and Sanitary Wastes. A plot plan of the Process Waste Management Facility is giv in Figure 2.1.3.2-1.

2.1.3.3 *Administration*

The Administration building houses administrati and engineering offices, a central records storage are meeting and conference rooms, and Human Resourc offices. It also houses accounting and computer faciliti used for administrative/payroll operations and records sto age, a control mail facility, a public information displa and miscellaneous storage and service areas.

2.1.3.4 *Personnel Services*

The personnel services building is a single-story struc ture that houses a cafeteria and a multipurpose trainin facility.

The major functional areas of the cafeteria are the din ing room, scramble-type serving area, dish washing area food receiving, storage, staging, preparation area, and a waste handling area. The cafeteria is operated by a privat commercial vendor and is capable of 24-hr operation.

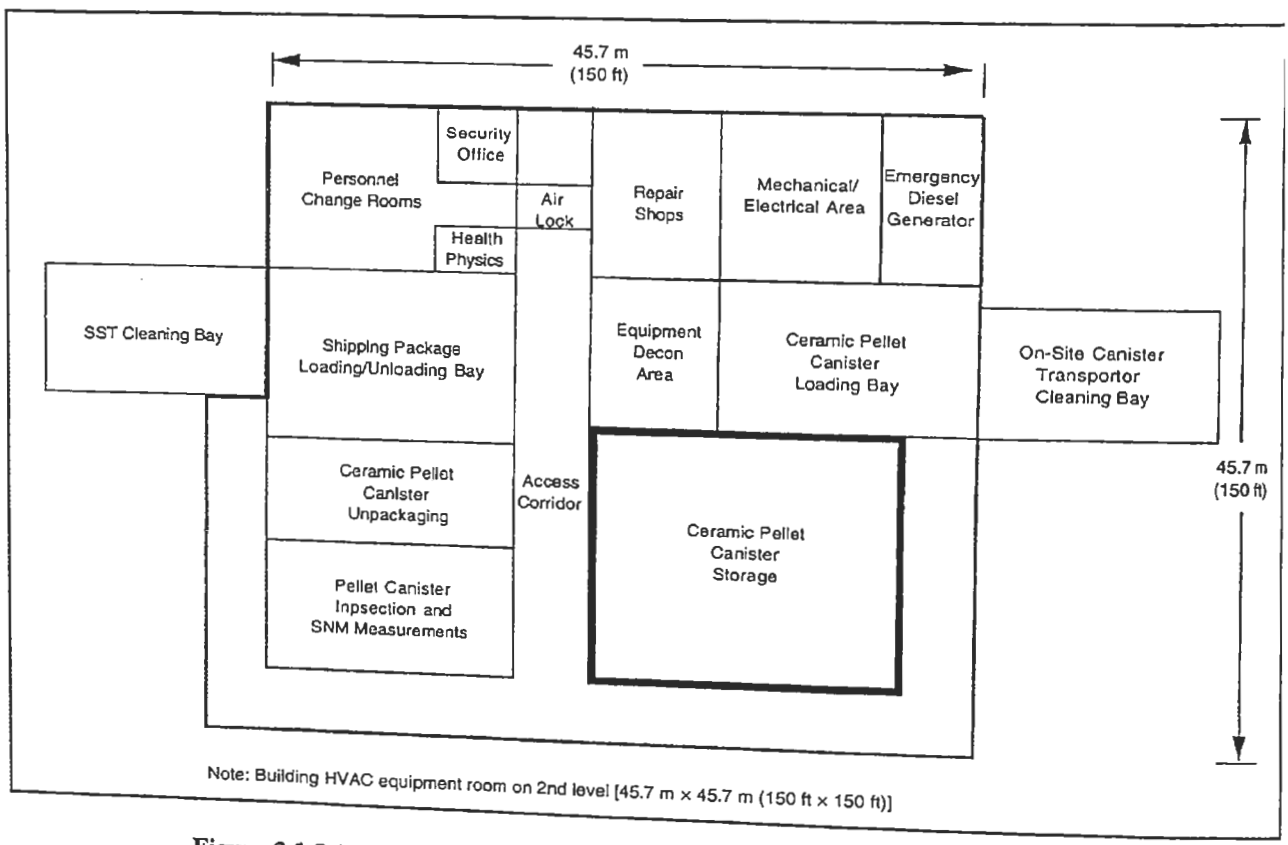


Figure 2.1.3.1-1. Surface Processing Facility Receiving Sub-Facility Plot Plan.

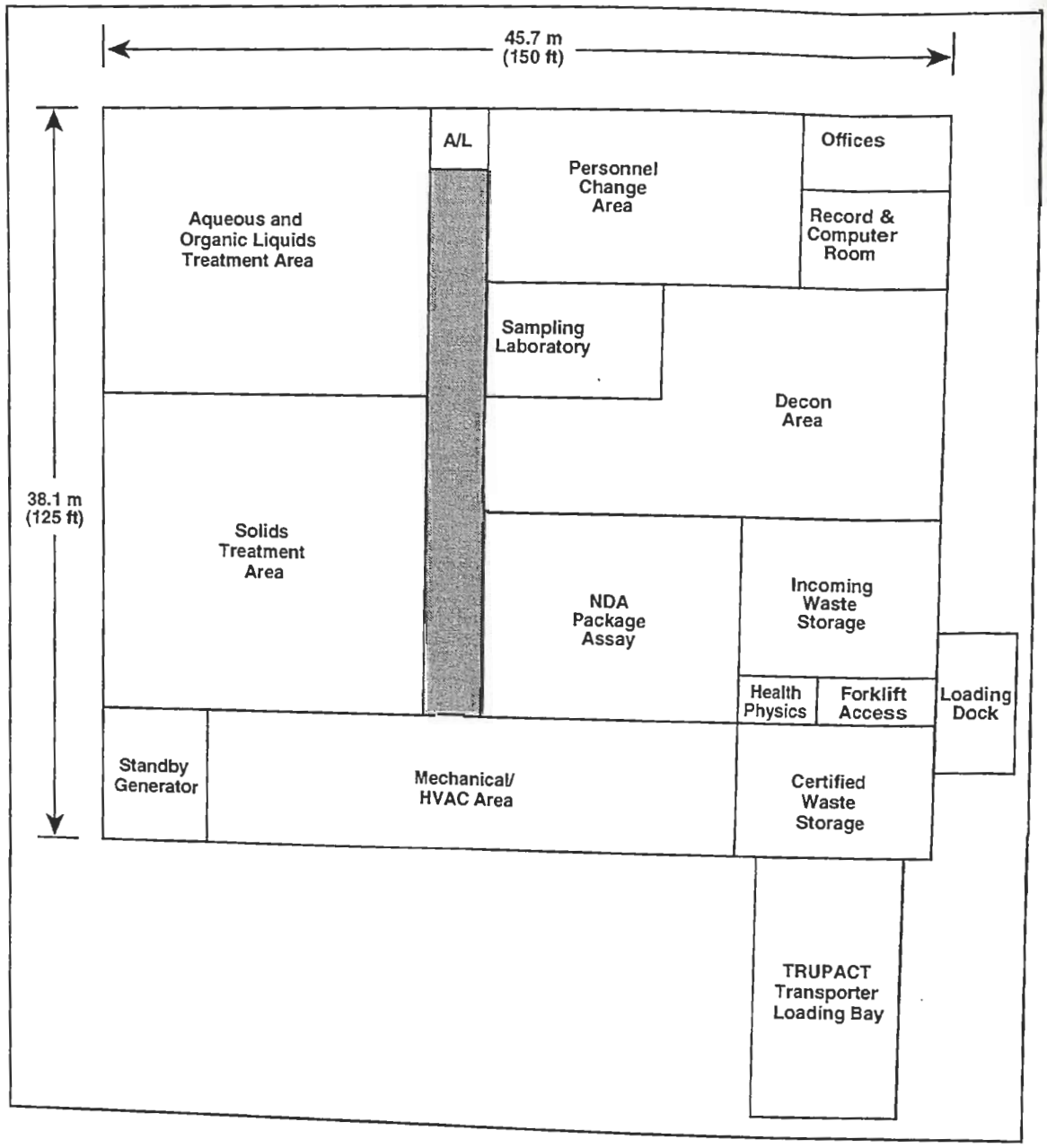


Figure 2.1.3.2-1. Process Waste Management Facility Plot Plan.

in an electrical power switchyard, located in the northeast corner of the main facility area, where the voltage is transformed to facility distribution levels. Power is provided to the borehole array area by low voltage overhead lines.

High-voltage buses within the Electrical Substation are installed overhead on steel or concrete structures. Surge voltage protection equipment, potential transformers, current transformers, and equipment for relaying and metering are installed on the high-voltage bus, the circuit breakers, and the transformers. The switchyard breakers are selected with appropriate interruption rating compatible with the fault current available from the transmission system. Power is distributed to the Main and Borehole Array Area by underground cables.

Emergency Power

Emergency power is provided by diesel generators located in the facility utility area. Emergency power will be provided for the safety class loads.

2.1.3.8 *Security Center*

The Security Center serves as the security administrative headquarters and contains a pistol firing range, armory, lockers, change rooms, training and meeting rooms, offices, and a storage room for supplies.

2.1.3.9 *Environmental, Safety, and Health*

Environmental, Safety, and Health is a fully equipped laboratory that is provided to perform analyses for utilities monitoring and control, environmental emissions and effluents monitoring, waste characterization, and health physics and industrial hygiene monitoring. Tests performed include radiochemistry (alpha, beta, and gamma radiation) and chemical analyses as needed. External dosimetry laboratories, radiation instrument laboratories, and a source calibration area are included. The building also includes offices and office support areas and common-use spaces such as lunch/break room and change/restrooms.

2.1.3.10 *Medical Center*

The Medical Center provides limited medical and wellness care services, and is particularly needed because of the likelihood of the Deep Borehole Disposal Facility being located in a remote area. Seriously injured or contaminated employees are externally decontaminated and are evacuated to a local emergency facility. This facility provides space for various medical services, such as first aid, dispensary, physical examinations, x ray and EKG, and laboratory space for various testing services and physical/industrial therapy. Office space for medical staff and records is included. Additional toilet facilities are provided for the employee drug testing program.

2.1.3.11 *Fire Station*

The Fire Station is provided to house the fire department fire engines, ambulances, and other emergency vehicles and emergency personnel.

2.1.3.12 *Emplacing Shift Office Trailers*

Offices and other facilities will be available for management and employees at the emplacing location.

2.1.3.13 *Emplacing Waste Management Facility*

Wastes produced during the emplacement process will be processed at the emplacement facility waste management building or transported to the main waste management building.

2.1.3.14 *Radiation Decontamination and Monitoring*

Separate Radiation Monitoring systems will be provided in the Emplacing–Borehole Sealing Facility and Main Facility Areas.

2.1.3.15 *Drilling Shift Office Trailers*

Office and rest areas will be provided at the Drilling and Emplacing–Borehole Sealing Facilities for employee convenience.

2.2 Design Safety

2.2.1 Earthquake

All plant structures, systems, and components (SSCs) will be designed for earthquake generated ground accelerations in accordance with *Design and Evaluation Guidelines for DOE Facilities Subjected to Natural Phenomena Hazards,* UCRL-15910 (DOE-STD-1020-92).

Under this guidance, the applicable seismic hazard exceedance probability of 2×10^{-3} for General Use (Performance Category 1), 1×10^{-3} for Low and Moderate Hazard (Performance Category 2 & 3), and 2×10^{-4} for High Hazard (Performance Category 4) SSCs will be used.

Seismic design considerations for Performance Category 3 and 4 SSCs will include provisions for such SSCs to function as hazardous materials confinement barriers, and also for adequate anchorage of building contents to prevent their loss of critical function during an earthquake. In essence, design considerations avoid premature unexpected loss of function and attempt to maintain ductile behavior in structures during earthquakes.

Characteristics of the lateral force design are as important as the magnitude of the earthquake load used for design. These characteristics include redundancy, ductility, the combining of elements to behave as a single unit, adequate equipment anchorage, allowance for the impact of nonuniformity and asymmetry in structures and equipment, detailing of connections and reinforced concrete elements, and the use of specified materials in their construction.

In addition to structural safety, proper operation of emergency systems during and after an earthquake is essential. The fire protection system, emergency power, water supplies, and the controls for the safety class equipment are examples of plant systems that must be available following an earthquake. As stated in Chapter 4 of

UCRL-15910 (DOE-STD-1020-92) under Survival of Emergency Systems, "earthquake-resistant design considerations extend beyond the dynamic response of structures and equipment to include survival of systems that prevent facility damage or destruction due to fires or explosions."

2.2.2 Wind

All new plant structures, systems, and components (SSCs) will be designed for wind or tornado load criteria in accordance with UCRL-15910 and the corresponding facility usage and performance goals. Wind loads will be based on the annual probability of exceedance of 2×10^{-2} for General and Low Hazard (Performance Category 1 & 2), 1×10^{-3} for the Moderate Hazard (Performance Category 3), and 1×10^{-4} for the High Hazard (Performance Category 4) SSCs. The sites for which tornadoes are the viable wind hazards will be designed for the annual probability of exceedance of 2×10^{-5} as defined in Table 5-3 of *Design and Evaluation Guidelines for DOE Facilities Subjected to Natural Phenomena Hazards*, UCRL-15910 (DOE-STD-1020-92).

Wind design criteria will be based on annual probability of exceedance, importance factor, missile criteria, and atmospheric pressure change as applicable to each performance (usage) category as specified in Table 5-2 of UCRL-15910.

As stated in UCRL-15910, characteristic safety considerations will be reflected in the design of the system in that, "the main wind-force resisting system must be able to resist the wind loads without collapse or excessive deformation. The system must have sufficient ductility to permit relatively large deformations without sudden or catastrophic collapse. Ductility implies an ability of the system to redistribute loads to other components of the system when some part is overloaded."

2.2.3 Floods

All facilities and buildings should preferably be located above the critical flood elevation (CFE) from the potential flood source (river, dam, levee, precipitation, etc.) or the site/facility will be hardened to mitigate the effects of the flood source such that performance goals are satisfied. Emergency operation plans will be developed to safely evacuate employees and secure areas with hazardous, mission-dependent, or valuable materials. The extent of the flood hazard will be determined using the appropriate usage (performance) category for determining the "Annual Hazard Probability of Exceedance," which is 2×10^{-3} for General Use (Performance Category (1), 5×10^{-4} for Important or Low Hazard (Performance Category 2), 1×10^{-4} for Moderate Hazard (Performance Category 3), and 1×10^{-5} for High Hazard (Performance Category 4) facility as defined in Chapter 6 of UCRL-15910. For moderate- and high-hazard facilities located below the design basis flood (DBFL) elevation, the design must be developed so that continued facility operation is provided.

The CFE will be determined by obtaining the appropriate DBFL. The DBFL is the peak hazard level (flow rate, depth of water, etc.) corresponding to the mean annual Hazard Probability of Exceedance" or combination of flood hazards (river flooding, wind–wave action, and corresponding loads associated with peak hazards and applicable load combinations (hydrostatic and/or hydrodynamic forces, debris loads, etc.).

Site drainage must comply with the regulations of governing local agency. The minimum design level the Storm Water Management System is the 25-yr, storm, but potential effects of larger storms up to the yr, 6-hr storm will also be considered. However, S Water Management Systems must prevent the CFE being exceeded. Accordingly, for some facilities, S Water Management Systems may have to be designed more extreme storms.

Whenever possible, all facilities in performance egories above the General Use Category (Performance egory (1) will be constructed with the lowest floor of structure, including subsurface floors, above the lev the 500-yr flood. This requirement can be met by s and/or flood protection. Whenever possible, all fac including their basements in all performance categ will be sited above the 100-yr flood plain (DOE 64 Section 0111-2.5).

2.2.4 Fire Protection

The fire protection systems of the plant and its ciated support buildings will be in accordance with orders and National Fire Protection Association Code Standards.

Redundant firewater supplies and pumping cap ties (electric motor drivers with diesel backup) will b stalled to supply the automatic and manual fire prote systems located throughout the site. One supply tan one set of pumps will be designated to meet Design Earthquake requirements. Appropriate types of fir tection systems will be installed to provide life safety vent large-loss fires, prevent production delay, ensure fire does not cause an unacceptable on-site or off-s lease of hazardous material that will threaten the p health and safety or the environment and to minimiz potential for the occurrence of a fire and related pe

Specific production areas and/or equipment will be provided with the appropriate fire detection and suppression features as required with respect to the unique hazard characteristics of the product or process. A fire hazards analysis will be performed to assess the risk from fire within individual fire areas of the facility.

All sprinkler water that has been discharged in the Surface Processing Facility and the Emplacing–Borehole Sealing Facility will be contained, monitored, sampled, and (if required) retained until it can be disposed of safely.

2.2.5 Safety Class Instrumentation and Control

The safety classification of instrumentation and controls will be derived from the safety functions performed. This safety classification is based on DOE 6430.1A and DOE 5481.1B.

Safety class instrumentation will be designed to monitor identified safety related variables in safety class systems and equipment over expected ranges for normal operation, accident conditions, and safe shutdown. Safety class controls will be provided, when required, to control these variables.

Suitable redundancy and diversity will be used when designing safety class instrumentation to ensure that safety functions can be completed, when required, and that a single-point failure will not cause loss of protective functions. Redundant safety class signals must also be physically protected or separated to prevent a common event from causing a complete failure of the redundant signals. IEEE 379 and IEEE 384 provide the design bases for redundancy and separation criteria. Safety class instrumentation will be designed to fail in a safe mode following a component or channel failure. Safety class UPS power will be provided when appropriate.

2.2.6 Nuclear Criticality

2.2.6.1 Criticality Safety of Surface Operations

The design of the Deep Borehole Facility will include the basic controls for assuring nuclear criticality safety in the Surface Processing Facility and the Emplacing–Borehole Sealing Facility, during on-site transportation of plutonium feed materials between the site perimeter and the Surface Processing Facility, and during transportation of processed disposal form from the Surface Processing Facility to the Emplacing–Borehole Sealing Facility. The process designs will satisfy the double contingency principle, that is, "process designs shall incorporate sufficient safety factors so that at least two unlikely, independent, and concurrent changes in process conditions must occur before a criticality accident is possible" from DOE 6430.1A. Basic control methods for the prevention of nuclear criticality include the following:

1. Provision of safe geometry (preferred).
2. Engineered density and/or mass limitation.
3. Provision of fixed neutron absorbers.
4. Provision of soluble neutron absorbers.
5. Use of administrative controls.

Although geometric controls are used extensively wherever practical, there are cases where geometric control alone cannot practically provide assurance of criticality safety. In these cases, engineered controls can be used to control neutron moderation, neutron absorbing poisons, as well as the mass, concentration/density of the materials.

2.2.6.2 Criticality Regulations for Surface Processing

Technical criteria for criticality safety in Surface Processing Facility Operations will be mission-specific but may be based on HLW requirements given in 10 CFR 60.131 (b)(7): "All systems for processing, transporting, handling, storage, retrieval, emplacement, and isolation of radioactive waste shall be designed to ensure that a nuclear criticality accident is not possible unless two unlikely, independent, and concurrent or sequential changes have occurred in the conditions essential to nuclear criticality safety. Each system shall be designed for criticality safety under normal and accident conditions. The calculated effective multiplication factor (K_{eff}) must be sufficiently below unity to show at least a 5% margin, after allowance for the bias in the method of calculation and the uncertainty in the experiments used to validate the method of calculation." That is, the criticality safety requirement specified in this document is that the effective criticality coefficient be maintained at a value less than 0.95.

2.2.6.3 Post-Emplacement Downhole Criticality Safety

In the context of the present deep borehole disposal facility design, downhole criticality safety events that are of concern can be classified into three broad categories as follows:

Category 1. Criticality in Undisrupted Emplacement Configuration

Category 1.1. Criticality in undisturbed initial emplacement configuration

Category 1.2. Criticality in emplacement configuration disturbed only by material property alterations

Category 2. Criticality in Disrupted Emplacement Configurations

Category 2.1. Criticality in emplacement accident configurations

Category 2.2. Criticality in disrupted configurations due to natural phenomena

Category 3. Criticality due to Geochemical Reconcentration

Category 3.1. Criticality due to geochemical reconcentration in borehole

Category 3.2. Criticality due to geochemical reconcentration in geosphere

In this uncanistered design concept, downhole criticality is controlled and prevented by adjusting the plutonium loading and the concentrations of neutron absorbing additives in the disposal form for criticality safety under the design assumption that the pellets are close-packed at the maximum volume fraction that can be achieved. The criticality analyses used for designing the emplacement configuration must account for not only the presence of the fissile material, but also the moderation, reflection, and absorption nuclear properties of the different materials, and the properties of some portion of the host rock itself. In particular, it is necessary to consider the moderating effects of hydrogen in the bound water in the grouts and the brine invading the interstitial pore space of all materials within the borehole.

In addition to the above analyses, which are required to establish criticality safety at the time of initial emplacement, additional short-term, intermediate-term, and long-term scenarios will have to be considered to evaluate criticality safety under normal operating and natural event–induced accident conditions. Long-term criticality evaluations are necessary because both ^{239}Pu and its alpha-decay product ^{235}U are fissile and very long lived (half-lives 24,400 yr and 7.1×10^8 yr, respectively). In particular, short-term scenarios in which the emplacement configuration remains unaltered, but the flow barriers to brine influx from the surrounding geosphe[illegible] be considered. Furthermore, it is n[illegible] scenarios in which the geometric confi[illegible] ment is completely disrupted, the pl[illegible] posal form is redistributed either by ph[illegible] or by leaching out by brine, and brine[illegible] dissolved at another location in the bo[illegible] displaces plutonium without brine fro[illegible]

However, the long-term risk of cr[illegible] tonium accumulation, either within the[illegible] an undetected closely spaced set of fi[illegible] rounding host rock, must be evaluated[illegible] may occur due to *slow but continuous* [illegible] nium from the disposal form by recircu[illegible] port into other regions, and reconcentra[illegible] through continuous precipitation or sor[illegible] ent conditions of temperature and bri[illegible] existence of sufficiently large brine flo[illegible] nating from thermohaline convective i[illegible] in fractures or other mechanisms, woul[illegible] such reconcentration scenarios to be of c[illegible] preliminary estimates show that even [illegible] gradients have a strongly stabilizing effe[illegible] initiation of brine circulation.

Analyses of Category 1 Criticali[illegible]

The preliminary criticality analyse[illegible] performed show that the immobilized ceramic pell[illegible] grout emplacement design presented in this report is[illegible] robust and safe under Category 1 criticality event scen[illegible]

Computational Procedure

The criticality calculations were performed using V[illegible] sion 4a of the *Monte Carlo Neutron and Photon Tr[illegible] port (MCNP)* code developed by the Los Alamos Nati[illegible] Laboratory (LANL). The high-density, pointwise co[illegible] ous-energy cross sections from the LANL ENDEF-V[illegible] tron cross section library were used for the nuc[illegible] properties of the materials. This cross section libra[illegible] the most recent and appropriate for calculating the cr[illegible] cality coefficient K_{eff} for "slow" near-critical configu[illegible] tions. The calculations were performed for a uniform[illegible] emplaced 1 m section of a 0.91-m-diam (36-in.) boreh[illegible] assuming that the borehole extends to infinity in both[illegible] rections parallel to its axis. Perfect reflection bound[illegible] conditions were used at the top and bottom boundaries[illegible] mimic the infinitely long borehole. Neutron transport[illegible] the granite host rock was modeled to a depth of 1 m in[illegible] radial direction with a perfectly absorbing boundary co[illegible] dition imposed at the outer surface. Although neutro[illegible] arriving at this boundary leave the computational dom[illegible]

and do not return to it, the calculations show that the neutron flux moving past this boundary is reduced to negligible levels because of moderation and thermalization of the neutrons by the 1 m of granite.

The elemental compositions of the ceramic, granite, grout, and brine used in the criticality calculations are given in Table 2.2.6.3-1. Natural abundance isotopic ratios are used for each element except the fissile materials. The emplaced plutonium was assumed to be ^{239}Pu without admixtures of ^{238}Pu and ^{240}Pu, although an isotopic composition of 93% ^{239}Pu, 6% ^{240}Pu, and 1% trace isotopes was assumed for the ceramic pellet feed to the Deep Borehole Disposal Facility. The presence of the ^{240}Pu at this level could somewhat alter the results. Also, the criticality analyses presented here do not consider the effects of production of fissile daughters of ^{239}Pu, and in particular do not include the ^{235}U produced by alpha decay.

Brine salinities as high as 500 grams of total dissolved solids per liter, and averaging 300 g/L, have been reported at depths of 3-4 km in crystalline rock formations with undisturbed connate water. Because the chlorine in the brine absorbs neutrons significantly, the salinity of the brine was assumed to be a conservative 50 g/L. This assumption was made to avoid taking excessive credit for neutron absorption by chlorine, which has a large neutron capture cross section, and other constituents because the continued existence of high salinity levels should not be depended on to ensure criticality safety. The composition of the brine used here was obtained from measurements made at a depth of 1,200 m in the deep borehole drilled at the Kola Peninsula in Russia.

The ceramic pellets are ceramic-coated 2.54-cm-diam (1-in.) spheres. The maximum packing volume fraction for spherical pellets is 64%. The 60% volume fraction assumed here is lower than the maximum packing volume fraction by 4% to allow for packing inefficiencies during emplacement. To reduce the cost of immobilization of plutonium in ceramic pellets, only half of the 60% volume fraction of ceramic pellets is Pu loaded, while the remainder is inexpensive uncoated commercial-grade ceramic of the same composition. Therefore, the effective Pu-loading mass fraction of the total 60% ceramic volume fraction is equal to half that of the Pu-loaded ceramic pellets. The modeling methodology assumes uniform mixture of the Pu-loaded and non-Pu-loaded pellets within a continuum approximation scale much larger than the individual pellets and does not account for pellet-to-pellet variations.

The ceramic coating material is assumed to have the same composition as the ceramic in the interior of the pellet. The ceramic is assumed to be a titanate-based Synroc ceramic with 95% zirconolite ($CaZrTi_2O_7$), 2.5% Al_2O_3,

Table 2.2.6.3-1. Chemical Compositions of Materials Used in Criticality Analyses.

Chemical Element(1)	Ceramic	Granite	Grout	Bentonite	Brine
Density g/cm^3	4.00	2.80	2.08	1.70	1.05
Porosity %	0.0	0.0	20.0	37.0	
Si		0.32805	0.28471	0.32000	
O	0.33180	0.48604	0.53732	0.49000	0.84590
Ti	0.28225	0.00234			
Al	0.00413	0.07658	0.04338		
Fe		0.02482	0.01085		
Mn		0.00093			
Mg		0.00531		0.02000	
Ca	0.11655	0.01422	0.07616	0.00200	0.01124
Na		0.02582	0.01598	0.03000	0.00603
K		0.03412	0.01717	0.00400	
H		0.00094	0.01618		0.10658
P		0.00083		0.00100	
Cl			0.00305		0.03025
Zr	0.26527				

(1) Weight fraction of component chemical elements.

Category 1. Criticality in Undisrupted Emplacement Configuration

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Category 2. Criticality in Disrupted Emplacement Configurations

Category 2.1. Criticality in emplacement accident configurations

Category 2.2. Criticality in disrupted configurations due to natural phenomena

Category 3. Criticality due to Geochemical Reconcentration

Category 3.1. Criticality due to geochemical reconcentration in borehole

Category 3.2. Criticality due to geochemical reconcentration in geosphere

In this uncanistered design concept, downhole criticality is controlled and prevented by adjusting the plutonium loading and the concentrations of neutron absorbing additives in the disposal form for criticality safety under the design assumption that the pellets are close-packed at the maximum volume fraction that can be achieved. The criticality analyses used for designing the emplacement configuration must account for not only the presence of the fissile material, but also the moderation, reflection, and absorption nuclear properties of the different materials, and the properties of some portion of the host rock itself. In particular, it is necessary to consider the moderating effects of hydrogen in the bound water in the grouts and the brine invading the interstitial pore space of all materials within the borehole.

In addition to the above analyses, which are required to establish criticality safety at the time of initial emplacement, additional short-term, intermediate-term, and long-term scenarios will have to be considered to evaluate criticality safety under normal operating and natural event–induced accident conditions. Long-term criticality evaluations are necessary because both ^{239}Pu and its alpha-decay product ^{235}U are fissile and very long lived (half-lives 24,400 yr and 7.1×10^8 yr, respectively). In particular, short-term scenarios in which the emplacement configuration remains unaltered, but the flow barriers to brine influx from the surrounding geosphere have failed, must be considered. Furthermore, it is necessary to consider scenarios in which the geometric configuration at emplacement is completely disrupted, the plutonium in the disposal form is redistributed either by physical rearrangement or by leaching out by brine, and brine bearing plutonium dissolved at another location in the borehole invades and displaces plutonium without brine from the pore space.

However, the long-term risk of criticality due to plutonium accumulation, either within the borehole or within an undetected closely spaced set of fractures in the surrounding host rock, must be evaluated. Such a criticality may occur due to *slow but continuous* leaching of plutonium from the disposal form by recirculating brine, transport into other regions, and reconcentration at one location through continuous precipitation or sorption under different conditions of temperature and brine chemistry. The existence of sufficiently large brine flow velocities, originating from thermohaline convective instability of brine in fractures or other mechanisms, would be necessary for such reconcentration scenarios to be of concern. However, preliminary estimates show that even moderate salinity gradients have a strongly stabilizing effect and prevent the initiation of brine circulation.

Analyses of Category 1 Criticality Events

The preliminary criticality analyses that have been performed show that the immobilized ceramic pellets-in-grout emplacement design presented in this report is very robust and safe under Category 1 criticality event scenarios.

Computational Procedure

The criticality calculations were performed using Version 4a of the *Monte Carlo Neutron and Photon Transport (MCNP)* code developed by the Los Alamos National Laboratory (LANL). The high-density, pointwise continuous-energy cross sections from the LANL ENDEF-V neutron cross section library were used for the nuclear properties of the materials. This cross section library is the most recent and appropriate for calculating the criticality coefficient K_{eff} for "slow" near-critical configurations. The calculations were performed for a uniformly emplaced 1 m section of a 0.91-m-diam (36-in.) borehole, assuming that the borehole extends to infinity in both directions parallel to its axis. Perfect reflection boundary conditions were used at the top and bottom boundaries to mimic the infinitely long borehole. Neutron transport into the granite host rock was modeled to a depth of 1 m in the radial direction with a perfectly absorbing boundary condition imposed at the outer surface. Although neutrons arriving at this boundary leave the computational domain

and 2.5% TiO_2 by mass and to be 4.0 g/cm^3 in density. Because of the relatively large neutron capture cross section of Ti and the large mass fraction of Ti in the ceramic, the ceramic pellet material itself serves as an effective neutron poison. The grout in the ceramic pellet–grout mix is assumed to consist 80% by volume of NBS ordinary cement and 20% by volume of brine of the same composition as that in the host rock (given above). The composition of the NBS Ordinary Cement was obtained from *Criticality Calculation with MCNP, A Primer.* The grout composition given in Table 2.2.6.3-1 includes the 20% by volume of brine.

Category 1.1 Criticality Analyses

Criticality events belonging to Category 1.1 relate to conditions at initial emplacement without any alteration of the emplaced materials. Criticality calculations were performed for this case for an emplaced ceramic pellet–grout mix consisting of 30% by volume Pu-loaded ceramic pellets, 30% by volume non-Pu-loaded ceramic p and 40% by volume grout. The Pu loading of the Pu-l ceramic pellets was varied over the range of 0.5, 1.0 2.0, 10.0, and 20.0% by mass corresponding to Pu ings of 0.25, 0.5, 0.75, 1.0, 5.0, and 10.0% by mass fo combined mass of Pu-loaded and in non-Pu-loaded cer pellets. For each of these Pu loadings, gadolinium neu absorber concentrations of 0.0, 0.1, and 1.0 gadoli moles per plutonium mole were considered. The cri ity coefficient for pellet–grout–brine and pellet-b mixes are shown in Figures 2.2.6.3-1 and 2.2.6.3-2 spectively, for these three cases of Pu loading. The Pu ing per unit length along the borehole is also show provide a basis for comparing the Pu loading betw Immobilized and Direct Disposal deep borehole alte tive designs. These results show that:

1. The average Pu loading of 0.5% average Pu loa by mass in present design is heavily subcritical (K_{eff} 0.69) even without addition of any gadolinium a

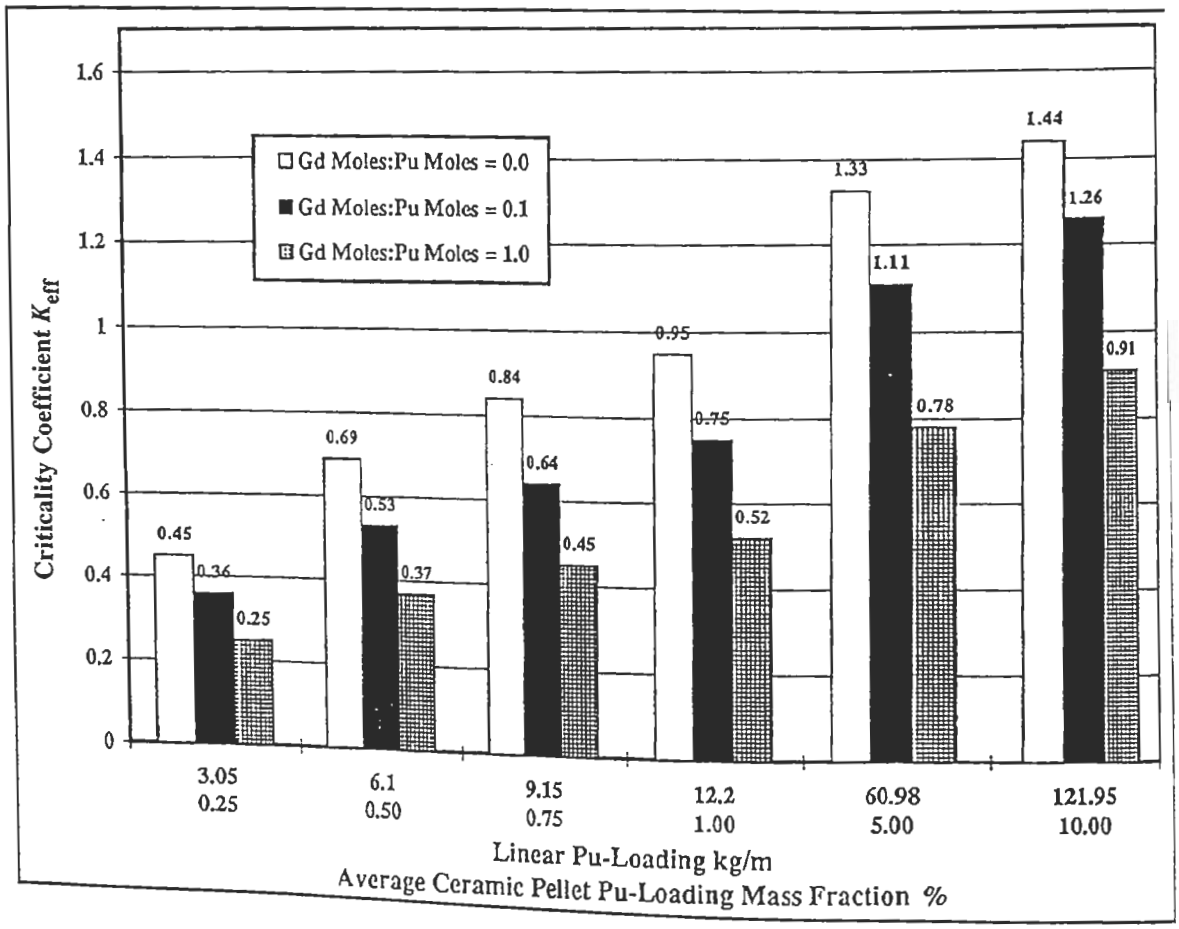


Figure 2.2.6.3-1. Criticality Analysis for Ceramic Pellet–Grout–Brine Mixture in the Borehole.

cylindrical disk 10 m in diameter. The ceramic pellets were assumed to remain close-packed at 60% volume fraction and the grout to be brine saturated. The boundary conditions were those described previously for the 0.91-m-diam (36-in.) borehole. This computation was a part of an attempt to determine whether there was a critical Pu loading below which a volume of ceramic pellet–grout mix of unlimited size would become critical. The criticality coefficient that was computed was equal to 0.88, indicating a high margin of criticality safety. This computation also can be used to assess the safety of an accident at the surface where a large volume of ceramic pellet–grout mix is accidentally released onto the ground and spreads out into a cylindrical pile.

Analysis of Category 3 Criticality Events

Category 3 criticality events are criticality events induced by slow geochemical reconcentration of plutonium due to the *slow but continuous* dissolution of the emplaced plutonium disposal form by flowing subsurface brines, mobilization and transport of the plutonium as a solute to another location in the borehole or the host rock mass, and reconcentration at this location due to precipitation out of solution and/or absorption from solution on the rock surfaces.

Because of the very small release rates, the process of reconcentration will require the persistence over a long time of continuous or episodic dissolution–reconcentration activity, and the overcoming of many dissolution/reprecipitation are the limiting factors for a critical mass to form. The continuous dissolution and reconcentration process will depend on the presence of an adequate flow velocity of brine, the existence of different temperature, pressure, and geochemical conditions favorable to dissolution at the source location, and reprecipitation at the criticality location as a mineral containing either plutonium or its fissile decay products in dilute concentrations. It will also require the existence of a sufficiently large volume of appropriately configured void space in the host rock, within intergranular pores, fracture sets or vugular cavities, for the mineral to be deposited with fissile material concentration sufficient to form a critical mass.

If a critical mass forms in the subsurface, then depending on the kinetics of the criticality event, a substantial amount of energy may be released in the subsurface. This energy, primarily in the form of heat, would increase the temperature, generate steam, redissolve and expel the fissile material containing minerals from the critical mass along fractures, and deplete the fissile material content as a result of the fissioning process. The expulsion of water in the brine may also increase the solids concentration beyond the solubility limits and cause rapid precipitation of plutonium bearing minerals in the fractures. Also, expulsion of water would reduce its moderating effect on neutrons while the expulsion or precipitation of other chemical constituents of brine (such as chlorine, which is a good neutron absorber) would alter the rate of fissioning. Most, but not all, of these events are likely to lead to shutting down of the nuclear reaction quickly until the critical mass reforms slowly through geochemical reconcentration over geologic time and a criticality event recurs as one of a series of such events.

Thus, Category 3 criticality events are the result of a complex series of coupled phenomena. These events have not been analyzed in the current phase of the program. Although the occurrence of such criticality events is considered to be "beyond extremely unlikely," they will be studied as a part of the research and development program in the future.

2.2.6.4 Regulations for Post-Emplacement Downhole Criticality

Technical criteria for criticality safety for subsurface downhole conditions have not been defined in the existing regulations. To the extent that plutonium is buried in an ancient stable rock formation, it has been speculated that the need for long-term criticality control may be minimal if the consequences of criticality to the biosphere is negligible. However, no systematic studies of downhole criticality at deep borehole conditions have been made to verify these speculative opinions. Therefore, these analyses have to be performed to permit the establishment design criteria for criticality safety in the subsurface during the pre-closure emplacement operations and post-closure performance periods.

2.2.7 Ventilation

The HVAC system design for the Surface Processing and the Emplacing–Borehole Sealing facilities will meet all general design requirements in accordance with DOE 6430.1A, Section 1550, and ASHRAE guides.

The HVAC system provides environmental conditions for the health and comfort of personnel and for equipment protection. Typically, the ventilation system will be designed to maintain confinement to preclude the spread of airborne radioactive particulates or hazardous chemicals within the facilities and to the outside environment.

The design includes engineered safety features to prevent or mitigate the potential consequences of postulated design basis accident events.

2.3.1.3 Protected Areas (PA)

Protected Areas (PA) are secured with physical barriers consistent with site specific requirements. Category I and II materials can be stored or handled only in PA areas (DOE Order 5633.3A). Access to these areas and to the material stored or handled therein should be limited to persons whose trustworthiness has been predetermined and to persons in their escort. General access to these areas should be kept to the minimum necessary to accomplish the tasks appropriate for such areas. All persons and packages entering leaving PA areas should be subject to routine search to prevent the introduction of articles of sabotage or the unauthorized removal of nuclear material. Appropriate fixed instrumentation should be provided to assist with routine monitoring of personnel entering/exiting PA areas. Private motor vehicles should be prohibited from access to PA areas. Whenever persons are present in a PA area, those areas should be under constant surveillance. The surveillance can be affected by mutual observation of two or more coworkers (e.g., the "two-man rule"). The PA area is arranged with a single exit/entry point with auxiliary emergency exits fitted with alarms.

2.3.1.4 Storage Areas

Storage areas located in the receiving and processing areas (see Figure 2.1.3.1-1) should be of a "strong room" design and construction and should minimally meet DOE Order 5634.1B. They should be provided with alarms and adequate locks. The issue of keys or key cards should be closely controlled. Access to storage should be strictly limited to assigned persons or to persons under appropriate escort. Where nuclear material is stored overnight in work areas or in sub-storage structures, specially authorized procedures should be used to protect the area. Alarms, patrols, TV surveillance monitors, can be used to help satisfy this requirement. Nearby areas shall provide space, shielding, and access for weighing, gamma fingerprinting (measurement), verification of bar codes for the primary containers, and verification of empty storage locations.

2.3.1.5 Access Control

All persons entering a PA should be issued with special passes or with appropriate registered badges. Badging of persons entering LA or PA areas should follow graded procedures noted below.

Type I: An employee whose duty permits or requires continual access to the area.

Type II: Other employees who are otherwise permitted access to the area.

Type III: Temporary personnel with appropriate business in the area and escorted by employees with Type I or Type II badges as appropriate.

Type IV: Visitors and other guests escorted by employees with Type I or Type II badges as appropriate.

Passes and badges should be designed to obviate counterfeiting.

2.3.1.6 Key Control

Records must be kept of all persons having access to or possession of keys or key cards that access the containment or storage of nuclear material. Arrangements should be made to minimize the possibility of key duplication and the combinations, where appropriate, should be changed at suitable intervals.

2.3.1.7 Communications

Independent duplicate transmission systems for two-way voice communication should be provided for activities involving intrusion detection, assessment, and response. This should include links between guards, their headquarters, and the respective response forces. Independent, duplicate transmission systems, including independent power supplies, should be provided between sensors and alarm display (audible and/or visual) areas.

2.3.1.8 Protective Forces

A 24-hr armed guarding service must be provided to perform routine internal and external patrols. The guards should report at scheduled intervals to local or other security forces during non-working hours. The overall objective of this force is to prevent the unauthorized removal of nuclear materials. Appropriate backup forces should be identified to assist the active on-site force with this task as required.

2.3.1.9 Employee Training

All employees should be annually informed of the importance of effective physical protection measures and be trained in their implementation. Notices on the subject should be conspicuously posted throughout the facility.

2.3.1.10 Material Security Transfer

Every nuclear material handler should be required to conform to procedures transferring custody of the nuclear

physical protection of the site include site fencing, intruder detection devices, site lighting and closed circuit remote viewing systems, communications systems, personal access/egress control systems, guardhouses, and vehicle control stations (rail, truck, and passenger vehicles). The PA and LA area fences of the site will be lighted at night and will be protected by intruder alarm systems and remote surveillance capabilities 24 hours a day.

2.3.2.6 Computer Security

The facility will develop an overall computer security plan so that hardware, software, and database integrity are protected against site-specific threats. This plan will include protection of computer related activities for physical protection as well as for material control and accountability.

2.3.3 Material Control and Accountability

It is expected that the amount of nuclear material transported to the site, minus any amount held captive in waste-stream residues from processing activities, will equal the amount of material deposited in the site's borehole. An integrated site material balance system must be set in place to ensure that this balance is accomplished and available for verification. Measurement systems for the determination of nuclear materials received, diverted through waste streams, or otherwise disposed must be provided as an integral component of the material accounting activity. These systems will be periodically evaluated for precision and accuracy and for the estimation of measurement uncertainty. Material Balance and Accounting combines elements of Waste Monitoring, Material Control and Accountability Measurements, Nuclear Material Control, and Material Accountability as outlined below.

2.3.3.1 Material Accountability

The accountability portion of the Safeguards system provides timely information for the location and amount of all nuclear materials in the facility and is designed to detect abrupt or protracted (multiple) thefts/diversions. The Accountability System provides a means of physically accounting for the disposition of nuclear material and is supported by established measurement control methods and procedures. New technologies and automated techniques will be implemented where practical to reduce requirements for employee access to accountable nuclear materials and to reduce employee exposure to hazardous environments.

The Borehole Disposal Facility will be subdivided into Material Balance Areas (MBAs) for fissile material control and accounting. This covers both the Surface Processing and Emplacing--Borehole Sealing Facilities.

The Receiving, Processing, and Process Waste Management Buildings together form a Material Balance Area (MBA). The plutonium receiving area will satisfy all physical security requirements as described in DOE Order 5632.1C and DOE M5632.1C-1. When the fissile material is classified because of configuration/content, etc., it shall receive the physical protection required by the highest level of classification appropriate for its potential military application.

The amount of nuclear material entering this MBA complex is determined by shipping records and may be validated by direct measurement. Chemical, hazardous, and radioactive waste residues, which are the result of processing activities, are removed from Receiving and Processing Building and may be placed in limited storage for less than 90 days from the time of their generation. During this period, waste containers must be assayed for nuclear material and monitored for surface contamination before they leave the Waste Handling Area. The fissile material will be prevented from leaving the MBA until either satisfactory material balance is ensured or unless other factors can reasonably guarantee that the waste contains no accountable nuclear material.

2.3.3.2 Nuclear Material Control

The material control portion of the Safeguards System governs internal transfer (or movement), location, access, and use of nuclear material; it also monitors the status of process flows and inventories. The Material Control System is closely associated with, and uses data (as needed) from, the Site Process Control, Surface Criticality Safety, ES&H, and Access Control Systems to detect abnormal situations involving nuclear material and/or MC&A system components.

2.3.3.3 MC&A System Integration

This system monitors the storage, processing, and transfer of nuclear materials to detect non-normal events so that no nuclear materials are inadvertently lost, no unauthorized removals occur, and nuclear materials are accounted for and adequately measured. Exact performance of the MC&A system is driven by required loss detection sensitivities that are capable of detecting losses and localizing inventory balances for anomaly resolution. The nuclear MC&A system ties closely with the physical security system of the facility to provide credible assurance that no theft or diversion of nuclear material has occurred.

2.3.4 IAEA Safeguards Requirements

The objective of IAEA safeguards is the timely detection of the diversion of significant quantities of nuclear materials to activities that have military applications. Material accountancy is used together with containment and surveillance as complementary safeguards techniques. A system of accounting for the control of all nuclear materials will be based on a structure of material balance areas (MBA).

2.3.4.1 General Accountability

To satisfy IAEA verification requirements, the site must establish acceptable procedures for identifying, reviewing, and evaluating differences in shipper–receiver measurements, for taking acceptable physical inventories, and for the evaluation of accumulations of unmeasured inventory and unmeasured losses. Additionally, an acceptable system of records showing, for each MBA, receipts for changes involving transfers into and out of such areas. Provisions must also be made to ensure that accounting procedures and other arrangements are being operated correctly. All of these feature should be accommodated by the general Materials Balance and Accounting activities described in Section 2.3.2.

2.3.4.2 Records Systems

Borehole site records shall be retained for at least 5 yr, but facility post-closure security and safeguarding requirements may dictate retention of these records for a much longer period. This applies to operating records, accounting records, calibration records, etc.

2.3.4.3 International Inspection Provisions

An International Inspection Area (IIA) is likely to be a required component of the site. An IIA is used by international inspectors for inspection and verification of the plutonium. Prior to facility attachment negotiations with IAEA, this inspection is expected to be limited to PCV identification, gross weight, and gross radiation count. The IIA houses equipment provided by the international agency and contains files necessary to carry out authorized surveillance without allowing access to classified information. Inspection activities also include site visits for the purpose of reviewing records and information recorded by installed instrumentation and CCTV cameras that belong to the inspecting organization. Equipment located inside the inspection area may be operated by the inspectors remotely through a control room with direct viewing into the inspection area. Special uninterruptable power supply (UPS) and other systems would be provided by international agreements.

2.3.5 Safeguards and Security Requirements Related to Proliferation Resistance of the Ceramic Pellet Plutonium Disposal Option

The facility is projected to sustain a disposal rate year of 5 t of Pu immobilized in 500 t of inert ceramic material. Surge rates are anticipated to increase this by a factor of 2 to 10 t of Pu per year in 1,000 t of ceramic material. Thus, the facility must handle a minimum of 2 of Pu per operating day and twice this amount during surge operation. In addition, the Facility requires a 1-month inventory (417 kg) of Pu-loaded ceramic material in storage for processing operations. At the Receiving Facility, material will be received in 208-L (55-gal) drums containing 14,860 pellets and 5.1 kg of plutonium, which will be opened, inspected, and resealed. Furthermore, the operations associated with the bucket delivery and pocket delivery modes of emplacement of the pellet–grout mixture within the borehole involve processing of batches of pellets containing 834 kg and 200 kg of plutonium, respectively. These figures represent the plutonium flow rates in the areas where handling, interim storage, and disposal operations are being carried out.

DOE Orders set rigid guidelines for determining Category I, II, III, and IV materials when Pu is the attractive element. Each sample category is defined by an "attractiveness level," which grades the material against a set of criteria associated with its material form and/or elemental purity, and a "kilogram quantity level," which is simply a measure of the mass of Pu present in the sample. The Category assigned to a collection of Pu-laden material directly determines their security protection level. High-grade Pu materials, without regard to form, are identified as Category I or II materials and require the highest level of protection if they exceed an aggregate Pu mass of 2 kg. From the discussion in preceding paragraph, although each pellet contains only 0.3432 g of Pu, the expected collections of pellets in any one place at the facility could exceed the 2 kg limit to allow for projected disposal operation rates.

A fundamental uncertainty regarding material attractiveness for immobilized forms is whether, for example, high-grade plutonium, immobilized and diluted in an inert matrix, can be identified with a lower level of attractiveness (i.e., classified as "other materials" with an attractiveness level E and a corresponding Category IV assignment). In principle, this would significantly lower the fissile material category and would thereby lower the necessary level of protection. Pelletized forms are small [2.54-cm-diam (1-in.)] spheres that have the potential to be easily removed from a site if handled in small batches

and in the absence of strict monitoring protocols. Thus, in the proposed Facility design, even though it would require the diversion of a great many pellets to provide a critical level of concern, the pellets will be handled in large batches under strict monitoring protocols to significantly reduce the diversion potential of individual pellets.

The issue of protection levels for Pu pelletized forms can be considered from another perspective as well. The term "Spent Fuel Standard" was coined by the National Academy of Sciences (1994) in their study *Management and Disposition of Excess Weapons Plutonium.* In brief, the NAS study suggested that Pu disposal forms should be "...rendered at least as proliferation resistant as the Pu existing in commercial spent fuel..." and stated that "...deep boreholes represent a class of options that go a long way towards eliminating the proliferation risks posed by excess weapons plutonium..." A recent interpretation by Rhoads (1995) of this standard succinctly states that the "...form of a material alone does not provide sufficient proliferation resistance." While the NAS study clearly focused on the attributes of the disposal form in the definition of the "Spent Fuel Standard," it failed to clearly state that the increased proliferation resistance conferred on a disposition method by physical inaccessibility and the prohibitive cost of retrieval of the disposed material should be included in the "Spent Fuel Standard." Clearly, the principal means by which the Deep Borehole Disposal concept satisfies the need for proliferation resistance is by making the material physically inaccessible Therefore, in applying the "Spent Fuel Standard," to this Deep Borehole Immobilized Disposal Alternative, the Standard should be more broadly interpreted to include not only the proliferation resistance conferred by the dilute form of the plutonium immobilized in ceramic pellets, but also the physical inaccessibility to all except the host country in possession of the site and the high cost of physically retrieving the disposed material.

In summary, when viewed from the perspectives of both the DOE regulations and the protection standards derived from the NAS study, at this time the Safeguards and Security requirements for the Pu-loaded ceramic pellet disposal option cannot be significantly moderated or relaxed below those stated above.

3. GENERIC SITE DESCRIPTION, SITE MAP, AND LAND USE REQUIREMENTS

3.1 Generic Site Description

The Deep Borehole Disposal Facility site described here is a generic site at a *hypothetical* geographical location in the United States called Deep Rock, USA. In developing this generic site description, the characteristics of an ideal site have been used for guidance to arrive at a realistic description of a site that can be found in a number of areas in the continental United States. Site information is provided at a level of detail sufficient to make an approximate assessment of the environmental impact at the site. The data provided includes the geographical and topographical features of the area, the subsurface geology and hydrology, the climate, the levels of seismic activity and wind speeds, the population densities and population centers, rail, road and air traffic access ways, and a site map.

3.1.1 Geographic Setting

The Deep Rock site, shown in Figure 3.1.1-1, is located in a rural area surrounded by farmland and characterized by low, rolling terrain. The average elevation above sea level is 200 m. The topography of the area is rather flat with a maximum topographic relief of 25 m over the 20 km × 20 km area shown in Figure 3.1.1-1. The Deep Rock River is a small river (8 m average depth × 100 m average width) that originates in a drainage basin (1,600 km^2 area) located on a low plateau (20 m high) to the north of the site. Approximately 815 million m^3 of water flows down the river each year with a threefold increase in flow rate during spring over that during summer. The river flows down off the plateau onto a flat plain and then flows to the southeast parallel to the northwest–southeast trending bluff at the plateau boundary. About 5 km

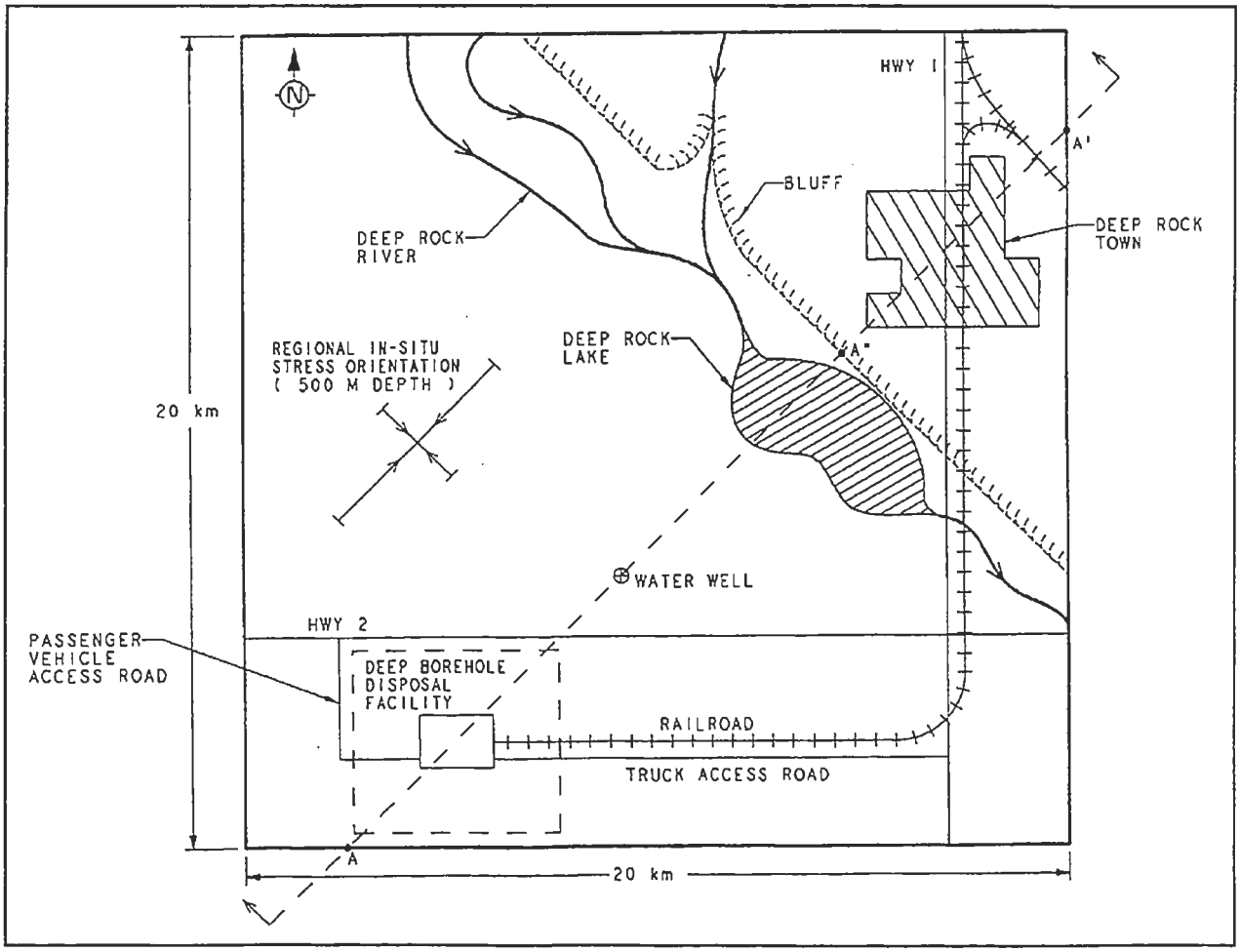


Figure 3.1.1-1. Geographic Generic Site Area Map of Deep Borehole Disposal Facility.

Ecology

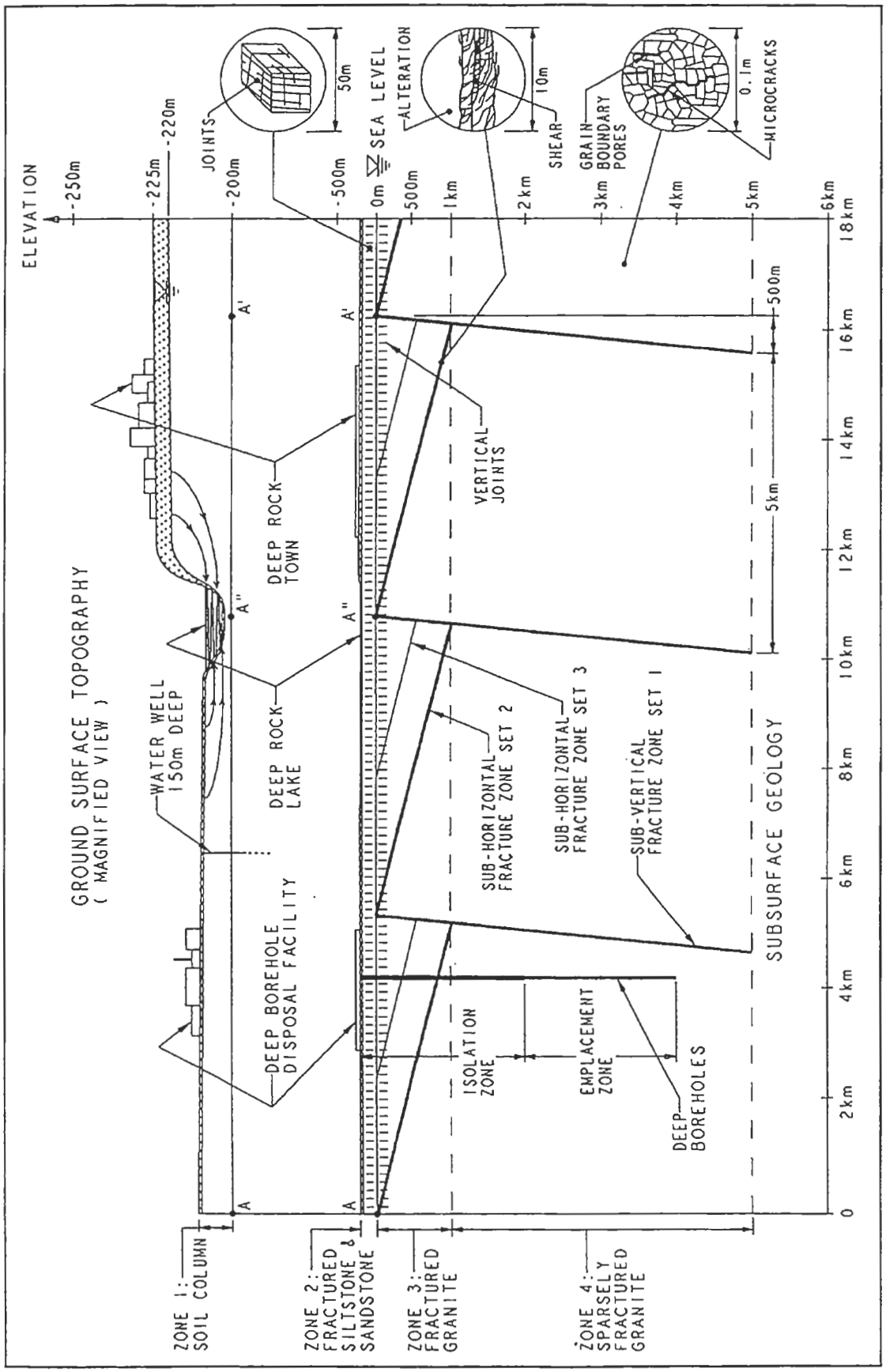


Figure 3.1.5-1. Geologic Cross Section on A-A′ (Figure 3.1.1-1) of Hydrogeologic Features at the Deep Borehole Disposal Facility Site.

Table 3.1.5-1. Hydraulic and Transport Properties of the Hydrogeologic Zones.

Hydrogeologic zone	Depth range (m)	Thickness (m)	Porosity (fraction)	Horizontal/ longitudinal permeability (m^2)	Vertical/ lateral permeability (m^2)	Partition coefficient K_d (mL/g)	Retardation factor R for Pu[1]	Salinity (g/L)
Zone 1: Soil cover	–275 to –250	25	3.0×10^{-1}	1.0×10^{-13}	5.0×10^{-13}	301	1,200	0.1
Zone 2: Fractured siltstone, sandstone	–250 to 0	250	5.0×10^{-2}	1.0×10^{-15}	5.0×10^{-15}	146	31,900	0.5
Zone 3: Moderately fractured granite	0 to 250	250	1.0×10^{-2}	1.0×10^{-17}	5.0×10^{-15}	10.5	2,900	10
Zone 3: Moderately fractured granite	250 to 1,000	750	5.0×10^{-3}	1.0×10^{-17}	1.0×10^{-16}	10.5	5,840	10
Zone 4: Sparsely fractured granite	1,000 to 2,000	1,000	3.0×10^{-3}	1.0×10^{-21}	1.0×10^{-21}	3.02	2,810	50
Zone 4: Sparsely fractured granite	2,000 to 3,000	1,000	2.0×10^{-3}	1.0×10^{-22}	1.0×10^{-22}	1.78	2,490	100
Zone 4: Sparsely fractured granite	3,000 to 5,000	2,000	1.0×10^{-3}	1.0×10^{-23}	1.0×10^{-23}	1.31	3,660	150
Zone 4: Sparsely fractured granite	5,000 to 8,000	3,000	1.0×10^{-4}	1.0×10^{-24}	1.0×10^{-24}	0.78	21,700	300
Fault Zone Set 1	0 to 1,000	20	5.0×10^{-2}	1.0×10^{-13}	5.0×10^{-14}	21.5	900	10
Fault Zone Set 1	1,000 to 2,000	20	4.0×10^{-2}	5.0×10^{-14}	2.5×10^{-14}	8.17	432	50
Fault Zone Set 1	2,000 to 3,000	20	3.0×10^{-2}	1.0×10^{-14}	5.0×10^{-15}	5.83	415	100
Fault Zone Set 1	3,000 to 5,000	20	2.0×10^{-2}	5.0×10^{-15}	2.5×10^{-15}	4.90	529	150
Fault Zone Set 2	0 to 1,000	20	5.0×10^{-2}	1.0×10^{-13}	5.0×10^{-14}	21.5	900	10
Fault Zone Set 3	0 to 500	5	5.0×10^{-2}	1.0×10^{-13}	5.0×10^{-14}	21.5	900	10

[1] Retardation factor (dimensionless) is defined by $R = 1 + [(1 - \phi)/\phi]\rho K_d$, where ϕ is the porosity, ρ is the solid density (g/mL), and K_d is the partition coeffient (mL/g).

The deep groundwater system is hydraulically connected to the fractured Zone 2 primarily through the subvertical joints in Zone 3. Therefore, any surface recharge into the deep groundwater flow system must occur through water infiltrating downwards from the Deep Rock River through the joints in Zones 2 and 3 to the faults in Fault Zone Sets 2 and 3 and to a lesser extent in Fault Zone Set 1. However, because the low topographic relief at the surface provides minimal hydraulic potential difference for driving fluid flows, and, because the permeabilities of the rock in Zone 4 and the fractures in Fault Zone Set 1 below 2 km depth are very low, it is unlikely that the deep groundwater flow is significantly affected by surface recharge.

3.1.6 Seismicity and Geologic Stability

It is known that the region in which Deep Rock Site is located is extremely stable tectonically with no recorded earthquakes with a Mercalli intensity above V. It falls in the 0–1 seismic zone category range, as defined in the Uniform Building Code, corresponding to seismic accelerations of less than 0.075 g. The region does not have any recorded volcanic or geothermal activity, and exploratory drilling for resource delineation and scientific purposes have established that the underlying crystalline rock has remained undisturbed for hundreds of millions of years. The geothermal gradient in this rock is moderate and relatively uniform at 15°C/km. The salinity gradient, however, exhibits significant variation on shorter spatial scales superimposed on an increasing average trend with increasing depth. For example, as indicated in Table 3.1.5-1, the average salinity gradient at the site increases from 1% per km between 0–1 km depth, to 4% per km between 1–2 km depth, to 6% per km between 2–3 km depth; the salinity appears to reach a maximum of about 350 g/L beyond 8 km depth. Dating studies performed on the brines below 1.5 km depth indicate that they are likely to be the original connate waters trapped in the rock at the time the crystalline rock masses were first formed.

3.1.7 Site Map

The Site Map of the Deep Borehole Disposal Facility is given in Figure 3.1.7-1. The map shows the Security Boundaries and Buffer Zone surrounding the facility. It also shows the 4 boreholes required by this immobilized deep borehole disposal facility design and the spacing between the boreholes in the array. Detailed descriptions of the facilities are given in Section 2.1.3. Figure 2.1.2-2 shows in more detail the layout of the facility in both the Main Facility and Borehole Array areas. It also shows the access routes for off-site transportation, and the two on-site transportation routes for trucks bearing the disposal form.

3.2 Land Area Requirements During Operation

The number of acres required to accommodate the footprints of the Deep Borehole facilities is listed in Table 2.1.3-1, Facilities Data. The Deep Borehole Disposal Facility requires approximately 2,041 hectares (5,044 acres) of land for the entire facility and its 1.6-km-wide (1-mile) Buffer Zone. Of this area, 32 hectares (78 acres) is occupied by the Main Facility, 25 hectares (62 acres) by the Borehole Array, and 1,873 hectares (4,628 acres) by the Buffer Zone. The total land area disturbed during the operation period is approximately 56 hectares (139 acres).

During the Closure period, the main facility area of the Deep Borehole Disposal Facility will be restored and returned to natural conditions. During closure activities the Deep Borehole Disposal Facility requires the same land area as during its operation phase, and the total disturbed land area will be the same at approximately 56 hectares (139 acres).

During the Post-Closure period the Borehole Array area of 25 hectares (62 acres) will be declared a limited access area indefinitely, and a 1.6-km (1-mile) Buffer Zone of 1,358 hectares (3,355 acres) may also be declared off limits. Thus, the Borehole Array area will require approximately 1,383 hectares (3,417 acres) to be declared off limits. The total disturbed land area during the Post-Closure period will be the approximately 0.1 hectare (0.25 acre) occupied by the 15 m × 15 m (50 ft × 50 ft) concrete security and anti-water infiltration caps installed above the four boreholes.

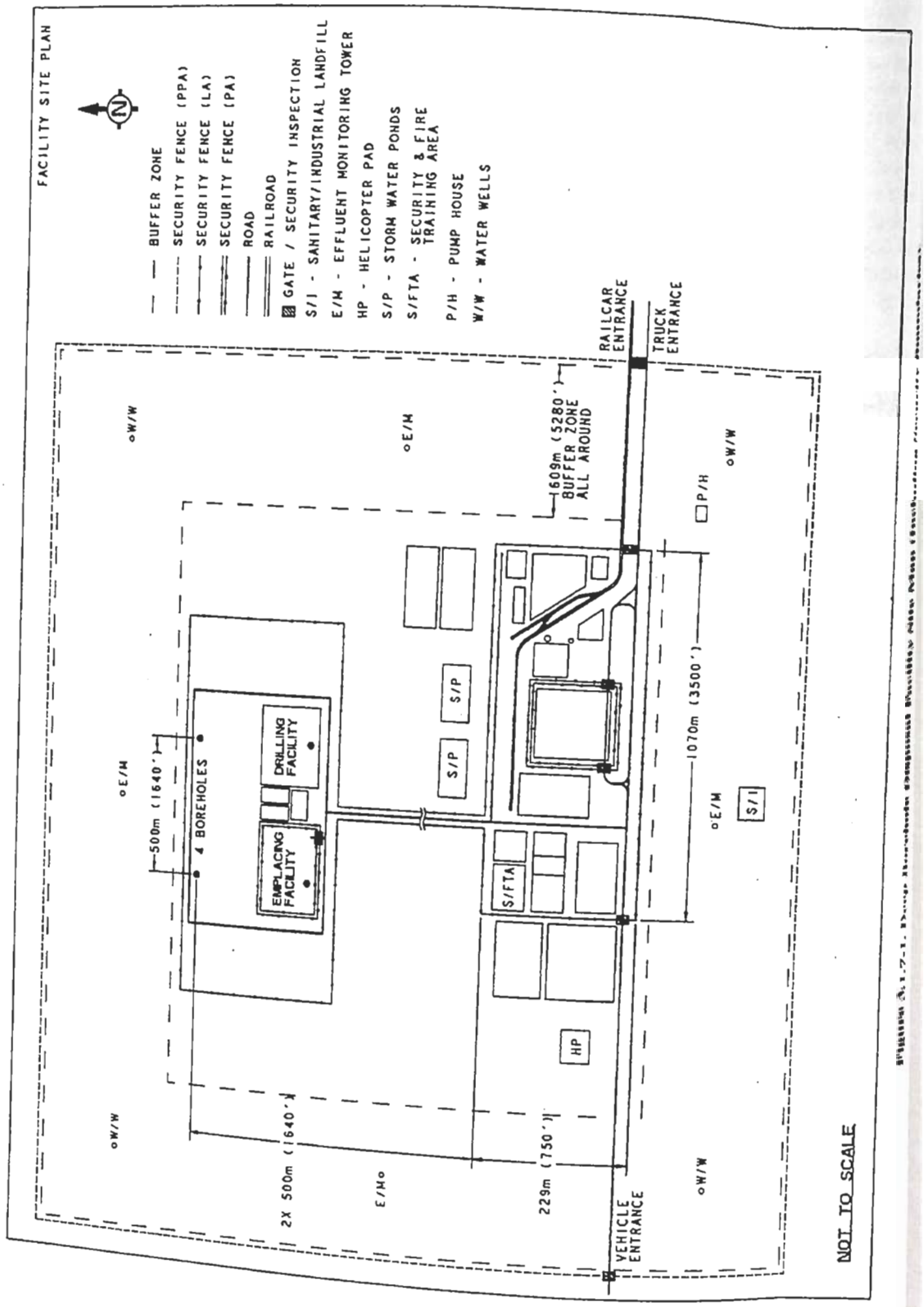
3.3 Land Area Requirements During Construction

3.3.1 Land Use

The Deep Borehole Disposal Facility requires approximately 4 hectares (10 acres) of land for construction laydown and warehousing and 2 hectares (5 acres) for construction parking.

3.3.2 Off-Site Transportation

A minimum of 1.6-km (1-mile) two-lane paved road and railroad spur track will have to be constructed to the Deep Borehole Disposal Facility site for workers transportation and material and equipment delivery. The length of the road connections depends on the specific site.


FACILITY SITE PLAN
N
— — BUFFER ZONE
SECURITY FENCE (PPA)
SECURITY FENCE (LA)
SECURITY FENCE (PA)
ROAD
RAILROAD
GATE / SECURITY INSPECTION
S/I - SANITARY/INDUSTRIAL LANDFILL
E/M - EFFLUENT MONITORING TOWER
HP - HELICOPTER PAD
S/P - STORM WATER PONDS
S/FTA - SECURITY & FIRE TRAINING AREA
P/H - PUMP HOUSE
W/W - WATER WELLS
RAILCAR ENTRANCE
TRUCK ENTRANCE
609m (5280') BUFFER ZONE ALL AROUND
W/W
E/M
P/H
4 BOREHOLES
500m (1640')
DRILLING FACILITY
EMPLACING FACILITY
S/P
S/FTA
HP
S/I
1070m (3500')
2X 500m (1640')
229m (750')
VEHICLE ENTRANCE
NOT TO SCALE

4. PROCESS DESCRIPTIONS

The Deep Borehole Disposal Facility accepts plutonium immobilized in ceramic-coated ceramic pellet disposal form. Other options exist, such as plutonium immobilized in glass or directly as metal, chopped pits, or plutonium dioxide. The disposal form is emplaced in deep competent rock with ancient, nearly dormant brine. It is sealed in place to minimize brine intrusion and to prevent criticality. The disposal form is received and stored at the surface processing facility pending transportation on-site to the emplacement facility where it will be mixed with grout. Deep boreholes are drilled to a depth of about 4 km and partially cased. The emplacement and sealing facility is located near the boreholes to prepare the ceramic pellet–grout mix and emplace it at depth in the boreholes.

4.1 Surface Processing Facility

4.1.1 Function

The process flow diagram for the Surface Processing Facility is shown in Figure 4.1.1-1 together with its waste treatment process flow diagram. The overall facility flow diagram was previously presented in Figure 2.1.1-1. The immobilized Pu-loaded coated ceramic pellet disposal form is delivered in transportation containers to the Surface Processing Facility from an immobilization facility. In the Surface Processing Facility, the transportation containers are opened and inspected, and if more than a specified number of ceramic pellets are damaged the container is closed and returned to the immobilization facility. The containers meeting the acceptance criteria are stored in the Facility until required by the Emplacing–Borehole Sealing Facility as feed material.

At the emplacement facility, the coated Pu-loaded ceramic pellets in these containers are mixed with an equal volume of uncoated non-Pu-loaded filler ceramic pellets. The ceramic pellet mixture is then mixed with grout to produce a ceramic pellet–grout feed material with 30% by volume Pu-loaded ceramic pellets, 30% by volume non-Pu-loaded ceramic pellets, and 40% by volume grout for emplacement in the borehole. The filler ceramic pellets are inexpensive uncoated commercial grade pellets of the same ceramic chemical composition as the Pu-loaded ceramic pellets produced by the immobilization facility. The purpose of the filler ceramic pellets is to reduce the effective plutonium loading of the mixture of 1% Pu-loaded pellets and the non-Pu-loaded pellets to 0.5% by mass. In this way, an additional measure of criticality safety is achieved while cutting the volume and cost of the Pu-loaded ceramic pellets in half.

The pellet–grout mix is emplaced by one of two methods: delivery by a bucket lowered into the borehole or by pumping down a delivery pipe inserted into the borehole. With the latter method, this pellet–grout mix is pumped into a 152-m-long (500-ft) pipe bucket and the bucket is lowered into the borehole. Under gas pressure, the mix is slowly released from the bucket. During this process, a vibratory compactor attached to the bucket is used to compact the most recently released part of the pellet–grout mix. The emplacement and sealing procedures are described in Section 4.3.1.

4.1.2 Feeds

The plutonium disposal form is a ceramic-coated plutonium-loaded ceramic pellet produced at a separate immobilization facility. The ceramic pellets are assumed to be delivered in drums in DOT approved transportation containers via transportation trucks meeting security requirements appropriate to this disposal form. Confirmatory and accountability measurements are made after unpacking the pellet-containing drums. The ceramic pellets, prior to being mixed with grout, are stored in a shielded storage vault in the drums in which they are delivered. The uncoated non-Pu-loaded ceramic pellets are purchased from a commercial vendor and are delivered to the site in 208-L (55-gal) drums by commercial trucks.

The feed rate of the ceramic coated plutonium loaded ceramic pellet disposal form to the Surface Processing Facility is the equivalent of 5 t/yr of plutonium. At a plutonium loading of 1.0% by weight (without neutron absorber poisons) this amounts to 500 t/yr of ceramic disposal form. The feed rate of the uncoated non-Pu-loaded ceramic pellets is also equal to 500 t/yr.

4.1.3 Products

Ceramic pellets are transferred to the Emplacing–Borehole Sealing Facility for mixing with grout via an intrasite transporter. The ceramic pellets are dumped to a feed bin in the grouting facility. They are metered in a feed hopper and are mixed with a batch of premixed cement grout in a grouting vessel. At present, the grout is assumed to be cement based, but the grout composition may be changed in the future (e.g., a bentonite clay based product) when planned R&D results become available to guide the selection of an appropriate grout. The ceramic pellet–grout mixture is transferred to the emplacing facility and is emplaced in the borehole. The used ceramic shipping container is recycled after decontamination.

The Surface Processing Facility receives, stores, and ships approximately 500 t/yr of Pu-loaded ceramic to the Emplacement Facility. During surge operation at 10 t/yr of plutonium, this rate will double to 1,000 t/yr.

4.1.4 Utilities Required

The processing at surface facilities requires electrical power, compressed air cylinders, and water for utility functions.

4.1.5 Chemicals Required

Cement grout and grout additives are used to mix with the ceramic pellets.

4.1.6 Special Requirements—Support Systems

The process systems required to support the disposition process include the cold chemical makeup systems, process gas supply systems, feed and product storage systems, and material control and accountability system:

- *Storage Vaults:* For ceramic aggregate shipping container storage, 3 months storage capacity.
- *Cold Chemical Storage and Makeup System:* For cement, cement additives, etc. storage. Storage capacity of 3 months for storage tanks or silos and one day for makeup tanks.
- *Gas Supply System:* For glovebox gas in the Process Waste Management Facility, 3 months storage capacity.
- *Material Control and Accountability System:* A material control and accountability system with nondestructive assay and computer systems is required for plutonium material control and accountability (MC&A). The system includes bar code readers, scales, nondestructive assay devices, tamper-indicating item inventory devices, and computers. MC&A is applied to every process transfer point that involves plutonium material. Also, a SNM physical inventory is performed every 6 months in accordance with DOE Order 5630.2.

4.1.7 Waste Generated

4.1.7.1 Emissions and Effluents

Under normal operating conditions, no radioactivity will be released to the atmosphere during inspection of the transportation containers. If any ceramic pellets that are delivered are damaged, small amounts of plutonium-containing ceramic dust could escape during the inspection process. In that event, the escaped dust will be collected by the process area ventilation system. Air exhaust from plutonium handling and storage areas of the Receiving and Process Facility are discharged to the atmosphere in an exhaust stack after two-stage HEPA filtration. The stack release is continuously monitored by an isokinetic air monitoring system.

4.1.7.2 Solid and Liquid Wastes

The wastes generated by the Surface Processing Facility will be sampled for radioactivity and, if free of radiation, will be stored for disposal in an off-site sanitary/industrial disposal facility. If contaminated with radiation, they will be treated as low-level/TRU waste. Solid waste generated from process operations at the surface facilities includes shipping packing materials, deformed Pu-loaded ceramic pellet shipping containers, wipes and rags, gloves and paper clothing, and HEPA filters. Liquid waste includes wash water from container decontamination, spent pump oils, and TCA cleaning solvent. The wastes are sent to the waste handling building for treatment.

4.2 Drilling Facility

4.2.1 Function

The process flow diagram for drilling is given in Figure 4.2.1-1 together with the waste treatment process flow diagram for the Drilling Facility. The operations involved in drilling are the preparation of the drilling mud with appropriate additives and maintaining the mud column at the proper density, pumping water out when needed to control water inflow from conductive aquifers and fractures, using mud additives and plugging back these features to control the inflows, and installing steel casing and cementing behind the casings as the drilling progresses. The rock cuttings may be left in the mud pits rather than being transported to another location for disposal as may be required by state and local regulations. It is customary to leave the cuttings in the mud pit and to cover the mud pit with soil following completion of the drilling process.

The borehole will be drilled using technology that has been used extensively in the petroleum industry. The drilling system consists of a drill rig (or derrick), which is used to lower and raise the drill pipe and the drill bit in the borehole, and the associated drilling mud- and fluids-handling support facilities. A motorized winch called the draw works provides the lifting power of the derrick. The drillstring (a series of connected pipe sections) permits the control of the drill bit itself. A mud mixture containing water, compressed air, and possibly bentonite is pumped into the borehole to bring up to the surface the material

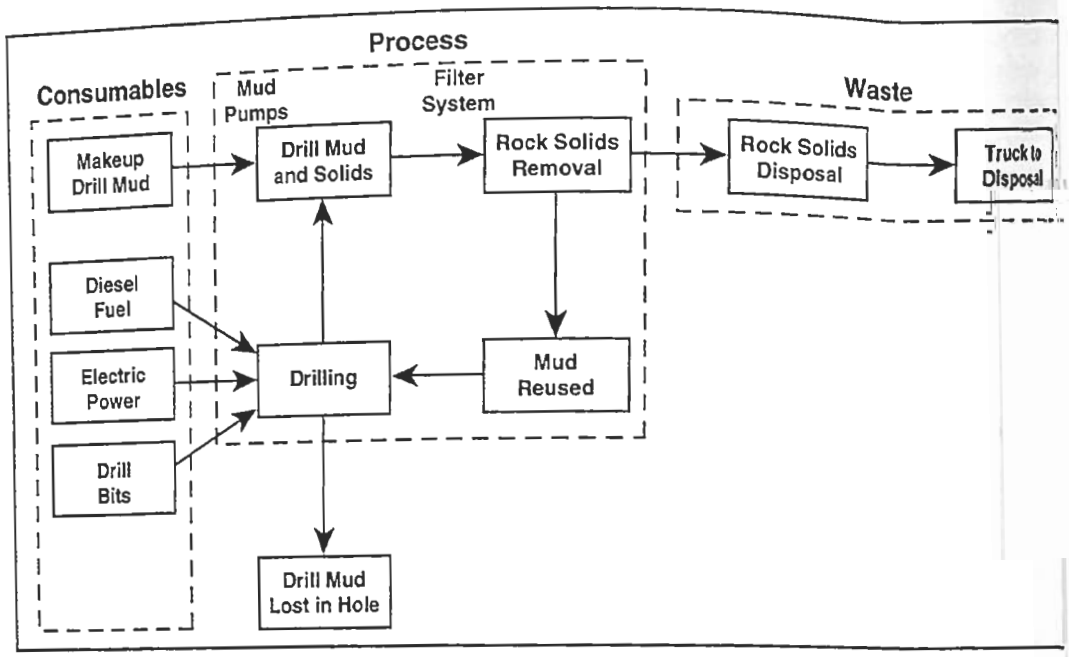


Figure 4.2.1-1. Drilling Process Flow Diagram.

that has been drilled from the borehole. The drilling mud is sent into a shale shaker to allow the solids to settle out. The mud is then filtered to remove the fine particles and is returned to the pumping system. When drilling holes of large size, it is more appropriate to use what is referred to as dual string drilling. In this configuration, two drill pipes are used, one inside the other. The drilling fluid flows into the hole through the outer pipe in the annulus, and the cuttings flow through the center pipe up to the top of the borehole. Holes larger than about 0.66 m (26 in.) diameter are generally drilled in this manner. This is done to reduce the amount of drilling fluid that is required. The most important component in the drill rig is the drill bit, which consists of rolling cones with cutters distributed on their surfaces. The cutters are typically made from hardened steel or tungsten carbide. Diamond bits could also be used. In this case, industrial diamonds are impregnated into the drilling surface of the bit.

Large diameter boreholes are usually drilled with the borehole diameter decreasing with depth in a stepwise fashion as shown in Figure 4.2.1-2. The process starts with a relatively large diameter drill bit, which is used to drill down to some desired depth. A metal liner (or casing) that has an outside diameter smaller than the borehole is then inserted into the borehole. A cement slurry is then pumped at high pressure in the annulus between the casing and the rock formation. Casing the borehole and cementing behind it serves several purposes. First, it seals the void space between the casing and the borehole wall and eliminates this pathway for convective fluid circulation and transport of mobilized plutonium to the biosphere. Because it is a key factor that would affect the performance of the Deep Borehole Disposal Facility, it is essential that a high quality cementing job be performed under a strict quality assurance program that employs borehole logging tools for verification. Second, it prevents ground water in aquifers in the upper portion of the hole from entering the borehole and flooding it. Third, at greater depth it will prevent brines from entering the borehole during drilling. Fourth, it prevents collapse of the borehole in the upper regions of the borehole where more unstable soils and unconsolidated rocks are usually found. Lastly, it permits the sealing of fractures in the rock formations that intersect the borehole. The casing and cementing process is diagram is shown in Figure 4.2.1-3.

At specific locations in the borehole, the hole will be under-reamed (i.e., undercut) to a diameter larger than that of the basic hole. Special cutting tools exist for drilling and enlarging the hole diameter to provide a seat for seal plugs at various depths. The seals and plugs are required to prevent the vertical migration of fluids; they will be installed in the emplacement zone during emplacement of the ceramic pellet–grout mix and in the isolation zone during closure of the borehole.

The drilling operation has been examined by drilling experts from Reynolds Electric and Engineering Co., Inc. (REECO) for purposes of determining the data required for this report; their detailed analysis can be found in Russell (1994). They estimated that the time required

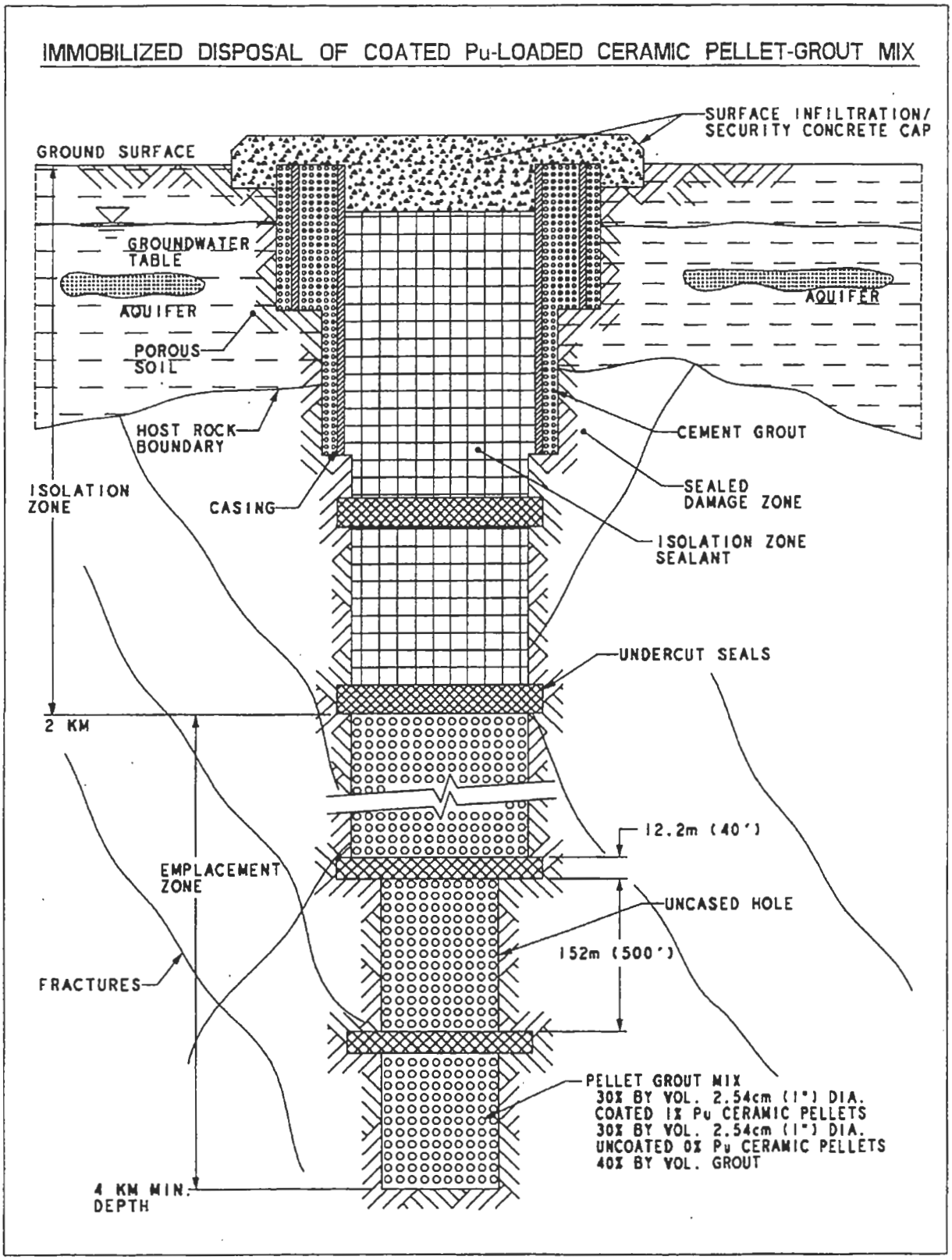


Figure 4.2.1-2. Borehole Configuration Geometry for Immobilized Disposal of Coated Ceramic Pellets in Grout.

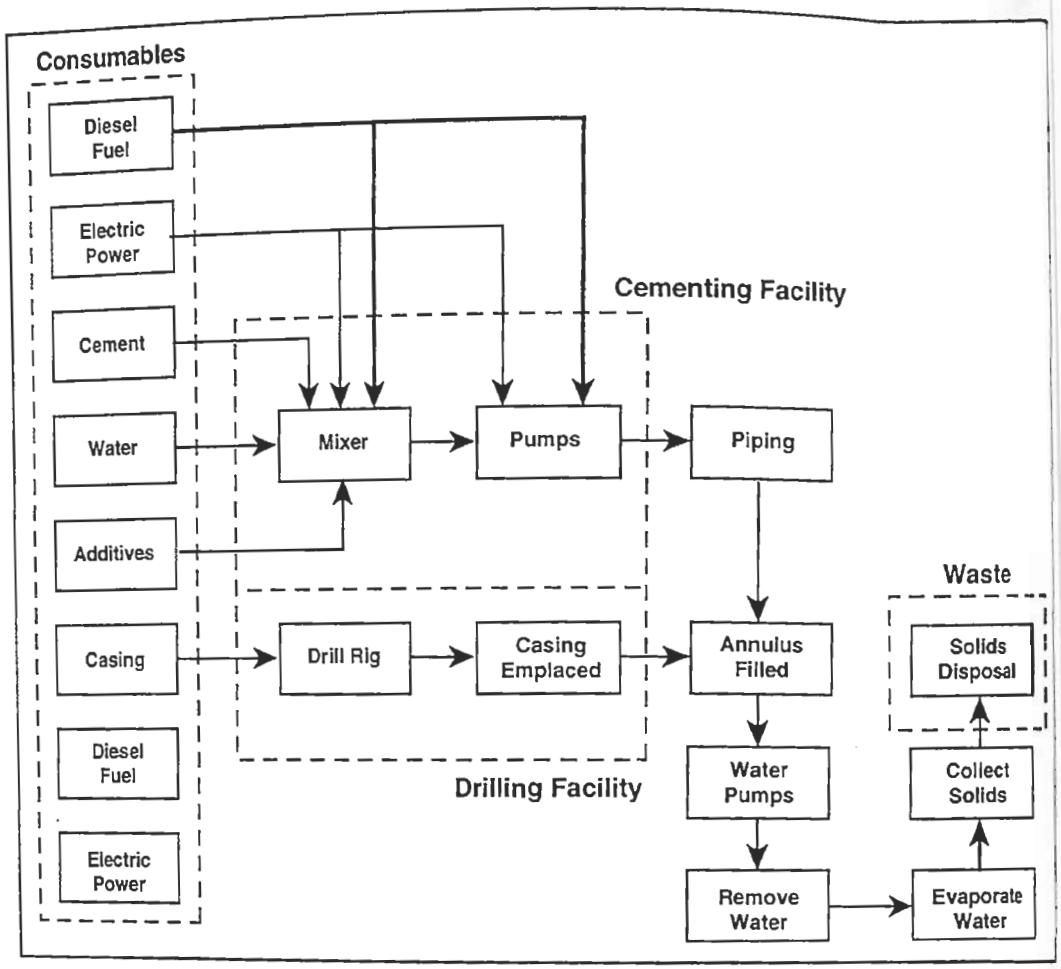


Figure 4.2.1-3. Casing and Cementing Process Flow Diagram.

drill a single borehole of the diameter and depth considered here is from 10 to 11 months using two 12-hr shifts a day by rotating three crews.

Other borehole size and configuration scenarios might be desirable for this application. For example, depending upon the particular geology at the selected site, a larger number of deeper boreholes of smaller diameter may be optimal from the standpoint of drilling efficiency. On the other hand, where the geology permits, shallower boreholes of larger diameter may be optimal from the standpoint of emplacement volumetric efficiency and may reduce the total number of holes required to emplace a fixed amount of plutonium. However, the feasibility and advantages of these different alternatives will depend upon their impact on the upstream processes (such as disposal form transportation, processing, and packaging) and must evaluated from a systems viewpoint.

A substantial development effort to design the drill rigs, handling equipment, and high-strength steel casing will be required. The drill rig design is most likely to be a scaled-up version of a high-capacity petroleum indus drill rig.

4.2.2 Feeds

Very large quantities of materials such as drill muds, grouts, casing, and chemical additives will be quired for operating the Drilling Facilities. These are scribed below.

The drilling process requires the circulating water drilling muds to be periodically replaced by fresh water, and chemicals. The chemicals include polym soaps, and pH-control additives.

The process of plugging back conductive aquifers and sealing fractures and the near-borehole damage requires specially formulated API (American Petrole Institute)–grade grouts and grout additives as feed mate als. The exact composition of the drilling mud cannot determined until a site has been selected and the geolo has been identified to some degree.

The process of casing the borehole in the upper 2 km isolation zone and cementing behind the casings to plug the voids between the casing and the borehole requires specially formulated grouts and steel casing pipes of various diameters and wall thicknesses.

4.2.3 Products

There are no products in this operation. Wastes generated by the process are identified in Section 4.2.7.

4.2.4 Utilities Required

A diesel generator will provide operating power to each drilling rig. A backup diesel generator is also provided for each drilling rig.

4.2.5 Chemicals Required

The primary process materials required for the drilling process are those required to prepare the drilling mud. No treatment of the small amounts of briny water in the borehole will be required. It will be contained by the sealing process by in situ solidification of the grout pumped into the borehole and will be incorporated into the cement during its hydration and solidification. Additional grouts are required for sealing the soil and rock formations and cementing behind the casing.

4.2.6 Special Requirements

4.2.6.1 Monitoring for Naturally Occurring Radiation

Drilling operations have a small potential for releasing naturally occurring radiation into the atmosphere where it might affect workers. Therefore, monitoring at the top of the borehole and bottom of the drill string for alpha, beta, and gamma radiation during drilling operations will be required.

4.2.6.2 Monitoring for Hydrogen Sulfide

A potential exists for hydrogen sulfide to be released from the rock formations during drilling. Thus, there will need to be monitoring at the borehole to ensure the safety of the workers.

4.2.7 Waste Generated

4.2.7.1 Emissions and Effluents

With the exception of engine exhaust fumes and dust, there are no atmospheric emissions in the drilling process. The primary effluents from drilling are the overflow of briny water from the mud ponds and the briny water that would be pumped out from the well from conductive features in the rock. These wastewaters are treated as described in Section 4.2.7.2.

4.2.7.2 Solid and Liquid Wastes

The solid rock cuttings brought out of the borehole by the drilling mud settles out in the drilling mud pit. For a telescoping borehole with a 1.83-m-diam (72-in.) hole drilled to 24.7 m (81 ft), a 1.32-m-diam (52-in.) hole to 2 km (6,560 ft), a 0.91-m-diam (36-in.) hole to 3 km (9,840 ft), and a 0.66-m-diam (26-in.) hole drilled to 4 km (13,120 ft), the volume of rock removed from a single borehole would be about 3,340 m^3. The cuttings volume, however, would be as much as 1.5 times this volume because of bulking. These cuttings would contain some of the drilling mud additives and the briny water at depth. The exact makeup of the additives will not be known until the geology of the site has been ascertained and an appropriate mud program developed. However, they will be selected from approved standard stock items in the petroleum industry. A common drilling practice is to leave the cuttings in the mud pit, which is covered with soil at the completion of drilling operations. Should future or local regulations require other disposal methods, the pits can be lined and the cuttings removed for alternative disposal.

Wastewater generated by the drilling process is tested and then treated as needed by allowing the water to evaporate and burying the residual solids in the mud pits. There is no expectation that the water from the drilling mud will require any treatment.

4.3 Emplacing–Borehole Sealing Facility

4.3.1 Function

The flow diagram for the Emplacing–Borehole Sealing process is given in Figure 4.3.1-1. The pellets are transported by truck from the Surface Processing Facility to the emplacement facility. The emplacement/cementing facility is located at a borehole that has been drilled and cased after aquifer, fracture, and near-borehole damage zones in the upper 2 km sealing zone have been sealed. Also, as a part of drilling the borehole, fractures and near-borehole damage zones in the lower 2 km emplacement zone will be sealed. The feasibility of sealing these features in the host rock in a large-diameter uncased borehole using, for example, multiple inflatable packers set at depth and injecting between them must be evaluated in the field.

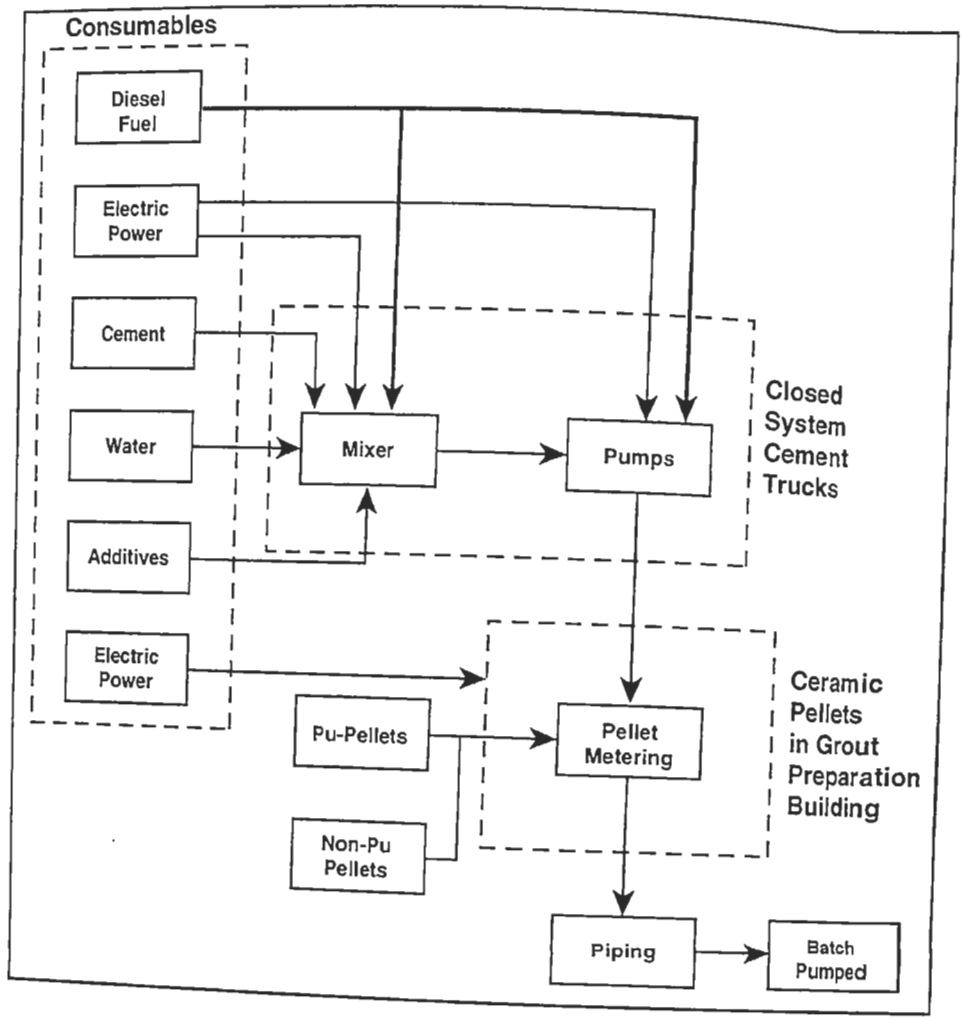


Figure 4.3.1-1. Pellet–Grout Mix Emplacement Process Flow Diagram.

The cementing trucks mix and deliver the grout slurry to the ceramic pellet–grout mix preparation building. The pellets are metered into the grout and further mixed prior to emplacement in the borehole by the bucket or pipe delivery methods. Two processes are being considered for the delivery of the ceramic pellet–grout mix to the emplacement depth of the borehole: (1) emplacement by bucket and hoist and (2) emplacement by pumping the pellet–grout mix down a delivery pipe. These two processes and the associated equipment are described below.

The Bucket Emplacement Process

The bucket emplacement process consists of filling a 0.41-m (16-in.) outside diameter × 152-m-long (500-ft) pipe "bucket" with the pellet–grout mix at the surface, delivering the load to the emplacement depth within the borehole, and releasing it at a controlled rate while withdrawing the bucket upwards. Figure 4.3.1-2 shows the manner in which the bucket is filled with the pellet–grout mix at the top of the borehole. Figure 4.3.1-3 shows the bucket delivering its pellet–grout load at the emplacement depth.

The bucket is made up of 6.1-m-long (20-ft) casing-like sections of pipe that are threaded together section-by-section to a full length of 152 m (500 ft) while being lowered within the borehole at the entrance to the borehole. The bucket is lowered to emplacement depth using a pipe string and a crane hoist. A transition section exists at the top of the bucket to allow connection of the bucket to the pipe string. The bucket has a remotely controlled release valve at its bottom for releasing the pellet–grout mix at the emplacement location. A column of water and/or air pressure will be used to eject the slurry from the bucket. A piston-like wiper, which will be retained inside of the bucket, will be employed to prevent the column of water from mixing with the cement. The bucket will need to be checked for contamination due to pellet breakage and may be decontaminated before reuse.

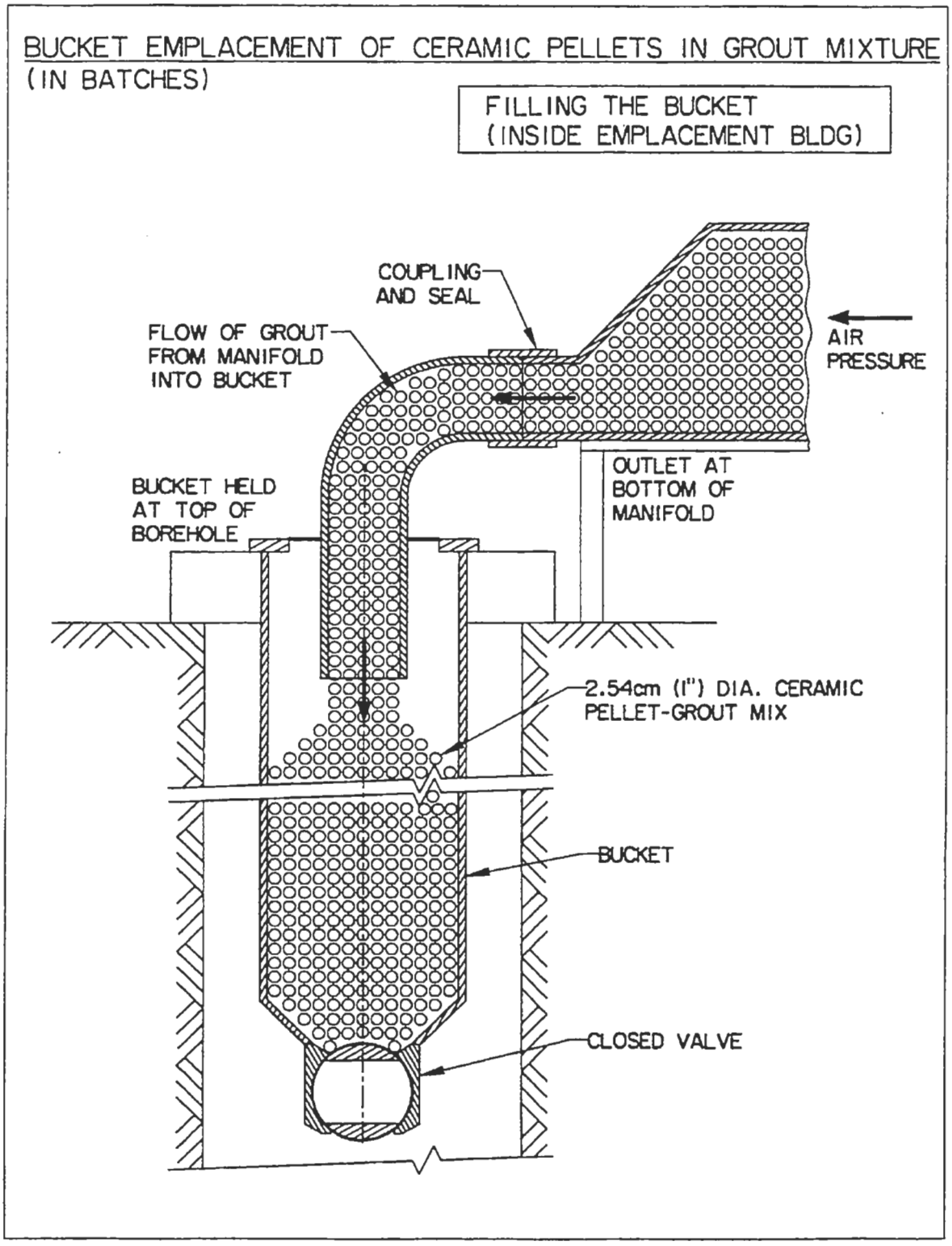


Figure 4.3.1-2. Bucket Emplacement Method—Bucket Filling Process.

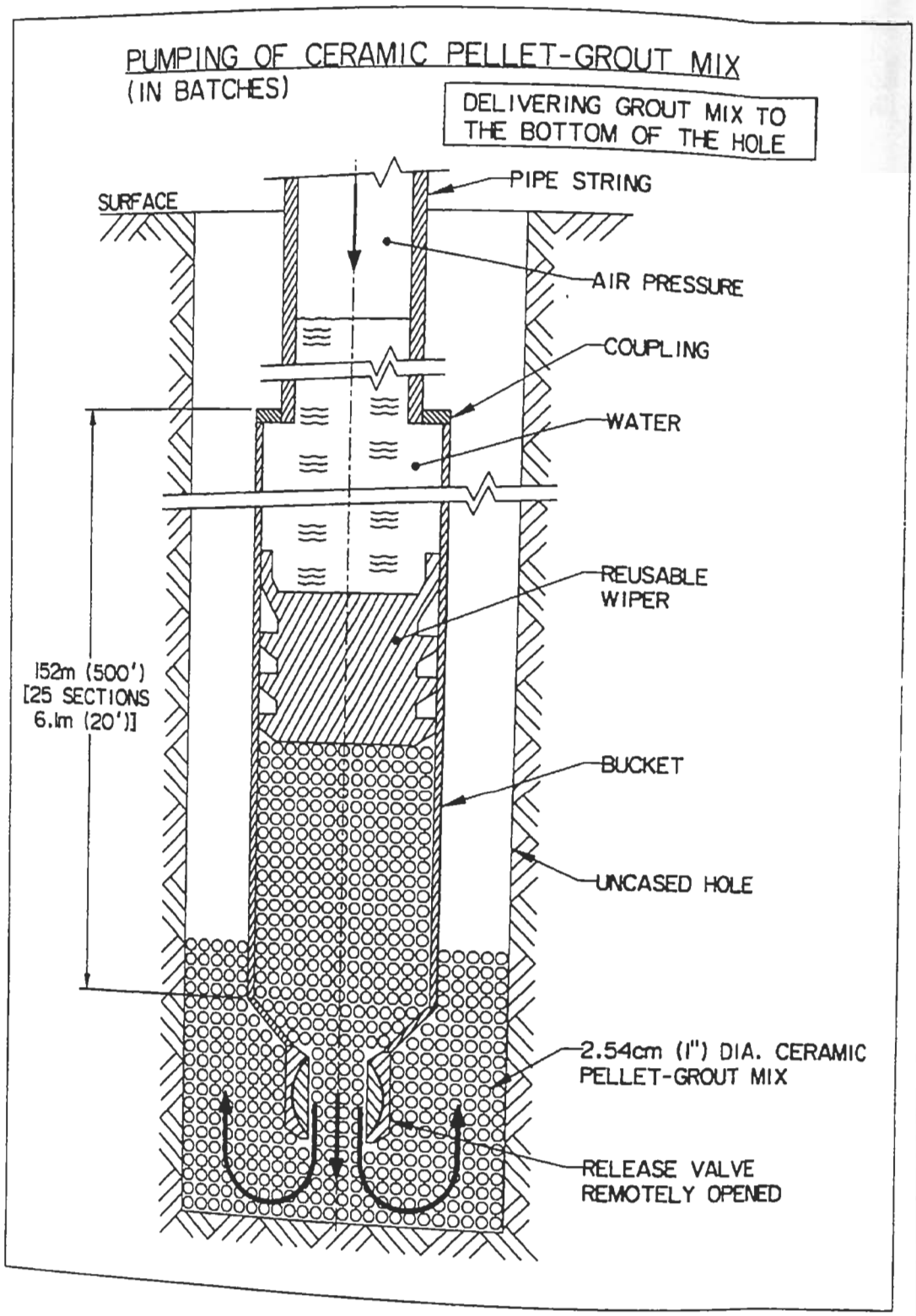


Figure 4.3.1-3. Bucket Emplacement Method—Delivery Process.

The bucket receives its pellet–grout load from the mixer located within the containment building. The mixer, which has a rotating type concrete mixer section, mixes the slurry to reduce voids and air pockets between the pellets. The mix is poured into a hopper and is subsequently driven under air pressure into the bucket through an articulated delivery pipe in batches. Only a 6.1-m (20-ft) section of the bucket will be filled at one time to minimize the likelihood of damaging the pellets as they enter the bucket. The delivery pipe will be raised as the bucket is filled to facilitate the process.

It is estimated that a completely filled bucket would be about 113,400 kg. The time required to lower the bucket to a 4-km depth will be about 8 hr, which requires the use of appropriate chemical additives to prevent setting of the grout within the bucket. Halliburton Services of Duncan, OK, a major supplier of oil well cements and equipment, can produce a blend of additives and grout that will have the required delay in setup time. During emplacement by the bucket method, the emplacement facility would have to operate in 12-hr shifts. It is expected that this would be necessary about once per month, or a total of 120 times, during the ten-year operational period of the Facility.

This emplacement method will adopt operational procedures similar to those used by LLNL during nuclear device emplacement operations at the Nevada Test Site in which canisters are lowered into boreholes on well-casing pipe strings. The process involves the use of a crane, a subbase, and casing pipe. When the crane is not supporting the emplacement string, the subbase structure supports the load. A heavy lift subbase exists in the DOE inventory with a rated capacity of 635,000 kg of load. The subbase is a custom-built welded steel structure [6.1 m × 15.2 m × 6.1 m tall (20 ft × 50 ft × 20 ft)] designed for emplacement operations in underground nuclear testing. Nuclear Explosive Safety rules in DOE 5610.11 govern the operations associated with the emplacement of a nuclear devices in borehole for testing. These safety rules also provide an excellent basis for establishing safety factors, specifying equipment requirements, and controlling operations associated with bucket emplacement of the Pu-loaded ceramic pellet–grout mix within boreholes.

Pumped Emplacement Process

The pumped emplacement method provides an alternative to the bucket emplacement of the ceramic pellet–grout mix. In this method batches of ceramic pellet–grout mix are pumped down a 15.2-cm-diam (6-in.) delivery pipe under water and/or air pressure, as indicated in Figure 4.3.1-4. This technique is preferred to directly pumping the pellet–grout mix using a conventional concrete pump to avoid breaking pellets during pumping. The batch of slurry will be in the form of a slug of finite length pushed from behind by a piston-like ceramic wiper at its trailing edge and prevented from breaking up at its leading edge by a similar ceramic wiper. The primary function of the wipers is to prevent breakup of the slug into small sections and falling down the delivery pipe and to provide a stable surface for the driving pressure to act on. The mix will be pushed out of the mixer and into the pipe using the water and/or air pressure, and the ceramic wipers will be introduced ahead of and behind the slug at the outlet port of the mixer. The mixing of the slurry and the delivery into the pipe will be performed within the containment building, which will completely cover the entrance to the borehole. A remotely controlled release valve at the bottom of the delivery pipe at emplacement depth will be used to control the rate at which the slug moves down the borehole and ejects out into the borehole. The ceramic wipers will be allowed to eject into the borehole and will be emplaced with the pellet–grout mix as shown in Figure 4.3.1-5. The wipers will be made with ceramic material similar to that of the pellets so as to maintain the chemistry in the emplacement zone unaltered and to ensure compatibility with the emplaced material. As it is released into the borehole, the pellet–grout mix will be compacted using a vibratory compactor attached to the bottom of the bucket, below the release valve. This is shown in Figure 4.3.1-6. The length of each slug that is pumped will be adjusted to fit the optimal batch size although it is possible to simultaneously move several slugs down the delivery pipe. Currently, the batch size is assumed to be 10 t of 1% Pu-loaded ceramic pellets (i.e., 100 kg of Pu) mixed with 10 t of non-Pu-loaded ceramic pellets and 6.8 t of grout. This represents a total ceramic pellet–grout mix volume of 8.46 m^3 and a slug length of 464 m within the 15.2-cm-diam (6-in.) delivery pipe. At this slug length, 125 slugs would be required to emplace 12.5 t of Pu in the emplacement zone of one borehole.

In this delivery method, it is possible to isolate the gases in emplacement section of the borehole by using two inflatable packers mounted on two independently movable concentric pipes as shown in Figure 4.3.1-4. This isolates any emissions from broken Pu-loaded pellets from the upper regions of the borehole that may be in communication with the biosphere. The lower packer is mounted on the delivery pipe while the upper packer is mounted on a larger pipe that is concentric with the delivery pipe. By alternately deflating, inflating, and moving these two packers, as indicated in the ceramic pellet–grout mix delivery and relocation cycle shown in Figure 4.3.1-5, it is possible to "walk" the outlet section of the delivery pipe up the borehole without exposing the upper region of the borehole to contamination. During delivery, the delivery pipe is raised in small steps by the crane. The air displaced

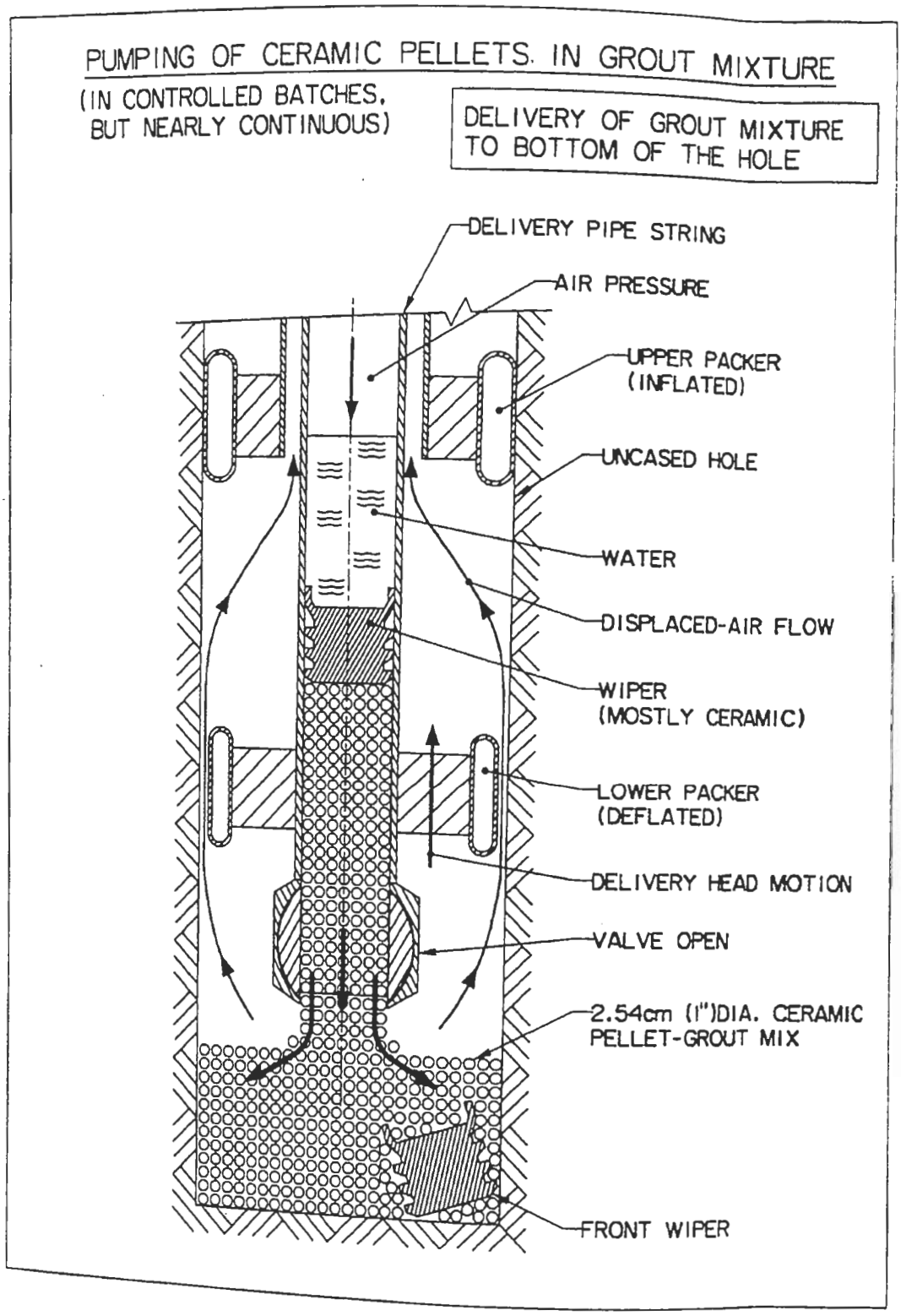


Figure 4.3.1-4. Pumped Emplacement Method—Delivery Process.

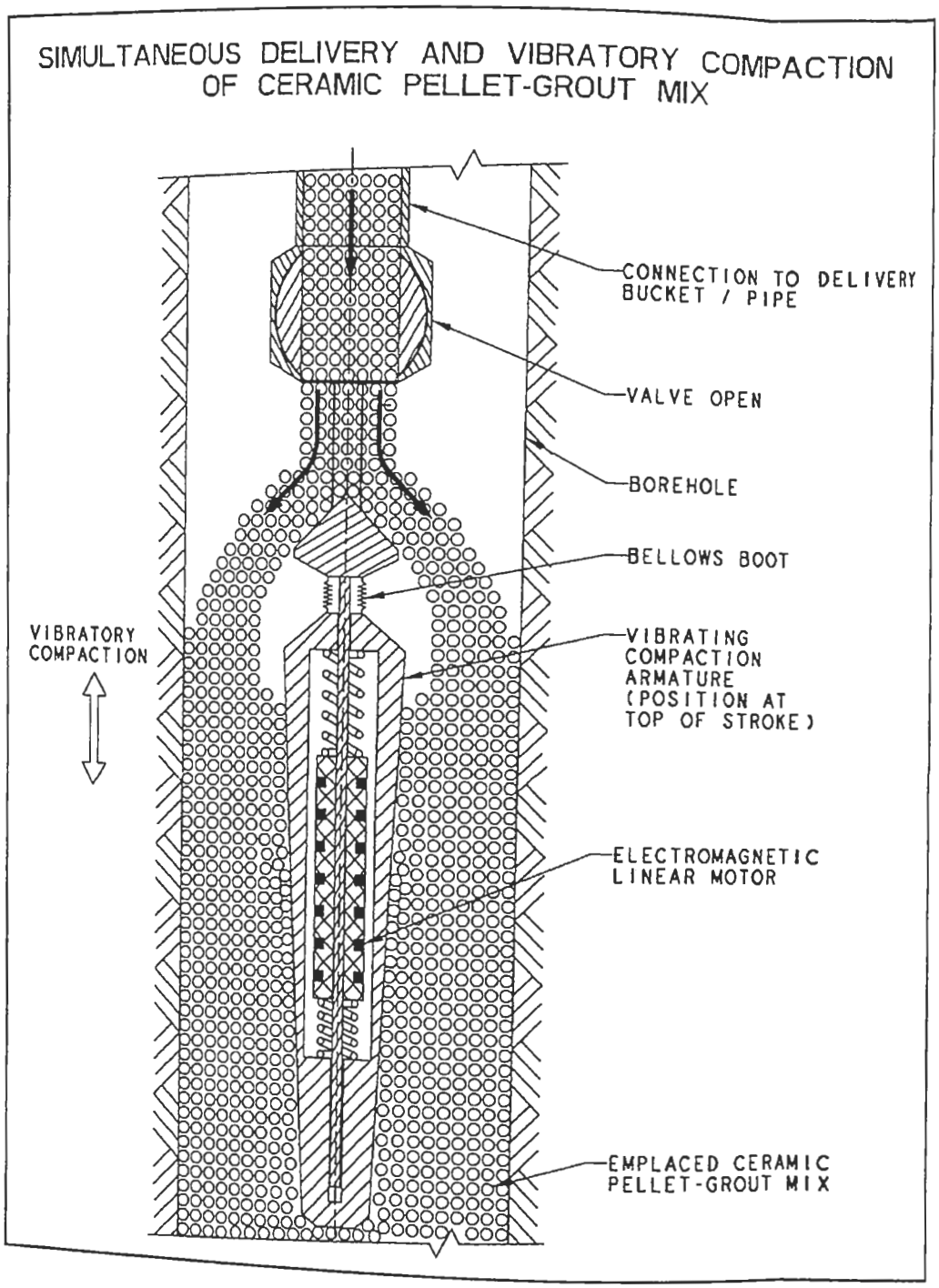


Figure 4.3.1-6. Pumped Emplacement Method—Vibratory Compaction of Mix.

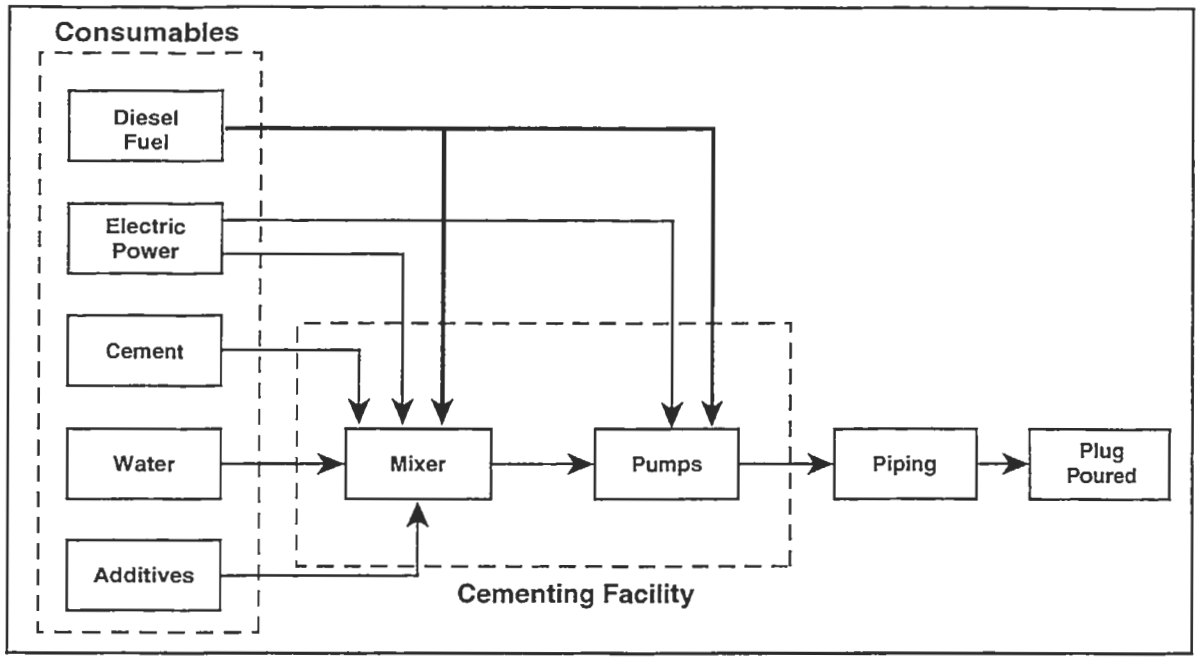


Figure 4.3.1-7. Cementing/Sealing Process Flow Diagram.

by emplacement and the pumped-out vent air flows through the annulus between the two pipes to the surface and is filtered by two-stage HEPA filters within the containment building prior to release to the atmosphere. The packers minimize the potential for radioactive material contamination of the open isolation zone and the containment building and supplement isolation provided by the containment building. However, all workers entering the containment building will be required to wear SCBA systems and protective suits. When emplacement is completed, the removed sections of delivery pipe will be checked for radioactivity and decontaminated as needed.

This method of delivering the pellet–grout mix to the emplacement zone does not require a very large crane, grouts with long setting times, the handling of a large, heavy bucket with the attendant safety risks, and the very long trip times that make bucket emplacement a slow process. It is a very simple technique that strongly resembles cementing jobs in the oil and gas industry. However, pumped delivery does not offer the degree of positive control over the pellet emplacement provided by the bucket delivery method.

The equipment in the Ceramic Pellet–Grout Mix Preparation Building will require periodic decontamination. Potentially contaminated water, cement, and equipment from the Ceramic Pellet–Grout Mix Preparation Facility will be sent to the Process Waste Management Building in the Emplacing–Borehole Sealing Facility.

The casing, cementing, and borehole sealing process flow diagram is given in Figure 4.3.1-7. Periodically, when one or more batches have been pumped, a hydraulic and transport seal, manufactured from special materials, is installed. When the entire 2-km emplacement zone is filled in this way, a long hydraulic and transport seal is installed at the top of the emplacement zone. Next the borehole is filled with concrete with periodic hydraulic and transport seals, and a dual-purpose security and anti-water infiltration cap is installed at the entrance to the borehole at ground level.

4.3.2 Feeds

Pu-loaded ceramic pellets and the non-Pu-loaded ceramic pellets, approximately 2.54 cm (1 in.) in diameter, are the primary feeds to the Emplacing–Borehole Sealing Process. The Pu-loaded ceramic pellets are delivered in transportation containers and are inspected and stored in the Receiving and Processing Building. In addition, a feed stream of cement and additives will be required for installing the plugs/seals. The exact makeup of these cement mixtures will be determined to satisfy the performance requirements for the cement in the borehole environment.

4.3.3 Products

There are no products in this operation. Wastes generated by the process are identified in Section 4.3.7.

4.3.4 Utilities Required

Process water, compressed air, and electrical power facilities would be supplied to the Emplacing–Borehole Sealing Facility for use in the ceramic pellet–granite aggregate grout mix preparation and the sealant preparation.

4.3.5 Chemicals Required

The primary process materials required for the Emplacing–Borehole Sealing process are those required to prepare the emplaced ceramic pellet–grout mix and the borehole sealants. These include chemical additives such as water reducers, superplasticizers, silica fume, fly ash, extenders, and swelling additives. Cement grout and cement additives are mixed with the ceramic pellets to form a ceramic pellet–grout slurry.

4.3.6 Special Requirements

A material control and accountability system with nondestructive assay and computer systems is required for plutonium material control and accountability (MC&A).

4.3.7 Waste Generated

4.3.7.1 Emissions and Effluents

The primary atmospheric emissions produced by this process are the dusts raised by the handling of solid cement, sand, aggregate, silica fume, fly ash etc. during the preparation of the concretes and sealants. In addition, exhausts will be produced from the diesel engines of the power generation sets.

4.3.7.2 Solid and Liquid Wastes

The primary wastes produced by this process are the uncontaminated solid waste cement, sand, aggregates, and decontaminating water. The solid wastes will be disposed of at a landfill.

Contaminated waste water may be generated by equipment cleaning operations and pumping out of excess brine collected within the borehole. The contaminated waste waters will be sampled for radioactivity and brine chemical composition. The sample is first tested for radioactivity from any damaged ceramic pellets and, if not contaminated, is returned to the mud pits. If the water is contaminated, then it is routed to the Process Wastewater Management Facility.

4.4 Waste Management Facility

4.4.1 Waste Management Systems

The waste management of the borehole facili
cludes waste handling and treatment operations fo
cessing the transuranic (TRU) waste, low-level
(LLW), hazardous mixed waste (MW), and industrial
in aqueous, organic liquid, or solid form generated
the borehole disposition operations or from site activ
The waste management is in accordance with DOE
5820.2A and Resource Conservation and Recover
(RCRA). Transuranic (TRU) waste generated from
hole operations is based on disposal to the Waste Isol
Pilot Plant (WIPP) in accordance with WIPP Waste
ceptance Criteria. The waste management process
diagram is shown in Figure 4.4.1-1.

4.4.1.1 Waste Treatment and Storage Systems

The radioactive wastes are processed in a pro
waste handling facility in the Emplacing–Borehole S
ing Facility. The waste treatment process includes as
examination, sorting, separation, concentration, size
duction, special treatment, and thermal treatment.
wastes are converted to water meeting effluent standa
grouted cement, or compacted solid waste as final f
products for disposal. Solid TRU wastes are packa
assayed, and certified prior to shipping to the WIPP
permanent emplacement. Low-level solid wastes are
veyed and shipped to a shallow land burial site for
posal. A small quantity of solid mixed waste are packa
and shipped to a DOE waste treatment facility pendi
future processing. The waste treatment processing a
performs equipment and waste container decontaminat
operations.

4.4.1.2 Utility Wastewater Treatment

Utility Waste Treatment treats wastewater generat
from utility operations. This wastewater consists of co
ing tower blowdown and boiler blowdown. Utility Was
water Treatment consists of reverse osmosis followed
evaporation and spray drying. Reclaimed water produc
is used as makeup to the cooling water tower. A dry re
due is disposed of as solid industrial waste.

4.4.1.3 Process Wastewater Management

Process Waste management facility contains equi
ment and processes for the treatment of conventiona
hazardous, radioactive, and mixed liquid wastes. In add
tion to the process equipment, ancillary facilities are pr

vided such as the electrical room, control room, process laboratory and changehouse/boundary control station, mechanical (HVAC) room, lunch/break room, and offices. The facilities are designed to the requirements of a moderate-hazard facility, as defined by UCRL-15910 (DOE-STD-1020-92) and DOE order 6430.1A.

Process Waste Management treats wastewater that is generated by the Surface Processing Facility and Pellet–Grout Mix Preparation Sub-Facility processes as well as the Emplacing–Borehole Sealing Facility processes. Wastewater originating in the borehole array area is pumped through underground pipes to the Process Waste Treatment facility. Such wastewater is expected to primarily consist of mopwaters and cleaning solutions, sealants and additives, drilling mud additives, grout additives, and machine coolant wastes.

A substantial amount of wastewater will be generated by the drilling facility as overflow water from drilling mud settlement ponds. Also, water pumped out from the borehole during drilling, emplacing, and sealing operations requires treatment. Treatment processes are arranged so that cross-contamination of radioactive, hazardous, and conventional wastes will not occur. Provisions will be made to obtain samples of wastewater for analysis prior to treatment.

Support facilities include a chemicals storage room and mixing area located outside any radiation control areas. A control room, laboratory, offices, lunch/break room, lavatories, electrical service room, and mechanical service room will be provided. Boundary controls must be implemented, as needed, to isolate activities that take place in radiation control zones.

Effluent from Process Waste Treatment is designated as reclaimed water recycle and is used as makeup water to the cooling tower.

4.4.1.4 Sanitary Wastewater Treatment

Sanitary Waste Treatment is designed to handle 37,850 L/day of plant sanitary sewage and includes the collection piping system from all plant facilities. Hazardous chemicals, process waters, and contaminated streams will be kept out of the system. Wastewater from wash stations is collected in tanks and sampled for contamination before release to Sanitary Waste Treatment. If any streams are found to be contaminated, the wastewater is discharged to Process Wastewater Treatment. The treated wastewater effluent from Sanitary Waste Treatment is designated as reclaimed water recycle and is used as makeup water to the cooling tower. Sludge generated by Sanitary W water Treatment is dewatered and shipped to an on sanitary/industrial landfill. The treatment system con of primary, secondary, and tertiary treatment with di fectant. Necessary controls will be implemented so radionuclides will not be present in sanitary wastew

4.4.1.5 Waste Heat Management

Waste heat generated from process water cooling HVAC chiller systems is dissipated to environment b cooling tower system located in the Support Utilities A

4.4.1.6 Storm Water Management

Storm Water Management impounds all storm wa runoff from the facility and includes retention facilit and monitoring equipment. Discharged water can be us as cooling tower makeup or discharged to natural dra age. If the storm water were to become contaminated, t storm water would be treated before discharge.

4.4.2 Waste Management Feeds

Radioactive contaminated feeds arise from cleani of incoming ceramic pellet containers, process wash li uids, and excess water being output from the boreho Additional contaminated and uncontaminated waste pr cess feeds arise from sealant residues, contaminated r agent containers, deformed shipping containers, wipe rags, paper clothing, TCA cleaning solvent, and spent pum oils are solid and liquid feeds. Feeds from drilling includ briny water and solid rock cuttings. Feeds from emplace ment and borehole sealing include unconsumed solid wast cement, sand, and aggregates that contain chemicals use with concrete and sealants, and possibly contaminate wastewater.

4.4.3 Waste Management Function Products

Waste management function products may include certified TRU or LLW or MW. Domestic sanitary waste will be processed into liquids for sewage treatment and solids for sanitary landfills.

4.4.4 Waste Management Functon Special Requirements

The waste treatment processes requires decontaminating solutions for the decontamination process. An estimated 7,030 kg of decontaminating detergent will be required.

5. RESOURCE NEEDS

5.1 Materials/Resources Consumed During Operation

5.1.1 Utilities Consumed

5.1.1.1 Surface Processing Facility

The estimated annual utility requirements for operation of the Surface Processing Facilities are shown in Table 5.1.1.1-1.

5.1.1.2 Drilling and Emplacing–Borehole Sealing

The utilities required by the drilling, emplacement–sealing operations are summarized in Table 5.1.1.2-1. The values represent the average annual expected consumption.

5.1.2 Water Balance

The raw water requirement for the Deep Borehole Disposal Facility is about 138 million liters per year (Dry Site), of which 87.1 million liters is consumed by the main facility area and 50.7 million liters per year is consumed by the Drilling and Emplacing–Borehole Sealing Facilities in the borehole array area. The Raw Water Subsystem includes production wells, supply pumps, and transfer piping to the Facility Water Subsystem. Figure 5.1.2-1 shows the Annual Water Balance (Dry Site) for the Facility. There will be no significant difference in the raw water requirement between dry and wet sites. The main difference between dry and wet sites on the water supply system will be will be (1) the source of raw water will be a river or lake for a wet site and water wells for a dry site, (2) the storm water impounding ponds and drains will be smaller

Table 5.1.1.1-1. Utilities Consumed by the Surface Processing Facility During the Operation Period.

Utility	Annual Average Consumption	Peak Demand(1)
Electricity	5,800 MWh	2 MW
Diesel Fuel	16,280 L	N/A
Natural Gas	4,810,000 m^3 (2)	N/A
Raw Water (Dry Site)	87,100,000 L	N/A
Raw Water (Wet Site)	87,100,000 L	N/A

(1) Peak demand is the maximum rate expected during any hour.

(2) Standard cubic meters measured at 1.034 kg/cm^2 (14.7 psia) and 15.6°C (60°F).

Table 5.1.1.2-1. Utilities Consumed by the Drilling and Emplacing-Borehole Sealing Facilities During the Operation Period.

Utility	Annual Average Consumption	Peak Demand(1)
Electricity	300 MWh	0.3 MW
Gasoline and Diesel Fuel	757,000 L	750 L
Natural Gas	0 m^3 (2)	N/A
Raw Water (Dry Site)	50,700,000 L	N/A
Raw Water (Wet Site)	50,700,000 L	N/A

(1) Peak demand is the maximum rate expected during any hour.

(2) Standard cubic meters measured at 1.034 kg/cm^2 (14.7 psia) and 15.6°C (60°F).

Table 5.1.3.1-1. Annual Chemicals or Materials Consumed by the Surface Processing Facility During Operation.

Nonradiological Material	Quantity
Solids	
Filler Ceramic Pellets	500 t
Cement	210 t
Cement Additives	10 t
Decon detergent	5,440 kg
Non-ionic polymer (water treatment)	136 kg
Phosphates/Phosphonates (water treatment)	907 kg
Liquids	
Deionized Water (for ceramic pellet–grout mix)	94,630 L
Gases	
Nitrogen gas	500 cylinders

for a dry site, (3) the evaporation and groundwater seepage losses from retention ponds will be higher for a dry site, and (4) the cooling water tower system will have to be larger for a dry site.

5.1.3 Chemicals Consumed

5.1.3.1 Surface Processing Facility

The estimated annual material consumptions during the operation period of the Surface Processing Facilities are listed in Table 5.1.3.1-1.

5.1.3.2 Drilling and Emplacing–Borehole Sealing

The materials required for the drilling and emplacement–sealing operations is listed in Table 5.1.3.2-1. The table lists the requirements for the entire project, not annual usage. The steel will be used for the borehole casing. The bentonite will be used in the cements and in the drilling fluids. The sodium citrate and silica flour will be used in the cement mixes. The polymers will be used in the drilling mud and the cement mixes. Some of the polymers and bentonite will become waste from the drilling process. The water will be used for drilling fluid (mud) and for producing the cements. The air will be used by compressors for the drilling process.

5.1.4 Radiological Materials Required

There are no radioactive material requirements e cept the 50 t of plutonium in the 5,000 t of 1% Pu-loade ceramic pellet feed material over the 10-yr period of e eration of the Deep Borehole Disposal Facility.

5.2 Materials/Resources Consumed During Construction

5.2.1 Utilities

The estimated total energy resources and water co sumption requirements during construction of the bor hole surface facilities are shown in Table 5.2.1-1.

5.2.2 Nonradiological Materials

The estimated quantity of materials required for co struction of the borehole surface facilities is shown in Tab 5.2.2-1.

5.2.3 Land use

The Deep Borehole Disposal Facility requires approx mately 4 hectares (10 acres) of land for construction lay down and warehousing and 2.4 hectares (6 acres) for co struction parking.

Table 5.1.3.2-1. Nonradiological Materials Consumed by the Drilling and Emplacing-Borehole Sealing Facility During the Operation Period.

Nonradiological Material	Quantity
Solids	
API Class D, G, and F Cements	34,000,000 kg
Steel (Casing)	9,070,000 kg
Bentonite	907,000 kg
Sodium Citrate	340,000 kg
Silica Flour	340,000 kg
Polymers	340,000 kg
Liquids	
Water (for mud and cement, included in raw water total in Table 5.1.1.2-1)	41,600,000 L
Decon Detergent	7,030 kg

Table 5.2.1-1. Utilities Consumed During the Construction Period.

Utility	Total Consumption	Peak Demand(1)
Electricity	1,700 MWh	0.8 MW
Diesel Fuel	3,407,000 L	N/A
Gasoline	2,271,000 L	N/A
Propane	340,700 L	N/A
Raw Water	41,630,000 L	N/A

(1) Peak demand is the maximum rate expected during any hour.

Table 5.2.2-1. Materials Consumed During the Construction Period.

Material	Total Quantity
Concrete	25,000 m^3
Steel	5,800 t
Copper	85 t
Lumber	1,400 m^3
Asphalt	3,700 t

7. WASTES AND EMISSIONS FROM THE DEEP BOREHOLE DISPOSAL FACILITY

Wastes and emissions as described in the PEIS may not correlate exactly to those in this report because of differing categorizations.

7.1 Wastes and Emissions During Operation

The annual wastes and emissions released during operation of the Deep Borehole Disposal Facility are estimated in the following subsections. A 10-yr emplacement operation schedule is assumed.

7.1.1 Emissions

Estimated annual quantities of air pollutant emissions from operation of the Deep Borehole Disposal Facility are shown in Tables 7.1.1-1 and 7.1.1-2. The emissions are based on the annual fuel and gas consumption estimated in Tables 5.1.1.1-1 and 5.1.1.1-2.

Chemical processes that may lead to the release of contaminant over time are unlikely in the abbreviated times associated with unloading of Pu-loaded ceramic pellets,

Table 7.1.1-1. Chemical Emissions Generated by the Surface Processing Facility During the Operation Period.

Chemical	Annual Emissions (kg)
Criteria Pollutants	
Sulfur Oxides	77
Nitrogen Oxides	953
Particulates	8,620
CO	345
Hydrocarbons	86
Other Chemicals	
Volatile Organic Compounds	trace
Water Vapor (cooling tower)	40,824,000

Table 7.1.1-2. Chemical Emissions Generated by the Drilling and Emplacing-Borehole Sealing Facility During the Operation Period.

Chemical	Annual Emissions (kg)
Criteria Pollutants	
Sulfur Oxides	2,720
Nitrogen Oxides	30,390
Particulates	2,720
CO	10,890
Hydrocarbons	2,720
Other Chemicals	
None	

Table 7.1.2-2. Solid and Liquid Wastes Generated by the Drilling and Emplacing-Borehole Sealing Facilities During the Operation Period.

Category	Annual Quantities	
	Solid	Liquid
Hazardous Wastes		
Decon Water		69,600 L
Oil/Antifreeze/Hydraulics		69,600 L
Rags, etc.	1,090 kg	
Nonhazardous Sanitary Wastes	Section 7.1.2.7	Section 7.1.2.7
Nonhazardous Wastes		
Rock Cuttings from Boreholes	1,220 m^3	
Bentonite	31,750 kg	
Polymers	6,800 kg	

7.1.2.1 High-Level Wastes

There is no high-level radioactive waste generated from operation of the Deep Borehole Disposal Facility.

7.1.2.2 Transuranic Wastes

Transuranic wastes will be generated from process and facility operations, equipment decontamination, failed equipment, and used tools. Transuranic wastes are treated on-site in a waste handling facility to form grout or compact solid waste. Treated transuranic waste products are packaged, assayed, and certified prior to shipping to the Waste Isolation Pilot Plant (WIPP) for disposal.

7.1.2.3 Low-Level Wastes

Low-level wastes generated from operations of the Deep Borehole Disposal Facility are treated with sorting, separation, concentration, and size reduction processes. Final low-level waste products are converted to solid form, surveyed for radioactivity, and shipped to a shallow land burial site for disposal.

7.1.2.4 Mixed Transuranic Wastes

A small quantity of solid mixed waste, mainly rubber gloves and leaded box-gloves in the waste handling facility, will be generated from operation of the Deep Borehole Disposal Facility. The mixed waste is packaged and shipped to another DOE waste management facility (e.g., INEL at Idaho) for temporary storage pending final treatment and disposal.

7.1.2.5 Mixed Low-Level Wastes

Mixed wastes generated from the Deep Borehole Disposal Facility with radioactivity level below transuranic level (100 nCi/g) will be classified as mixed low-level wastes and will be treated in the same manner as the mixed transuranic wastes described in Section 7.1.2.4.

7.1.2.6 Hazardous Wastes

Hazardous wastes will be generated from chemical makeup and reagents for support activities and lubricant for drilling and emplacement machinery. Hazardous wastes will be managed and hauled to commercial waste facility offsite for treatment and disposal according to EPA RCRA guidelines.

7.1.2.7 Nonhazardous (Sanitary) Wastes

Non-hazardous sanitary liquid wastes generated in the Deep Borehole Disposal Facility are transferred to an on-site sanitary waste system for treatment. Non-hazardous solid wastes, such as domestic trash and office waste, are hauled to offsite municipal sanitary landfill for disposal.

7.1.2.8 Nonhazardous (Other) Wastes

Other nonhazardous liquid wastes generated from facilities support operations (e.g., cooling tower and evaporator condensate) are collected in catch tank and sampled before reclamation for other recycle use or release to the environment.

Table 7.2.1-1. Emissions During the Peak Construction Year.

Chemical	Total Emissions (kg)
Criteria Pollutants	
Sulfur Oxides	7,940
Nitrogen Oxides	97,500
Particulates (dust)	658,000
CO	635,000
Hydrocarbons	7,940
Other Chemicals	
Volatile Organic Compounds	trace

Table 7.2.2-1. Total Solid and Liquid Wastes Generated During Construction.

Waste Category	Quantity
Hazardous Solids	73 m^3
Hazardous Liquids	11,360 L
Nonhazardous Solids	
Concrete	382 m^3
Steel	163 t
Sanitary	918 m^3
Other	84 m^3
Nonhazardous Liquids	
Sanitary	32,170,000 L
Other	5,300,000 L

The combined waste from the drilling, emplacement operations is summarized in Table 7.1.2-2. The waste consists of rock cuttings, bentonite, and polymers used during drilling. These wastes will all end up in the mud pits. It is customary within the drilling industry to leave all of these wastes in the mud pits rather than ship them off site. After drilling is complete, the pits are generally filled up with earth and leveled. There is expected to be no treatment of these wastes unless testing indicates otherwise. The rock cuttings are shown in the table only as a volume since the rock will vary in density.

7.2 Wastes and Emissions Generated During Construction

The estimated wastes and emissions generated during construction of the Deep Borehole Disposal Facility are given in the following sections. A 3-yr construction schedule is assumed.

7.2.1 Emissions

Estimated emissions from construction activities of the Deep Borehole Disposal Facility during the peak construction year are shown in Table 7.2.1-1. The emissions are based on the construction land disturbance and vehicle traffic (for dust particulate pollutant) and the fuel and gas consumption (for chemical pollutants) estimated in Tables 5.2.1-1 and 5.2.2-1. The peak construction year is based on a construction schedule as the labor force distribution shown in Table 6.3-1.

7.2.2 Solid and Liquid Wastes

Estimated total quantity of solid and liquid wastes generated from activities associated with construction of the Deep Borehole Disposal Facility is shown in Table 7.2.2-1. The waste generations are based on factors from historic data on construction area size and construction labor force estimated in Table 6.3-1. Solid wastes generated during the construction period are hauled offsite for disposal.

7.2.2.1 Radioactive Wastes

There are no radioactive wastes generated during construction of the Deep Borehole Disposal Facility.

7.2.2.2 Hazardous Wastes

Hazardous wastes generated from construction activities, such as motor oil, lubricant, and drilling fluid from vehicles and drilling machinery, will be managed and hauled to commercial waste facility offsite for treatment and disposal according to EPA RCRA guidelines.

7.2.2.3 Nonhazardous Wastes

Solid nonhazardous wastes generated from construction activities (e.g., construction debris and rock cuttings), are to be disposed of in a sanitary landfill. Liquid nonhazardous wastes are either treated with a portable sanitary treatment system or hauled off-site for treatment and disposal.

8. DESIGN PROCESS FOR ACCIDENT MITIGATION

PURPOSE

The Deep Borehole Disposal Facility for disposing of the excess weapons-usable fissile materials (approximately 50 t) is a Hazard Category 1 facility as defined in DOE-STD-1027-92. As such, it will require a detailed Safety Analysis Report (SAR) and Risk Assessment under DOE Order 5480.23 before the facility is licensed for operation. In the PEIS phase, an accident analysis and risk assessment must be performed to provide a broad evaluation of potential accidents, and the basic design and mitigative features must be incorporated into the facility to reduce the impact of the accidents. This requires a qualitative evaluation of the risk of facility operation to public health and safety, including the magnitude of release of plutonium outside the facility due to the postulated bounding accidents. The frequency or probability of the accidents or events is also estimated qualitatively with a quantitative frequency range assigned to each qualitative frequency class. This approach is an approved methodology that complies with DOE-STD-3009-94, the guidance document for DOE Order 5480.23. This guidance document provides prescriptive methods for hazard analysis and accident analysis for the Safety Analysis Report for facilities of Hazard Categories 1, 2, and 3 based on a graded approach.

According to DOE-STD-3009-94, Chapter 3, a hazard analysis is required to be performed as a prerequisite to a quantitative accident analysis that forms a part of the SAR. This accident analysis is performed to provide guidance for the design of the structures, systems, and components (SSCs) that are classified as Safety Related and/or Safety Significant. The accident analysis is performed at two levels. The first analysis level consists of deterministic analyses for sizing and designing the structures, systems, and components for safe operation. The second analysis level consists of a probabilistic assessment for estimating the overall risk of facility operation to workers and the public. This Probabilistic Risk Assessment (PRA) supplements the deterministic analysis of the first level to provide insight into the hidden vulnerabilities in the design and operation of the facility. The PRA is performed at different levels of detail depending on the regulatory compliance requirements and to support facility life-cycle management decisions. The risk assessment for regulatory compliance is performed to determine the risk posed by facility operation to workers and the public and to ensure that DOE safety goals are met by satisfying the evaluation guidelines of DOE-STD-3005-94 (DRAFT).

SCOPE

The risk assessment must show that the facility will satisfy all appropriate ES&H safety requirements and national and international regulations for each of two operational phases: (1) Pre-Closure Construction, Operating, and Closure Period (assumed to be about 10 yr in duration) and (2) Post-Closure Performance Period, which extends from the time the borehole is sealed and plugged to an indefinite, geologically long time. A full-fledged risk assessment, covering both the Pre-Closure and the Post-Closure phases of facility construction, operation, closure, and post-closure performance, cannot be performed in the current pre–conceptual stage of facility design because of the lack of site characteristics data, detailed facility systems data, the required resources, and time for performing the analyses. Therefore, it is assumed that only a qualitative risk assessment of limited scope will be performed on the basis of the following assumptions and data provided in this report:

1. Risk assessment is limited to the Pre-Closure Phase of the facility and will not address its Post-Closure Phase performance. The Post-Closure phase requires long-term performance analyses that require a program of research to develop the necessary information. Therefore, this analysis is deferred to a future study. The quantitative full-scope risk assessment using system models for the Pre-Closure phase will be performed along with the SAR preparation stage in the development and design of the facility.

2. Bounding accident scenarios are classified into Design Basis Accidents and Beyond Design Basis Accidents.

3. The frequency of each accident scenario will be based on engineering judgment because the design or site characteristics of the facility are not developed well enough to justify use of rigorous risk analysis techniques.

4. Accident frequencies will be assigned qualitative levels of the annual probability of occurrence according to DOE-STD-3009-94:

   Anticipated ($10^{-1} \geq p > 10^{-2}$)
   Unlikely ($10^{-2} \geq p > 10^{-4}$)
   Extremely Unlikely ($10^{-4} \geq p > 10^{-6}$)
   Beyond Extremely Unlikely ($10^{-6} \geq p$).

5. An estimate of the amount of each hazardous material at risk in an accident.

6. An estimate of the fraction of each hazardous material at risk that becomes airborne in respirable form.

7. An estimate of the fraction of each respirable airborne hazardous material in each accident that is removed by the ventilation system filters.

8.1 Operational and Design Basis, and Beyond Design Basis Bounding Accidents

8.1.1 Operational and Design Basis Accidents

In this Section, the different categories of Operational and Design Basis Accidents are first described. Each accident scenario is then defined in sufficient detail to develop the basis for estimating the accident frequency and the release rates for the hazardous materials. The information for these scenarios is summarized in Table 8.1.1.32-1 in Section 8.1.1.32.

The major categories of accidents in this class are defined according to DOE-STD-3009-94, Section 3.4.2:

- *Category 1*: Natural Phenomena Events/Accidents for the site (e.g., earthquakes, wind/tornadoes, floods).

- *Category 2*: External Man-Made Accidents (e.g., aircraft crashes, nearby industrial facility accidents).

- *Category 3*: Internal Operational or Process-Related Accidents (e.g., fires, explosions, spills, criticality events).

These accidents are analyzed to evaluate the capability of the facility structures, systems, and components to limit the risk to the public to within the acceptable limits proposed in the evaluation guidelines.

Category 1: Natural Phenomena Events/ Accidents

Earthquake Hazard

The generic site description for the deep borehole facility recommends the selection of a U.S. site in a region of high tectonic and seismic stability (e.g., a site where there are no recorded earthquakes with a Mercalli intensity of over V). Using this guideline, the site is likely to be chosen in the Seismic Zone 1 according to the Uniform Building Code (UBC). This zone has a maximum acceleration of 0.075 g (See Figure 23-2 of UBC-1991). The design of the facility structures, systems, and components will be based on this acceleration level for the Design Basis Earthquake (DBE) and will follow the design criteria of DOE-STD-1020-94 for Performance Category PC-3 (see definition in DOE order 5480-28). From Table 2-1 of DOE-STD-1020-94, for Performance Category PC-3, the seismic hazard exceedance level is 5×10^{-4} with a return period of 2,000 yr for sites distant from tectonic plate boundaries. The preferred site, as recommended in the generic site description, is in an extremely stable tectonic region distant from tectonic plate boundaries. Therefore, the use of the UBC seismic zone 1 g level for the DBE, and design criteria from DOE-STD-1020-94 for design of the SSCs, are justified. The risk due to this earthquake hazard will be negligible. The effect of an earthquake on the surface facilities will be more pronounced than that on the emplacement region of the deep borehole if no active faults are present near the emplacement region. The absence of active faults is an important site selection criterion for the Deep Borehole Disposal Facility.

Wind/Tornado Hazard

The generic site description for the facility location assumes a windy location, with winter blizzards and spring and summer tornadoes. Chapter 3 (p. 3-1) of DOE-STD-1020-94 states that "wind speeds associated with straight winds typically are greater than tornado winds at annual exceedance probabilities greater than approximately 1×10^{-4}." Tornado design criteria are specified only for SSCs in Performance Categories 3 and higher, where hazard exceedance probabilities are less than 1×10^{-2}. In determining wind design criteria for Performance Categories 3 and higher, the first step is to determine if tornadoes should be included in the criteria. The decision can be made on the basis of geographical location, using historical tornado occurrence records. Because the facility design will have to follow DOE-STD-1020-94, Chapter 3 for Wind/Tornado design with appropriate missile criteria for Performance Categories 3 given in Table 3-1 of the standard, it is expected that the consequence due to wind hazard will be insignificant. It is also assumed that adequate administrative control will be established for severe blizzard conditions by a sitewide warning and response plan. Therefore, high wind and blizzard conditions are screened out because the consequences are negligible. Site-specific quantitative probabilistic wind hazard analysis will be performed only when a particular site (instead of a generic site) is selected.

Flood Hazard

The generic site description recommends that, for the elimination of the flood hazard, the site should be selected

become stuck in the emplacement zone. The probability of the bucket becoming stuck in the borehole emplacement zone above its intended release location is only marginally greater than the probability of becoming stuck in the isolation zone due to the fact that the casing stops at the top of the emplacement zone. The casing provides added stability to the upper regions of the borehole. If, despite the preventative measures, a bucket were to become completely stuck above the emplacement point, it could be cemented in place as a last resort. In that case no release of Pu would occur. It is "beyond extremely unlikely" that a bucket would rupture as a result of becoming stuck in the borehole. The large void space below the bucket would be filled and sealed.

8.1.1.15 Bucket Emplacement: Failure to Open of Bucket Pellet Release Valve (Category 3)

The valve at the bottom of the bucket acts as the release mechanism allowing the pellets and cement to flow into the borehole after the bucket has reached its release depth. This valve is critical to the emplacement system since a failure to release the pellets may result in a bucket becoming an emplacement canister. By the time the bucket is raised to the top of the borehole, the cement probably will have set up in the bucket. One response is to emplace the bucket and cement around it. The likelihood of the valve failing is probably "extremely unlikely," because such a critical system would be tested often before usage and, in addition, methods would be designed to separate the valve end of the bucket from the main bucket structure. The immediate severity of the accident is nonexistent, because no release of material will occur. There may be some minor long term impacts caused by corrosion products associated with buried parts of the bucket.

8.1.1.16 Bucket Emplacement: Premature Opening of Bucket Pellet Release Valve (Category 3)

If the valve at the bottom of the bucket were to open prematurely, the pellets and cement would free-fall to the bottom of the borehole. This would almost certainly result in broken and fractured ceramic pellets. The response would be to pump cement in on top of the pellets to seal up the borehole. The likelihood of the valve failing is "extremely unlikely" as such a critical system would be tested often before usage. The severity of breakage will be mitigated by the presence of water at the bottom of the borehole due to influx from the surrounding rock. The water will reduce the impact, reduce the level of damage to the pellets, and help to contain any Pu generated by the breakage of pellets. This is further assisted by the fact that the Pu is immobilized in the ceramic matrix of the pellets.

The source Pu at risk in this accident scenario is approximately 834 kg, the total Pu contained in one bucket. It is assumed that as a result of the premature release, 50% of the pellets will fracture, releasing all of the Pu that they contain into their surroundings. They will not have the protection provided by the bucket upon impact. The pellets will be wet due to the presence of the cement slurry, which will keep the airborne release to a 6×10^{-6} fraction of the released material. This is based on data from the *Nuclear Fuel Cycle Facility Accident Analysis Handbook, NUREG-1320.* The respirable fraction is therefore 3×10^{-6}. The containment building covering the borehole during emplacement will further contain the particles. The two stage HEPA filters used by the containment building will provide an additional 10^{-6} reduction in the number of airborne particles released into the atmosphere bringing the final release fraction to 3×10^{-12}.

8.1.1.17 Bucket Emplacement: Pellet–Grout Mix Solidifies in Bucket Before Release (Category 3)

In this scenario, the cement sets up in the bucket before it can be released into the bottom of the borehole. This could be caused by errors in preparing the cement mix, such as the addition of too much retardants or water, that cause a reduction in set time. It is also possible that a significant delay in lowering the bucket to the bottom could cause the cement to set prior to release. The significance of this scenario is the same as that when a stuck release valve fails to open. The corrective response is either to abandon the bucket and cement around it or to design for the bucket to break away from and release the solidified column. The likelihood of occurrence of this accident is "extremely unlikely." The mix formulation will be carefully controlled to prevent the cement from adversely influencing the fluid chemistry in the borehole. If the mix is chosen to provide a very long set time that provides a substantial difference between setup and the time to lower the bucket, operational delays will be unlikely to cause this scenario to occur. The immediate severity of the accident is nonexistent, because no release of material will occur. There may be some minor long term impacts caused by corrosion products associated with the bucket.

8.1.1.18 Bucket Emplacement: Pellet–Grout Mixing System Breaks Pellets (Category 3)

The pellets will have to be mixed with the cement and then pushed under water, air pressure, or gravity into

the bucket. The possibility exists for some of the pellets to break or crack due to unforeseen events in the emplacement process. The surfaces of the pellets will be wetted with cement, helping to limit the amount of the Pu from the pellets that becomes airborne. The contamination is expected to be limited to the mixing system and the bucket used for emplacement. It is "extremely unlikely" that pellets could be damaged since the process will be tested with unloaded pellets to prevent this type of accident.

The source Pu at risk in this accident scenario is approximately 834 kg, the total Pu contained in one bucket. It is assumed that as a result of rough handling during mixing and delivery to the bucket that 1% of the pellets will fracture, releasing all of the Pu they contain into the surroundings. The pellets will be water wet due to the presence of the cement slurry. Based on data from NUREG-1320, this will limit the airborne release to a 6×10^{-6} fraction of the released material. Therefore, the respirable fraction is 6×10^{-8}. The containment building covering the borehole during emplacement is designed to contain and limit the airborne particulate releases. The two stage HEPA filters used by the containment building will provide an additional 10^{-6} reduction in the number of airborne particles released into the atmosphere, bringing the final release fraction to 6×10^{-14}.

8.1.1.19 Bucket Emplacement: Pellets Break Upon Release (Category 3)

Upon release, the pellet–grout mix will flow out into the borehole. The weight of the column in the bucket and pressure that will be needed to push out the mix could cause some of the pellets to break due to unforeseen variations in the emplacement process. The severity of breakage will be mitigated by the presence of water at the bottom of the borehole due to influx from the surrounding rock. The water will reduce the impact, reduce the level of damage to the pellets, and will help contain any Pu generated by the breakage of pellets. This is further assisted by the fact that the Pu is immobilized in the ceramic matrix of the pellets. The severity of such an accident is expected to be low since contamination is expected to be limited to the borehole and the area just surrounding it given that a containment building covers the borehole. It is "unlikely" that a significant number of pellets could be damaged since the process will be tested with unloaded pellets to prevent this type of accident.

The source Pu at risk in this accident scenario is approximately 834 kg, the total Pu contained in one bucket. It is assumed that as a result of rough handling during mixing and delivery to the bucket that 1% of the pellets will fracture, releasing all of the Pu that they contain into their surroundings. The pellets will be water wet due to the presence of the cement slurry. Based on data from NUREG-1320, this will keep the airborne release to a 6×10^{-6} fraction of the released material. Therefore, the respirable fraction is 6×10^{-8}. The containment building covering the borehole during emplacement will further contain the particles. The two stage HEPA filters used by the containment building will provide an additional 10^{-6} reduction in the number of airborne particles released into the atmosphere, to yield a final release fraction of 6×10^{-14}.

8.1.1.20 Bucket Emplacement: Emplacement Facility Combustibles Fire (Category 3)

Flammable products at the Emplacement and Sealing Facility include engine oil and diesel fuel. These materials are associated with the generators needed for power on the emplacement crane and/or the drill rig. A crane will have an engine to provide the lifting power needed. A large fire in close proximity to a bucket could conceivably result in damage of the pellets in the uppermost portion of the bucket. Recall that the bucket will be hanging in the borehole while being filled with only its top exposed. This could result in a low-severity accident given that the Pu is immobilized and its position below the ground surface, which offers some fire protection. The likelihood of this accident scenario is "extremely unlikely," given that the generators and the crane engine will be located a considerable distance [30.5 m (100 ft) or more] from the bucket. No release is expected given the level of protection provided by the bucket and the containment building.

8.1.1.21 Bucket Emplacement: Emplacement Facility Electrical Fire (Category 3)

The extensive use of electric motors to drive the major mechanical systems of the emplacement facility, makes it conceivable that an electrical fire could occur. These motors will be located much closer to the bucket than to the generators that power them. They could be as close as 3.05 m (10 ft) from a bucket being filled prior to emplacement. For this reason, a fire sprinkler system will be employed to quickly suppress any electrical fires. It is "extremely unlikely" that a fire associated with this equipment would occur. No release of Pu is expected because of the containment provided by the bucket. In addition, the fire is expected to be small and brief.

8.1.1.22 Loss of Electrical Power (Category 3)

The Emplacement and Sealing Facility employs both generators and off-site electricity to power its systems.

Critical systems, such as HEPA filtered ventilation, will be designed with emergency backup power supplies. Therefore, a loss of electrical power will not result in a release of radioactivity. This scenario is deemed to be "anticipated" given that it can be expected to occur at a nominal frequency of about once per year.

8.1.1.23 Pumped Emplacement: Rupture of the Delivery Pipe (Category 3)

If the delivery pipe were to rupture, the pellets and cement would free-fall to the bottom of the borehole. This would probably result in some broken and fractured ceramic pellets. The response would be to pump cement in on top of the pellets to seal up the borehole. The likelihood of the pipe rupturing is "extremely unlikely" as such a critical system would be tested often before use. The severity will be mitigated by the fact that the borehole will be filled at the bottom with water due to influx from the surrounding rock. The water will reduce the impact, reduce the level of damage to the pellets, and will help limit the amount of Pu that becomes airborne due to the breakage of pellets. The pellets will also be wetted by the water in the cement slurry. Also, immobilization of the Pu in the ceramic matrix of the pellets will assist in limiting the amount of Pu that becomes airborne.

The source Pu at risk in this accident scenario is 100 kg, the total Pu contained in a single pumped batch. It is assumed that a rupture is not discovered until an entire batch had been pumped. Here 50% of the pellets will fracture, releasing all of the Pu they contain into the surroundings. It is also assumed that no protection is provided by the ruptured pipe. The pellets will be wet due to the presence of the cement slurry. Based on data from NUREG-1320, wetting of the slurry will limit the airborne release to a 6×10^{-6} fraction of the released material. The respirable fraction is therefore 3×10^{-6}. The containment building covering the borehole during emplacement will further contain the particles. The two stage HEPA filters used by the containment building will provide an additional 10^{-6} reduction in the number of airborne particles released into the atmosphere to yield a final release fraction of 3×10^{-12}.

8.1.1.24 Pumped Emplacement: Pellet–Grout Mix Solidifies in Delivery Pipe (Category 3)

In this scenario, the cement batch sets up in the delivery pipe before it can be released completely into the bottom of the borehole. This could be caused by errors in preparing the cement mix, such as the addition too much retardants or water, that cause a reduction in set time. It is also possible that a significant delay in pumping the batch could cause the cement to set prior to release. The corrective response is either to abandon the pipe and cement around it or to design for the pipe to break away from and release the solidified column. It would be difficult to remove the pipe from the borehole once the cement has set up inside. The likelihood of this occurrence is "unlikely." The mix formulation will be carefully controlled to prevent the cement from adversely influencing the fluid chemistry in the borehole. A very long set time may cause operational delays while a very short set time will cause this scenario to occur. The immediate severity of the accident is nonexistent, because no release of material will occur. There may be some minor long term impacts caused by corrosion products associated with the delivery pipe. These impacts could be more significant if the batch sets up in the upper portion of the delivery pipe near the top of the borehole. The concern is that post-closure, the disposed material could more easily reach the biosphere. The severity of this is difficult to estimate and further study is required.

8.1.1.25 Pumped Emplacement: Dropped Delivery Pipe (Category 3)

A failure of a mechanical system on the crane/drill rig or an operator error could cause the delivery pipe to be dropped to the bottom of the borehole during emplacement. A total free-fall is less likely to occur than a rapid descent into the borehole. The measures discussed previously for the case of a bucket being dropped are intended to prevent such an accident from occurring. The likelihood of this type of accident is deemed to be "extremely unlikely." The severity of the accident can be significant as a ruptured delivery pipe could release substantial quantities of ceramic pellets that are damaged (broken or cracked) into the unsealed borehole. The impact is likely to be fairly localized onsite with minimal impacts to offsite areas due to the presence of the containment building over the borehole. One response to the accident would be to cement the dropped pipe in place, assuming that the release valve has been damaged, so as to prevent the spread of material from the borehole. There may be some minor long term impacts caused by corrosion products associated with the pipe.

The source Pu at risk in this accident scenario is 100 kg, the total Pu contained in a pumped batch. It is assumed that as a result of the pipe being dropped 10% of the pellets will fracture releasing all of the Pu they contain into the surroundings. The pellets will be wet due to the presence of the cement slurry. Based on the data in NUREG-1320, the wetting will keep the airborne release to a 6×10^{-6} fraction of the released material. Therefore,

the respirable fraction is 6×10^{-7}. The containment building covering the borehole during emplacement will further contain the particles. The two stage HEPA filters used by the containment building will provide an additional 10^{-6} reduction in the number of airborne particles released into the atmosphere to yield a final release fraction of 6×10^{-13}.

8.1.1.26 *Pumped Emplacement: Delivery Pipe Becomes Stuck in Borehole (Category 3)*

The measures previously discussed for stuck bucket can be applied to a stuck delivery pipe in pumped emplacement. From these measures it is "beyond extremely unlikely" that the delivery pipe will become stuck in the borehole. The delivery pipe will be about 15.2 cm (6 in.) in diameter, and the borehole will be 0.66 m (26 in.) in diameter in the lowest part of the borehole. If by some unlikely event, a delivery were to become completely stuck in the borehole and the cement were to set up inside, it would have to be broken up by drilling and allowed to fall into the bottom of the borehole, or it could be cemented in place if it were deemed to be deep enough to achieve isolation. It is "beyond extremely unlikely" that a pipe would rupture as a result from becoming stuck in the borehole. Therefore, it is assumed that no release of Pu would occur. The concern is that post-closure, the disposed material could more easily reach the biosphere. The severity of this is difficult to estimate, and further study is required. There may be some minor long term impacts caused by corrosion products associated with the pipe.

8.1.1.27 *Pumped Emplacement: Pellet–Grout Mixing System Breaks Pellets (Category 3)*

The pellets will have to be mixed with the cement and then pushed under water, air pressure, or gravity into the delivery pipe. This process could cause at least some of the pellets to break or crack due to unforeseen events. The surfaces of the pellets will be wetted with cement, which will help to contain the Pu from the pellets. The contamination is expected to be limited to the mixing system and the pipe used for delivery. It is "unlikely" that a significant number of pellets could be damaged because the process will be tested with unloaded pellets to prevent this type of accident.

The source Pu at risk in this accident scenario is 100 kg, the total Pu contained in a pumped batch. It is assumed that as a result of rough handling during mixing and delivery to the pipe that 1% of the pellets will fracture, releasing all of the Pu that they contain into their surroundings. The pellets will be wet due to the presence of the cement slurry. Based on the data in NUREG-1320, wetting will limit the airborne release to a 6×10^{-6} fraction of the released material. Therefore, the respirable fraction is 6×10^{-8}. The containment building covering the borehole during emplacement is designed to contain and limit the airborne particulate releases. The two stage HEPA filters used by the containment building will provide an additional 10^{-6} reduction in the number of airborne particles released into the atmosphere, bringing the final release fraction to 6×10^{-14}.

8.1.1.28 *Pumped Emplacement: Pellet–Grout Mix Breaks Upon Release (Category 3)*

Upon release, the pellet–grout mix will flow out into the borehole from the end of the delivery pipe. The weight of the column in the pipe, and pressure that will likely be needed to push out the mix, could cause some of the pellets to break due to unforeseen process variations. The amount of damage will be mitigated by the fact that the borehole will be filled at the bottom with water due to influx from the surrounding rock. The water will reduce the impact, reduce the level of damage to the pellets, and will help contain any Pu generated by the breakage of pellets. This is further assisted by the fact that the Pu is immobilized in the ceramic matrix of the pellets. The severity of such an accident is expected to be low since contamination is expected to be limited to the borehole and the area just surrounding it given that a containment building covers the borehole. It is "unlikely" that pellets could be damaged because the process will be tested with unloaded pellets to prevent this type of accident.

The source Pu at risk in this accident scenario is 100 kg, the total Pu contained in a pumped batch. It is assumed that as a result of rough handling during mixing and delivery to the pipe that 1% of the pellets will fracture, releasing all of the Pu that they contain into their surroundings. The pellets will be wet due to the presence of the cement slurry. Based on data from NUREG-1320, this will keep the airborne release to a 6×10^{-6} fraction of the released material. Therefore, the respirable fraction is 6×10^{-8}. The containment building covering the borehole during emplacement will further contain the particles. The two stage HEPA filters used by the containment building will provide an additional 10^{-6} reduction in the number of airborne particles released into the atmosphere, to yield a final release fraction of 6×10^{-14}.

8.1.1.29 *Pumped Emplacement: Emplacement Facility Combustibles Fire (Category 3)*

Flammable products at the Emplacement and Sealing Facility include engine oil and diesel fuel. These materials are associated with the generators needed for power on the emplacement crane or drill rig. A crane will have an engine to provide the lifting power needed. A large fire in close proximity the delivery pipe could result in damage to the pellets in the uppermost portion of the pipe. Recall that the pipe will be hanging in the borehole while being filled with only its top exposed. This could result in a low severity accident, given that the Pu is immobilized and its position below the ground surface offers some fire protection. The likelihood of this accident scenario is "extremely unlikely" given that the generators and the crane engine will be located a considerable distance [30.5 m (100 ft) or more] from the delivery pipe. No release is expected given the level of protection provided by the pipe and the containment building.

8.1.1.30 *Pumped Emplacement: Emplacement Facility Electrical Fire (Category 3)*

The extensive use of electric motors to drive the major mechanical systems of the emplacement facility, makes it conceivable that an electrical fire could occur. These motors will be located much closer to the delivery pipe than to the generators that power them. They could be as close as 3.05 m (10 ft) from a pipe being filled during emplacement. For this reason, a fire sprinkler system will be employed to quickly suppress any electrical fires. It is "extremely unlikely" that a fire associated with this equipment would occur. No release of Pu is expected due to the containment that is provided by the delivery pipe. In addition, the fire is expected to be small and brief.

8.1.1.31 *Pumped Emplacement: Loss of Electrical Power (Category 3)*

The Emplacement and Sealing Facility employs both generators and off-site electricity to power its systems. Critical systems, such as HEPA filtered ventilation, will be designed with emergency backup power supplies. Therefore, a loss of electrical power will not result in a release of radioactivity. This scenario is deemed to be "anticipated" given that it can be expected to occur at a nominal frequency of about once per year.

8.1.1.32 *Summary of Design Basis Accident Scenarios and Release Fractions*

See Table 8.1.1.321-1 below.

Table 8.1.1.32-1. Summary of Design Basis Accident Scenarios and Release Fractions.

Section	Accident Scenario	Accident Frequency(1)	Source Term at Risk	Respirable Fraction	Fraction Released
8.1.1.1	Earthquake	Extremely unlikely	5 kg Pu	10^{-7}	10^{-13}
8.1.1.2	Tornado	Extremely unlikely	NA	No release	No release
8.1.1.3	Flood	Extremely unlikely	NA	No release	No release
8.1.1.4	Pu storage container breakage	Unlikely, 10^{-5}/drum/yr	5 kg Pu	10^{-7}	10^{-15}
8.1.1.5	Pu storage container breach	Unlikely 10^{-6}/handling	5 kg Pu	10^{-7}	10^{-15}
8.1.1.6	On-Site Pellet Transporter Accident	Unlikely, 1.6×10^{-6}/truck km	5 kg Pu	No release	No release
8.1.1.7	Pellet–Grout Mixing Process Facility Fire	Extremely Unlikely	5 kg Pu	10^{-7}	10^{-13}
8.1.1.8	Ceramic Pellet Spill	Unlikely	0.5 kg Pu	10^{-7}	10^{-15}
8.1.1.9	Pellet–Grout Mix Spill	Anticipated	0.5 kg Pu	6×10^{-6}	6×10^{-14}
8.1.1.10	Failure of Ventilation Blower	Anticipated 0.5/yr	NA	No release	No release
8.1.1.11	Loss of Electrical Power	Anticipated 1/yr	NA	No release	No release

Table 8.1.1.32-1. Summary of Design Basis Accident Scenarios and Release Fractions (Continued).

Section	Accident Scenario	Accident Frequency(1)	Source Term at Risk	Respirable Fraction	Fraction Released
	BUCKET EMPLACEMENT				
8.1.1.12	Bucket Dropped during Emplacement	Extremely Unlikely	834 kg Pu	6×10^{-7}	6×10^{-13}
8.1.1.13	Bucket Stuck in the Isolation Zone	Extremely Unlikely	834 kg Pu	No Release	No Release
8.1.1.14	Bucket Stuck in Emplacement Zone	Extremely Unlikely	834 kg Pu	No Release	No Release
8.1.1.15	Failure of Release—Fails to Open	Extremely Unlikely	834 kg Pu	No Release	No Release
8.1.1.16	Failure of Release—Opens Early	Extremely Unlikely	834 kg Pu	3×10^{-6}	3×10^{-12}
8.1.1.17	Pellet–Grout Sets in Bucket	Extremely Unlikely	834 kg Pu	No Release	No Release
8.1.1.18	Mixing System Breaks Pellets	Extremely Unlikely	834 kg Pu	6×10^{-8}	6×10^{-14}
8.1.1.19	Pellets Break During Release	Unlikely	834 kg Pu	6×10^{-8}	6×10^{-14}
8.1.1.20	Emplacement Facility Fire—Combustibles	Extremely Unlikely	834 kg Pu	No Release	No Release
8.1.1.21	Emplacement Facility Fire—Electrical	Extremely Unlikely	834 kg Pu	No Release	No Release
8.1.1.22	Loss of Electrical Power	Anticipated	N/A	No Release	No Release
	PUMPED EMPLACEMENT				
8.1.1.23	Rupture of Delivery Pipe	Extremely Unlikely	100 kg Pu	3×10^{-6}	3×10^{-12}
8.1.1.24	Pellet–Grout Solidifies in Delivery Pipe	Unlikely	100 kg Pu	No Release	No Release
8.1.1.25	Delivery Pipe Dropped	Extremely Unlikely	100 kg Pu	6×10^{-7}	6×10^{-13}
8.1.1.26	Delivery Pipe Stuck in the Borehole	Beyond Extremely Unlikely	100 kg Pu	No Release	No Release
8.1.1.27	Mixing System Breaks Pellets	Unlikely	100 kg Pu	6×10^{-8}	6×10^{-14}
8.1.1.28	Pellets Break During Release	Unlikely	100 kg Pu	6×10^{-8}	6×10^{-14}
8.1.1.29	Emplacement Facility Fire—Combustibles	Extremely Unlikely	100 kg Pu	No Release	No Release
8.1.1.30	Emplacement Facility Fire—Electrical	Extremely Unlikely	100 kg Pu	No Release	No Release
8.1.1.31	Loss of Electrical Power	Anticipated	N/A	No Release	No Release

(1) Corresponds to terminology defined in DOE-STD-3009-94.

Descriptive Word	Annual Frequency
Anticipated	$10^{-1} \geq p > 10^{-2}$
Unlikely	$10^{-2} \geq p > 10^{-4}$
Extremely Unlikely	$10^{-4} \geq p > 10^{-6}$
Beyond Extremely Unlikely	$10^{-6} \geq p$

Mitigation features: Accumulation of hydrogen within the battery room would require that the UPS be isolated from process ventilation system.

8.1.2.3 Pellet Storage Criticality (Category 3)

In accordance with NUREG-3.35 (*Nuclear Regulatory Guide*), the postulated pellet storage criticality event involves 10^{18} fissions in the initial pulse, followed by 47 additional pulses, for a total of 10^{19} fissions in 8 hr. The criticality event characterized here is estimated to result in 100% noble gas fission products; of these 25% are halogen (iodine) radionuclides that would become airborne. These radioactive materials would be released to the Zone 1 ventilation system. The exhaust HEPA filters do not mitigate the release of noble gases and halogens.

The plutonium concentration in the ceramic pellet design is sufficiently low to maintain criticality safety under all postulated accidents and natural phenomena conditions. The facility is designed to preclude flooding in the storage area. Therefore, a nuclear criticality accident in the pellet storage vault is judged to be a "beyond extremely unlikely" accident.

8.1.2.4 Pellet–Grout Mixing Process Criticality (Category 3)

In accordance with NUREG-3.35, the criticality events involve 10^{18} fissions in the initial pulse, followed by 47 additional pulses, for a total of 10^{19} fissions in 8 hr. The criticality event described here is estimated to result in 100% noble gas fission products; of these 25% are halogen (iodine) radionuclides that would become airborne. These radioactive materials would be released to the Zone 1 ventilation system. The exhaust HEPA filters do not mitigate the release of noble gases and halogens.

The plutonium concentration in the ceramic pellet design is sufficiently low to maintain criticality safe under all postulated accidents during pellet–grout mixing process conditions. Therefore, a nuclear criticality accident in the grout pellet mixing process is judged to be a "beyond extremely unlikely" accident.

Mitigation features: Plutonium concentration in the pellet is designed to ensure that an accidental chain reaction is not credible, even under water saturated fully reflected conditions.

8.1.2.5 Summary of Beyond Design Basis Accident Scenarios and Release Fractions

See Table 8.1.2.5-1 below.

8.2 Facility-Specific Accident Mitigating Features

Safety features will be designed to mitigate the consequences of the postulated accident scenarios. These features are identified and discussed after each accident scenario description along with their probability of failure and impact on the plutonium release frequency. These features are summarized here for ease of locating them as an aid to design.

The main mitigating features are of two classes:

1. Confinement/Containment Systems
2. Accident Progression Control Systems

These features are in addition to the prevention and protection systems that are built into the design, construction, installation, fabrication, operation, and quality assurance of the structures, systems, and components (SSCs) by using industry standard practice and methods. In addition, design margins (e.g., safety factors, increased tolerance, beyond design performance parameters) provide resistance to the occurrence of accidents.

The main mitigating feature of the confinement group is the ventilation system with HEPA filter. Redundant HEPA filters provide mitigation for release of plutonium to the outside environment in the event of an accident that compromises the prevention and protection systems.

The main suppression feature is the automatic fire sprinkler systems and similar systems that assist operator actions for mitigation.

Seismically hardened design, tornado dampers, fire dampers, and construction of the facility grade above the maximum probable flood level (MPF) are examples of protection features that will be considered from the preliminary design stage through the construction stage.

Storage container design with low seal stress minimizes the container breakage. Shipping packages and casks will be designed with double containment for transportation safety.

Table 8.1.2.5-1. Summary of Beyond Design Basis Accident Scenarios and Release Fractions.

Section	Accident Scenario	Accident Frequency[1]	Source Term at Risk	Respirable Fraction	Fraction Released
8.1.2.1	Failure of Ventilation Filter	Beyond Extremely Unlikely	0.5 kg Pu	6×10^{-6}	6×10^{-12}
8.1.2.2	Uncontrolled Chemical Reaction	Beyond Extremely Unlikely	5 kg Pu	10^{-6}	10^{-12}
8.1.2.3	Pellet Storage Criticality	Beyond Extremely Unlikely	10^{19} prompt fissions in 8 hr noble gas and halogen fission products release	1 noble gas 0.25 halogen	1 noble gas 0.25 halogen
8.1.2.4	Pellet–Grout Mixing Criticality	Beyond Extremely Unlikely	10^{19} prompt fissions in 8 hr noble gas and halogen fission products release	1 noble gas 0.25 halogen	1 noble gas 0.25 halogen

[1] Corresponds to terminology defined in DOE-STD-3009-94.

Descriptive Word	Annual Frequency
Anticipated	$10^{-1} \geq p > 10^{-2}$
Unlikely	$10^{-2} \geq p > 10^{-4}$
Extremely Unlikely	$10^{-4} \geq p > 10^{-6}$
Beyond Extremely Unlikely	$10^{-6} \geq p$

Redundant on-site emergency power system and UPS as a backup to the off-site power system is another important mitigation system against loss of off-site power. The battery room ventilation system mitigates the buildup of hydrogen gas in the room. Cranes, hoists, storage racks, and borehole steel lines are all designed for fail-safe operation.

The plutonium concentration in the coated ceramic pellets has been specified at level low enough to ensure that an accidental chain reaction would not cause a criticality accident under *any* dry and water-saturated operational and accident condition. Furthermore, the tough non-Pu-loaded ceramic coating of the ceramic pellets provides a substantial primary containment barrier to the release of plutonium to the environment during pre-closure surface processing and borehole emplacement operations.

large quantity of plutonium per package, shipment by the Safe Secure Transport System by Safe Secure Trailer (SST) is required.

Currently Available Packages

A preliminary search of available packages for the bulk transportation of Pu-loaded ceramic pellets indicates that there are no currently certified NRC-, DOT-, or DOE-approved packages with volumes large enough to contain 2.5 to 5 kg of Pu in ceramic pellet form at 1% Pu loading by mass. The capacity of the DOT-6M specification package is limited by the 2R inner vessel volume to about 2.294 L (140 $in.^3$). This limits the amount of pellet-form plutonium in one 6M/2R package to impractically low gram quantities (55 g). There are NRC certified Type B packages with adequately large cavity volumes. However, these packages, intended for the transport of highly radioactive materials, are large and heavy because of shielding requirements and are severely restricted in Pu quantity to the extent that they are not practical for bulk shipment of large volumes of ceramic pellets at low plutonium loadings. The DOE DC-1 package, designed and certified by the Martin Marietta Energy Systems Y-12 Plant, may be adapted to this application by modifying and recertifying the package for Pu-loaded ceramic pellets. A more suitable package is the Type B 208-L (55-gal) drum package, shown in Figure 9.2.1-1, that is currently being designed by Westinghouse, Hanford. This design, however, is in the pre–conceptual design phase, and additional work would be required to certify this package for the Pu-loaded ceramic pellets.

A comparison between the 6M/2R, DC-1, and two loading variants of the Westinghouse Type B drum at 0.055, 0.41, 3.6, and 5.1 kg of plutonium per package, respectively, is given in Table 9.2.1-1. The cost estimates in the table assume that these packages are decontaminated and reused as long as they meet the required tests prior to shipment. The Deep Borehole Disposal Facility requires

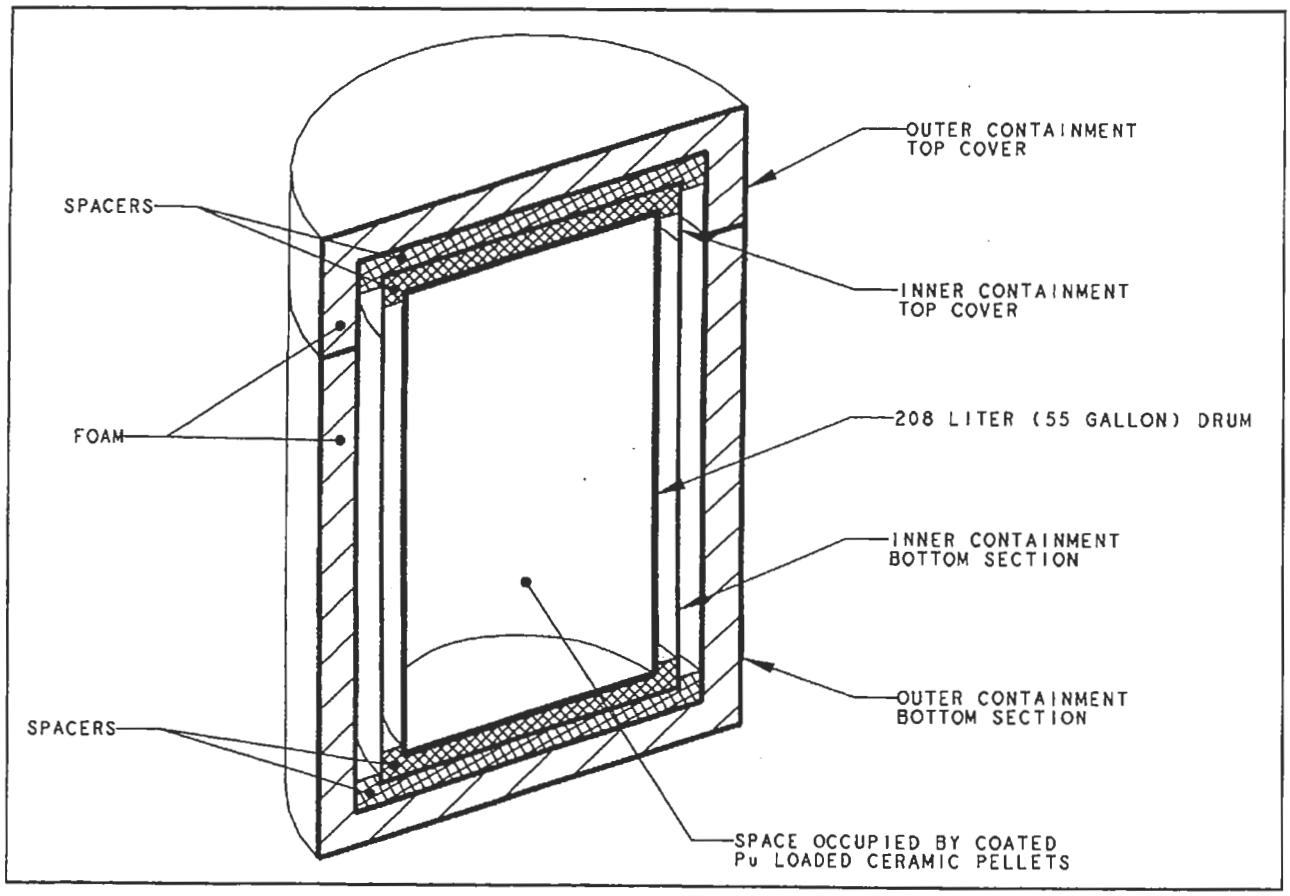


Figure 9.2.1-1. Modified Westinghouse Hanford Type B 208-L (55-gal) Drum Package.

Table 9.2.1-1. Candidate Packages for Transporting Immobilized Ceramic Pellets.

Package Type		DOT 6M/2R[1]	Martin Marietta DC-1[1]	Westing. Hanford Type B[1] (3.6 kg)	We Ha Typ (5.
Plutonium/Pellet	(g)	0.3432	0.3432	0.3432	0.
Weight/Pellet	(g)	34.32	34.32	34.32	3
Pellet packing vol. fraction	(%)	60	60	60	
Plutonium/package	(kg)	0.055	0.41	3.6	
Pellets/package		160	1,195	10,490	14
Pellet weight/package	(kg)	5.5	41	360	5
(Pellets + Package) Weight	(kg)	92	391	820	1,
2-Month Supply of Packages		15,152	2,032	232	1
Total # of Packages Shipped		909,091	121,920	13,920	9,
Cost/Package	(US $)	2,000	6,000	10,000	10
Total purchase cost[3]	(US $M)	18.18	12.19	2.32	1.

[1] Completely filled to maximum capacity.

[2] Container design and loading proposed for the Deep Borehole Facility, filled nearly to maximum (16,100 pellets).

[3] Cost of a 2-month supply of packages: Deep Borehole inventory (1-month supply), Immobilizatio storage, and Transportation pipeline (1-month supply).

an estimated 1-month supply of ceramic pellets in inventory for processing. The 2-month supply of packages in Table 9.2.1-1 assumes that an additional 1-month supply of packages would be in the transportation pipeline, both in transit and in storage at the immobilization facility awaiting shipment.

The Type B 208-L (55-gal) drum package being designed by Westinghouse, Hanford is the package preferred at this time for the Pu-loaded ceramic pellet option because its simpler design and larger capacity would reduce the cost of the packages, the cost of transportation, and perhaps more important, the handling costs during pellet packaging and processing. Even larger packages with double containment, and other alternatives, will be considered in the future for bulk shipment of the Pu-loaded pellets. The design and certification of an entirely new package will cost between $1.5 million and $3.0 million and will require from 3 to 5 yr. Modification of the Westinghouse Hanford 5.1-kg Type B package and its certification for transporting Pu-loaded ceramic pellets will require less time and is estimated to cost abou lion.

9.2.2 Transported Fissile Materials Shipping Volumes

The input material streams that require tra between the Deep Borehole Disposal Facility a locations are listed in Table 9.2.2-1. The only input material to the facility are the 1% Pu-loa ceramic pellets from the Immobilization Facili tion, the non-Pu-loaded, uncoated, commercial ceramic pellets are also identified here. The Westinghouse Hanford 5.1 kg Type B package above is assumed to be the package used for t the Pu-loaded coated ceramic pellets from the zation Facility to the Deep Borehole Disposal Fa maximum cargo weight of an SST of 5,443 kg (permits only 5 of these packages to be transp SST per shipment.

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High-level nuclear waste: Highly radioactive fission products resulting from reactor operations and nuclear fuel reprocessing that has radioactivity exceeding certain regulatory radiation limits.

Isolation zone: The upper part of a deep borehole (2 km) extending from the top of the emplacement zone to the ground surface used to seal and isolate the emplaced disposal form from the biosphere.

Main Facility: The southern part of the Deep Borehole Disposal Facility that includes all facility buildings and storage areas excluding the Borehole Array in the northern part. This includes the Surface Processing Facility, the Utility Support Facility, the Plant Waste Management Facility, the Central Warehouse, the Administration offices, Security, ES&H and Medical Centers, the Fire Station, and the personnel services building.

Mud: The fluid used in the drilling process. Often contains additives that cause it to appear mud-like.

Operation period: The period extending from the commissioning of the facility for acceptance of plutonium for disposal to the emplacement of the final load of plutonium and termination of accepting plutonium for disposal.

Post-closure period: An indefinitely long period (hundreds of millions of years) extending from closure of the facility to a time when the emplaced waste is no longer a security or safety hazard. It is expected that at least during the early years, the facility will be safeguarded and monitored.

Pre-closure period: The period covering the construction, operation, and closure (decontamination and decommissioning) phases of the Deep Borehole Disposal Facility.

Surface Processing Facility: The plutonium processing area of the Deep Borehole Facility in the receiving and processing building in the Main Facility area.

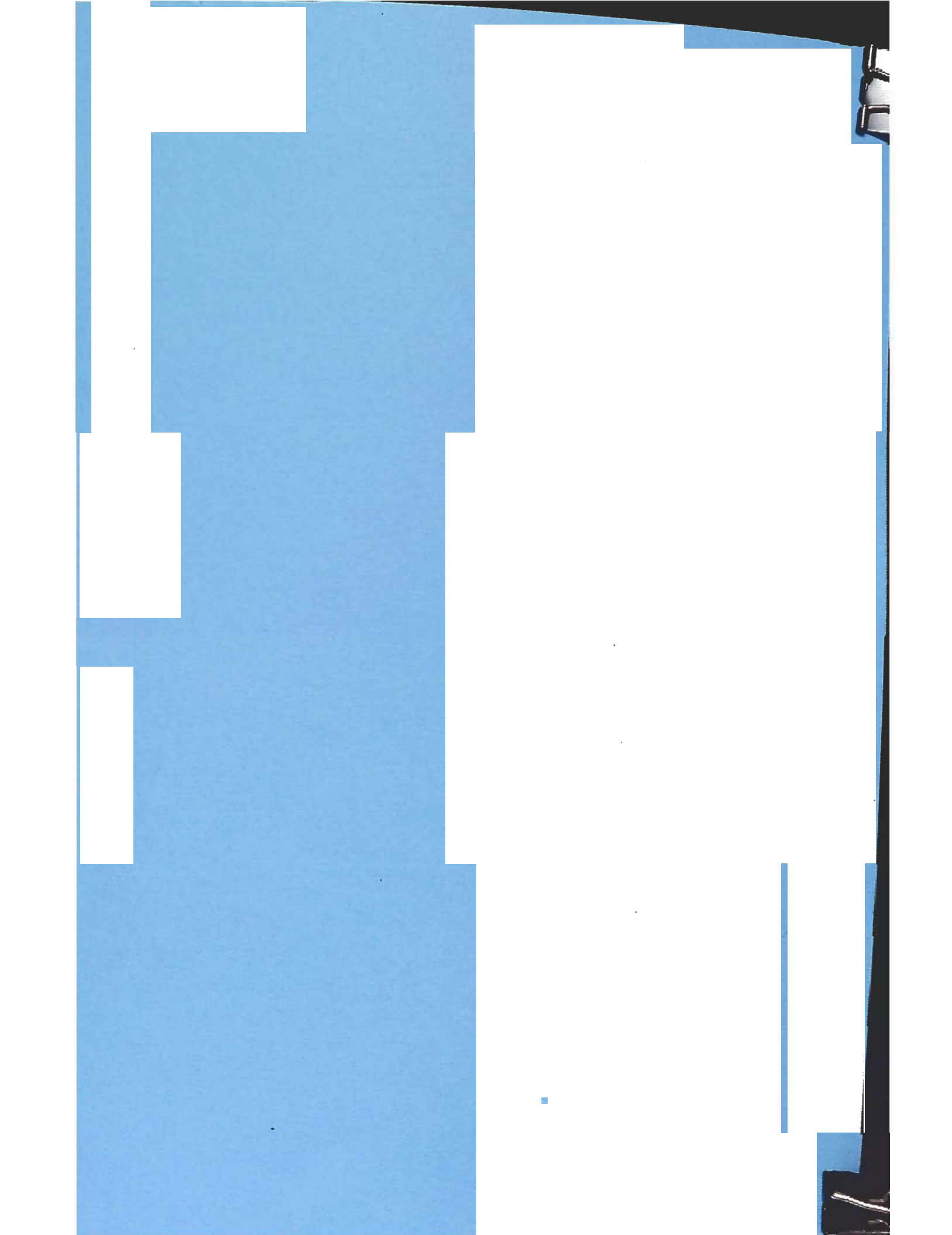
Sealant: A generic term used to refer to materials used to install low permeability seals within the borehole. The sealant materials for each of these uses are generally different and are as yet undefined, although many candidate materials are being considered. The latter include grout, bentonite, bentonite/sand mixtures, and other naturally occurring clays.

Transportation containers: The interior part 208-L (55-gal) drum primary container of the transportation package used for transporting the Pu-loaded ceramic coated ceramic pellet disposal form from the Immobilization Facility to the Deep Borehole Disposal Facility.

Transportation package: The 208-L (55-gal) drum primary container plus the external double containment assembly used for transporting the Pu-loaded ceramic coated ceramic pellet disposal form from the Immobilization Facility to the Deep Borehole Disposal Facility.

11.2 Acronyms and Abbreviations

CFE	Critical Flood Elevation
DBE	Design Basis Earthquake
DBF	Design Basis Flood
DBT	Design Basis Tornado
DOE	Department of Energy
DOT	Department of Transportation
EIS	Environmental Impact Statement

EKG	Electrocardiogram
EPA	Environmental Protection Agency
ES&H	Environmental Protection And Health
FMCD	Fissile Materials Control and Disposition
HEPA	High Efficiency Particulate Air
HLW	High-Level Waste
HVAC	Heating, Ventilating, and Air Conditioning
IAEA	International Atomic Energy Agency
km	Kilometers
KTB	German Scientific Drilling Program
LA	Limited Area
LANL	Los Alamos National Laboratory
LLW	Low-Level Waste
LLNL	Lawrence Livermore National Laboratory
MAA	Material Access Area
MC&A	Materials Control & Accountability
MBA	Materials Balance Area
MPF	Maximum Probable Flood
MVA	Megavolt Amperes
MW	Megawatt, Mixed Waste
MWh	Megawatt Hours
NESHAP	National Emission Standards for Hazardous Air Pollutants
NRC	Nuclear Regulatory Commission
OSHA	Occupational Safety And Health Administration
PA	Protected Area
PEIS	Programmatic Environmental Impact Statement
PPA	Property Protected Area

PRA	Probabilistic Risk Assessment
psia	Pounds Per Square Inch Absolute
R&D	Research and Development
RCRA	Resource Conservation And Recovery Act
ROD	Record of Decision
S&S	Safeguards And Security
SAR	Safety Analysis Report
SFM	Surplus Fissile Material
SKB	Swedish Nuclear Fuel & Waste Management Co., Sweden
SNM	Special Nuclear Material
SSC	Structures, Systems, and Components
SST	Safe Secure Trailer
t	Metric Ton (1,000 kg)
TRU	Transuranic Waste
UPS	Uninterruptible Power Supply
VA	Vulnerability Threat Assessment
WIPP	Waste Isolation Pilot Plant