

# Fissile Materials Disposition Program

## Alternative Technical Summary Report: Ceramic Greenfield Variant

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## Executive Summary

The Department of Energy (DOE) is examining options for placing weapons-usable surplus nuclear materials principally plutonium (Pu) and highly enriched uranium (HEU) in a form or condition that is inherently unattractive and inaccessible for use in weapons either by the host country or by a subnational group. The potential environmental impacts of technologies to implement this objective for plutonium are described in the Fissile Materials Disposition (MD) Program's *Storage and Disposition of Weapons-Usable Fissile Materials Programmatic Environmental Impact Statement (PEIS)*.

The MD PEIS examined the following resource areas: land use, facility operations and site infrastructure; air quality and acoustics; water, geology and soils, biotic, cultural and paleontological resources; socioeconomics; human health, normal operations and facility accidents; waste management; and transportation.

The PEIS is only part of the process of arriving at a Record of Decision (ROD) for the Fissile Materials Disposition Program (FMDP). In Phase I of this process, a number of options were eliminated from further consideration. The surviving options can be grouped into three groups of alternatives treated as reasonable in the PEIS:

- 1) Plutonium burning in a once-through reactor cycle as mixed-oxide (MOX) fuel, followed by disposal in a repository,
- 2) Immobilization or fixation in an acceptable matrix to create an environmentally benign form for disposal in a repository, and
- 3) Disposal in deep boreholes (with or without prior fixation).

In Phase II of this process, variants of these alternatives are being examined in more detail to provide more complete information desired for a ROD which includes consideration of technical viability, cost, schedule, and other factors.

One purpose of Phase II documents is to provide the required information for the technical cost and schedule analyses of the baseline alternatives plus their variants. The purpose of this specific document is to provide the required information for one of the immobilization alternatives: ceramic greenfield facility (CGF) variant. The processing and site-specific approaches considered in this study are as follows:

- 1) Dry feed—A dry rather than wet process in which  $\text{PuO}_2$  is loaded directly into the ceramic form instead of  $\text{Pu}(\text{NO}_3)_4$ .
- 2) Direct CsCl loading—A dry rather than wet process in which CsCl is loaded directly into the ceramic form instead of a cesium oxide.
- 3) Cold press and sinter—A cold press and sinter process that replaces the hot pressing process.

- 4) ANL/W—Facilities at ANL/W are used for some of the front-end plutonium processing and all of the back-end immobilization processing.

Immobilization is the fixation of surplus fissile materials, in this case plutonium, in an acceptable matrix to create an environmentally benign form for disposal in a repository. In addition to the traditional characteristics required of an immobilization form to achieve isolation of the plutonium from the biosphere over geologic time periods, the immobilization form for the MD Program must also possess the property that it is inherently as unattractive and inaccessible as the fissile material from spent fuel. This latter requirement is similar to the wording of the "spent fuel standard" invoked in the National Academy of Sciences (NAS) study on plutonium disposition. From this perspective, high-level wastes (HLW) or separated cesium ( $^{137}\text{Cs}$ ), can be added with the fissile material into the waste form to create a radiation field that can serve as a proliferation deterrent.

The immobilization technology considered here is the incorporation of the plutonium and  $^{137}\text{Cs}$  radiation spiking in a titanate-based ceramic and then disposal of the plutonium-bearing ceramic in a HLW repository. This immobilization process is shown conceptually in Figure 1 and discussed in Section 1. The immobilization of HLW in a number of ceramic waste forms has been studied extensively since the late 1970s. (Boatner, L.A. and B.C. Sales. 1988. "Chapter 4 SYNROC." In: *Radioactive Waste Forms for the Future*. Luntze, W. and R.C. Ewing eds. North-Holland. Amsterdam. pp. 233-334). The ceramic form that has received the most attention is a Synthetic Rock (SYNROC) material. This is a titanate-based waste form composed primarily of zirconolite, perovskite, hollandite, and rutile phases. The ceramic waste form is attractive for immobilization purposes because of its extremely low leachability, existence of natural mineral analogues that have demonstrated actinide immobilization over geologic time scales, and the high solid solubility of actinides in the ceramic resulting in a reasonable overall waste volume.

These properties make incorporation of plutonium into ceramic an attractive option for the disposition of excess plutonium. Incorporation of plutonium into ceramic containing  $^{137}\text{Cs}$  would provide a form that would be relatively easy to store but would render retrieval of the plutonium more difficult. Many of the technologies needed to prepare plutonium in a ceramic with a proliferation-resistant  $^{137}\text{Cs}$  radiation spike are not available today. However, the effect of chloride on the waste form ceramic formulation, the effect of formulation and redox control, plutonium reaction kinetics, optimum neutron absorber, the solubility interaction of the neutron absorber and plutonium, proper equipment design for criticality process control, and accountability after spiking with  $^{137}\text{Cs}$  are issues requiring resolution. Some technical issues have been addressed in various studies, to various degrees of completeness. Research and development activities are required to verify the process to be viable and demonstrate that the product is of suitable durability for disposal in a repository. The desired form of the final product will determine the extent of technical issues such as long-term criticality safety and stability of the product after repository emplacement.

In the ceramic greenfield variant, the disposition process begins with the transportation of plutonium feed materials (pits, metal, oxides, residues, salts, unirradiated reactor fuel, etc.) to the disassembly, conversion, and immobilization facility site in Department of Transportation (DOT) approved shipping containers. Where required, each shipping container will provide double containment of the contents.

The shipping containers will be unpacked and accountability measurements will be conducted. The plutonium materials will then be converted to oxide and fed to the ceramic process. The plutonium concentration will be approximately 12 wt%. Once the material has been incorporated in the ceramic with  $^{137}\text{Cs}$ , recovery of the plutonium will require extensive processing to return it to a state readily transformed to weapons.

The plutonium ceramic will be loaded into canisters which are welded shut after loading. It is at this point that the NAS-recommended "spent fuel standard" is achieved. The radiation spike is sufficient to maintain a radiation field above 1 Gy (100 rad) per hour at 1 m (3 ft) for a period of about 30 to 60 years. These canisters will be stored in an onsite storage facility until transferred to the federal repository. The repository is expected to remain open for 100 years and then it will be sealed. Since the radiation barrier will be decaying with a 30-year half-life, safeguards will be necessary during the period that the repository is open. Once the repository is sealed, the repository is expected to provide a significant proliferation deterrent. Post closure monitoring (e.g., satellite surveillance or seismic monitors) is expected to contribute to the proliferation resistance of the immobilization disposition alternatives.

Section 2 examines technical issues associated with each step of the immobilization process from front-end processing to the final repository. This disposition variant is qualitatively assessed against the following eight criteria:

- Resistance to theft and diversion
- Resistance to retrieval by the host nation
- Technical viability
- Environment, safety, and health compliance
- Cost effectiveness
- Timeliness
- Fosters progress with Russia and others
- Public and institutional acceptance.

The front-end processing operations are pretreatment operations designed to prepare the different incoming plutonium material forms from storage as a suitable oxide feed stream to the back-end operation. These front-end operations are generally at the industrialization stage or have been demonstrated at the engineering scale. Development and demonstration of some unit operations such as for part declassification are required.

The back-end processing operations include preparing the oxide feed stream and the <sup>137</sup>Cs for calcine, hot pressing the filled ceramic bellows, and loading the plutonium and cesium ceramic pressed bellows into a canister. These operations have been demonstrated at the production scale using surrogates for the ceramic operations.

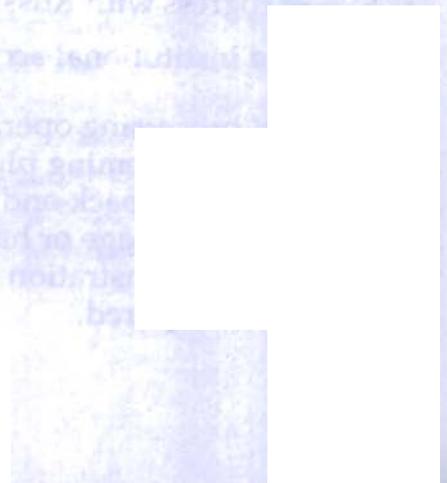
The dry feed approach for PuO<sub>2</sub> and direct CsCl loading require additional development for input specification and processing conditions. The cold press and sinter approach has been demonstrated at the engineering scale.

Disposition of the plutonium ceramic in a HLW repository involves regulatory and technical issues that require additional consideration.

This end-to-end immobilization variant combines functions from facilities previously described in and bounded by the PEIS process currently underway. For front-end processing in this variant, elimination of aqueous recovery lines results in significant reductions in aqueous waste solutions, processing equipment, associated facility space, utilities, and support systems. In the ANL-W approach, the need for new facilities is reduced due to the availability of existing facilities. For the back end, various process step improvements are proposed which reduce the waste streams, and the need for new facilities is reduced due to the availability of existing facilities.

The ceramic immobilization variant offers particular advantages in the immobilization of residue materials because of its ability to accommodate impurities without extensive pretreatment. It could become part of a hybrid option with another disposition technology.

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## 1.0 Variant Description

### 1.1 Introduction

Immobilization is the fixation of the surplus fissile materials in an acceptable matrix to create an environmentally benign form for disposal in a repository. In addition to the traditional characteristics required of an immobilization form to achieve isolation of the fissile material from the biosphere over geologic time periods, the immobilization form for the Fissile Materials Disposition Program (FM DP) must also possess the property that the fissile material is inherently as unattractive and inaccessible for weapons reuse as the fissile material in commercial spent fuel. This latter requirement is similar to the wording of the "spent fuel standard" invoked in the National Academy of Sciences (NAS) study on plutonium disposition. High-level wastes (HLW) or separated cesium ( $^{137}\text{Cs}$ ), can be added with the fissile material into the waste form to create a radiation field that increases the proliferation resistance and decreases reuse by the host nation in the following ways:

- Plutonium will be diluted with elements that must be removed by extensive chemical processing to return it to weapons usable purity.
- The immobilized plutonium canisters will contain approximately 2 tonnes (2000 kg; 2.2 tons) of mass, thereby forcing the use of heavy equipment to move the canisters.
- A gamma radiation barrier will be added to the immobilized plutonium canisters. The present concept is to add a radiation barrier that is greater than 1 Gy (100 rad) per hour at 1 m (3 ft) 30 years after fabrication.
- These canisters will then be sealed in casks and emplaced into drifts in a HLW repository where they will be monitored for 100 years before the repository is sealed.

This immobilization process is shown conceptually in Figure 1, Section 1.2.

Since the late 1970s, various ceramic waste forms have been considered for immobilization of HLW. These forms have received considerable attention because of their low leachability for actinides and fission products and the existence of mineral analogues in nature, which have demonstrated immobilization of rare earths, thorium, and uranium over geologic time periods. Ceramic immobilization of simulated HLW in a Synthetic Rock (SYNROC) material has been demonstrated at full scale at the Australian Nuclear Science and Technology Organisation (ANSTO). Laboratory-scale samples have been made with greater than 30 wt% plutonium and engineering scale samples have been made with greater than 10 wt% plutonium. A considerable amount

of research and development has been performed on this concept including a considerable amount of work with actinides.

The ceramic greenfield facility (CGF) variant presented in this report consists of the immobilization of plutonium in a titanate-based ceramic with  $^{137}\text{Cs}$  spiking to produce a radiation field that is uniformly distributed in the waste form.

The baseline is an approach using wet-feed processing to a hot pressing ceramic process operation at a greenfield site. Other process approaches to this baseline are greenfield Facilities utilizing dry-feed processing, direct loading of CsCl into the ceramic process, and a cold press and sinter ceramic-fabrication process instead of a hot-pressing operation. An additional approach is site-specific locating the facility at Argonne National Laboratory-West (ANL-W).

### 1.1.1 Assumptions and Design Basis

Major assumptions used in the development of the ceramic greenfield variant:

- The end-to-end immobilization facilities will receive plutonium as pits and in various stabilized plutonium forms stored as a result of the Defense Nuclear Facility Safety Board (DNFSB) Recommendation 94-1 Remediation Program as declared excess to national needs.
- The nominal feed of plutonium to the facility is 50 tonnes (56 ton).
- The campaign will take no more than 10 years to complete.

Additional assumptions for the variant are as follows:

- The immobilized surplus fissile materials package will contain an added radiation field to decrease its accessibility. For scoping purposes, a gamma radiation field barrier is assumed. The radiation field will be greater than 1 Gy (100 rad) per hour at 1 m (3 ft) from the package center surface for 30 years after initial fabrication. The source of the gamma radiation is  $^{137}\text{Cs}$  in the form of  $^{137}\text{CsCl}$  capsules currently stored at Hanford.
- The plutonium loading in the ceramic is a design parameter involving multiple tradeoffs that will be optimized during later phases of the design. The final design will consider fission product availability as well as form quality, facility size, safety factors, waste form acceptance criteria, safeguards and security, non-proliferation issues, etc. For this early design phase, the plutonium loading in the ceramic form is assumed to be 12% (by weight). This parameter is taken from demonstrated fabrication sizes (~33 kg [73 lb] using HLW surrogates), typical plutonium limits in glove box processing (~4 kg [9 lb] plutonium), and known plutonium loading data in ceramics (>10%).
- Design for criticality safety will meet applicable DOE orders and available NRC regulatory guides. Criticality control by batch mass control or equipment geometry are the preferred methods in the design. The use of a soluble nuclear

absorber (gadolinium, samarium, hafnium, etc.) in both the upstream liquid processing equipment and the final calcination/hot pressing equipment has been assumed. No process criticality analysis has yet been done. Criticality design issues within this report are based on engineering judgment and extrapolation from similar processes only. For this report the neutron absorber is assumed to be gadolinium.

- The ceramic canister size is a 36-cm (14 in.)-diameter by 2.4-m (8-ft)-high cylinder, which is within the current repository waste acceptance guidelines of a maximum diameter of 61.0 cm (2 ft) and 3.0 m (9.84 ft) high.
- As a true greenfield facility, construction and operation are assumed to be on a generic site (defined in Appendix F of *DOE Cost Guidelines*). After actual site selection, more specific site-related information will be required.
- The ceramic greenfield variant will process 5.0 tonnes (5,000 kg, 11,000 lb) of surplus fissile material annually. The operational life of the facility will be 10 years. Operations will be three shifts per day, seven days per week. Allowing normal time for remote maintenance, material control and accountability, etc., normal plant availability is considered to be 200 days per year. Nominal throughput is, therefore, 25 kg (55 lb) plutonium per day.
- The final ceramic product is contained in canisters and is stored onsite until it is transported to a HLW repository. Each product canister contains 20 compressed bellows with about 660 kg (1450 lb) of ceramic, which includes approximately 80 kg (176 lb) of plutonium, 52 kg (114 lb) of gadolinium, and 1 kg (2.2 lb, 87,000 Ci) of radioactive cesium.
- The ceramic product is assumed to be similar to SYNROC-C, which contains the mineral phases, zirconolite ( $\text{CaZrTi}_2\text{O}_7$ ), hollandite ( $\text{BaAl}_2\text{Ti}_6\text{O}_{16}$ ), perovskite ( $\text{CaTiO}_3$ ), and rutile ( $\text{TiO}_2$ ). The actual phases selected will be the result of a research program, and it is assumed that the composition of the ceramic-forming chemicals (precursors) will not affect the processing equipment or sequence.

### 1.1.2 Feed Materials

This end-to-end immobilization variant (ceramic greenfield facility) will receive the following material forms that are expected to be declared excess to national programmatic needs of the United States:

- |                                      |                                     |
|--------------------------------------|-------------------------------------|
| - Pits                               | - Clean oxide                       |
| - Clean plutonium metal              | - Impure oxide                      |
| - Impure plutonium metal             | - Uranium/plutonium-oxide           |
| - Plutonium alloys                   | - Sand, slag, and crucibles (SS&C)* |
| - Alloy reactor fuels (unirradiated) | - Oxide-like materials*             |
| - Oxide reactor fuels (unirradiated) | - Halide salts*                     |

\* The materials categories are expected to be converted to impure oxide as part of the DNFSB Recommended 94-1 stabilization program.

To maintain a consistent feed downstream and to minimize overall processing, the feeds will be blended.

### 1.1.3 Physical Layout Locations

The physical location of CGF process areas in the new greenfield facility are discussed in Section 1.4. No existing or upgraded structures will be used.

As a site-specific approach, the facilities at ANL-W are used. Front-end processing (disassembly and conversion) and contact-handled processes in the back end (immobilization) are located in the Fuel Manufacturing Facility (FMF), Zero-Power Physics Reactor (ZPPR), and new facilities. Remote processing in the back end will be conducted in Hot Fuel Examination Facility (HFEF) and Fuel Conditioning Facility (FCF). Onsite storage of the immobilized canisters will be located at Radioactive Waste Scrap Facility (RWSF). Lag storage of feed materials will use existing vaults in FMF and ZPPR.

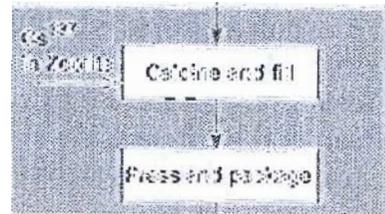
## 1.2 First-Level Flow Diagrams

The ceramic greenfield variant is shown on the first-level flow diagram (Figure 1). The feed materials to CGF will come from material that is stored as a result of the DNFSB Recommendation 94-1 Remediation Program. Prior to ceramic immobilization, many of the feeds require pretreatment. All of the pretreatment processing will take place in the pretreatment areas of the CGF in glove boxes. The pretreatment will convert the feed streams to oxides. The oxide product from pretreatment will be fed to ceramic immobilization equipment that is contained in shielded process cells of the facility.

### 1.2.1 Front-End Plutonium Processing—Disassembly and Conversion

The feed materials to the plutonium disposition facility coming from pits and the DNFSB Recommendation 94-1 storage will consist of metal (in pits or ingot form), oxides, unirradiated fuel units, and other plutonium compounds. These feed materials may need to be converted to oxides. The processing required for each feed type are:

- **Pits.** The pit is first disassembled. The metal is then removed from the pieces and converted to an oxide in the hydride/dehydride/oxidation operation. The oxide is packaged and stored as feed for the ceramic fabrication process.
- **Metals and Alloys.** Metals and alloys are converted to oxide. The oxide is packaged and stored for feed to the ceramic fabrication process.
- **Metal Reactor Fuel.** The metal fuel could be in the form of a bundle and clad in stainless steel. Hardware and cladding are removed in a decladding operation. The metal is then converted to the oxide using the hydride/dehydride/oxidation operation. The oxide is packaged and stored as feed for the ceramic fabrication process.



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**stai** Hardware and cladding are removed in the decladding operation.  
 The en size reduced. The oxide is packaged and stored as feed for the  
 process

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 Any dissolved pl...  
 converted to oxid...  
 as feed for the ce...

The plutonium compounds include material containi...  
 or ashes. The soluble salts are removed by washing...  
 is recovered by oxalate precipitation. The oxalate is...  
 calcination operation. The oxide is packaged and stored...  
 brication process.

**Bleeds.**

### 1.2.2 Back-End Ceramic Fabrication

The plutonium oxide material generated from the front-end processes will be immobilized in the back-end processes. In the first step, *Feed Preparation*, the plutonium oxide is dissolved or size reduced so that a homogenous and fully reacted product will be obtained. In the second step, *Calcine and Fill*, the plutonium nitrate or fine particulate plutonium oxide is blended with ceramic precursors, neutron absorbers, and a cesium-loaded titanate. The mixture is then calcined. In the third step, *Press and Package*, the calcined powder is hot pressured. The immobilized product is then loaded into a canister with packing material. The canisters are then stored onsite until they can be transferred to the HLW repository.

### 1.3 Second-Level Flow Diagrams

The first-level flow diagram for the ceramic greenfield alternative was expanded to two second-level flow diagrams. The two flow diagrams are designated as the front-end and the back-end processing. The front-end processing covers the conversions of the various feeds to oxides. The back-end processing covers the conversion of the oxides into an immobilized ceramic form.

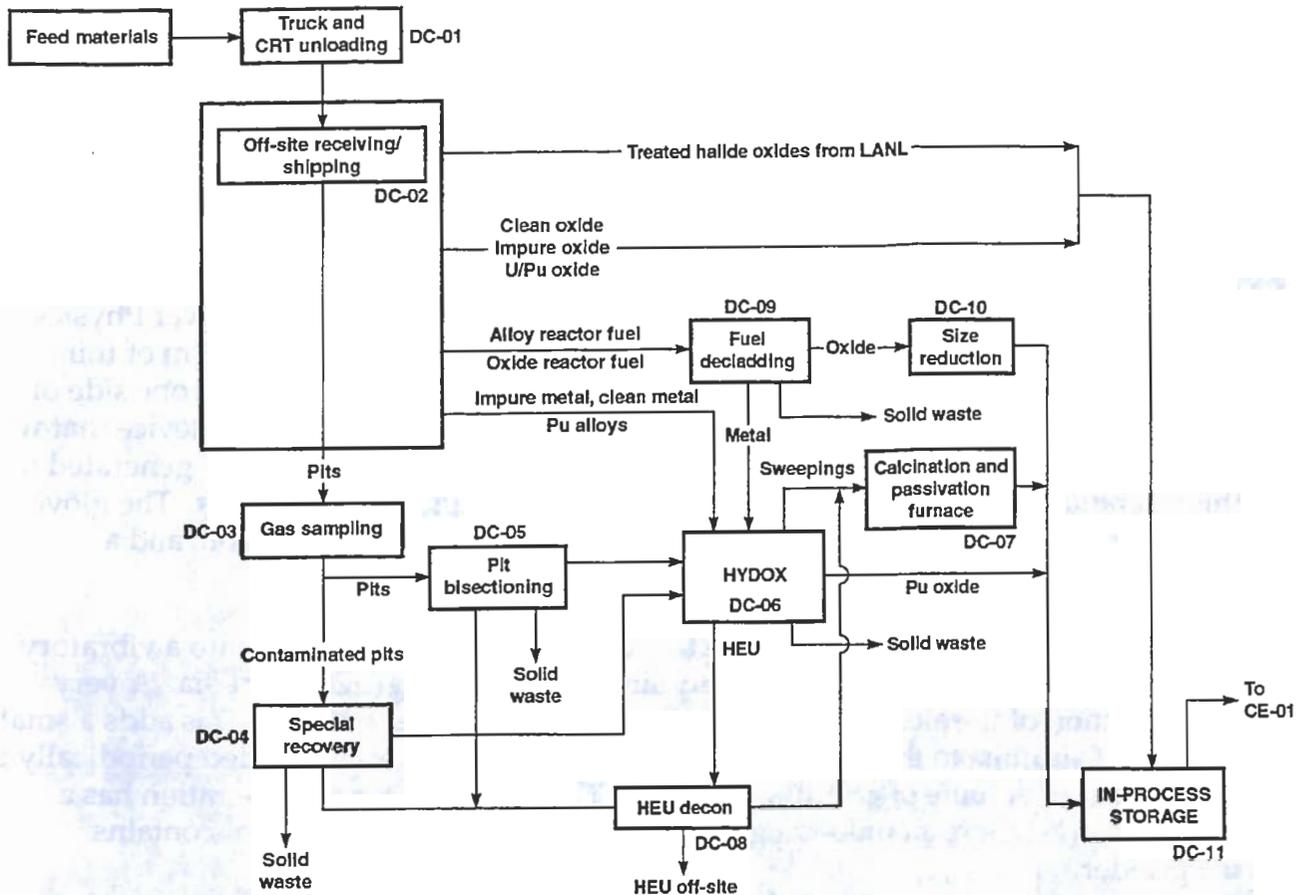
#### 1.3.1 Front-End Plutonium Processing—Disassembly and Conversion

The following are more detailed descriptions of the front-end plutonium disassembly and conversion (D&C) unit operations (Figure 2).

**DC-01 Truck and CRT Unloading.** Material shipments will be delivered to a truck and container restraint transport (CRT). Unloading dock where the delivery vehicle is a safe secure trailer/transporter (SST) will be washed and smear checked. The package plutonium cargo will then be unloaded. Initial assessments of radiation levels and container breaches are made during the unloading process to ensure a safe configuration for temporary storage while awaiting receiving and inspection. Shipping papers are checked, tamper indicating devices are inspected, and neutron counts are made on the packages. Emptied shipping CRTs and containers are inspected, decontaminated if necessary, and prepared for return.

**DC-02 Offsite Receiving/Shipping.** Receiving includes material confirmation, accountability, safety, and inventory measurements. The plutonium cargo is unpacked from the shipping containers, and repackaged in a suitable storage container in concert with the measurement activities. The repackaged material is then placed in the storage vault to await processing. Contaminated containers are decontaminated in a decontamination station where the material is retrieved and repackaged.

**DC-03 Gas Sampling.** All pits are gas sampled to check for potential contamination. Contaminated pits are sent to special recovery, while uncontaminated pits are sent to pit bisectioning.



10.D.0005.1D45p002

**Figure 2. Second-level flow diagram—ceramic greenfield, front-end disassembly and conversion.**

**DC-04 Special Recovery.** Contaminated pits are disassembled and the resultant parts are cleaned. Plutonium-bearing parts are separated out from other material. This operation consists of the following glove boxes and operations: disassembly, tool storage, bakeout, NDA, off-gas treatment, and subcomponent packaging.

**DC-05 Pit Bisectioning.** Pits are bisected to allow for plutonium removal using hydriding. This operation consists of one workstation for receiving and one workstation for the pit bisector.

**DC-06 Hydride/Dehydride/Oxidation.** Plutonium is reclaimed from the bisected parts and converted to oxide. The hydride/dehydride process is the method used to reclaim the plutonium and produce metal powder. The hydride/dehydride/oxidation method is used to reclaim the plutonium and produce oxide powder. This operation consists of several accountability workstations and a workstation for the hydriding unit.

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### 1.3.2 Back-End Ceramic Processing

The back-end processing converts the feed materials to ceramic inside canisters to provide a radiation barrier. The following describes the process:

**CE-01 Feed Preparation**  
The feed materials, including the ceramic precursors, will be blended with water and added to aid dissolution of the feed materials.

**CE-02 Calciner Feed Material**  
The feed materials will be added to a rotating slurry tank, 39 cm (15.4 in.) diameter, by 107 cm (42.1 in.) high. Ceramic precursors with water will be added to the slurry with a 45-degree offset angle, resembling a spiral, to promote mixing. The equipment will also accommodate the addition of

for storage and disposal. The following are descriptions for the back-end processing:

Plutonium nitrate solution will be combined with water and added to the slurry tank. The equipment will also accommodate the addition of active cesium and a soluble radiolytic water as needed. The slurry will be mixed in a rotating tank. The equipment will also accommodate the addition of

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The feed materials will be added to a batch. A variety of feed materials are added to this operation. The equipment will also accommodate the addition of

in the glove box line and team processing.

ted feed materials and converts them to ceramic inside canisters for storage and disposal. The following are descriptions for the back-end processing:

Plutonium nitrate solution will be combined with water and added to the slurry tank. The equipment will also accommodate the addition of active cesium and a soluble radiolytic water as needed. The slurry will be mixed in a rotating tank. The equipment will also accommodate the addition of



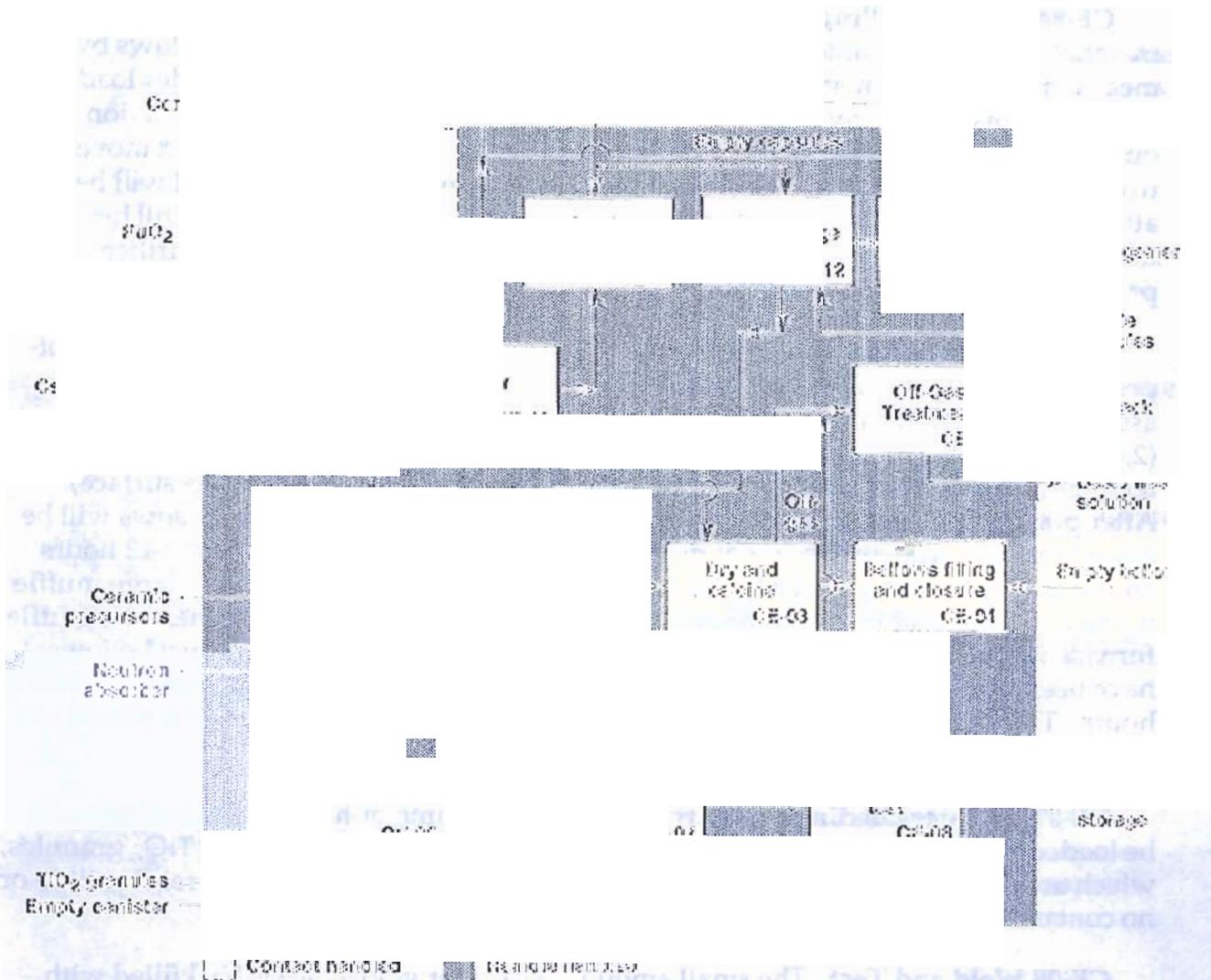


Figure 3. Second-level flow diagram –ceramic greenfield, back-end processing.

CE-03 Dry and Calcine. The drying and calcining will be conducted in a rotating

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while the furnace is rotating.

**CE-04 Bellows, Filling & Closure.** The dried and calcined ceramic precursor material loaded with plutonium will be removed and transferred to the bellows by means of a dustless transfer system. Bellows will be connected to the powder loading area by means of a sphincter seal. This seal will minimize airborne contamination outside of the bellows. After the powders have settled, the bellows will be removed from the sphincter seal and a bellows lid with off-gas tube already attached will be attached. The lid will be welded into place and the outside of the bellows will be decontaminated as necessary to minimize the spread of contamination in further processing.

**CE-05 Hot Pressing.** Welded and filled bellows will then be transferred to the hot-press assembly. The off-gas tube is attached to the off-gas system. The bellows assembly will then be heated slowly to 1200°C (2200°F) and pressed at 14,000 kPa (2,000 psi) for about 45 minutes. The product will be allowed to cool slowly to a temperature that can be handled remotely (600–800°C [1180–1470°F] at the surface). After pressing, the vent tube will be removed or bent flat. The product bellows will be placed into a muffle furnace for annealing. This operation would take up to 12 hours and would operate in parallel to the hot pressing operation. A sufficiently large muffle furnace should be able to accommodate at least 4 product bellows at a time. The muffle furnace will be held between 600°C and 800°C (1180–1470°F) until 4 product bellows have been loaded. Temperature will be ramped to about 1000°C (1830°F) and held for 6 hours. The furnace will then be cooled slowly to about 400°C (750°F) over a period of 6 hours.

**CE-07 Canister Loading.** Twenty 30-cm (12 in.)-diameter hot pressed bellows will be loaded into a canister, 36 cm (14 in.) diameter by 2.4 m (8 ft) long with TiO<sub>2</sub> granules, which are used as a packing material. The outside of the canister should receive little or no contamination during the process.

**CE-08 Weld and Test.** The small amount of canister void space is backfilled with helium and the canister lid is welded into place. The canister is removed through an air lock and decontaminated as necessary.

**CE-09 Receive CsCl Capsules.** CsCl capsules, approximately 6.67 cm (2.6 in.) in diameter and 52.77 cm (21 in.) in length, are received from Hanford and stored until processing. The CsCl is contained in double-walled stainless steel containers and contain an average of 430 g (0.95 lb) of Cs (540 g [1.2 lb] as CsCl). Approximately two-thirds is <sup>137</sup>Cs and one-third is <sup>135</sup>Cs. Since <sup>137</sup>Cs half life is 30 years, a significant amount the material will be decay product, an equimolar mixture of Ba and BaCl<sub>2</sub>. Each capsule will contain an average of 1080 g (2.4 lb) of the decay products.

**CE-10 Shear Capsules.** The outer container is cut open and the inner container is removed and sent to a shearing machine. After the inner container is cut open, the contents are removed and sent to *Dissolve CsCl* (CE-11). The stainless steel outer container is sent to LLW unless the inner container was breached, in which case the outer container is sent to *Greater than Class C LLW Management* (CE-13). In any case, the inner stainless steel container is sent to *Greater than Class C LLW Management*.

**CE-11 Dissolve CsCl.** The salt in the opened capsule is dissolved in hot water (alternatively dilute nitric acid could be used). Any precipitates that do not dissolve are sent to the calcine feed makeup tank. Precipitates will be dried for the dry feed process. The solution with dissolved CsCl and BaCl<sub>2</sub> is sent to the ion exchange column and the stainless steel capsule remnant is sent to *Greater than Class C LLW Management* (CE-13).

**CE-12 Ion Exchange.** The CsCl solution will be adjusted to the desired concentration and acidity and passed over a titanate-based inorganic ion exchange column. The NaCl effluent will be sent to aqueous processing, where the solution will be dried (water will be recovered and recycled) and, if necessary, the salt concentrate will be immobilized in zeolite or polyethylene. The loaded titanate column will be washed with a chloride-free solution, removed, wet milled as necessary, then sent to the calciner feed makeup step.

**CE-13 Greater Than Class C LLW Management.** Contamination from empty capsules will be removed with repeated washings in warm water. The residue solution will be used to dissolve CsCl, and the washed capsule will go to normal LLW.

**CE-29 Off-Gas Treatment.** Water in the off gas will be condensed and recycled. Acid gases will be scrubbed and remaining off gases will go to the HEPA filter system.

## 1.4 Facilities

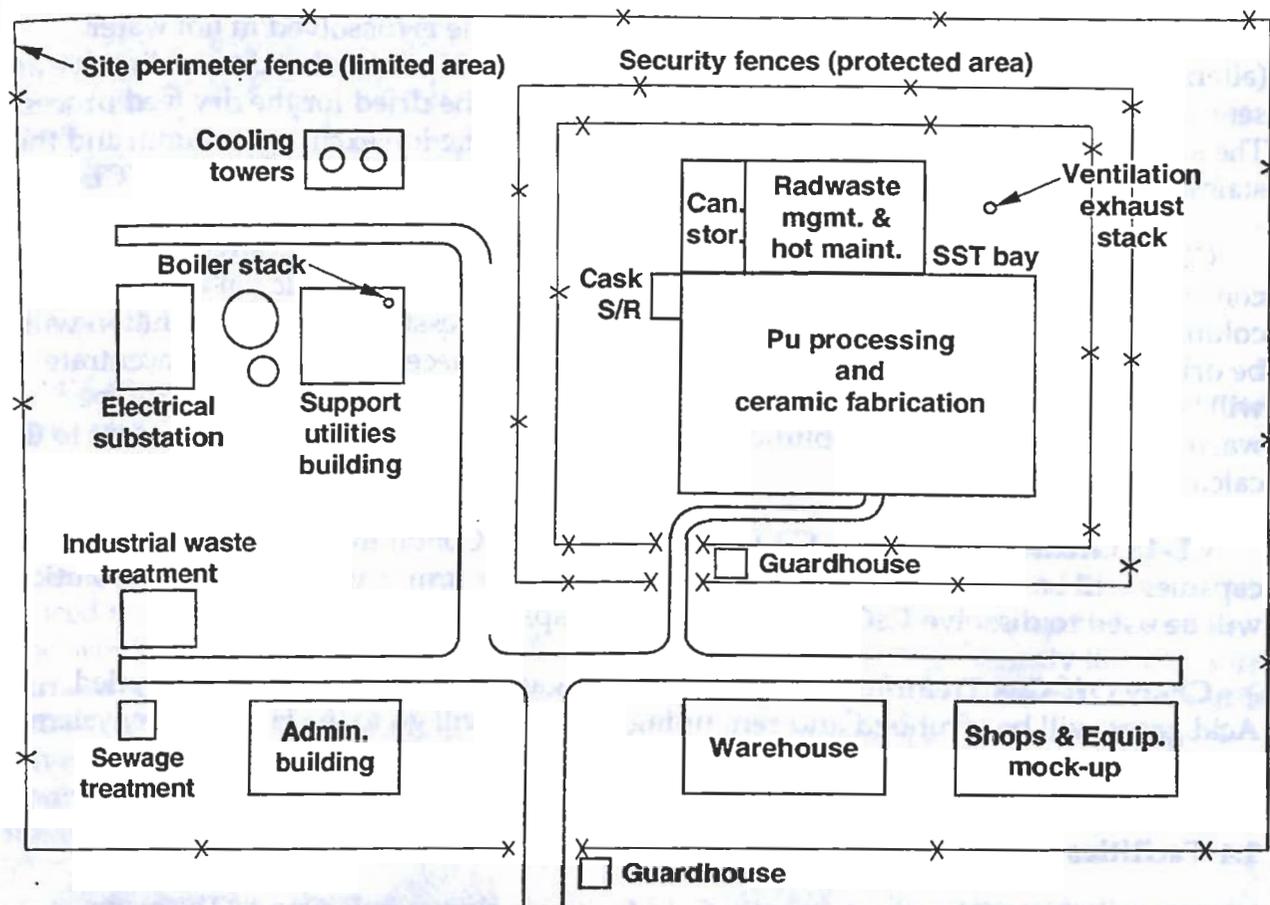
The site map of the ceramic greenfield facility is shown in Figure 4. The major features of the facility are a combined plutonium processing and ceramic fabrication building, a radwaste management/hot maintenance building, and associated support facilities. Table 1 provides major facility data.

### 1.4.1 Front-End Area Description

The front-end processing area will contain process equipment, auxiliary equipment, and personnel facilities for converting plutonium-bearing materials to plutonium oxide.

The primary front-end processing areas include the following functions: shipping and receiving, storage vaults, gas sampling, special recovery, pit disassembly, hydride/dehydride/oxidation, or alloy decontamination, passivation, decladding and size reduction, halide wash, precipitation and filtration, and pyrolysis and calcination. This building also includes space and equipment for chemical analyses, TRU waste disposal, nondestructive evaluation, shipping and receiving, maintenance shops, control rooms, R&D laboratories, and quality control.

The operations support area contains change rooms, decontamination facilities, maintenance offices & shops, operator training rooms, laboratories, and general storage areas. Source calibration of radiation-measuring instruments is performed here.



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Figure 4. Ceramic greenfield facility site map.

#### 1.4.2 Back-End Ceramic Fabrication Area Descriptions

The ceramic fabrication area is shown in Figures 5 and 6. The area is a reinforced-concrete structure housing a central "canyon" area where the main immobilization process is located and is surrounded by various support areas. The building houses the following main functional areas:

- Area for receiving plutonium chemical forms in safe secure transport/trailers (SSTs) and for receiving cesium capsules in shielded casks.
- Storage vault for SNM received.
- Analytical laboratory for analyzing process samples.
- Cold feed storage and preparation area for nonradioactive feed materials for the ceramic process (ceramic precursors and bellows).
- Equipment decontamination cell for decontaminating process equipment.

Table 1. Facility data and sizing.

Building name	Total area m <sup>2</sup> (Sq. Ft.)	Number of levels	Special materials	Construction type
Pu processing and ceramic fabrication				
Front-end processing area	1700 (18,000)	1	SNM	Reinforced concrete
Processing support area	6600 (71,000)	1	SNM	Reinforced concrete
Ceramic processing area	2680 (33,000)	2	SNM	Reinforced concrete
Management Building	1740 (18,750)	1	SNM	Reinforced concrete
Hot Maintenance Building	930 (10,000)	1	SNM	Reinforced concrete
Canister Storage Building	930 (10,000)	2 (one below grade)	SNM	Reinforced concrete
Support Utilities Building	930 (10,000)	1	None	Metal frame
Administration Building	1400 (15,000)	1	None	Metal frame
Warehouse	1900 (20,000)	1	None	Metal frame
Shops & Equipment Mockup	1900 (20,000)	1	None	Metal frame
Industrial Waste Treatment Building	740 (8,000)	1	None	Metal frame
Sanitary Waste Treatment Building	150 (1,600)	1	None	Metal frame
Guardhouses (2)	150 (1,600)	2	None	Reinforced concrete
Cold Chemical Storage	190 (2,000)	1	None	Metal frame
Cooling Tower	560 (6,000)	~		

- Shipping and receiving area for cold chemical feed materials, ceramic precursor, and bellows, and other nonradioactive materials.
- Facilities for accountability measurements of the special nuclear material (SNM) received or shipped.
- Facilities for mechanical and electrical support systems and clean equipment maintenance.
- Control room.

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Radwaste management  
and hot melt

Sample & remote  
analysis cells

Remote  
analysis

10X

Solid  
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Hot pressing &  
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Clean maintenance  
& repair shops

Remote analysis

~37 m  
(120 ft)

~73 m (240 ft)

Processing area, ground floor.

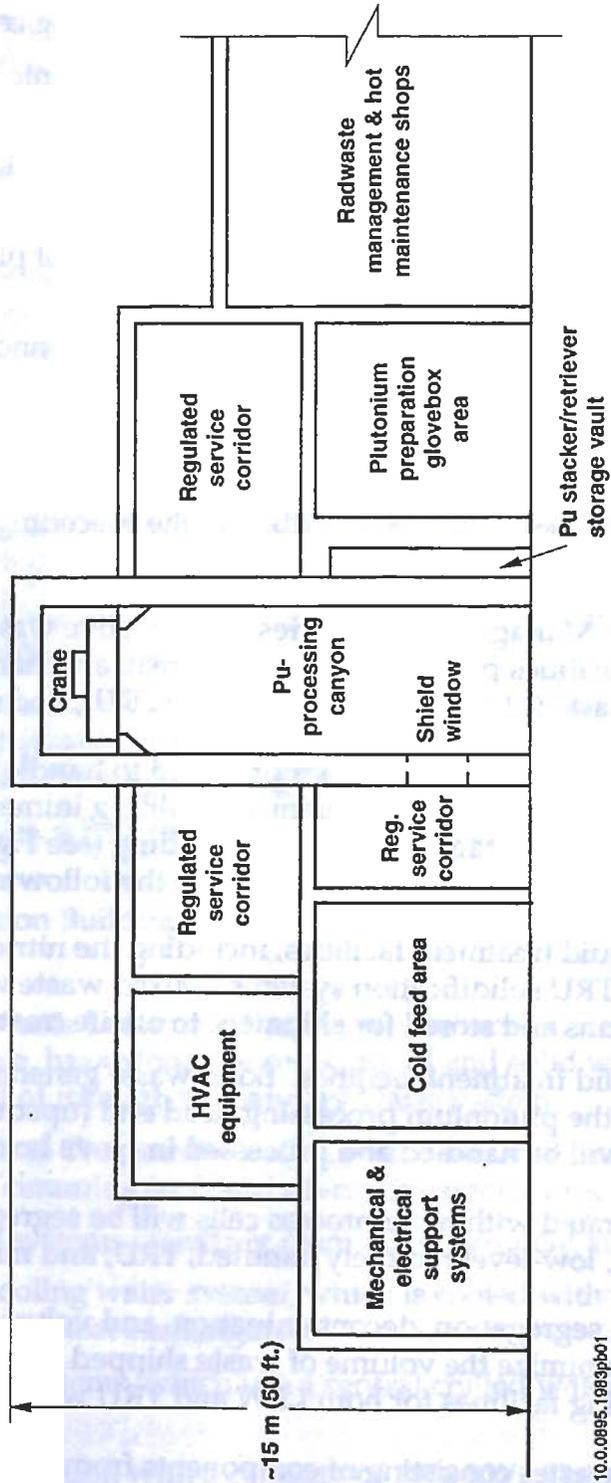


Figure 6. Ceramic processing area, cross section.



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and other wastes that have high cesium activity will be processed initially within the shielded processing cells.

- The off-gas treatment facilities. Gaseous radioactive wastes will be filtered, condensed, scrubbed, absorbed, etc., as required to meet DOE and other applicable regulatory requirements.

**Safeguards and Security (S&S) Facilities.** Safeguards and security facilities consist of the perimeter security system, including a guardhouse at each entry point to the site and to the inner security area.

**Other Facilities.** Other facilities include:

- The Hot Maintenance Shop, which provides facilities for maintenance and repair of process equipment from the Plutonium Processing and Ceramic Fabrication Facility, the Radwaste Management Building, and the Canister Storage Building.
- Shops and Mock-up Building, which houses clean maintenance, fabrication, mock-up, and repair shops.
- The Support Utilities Area, located outside the inner security fence, includes raw water treatment systems, water storage tanks, central chilled-water cooling system, and steam-heating boiler system.
- The cooling tower, which provides cooling for both the process and HVAC systems.
- An Administration Building.
- A warehouse.
- The Industrial Waste Treatment Facility for the receipt, treatment, and disposal of nonradioactive, hazardous chemical, liquid and solid wastes other than liquid wastes disposed of through the sanitary waste system.
- The Sanitary Waste Treatment Facility, which will treat sanitary wastes generated from ceramic greenfield alternative operations.
- Compressed air systems including plant air, instrument air, and breathing air.
- A closed-loop cooling water system, which is cooled with water from the cooling tower in plate-type heat exchangers.
- Building HVAC systems, which use a central chilled water system for building cooling.
- The electrical substation with a capacity of 3000 kW. The electrical system also includes two, redundant, 500-kW, emergency-power diesel generators, housed in a seismic and tornado-resistant structure, to ensure the operation of all safety related systems during a power outage.

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vault at the greenfield facility.\* The material requiring transport includes: pits, clean metal, impure metal, impure oxide, clean oxide alloys, halide oxides, and reactor fuel.

*Package Description.* The pits under the FMDP will be stored and transported in the Model FL or the AT-400A container. The various pits can utilize these containers by using different internal fittings.

The other plutonium material is assumed to be at onsite storage at the various DOE facilities. The material and package are assumed to meet *The Criteria for Safe Storage of Plutonium Metals and Oxides* stated in the DOE standard DOE-STD-3013-96, July 1996. This criteria states that all plutonium metal and oxides (excluding pits) over 50 wt% plutonium shall be stored in a storage container that includes a minimum of two nested hermetically sealed containers to serve as barriers to isolate the stored materials from the environment and to prevent contamination release.

For transporting the plutonium material (non-pit), the storage container would be loaded into another shipping container, a 6M/2R-like, which could provide double containment if required. Two 6M/2R-like package designs that could incorporate the storage container are the SAFKEG and the Chalfant. These specific designs would require modifications to ensure that the package criteria stated in DOE-STD 3013 are met. Further modifications would be required to ensure: 1) the packaging configuration incorporates the storage container, 2) analysis/testing is performed to show the abnormal and normal accident scenarios, and 3) the Safety Analysis Report is modified to show the changes.

Unirradiated reactor fuel forms to be shipped from the various DOE sites in this segment consist of unirradiated pellets, pins, and fuel assemblies. This material can be shipped either in these forms in an NRC-certified package like the model number MO-1 (Certificate number 9069) or as pellets in a 6M/2R-like package. In either case the material shipments will consist of Category I quantities with the requirement for safe secure transport/trailer. A review of these alternatives shows that shipment as pellets greatly reduces the number of individual shipments required if the MO-1 package is used. Additionally, shipment as pellets in a 6M/2R-like container by SST results in a further reduction of individual shipments.

As a result, the 6M/2R-like package is the preferred option for unirradiated reactor fuel shipment, and no distinction will be made between reactor fuel and other non-pit plutonium material when considering intersite transportation segment #1.

*Shipment Information.* A 10-year FMDP shipment campaign has been assumed with a total quantity of 50 tonnes (56 tons). There are three intersite transportation segments as shown in Figure 7. The requirements of these segments are described below. The total number of packages and shipments is shown in Table 2. Table 2 summarizes shipment

\* For the transportation analysis, it was assumed that the site would be located at an existing DOE facility. The scenario that created the longest transportation route was used to be conservative on cost. Therefore, Savannah River site located in Aiken, South Carolina, was used to calculate miles.

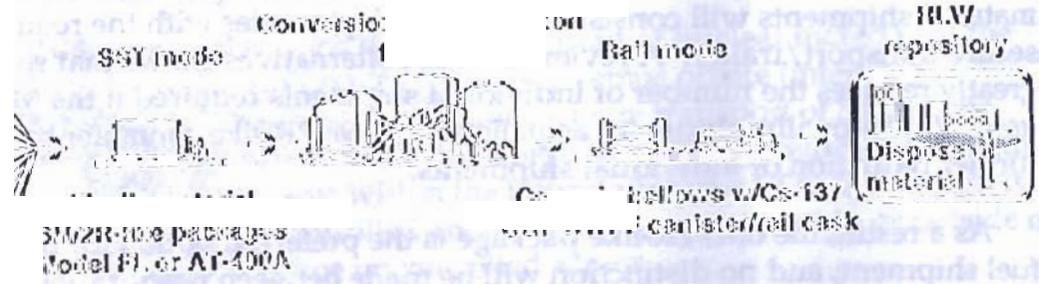
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	Intersite transportation Segment #1	Intersite transportation Segment
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— Hanford		
— Pantex		
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Figure 7. Simplified flow chart showing transportation s

Table 2. Parameters for intersite transportation segment #1.

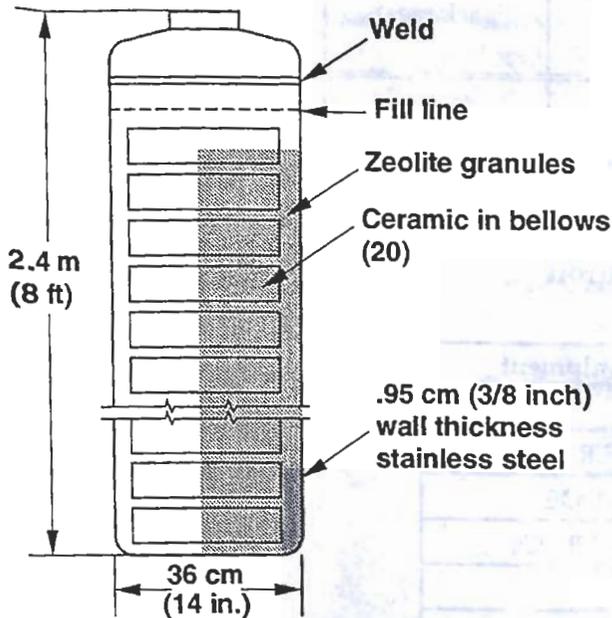
Average material storage container	Quantity Pu/ yr	Quantity Pu/ Campaign	# packages/ yr (6M/2R-like + pit packages)	Total # packages (6M/2R-like + pit packages)	SST shipments/ yr	SSTs shipment/ campaign
4.5 kg (9.9 lb)	5,000 kg (11,000 lb)	50,000 kg (110,000 lb)	3,100	31,000	110	1,100

Table 3. Parameters for intersite transportation segment #2.

Data	<sup>137</sup> CsCl shipment
<b>Packaging</b>	
Type	BUSS R-1
Certifying agency	NRC/DOE
Material weight /capsule	0.471 kg (1 lb) Cs
Capsules per packaging	10
<b>Average shipping volumes</b>	
Quantity material/yr	66 kg (145 lb) Cs
Capsules/yr	136
Capsules/life of project	1360
Shipments/yr	13.6
Shipments/life of project	136
<b>Routing</b>	
Mode of transport	Commercial rail or truck

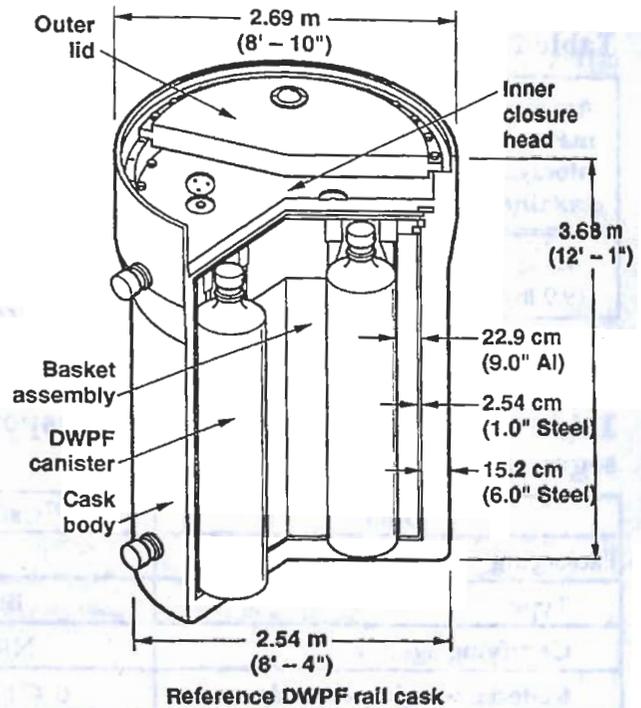
**Package Description.** DOE is currently developing a stainless steel canister for the Defense Waste Processing Facility (DWPF) to encapsulate defense high-level waste (DHLW) in borosilicate glass for emplacement in HLW repository. A modified version of the DWPF canister (CGF canister) is shown in Figure 8 and will be used to contain the ceramic waste forms. The CGF canister, which is smaller than the DWPF canister size, has a diameter of 36 cm (14 in.) and is 2.4 m (8 ft) high.

The additional packaging component required is a transportation cask which should also provide radiation shielding necessary for shipping the CGF canisters to the HLW repository. The SRS has completed a conceptual design study for a rail shipping cask for DWPF canisters. This HLW rail cask, shown in Figure 9, will hold five DWPF canisters. The development of the DWPF canister is being coordinated with the OCRWM. After the SRS HLW rail cask design is completed, certified, and approved by



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Figure 8. CGF canister.



Reference DWPF rail cask  
 Empty cask weight \_\_\_\_\_ 77,000 kg (169,200 lbs) (85 tons)  
 Loaded with 5 DWPF canisters \_\_\_\_\_ 87,000 kg (191,200 lbs)  
 (96 tons)

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Figure 9. SRS HLW rail cask.

the NRC for DHLW canister transport, it could also be certified and approved for shipping the CGF canisters to the HLW repository.

*Shipment Information.* Table 4 details the packaging requirements and mode of transport for the immobilized ceramic material.

### 1.5.2 Domestic Safeguards

The FMDP has established two major safeguards and security criteria. Resistance to theft or diversion by unauthorized parties (Criteria 1, domestic) and resistance to retrieval, extraction, and reuse by the host nation (Criteria 2, international), consider domestic and international perspectives based on two important factors, the "threat" addressed by these criteria, and the "regimes" that exist to address these threats.

The primary purposes of FMDP domestic safeguards and security (Criteria 1) is to assure nonproliferation of fissile material and classified information, along with instilling public and international confidence in those actions. Domestic safeguards and security is composed of two subsystems: nuclear materials control and accounting, and the physical protection of fissile material and nuclear weapons components against threats of diversion and theft, along with that of radiological and toxicological sabotage.

Table 4. Intersite transportation segment #3.

Data	Ceramic with <sup>137</sup> Cs
<b>Packaging</b>	
Type	CGF canister with SRS HLW rail cask
Certifying agency	Not currently certified
Material weight /canister	660 kg (1450 lb)
Canisters/rail cask	5
Wt Pu /canister	79.2 kg (174 lb)
<b>Average shipping volumes</b>	
Quantity material/yr	42,000 kg (92000 lb)
Shipments/yr	13
Canisters for life of project	640
<b>Routing</b>	
Mode of transport	Commercial rail or truck*

\*The above calculations are based on the preferred mode by rail.

Domestic safeguards primarily address unauthorized actions perpetrated by individuals and/or subnational groups (insiders or outsiders).

The detection and prevention of an unauthorized access or removal attempt (e.g., theft or diversion) depends on the levels of safeguards and physical protection at the facility. In general, safeguards are more easily applied and more readily verified when materials are in the **form of discrete, uniquely identifiable items**, as opposed to difficult-to-measure materials **in bulk form**, as may be found with **chemical processing activities**. The DOE and the NRC have established requirements for domestic safeguards and security. In the U.S., both the DOE and NRC have **specific orders or regulations** that identify physical protection, and material control and accountancy. There are measures that must be followed, as determined **and negotiated based upon the category and attractiveness of the fissile material**.

The responsibility of the domestic regime is to prevent unauthorized access to its material either by individuals or groups within its own weapons complex (such as disgruntled workers) or by national or international terrorist groups, criminal organizations, etc.

The domestic threats can be condensed as: *theft* (e.g., unauthorized removal of material by an individual or group outside of the host nations weapons complex); *diversion* (e.g., unauthorized removal of material by a member of the host nations own weapons complex); *retrieval* (unauthorized access by outside individuals or groups after final disposition); and *conversion* (the **conversion of retrieved material into weapons usable form**).

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facilities for handling wastes that require radiological control; and (2) a general support area consisting of "cold" facilities and the supporting infrastructure.

The disposal of immobilized waste forms in a repository is a solids handling process. (Figure 12) The loaded transportation casks containing immobilized plutonium forms are inspected at the repository in a repository boundary, and moved to a radiologically controlled area. The plutonium waste from casks will then enter a waste handling building through air locks, where minor decontamination takes place. Wash waters from the decontamination operation are sent to a waste treatment facility. In the waste handling building, the sealed canisters containing immobilized plutonium waste forms are removed from the transportation casks and the canisters containing the immobilized plutonium transferred to disposal casks. These disposal casks are decontaminated, if necessary, and transferred to a shielded storage vault to await emplacement underground. The disposal casks are coupled to a transporter and moved to drifts for disposal.

## 1.6 Other Approaches

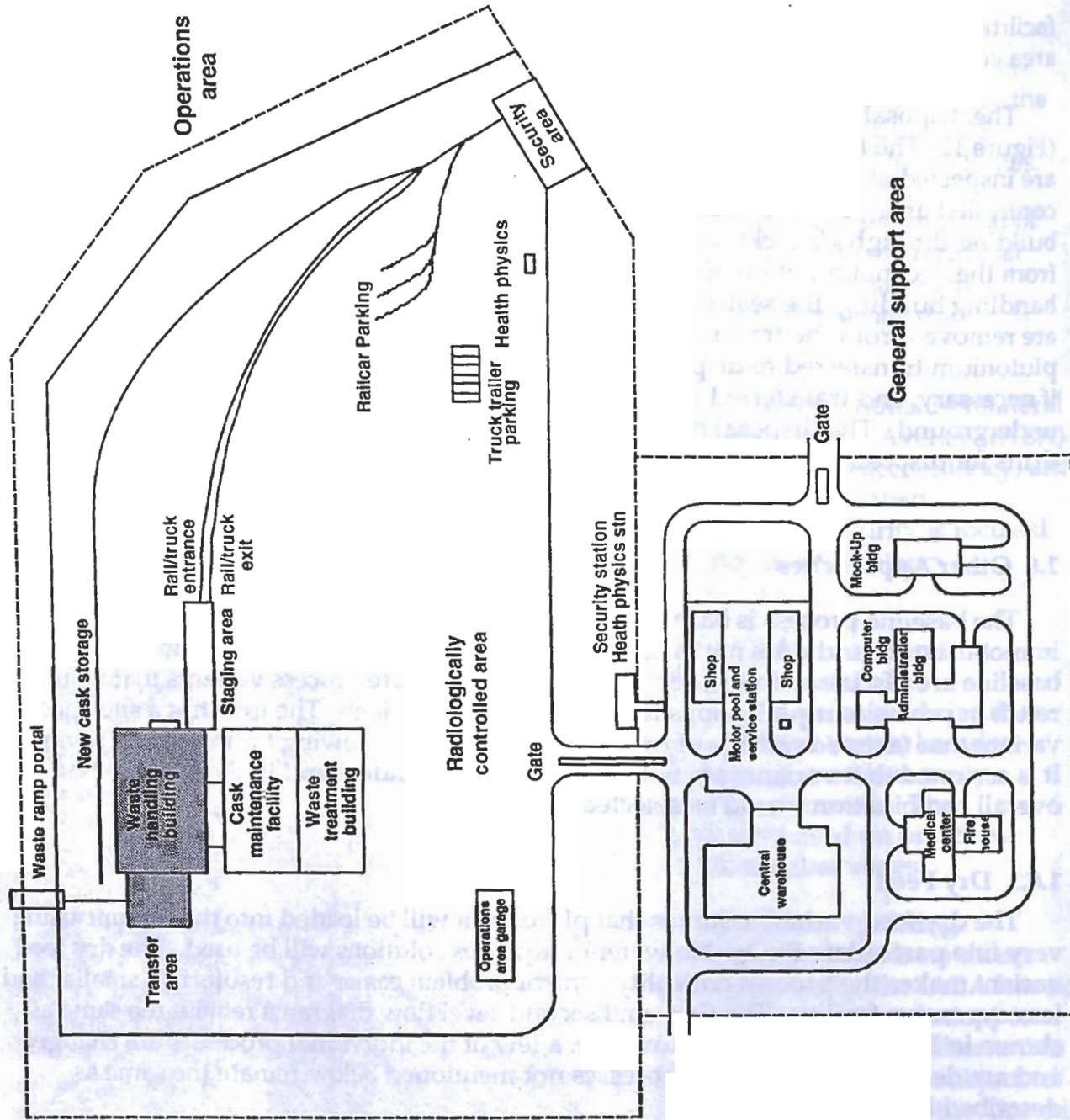
The baseline process is based on the best demonstrated data for ceramic immobilization and does not take credit for any existing facilities. Variants of the baseline are discussed in this section. The first three are process variants that would result in process simplifications and potential cost savings. The fourth is a site-specific variant that takes advantage of existing facilities, thus allowing for major cost savings. It is assumed that variants are not necessarily independent and in the end, the best overall combination would be selected.

### 1.6.1 Dry Feed

The dry feed variant assumes that plutonium will be loaded into the ceramic using very fine particulate  $\text{PuO}_2$ . No water or aqueous solutions will be used. The dry feed variant makes the process criticality control problem easier and results in a smaller and less expensive facility. The first- and second-level flow diagrams remain the same as shown in Figures 1, 2, and 3. However, a few of the individual processes are changed and are described below. All processes not mentioned below remain the same as described in Section 1.3.

**CE-01 Feed Preparation.** Incoming  $\text{PuO}_2$  powder will be size reduced by vibramilling to meet specifications for ceramic immobilization processes. Ground oxide powder will be checked to see if particle size meets specification before transferring to calciner feed makeup. Size characterization will be determined by an appropriate technique such as BET, SEM, or microsieving.

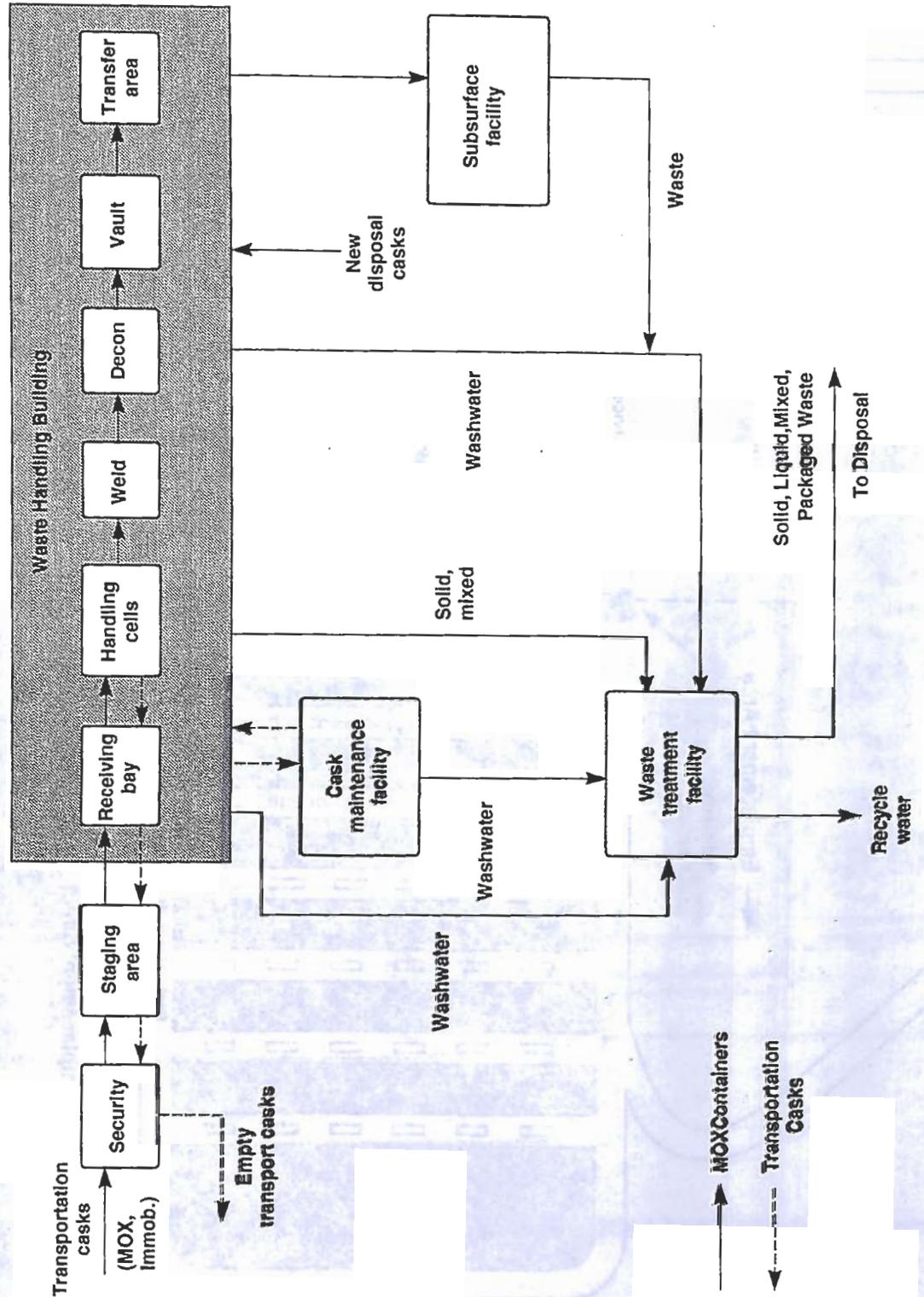
**CE-02 Calciner Feed Makeup.**  $\text{PuO}_2$  powder will be dry blended with ceramic precursors and dried titanate resin loaded with radioactive cesium. Neutron absorber



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Figure 10. Conceptual plan for repository surface facilities handling plutonium waste forms.





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Figure 12. Conceptual process flow diagram for handling plutonium waste forms,

will be fabricated directly into the precursor material. Dry powder blending will be conducted in a standard blending device such as a V-blender.

**CE-03 Dry and Calcine.** If required, the blended powders will be carefully transferred to flat trays and calcined at about 800°C (1470°F) in a large muffle furnace. This will remove any adsorbed moisture and begin the reaction process. This step may not be required for the dry process, if moisture content can be controlled within specified levels.

**CE-12 Ion Exchange.** The CsCl solution will be adjusted to the desired concentration and acidity and passed over a crystalline silicotitanate ion exchange column. The NaCl effluent will be sent to aqueous processing where the solution will be dried (water will be recovered and recycled), and if necessary the salt concentrate will be immobilized in zeolite or polyethylene. The loaded silicotitanate column will be removed and wet milled as needed, and then taken to dryness by heating and calcining the material. After drying, the <sup>137</sup>Cs loaded material is sent to the calciner feed makeup step.

**CE-29 Off-Gas Treatment.** Off gases will go to the HEPA filter system. Off gas will not contain significant amounts of moisture or NO<sub>x</sub>. Consequently, no recycling or abatement systems are needed.

### 1.6.2 Direct Loading of CsCl

In this variant, CsCl is loaded directly onto a zeolite without first dissolving in water or dilute acid. The flow diagram is very similar to the baseline, (Figures 1, 2, and 3) with a few exceptions. *Salt Blend Tank* (CE-25) replaces *Dissolve CsCl* (CE-11) and *zeolite Sorption* (CE25A) replaces *Ion Exchange* (CE-12). Processes not described below remain the same as discussed in Section 1.3.

**CE-13 Greater Than Class C LLW Management.** Contamination from empty capsules will be removed with repeated washings in molten salt. The residue salt will be returned to the *Salt Blend Tank* (CE-25) and the washed capsule will go to normal LLW.

**CE-25 Salt Blend Tank.** The salt blend tank is heated with a mixing agitator that functions to mix the CsCl and BaCl<sub>2</sub> into the salt matrix. Ba metal in the capsules is converted to BaCl<sub>2</sub> by reacting with a mild chlorinating agent such as FeCl<sub>3</sub> or UCl<sub>4</sub>. These salts are heated and thoroughly mixed to make them homogenous and at a proper temperature for loading onto the zeolite. The salt mixture is then transferred to the zeolite sorption furnace.

**CE-25A Zeolite Sorption.** The zeolite sorption step consists of hot-mixing anhydrous zeolite with the chloride salts from the blend tank. The chloride feeds are inserted into the blending furnace that contains the anhydrous zeolite. The zeolite sorbs all of the molten salt leaving a dry zeolite powder, which is transferred to the hot pressing step.

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the furnace will then be allowed to  
of air or argon

**CE-07 Canister Loading.** The 1-in. diameter by 1/2-  
poured into a 36-cm (14 in.)-diameter by 2.4-m (8 ft)-long  
also added to serve as a filler and packing material. The  
receive little or no contamination during the process. A  
decontaminated if necessary.

**Pressing.** The uranium  
mium will be carefully poured into a feeder h  
rial into an automated pressing machine. Pe  
meter by 1.8 cm (0.70 in.) high in the green (g  
15 tons) and at a rate

pellets will be transferred by a conveyor belt to the sintering oven. Cracked pellets will be conveyed to *Crushing and Milling* (CE-18).

**CE-16 Screening/Inspection.** After cold pressing and after sintering, pellets will be screened and inspected for cracking. Any cracked pellets will be removed and sent to *Crushing and Milling* (CE-18).

**CE-17 Sintering.** The cold-pressed pellets will be placed into a conveyor oven and heated to around 1300°C (2400°F) for several hours. To fully react, longer reaction times may be used. After sintering pellets will be approximately 2.5 cm (1 in.) in diameter by 1.3 cm (0.5 in.) high.

**CE-18 Crushing and Milling.** Reject pellets from *Screening/Inspection* (CE-16) after *Pellet Pressing* (CE-15) and after *Sintering* (CE-17) are crushing in a press and ground in a milling device.

#### 1.6.4 Ceramic Immobilization at ANL-W

The facilities at Argonne National Laboratory-West (ANL-W) are well suited for the ceramic immobilization process. In this site-specific variant, the overall flow diagram of the baseline process or any of the other process variants remains approximately the same except for a few changes to the specific processes as noted below. Figures 13 and 14 indicate the buildings at ANL-W where the ceramic alternative unit operations are located. Some of the front-end processing could be performed in the Fuel Manufacturing Facility (FMF) and the Zero-Power Physics Reactor (ZPPR) Facility. Additional new facilities will be required to handle all of the front-end processing. Back-end aqueous processing could be performed in the air cells of the Fuel Conditioning Facility (FCF) and the Hot Fuel Examination Facility (HFEF). Off-gas systems would need to be upgraded to handle water vapor and NO<sub>x</sub>. The ceramic fabrication process (Figure 14), canister loading, and canister welding processes could be performed in the argon cells of the FCF and the HFEF. Most of the support facilities required for the greenfield case are existing or adequately covered by existing facilities. An analytical laboratory exists onsite with adequate capabilities. Storage facilities can be provided in ZPPR for the incoming plutonium. Storage wells for the canisters of immobilized product, 30 cm (1 ft.) by 3 m (10 ft.), can be added in the Radioactive Waste Scrap Facility (RWSF). Minor upgrades to current DOE standards are required for the FMF, HFEF, and ZPPR Facilities.

**Front-End Processing.** Same as baseline. Processes would generally be performed in new glove boxes installed in existing and new facilities.

**Back-End Processing.** Back-end processes remain the same except as noted below. A suitable facility at the ANL-W site is given for each process.

**CE-01 Feed Preparation.** Same as baseline or variants. Process will be performed in the FMF, ZPPR, or air cells in the FCF or HFEF.

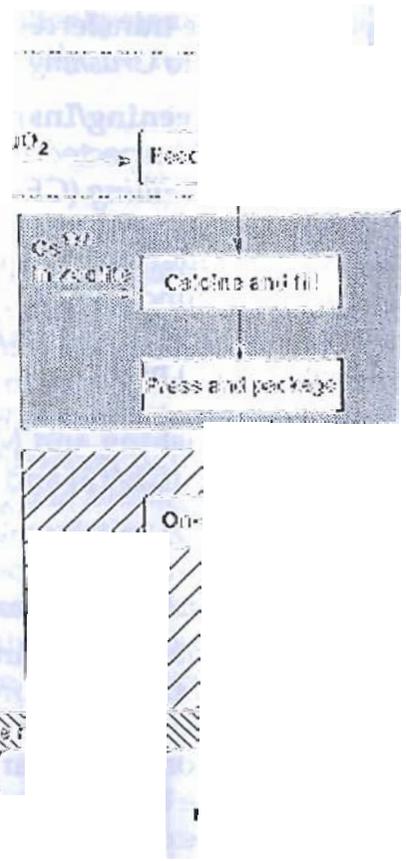


Figure 13. First-level flow d

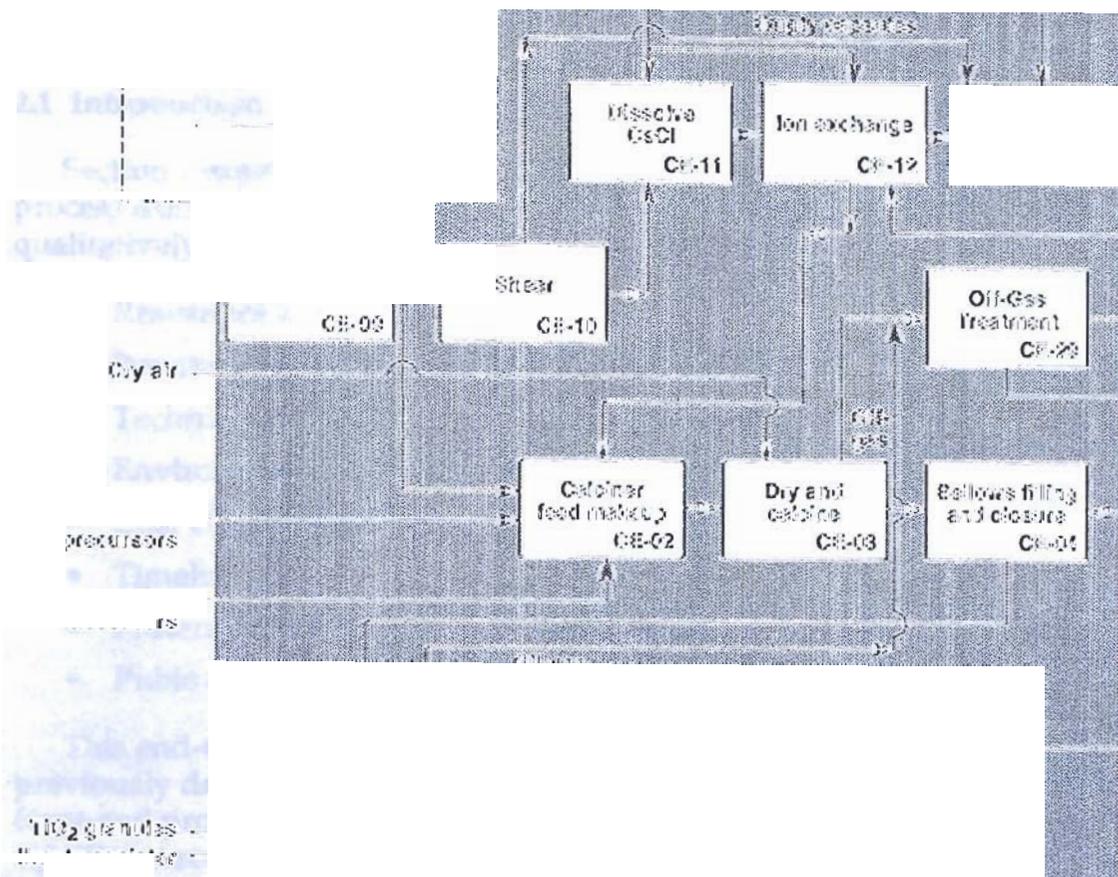
CE-02 Calciner Feed Mat  
performed in air cells in the

CE-03 Press and Calcine

and Closure. Same as baseline  
ag will be 25 cm (10 in.) in diameter and about 1  
ill be performed in the argon cell of the FCF or I

CE-05 Hot Pressing. Same as baseline or  
bellows is 25 cm (10 in.) in diameter rather f  
be performed in the argon cell of the FCF or

CE-10 Shear Capsules. Same as baseline or other  
d in the air cell in



Same as baseline or variants. Process will be performed in the ICI or HBBF.

management. Same as baseline or variant in the ICI or HBBF.

baseline or variants. New or upgraded

## 2.0 Criteria Assessment

### 2.1 Introduction

Section 2 examines technical issues associated with each step of the immobilization process from front-end processing to the final repository. This disposition variant is qualitatively assessed against the following eight criteria:

- Resistance to theft and diversion
- Resistance to retrieval by the host nation
- Technical viability
- Environment, safety, and health compliance
- Cost effectiveness
- Timeliness
- Fosters progress with Russia and others
- Public and institutional acceptance.

This end-to-end immobilization variant combines functions from facilities previously described in and bounded by the PEIS process currently underway. For front-end processing in this variant, elimination of aqueous recovery lines results in significant reductions in aqueous waste solutions, processing equipment, associated facility space, utilities, and support systems. In the ANL-W variant, the need for new facilities is reduced due to the availability of existing facilities. For the back end, various process step improvements are proposed which reduce the waste streams, and the need for new facilities is reduced due to the availability of existing facilities.

### 2.2 Resistance to Theft and Diversion

#### 2.2.1.1 Applicable Safeguards and Security Requirements and Measures

**Domestic Theft and Diversion (Criteria 1).** This criterion evaluates the system protection and resistance to theft by an outsider or an insider and retrieval after final disposition by outside groups. Theft or diversion of material refers to both overt and covert actions to remove material from the facility. This is perpetrated by unauthorized parties including terrorists, subnational groups, criminals, and disgruntled employees.

Protection of the material and information from these parties is a domestic responsibility, not an international one. There are a number of possible adversary groups with different motivations and capabilities. The actions could be overt such as a

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Figure 14. Second-level flow diagram.

The diagram illustrates the flow of information or materials through various stages. It includes several key components and processes:

- Input/Output:** The diagram shows inputs entering from the left and outputs exiting to the right.
- Processing Stages:** Multiple boxes represent different stages of processing or transformation.
- Control and Monitoring:** There are boxes labeled "Control" and "Monitoring" which likely represent feedback loops or regulatory mechanisms within the system.
- Storage and Distribution:** Some boxes may represent storage units or distribution points for the processed materials.

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- Input/Output:** The diagram shows inputs entering from the left and outputs exiting to the right.
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irect attack on a facility or they could involve covert measures which might utilize health and deception as well as possible help from an "insider." It is assumed that all facilities will meet the necessary safeguards and security requirements. Therefore, many of the safeguards and security standards are not directly discussed in this document. The threats to facilities will be different depending on the form of the material, the activities at the facility, and the barriers to theft (both intrinsic to the material and also to the facility). For each of the facilities in this alternative a brief discussion is presented below of the potential risks to theft.

The safeguards and security requirements for this alternative are primarily driven by the attractiveness of the material as defined in DOE Order 5633.3B and/or NRC requirements (10 CFR 73 and 74).

**Material Form.** An essential element in assuring the proliferation resistance of fissile material is the safeguards and security applied to the material, based on its form. The form of the material reflects the intrinsic properties of the material which dictates its attractiveness for its use in nuclear weapons. However, the form of the material alone does not provide proliferation resistance. Safeguards and security systems should be applied in a graded approach based on the form of the material and its attractiveness.

**DOE Category and Attractiveness Levels.** The DOE defines the attractiveness level of nuclear material through a categorization of types and compositions that reflects the relative ease of processing and handling required to convert that material to a nuclear explosive device. Table 5 comes from the DOE Order for *Control and Accountability of Materials* (5633.3B) dated 9-7-94.

The level of protection accorded to an attractiveness level is dependent on the quantity or concentration of the material. Each category of protection has its own requirements ranging from the Category I, highest level of protection, for assembled weapons, to Category IV for irradiated forms and less than three kilograms of low-grade material. Protection of the material is accomplished through a graded system of deterrence, detection, delay, and response as well as material control and accountability. Layers of protection may then be applied to protect material of greatest attractiveness within the innermost layer and with the highest controls. Material of lesser attractiveness does not require as many layers of protection and fewer controls.

Category I and/or strategic fissile material must be used or processed within a DOE approved Materials Access Area (MAA). The requirement for an MAA and vault-type room storage may mean that certain physical protection enhancements will be needed beyond what currently is present at existing facilities. The physical barriers at the protected area boundary normally consists of two barriers with a redundant intrusion detection system. The protected area boundary must also provide for a barrier from unauthorized vehicle penetration. The access control points into the protected area are normally made of a bullet-resistant material. Duress alarms will be necessary at all

**Table 5. (DOE) nuclear material attractiveness and safeguards categories for plutonium.**

	Attractiveness level	PU/U-233 category			
		I	II	III	IV <sup>a</sup>
<b>WEAPONS</b> Assembled weapons and test devices	A	All quantities	N/A	N/A	N/A
<b>PURE PRODUCTS</b> Pits, major components, buttons, ingots, recastable metal, directly convertible materials	B	≥2 kg (≥4.4 lb)	≥0.4 <2 kg (≥.9 <4.4 lb)	≥0.2 <0.4 kg (≥.4 <.9 lb)	<0.2 kg (<.4 lb)
<b>HIGH-GRADE MATERIAL</b> Carbides, oxides, solutions (≥25 g/l) nitrates, etc., fuel, elements and assemblies, alloys and mixtures, UF <sub>4</sub> or UF <sub>6</sub> (≥50% U-235)	C	≥6 kg (≥13 lb)	≥2 <6 kg (≥4.4 <13 lb)	≥0.4 <2 kg (≥.9 <4.4 lb)	<0.4 kg (<.9 lb)
<b>LOW-GRADE MATERIAL</b> Solutions (1–25 g/l), process residues requiring extensive reprocessing, moderately irradiated material, Pu-238 (except waste), UF <sub>4</sub> or UF <sub>6</sub> (≥20% < 50% U-235)	D	N/A	≥16 kg (≥35 lb)	≥3 <16 kg (≥6.6 <35 lb)	<3 kg (<6.6 lb)
<b>ALL OTHER MATERIALS</b> Highly irradiated forms, solutions (≥1 g/l), uranium containing < 20 % U-235 (any form or quantity)	E	N/A	N/A	N/A	Reportable quantities

<sup>a</sup> The lower limit for category IV is equal to reportable limits in this Order.

staffed access points. There will be enhanced entrance/exit inspections of personnel, vehicles and hand-carried items. MAA/protected area portals typically have metal detectors, fissile material detectors, and/or x-ray machines for hand-carried items.

### 2.2.2 Identification of Diversion, Theft, or Proliferation Risks

Tables 6–8 provide information about the flow of plutonium through this alternative, along with a description of the material and its changing attractiveness levels.

*Plutonium Processing Area.* The plutonium processing area will be a Category I facility. A number of different forms are received by the plutonium processing area (Cat. I-B through II-D). This material is converted into oxide (Category I-C). For this facility most of the material is in a very attractive form with minimal intrinsic barriers.

Table 6. Safeguards and security environment (CGF).

Facility	Activity	Duration	Environment					
			Through-put	Waste streams	Lag storage	Max inventory	Intrasite transport	# proc steps
Plutonium Processing	Pit and mixed feed processing	40 hrs.	5 tonnes/yr (5.6 tons)	Yes	Yes	~2 tonnes (2.2 tons)	No	TBD
Immobilization Facility	Immobilization in a ceramic matrix	TBD	5 tonnes/yr (5.6 tons)	Yes	Yes	5 tonnes (5.6 tons)	No	6
Intersite Transport	Immobilized matter to repository facility	TBD	5 tonnes/yr (5.6 tons)	No	No	N/A	N/A	N/A
High-Level Waste Repository	Receiving, NDA,* transfer to emplacement canisters	TBD	5 tonnes/yr (5.6 tons)	No	No	5 tonnes (5.6 tons)	Yes, to repository emplacement	N/A
	Emplacement in repository	Permanent disposal	5 tonnes/yr (5.6 tons)	No	No	50 tonnes (56 tons)	No.	N/A

\* If required.

Table 7. Safeguards and security material form (CGF).

Facility	Activity	Material form					
		SNM input	SNM output	Conc. of Pu	SNM category-attractiveness	Item mass/dimensions	Self protecting
Plutonium Processing	Pit and mixed feed processing	metal and oxide	metal and oxide	> 90%	I-B	TBD	No
Immobilization Facility	Immobilization in a ceramic matrix	oxide	oxide in ceramic	In 90% Out 12%	In - I-C Out - IV-E	660 kg (1450 lb) / 36 cm (14 in.) x 2.4 m (8 ft) stainless steel canister	In - No Out - Yes/Rad.
Intersite Transport	Immobilized matter to repository	oxide in ceramic	oxide in ceramic	12%	IV-E	87 tonnes (96 tons) ~2.6 m (8.5 ft) x 3.7 m (12 ft)	Yes/Rad
High-Level Waste Repository	Receiving, NDA,* hot cells, lag storage	oxide in ceramic	oxide in ceramic	12%	IV-E	22 tonnes (24 tons) ~1.6 m (5.2 ft) x 3.1 m (10 ft)	Yes/Rad.
	Emplacement in repository	oxide in ceramic		12%	IV-E	Emplacement canister	Yes/Rad.

\* If required.

There are a large number of processing steps that provide increased opportunities of covert theft. Since many of the processes involve bulk material, the accountability measures will involve bulk measurements. In the case of an overt theft attempt the targets of greatest concern would be the pits, pure metal, and oxides, which are very transportable. However, these materials would be under significant protection so that the risk associated with an overt event would be acceptable.

Table 8. Safeguards and security assurance (CGF).

Safeguards and Security Assurance						
Facility	Activity	# of MBAs	Type of accounting	Nuclear measurement	Classified matter	Accessibility**
Plutonium Processing	Pit and mixed feed processing	3	Bulk and item	Calorimetry, gamma, seg gamma neutron	In - yes Out - no	THN
Immobilization Facility	Immobilization in a ceramic matrix	6	Bulk and item	Weight, process data, gamma spec.	No	In - THN Out - CRY
Inter-site Transport	Immobilized matter to hlw repository	N/A	Item	N/A	No	CRY
High-Level Waste Repository	Receiving, NDA,* hot cells, lag storage	4	Item	TBD	No	CRY
	Emplacement in repository	TBD	Item	TBD	No	CRY

\* If required.

\*\* The materials can be touched, T, or are in a sealed container, C.

The container can be handled hands-on, H, or requires remote handling equipment, R.

The material/container target is in a large and/or bulky form that requires special handling equipment to be moved, Y, yes, or N, no.

**Ceramic Fabrication Area.** In the initial stages of handling and processing, the ceramic fabrication area will be a Category I facility. Within the facility material will be changing form and concentration, decreasing the protection category and attractiveness. With the addition of a self-protecting property the material meets the definition for Category IV-E.

In the ceramic fabrication area the oxide is mixed with a matrix material, reducing the attractiveness level. The final product is encased in a stainless steel canister, 36 cm (14 in.) × 2.4 m (8 ft.), and contains approximately 80 kg (176 lb) of plutonium, at a nominal concentration of 12 wt%. Once the immobilized material has been given a self-protecting barrier by the introduction of radioactive "spike" material (<sup>137</sup>Cs), the safeguards and security requirements are significantly reduced as the safeguards and security category is now that of IV-E (material producing a radiation dose rate in excess of 1 Sv (100 rems) per hour at a distance of 1 m (3 ft), is considered as Category IV-E. If after a period of time the self-protecting barrier no longer meets the above radiation dose criteria, then it may be considered as Category III-D, depending upon the quantity of fissile material present and the additional barriers that may exist at that time (as is true with commercial spent fuel). Protection against radiological sabotage should likewise not be significantly different than for existing commercial spent fuel.

The facility operations involve a large number of processing steps and relatively accessible bulk materials. As the plutonium oxide is blended with matrix materials, the concentration of the plutonium decreases. Since these forms are still relatively accessible and transportable (prior to addition of a radiation spike), they are attractive

targets for both covert and overt theft. After fabrication into final canisters, they are much less transportable (more resistant to overt theft). Likewise, the fissile material within the canisters is no longer physically accessible and becomes subject to item accountancy, further reducing the opportunities for covert theft. There is some concern with the capability to perform accurate accountancy measurements after this processing occurs, especially after the addition of the radiation spike. However, it is reasonable to assume that containment and surveillance, coupled with accurate measurements prior to spiking and item accounting thereafter, will be as acceptable in this facility as it is in others (i.e., spent reactor fuel). Research and development should be conducted, however, to assure that the best technically viable methods can be used to satisfy the public and the international community that this concern, for weapons program materials, has been adequately addressed.

*Repository.* The immobilized material is received in shipping casks. In the surface staging area the canisters are removed and placed into disposal casks. The disposal casks are moved to the subsurface facility and the casks are placed into the tunnel drifts. The casks enter the drifts through sealed doors that are opened to allow cask emplacement. Each drift is secured after it is "filled" with casks. The material is highly radioactive and each cask weighs approximately 22 tonnes (24 tons). The material is a low-attractiveness target for both covert and overt theft.

**Risk Assessment.** The measures identified for this criteria are the *environmental conditions, material form, and safeguards and security assurance*. These measures are briefly described below and a qualitative discussion of the relative risks is presented for each the facilities in this alternative. Table 9 summarizes the potential risks. This assessment is highly qualitative, and based on available data.

**Table 9. Potential risks for threats and criteria 1 & 2 (CGF).**

	Plutonium conversion	Immobilization Facility	Intersite Transit	High-Level Waste Repository	After repository emplacement
<b>Threat</b>					
Covert Threat	High	High-Medium	Low	Low	Low
Overt Threat	Medium	Medium	Low	Low	Low
Diversion	High	High-Medium	Low	Low	Low
<b>Criteria 1</b>					
Material Form	High	High-Medium	Low	Low	Low
Environment	Medium Low	Medium	Low	Low	Low
Safeguards and Security	High	High-Medium	Low	Low	Low
<b>Criteria 2</b>					
Detection	High	High-Medium	Medium	Medium	Low
Irreversibility	High	High-Medium	Medium	Medium	Low

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case of pit conversion the attractiveness goes from I-B to I-C. For oxides and other high-grade material the attractiveness level remains at I-C. The material has overall very low intrinsic barriers, and is transportable. It has a very low radiological barrier primarily due to the presence of americium. In most cases, it is in a very pure form, as a metal or oxide, and its isotopic composition makes it very usable for a nuclear device. Because pits and some other weapons usable materials are being processed, some of the material and waste streams will be classified.

*Ceramic Fabrication Area.* As in the case of the plutonium processing area, the primary initial feed material, is composed of very attractive material (I-C). The intrinsic attributes of this material are the same as described above. Once the material has been blended it would be more difficult to convert to a weapons usable form. Additionally, the concentration of the plutonium is lower, substantially greater amounts of material would be required to acquire a significant quantity of plutonium. Once the material is placed into canisters its chemical, isotopic, and radiological attributes would not change but its mass/dimensions would increase, thus making it more difficult to move and easier to maintain surveillance, control, and accountability.

With the addition of highly radioactive fission products, chemical processing to convert the material into a weapons usable form becomes much more difficult.

*Repository.* The canisters delivered to the repository are highly radioactive and so intrinsic barriers are quite high. The radiological and isotopic attributes are time dependent and eventually the material would no longer be self-protecting because the radiological barrier would decrease by approximately an order of magnitude in 9 to 100 years.

**Safeguards and Security Assurance**—the effectiveness of safeguards and security protection depends on the material control and accountability characteristics, and physical protection capabilities (not directly discussed here) of the processes and facilities. Safeguards and security assurance data is summarized in Table 8.

*Plutonium Processing Area.* Material received into this area (e.g., pits) would utilize item accountability. Once the material has been removed from the container, bulk accountability would be necessary. Many of the items are small and many operations involve hands-on activities. In addition to destructive assay, other nondestructive assay (NDA) would be performed. The pits and some other material will be classified. This may also apply to waste streams.

*Ceramic Fabrication Area.* During the initial processing operations, bulk accountability would be conducted. Once the material is placed into the canisters, item accountability would be performed. Although devices are being developed to perform nondestructive assay on such items as fuel rods and other assemblies, this is still a very time-consuming activity. Once the material is placed inside the canisters, it is no longer accessible, and requires special handling equipment to be moved.

Item accountancy is used to account for canister assemblies. Markings and seals on the canisters can also be used to verify material. Special handling equipment is required to move these assemblies, and once they have a radiation barrier remote handling is necessary. For immobilized-spiked material, some nondestructive assay measurements are possible but they are generally used to confirm the presence of the radiation barrier and not to accurately account for the plutonium. Using the initial material information and the accountancy records from the facility processes, the quantity of material can be estimated.

*Repository.* Item accountability is used for the casks. No access is available to the material itself although access to the casks is possible. All movements of the casks require special handling equipment.

### **2.2.3 Ability to Achieve the Spent Fuel Standard**

The "spent fuel standard" means that the material is as inherently unattractive and inaccessible as plutonium in commercial spent fuel. The final disposition form, environment, and safeguards and security for this alternative meets the spent fuel standard. Both significant extrinsic (facility) and intrinsic (related to the material form) barriers exist. Since the radiological barrier is time dependent, this attribute will, over a long period of time, decrease and the material will not necessarily be self-protecting. Prior to the addition of the radiation spike, the material does not meet the spent fuel standard, therefore, protection commensurate with its attractiveness level must be provided.

### **2.2.4 Safeguards and Security Transportation Related Issues**

For intersite Category I material, safe secure trailers/transport will be used to move the material between facilities. A secure loading/unloading area must be available to ship/receive, verify, and store the Category I material. With respect to other transport activities (e.g., between processing and storage), there are inherently lesser safeguards and security risks for overt theft scenarios and a much lower risk for covert theft attempts. Minimizing the number and/or duration of the transport steps is desirable.

## **2.3 Resistance to Diversion, Retrieval, Extraction, and Reuse by Host Nation**

### **2.3.1 Applicable Safeguards and Security Requirements and Measures**

**International Diversion, Retrieval, Extraction, and Reuse (Criteria 2).** This criterion evaluates the system resistance to diversion of material before final disposition by the weapon state itself, retrieval of material after final disposition by the weapon state itself, and conversion of the material back into weapon usable form covertly by the host nation/state. Again the material form, environment, and safeguards are particularly important for detecting the diversion, retrieval, and extraction activities. Additionally, the irreversibility of the material form is important for assessing its reuse in nuclear weapons. Nuclear material for this alternative falls under the International

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### 2.3.2 Possible Diversion, Reuse, and Retrieval Ri

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host nation may choose to use overt measures to c  
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accountability measures. The vulnerability to diversion is dependent on the material form and the ability to retrieve and convert the material into a weapons usable form. Therefore, if we were to evaluate each of the facilities for this alternative there may be some differences. Because of inherent limitations on the accuracy of nondestructive assay measurements there is an increased risk of diversion at high throughput facilities. This is where containment/surveillance plays an important role in ensuring material accountability. For each of the facilities in this alternative, a brief discussion of some of the potential risks to diversion is presented. Existing domestic protective measures will help mitigate these risks, as a covert attempt to divert a significant quantity will require multiple accomplices and greater amounts of material control and accountability steps to be subverted in order to avoid detection.

*Plutonium Processing Area.* Because this area has significant processing and is handling large quantities of material, there is an increased risk for possible diversion. Since the high attractiveness or direct weapons use capability of the material in this facility conversion and reuse are easier, the ability to detect these covert activities in a timely fashion is diminished.

*Ceramic Fabrication Area.* Similar issues exist in this facility for the initial process operations as for the plutonium processing facility. After the material has been blended, it becomes a less attractive target. Once the material is placed into assemblies, and item accountancy is used, the possibility for diversion is reduced. Because the assemblies are large and require special handling equipment, containment/surveillance measures can more easily detect diversion attempts.

After the radiation barrier has been added, the material attractiveness for reuse is significantly reduced.

*Repository.* The high intrinsic barriers of the canisters and large mass of the casks make diversion more difficult. Since the radiological barrier is time dependent, it is necessary that other measures be utilized to help minimize the threat of diversion. Placement of the material in an underground repository makes retrieval of this material extremely difficult. Additional safeguards and security and containment/surveillance measures should be utilized to help safeguard this material, particularly for long time periods. It is also important that high accountability of the material be maintained so that there is the highest level of confidence that the material was not diverted and was in fact placed into the repository.

The measures of the environment, material form, and safeguards and security contribute to this criteria. Thus the information found in the provided tables are applicable; however, the capabilities of the adversary (e.g., the host nation) must be considered when analyzing this information. The primary measures of resistance are the irreversibility of the material forms (e.g., the ability to convert the material into weapons usable form) and the ability to detect diversion, retrieval, and conversion.

**Difficulty of Diversion, Retrieval, Extraction, and Reuse.** This establishes the timeliness and irreversibility criteria and the level of safeguards required.

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*Ceramic Fabrication Area.* The problems discussed with the plutonium process area (except there is no classified material) exist in the initial operations in this fa After the material has been blended

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individual items will be accounted for, and this will increase the ability to detect diversion.

Once the material has a radiation barrier, it will require special, and remote, handling equipment and will reduce the risk of diversion, and increase the probability of detection.

*Repository.* The casks will be sealed, item accountancy performed, and containment/surveillance measures implemented. Because the size and mass of these casks is quite large, the risk to diversion is lowered. The emplacement of this material in a HLW repository, along with continuing containment/surveillance measures, will ensure the risk after disposition remains acceptable.

## 2.4 Technical Viability

Since the late 1970s, immobilization of HLW in a number of ceramic waste forms has been studied extensively. During this time, the ceramic form that has received the most attention is a Synthetic Rock (SYNROC) material. This is a titanate-based waste form composed primarily of zirconolite, perovskite, hollandite, and rutile phases. In SYNROC, zirconolite and perovskite are the actinide host phases where zirconolite is the more durable and hence more desirable phase. For immobilization of actinides and HLW, other ceramic phases have also received considerable attention. These include pyrochlore, zircon, and monazite.

A significant characteristic of the ceramic waste form is its extremely low leachability, particularly for actinides. Normalized leach rates from SYNROC range from  $10^{-5}$  to  $10^{-8}$  g/m<sup>2</sup>-d ( $10^{-8}$ – $10^{-11}$  lb/yd<sup>2</sup>-d) at 70°C (158°F) in deionized water. Leach rate varies with the actinide element. For those tested, neptunium has the highest rate and curium the lowest. Normalized plutonium leach rate is around  $10^{-6}$  g/m<sup>2</sup>-d ( $10^{-9}$  lb/yd<sup>2</sup>-d). Initial tests with gadolinium show that the leach rate is around  $10^{-4}$  g/m<sup>2</sup>-d ( $10^{-7}$  lb/yd<sup>2</sup>-d) at 90°C (160°F) in deionized water. However, samples contained some glass phases and are probably upper limits for the Gd leach rate. Total dissolution rate of ceramic is also extremely low, around 0.15 nm (0.16 n yd;  $5.8 \times 10^{-9}$  in.) per day for SYNROC at 150°C (300°F) in deionized water.

Ceramics, a crystalline material is sensitive to radiation damage effects. Ceramics lose crystallinity becoming metamict at around  $10^{16}$  alpha decays per milligram. In the process, the ceramic can swell up to 10% in volume. However, leach rates of actinides from metamict ceramics remain about the same ranging from no increase to at most a factor of 100 increase. In some cases, leach rates of actinides have been found to decrease with increasing alpha doses. This phenomenon is thought to result from pH changes of the leachate solution caused by preferential leaching of alkali and alkaline earth elements.

As an additional benefit, zirconolite, pyrochlore, zircon, and monazite all have mineral analogs in nature that have demonstrated actinide immobilization over geologic time scales. This geologic data is extremely valuable for defending the long-term predictability and durability of these and related ceramic phases. Both the low leachability and long-term predictability of ceramic waste forms will benefit the licensing process of a plutonium ceramic waste form.

For the material disposition application, a significant solid solubility of actinides in SYNROC is particularly important. This permits immobilization of plutonium in a reasonable overall waste volume. Zirconolite is known to incorporate about 10 wt% plutonium in the +4 state. Additional plutonium can be incorporated into zirconolite in the +3 state. Higher concentrations of plutonium cause the zirconolite to convert to the pyrochlore phase, which is not a significant problem since pyrochlore is also extremely durable and leach resistant. The pyrochlore phase can accommodate at least 30 wt% plutonium into its structure.

#### 2.4.1 Technical Viability of Front-End Plutonium Processing

The front-end processing consists of several different processes to convert plutonium DNFSB Recommendation 94-1 storage forms to those needed by the immobilization back end. Most of the processes are in current use in the Weapons Complex or in industry. The major processes are: Hydride/ Dehydride/ Oxidation (DC-06a); Halide Wash (DC-15); Precipitation and Filtration (DC-16); Pyrolysis and Calcination (DC-13); and Organic Destruction (WS-09).

**DC-01 Truck and CRT Handling and DC-02 Receiving.** The operations in this area involve material handling techniques which have been utilized throughout the DOE complex for many years. Initial accountability confirmation analyses utilize nondestructive analysis technology that has been routinely used for production operation. Storage of shipping containers in a facility with an automated stacker-retriever system has been demonstrated at several sites. Accurate accountability measurements will utilize standard nondestructive methods such as calorimetry and segmental gamma scanning.

**DC-03 Gas Sampling.** The internal gas pits will be sampled utilizing a laser system similar to one utilized in production operations at the Pantex site. Improvements in the system are currently under development at the Los Alamos National Laboratory.

**DC-04 Special Recovery.** The processes for handling contaminated pits have been demonstrated on a production-scale at the Los Alamos National Laboratory.

**DC-05 Pit Bisectioning.** Disassembly of pits has been performed on a production-scale at the Rocky Flats plant using modified lathe technology. Improved techniques and equipment, which cut the pits without the formation of chips and turnings, are under development at the Lawrence Livermore National Laboratory.

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**Technical Risk**

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form appears to be small compared  
spent fuel. However, the cumulativ

doses, from both the commercial spent fuel and th

the envelope permitted by regulation. Since the EPA has remanded the regulation governing long-term performance and since a repository has not yet been licensed, calculations of such cumulative effects are not currently possible.

The NRC regulations for criticality control require that "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." [10 CFR Part 60.131 (b) (7)]. Preliminary calculations on as-fabricated criticality for the ceramic option, with a 1:1 molar ratio of plutonium to neutron absorber, shows that the  $k_{eff}$  of 0.95 or less as prescribed by NRC can be met. The effects of waste form and waste package degradation and the potential loss of neutron absorbers on criticality control are currently uncertain. An experimental program and further analyses are underway to assess these risks.

Although the NRC allows only limited credit for neutron absorbers for the commercial SNF, in recent communications with DOE, the NRC has postulated the potential use of low-solubility neutron absorbers for weapons plutonium for criticality control. This suggestion has been made as part of the early development efforts that DOE should undertake in establishing a strong rationale for criticality control, especially where excess weapons-usable fissile materials are being disposed in a repository. The experimental program and additional analyses are completely consistent with these suggestions.

Developing scenarios for dissolution and reprecipitation of the ceramic and demonstrating a strong case for the efficacy of using neutron absorbers in the immobilized waste forms may allow for higher plutonium loading in the ceramic. This is consistent with the current thinking of the NRC, who in recent communications with DOE, has suggested the examination of the potential use of low-solubility neutron absorbers for criticality control. This suggestion has been made as part of the early development efforts that DOE is undertaking to establish a strong rationale for criticality control, especially where excess weapons-usable fissile materials are being disposed in a repository. The calculational assumptions that are ultimately deemed reasonable by the NRC for treating criticality in the case of degraded waste forms and engineered barrier systems will determine the acceptable plutonium loadings in the ceramic wastefrom. Until the allowable assumptions are clarified, degraded-mode calculations of criticality are not judged to be limiting to the acceptable loading in the ceramic.

The definition of these scenarios is very dependent on the specific ceramic compositions and the details of the engineered barrier system used, neither of which has been fully identified nor discussed with the NRC to date. As a result, there is some technical risk that acceptable formulations and engineered barrier systems might not be found, except for extremely low-plutonium loadings in the ceramic. Nevertheless, this risk is regarded as low and comparable to that associated with acceptable engineered barrier systems for spent commercial LWR fuel and vitrified defense wastes.

## 2.5 ES&H Summary (Deltas/Improvements over PEIS)

The PEIS analysis currently underway is based on individual data calls for separate pit disassembly and conversion, conversion and stabilization, and immobilization facilities.

This end-to-end immobilization alternative combines functions from these previously described facilities. The PEIS impact analysis is considered bounding for this alternative; however, facility consolidation, process simplifications and improvements result in substantial ES&H benefits over the bounding case being analyzed in the PEIS. These improvements are discussed below.

### 2.5.1 Front-End Processes

The front-end processes for immobilization presented in this report offer substantial ES&H improvements over the base case being analyzed in the PEIS.

The pit disassembly and conversion and plutonium conversion and stabilization new facilities and process flow diagrams being analyzed in the PEIS are the base case and produce clean metal or >50% oxide to meet the long-term storage standard. This requires residue processing lines that generate aqueous waste solutions.

The front-end flow diagram for immobilization has been tailored and simplified to meet the immobilization process requirements. Aqueous recovery lines and process steps to purify oxide have been eliminated since impure oxide is satisfactory feed for the immobilization process. The process to separate plutonium from uranium solutions has been eliminated.

These changes result in significant reductions in aqueous waste solutions, processing equipment, associated facility space, utilities, and support systems. Personnel radiological exposure will also be reduced since the eliminated equipment will not be operated, maintained, decontaminated, and decommissioned. In the site-specific variant at ANL-W, facilities for plutonium processing exist. Some support facilities also exist. Thus, building of new facilities is reduced from the case being analyzed in the PEIS.

### 2.5.2 Back-End Processes

Relative to the process being analyzed in the PEIS, the baseline ceramic immobilization process in this summary differs significantly in a few areas. First, the silver-assisted dissolution system is replaced by a cascade or slab dissolver. The plutonium-oxide dissolution rate may be reduced, but silver-nitrate solutions are not part of any waste streams. Second, no metal is received in the back-end processing. All metal is converted to oxide in the front-end processes. Third, the ion exchange resin for removing chloride from CsCl and preparing it for further processing is an inorganic resin that is incorporated into the final immobilized product rather than an organic resin assumed in the PEIS that is regenerated and disposed of after limited use.

In the dry feed variant, the plutonium-oxide is not dissolved. This eliminates the dissolution system and simplifies the off gas treatment system. Water recycling and NO<sub>x</sub> abatement systems in the off-gas is reduced or eliminated. In addition, the elimination of water from the processes with plutonium reduces criticality concerns.

In the direct CsCl loading variant, the CsCl is not dissolved in water or nitric acid. Water recycling and NO<sub>x</sub> abatement systems in the off-gas are reduced or eliminated. An aqueous LLW salt stream is also eliminated.

In the cold press and sinter variant, there are no significant differences.

In the site-specific variant at ANL-W, facilities for the hot cell processing are existing. However, a new out-gas system will be needed for the baseline and variants, which use gaseous solutions. Support facilities that would be needed are also existing. Thus, building of new facilities is minimal and, consequently, considerably less than the case being analyzed in the PEIS.

All of the above changes from the case being analyzed in the PEIS are improvements resulting in less environmental impacts. Thus, they are bounded by the PEIS.

## 2.6 Costing Data—Ceramic Greenfield Alternative

The approach to costing the ceramic greenfield alternative and its variants is a life cycle cost (LCC) methodology. Costs are developed for the total overall project including initial R&D, licensing/permitting, design, construction, operation, and final decommissioning. These costs are then analyzed and plotted against the end-to-end alternative schedule to provide constant-dollar cash flows, which can then be discounted at the appropriate real discount rate. The two major figures-of-merit for each alternative are the following: 1) the constant-dollar front-end costs, i.e., all life cycle costs prior to normal operation of each facility (this is what the government must spend to develop, design, construct, and startup a given facility); and 2) the discounted total life cycle cost, which includes all "cradle to grave" project costs paid by the government and including front-end costs, revenues (if any), recurring costs, and end-of-life costs.

"Lump sum" constant-dollar costs for each major facility were developed. Schedule considerations only affect the way in which the lump sum costs are "spread." Each lump sum cost, however, is compatible with the baseline schedule. Table 10 summarizes the lump sum constant-dollar costs by facility for the baseline and the variant based on use of ANL-W facilities. (Costs are in millions of 1996 dollars). Operating assumptions and design bases for front-end and back-end costing are presented in Table 11. The estimated duration of the plutonium immobilization campaign will be 10 years. Operations shall be three shifts per day, seven days per week. Allowing normal time for remote maintenance, accountability, criticality control, etc., a normal operation year should be 200 days.

**Table 10. Summary constant-dollar life cycle costs for ceramic greenfield alternative (\$M 1996).**

Facility	Pu processing	Immobilization	Repository	Total end-to-end alternative
<b>Baseline</b>				
Up-front costs	858	950		1808
Other life cycle (10 yrs of operations) plus D&D	823	1722	320	2865
<b>Total life cycle costs</b>	<b>1681</b>	<b>2672</b>	<b>320</b>	<b>4673</b>
<b>ANL-W variant</b>				
Front-end costs	858	310		1168
Other life cycle (10 yrs of operations) plus D&D	823	1496	320	2639
<b>Total life cycle costs</b>	<b>1681</b>	<b>1806</b>	<b>320</b>	<b>3807</b>

Note: Reflects final System Analysis values, ORNL, 11/9/95, with agreed to adjustments.

**Table 11. Front-end and back-end operating assumptions and design basis.**

Assumptions	
Plant capacity	5 tonnes (5.6 tons) Pu/yr
Average plant throughput	25 kg (55 lb) Pu/day
Plant location	Kenosha, WI.
Plant owner	U.S. Government (DOE)
Process building type	Seismic Category 1 for Pu handling areas
NEPA, safety, permitting	DOE/with NRC license
Feedstocks:	
front end	Pits and other surplus plutonium forms
back end	Plutonium oxide
Plant operational lifetime / total Pu processed	10 years/50 tonnes (56 tons) Pu
Time from ROD to hot startup (greenfield)	12 years
Time from ROD to hot start-up (ANL/W variant)	10 years
Data source for cost information	DWPF, Bechtel, LANL, and LLNL

### 2.6.1 Plutonium Processing (Non-Remote Handled) Operating Assumptions

Since front-end plutonium processing operation is dominated by the shipping/receiving and recovery operations, our assumptions are that all non-remote handled operations for the end-to-end alternative will be contained in a single plutonium facility. Specific examples include all plutonium recovery operations and all immobilization operations not involving the use of radionuclide spikes such as  $^{137}\text{Cs}$  or high-level waste. Such operations require similar glove box and ventilation systems as those used for the recovery operations and would not be contained in a separate facility in any reasonable implementation.

The facility sizing and cost estimates were developed using the cost estimating procedure outlined above and are based on the second-level flow diagrams for this facility. R&D costs are those for the specific operations identified on the second-level flow diagrams that can be performed in a standard plutonium processing facility (e.g., no remote handled operations, only glove box operations). Post construction startup costs are estimated as 1.5 years of operating costs based on the anticipated startup schedule. Waste disposal costs are based on plutonium throughput and are costed at \$10,000 per drum for TRU waste and \$2,000 per drum for LLW.

Table 12 shows the summary of the plutonium processing LCC costs for the baseline and ANL-W variant. The upper portion (TPC) of Table 12 shows the front-end cost broken up into the categories specified in the cost estimating guidelines. The rightmost column shows the assumptions corresponding to each entry.

### 2.6.2 Back-End Ceramic Cost Basis

Back-end remote handled facility costs are estimated at a preconceptual level. The greenfield project location is assumed to be Kenosha, Wisconsin, EPRI hypothetical West/West Central site. The pricing level is based on 3rd quarter 1995 dollars. Escalation is excluded. The estimates also assume a normal schedule without delays. Also excluded are cost of land, roads, and utilities outside fence line.

Noteworthy preoperational costs include R&D, Wasteform qualification, NEPA/Licensing, and costs for core team from completion of Title II design to award of license.

The capital cost estimates are based on costs of major process equipment, process support systems, utility and service systems, plant buildings and site requirements. The method of estimating is based on the following:

- Major process systems—equipment cost including cost per item plus factored cost of bulk materials (piping, etc.)
- Process support systems—equipment costs (where available), allowances or capacity and size x factor

**Table 12. Plutonium processing LCC summary for ceramic greenfield alternative and ANL/W variant (\$M 1995).**

End-to-end alternative	Cost	Basis
"PREOPERATIONAL" UP-FRONT COSTS		Per SA model
1. R&D	89	R & D estimate LANL/LLNL
2. NEPA, licensing, permitting	35	
3. Conceptual design	10	
4. Q/A, site qualification, safeguards and security	8	
5. Postconstruction startup	49	
6. Risk contingency	37	
SUB OPC	228	
"CAPITAL" OR "TPC" UP-FRONT COSTS (TEC)		
7. Title I, II, III engineering, design and inspection Capital	96	
8a. Capital equipment	146	
8b. Direct and indirect construction/modification	235	
9. Construction management (% of category 8)	23	
10. Initial spares (technology dependent)	3	
11. Allowance for indeterminates (AFI) (% of Cats 7-10)	126	
12. Risk contingency	0	
SUB TEC	629	
Subtotal up-front costs	857	
Pu processing at LANL (Halides)	1	
TOTAL UP-FRONT COST	858	
13. Operations and maintenance staffing	330	
14. Consumables including utilities	80	
15. Major capital replacements or upgrades (% of capital)	190	
16. Waste handling and disposal (TRU, mixed and LLW)	70	Unit costs from ORNL
17. Oversight —DOE or NRC	10	
18. M&O Contractor fees (% if different than 2%)	20	
19. Payments-in-lieu-of-taxes to local communities (PILT) (1%)	10	
20. D&D	63	
21. Revenues (if applicable)	n/a	
22. Government subsidies or fees to private-owned facilities	n/a	
23. Transportation of Pu forms to facility	50	ORNL T&P estimate
24. Storage of Pu at existing 94-I site facility		
SUB OF THE LCCs	823	
TOTAL LCC FRONT-END FACILITY	1681	

- Utility and service systems—capacity and size x factor
- Plant buildings (facilities)—preconceptual quantity takeoffs, HVAC, special features (lined cells, etc.) or \$/sq. ft or \$/cu. ft.

The capital cost estimate includes direct costs, indirect field costs, total field costs, contractors costs and profit, construction management, A-E cost, management costs, initial spares, and contingency wages, consumables, material and maintenance expenditures, and waste disposal.

Operation costs for personnel wages are based on facility manpower loading from the PEIS Data Input Report. The cost for facility maintenance and spares is estimated using a factor of 4% of facility capital costs. Consumables items such as chemicals are based on data in "Chemical Marketing Report" dated 1989. The cost for utilities and services, including materials, safety, environmental and security to operate the facilities, is estimated using a factor of 10% of the personnel wages. These cost factors are based on previous experience with projects of similar scope.

The operation and maintenance (O&M) cost estimate include costs for personnel. Waste disposal is based on unit volume costs for disposal of transuranic (TRU) waste to the Waste Isolation Pilot Plant (WIPP) and low-level solid wastes to a shallow land burial site. A 15% contingency is included in the operating cost.

Tables 13a and 13b show the summary of the back-end ceramic fabrication processing LCC costs for the baseline and ANL-W variant.

### 2.6.3 Repository Costs

The estimated cost for disposal of the immobilized waste forms in a repository is based upon information contained in the Federal Register notice (52 FR 31508) published by the Department of Energy on August 20, 1987, and entitled "Civilian Radioactive Waste Management: Calculating Nuclear Fund Disposal Fees for DOE Defense Program Waste." This document from the Office of Civilian Radioactive Waste Management (OCRWM) is a public notice of its approach to interpreting the requirement, under the Nuclear Waste Policy Act of 1982, for allocating the costs of developing, constructing, and operating repositories between atomic energy defense wastes and commercial high-level spent fuel.

In this notice, DOE identified a preferred cost-sharing approach between defense and civilian wastes. "According to the formula, the repository costs per canister of DHLW is approximately \$500K based on a total life cycle cost analysis completed in September 1995," "Analysis of the Total Life Cycle Cost of the Civilian Radioactive Waste Management Program," DOE/RW-0479, US Department of Energy, Office of Civilian Radioactive Waste Management, September 1995."

**Table 13a. Back-end immobilization LCC summary—ceramic greenfield facility (\$M 1995).**

End-to-end alternative	Cost 1995 \$M	Basis
<b>"PREOPERATIONAL" OR "OPC" COSTS</b>		
1. R&D. Waste form qualification	49, 40	R&D estimate.
2. NEPA, licensing, permitting Core A/E and program team from end of Title II to issue of license	20, 28	\$10M/yr × 2.75 years
3. Conceptual design	11	
4. Q/A site qualification, safeguards and security	9	
5. Post-construction startup	141	
6. Risk contingency	74	
SUB OPC	372	
<b>"CAPITAL" OR "TPC" UP-FRONT COSTS (TEC)</b>		
7. Title I, II, III engineering, design and inspection	105	Incl. Home office management
8a. Capital equipment	(in 8b)	
8b. Direct and indirect construction	277	
9. Construction management (% of category 8)	29	
10. Initial Spares (technology dependent)	17	
11. Allowance for indeterminates (AFI)	150	
12. Contingency	0	
SUB TEC	578	
<b>TOTAL UP-FRONT (TPC) FOR BACK-END FACILITY</b>		
	950	
<b>OTHER LIFE CYCLE COSTS</b>		
Operations and maintenance (860) Staff size	937	PEIS Data Input Report
14. Consumables including utilities	100	Chem. Marketing Prices Rep
15. Major capital replacements or upgrades (% of capital)	230, 198	Est. 4% of Facility Capital Cost 15% total operation cost contingency
16. Waste handling and disposal	54	K.A.Williams Cost Info 6/14,
17. Oversight—DOE or NRC	10	
18. M&O Contractor fees (2%)	40	
19. Payments-in-lieu-of-taxes to local communities(PILT) (1%)	20	
20. D&D	58	
21. Revenues (if applicable)	0	
22. Government subsidies or fees to private-owned facilities	0	
23. Transportation of CS <sup>137</sup> to facility	75	
24. Storage of Pu at existing 94-I site facility		
SUB OTHER LCC	1722	
<b>TOTAL BACK-END LCC</b>	<b>2672</b>	

Table 13b. Back-end immobilization LCC summary—ceramic-greenfield ANL-W variant facility (\$M 1995).

End-to-end alternative	Cost 1995 \$M	Basis
<b>"PREOPERATIONAL" OR "OPC" COSTS</b>		
1. R&D. Waste form qualification	49, 40	R&D estimate.
2. NEPA, licensing, permitting Core A/E and program team from end of Title II to issue of license	22, 28	\$10M/yr × 2.75 years
3. Conceptual design	2	
4. Q/A site qualification, safeguards and security	9	
5. Post-construction startup	14	
6. Risk contingency	41	
SUB OPC	205	
<b>"CAPITAL" OR "TPC" UP-FRONT COSTS (TEC)</b>		
7. Title I, II, III engineering, design and inspection	18	Incl. Home Office Management
8a. Capital equipment	(in 8b)	
8b. Direct and indirect construction	35	
9. Construction management (% of category 8)	5	
10. Initial Spares (technology dependent)	12	
11. Allowance for indeterminates (AFI)	35	
12. Contingency	0	
SUB TEC	105	
TOTAL UP-FRONT (TPC) FOR BACK-END FACILITY	310	
<b>OTHER LIFE CYCLE COSTS</b>		
13. Operations and maintenance Staff size (860)	937	PEIS Data Input Report
14. Consumables including utilities	107	Chem. Marketing Prices Report
15. Major capital replacements or upgrades (% of capital)	84, 177	Est. 4% of Facility Capital Cost. 15% total operation cost contingency
16. Waste handling and disposal	54	K.A.Williams Cost Info 6/14/95
17. Oversight—DOE or NRC	10	
18. M&O Contractor fees (2%)	27	
19. Payments-in-lieu-of-taxes to local communities(PILT) (1%)	14	
20. D&D	11	
21. Revenues (if applicable)	0	
22. Government subsidies or fees to private-owned facilities	0	
23. Transportation of <sup>137</sup> Cs to facility	75	
24. Storage of Pu at existing 94-I site facility	0	
SUB OTHER LCC	1496	
TOTAL BACK-END LCC	1806	

## 2.7 Schedule

### 2.7.1 Overall Schedule

Preliminary, estimated schedules to deploy, operate and decommission (or convert) the ceramic greenfield immobilization alternative and ANL-W variant facilities have been developed by combining schedules for the front-end and immobilization facilities, even though for this greenfield case these are planned as a single combined facility. These combined schedules are presented in tabular form in Tables 14a, 14b, 15a, 15b and in Gantt chart form in Figures 14a, 14b, 15a, and 15b at the end of this section. The currently scheduled date of the Programmatic Environmental Impact Study (PEIS) Record of Decision (ROD) is in the last quarter of 1996.

A new capital project will be required to implement the ceramic greenfield plutonium immobilization alternative, which includes the design and construction of a new facility or the ANL-W variant, which includes modifications of existing DOE facilities. An assumption is that DOE line item projects will be conducted in accordance with DOE Orders and the congressional funding cycle. The planning basis is that key decisions (KD) for Approval of Mission Need (0), Approval of New Start (1), Commence Detailed Design (2), Commence Construction (3), and Commence Operations (4) will be performed by the DOE in support of this plutonium immobilization alternative.

The following discusses the baseline. For the ANL-W variant the discussion is similar to that for the ceramic greenfield alternative. An R&D program has been identified to develop and demonstrate the immobilized formulation and process equipment.

National Environmental Protection Act (NEPA) activities are included. For the ceramic greenfield with new NRC licensed facilities, it is assumed that an *Environmental Information Report* with a preferred site, and evaluation of alternatives is submitted to NRC for their NEPA action to issue a license.

Permitting activities are indicated. Preparation of a Safety Analysis Report is included. Title I & II (preliminary and detailed) design durations are indicated. Construction and procurement durations are included. Cold startup, preoperational testing, and an Operational Readiness Review (ORR) of the facility is included, followed by hot startup and operations.

The time to process the reference 50 tonnes (56 tons) of plutonium will vary with plutonium loading and actual operating scenarios. For planning purposes, the estimated duration of the plutonium immobilization campaign is 10 years. (Detailed performance modeling by Systems Analysis presented in other sections of this report may indicate variations from the nominal 10-year planning basis). Process improvements, plutonium immobilization experience, and increased plutonium loading could shorten this schedule. (Note: The schedules for the front-end and immobilization

Table 14a. Baseline front-end facility schedule breakout.

Task no.	Task name	Duration	Start date	Finish date	Predecessors
1	Congressional funding and initial activities	1287d	10/2/95	9/5/00	
2	ROD KD 0 Approval for Mission Need	0d	1/1/97	1/1/97	
3	Title I Authorization Process	104w	1/1/97	12/29/98	2
4	Full Funding Authorization Process	88w	12/30/98	9/5/00	3
5	R&D funding	0d	10/2/95	10/2/95	
6	A-E selection	12w	1/1/97	3/25/97	2
7	Select NEPA contractor	12w	1/1/97	3/25/97	2
8	R&D, demo, test, integrated prototyping and proc. eng.	1584d	10/2/95	10/25/01	
9	HYDOX	522d	10/2/95	9/30/97	5
10	NDA	522d	10/2/95	9/30/97	5
11	Bisector	522d	10/2/95	9/30/97	5
12	ARIES Integrated dismantlement prototype	522d	10/2/95	9/30/97	5
13	HEU Decon	522d	10/1/97	9/30/99	
14	Salt processing	522d	10/1/97	9/30/99	
15	Non-Pu component declass.	522d	10/1/97	9/30/99	
16	ZPPR fuel proc.	522d	10/1/97	9/30/99	
17	Integrated prototyping and eng	108w	10/1/99	10/25/01	12,13,14,15,16
18	Conceptual design, NEPA support for license application, permitting	1600d	3/26/97	5/13/03	
19	NEPA support for license application	60w	4/21/99	6/13/00	7,21
20	Permitting	320w	3/26/97	5/13/03	6,7
21	Conceptual Design	108w	3/26/97	4/20/99	6
22	Project authorization, Title I design, prepare license appl. w/ SAR, EIR	900d	1/1/97	6/13/00	
23	KD#1 Approval for start	0d	1/1/97	1/1/97	2
24	Title I Authorization	0d	12/29/98	12/29/98	3
25	Preferred Site Selection for lic. appl.	48w	1/1/97	12/2/97	2

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34		
35	ence	0d
36	Construction	0d
37	ment o, test, ORR	1320d
38		240w
39		138.4w
40	Installation	99.8w
41	p testing, ORR	48w
42		2400d
43	ence Operation	0d

46	D&D	144w
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Note: Schedule durations are nominal, the detailed date and of the scheduling program

Table 14a. Baseline front-end facility schedule breakout.

Task no.	Task name	Duration	Start date	Finish date	Predecessors
1	Congressional funding and initial activities	1287d	10/2/95	9/5/00	
2	ROD KD 0 Approval for Mission Need	0d	1/1/97	1/1/97	
3	Title I Authorization Process	104w	1/1/97	12/29/98	2
4	Full Funding Authorization Process	88w	12/30/98	9/5/00	3
5	R&D funding	0d	10/2/95	10/2/95	
6	A-E selection	12w	1/1/97	3/25/97	2
7	Select NEPA contractor	12w	1/1/97	3/25/97	2
8	R&D, demo, test, integrated prototyping and proc. eng.	1584d	10/2/95	10/25/01	
9	HYDOX	522d	10/2/95	9/30/97	5
10	NDA	522d	10/2/95	9/30/97	5
11	Bisector	522d	10/2/95	9/30/97	5
12	ARIES Integrated dismantlement prototype	522d	10/2/95	9/30/97	5
13	HEU Decon	522d	10/1/97	9/30/99	
14	Salt processing	522d	10/1/97	9/30/99	
15	Non-Pu component declass.	522d	10/1/97	9/30/99	
16	ZPPR fuel proc.	522d	10/1/97	9/30/99	
17	Integrated prototyping and eng	108w	10/1/99	10/25/01	12,13,14,15,16
18	Conceptual design, NEPA support for license application, permitting	1600d	3/26/97	5/13/03	
19	NEPA support for license application	60w	4/21/99	6/13/00	7,21
20	Permitting	320w	3/26/97	5/13/03	6,7
21	Conceptual Design	108w	3/26/97	4/20/99	6
22	Project authorization, Title I design, prepare license appl. w/ SAR, EIR	900d	1/1/97	6/13/00	
23	KD#1 Approval for start	0d	1/1/97	1/1/97	2
24	Title I Authorization	0d	12/29/98	12/29/98	3
25	Preferred Site Selection for lic. appl.	48w	1/1/97	12/2/97	2

Table 14a. Baseline front-end facility schedule breakout (cont.)

Task no.	Task name	Duration	Start date	Finish date	Predecessors
26	Title I Des and prep license appl. w/SAR	60w	4/21/99	6/13/00	3,21
27	NRC license application, NRC review process, NEPA/EIS, Title II des., NRC license, release for construction	1200d	6/13/00	1/18/05	
28	KD#2- Start Title II Design	0d	9/5/00	9/5/00	26,4,25
29	Submit license application and Env. Rpt.	0d	6/13/00	6/13/00	26,19
30	NRC licensing	240w	6/14/00	1/18/05	29
31	NRC NEPA process	104w	6/14/00	6/11/02	29
32	NRC issues final EIS	0d	6/11/02	6/11/02	31
33	Title II Design	96w	9/6/00	7/9/02	28
34	NRC license	0d	1/18/05	1/18/05	30,20
35	Approval to commence construction	0d	1/21/04	1/21/04	34FS-52w,33
36	KD#3/Release for Construction	0d	1/21/04	1/21/04	35
37	Construction, equipment installation, startup, test, ORR	1320d	1/21/04	2/10/09	
38	Construction	240w	1/21/04	8/26/08	36
39	Procurement	138.4w	1/21/04	9/14/06	36
40	Equipment Installation	99.8w	1/6/06	12/5/07	39FS-36w
41	Startup, Preop testing, ORR	48w	3/12/08	2/10/09	38FS-24w,40
42	Operations	2400d	2/10/09	4/24/18	
43	KD#4 Commence Operation	0d	2/10/09	2/10/09	41
44	Operation	480w	2/11/09	4/24/18	43
45	D&D	720d	5/24/17	2/25/20	
46	D&D	144w	5/24/17	2/25/20	44FS-48w

Note: Schedule durations are nominal, the detailed date and day information is not significant, it is merely a function of the scheduling program calendar.

Table 14b. ANL/W variant front-end facility schedule breakout.

Task no.	Task name	Duration	Start date	Finish date	Predecessors
1	Congressional funding and initial activities	1287d	10/2/95	9/5/00	
2	ROD KD 0 Approval for Mission Need	0d	1/1/97	1/1/97	
3	Title I Authorization Process	104w	1/1/97	12/29/98	2
4	Full Funding Authorization Process	88w	12/30/98	9/5/00	3
5	R&D funding	0d	10/2/95	10/2/95	
6	A-E selection	12w	1/1/97	3/25/97	2
7	Select NEPA contractor	12w	1/1/97	3/25/97	2
8	R&D, demo, test, integrated prototyping and proc. eng	1584d	10/2/95	10/25/01	
9	HYDOX	522d	10/2/95	9/30/97	5
10	NDA	522d	10/2/95	9/30/97	5
11	Bisector	522d	10/2/95	9/30/97	5
12	ARIES Integrated dismantlement prototype	522d	10/2/95	9/30/97	5
13	HELL Decon	522d	10/1/97	9/30/99	
14	Salt processing	522d	10/1/97	9/30/99	
15	Non-Pu component declass.	522d	10/1/97	9/30/99	
16	ZPPR fuel proc.	522d	10/1/97	9/30/99	
17	Integrated prototyping and eng	108w	10/1/99	10/25/01	12,13,14,15,16
18	Conceptual design, NEPA, permitting	1660d	1/1/97	5/13/03	
19	Preferred site selection	48w	1/1/97	12/2/97	2
20	NEPA/EIS and site selection	660d	12/21/99	10/30/01	7,22
21	Permitting	320w	3/26/97	5/13/03	6,7
22	Conceptual Design	108w	3/26/97	4/20/99	6
23	Project authorization, Title I design, PSAR	780d	1/1/97	12/28/99	
24	KD#1 Approval for start	0d	1/1/97	1/1/97	2
25	Title I Authorization	0d	12/29/98	12/29/98	3

Table 14b. ANL/W variant front-end facility schedule breakout (cont.)

Task no.	Task name	Duration	Start date	Finish date	Predecessors
26	Title I Des and PSAR	36w	4/21/99	12/28/99	3,22
27	Documentation to DNFSB, review process, Title II des., FSAR, DNFSB release for construction	1200d	12/28/99	8/3/04	
28	KD#2- Start Title II Design	0d	10/30/01	10/30/01	4,20,26
29	Submit documentation to DNFSB	0d	12/28/99	12/28/99	26
30	DNFSB oversight process	240w	12/29/99	8/3/04	29
31	Title II Design and FSAR	60w	10/31/01	12/24/02	28
32	DNFSB approval/KD#3/Release for Construction	0d	8/6/03	8/6/03	30FS-52w
33	Construction, equipment installation, startup, test, ORR	832d	8/6/03	10/12/06	
34	Construction	120w	8/6/03	11/22/05	32
35	Procurement	92.2w	8/6/03	5/11/05	32
36	Equipment Installation	62.2w	9/2/04	11/10/05	35FS-36w,17
37	Startup, Preop testing, ORR	48w	11/11/05	10/12/06	34FS-24w,36
38	Operations	2400d	10/12/06	12/24/15	
39	KD#4 Commence Operation	0d	10/12/06	10/12/06	37,21
40	Operation	480w	10/13/06	12/24/15	39
41	D&D	720d	1/23/15	10/26/17	
42	D&D	144w	1/23/15	10/26/17	40FS-48w

Note: Schedule durations are nominal, the detailed date and day information is not significant, it is merely a function of the scheduling program calendar.

Table 15a. Baseline immobilization facility schedule breakout.

Task no.	Task name	Duration	Start date	Finish date	Predecessors
1	Congressional funding and initial activities	1287d	10/2/95	9/5/00	
2	ROD KD 0 Approval for Mission Need	0d	1/1/97	1/1/97	
3	Title I Authorization Process	104w	1/1/97	12/29/98	2
4	Full Funding Authorization Process	88w	12/30/98	9/5/00	3
5	R&D funding	0d	10/2/95	10/2/95	
6	A-E selection	12w	1/1/97	3/25/97	2
7	Select NEPA contractor	12w	1/1/97	3/25/97	2
8	R&D, demo, test, integrated prototyping and proc. eng.	2697d	10/2/95	1/31/06	
9	Formulation, proc. & long term perf	175d	10/2/95	6/1/96	5
10	Balance of R&D, demo and test	1044d	10/1/96	9/29/00	
11	Integrated prototyping and eng	278.4w	10/2/00	1/31/06	10
12	Conceptual design, NEPA support for license application, permitting	1600d	3/26/97	5/13/03	
13	NEPA support for license application	60w	4/21/99	6/13/00	7,15
14	Permitting	320w	3/26/97	5/13/03	6,7
15	Conceptual Design	108w	3/26/97	4/20/99	6
16	Project authorization, Title I design, prepare license appl. w/ SAR, EIR	900d	1/1/97	6/13/00	
17	KD#1 Approval for start	0d	1/1/97	1/1/97	2
18	Title I Authorization	0d	12/29/98	12/29/98	3
19	Preferred Site Selection for lic. appl.	48w	1/1/97	12/2/97	2
20	Title I Des and prep license appl. w/SAR	60w	4/21/99	6/13/00	3,15
21	NRC license application, NRC review process, NEPA/EIS, Title II des., NRC license, release for construction	1200d	6/13/00	1/18/05	
22	KD#2- Start Title II Design	0d	9/5/00	9/5/00	20,4,19

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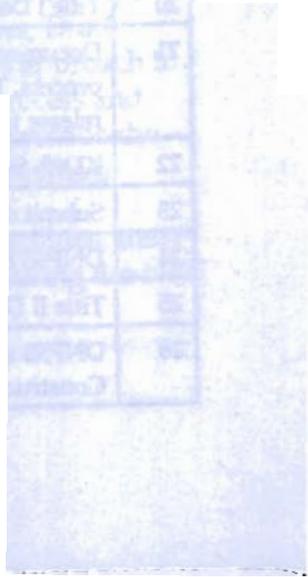
			96w			
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30	onstr	for Construction	0d	1/21/01	1/21/01	
31		equipment rump, test, ORR	1320d	1/21/01	2/10/09	
32			240w	1/21/01	8/26/08	
33			138.4w	1/21/01	9/14/06	
		tallation	93.8w	2/1/05	12/31/07	
		testing, ORR	48w		2/10/09	
36	Operations		2400d		4/24/18	
37	KD-4 Commence Operation		0d		2/10/09	35
38	Operation		480w		4/24/18	37
39	D&D		720d		2/25/20	
40	D&D		144w		2/25/20	38BS 18w

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12	Cont:				
13				2/9/97	2
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17	Project authorization, Title I FSAR	n, 780d		2/28/99	
18					2
19				1/29/9	3
20		36w			3,16
21					
22	-Start Title II	0d		0/30/01	
23	Submit document	0d		12/28/99	
24				8/3/01	
25	Title II Design and FSAR	60w	10/31/01	12/24/02	
26	DNFSB approval/KD3/R Construction	0d	8/6/03	8/6/03	

Table 15b. ANL/W variant immobilization facility schedule breakout (cont.)

Task no.	Task name	Duration	Start date	Finish date	Predecessors
27	Construction, equipment installation, startup, test, ORR	832d	8/6/03	6/13/06	
28	Construction	120w	8/6/03	11/22/05	26
29	Procurement	92.2w	8/6/03	5/11/05	26
30	Equipment Installation	62.2w	9/2/04	11/10/05	29FS-36w,11
31	Startup, Preop testing, ORR	48w	11/11/05	10/12/06	28FS-24w,30
32	Operations	2400d	10/12/06	12/24/15	
33	KD#4 Commence Operation	0d	10/12/06	6/13/06	31,15
34	Operation	480w	10/13/06	12/24/15	33
35	D&D	720d	1/23/15	10/26/17	
36	D&D	144w	9/24/14	6/27/17	34FS-48w

Note: Schedule durations are nominal, the detailed date and day information is not significant, it is merely a function of the scheduling program calendar.

facilities indicate the same start date, when in actuality a small lag time would be required so the front-end facilities could produce feed material prior to operation of immobilization processes.)

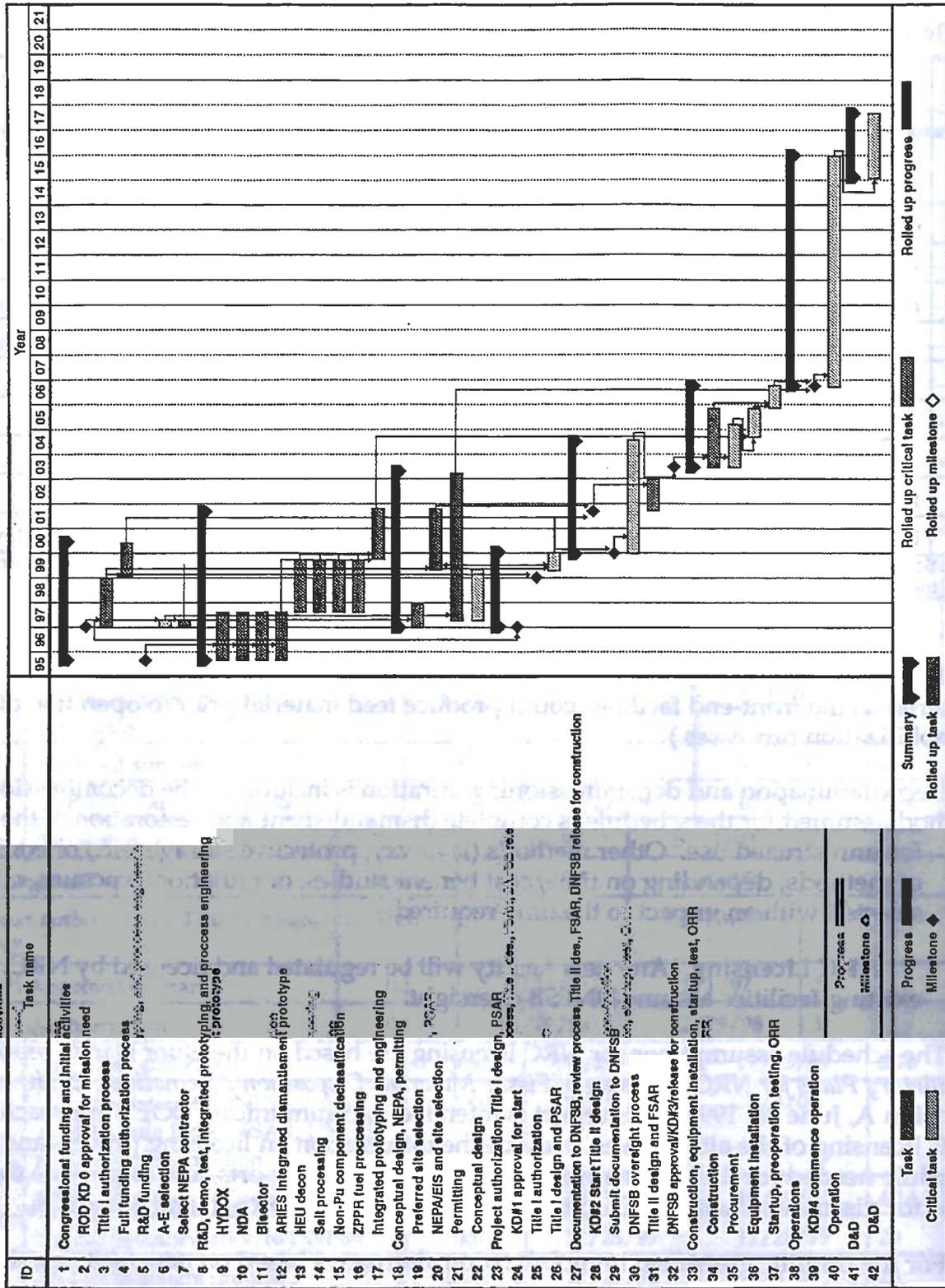
Decontamination and decommissioning duration is included. The decommissioning method assumed for the schedule is complete dismantlement and restoration of the site for unrestricted use. Other methods (layaway, protective storage, etc.) or combinations of methods, depending on time, cost benefit studies, or radiation exposure, might be selected with an impact to the time required.

**NRC Licensing.** Any new facility will be regulated and licensed by NRC, while existing facilities assume DNFSB oversight.

The schedule assumptions for NRC licensing are based on the Fluor Daniel report, *Regulatory Plans for NRC Licensing of Fissile Materials Disposition Alternatives, Draft Revision A*, June 26, 1995. This report is intended to communicate DOE's approach to NRC licensing of the alternatives, provide the information on licensing process and schedule needed for the Alternative Technical Summary Reports, and to provide the basis for discussions with NRC on the validity of DOE's approach and schedules.

For the ceramic greenfield immobilization alternative based on new facilities, there are three distinct license types each with distinct issues to be addressed during the NRC licensing process. The types are:

- Processing, governed by 10 CFR Part 70.



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Figure 15a. Baseline front-end plutonium processing schedule.

1. Complete funding and initial activities  
 2. RFP and approval for mission need  
 3. Initial construction process

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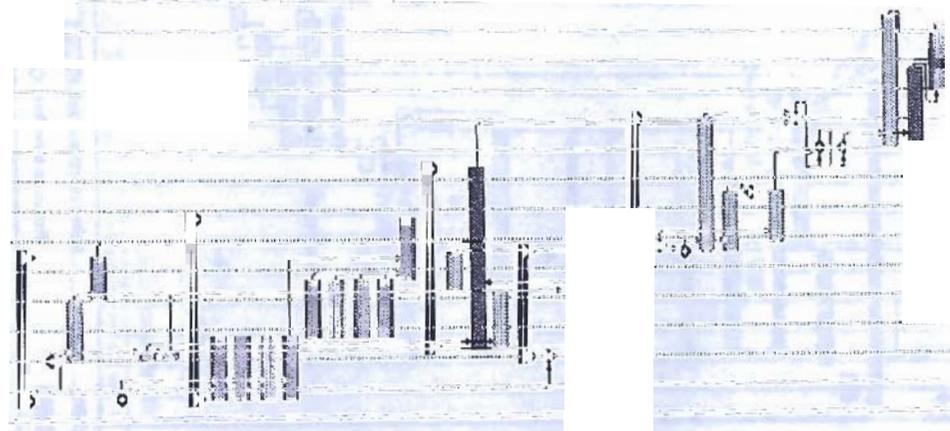
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 testing, O&M

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 15 O&M  
 16 O&M

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**Process**  
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- 24 NSC licensing
- 25 NSC MFPA process
- 26 NSC license final MS
- 27 Use # design

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Commercial Operation

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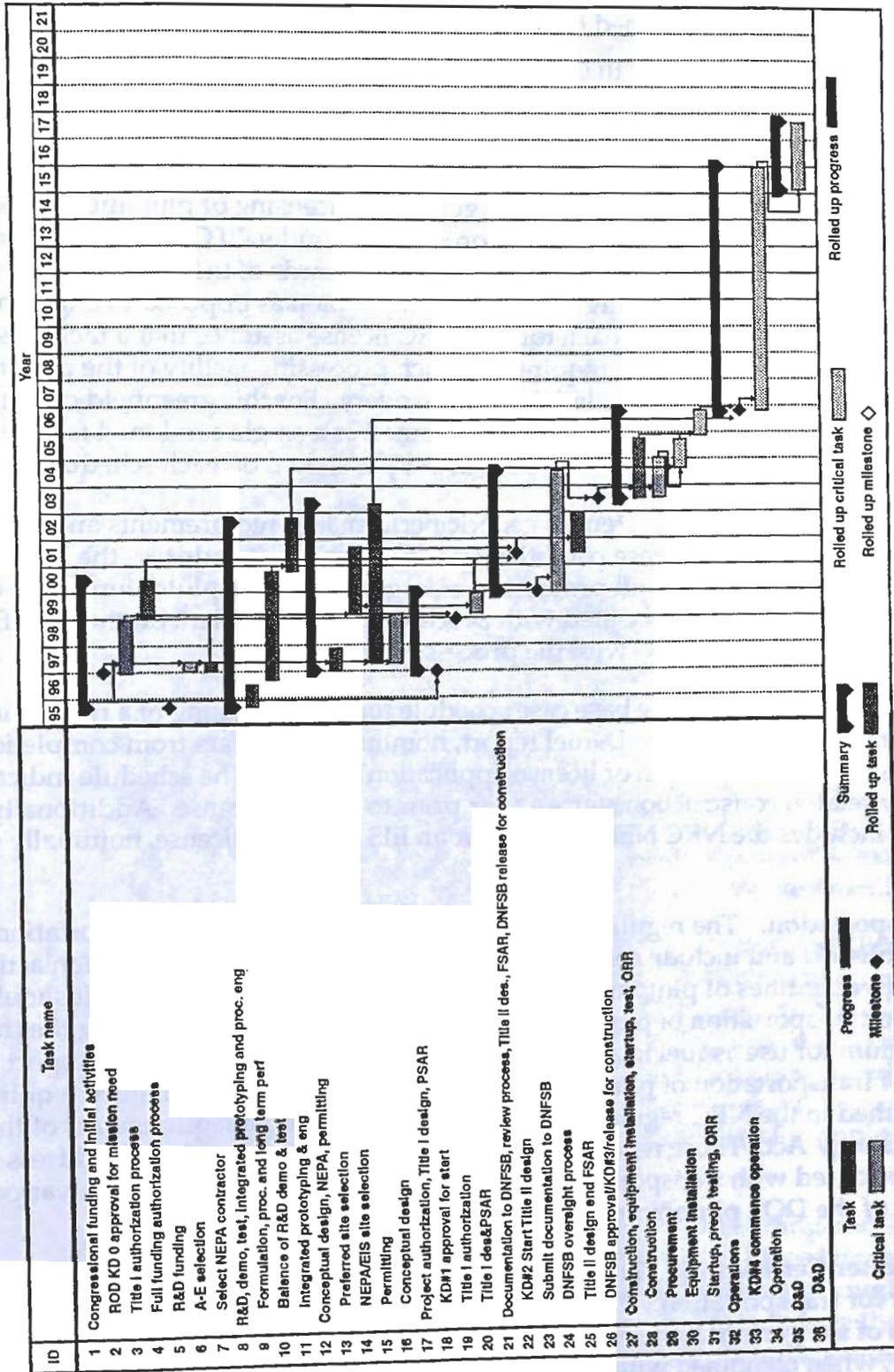


Figure 16b. ANL/W variant back-end ceramic fabrication.

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isions on whether and what ganization will be

responsible. The DOE is currently preparing an action plan for implementing these recommendations.

Decis

and licensing schedule

s. Within the base assumption of NRC licensing, Fluor Daniel personnel indicate there may be opportunity to improve on the schedule through proactive

ce the review time vements might be

critical path activity, improvements would ate.

**Congressional Funding.** The congressional funding cycle is a critical path activity. Improvements are not anticipated. However, delays would impact the overall disposition completion date.

**R&D.** The program identified to develop and demonstrate the immobilized formulation and process equipment will be better defined in the long range R&D plans being prepared. However, relative to licensing, permitting, and other critical path activities the needed development and demonstration will either be readily achievable in time to support the baseline schedule, or critical problems that disqualify an alternative will be identified early.

**Waste Form Certification and Qualification.** For the ceramic greenfield option, the waste form was developed and evaluated as a candidate form for HLW disposal, plutonium loading has been demonstrated, and natural analogs exist. The schedule shown assumes full certification can be accomplished within the activity duration for the balance of R&D, demonstration and test.

**Site-Specific EIS and Permitting.** Preparation of an Environmental Information Report with a preferred site, and evaluation of alternatives for submission to the NRC for their NEPA action to issue a license is a critical path activity. Delays or improvements would impact the overall disposition completion date. NRC NEPA action to issue a license, estimated at two years, is well within the NRC licensing, five-year critical path activity. Other permitting activities are not shown as critical path activities, but would need to be monitored closely during implementation to determine if delays would impact the overall disposition completion date.

**Title I and II Design, Procurement, Construction, and SAR Preparation.** Title I and SAR preparation support submittal of the NRC license application and are critical path activities. Delays or improvements would impact the overall disposition completion date. Title II design is well within the NRC licensing five-year critical path activity. Procurement, and construction, are critical path activities. Delays or improvements would impact the overall disposition completion date.

**Cold Startup and Preoperational Testing.** These activities offer opportunities to refine and improve on the schedule as more definition is achieved in the future. These are critical path activities, thus delays or improvements would impact the overall disposition completion date.

**Hot Startup and Operations.** These activities offer opportunities to refine and improve on the schedule as more definition is achieved in the future. Process improvements, plutonium immobilization experience, and increased plutonium loading could shorten the operational schedule. These are critical path activities, thus delays or improvements would impact the overall disposition completion date.

**Decontamination and Decommissioning.** D&D activities occur after disposition, and are not well defined at this point. While they are important to conclusion of the overall program, they do not impact the overall disposition completion date.

**Repository Availability.** Uniform linear shipments to a HLW repository are assumed. However, the immobilization alternative facilities planning basis includes storage for the entire inventory of dispositioned material. Thus material can be processed into the dispositioned form, and stored until a HLW repository is available.

## 2.8 Institutional Issues

### 2.8.1 International Issues

In the United States, institutional issues have come to play every bit as important a role as technology in arriving at major federal decisions. It is vital that federal agencies, in developing policy initiatives, recognize the key roles that building public and political support and the timely satisfaction of requirements of process and openness play in the success or failure of programs and projects. Experience has shown that projects endorsed by selection processes that fail to take these factors into account may be seriously delayed or possibly never implemented. Therefore, agencies need to consider both the public process by which decisions are reached and the actions needed to build sufficient governmental, political, and public support, if they hope to achieve acceptance of the policy or program.

The ultimate measure of public support will be the successful implementation and completion of the plutonium disposition alternatives selected in the Record of Decision. However, even to formally adopt a policy and move toward implementation, a number of necessary steps will, in fact, become tests of public and governmental acceptance. An early test may arise when legislation is proposed to provide a statutory base for the program. In this case, political support will be established by a majority of votes cast in the Congress to pass legislation. The votes of elected representatives will be influenced by their perception of the attitudes of their constituents. Measuring public attitudes on political issues is an uncertain undertaking.

The need to take action is clear. **The “no action” alternative will not suffice.** Plutonium exists and, in the long run, something must be done with weapons plutonium to minimize the risk to proliferation. The purpose of the Fissile Materials Disposition Program is proper, safe disposition of weapons plutonium to achieve these nonproliferation goals. While in the short term, only some of the plutonium materials must be dealt with on an urgent basis, early demonstration of one or more methods of disposition is important to establish programmatic momentum as soon as practicable. Early demonstration would also serve to show U.S. resolve in negotiations with Russia on disposition of Russian weapons plutonium.

### 2.8.2 Choice of Disposition Alternative

Under the immobilization alternative, surplus plutonium would be immobilized in an acceptable matrix to create a chemically stable form for disposal in a high-level waste repository. **The immobilized form would also meet the spent-fuel standard in that the**

estab

- Russia. Russia's nuclear-energy establishment also expects to fabricate its excess weapons plutonium and separated power reactor plutonium into MOX fuel for reactors but hasn't actively to do so. Before the collapse of the Soviet Union, the plan was to use the plutonium for the generation of fast-neutron power reactors. A significant part of Russia's nuclear-energy establishment where the funds to fabricate MOX fuel for power reactors; reactor fuel is to be remainder plutonium and

of the techni  
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interests and experience, in efforts that would lead to making  
weapons much more difficult.

The administration's nonproliferation policy states that the United States does not encourage the civil uses of plutonium and does not itself reprocess plutonium for either nuclear power or nuclear explosive purposes. However, the policy also states that the U.S. will maintain its existing commitments regarding the civil use of plutonium in Western Europe and Japan. In addition, the policy commits the U.S. to explore means to limit the stockpiling of plutonium from civil nuclear programs.

Since it is assumed that the FMDP is to be carried out under some degree of transparency and reciprocity, negotiations must be carried out to arrive at mutually acceptable conditions to preclude unintentional unilateral disarmament.

### 2.8.3 Sociopolitical Issues

**Inspection by the IAEA.** As noted by the NAS study, efforts to stem the spread of nuclear weapons are critically dependent on the strength and credibility of the systems and organizations given the responsibility to carry them out. A "key elements" of the President's September 27, 1993 Nonproliferation and Export Control Policy is to "submit U.S. fissile materials no longer needed for our deterrent to inspection by the International Atomic Energy Agency." Inspection by IAEA will provide added assurance to the public that all fissile material is accounted for, and that risks of theft and proliferation are minimized. The IAEA's traditional approach to safeguards focused on verifying declared facilities at declared sites. Even though the IAEA has always had statutory authority to inspect other sites, support from its key member states has not been sufficient to enable it to do so meaningfully to date. The IAEA does not have an enforcement or security function but rather it provides independent accounting and auditing functions. To participate in monitoring fissile materials released from nuclear weapons programs, IAEA will need greater resources.

### 2.8.4 Environment, Safety, and Health Issues

According to the NAS report, "the greatest dangers to public welfare associated with the existence and disposition of weapons plutonium are unquestionably those connected with national and international security. The preeminence of these security dangers, however, should not obscure the need for careful attention to the environment, safety, and health (ES&H) risks implied by the different approaches to weapons dismantlement, fissile materials storage, and long-term disposition of weapons plutonium."

The Stabilization Program is assumed to convert the plutonium to a form compatible with the DNFSB Recommendation 94-1. The short-term ES&H concerns must be coordinated with the nuclear nonproliferation objectives. The December 1995 *Plutonium Stabilization and Immobilization Workshop* is an example of the ongoing effort needed to maintain communication and promote a common understanding on stabilization and immobilization technology requirements.

New and more stringent ES&H regulations are being imposed on the U.S. nuclear weapons complex. These are dynamic standards, and can be expected to continue to



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