

Fissile Materials Disposition Program

Alternative Technical Summary Report: Ceramic Greenfield Variant

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August 26, 1996

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Acknowledgments

Organizations that provided major contributions to the development of this report include:

- Lawrence Livermore National Laboratory
- Bechtel
- Australian Nuclear Science and Technology Organisation
- Science Applications International Corporation

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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 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}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}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}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}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}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}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 ^{137}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_2 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.

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 (FMDDP) 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}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}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 1Gy (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}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 (CaTiO_3), and rutile (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.

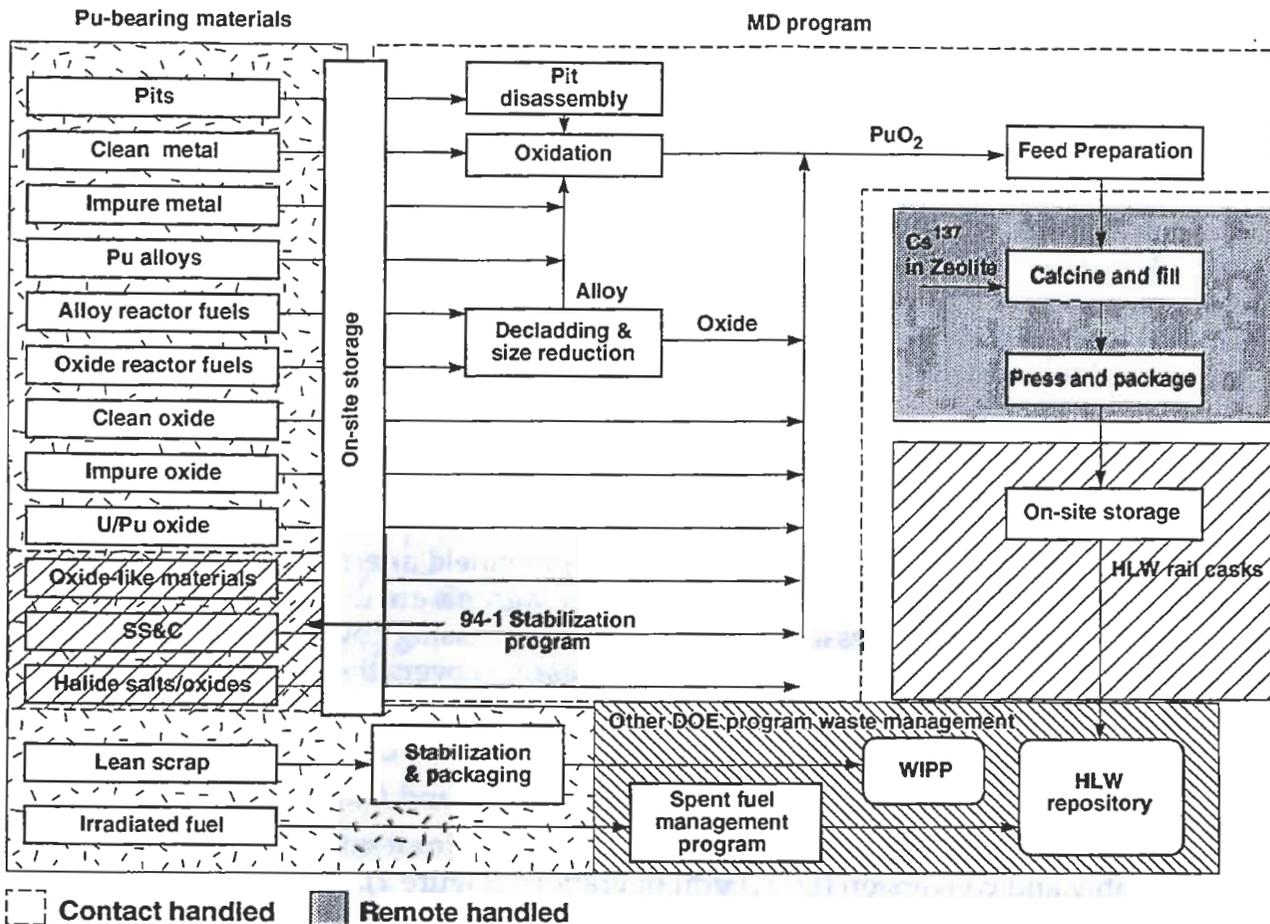
1.2 First-Level Flow Diagrams

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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Figure 1. First-level flow diagram; end-to-end ceramic greenfield alternative.

- **Oxide Reactor Fuel.** The oxide fuel could be in the form of a bundle and clad in stainless steel. Hardware and cladding are removed in the decladding operation. The oxide is then size reduced. The oxide is packaged and stored as feed for the ceramic fabrication process.
- **Oxides.** The oxides are simply stored as feed for the ceramic fabrication process.
- **Plutonium Compounds.** The plutonium compounds include material containing halide salts and incinerator ashes. The soluble salts are removed by washing. Any dissolved plutonium is recovered by oxalate precipitation. The oxalate is converted to oxide by a calcination operation. The oxide is packaged and stored as feed for the ceramic fabrication process.
- **Blends.**

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.

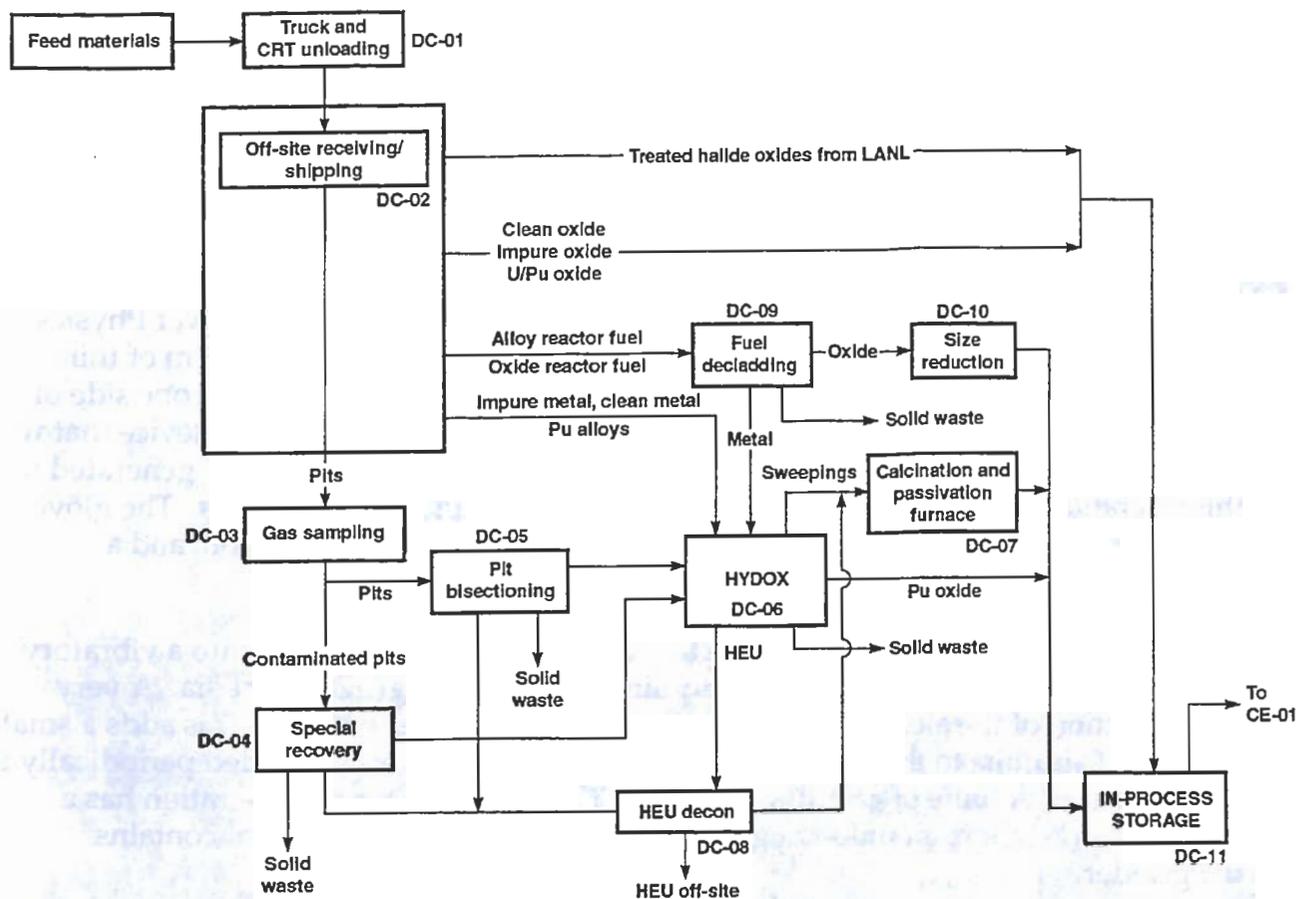
1.3.1 Front-End Plutonium Processing—Disassembly and Conversion

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, 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.



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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.

DC-07 Calcination and Passivation Furnace. A calcination and passivation furnace will convert glove box sweepings into stable oxide. This operation will consist of an open workstation and a workstation containing the passivation furnace.

DC-08 HEU Decontamination. HEU having economic value will be decontaminated with an acid bath, rinsed, and packaged for shipment to a reprocessing facility.

DC-09 Fuel Decladding. The major feed to this operation is Zero-Power Physics Reactor (ZPPR) fuel. ZPPR fuel is stainless-steel-clad metal fuel in the form of thin plates. The decladding operation will employ a planing operation where one side of the cladding will be removed. The fuel element will then be sent through a device that will pull the stainless steel hull away from the metal fuel. The primary waste generated in this operation will be the stainless steel cladding hulls and spent tool bits. The glove box for this operation has a receiving workstation, a planing workstation, and a decladding workstation.

DC-10 Size Reduction. The oxide fuel element pellets will be fed into a vibratory grinder. The vibratory grinder uses alumina pellets as the grinding media. A very small fraction of the alumina pellets is eroded away with each batch. This adds a small amount of alumina to the ground oxide. New alumina pellets are added periodically to maintain a set volume of grinding medium. The glove box for this operation has a loading workstation, an unloading workstation, and a workstation that contains the grinder.

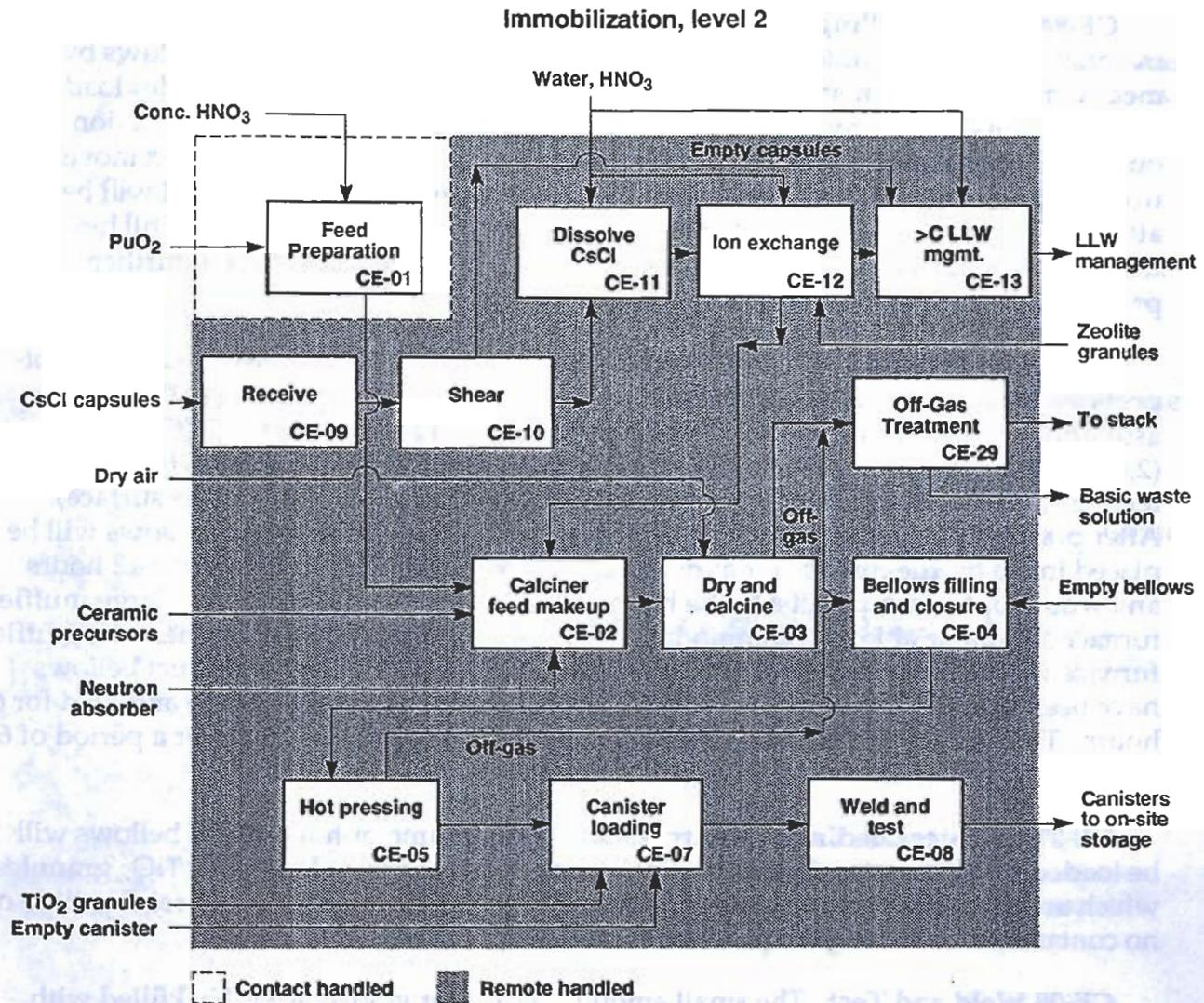
DC-17 In-Process Storage. Oxide will be removed from the glove box line and placed into in-process storage prior to being fed to downstream processing.

1.3.2 Back-End Ceramic Fabrication

The back-end processing (Figure 3) takes the pretreated feed materials and converts them to ceramic inside canisters for storage and disposal. ^{137}Cs is added to provide a radiation barrier. The following are descriptions for the back-end processing.

CE-01 Feed Preparation. Incoming PuO_2 will be converted to plutonium nitrate by dissolving in concentrated nitric acid using a slab or cascade dissolver. Undissolved heels will be blended with fresh material and recycled. Various constituents may be added to aid dissolution or minimize corrosion effects on downstream equipment.

CE-02 Calciner Feed Makeup. Plutonium nitrate solution will be added to a rotating slurry tank, 30 cm (12 in.) diameter, by 107 cm (42 in.) long, for feed makeup. Ceramic precursors with radioactive cesium and a soluble neutron absorber will be added to the slurry with additional water as needed. The slurry tank will rotate at an offset angle, resembling a cement mixer. Veins will run the length of the tank along the inside wall to promote mixing. The equipment will also accommodate a stirrer blade in the center of the slurry tank.



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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 tank inside a high-temperature furnace (i.e., rotary calciner). The tank is the same size and dimensions as that used for the calciner feed makeup, 30 cm (12 in.) diameter by 107 cm (42 in.) long. The tank will also have veins inside to help stirring. If desired, the process could be conducted in the same tank as used for the calciner feed makeup. In this case, the furnaces are turned on, but the material is not moved. Alternatively, the slurry from Calciner Feed Makeup (CE-02) will be poured into the drying and calcining tank. Additional water will be used as necessary to wash away any holdup from the slurry tank. The slurry will first be heated to around 150°C (300°F) to remove bulk water. The temperature will then be increased to between 650°C (1200°F) and 850°C (1560°F) to dry and calcine the material. Calcination will be conducted under a flush of air or argon 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 TiO₂ 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 ¹³⁷Cs and one-third is ¹³⁵Cs. Since ¹³⁷Cs half life is 30 years, a significant amount the material will be decay product, an equimolar mixture of Ba and BaCl₂. 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 BaCl₂ 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

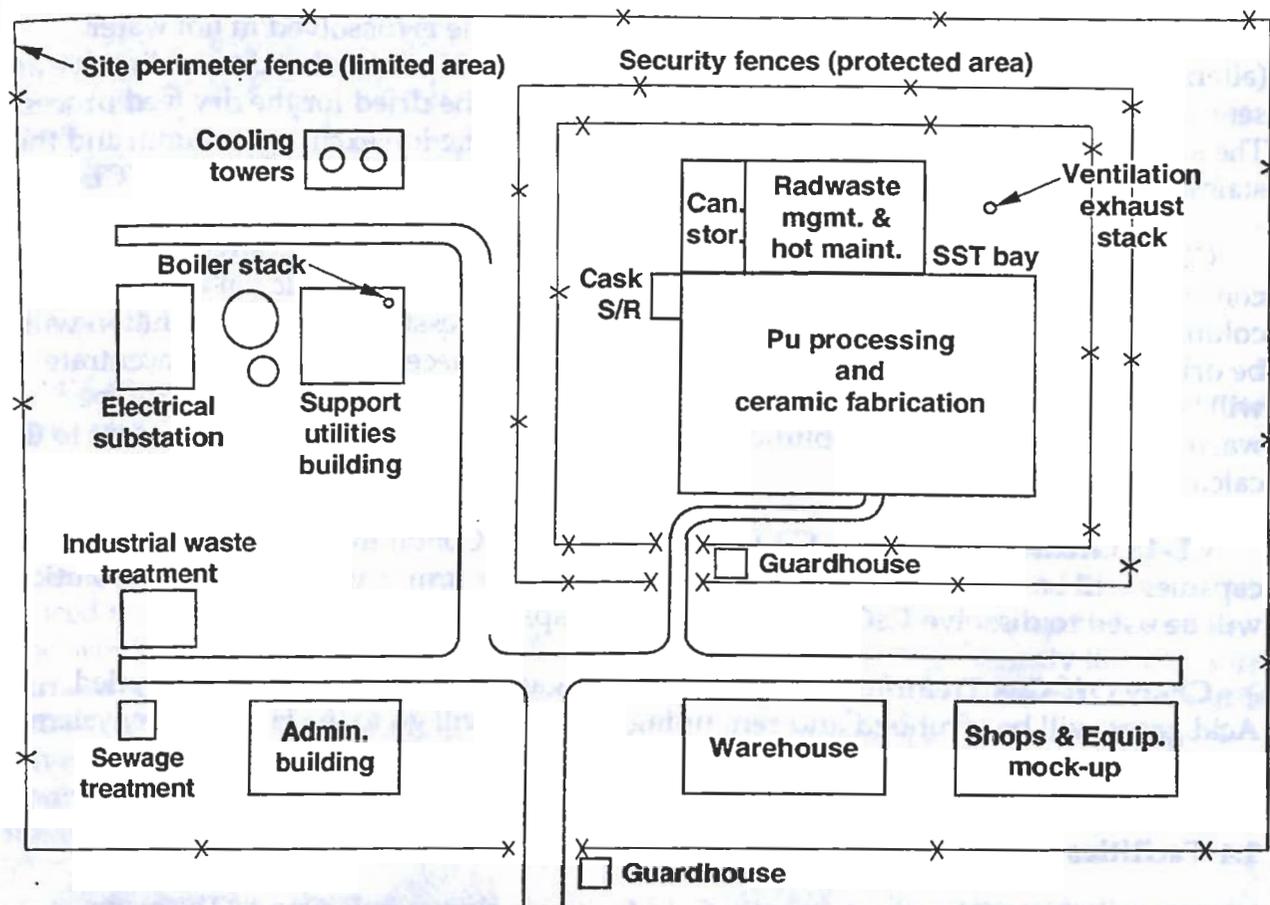
The site map of the ceramic greenfield facility is shown in Figure 4. The major features of the facility are a combined plutonium processing and ceramic fabrication building, a radwaste management/hot maintenance building, and associated support facilities. Table 1 provides major facility data.

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 ² (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.

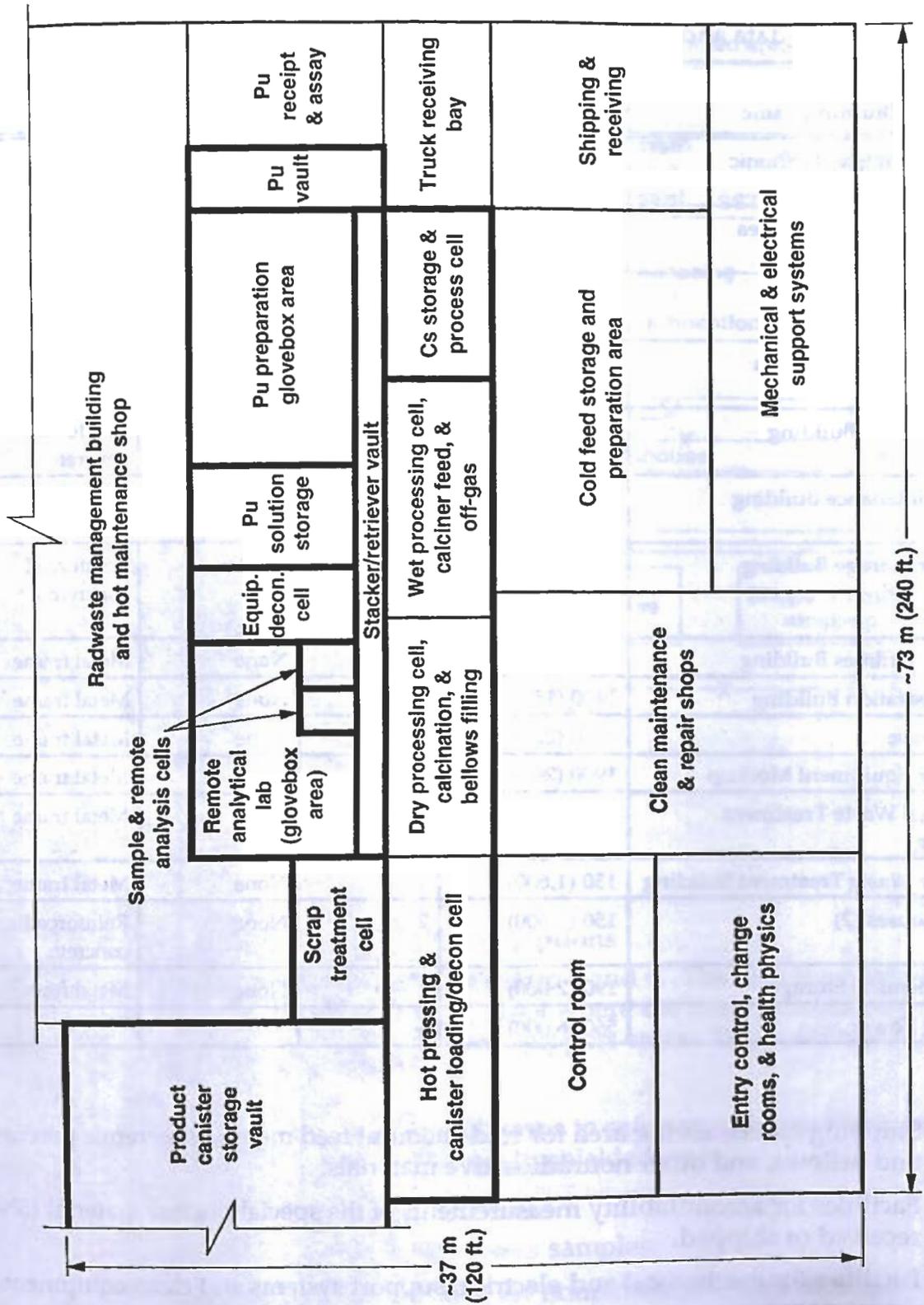


Figure 5. Ceramic processing area, ground floor.

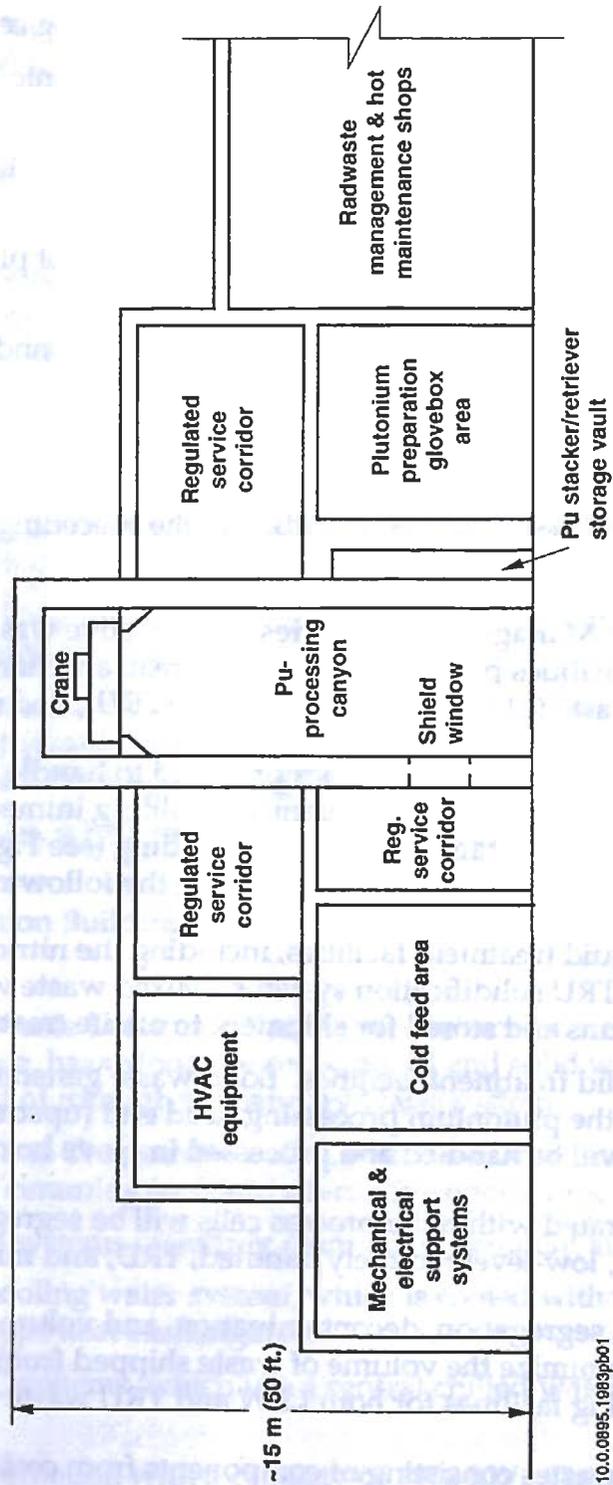


Figure 6. Ceramic processing area, cross section.

- Remotely operated cesium cell for storing and handling cesium capsules.
- Remotely operated canyon area for operating the ceramic immobilization process, including loading compressed bellows into product canisters.
- Storage vault served by a remotely operated stacker/retriever for storing in-process plutonium and cesium.
- Scrap treatment cell to allow treatment and recycling of plutonium from contaminated process materials.
- Area for entry control to the facility, personnel rooms, and health physics operators.

1.4.3 Balance of Plant Facilities

In addition to the process facilities described in the preceding sections, the CGF includes the following support facilities and systems.

Radioactive Waste Management Facilities. Radioactive waste management facilities include the facilities provided to monitor, treat, and handle radioactive wastes, including low-level waste (LLW), transuranic waste (TRU), and mixed wastes.

Radioactive waste management facilities provided to handle these radioactive wastes are located in the Radwaste Management Building immediately adjacent to the Plutonium Processing and Ceramic Fabrication Building (see Figure 4). The radioactive waste treatment systems housed in this area include the following:

- The process liquid treatment facilities, including the nitric acid recovery system and the LLW/TRU solidification systems. Mixed waste will be segregated from other waste forms and stored for shipment to offsite treatment facilities.
- The process solid treatment facilities. Solid waste generated from glove box operations for the plutonium processing head end (upstream of the addition of Cs) generally will be handled and processed in glove box enclosures.

Solid wastes generated within the process cells will be segregated remotely into low-level contact handled, low-level remotely handled, TRU, and mixed waste.

Solid waste assay, segregation, decontamination, and volume-reduction facilities will be provided to minimize the volume of waste shipped from the facility. Waste packaging and shipping facilities for both LLW and TRU waste will be provided.

Solid radioactive wastes consisting of components from cesium processing and systems to handle, treat, and store these wastes will be housed within the shielded process cells. These components generally are not expected to be highly contaminated and will be processed initially within the heavily shielded cells. When the activity is verified to be low enough, additional processing will be carried out as needed within normal glove box enclosures or bagged out into suitable containers. Primary containers

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.

1.5 Cross-Cutting Technologies

1.5.1 Transportation

Overview. The transportation and packaging function provides the means to transport the surplus fissile material and other radioactive material to and from various DOE facilities. The transport and package requirements for each transportation leg and transportation or packaging regulatory requirements are presented below.

Regulations. Transportation of plutonium and associated wastes will be subject to government regulations such as those of the Nuclear Regulatory Commission (NRC), the Department of Transportation (DOT), and the Department of Energy (DOE). Different regulations may apply for different portions of the immobilized end-to-end option depending upon which agency has authoritative control. FMDP assumes that any new facility will be licensed by the NRC. For any currently existing facility it is assumed that the DNFSB will be the reviewing agency. For scheduling purposes, the time required is assumed to be the same for the NRC and DNFSB.

The NRC regulation (10 CFR 71) establishes the requirements for packaging, preparation for shipment, and transportation of licensed material and for the procedures and standards for obtaining NRC approval of packaging and shipping procedures for fissile material and Type B quantities of other licensed materials. (A quantity of weapons-grade plutonium in excess of ~25 mg [8.8×10^{-4} oz] constitutes a Type B quantity per 10 CFR 71.) 10 CFR 71 incorporates, by reference, DOT regulation 49 CFR 170-189. Whenever possible, the DOE transports radioactive materials under NRC regulations. However, for the purpose of national security, 49 CFR 173.7 (b) allows the DOE to ship radioactive material under escort by personnel designated by the DOE, thus waiving the DOT regulations in 49 CFR 170-189. This exemption, however, is rarely used and its use is not anticipated for FMDP.

There are different requirements for the transportation of nuclear materials if the movement of materials is considered onsite (intrasite) versus offsite (intersite). Currently there are no federal regulations governing onsite transport of hazardous materials. For DOE facilities, onsite and offsite transportation requirements are defined in DOE Order 460.1. Onsite is any area within the boundaries of a DOE site or facility that is fenced or otherwise access-controlled and offsite is any area within or outside of a DOE site to which the public has free uncontrolled access.

Transportation System. The transportation system is described below and shown graphically in Figure 7. There are three intersite transportation segments for the end-to-end immobilized option. Intrasite transportation occurs at Westinghouse Hanford, the greenfield site where the conversion/stabilization facility is co-located with the ceramic immobilization facility, and the HLW repository.

Intersite Transportation—Transportation Segment #1—During this segment, fissile material located at various DOE facilities is transported to the onsite temporary storage

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.

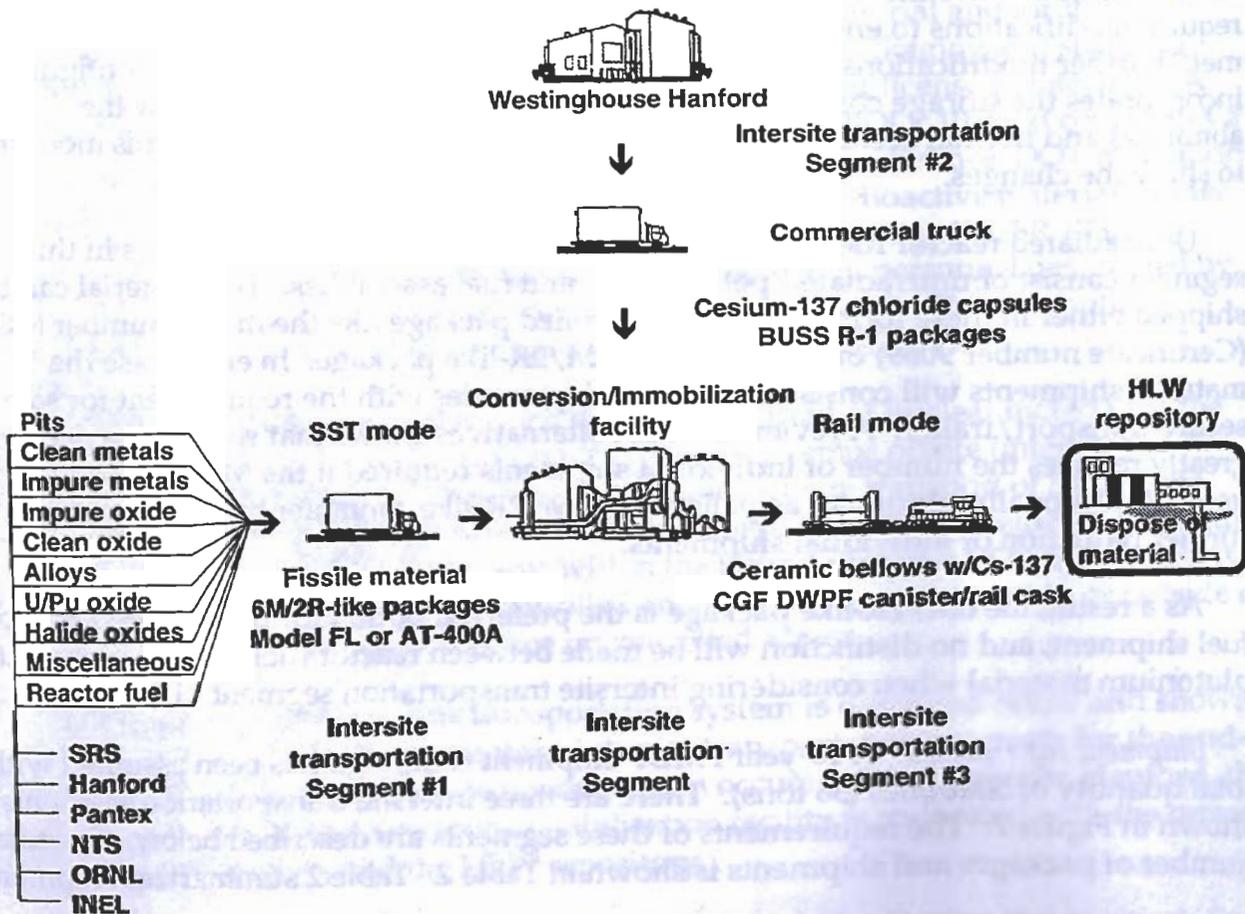
Shipment Information. A 10-year FMDP shipment campaign has been assumed with a total quantity of 50 tonnes (56 tons). There are three intersite transportation segments as shown in Figure 7. The requirements of these segments are described below. The total number of packages and shipments is shown in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

information that was applied to all FMDP alternatives in order to provide an even comparison between alternatives. The amount of detail in Table 2 has been limited due to classification issues.

Transportation Segment #2—During this segment, ¹³⁷Cs chloride capsules are transported from Hanford in Richland, Washington and taken to the greenfield facility. The CsCl capsules are transported as a Type B quantity of special form radioactive materials. The BUSS R-1 packaging (NRC certificate no. 9511) was developed for shipment of the Hanford capsules and is routinely used for shipping the capsules. The BUSS R-1 has the size capacity to hold up to 16 capsules but is limited due to heat output of the material. The CsCl capsules can be transported by commercial truck or rail carrier licensed for radioactive material transport. This information is summarized in Table 3.

Transportation Segment #3—During this segment, 20 hot pressed ceramic bellows loaded with 12% weapons grade plutonium and with ¹³⁷Cs as a radiation barrier are transported from the ceramic greenfield facility to the HLW repository.



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Figure 7. Simplified flow chart showing transportation segments.

Table 2. Parameters for intersite transportation segment #1.

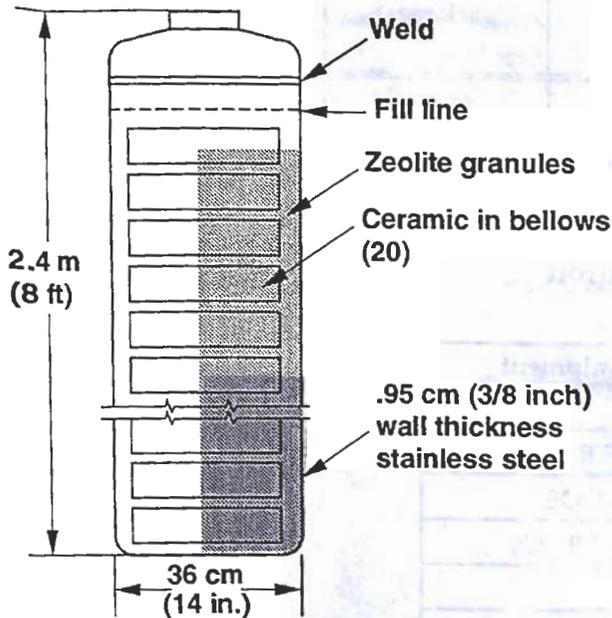
Average material storage container	Quantity Pu/ yr	Quantity Pu/ Campaign	# packages/ yr (6M/2R-like + pit packages)	Total # packages (6M/2R-like + pit packages)	SST shipments/ yr	SSTs shipment/ campaign
4.5 kg (9.9 lb)	5,000 kg (11,000 lb)	50,000 kg (110,000 lb)	3,100	31,000	110	1,100

Table 3. Parameters for intersite transportation segment #2.

Data	¹³⁷ CsCl shipment
Packaging	
Type	BUSS R-1
Certifying agency	NRC/DOE
Material weight /capsule	0.471 kg (1 lb) Cs
Capsules per packaging	10
Average shipping volumes	
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
Routing	
Mode of transport	Commercial rail or truck

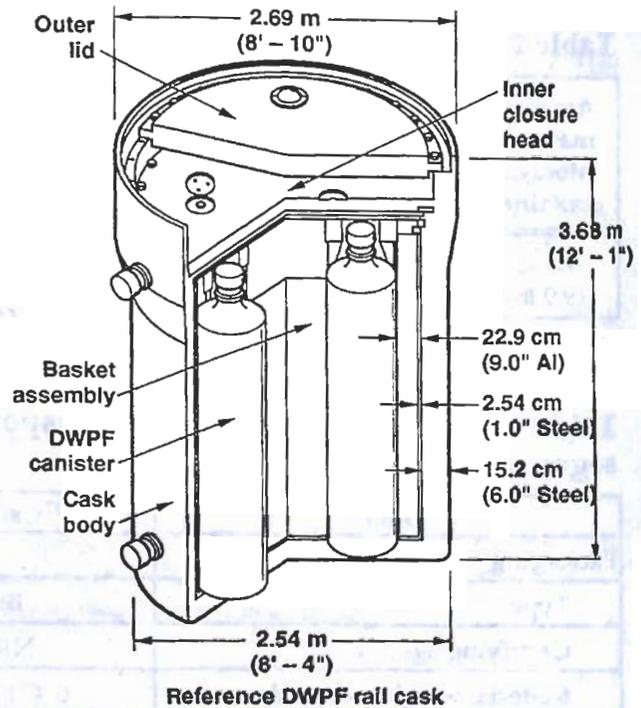
Package Description. DOE is currently developing a stainless steel canister for the Defense Waste Processing Facility (DWPF) to encapsulate defense high-level waste (DHLW) in borosilicate glass for emplacement in HLW repository. A modified version of the DWPF canister (CGF canister) is shown in Figure 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 ¹³⁷ Cs
Packaging	
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)
Average shipping volumes	
Quantity material/yr	42,000 kg (92000 lb)
Shipments/yr	13
Canisters for life of project	640
Routing	
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).

3 International Safeguards and Nonproliferation

The responsibility of the international regime is to prevent the host country from diverting, retrieving, or converting material that has been declared surplus. Thus, the context of safeguards and security should be viewed not only from the U.S. DOE perspective, but from the perspective of another country looking at the United States.

The international threats can be condensed as: *diversion* (unauthorized removal of material by the host nation itself in violation of the international regime before final disposition has taken place); *retrieval* (unauthorized access by the host nation in violation of the international regime after final disposition); and *conversion* (the conversion of retrieved material into weapons usable form).

This area includes FMDP activities that may be affected by international or bilateral agreements, including areas subject to the International Atomic Energy Agency (IAEA). International safeguards comprise two subsystems: nuclear materials accountancy; and materials containment and surveillance both of which are required to satisfy international inspection agreements. International safeguards and security is focused on the independent verification of material use through material accountancy programs, and containment and surveillance systems.

The IAEA has established safeguards criteria for the materials control and accountability and the containment and surveillance of fissile material. The requirements in this area are derived from IAEA statutes and informational circulars. The IAEA, in concert with member states (most notably the United States) has also developed recommendations for states to develop appropriate domestic security measures, but they are recommendations, and not audited requirements. The safeguards criteria and security recommendations are typically based on practices followed in the United States and agreed upon by the IAEA member states.

Domestically, the DOE and NRC are the safeguards and security "policing agencies," depending upon jurisdiction. However, internationally there is no direct police organization for domestic safeguards and security. Specifically, the IAEA has no jurisdiction or obligation to oversee the measures taken by a state (or host nation) to address unauthorized access to special nuclear material (Criteria 1). In this alternative it is assumed that all facilities except the plutonium processing facility will be subject to IAEA safeguards. Depending on agreements that would be made, between the United States and the IAEA, part of the plutonium processing facility may come under IAEA safeguards. The key issue here being the protection of classified information known as Restricted Data (nuclear weapons design information).

1.5.4 Process Description for Disposal of Plutonium Wastes in a HLW Repository

The repository facility is for permanent disposal of plutonium waste forms, a surface facility (Figure 10) for receipt and handling of wastes, and a subsurface facility (Figure 11) for permanent isolation of the wastes from the accessible environment. The surface facility contains two separate areas: (1) an operations area containing all the

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

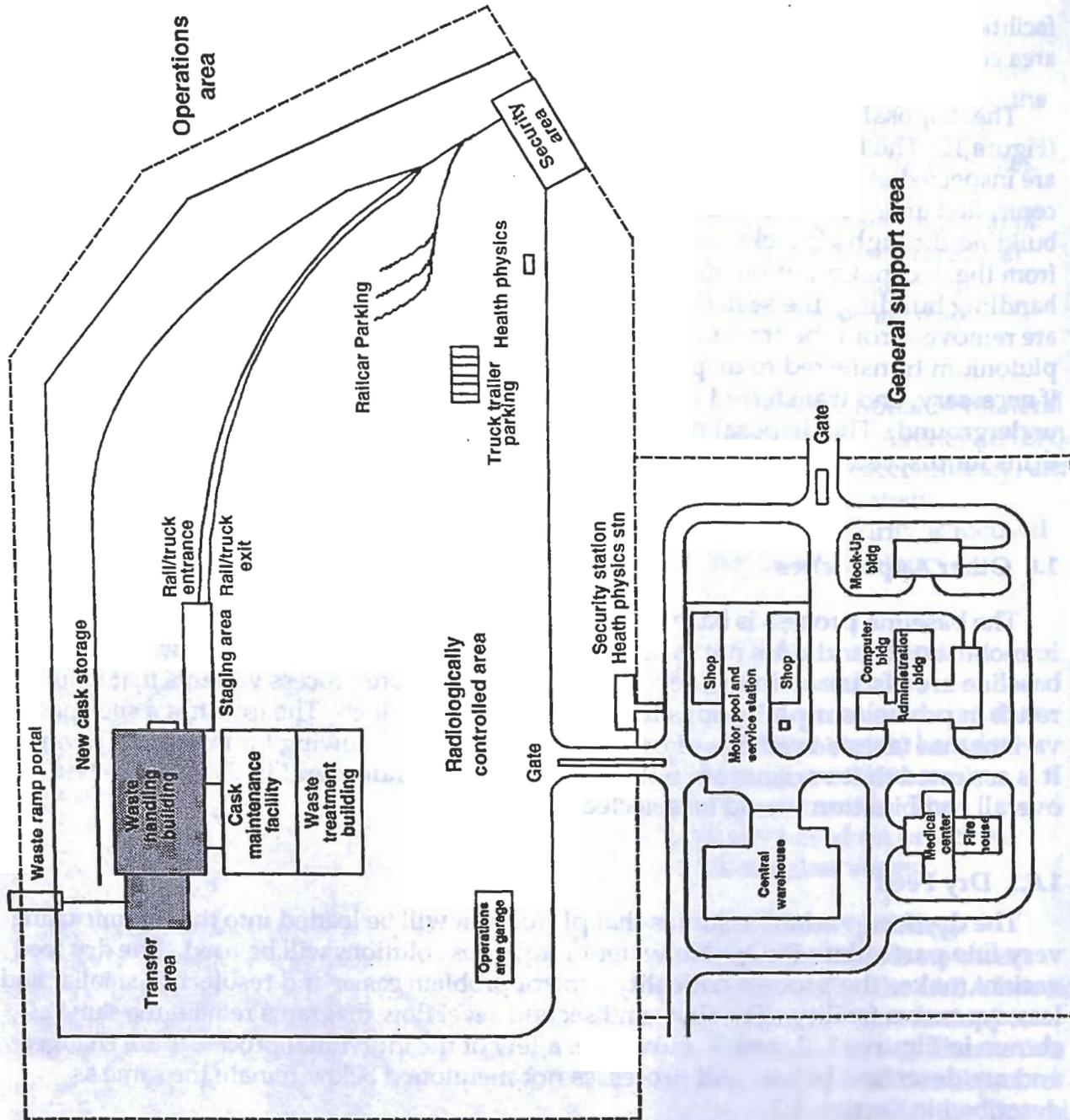
The baseline process is based on the best demonstrated data for ceramic immobilization and does not take credit for any existing facilities. Variants of the baseline are discussed in this section. The first three are process variants that would result in process simplifications and potential cost savings. 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 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.

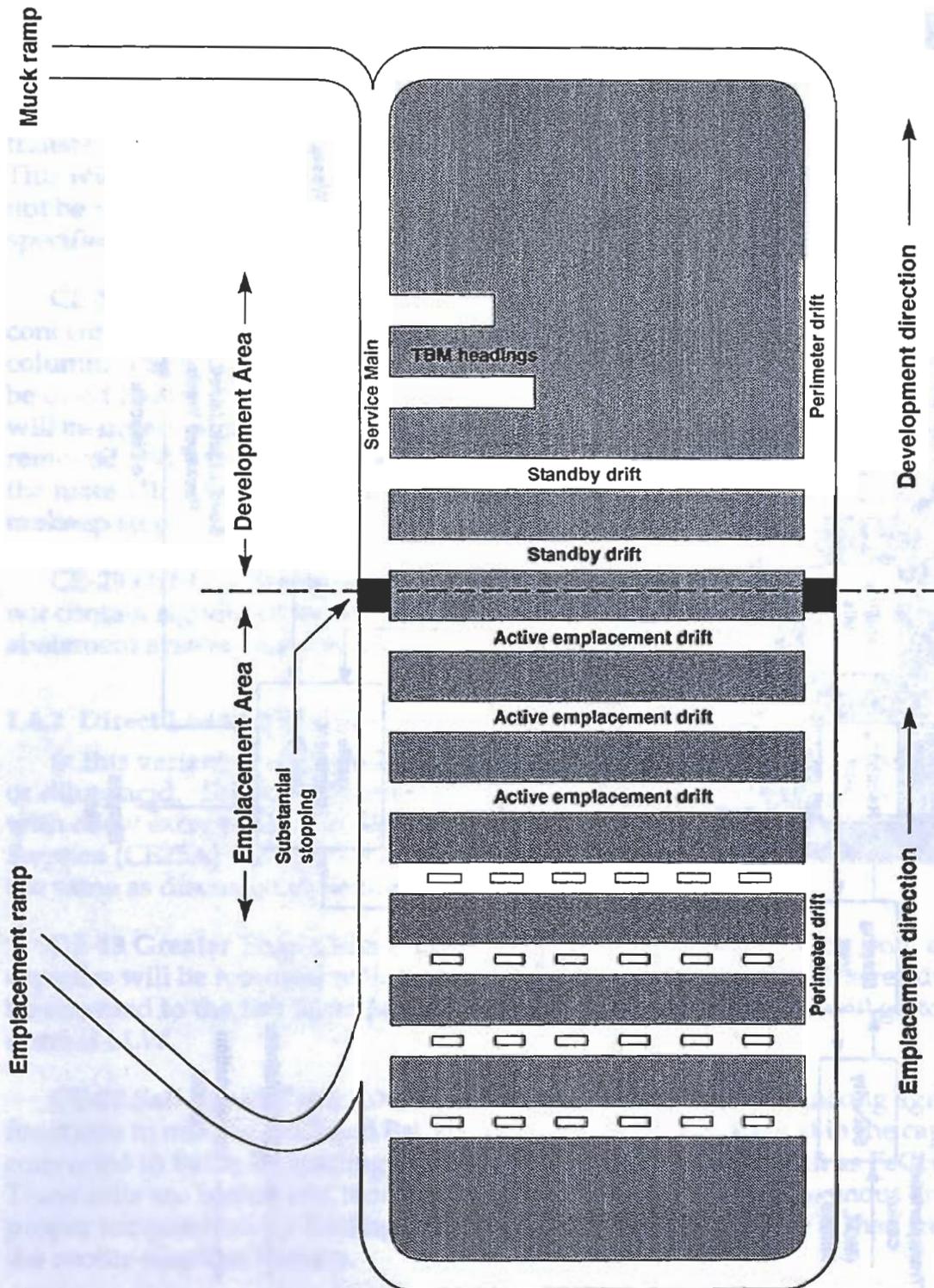
CE-01 Feed Preparation. Incoming PuO_2 powder will be size reduced by vibramilling to meet specifications for ceramic immobilization processes. Ground oxide powder will be checked to see if particle size meets specification before transferring to calciner feed makeup. Size characterization will be determined by an appropriate technique such as BET, SEM, or microsieving.

CE-02 Calciner Feed Makeup. PuO_2 powder will be dry blended with ceramic precursors and dried titanate resin loaded with radioactive cesium. Neutron absorber



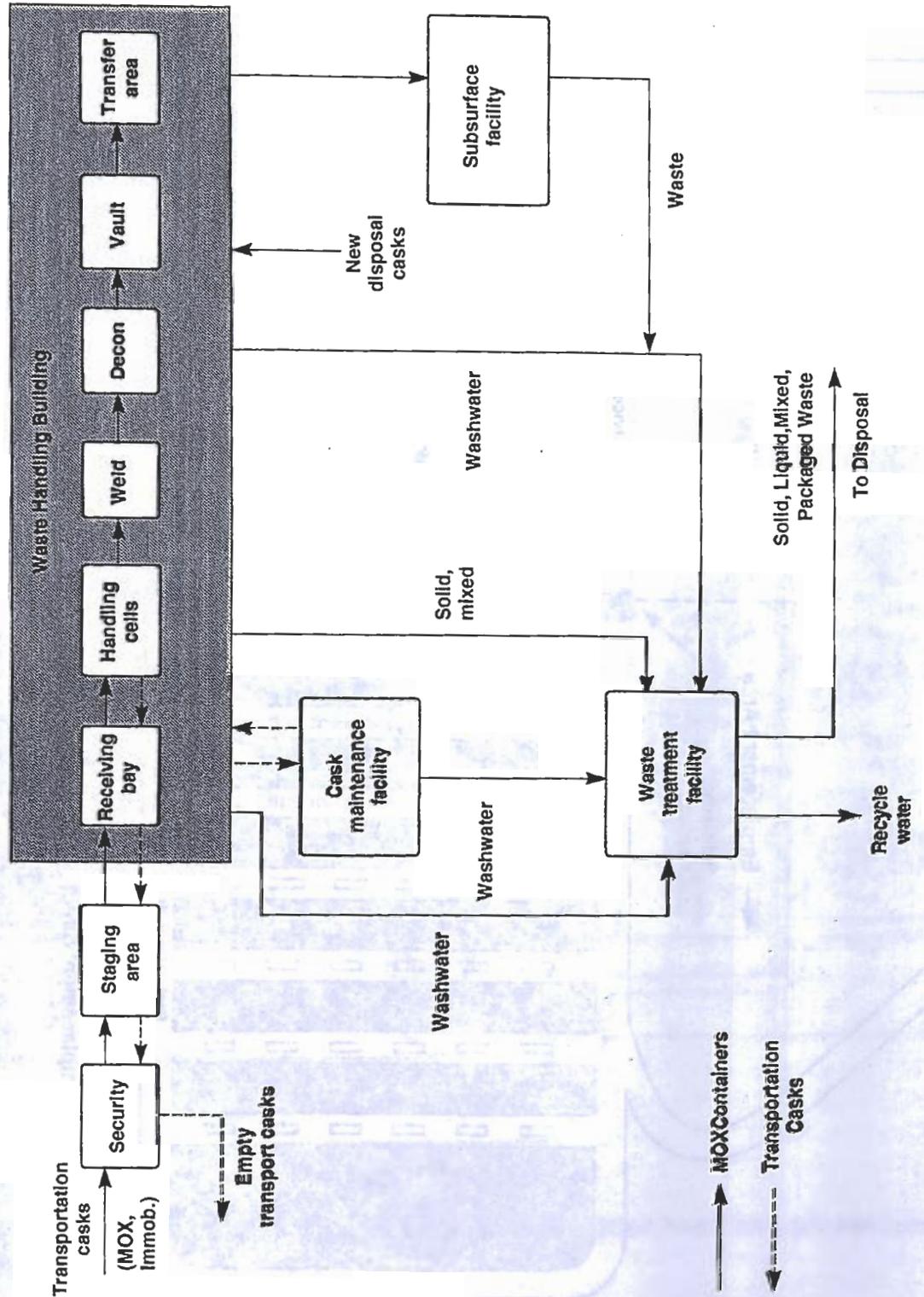
10.0.0895.1991pb01

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



10.0.0895.1989pb01

Figure 11. Conceptual layout for isolation of plutonium waste forms.



10.0.0895.1990 pb01

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 ¹³⁷Cs 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_x. 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 BaCl₂ into the salt matrix. Ba metal in the capsules is converted to BaCl₂ by reacting with a mild chlorinating agent such as FeCl₃ or UCl₄. 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.

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_x . Consequently, no recycling or abatement systems are needed.

1.6.3 Cold Press and Sinter

The cold press and sinter variant assumes that a cold pressing and sintering process will be used to fabricate the ceramic waste form rather than a hot-pressing method. One significant difference is that some pellet failures are expected at the cold pressing and the sintering steps. The first-level flow diagram remains the same, but the second-level flow diagram revises slightly. The following changes are made to the baseline flow diagram (Figure 3): *Milling and Granulation* (CE-14) replaces *Bellows Filling and Closure* (CE-04); and *Pellet Pressing* (CE-15), *Screening/Inspection* (CD-16), and *Sintering* (CE-17), replace *Hot Pressing* (CE-05). To accommodate failed pellets, *Crushing and Milling* (CE-18) is added between *Screening/Inspection* (CE-16) and *Milling and Granulation* (CE-14). All other processes are the same as described for the baseline process unless otherwise specified in the descriptions below. Even though the cold press and sinter option has more process steps, the facility size is not changed significantly. The major advantage of the cold press and sinter option is increased throughput. One hot press can accommodate about 0.5 kg (1.1 lb) of plutonium an hour whereas an automated cold press can easily process 12.2 kg (27 lb) of plutonium an hour.

CE-03 Dry and Calcine. The drying and calcining will be conducted in a rotating tank inside a high-temperature furnace (i.e., rotary calciner). The tank is the same size and dimensions as that used for the calciner feed makeup. The tank will also have veins inside to help stirring. If desired, the process could be conducted in the same tank as the calciner feed makeup. In this case, the furnaces are turned on but the material is not moved. Alternatively, the slurry from the Calciner Feed Makeup will be poured into the Drying and Calcining tank. Additional water will be used as necessary to wash away any holdup from the slurry tank. The slurry will first be heated to around 150°C (300°F) to remove bulk water. The temperature will then be increased to between 650°C (1200°F) and 850°C (1560°F) to dry and calcine the material. A binder material will be added and the furnace will then be allowed to cool. Calcination will be conducted under a flush of air or argon while the furnace is rotating.

CE-07 Canister Loading. The 1-in. diameter by 1/2-in. high ceramic pellets are poured into a 36-cm (14 in.)-diameter by 2.4-m (8 ft)-long canister. TiO_2 granules are also added to serve as a filler and packing material. The outside of the canister should receive little or no contamination during the process. After loading, the canister will be decontaminated if necessary.

CE-15 Pellet Pressing. The dried and calcined ceramic precursor material loaded with plutonium will be carefully poured into a feeder hopper, which will deliver the oxide material into an automated pressing machine. Pellet size will be about 3.6 cm (1.4 in.) diameter by 1.8 cm (0.70 in.) high in the green (presintered) state. Pellets will be pressed at a load of about 5 tonnes (6 tons) and at a rate of about 60 per minute. Presse

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_x. 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.

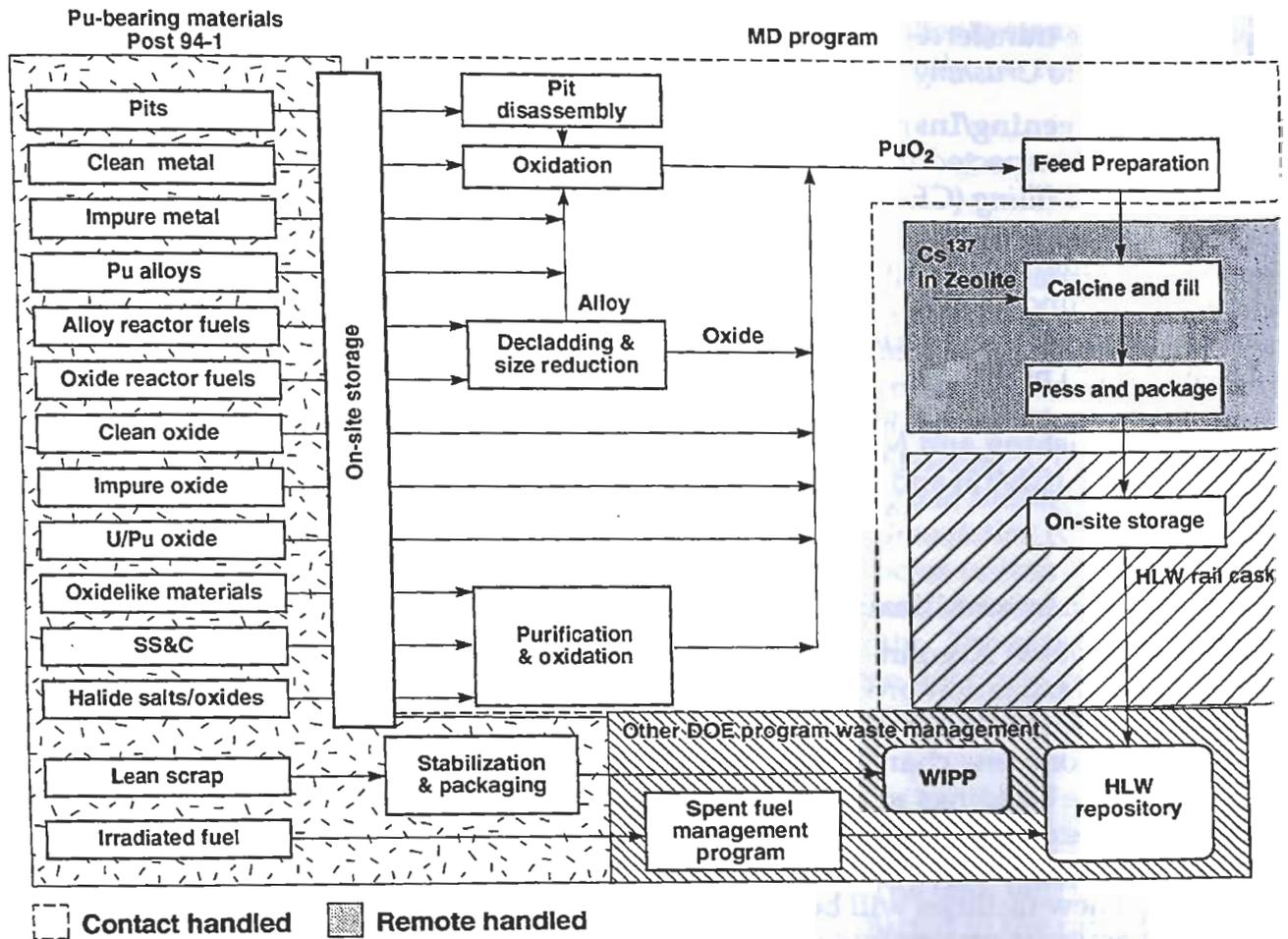


Figure 13. First-level flow diagram end-to-end ceramic variant at ANL-W.

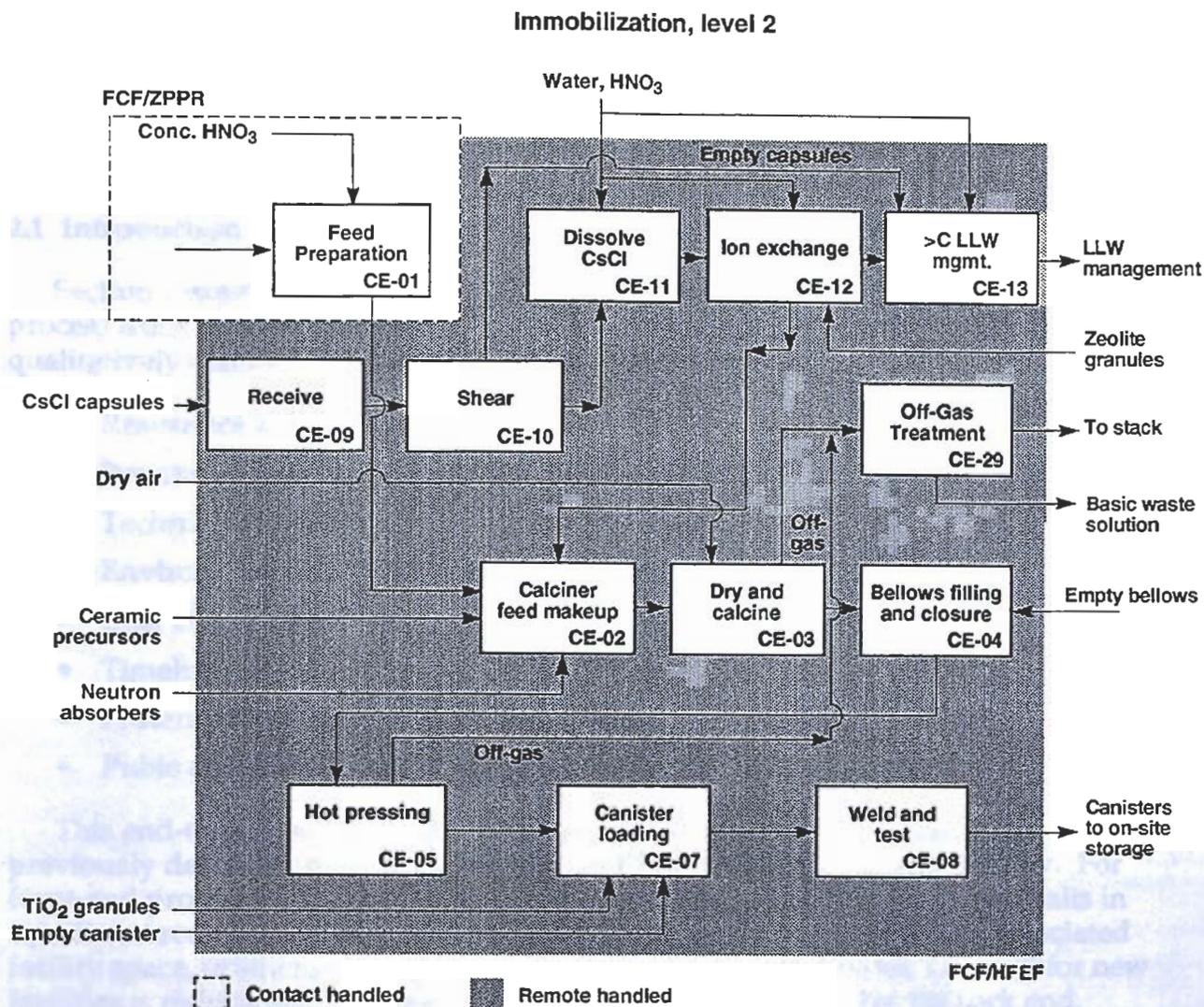
CE-02 Calciner Feed Makeup. Same as baseline or variants. Process will be performed in air cells in the FCF or HFEF.

CE-03 Dry and Calcine. Same as baseline or variants. Process will be performed in air cells in the FCF or HFEF.

CE-04 Bellows, Filling and Closure. Same as baseline or variants except bellows hot pressing will be 25 cm (10 in.) in diameter and about 13 cm (5-1/4 in.) in length. Process will be performed in the argon cell of the FCF or HFEF.

CE-05 Hot Pressing. Same as baseline or variants except as noted above that the bellows is 25 cm (10 in.) in diameter rather than 30 cm (12 in.) in diameter. Process will be performed in the argon cell of the FCF or HFEF.

CE-10 Shear Capsules. Same as baseline or other variants. Process will be performed in the air cell in the FCF or HFEF.



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Figure 14. Second-level flow diagram—ceramic variant at ANL-W.

CE-11 Dissolve CsCl. Same as baseline or other variants. Process will be performed in the air cell in the FCF or HFEF.

CE-12 Ion Exchange. Same as baseline or variants. Process will be performed in the air cell in the FCF or HFEF.

CE-13 Greater Than Class C LLW Management. Same as baseline or variants. Process will be performed in the air cell in the FCF or HFEF.

CE-29 Off-Gas Treatment. Same as baseline or variants. New or upgraded system will be required.

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 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

CP-14 Dissolve Cell. Same as previous or other variants. Prices will be the same as for CP or HCP.

CP-14 Dissolve Cell. Same as previous or other variants. Prices will be the same as for CP or HCP.

CP-14 Dissolve Cell. Same as previous or other variants. Prices will be the same as for CP or HCP.

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CP-14 Dissolve Cell. Same as previous or other variants. Prices will be the same as for CP or HCP.

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 ^a
WEAPONS Assembled weapons and test devices	A	All quantities	N/A	N/A	N/A
PURE PRODUCTS 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)
HIGH-GRADE MATERIAL Carbides, oxides, solutions (≥25 g/l) nitrates, etc., fuel, elements and assemblies, alloys and mixtures, UF ₄ or UF ₆ (≥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)
LOW-GRADE MATERIAL Solutions (1–25 g/l), process residues requiring extensive reprocessing, moderately irradiated material, Pu-238 (except waste), UF ₄ or UF ₆ (≥20% < 50% U-235)	D	N/A	≥16 kg (≥35 lb)	≥3 <16 kg (>6.6 <35 lb)	<3 kg (<6.6 lb)
ALL OTHER MATERIALS 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

^a 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.) x 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 (¹³⁷Cs), 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
Threat					
Covert Threat	High	High-Medium	Low	Low	Low
Overt Threat	Medium	Medium	Low	Low	Low
Diversion	High	High-Medium	Low	Low	Low
Criteria 1					
Material Form	High	High-Medium	Low	Low	Low
Environment	Medium Low	Medium	Low	Low	Low
Safeguards and Security	High	High-Medium	Low	Low	Low
Criteria 2					
Detection	High	High-Medium	Medium	Medium	Low
Irreversibility	High	High-Medium	Medium	Medium	Low

Environmental Conditions—the logistics, physical location, and the state during processing, transportation, or storage affect the opportunities for theft. When the logistics are complex (e.g., transfers and process locations), there are more opportunities for theft. The more inaccessible the physical location (e.g., storage locations), the fewer opportunities for theft. Table 6 summarizes the safeguards and security environmental data.

Plutonium Processing Area. This area involves a large number of processing steps with a relatively high throughput. Based on the quantity and attractiveness of the material, this will be a Category I facility. Waste streams containing fissile material will be generated and thus will require monitoring to prevent possible theft or use as a diversion path. There will be lag storage in a active vault. There will be no intrasite transport movements (i.e., outside of the facility). Safe secure transport/trailers will be used to deliver and pick up the material. Although operations for a single batch are relatively short, there will be a large number of batches needed to meet the proposed throughput obligations, and therefore the opportunities for possible adversary actions are numerous.

Ceramic Processing Area. The initial environment for the ceramic processing area is very similar to that of the plutonium processing. This will be a Category I facility with a high throughput and a nearly continuous operation. Safe secure transport/trailers will be used to deliver the material, but not for the lower-attractiveness material leaving the facility. No intrasite transport will be required outside the MAA. Waste streams containing fissile material will be generated during processing activities.

Once the material has been immobilized, it will be stored in a separate location (Category IV-E) and the only transport will involve moving the assemblies from the storage area to the repository. No fissile material waste streams are generated in storage.

Repository. In the surface staging area the canisters are removed from the transport casks and placed into disposal casks. The disposal casks at some later time 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. The sealed doors are what secure the drift and waste packages; final "securing" will not occur until the end of the performance period (currently expected to be 100 years from start of emplacement).

Material Form—attractiveness based on physical, chemical, or nuclear (isotopic and radiological) makeup of the nuclear material during processing, transportation, or storage. The risk of theft for weapon use is reduced if the material is only available in small quantities, the physical and chemical form of the material or matrix that makes recovery difficult, or the material has an unattractive isotopic composition. Table 7 summarizes safeguards and security form data.

Plutonium Processing Area. The material received at the plutonium processing area is the most attractive material in this alternative (e.g., pits, pure metal, and oxide). In the

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

Atomic Energy Agency (IAEA) categories of unirradiated direct use. Some of the other fissile material in the FMDP are not considered by the IAEA. The only existing worldwide inspection regime that exists to address this threat is the IAEA. One mission of the IAEA is timely detection of the diversion of nuclear material from declared nuclear activities. An important measure used by the IAEA is the "significant quantity," which is 8 kg (18 lb) for plutonium. Since the state owns and operates the physical protection and material control and accountancy measures, the IAEA does not rely on these systems to fulfill their obligations. However, IAEA does independent verification of the data from the state's system of material control and accountancy. The IAEA, in performing its safeguards inspection activities, audits the facility records and makes independent measurements of selected samples of each kind of nuclear material in the facility. To help them fulfill their responsibilities, this verification is coupled with a technology known as containment and surveillance, which is designed to provide "continuity of knowledge" during inspector absence. Much of the containment/surveillance equipment used by the IAEA is very similar in technology, and in some cases nearly identical, to the seals and surveillance equipment used by national authorities in physical protection functions. Although the technologies may be the same, the objectives are different. For example, domestic requirements are usually monitored in real, or near-real, time. However, the IAEA may use unattended monitors (CCTV recording, etc.) and return to a site only once every 3 months to check and verify activities.

The philosophies and implementation of international safeguards (commonly referred to as IAEA safeguards) are substantially different from domestic safeguards and security (as DOE and NRC practice). It is likely that these activities will require additional accountability verification (e.g., identification, weighing, sampling and analysis and nondestructive assay), increased inventories and item checks, containment/surveillance measures installed throughout the facilities (e.g., surveillance, seals, monitors, tags), and space for inspectors and equipment for independent measurements by international inspectors. Additionally, classified and other sensitive information may need to be protected differently than what might currently be implemented, because of the presence of IAEA uncleared foreign national inspectors. Under current laws certain information cannot be divulged to IAEA inspectors (e.g., disclosure of weapons design information violates the Atomic Energy Act and the 1978 Nuclear Nonproliferation Act). Therefore at least part of these facilities may not be under international safeguards, therefore verification by the IAEA is not possible, until agreements between the IAEA and the United States can be accomplished. A number of different options that are being considered address this problem.

2.3.2 Possible Diversion, Reuse, and Retrieval Risks

As previously mentioned, the threat for this criteria is the host nation. Although the host nation may choose to use overt measures to obtain material, the greatest concern is with covert diversion and retrieval. Because the state has responsibility for physical protection and material control and accountability, the IAEA will independently verify material accounting. Containment and surveillance is used to complement the materi

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.

Plutonium Processing Area. This area involves very attractive material and high throughputs. The accessibility of the material, low intrinsic barriers and the large number of processing steps makes the risk to possible diversion a concern. Once the material has been diverted the pure metal and oxide could be reused in a nuclear device relatively easily. Because pits and other material in this facility are classified, they would not be under international safeguards unless restricted data could be protected.

Ceramic Processing Area. The attractiveness of the material in the early processing steps is similar to the plutonium processing activities. When the material is blended, the concentration of plutonium is decreased and a much greater quantity of material would need to be diverted. Once the material is blended and placed into assemblies, the material becomes more difficult to divert. If diversion does occur, chemical barriers exist to make conversion and reuse expensive and time consuming.

Once the material has been given the radiological barrier, handling the material becomes more difficult and thus the risk of diversion and reuse are lower (spent fuel standard).

Repository. The high radiological barrier coupled with storage of the material in massive casks in a deep geologic repository makes diversion very difficult, expensive, and easily detected by containment/surveillance measures. Even if the material could be diverted, a considerable effort would be required to convert this material into a weapons usable form.

Assurance of Detection of Retrieval and Extraction. The difficulty of detection or diversion of a significant quantity of material. This depends on the following factors:

- Ability to measure material, which includes processing that is underway, accuracy of applicable nondestructive assay techniques, the presence of waste streams, and classification issues which may prohibit measurement, and whether item accountancy instead of bulk accountancy methods can be applied.
- Containment and surveillance systems.
- Timeliness of detection.

Plutonium Processing Area. This area will involve large quantities of bulk material and very high throughputs. This makes material accountability very difficult and in some ways inadequate for the IAEA requirements. It will be necessary to have containment/surveillance, as well as other safeguards and security measures, to ensure that material is not being diverted. The presence of classified material/information further complicates safeguards with respect to international inspection.

Ceramic Fabrication Area. The problems discussed with the plutonium processing area (except there is no classified material) exist in the initial operations in this facility. After the material has been blended, a greater amount of material will be required to accumulate a significant quantity. Once it has been placed into assemblies, the

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/m²-d (10^{-8} – 10^{-11} lb/yd²-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/m²-d (10^{-9} lb/yd²-d). Initial tests with gadolinium show that the leach rate is around 10^{-4} g/m²-d (10^{-7} lb/yd²-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; 5.8×10^{-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.

DC-06 Hydride/Dehydride/Oxidation. This process has been demonstrated in operation on both a full-scale and engineering test scale at Lawrence Livermore National Laboratory. Hemishells for returned weapons pits have been produced through the separate steps sufficiently to demonstrate operational and design, however, combined operation in a single production unit is still required. Current experiments with oxides produced by hydride/dehydride/oxidation from a pit are in process at Lawrence Livermore National Laboratory.

DC-07 Calcination and Passivation Furnace. The calcination-passivation is basically a muffle-type furnace that is commercially available. Plutonium-bearing materials (e.g., glove box floor sweepings) have been oxidized in this type furnace many years throughout the DOE complex.

DC-08 HEU Decontamination. HEU parts have been decontaminated by washing at Rocky Flats on a production-scale for several years. Los Alamos National Laboratory is developing an electrolytic process that is expected to significantly reduce the generation of liquid waste. Feasibility of the process has been demonstrated at laboratory-scale, but requires demonstration on a production scale.

Most of the processes used in the front end are on the industrialization scale. Remaining technologies are in the engineering-scale testing or transitioning to industrialization stage.

DC-09 Fuel Decladding. These operations are currently used in industrial-scale processes.

DC-10 Size Reduction. Size reduction of plutonium oxide utilizes vibratory grinding, which is a standard operation in commercial industry. Plutonium size reduction has been performed on production-scale in the manufacture of mixed oxide fuel (plutonium/uranium oxide fuel).

DC-11 In-Process Storage. This interim lag storage will be similar to the storage techniques used in DOE complex facilities for many years.

2.4.2 Technical Viability of Back-End Ceramic Immobilization

The immobilization back-end process prepares the front-end plutonium feed for mixing with the radioactive cesium spiking agent, calcines the plutonium feed, and hot presses that product into a ceramic waste form suitable to send to a geologic repository. The major unit operations are Feed Preparation (CE-01), Feed Makeup (CE-02), Dry and Calcine (CE-03), Hot Pressing (CE-05), and Ion Exchange (CE-12).

CE-01 Feed Preparation. This oxide dissolution process has been demonstrated world wide on a production scale for a number of years. Dissolution of plutonium oxide in nitric acid solutions with HF is a standard process in the DOE weapons complex.

CE-02 Calciner Feed Makeup. In this process, the plutonium nitrate solutions is blended with a soluble neutron absorber and ceramic precursors. ANSTO has demonstrated the process at full scale using simulated HLW solutions. This process has also been demonstrated at small scale at LLNL, ANSTO, and other laboratories to make actinide loaded ceramics, which are homogenous and fully reacted.

CE-03 Dry and Calcine. In this process, the blended slurry from the feed makeup step is dried and calcined. ANSTO has demonstrated this process at full scale using HLW simulates. Process has also been demonstrated at small and moderate scales at LLNL, ANSTO, and other laboratories to make actinide loaded ceramics.

CE-05 Hot Pressing. This step has been demonstrated at production scale using simulated HLW. Scale of the process was approximately 30 kg (66 lb) ceramics hot pressed in 30-cm-(12 in.) diameter bellows. Scale of processes in the ceramic greenfield facility closely follows the demonstrated scale of the SYNROC demonstration plant at ANSTO. The demonstrated fabrication rate was 10 kg/hr (22 lb/hr), which vastly exceeds that proposed in this alternative. Although ceramic immobilization has been demonstrated at full scale using surrogates, large-scale demonstration of the process using plutonium and neutron absorbers is still needed.

CE-12 Ion Exchange. This process has been demonstrated at the laboratory scale using ppm-level cesium solutions. To maximize product durability, radioactive cesium in the CsCl capsules will need to be separated from the chloride ions. This will be accomplished using and inorganic ion exchange resin, which will preferentially extract the cesium from an aqueous solution containing the dissolved contents of the capsules. The loaded resin will then be washed or dried and used as feed in ceramic fabrication process. Chlorine will not be absorbed onto the resin and if some of the barium decay product is extracted from solution and onto the resin, it will have no effect on the product ceramic since it already contains barium. A particular class of titanate-based inorganic ion exchange resins have been demonstrated to extract cesium and strontium selectively from HLW solutions with decontamination factors around 10^4 ml/g (10^3 gal/lb) from ppm-level aqueous solutions. These zeolite-like materials are called crystalline silicotitanates, and they are a compatible feed material to the ceramic immobilization process. Cesium loadings up to 1% are easily obtained. Only 0.15% ^{137}Cs is required in the final product.

Dry Feed. For dry feed, the PuO_2 input specifications and the processing conditions to obtain fully reacted, homogenous, and dense products are not known. It is expected that particle size requirements for the input PuO_2 powder will require that its size is around 1 micron or less and preferably not high fired. Obtaining good product homogeneity and density is not expected to be a problem. Obtaining complete reaction may require longer hot pressing times or additional heat treatment, but will be achievable if the input PuO_2 particle size is sufficiently small. As long as the product is fully reacted, product durability will remain unchanged.

Direct Loading of CsCl. It is not known quantitatively how the amount of chloride in the waste form will affect durability. Direct loading CsCl to make the waste form is

similar to work at ANL to make HLW chloride waste forms using zeolites. An additional concern is the volatilization of CsCl in the drying and calcining and hot pressing steps.

Cold Press and Sinter. There are a few significant differences in the cold press and sinter approach. The precursor material will be more coarse. Precursor particle size will be optimized to obtain maximum product densities, which will be between 90 and 95% but not greater than 98% as obtained with hot pressing. The cold press and sinter fabrication method has been demonstrated with considerable success at LLNL for making ceramic waste forms with a variety of RCRA metals and radioactive surrogates. Fabrication of plutonium-loaded ceramics by this method is just beginning. It is expected that ceramics made in this manner will initially be slightly less durable than hot pressed ceramics. It is expected, however, that the durability will probably be about the same after long time periods when the form has turned metamict.

ANL-W Option. Where the facilities at Argonne West are used, the process is similar to the baseline. With some modifications, the facility is more than adequate to accomplish the immobilization of 50 tonnes (55 tons) of plutonium in ceramic within the 10-year period.

2.4.3 Technical Viability—Repository Ceramic Greenfield Alternative

Regulatory Risk. Any waste form accepted for disposal in a HLW repository must comply with the provisions of the Nuclear Waste Policy Act (NWPA), as amended. According to Section 2(12)A of the NWPA, the definition of high-level waste does not explicitly include a ceramic form loaded with plutonium. However, under Section 2(12)B of the NWPA, the NRC has the authority to classify this waste form as high-level waste through rulemaking. Such rulemaking or clarification in the authorizing legislation will be necessary before this waste form can be considered for disposal in an NWPA repository. The final disposal of this waste form will have to follow the licensing provisions of 10 CFR Part 60 and the applicable NEPA process. Further, it is current policy of the DOE not to accept any wastes that include components regulated as hazardous under RCRA in the first HLW repository; absence of such RCRA regulated materials will have to be demonstrated prior to acceptance into the repository.

2.4.4 Technical Risk

The primary technical viability and risk issue related to the disposal of immobilized ceramic waste forms in a repository is associated with long-term performance. This is necessary to satisfy the licensing requirements of 10 CFR 60. The long-term performance issues are comprised of doses to a population in the accessible environment, and precluding criticality (as fabricated, degraded mode, and external) during all phases of the repository operation, including the period of isolation.

The contributions to dose by the ceramic waste form appears to be small compared to that predicted from uranium-based commercial spent fuel. However, the cumulative doses, from both the commercial spent fuel and the ceramic must be shown to be within

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_x 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_x 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
Baseline				
Up-front costs	858	950		1808
Other life cycle (10 yrs of operations) plus D&D	823	1722	320	2865
Total life cycle costs	1681	2672	320	4673
ANL-W variant				
Front-end costs	858	310		1168
Other life cycle (10 yrs of operations) plus D&D	823	1496	320	2639
Total life cycle costs	1681	1806	320	3807

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}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
"PREOPERATIONAL" OR "OPC" COSTS		
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	
"CAPITAL" OR "TPC" UP-FRONT COSTS (TEC)		
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	
TOTAL UP-FRONT (TPC) FOR BACK-END FACILITY		
	950	
OTHER LIFE CYCLE COSTS		
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 ¹³⁷ to facility	75	
24. Storage of Pu at existing 94-I site facility		
SUB OTHER LCC	1722	
TOTAL BACK-END LCC	2672	

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

End-to-end alternative	Cost 1995 \$M	Basis
"PREOPERATIONAL" OR "OPC" COSTS		
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	
"CAPITAL" OR "TPC" UP-FRONT COSTS (TEC)		
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	
OTHER LIFE CYCLE COSTS		
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 ¹³⁷ 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

Table 14a. Baseline front-end facility sche

Task no.	Task name	Duration
26	Title I Des and prep license appl. w/SAR	60w
27	NRC license application, NRC review process, NEPA/EIS, Title II des., NRC license, release for construction	1200d
28	KD#2- Start Title II Design	0d
29	Submit license application and Env. Rpt.	0d
30	NRC licensing	240w
31	NRC NEPA process	104w
32	NRC issues final EIS	0d
33	Title II Design	96w
34	NRC license	0d
35	Approval to commence construction	0d
36	KD#3/Release for Construction	0d
37	Construction, equipment installation, startup, test, ORR	1320d
38	Construction	240w
39	Procurement	138.4w
40	Equipment Installation	99.8w
41	Startup, Preop testing, ORR	48w
42	Operations	2400d
43	KD#4 Commence Operation	0d
44	Operation	480w
45	D&D	720d
46	D&D	144w

Note: Schedule durations are nominal, the detailed date and of the scheduling program calendar.

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

Table 15a. Baseline immobilization facility schedule breakout (cont.)

Task no.	Task name	Duration	Start date	Finish date	Predecessors
23	Submit license application and Env. Rpt.	0d	6/13/00	6/13/00	20,13
24	NRC licensing	240w	6/14/00	1/18/05	23
25	NRC NEPA process	104w	6/14/00	6/11/02	23
26	NRC issues final EIS	0d	6/11/02	6/11/02	25
27	Title II Design	96w	9/6/00	7/9/02	22
28	NRC license	0d	1/18/05	1/18/05	24,14
29	Approval to commence construction	0d	1/21/04	1/21/04	28FS-52w,27
30	KD#3/Release for Construction	0d	1/21/04	1/21/04	29
31	Construction, equipment installation, startup, test, ORR	1320d	1/21/04	2/10/09	
32	Construction	240w	1/21/04	8/26/08	30
33	Procurement	138.4w	1/21/04	9/14/06	30
34	Equipment Installation	99.8w	2/1/06	12/31/07	33FS-36w,11
35	Startup, Preop testing, ORR	48w	3/12/08	2/10/09	32FS-24w,34
36	Operations	2400d	2/10/09	4/24/18	
37	KD#4 Commence Operation	0d	2/10/09	2/10/09	35
38	Operation	480w	2/11/09	4/24/18	37
39	D&D	720d	5/24/17	2/25/20	
40	D&D	144w	5/24/17	2/25/20	38FS-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 15b. ANL/W variant 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	1845d	10/2/95	10/25/02	
9	Formulation, proc. and long term perf	175d	10/2/95	6/1/96	
10	Balance of R&D, demo and test	1044d	10/1/96	9/29/00	
11	Integrated prototyping and eng	108w	10/2/00	10/25/02	10
12	Conceptual design, NEPA, permitting	1660d	1/1/97	5/13/03	
13	Preferred site selection	48w	1/1/97	12/2/97	2
14	NEPA/EIS and site selection	660d	4/21/99	10/30/01	7,16
15	Permitting	320w	3/26/97	5/13/03	6,7
16	Conceptual Design	108w	3/26/97	4/20/99	6
17	Project authorization, Title I design, PSAR	780d	1/1/97	12/28/99	
18	KD#1 Approval for start	0d	1/1/97	1/1/97	2
19	Title I Authorization	0d	12/29/98	12/29/98	3
20	Title I Des and PSAR	36w	4/21/99	12/28/99	3,16
21	Documentation to DNFSB, review process, Title II des., FSAR, DNFSB release for construction	1200d	12/28/99	8/3/04	
22	KD#2- Start Title II Design	0d	10/30/01	10/30/01	4,14,20
23	Submit documentation to DNFSB	0d	12/28/99	12/28/99	20
24	DNFSB oversight process	240w	12/29/99	8/3/04	23
25	Title II Design and FSAR	60w	10/31/01	12/24/02	22
26	DNFSB approval/KD#3/Release for Construction	0d	8/6/03	8/6/03	24FS-52w

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.)

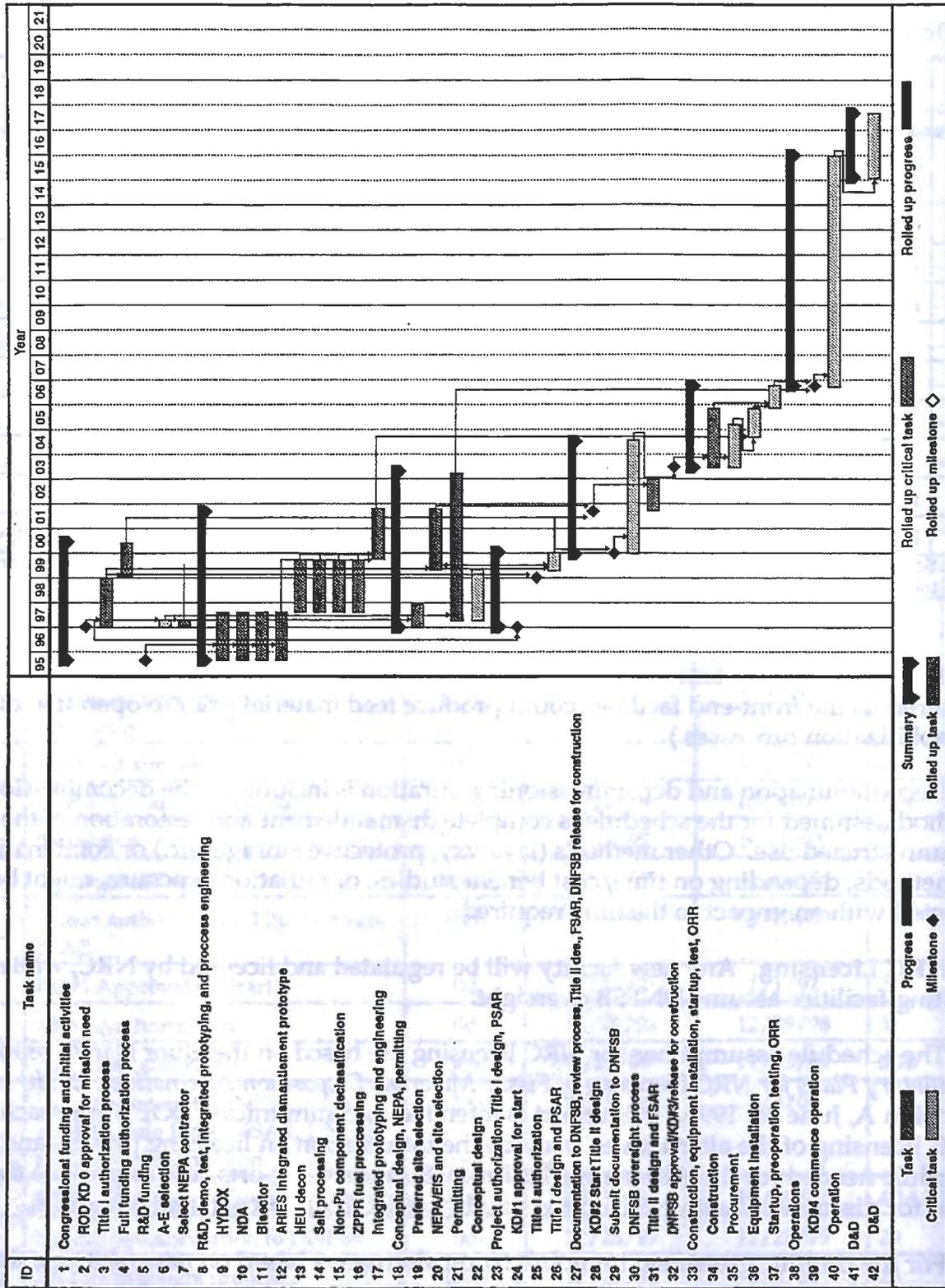
Decontamination and decommissioning duration is included. The decommissioning method assumed for the schedule is complete dismantlement and restoration of the site for unrestricted use. Other methods (layaway, protective storage, etc.) or combinations of methods, depending on time, cost benefit studies, 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.

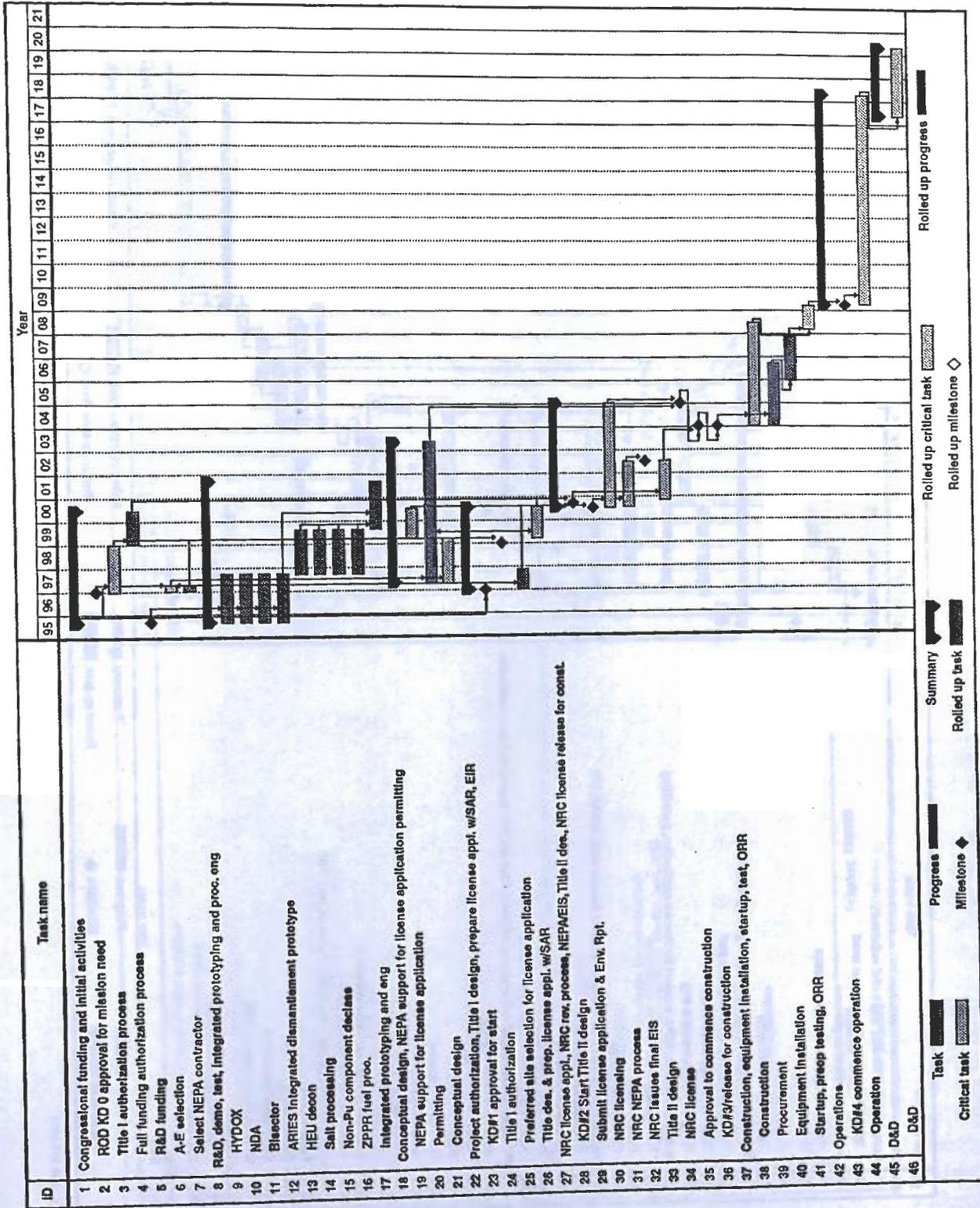
For the ceramic greenfield immobilization alternative based on new facilities, there are three distinct license types each with distinct issues to be addressed during the NRC licensing process. The types are:

- Processing, governed by 10 CFR Part 70.



10.0.0696.1926pb01

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



10.0.0896.1927p001

Figure 15b. ANL/W variant front-end processing schedule.

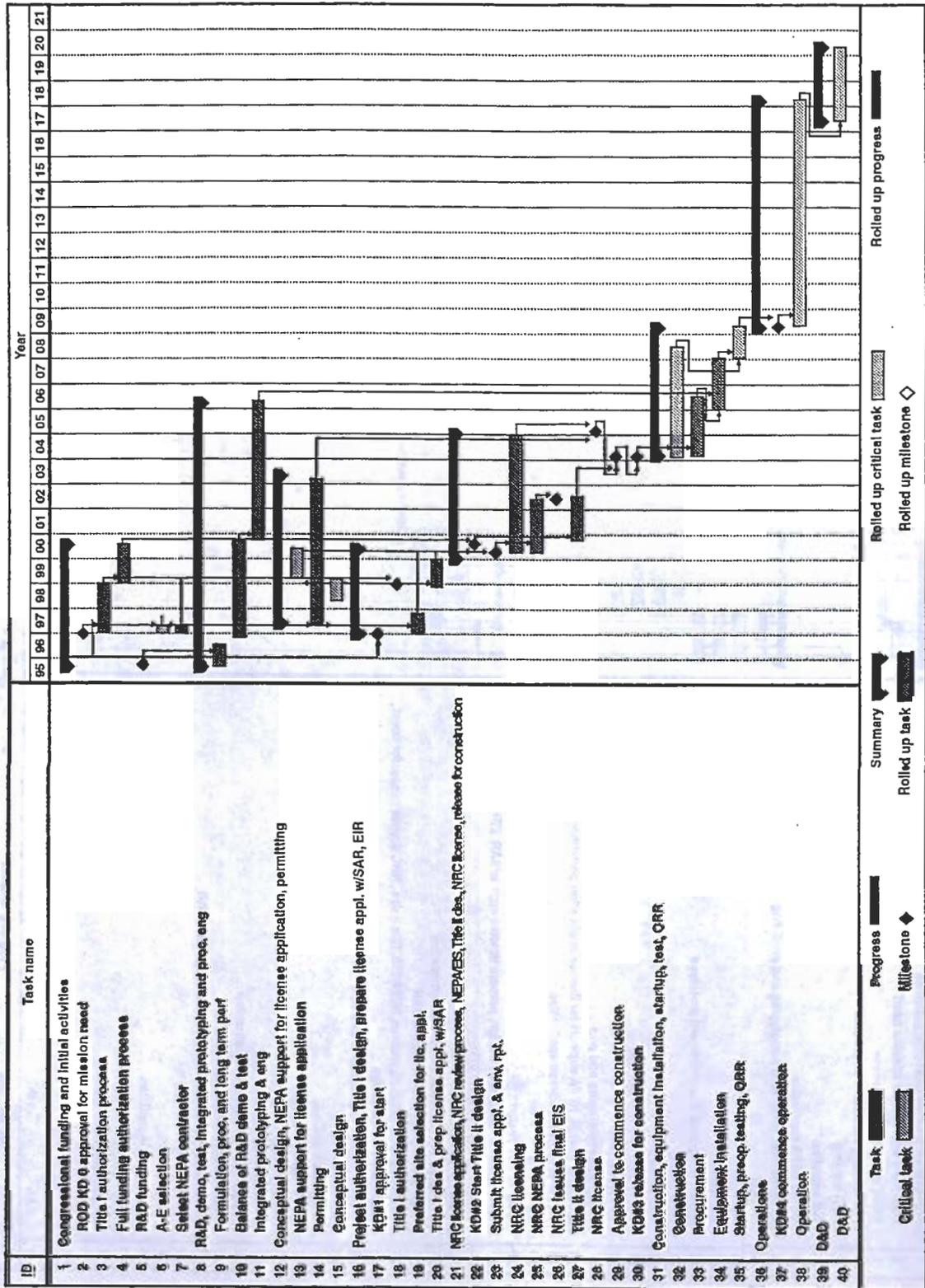


Figure 16a. Baseline back-end ceramic fabrication.

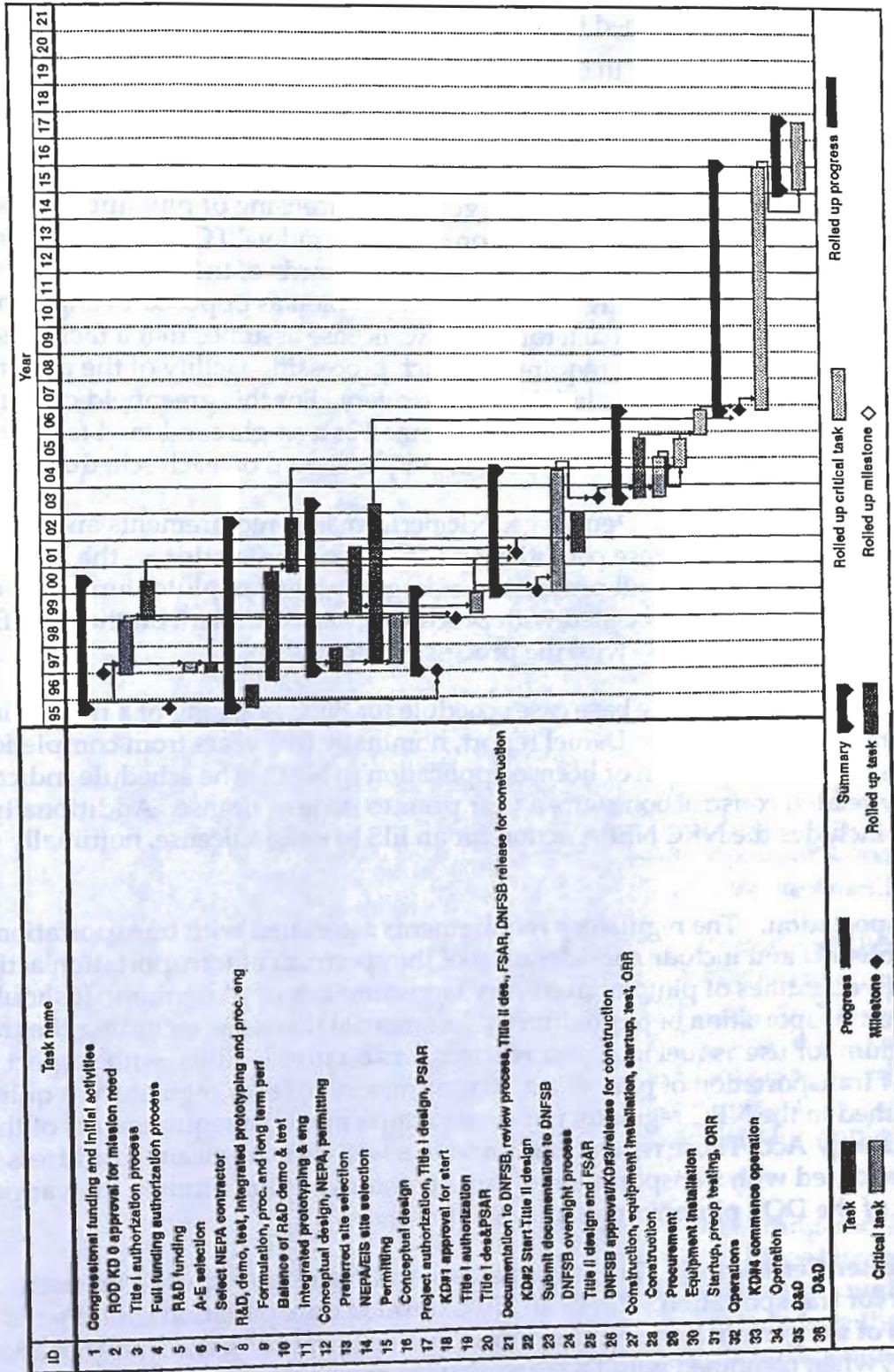


Figure 16b. ANL/W variant back-end ceramic fabrication.

- Transportation, governed by 10 CFR Part 71.
- Disposal, governed by 10 CFR Part 60.

A brief discussion of the license types, extracted from the Fluor Daniel report, and their impact on the schedule follows.

Processing. Since generic regulations governing licensing of plutonium processing facilities are not in place, facility-specific proceedings under 10 CFR Part 70 is probably the more efficient approach to address the specific hazards of the various types of processing facilities with limiting conditions of operation as opposed to engaging in a rulemaking process. The approach for this NRC license assumes that a facility-specific license under 10 CFR Part 70 is required for each processing facility of the preferred alternative. A hearing is likely, with broad discovery. For this greenfield case, the front-end and immobilization facilities are planned as a single combined facility, so one license is assumed, although the licensing activity is shown on each schedule.

The existing regulation system of generic performance requirements and development of specific license conditions provide a means to address the issues associated with possession and processing of large amounts of **plutonium**. The detailed regulatory requirements associated with processing are dependent on the specific activities and risks associated with the processing technology.

The schedule includes the base case schedule for NRC licensing of a processing facility presented in the Fluor Daniel report, nominally five years from completion of Title I design and submission of license application to NRC. The schedule indicates nonsafety related construction starts a year prior to issue of license. Additionally, the schedule includes the NRC NEPA action for an EIS to issue a license, nominally two years.

Transportation. The regulatory requirements associated with transportation are well established and include consideration of the spectrum of transportation activities from small quantities of plutonium to very large amounts of **plutonium**. It should be noted that transportation of plutonium by commercial licensees, including the transport of plutonium for use as fuel in power reactors, has occurred. Thus, with respect to the activity of transportation of plutonium, a comprehensive set of regulatory requirements is established in the NRC regulatory system to implement the requirements of the Atomic Energy Act. Those regulations provide a well defined means to address the issues associated with transportation of large amounts of plutonium in the various elements of the DOE plutonium disposition program.

Container Certification. The immobilization alternatives require a licensed container for transportation. Use of an NRC certified transportation container is a condition of the general license. The review and certification of the transportation container, when combined with DOT regulations regarding carriage, provides the means for the NRC to conclude that the means to transport the radioactive material does not compromise public health and safety. Transportation container certification is an independent licensing activity.

The Fluor Daniel report presents the base case schedule for NRC certification of a transportation container, which has a nominal two-year duration, based on required procedural steps. Although there is provision for a hearing, it is unlikely to occur since no one, single community or area is impacted by the certification of a transport cask.

This activity for certification of a transportation container is well within the nominal five-year NRC licensing application duration shown on the schedule.

A family of potential packages, 6M/2R-like packages, can be used for transporting the fissile material (excluding pits). These packages would require modification to insure that the package criteria stated in DOE-STD 3013-94 are met. Further modifications would be required to ensure the following: that the packaging configuration incorporates the PCV, analysis/testing is performed to show the abnormal and normal accident scenarios, the Safety Analysis Report (SAR) is modified to show the changes, and the package is certified for the material considering the packaging configuration.

Disposal. Following rulemaking or clarification in authorizing legislation for emplacing the immobilized forms in a HLW Repository, a license amendment will have to be submitted to NRC for these waste forms. Further, the NEPA process which incorporates these wastes into a repository will also have to be followed.

2.7.2 Uncertainties

The preliminary, estimated schedule presented in tabular form in Tables 15 and 16 and in Gantt chart form in Figure 15 and 16 is a logic network defined by activity durations and logical ties between them. As such, it lends itself to examination of the impacts in schedule variations. However, at this stage such analysis has not been done.

Permitting and Licensing. Any new facility will be regulated/licensed by NRC. However, DOE external oversight activities may influence the planning basis for these facilities. The Advisory Committee on External Regulation of DOE Nuclear facilities made recommendations to the Secretary on external regulation in early 1996. Recommendations from this committee will influence decisions on whether and what facilities will be regulated externally, and what external organization will be responsible. The DOE is currently preparing an action plan for implementing these recommendations.

Decisions on external regulation could impact the permitting and licensing schedule durations. Within the base assumption of NRC licensing, Fluor Daniel personnel indicate there may be opportunity to improve on the schedule through proactive identification of issues and active dialog with NRC to try to reduce the review time (their preliminary judgments indicate 4-6 month schedule improvements might be achieved). Since this is a five-year-long, key critical path activity, improvements would impact the overall disposition completion date.

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

fissile material would be mixed with high-level wastes or other radioactive isotopes and immobilized to create a radiation field that could serve as a proliferation deterrent comparable to commercial spent nuclear fuel.

However, we cannot pursue the problem of disposing of our tens of metric tons of excess U.S. separated plutonium in a vacuum. There is a very important international context:

- **Excess Russian Weapons Plutonium.** Russia has even more excess weapons plutonium than the U.S., and.
- **Separated Civil Plutonium.** Russia, Western Europe, Japan and India have in addition a combined total of about 91 tonnes (100 tons) of separated civilian, but weapons usable plutonium. This inventory is still increasing at a rate of 14 tonnes (15 tons) per year as the rate of separation of plutonium from power-reactor fuel still greatly exceeds the rate at which it is being fabricated into mixed-oxide fuel
- **Approximately 20% of the world's electricity today is generated in nuclear plants; since plutonium is produced as a by-product of this irradiation, the burning of plutonium begins very soon after the fuel rods are inserted into the reactor. As a result, nearly 50% of the heat and electricity generated in those reactors comes from the burning of plutonium.**

There currently appears to be little question in the minds of foreign nuclear energy establishments as to how they will dispose of their separated plutonium:

- **West Europe.** Virtually all plutonium separated from West European power reactor fuel is to be fabricated into MOX fuel for light-water power reactors;
- **Japan.** Most of the plutonium separated from Japanese power reactor fuel is to be similarly recycled into MOX fuel for light water reactors with the remainder being fabricated into MOX fuel for Japan's demonstration fast-neutron and advanced-converter reactors.
- **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 moved decisively to do so. Before the collapse of the Soviet Union, the plan was to use the civilian plutonium as startup fuel for a new generation of fast-neutron plutonium breeder reactors. That is still the plan of a significant part of Russia's nuclear establishment but it is not clear at this time where the funds to build these reactors would come from.

The international implications of U.S. plutonium disposition strategy deserves both analysis and public debate. A primary objective of the technical evaluation process will be to prepare the United States to engage Russia, and other nations with relevant interests and experience, in efforts that would lead to making reuse of the plutonium for 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

change over time. Currently, ES&H requirements set the pace for each stage of plutonium processing throughout the immobilization processes. The time required to implement any immobilization choice will be heavily influenced by the licensing and approval process, including the extended safety and environmental analysis required for each option. Ultimately, these ES&H standards will affect the ease and cost of achieving different immobilization options.

2.8.5 ANL-W Facilities

In the site-specific variant in this immobilization alternative, the facilities at ANL-W are used rather than entirely new facilities. This reduces cost and environmental impacts of building a new facility, but raises some programmatic institutional issues. The ANL-W facilities have been used primarily to support the fast breeder reactor Integral Fast Reactor (IFR) program. This program is now terminated, but the technology developed from this program is useful to treat spent nuclear fuel to create metal and glass-bonded zeolite waste forms (GBZ). The spent fuel that would likely be treated is from the EBR-II which is onsite and processing would be completed by 2000. However, the ceramic immobilization facility would not begin processing until around 2006. This leaves about six years where the facility has no mission and must be maintained. Several possibilities exist for use of the facility during this intermittent time. One is for treatment of spent fuel from other facilities besides EBR-II. Another is as an immobilization facility for creating glass ceramic or ceramic waste forms to immobilize INEL HLW calcine. The six year gap could also be reduced by accelerating startup of operations. In any case, significant coordination between the Spent Nuclear Fuel Program and the Fissile Materials Disposition Program will be needed.

3.0 Acronyms

ANL-W	Argonne National Laboratory-West
ALARA	As Low As Reasonably Achievable
ANSTO	Australian Nuclear Science and Technology Organisation
Ba	Barium
BaCl ₂	Barium chloride
CCC	Ceramic Can-in-Canister
C/S	Containment and Surveillance
CCTV	Closed Circuit Television
CFR	Code of Federal Regulations
CGF	Ceramic Greenfield Facility
CRT	Container Restraint Transport
CRWMS	Civilian Radioactive Waste Management System
Cs	cesium
CsCl	cesium chloride
DHLW	Defense High-Level Waste
DNFSB	Defense Nuclear Facilities Safety Board
DOE	Department of Energy
DOT	Department of Transportation
DP	Defense Programs
DWPF	Defense Waste Processing Facility @ SRS
EM	Environmental Management
ET	Electrometallurgical Treatment
EIS	Environmental Impact Statement
FCF	Fuel Conditioning Facility at ANL-W
FM	Fissile Materials
FMDP	Fissile Materials Disposition Program
FMF	Fuel Manufacturing Facility at ANL-W
GBZ	Glass Bonded zeolite
GMODS	Glass Materials Oxidation Dissolution System
Gy	Gray
HEME	High-Efficiency Mist Eliminator
HEPA	High-Efficiency Particulate Air (filter)

HEU	highly-enriched uranium
HFEF	Hot-Fuel Examination Facility @ ANL-W
HLW	High-Level Waste
HVAC	Heating, Ventilating, and Air Conditioning
IAEA	International Atomic Energy Agency
IFR	Integral Fast Reactor
INEL	Idaho National Engineering Laboratory
ISG	International Safeguards
LCC	Life-Cycle Costs
LLNL	Lawrence Livermore National Laboratory
LLW	Low-Level Waste
MAA	Materials Access Area
MAUA	Multi-Attribute Utility Analysis
MC&A	Materials Control and Accountability
MD	Materials Disposition
MEO	Mediated Electrochemical Oxidation
MOX	Mixed Oxide: (U, Pu)O ₂
MSO	Molten Salt Oxidation
NaCl	sodium chloride
NAS	National Academy of Sciences
NDA	Non-Destructive Analysis
NEPA	National Environmental Policy Act
nm	nanometer (10 ⁻⁹ meters)
NO _x	Mixed nitrogen oxides
NRC	Nuclear Regulatory Commission
NSR	New Special Recovery
n yd	nano yards (10 ⁻⁹ yards)
OCRWM	Office of Civilian Radioactive Waste Management
Oy	Oralloy
PA	Protected Area
PCV	Primary Containment Vessel
PEIS	Programmatic Environmental Impact Statement
PSF	Plutonium Storage Facility
Pu	Plutonium
R&D	Research and Development
RCRA	Resource Conservation and Recovery Act

ROD	Record of Decision
RWSF	Radioactive Waste Scrap Facility
SAR	Safety Analysis Report
S&S	Safeguards & Security
SCFM	Standard Cubic Feet per Minute
SEM	Scanning Electron Microscope
SGT	Safeguard Transporter
SNF	Spent Nuclear Fuel
SNM	Special Nuclear Material
SQ	Significant Quantity
SRS	Savannah River Site
SST	Safe Secure Trailer/Transport
SYNROC	Synthetic Rock
TID	Tamper Indicating Devices
TRU	Transuranic Waste
TSLCC	Total Life-Cycle Cost
U	uranium
VAM	Vitrification Adjunct Melter
VCC	Vitrification Can-in-Canister
VGf	Vitrification Greenfield Facility
WAO	Wet Air Oxidation
ZPPR	Zero Power Physics Reactor @ ANL-W