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Fissile Materials Disposition Program

Alternative Technical Summary Report: Ceramic Can-in-Canister Variant

August 26, 1996

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Fissile Materials Disposition Program

Alternative Technical Summary Report: Ceramic Can-in-Canister Variant

Leonard W. Gray

August 26, 1996

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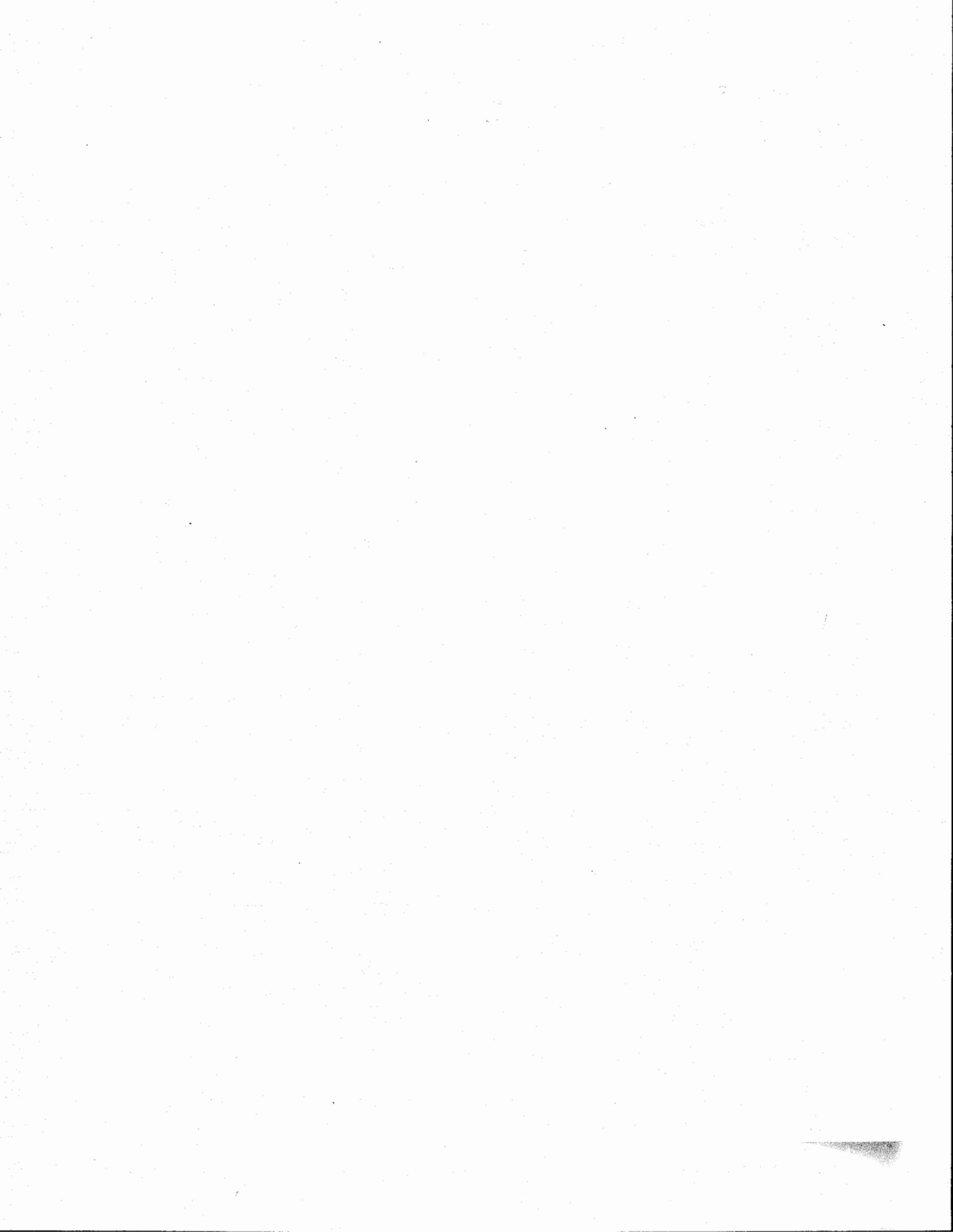
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Work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract W-7405-ENG-48.

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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 sub-national 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 Record of Decision 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 variants plus their optional approaches. The purpose of this document is to provide the required information for one of the immobilization variants: the ceramic can-in-canister (CCC) variant with dry feed at the Savannah River Site (SRS) using HLW glass to surround the plutonium-ceramic cans. Other approaches considered in this document are a wet feed to replace the dry feed preparation operation in the immobilization step, and substitution of a hot press operation for the cold press and sinter operation.

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

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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, blended, and fed to the ceramic process using a dry-feed preparation process where the plutonium oxide will undergo solid state reaction with the ceramic precursors to yield a solid solution with a plutonium concentration of approximately 12 wt% or less. Once the plutonium has been immobilized in the ceramic matrix, recovery of the plutonium will require extensive processing to return it to a state that can be readily transformed to weapons. The plutonium receipt, pretreatment, and ceramic immobilization will take place in existing "cold" areas of the 221-F canyon building.

The plutonium ceramic is contained in small steel cans which are sealed. The actual shape used could vary from that presented in this document. After a period of lag storage, the prepared cans of plutonium ceramic will be loaded into Defense Waste Processing Facility (DWPF) canisters and transported to the DWPF at the Savannah River Site. By using the steel cans, the plutonium ceramic in a stable non-particulate form, has enhanced handling safety and is kept physically separate from the DWPF process. In the DWPF, HLW glass will be poured around the cans inside of the DWPF canisters. This approach preserves all of the key process control elements of the existing waste qualification program. It is at this point that the "spent fuel standard" is achieved. The radiation spike is sufficient to maintain a radiation field above 1 Gy (100 rad) per hour for a period of about 30 to 60 years. These canisters will be stored in an interim surface storage facility similar to the glass storage facility used to store DWPF HLW glass until transferred to the HLW repository. The repository is expected to be open for 100 years and then 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 secured, then 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 variants.

The wet feed preparation is a process variation that is being evaluated. Wet feed preparation adds a nitric acid dissolution step that would both reduce particulate generation and potentially allow for accepting a broader range of feeds without purification or pre-conversion to the oxide form.

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.

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 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. From this perspective, high-level wastes (HLW) or other radioactive species, such as 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 incorporation of the plutonium in titanate-based ceramic pellets in cans surrounded by high level waste glass with subsequent disposal in an HLW repository. This immobilization process is shown conceptually in Figure 1, and discussed in Section 1. For this variant, the addition of SRS HLW is the source of radiation.

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*. Lutze, 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 in cans surrounded by HLW glass would provide a form that would be relatively easy to store but would render retrieval of the plutonium difficult. Many of the technologies needed to prepare plutonium in a ceramic with a proliferation resistant HLW radiation spike exist 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 adding HLW glass are issues requiring resolution. Some of these technical issues have been addressed in various studies, to various degrees of completeness. Nevertheless research and development activities are required to verify the scalability of the production process and to 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 can-in-canister variant, the disposition process begins with the transportation of plutonium feed materials (pits, metal, oxides, unirradiated reactor fuel, etc.) to the disassembly, conversion, and immobilization facility site in Department

facility space, utilities, and support systems. The front-end processing also uses existing facilities which reduces the environmental impacts from construction. The back-end processing, because it uses existing facilities as well and needs no new facilities, also reduces the environmental impact from construction. The number of additional DWPF canisters required for this case is significantly less than for the ceramic greenfield case. In the hot pressing variant, additional new facilities (but no new buildings) are needed.

Cost and schedule information for the ceramic can-in-canister at SRS variant reported here were summarized in the *Technical Summary Report for Surplus Weapons-Usable Plutonium Disposition*, July 1996, which concludes that can-in-canister variants are the most attractive immobilization approach based on cost considerations.

- Environment, safety and health compliance.
- Cost effectiveness.
- Timeliness.
- Fosters progress with Russia and others.
- Public and institutional acceptance.

The ceramic can in canister immobilization process consists of front-end and back-end processing operations. The front-end processing operations are pretreatment operations designed to prepare the different incoming plutonium material forms to 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. Individual operations such as development and demonstration of systems for part declassification are required. Cold pressing and sintering the ceramic powder and loading the plutonium ceramic pellets into cans have been demonstrated at the engineering scale using surrogates for ceramics. Dry feed of PuO_2 requires additional development for input specification and processing conditions. The hot pressing in bellows has been demonstrated at the production scale using surrogates.

The back-end processing operations immobilize the plutonium ceramic cans, which are in a rack inside a DWPF canister, by pouring HLW glass around them. These operations have been demonstrated at the engineering scale using surrogates for the ceramic operations and the production scale HLW glass operations at DWPF.

Disposition of the plutonium ceramic with a HLW radiation barrier in a mined geologic repository involves regulatory and technical issues that require additional consideration.

The high leveraging of existing facilities without undue impact on the DWPF Facility make this variant favorable in both cost and schedule.

Hybrid disposition approaches, in which different feed materials (e.g., pure plutonium oxide from pits versus impure plutonium feeds) go different routes, open the possibility of utilizing existing facilities in different ways to achieve FMDP objectives. As an example, the completed but never used New Special Recovery (NSR) Facility at SRS could be used as designed to directly support the immobilization portion of a hybrid variant with relative little modification. The pit recovery operation, which support the MOX fuel fabrication portion of the hybrid, could then be co-located with the MOX fuel fabrication operations with little impact since the required backup chemical operations would be available at the NSR facility at SRS. Other possible uses of present facilities are also possible and these approaches need to be further evaluated.

This end-to-end immobilization variant combines functions from facilities previously described in and bounded by the PEIS process currently under way. For front-end processing in this variant, elimination of aqueous recovery lines results in significant reductions in aqueous waste solutions, processing equipment, associated

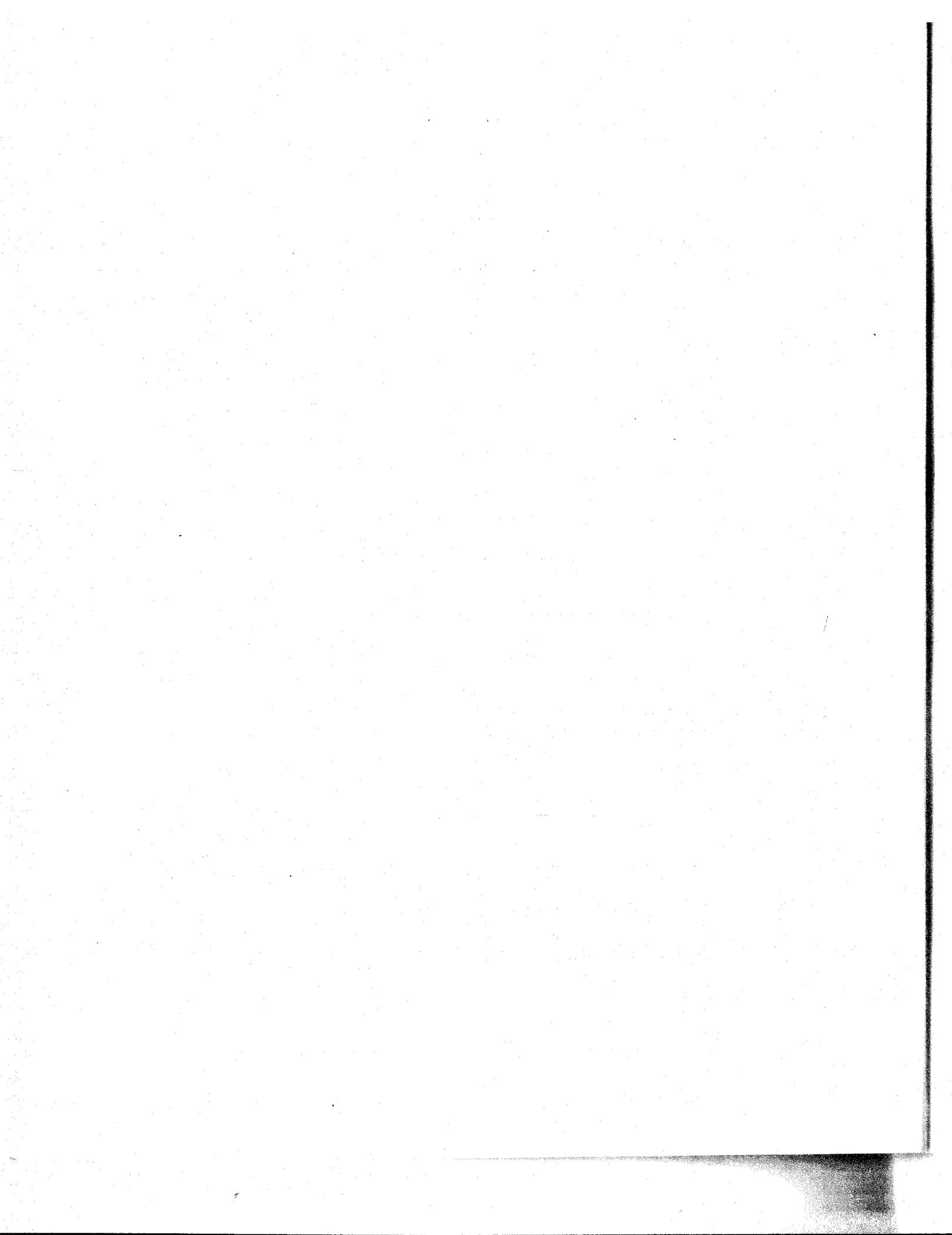
1.0 Variant Description

1.1 Introduction

Immobilization is the fixation of the surplus fissile materials in an acceptable matrix such as ceramics or glass 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 (FMDP) must also possess the property that it is inherently as unattractive and inaccessible 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 canister. 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.

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% plutonium and engineering-scale samples have been made with greater than 10% plutonium. A considerable amount of research and development has been performed on this concept including a considerable amount of work with actinides.



1.1.1 Assumptions and Design Basis

Major assumptions used in the development of the ceramic can-in-canister variant include the following:

- 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) 94-1 Recommendation Remediation Program and declared excess for national needs.
- The nominal feed of plutonium to the facility is 50 metric tonnes (56 tons).
- The campaign will take no more than 10 years to complete.

Additional assumptions for the variant are:

- 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 on the order of 1 Gy (100 rad) per hr at 1 m (3 ft) from the package center surface for 30 years after initial fabrication. The source of the gamma radiation is primarily ^{137}Cs from HLW obtained from the waste tanks at SRS.
- 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 less than or equal to 12% (by weight). This parameter is taken from demonstrated fabrication size (~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%).
- The ceramic can-in-canister facility will process 5000 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 or 8.3 kg (18.4 lb) per shift.
- 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 neutron absorber such as gadolinium, samarium or hafnium in both the upstream liquid processing equipment and the final calcination/and sintering equipment has been assumed. Criticality analysis is incomplete. 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-can-in-canister facility variant presented in this report describes the immobilization of plutonium in a titanate based ceramics matrix in individual cans. These cans are placed in a Defense Waste Processing Facility (DWPF) canister and glass containing high-level waste (HLW) is poured into the canister around the cans to produce a radiation field in the final product. This immobilization option uses the existing 221-F canyon building at Savannah River Site (SRS) modified to produce the plutonium ceramic cans. The canisters are filled with SRS HLW glass at the DWPF. Table 1 shows the location of each process area. This immobilization process is shown conceptually in Fig. 1 in Section 1.2.

The baseline variant uses a dry feed and cold press and sinter process for the ceramic formation operations.

Other approaches for this variant include a wet feed option and hot pressing option.

The CCC variant was selected for evaluation because it offers several process, environmental, schedule, and cost benefits over the base case Ceramic Greenfield Facility (CGF) including:

- An effective means to immobilize plutonium using existing DOE facilities. While some of these facilities will require upgrading, no new facilities will have to be constructed.
- CCC uses HLW as the radiation spike. This HLW is already slated for immobilization in borosilicate glass; therefore, this option provides a beneficial use for this waste.
- Plutonium-ceramic forms are placed in sealed stainless steel cans. These cans form a barrier between the plutonium and the HLW which is a potential concern in some of the variants with respect to intermixing actinides which would introduce the need for criticality controls.
- These stainless steel cans prevent introduction of plutonium into process systems within the DWPF reducing safeguards and security and criticality concerns.
- Using existing facilities provides significant cost and schedule benefits over other variants.
- Long term environmental concerns and costs are less than in the greenfield case with this variant because fewer additional canisters will be generated and thus fewer canisters will end up in the repository.
- Another approach to this variant (Wet feed preparation) offers the potential to substantially reduce feed preparation operations.

- The final ceramic product in cans surrounded by HLW glass is contained in canisters and is stored onsite until it is transported to a HLW repository. DWPF canisters will be 61.0 cm (2 ft.) diameter and 3.0 m (10 ft.). Each canister contains 20 cans approximately 12 cm (4.8 in.) diameter by 0.58 m (23 in) long. Each can contains about 21 kg (46 lb.) of ceramic pellets for a total of 50 kg (110 lb.) of plutonium per canister.
- The plutonium containing ceramic product is assumed to be similar to SYNROC-C, which contains the mineral phases zirconolite ($\text{CaZrTi}_2\text{O}_7$), and perovskite (CaTiO_3), and rutile (TiO_2). The actual phases selected for the plutonium containing ceramic will be the result of a research and development program. It is assumed that the composition of the ceramic-forming chemicals (precursors) will not affect the processing equipment or sequence.
- The ceramic can-in-canister facility is assumed to be operated in existing facilities at the SRS where the existing DWPF will be used to pour HLW glass around the immobilized form. After actual site selection, more specific site-related information will be required.

1.1.2 Feed Materials

This end-to-end immobilization variant (ceramic can-in-canister facility) will receive the following material forms which 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 crucible (SS&C)* |
| - Alloy reactor fuels (unirradiated) | - Oxide-like materials (residues)* |
| - Oxide reactor fuels (unirradiated) | - Halide salts* |

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

1.1.3 Physical Layout Locations

The facilities at SRS would be used. Contact handed processes would be performed in the 221F facility. The immobilized plutonium ceramic cans would be transferred to the Defense Waste Processing Facility (DWPF) in DWPF canisters. At the DWPF HLW containing ^{137}Cs glass will be poured around the cans.

* This material is expected to be converted to impure oxides as part of the DNFSB Recommendation 94-1 Stabilization program.

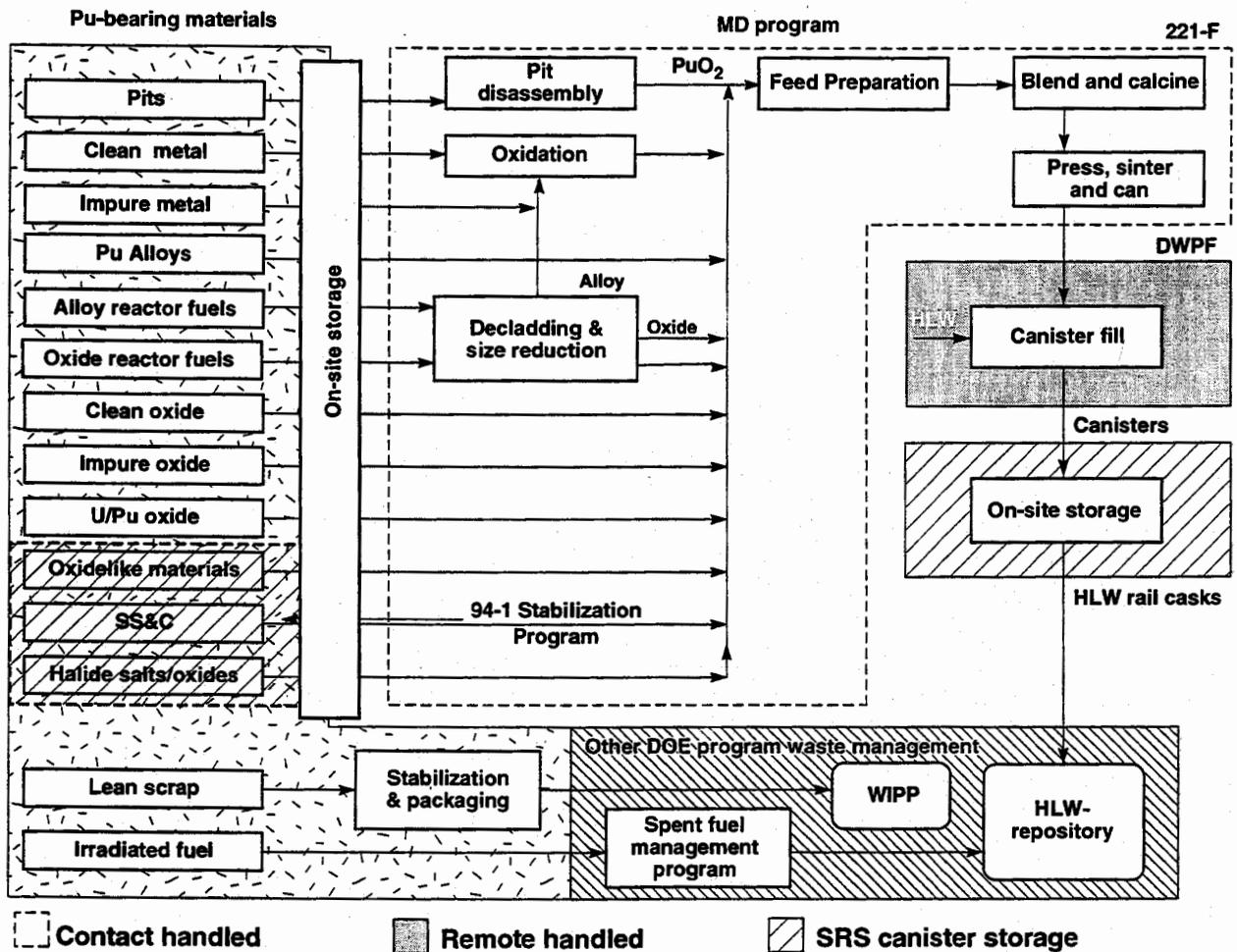
The physical location of process areas are shown in Table 1.

Table 1. Physical locations for proposed ceramic can-in-canister process equipment.

Process	Locations
Receiving, shipping, storage, sampling	221-F Plutonium Storage Facility (PSF)
Pit disassembly, dehydride/hydride/oxidation	221-F New Special Recovery (NSR)
Oralloy decontamination	221-F NSR
Special recovery	221-F Canyon 3rd Level
Fuel decladding	221-F Canyon 3rd Level
Feed preparation (dry feed)	221-F NSR
Oxide lag storage (dry feed)	221-F Canyon 3rd Level
Ceramic press and sinter (dry feed)	221-F Canyon 3rd Level
Off-gas treatment (dry feed)	221-F Canyon 3rd Level
Feed preparation (wet feed)	221-F Canyon 3rd Level
Oxide lag storage (wet feed)	221-F Canyon 3rd Level
Ceramic press and sinter (wet feed)	221-F Canyon 2nd Level
Off-gas treatment (wet feed)	221-F Canyon 2nd Level
Can decon (dry feed)	221-F Canyon 3rd Level
Can decon (wet feed)	221-F Canyon 2nd Level
Can weld & test (dry feed)	221-F Canyon 3rd Level
Can weld & test (wet feed)	221-F Canyon 2nd Level
Interim can storage	221-F Canyon 3rd Level
Place in canister	221-F Canyon 1st Level
Weld & test	221-F Canyon 1st Level
Interim canister storage	DWPF Service Building Interim Vault
Blend tank	DWPF Vitrification Building Hot Cell
DWPF melter	DWPF Vitrification Building Hot Cell
Canister decontamination	DWPF Vitrification Building Hot Cell
Weld & test	DWPF Vitrification Building Hot Cell
Off-gas treatment	DWPF Vitrification Building Hot Cell
Interim product storage	DWPF Glass Waste Storage Building Unit 2

1.2 First-Level Flow Diagrams

The ceramic can-in-canister variant is shown on the first-level flow diagram (Fig. 1). The feed materials to ceramic immobilization will come from plutonium pits and the material that is stored as stabilized materials from the DNFSB Recommendation 94-1 Remediation Program. Prior to ceramic immobilization, many of the feeds require pretreatment. All of the pretreatment processing, except halide removal and oxidation which is done at Los Alamos National Laboratory (LANL), will take place in the pretreatment areas of the ceramic can-in-canister facility in glove boxes. The pretreatment will convert the feed streams to oxides. The blended oxide product will be fed to ceramic immobilization equipment also located in 221-F. The immobilized plutonium ceramic forms will be placed in metal cans. These metal cans are then placed in a DWPF canister, and transferred to the DWPF at S-Area where HLW glass will be added to create a radiation barrier.



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Figure 1. First-level flow diagram, ceramic can-in-canister variant.

1.2.1 Front-End Plutonium Processing—Disassembly and Conversion (D&C)

The feed materials to the plutonium disposition facility resulting from 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.
- **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.
- **Blends.** Prior to feeding downstream unit operations, all feeds will be blended to provide a more uniform downstream feed and to minimize the amount of processing required.

1.2.2 Front-End Plutonium Processing-Ceramic Immobilization

The plutonium oxide material will be dissolved or size reduced in the *Feed Preparation* step 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 and neutron absorbers. The mixture is then calcined. In the third step, *Press and Package*, the calcined powder is densified and sintered. This portion of the operations is carried out in shielded glove boxes. The actual amount of plutonium in each can will be selected as the result of a development program. For the base case, approximately 2.6 kg (5.6 lbs) of plutonium is assumed. In the fourth step, *Can-in-Canister Fill*, the immobilized product is loaded into the canister and a canister top welded on. The actual number of cans loaded into the DWPF canisters will be selected as the result of a development program which includes a series of glass-pouring experiments. For the base case, 20 cans containing about 51 kg (113 lbs) of plutonium is assumed.

The first-level flow diagram, Fig. 1, indicates the processing steps for the front-end and back-end immobilization operations. The plutonium feed materials for this option

will be primarily blended plutonium oxide. The oxide will be received, cross-blended as required, and then converted to the ceramic form in stainless steel cans in the existing 221-F canyon building in F-Area. The cans will be subsequently loaded into a frame and placed inside an empty DWPF canister. The top head and nozzle of the canister will be welded on and the weld certified. Temporary storage may be provided in 221-F prior to transporting the canister to DWPF to be filled with HLW glass.

1.2.3 Back-End Processing-Adding in HLW Glass as Proliferation Deterrence

The plutonium ceramic cans in the DWPF canisters are transferred to the DWPF where the cans are surrounded by HLW glass and the canister welded shut. The filled and decontaminated canisters will be stored onsite in the interim until they are sent to final disposal.

1.3 Second-Level Flow Diagrams

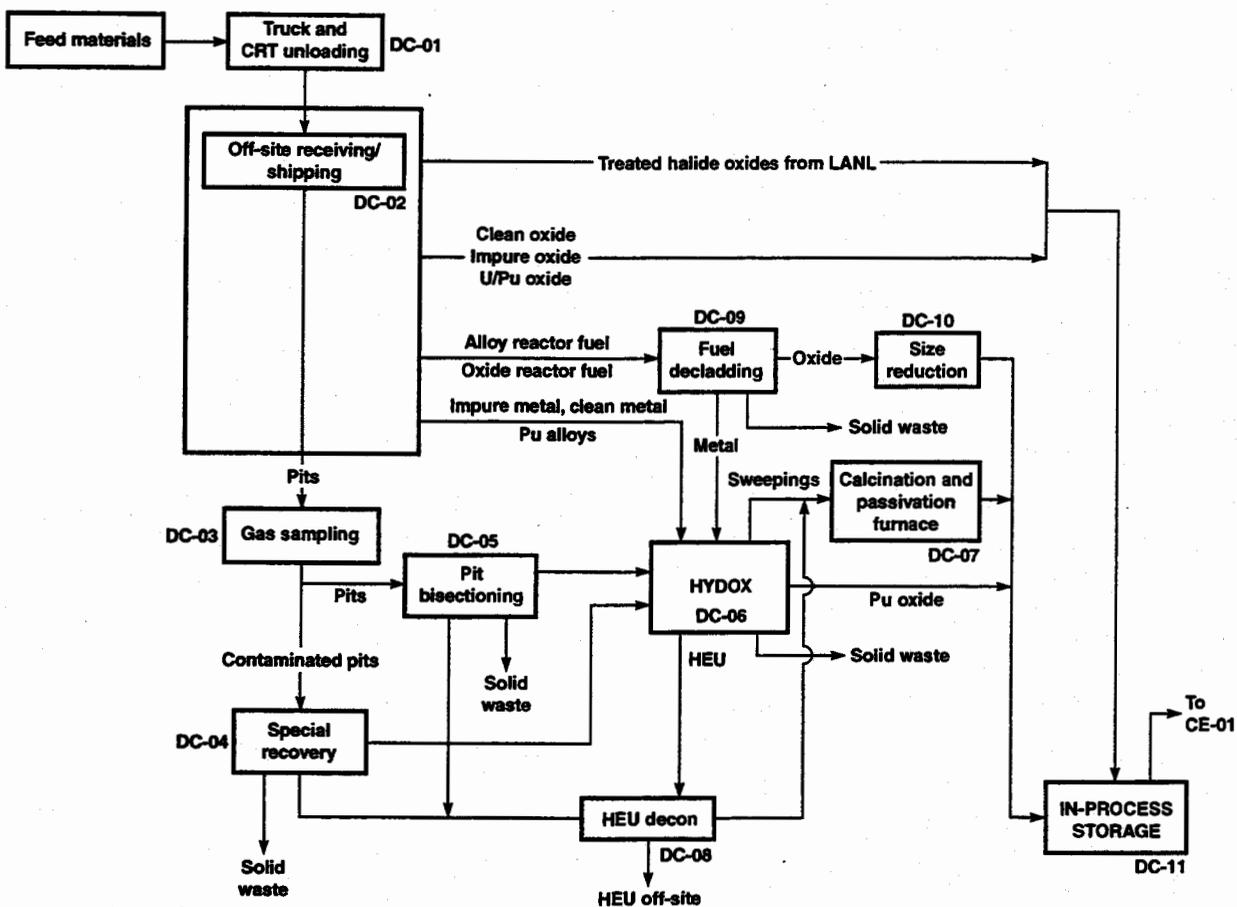
The first-level flow diagram processing within the ceramic can-in-canister facility was expanded to two second-level flow diagrams. The two flow diagrams are designated as the front-end disassembly and conversion and the front-end ceramic immobilization and back-end processing. The front-end covers the conversions of the various feed to oxides and converting the oxides into a ceramic form. The back-end covers surrounding the plutonium ceramic cans in HLW glass.

1.3.1 Front-End Processing - Disassembly and Conversion

The front-end disassembly and conversion (Figure 2) converts the large number of different feed materials that come from storage to oxides. The following are more detailed descriptions for the front-end processes. These operations are common to many of the immobilization variants.

DC-01 Truck and CRT Unloading. Material shipments will be delivered to a truck and container restraint transport (CRT) unloading dock where the delivery vehicles safe secure trailer/transport (SST) will be washed and smear checked. The packaged 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 indication devices (TIDs) inspected, and neutron counts are made on the packages. Emptied CRTS and shipping containers are inspected, decontaminated if necessary, and prepared for return.

DC-02 Off-Site 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 placed in the storage vault where it will await processing. Contaminated containers are decontaminated in a decontamination station where the material is retrieved and repackaged.



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Figure 2. Second-level flow diagram, ceramic can-in-canister, front-end disassembly and conversion.

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.

DC-04 Special Recovery. Contaminated pits are disassembled and the resultant parts are cleaned. Plutonium-bearing parts are separated from other material. This operation consists of the following glove boxes and operations: disassembly, tool storage, bakeout, nondestructive analysis (NDA), off gas treatment, and sub-component 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. The hydride/dehydride/oxidation method

is used to reclaim the plutonium and produce oxide. 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 dehulling 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.

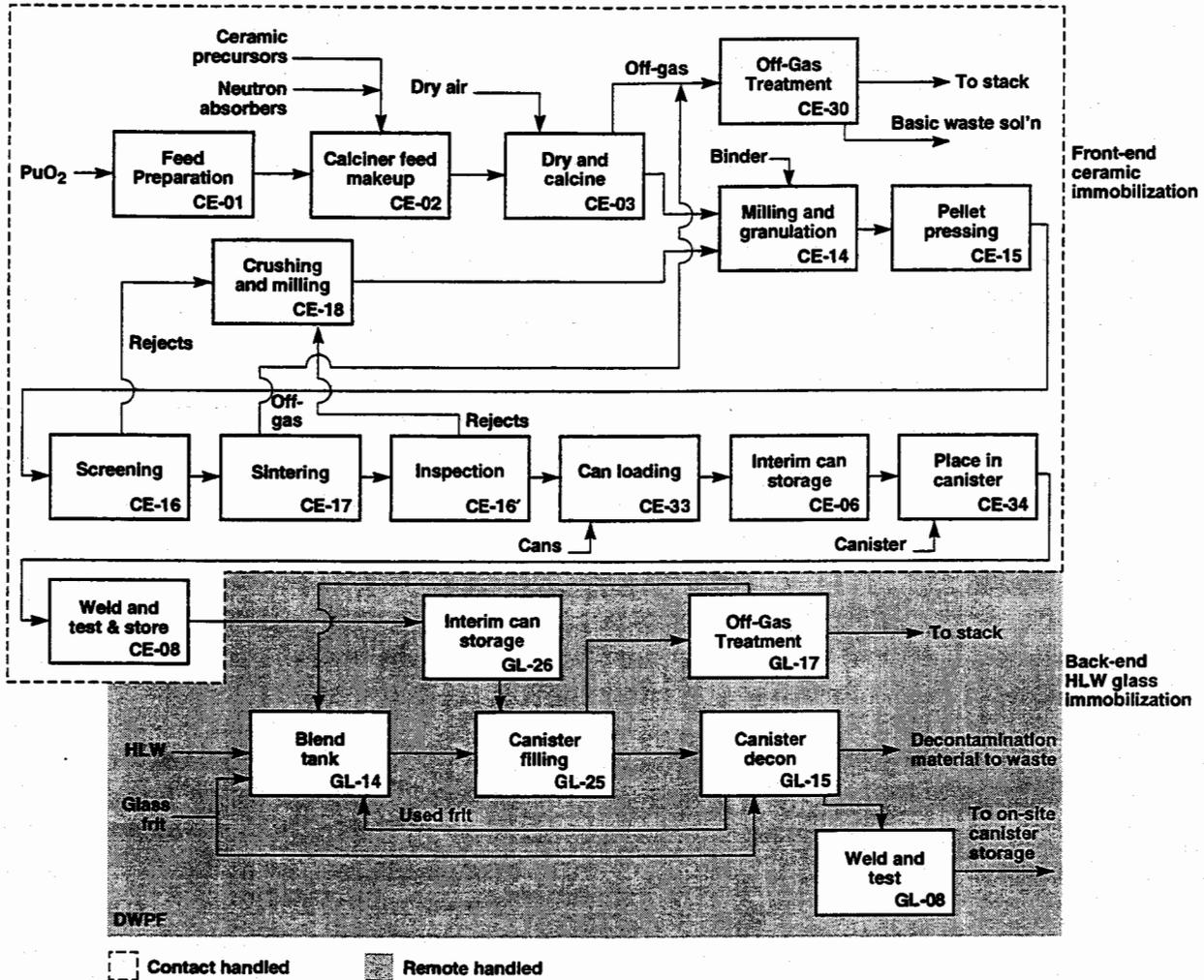
DC-11 In-Process Storage. Oxide will be removed from the glove box line and placed into storage prior to being fed to downstream unit operations.

1.3.2 Front-End Ceramic Immobilization Processing

The front-end ceramic processing (second-level flow diagram, Figure 3) takes the pretreated feed materials and converts them to ceramic for storage and disposal. The following are descriptions for the front-end ceramic unit operations.

CE-01 Feed Preparation. Incoming plutonium oxide will be cross-blended to prepare a consistent downstream feedstock while minimizing the amount of processing required. The blended 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 (CE-02). Size characterization will be determined by an appropriate technique such as BET, SEM, or microsieving.

Immobilization, level 2



10.0.0895.2005pb01/ angle

Figure 3. Second-level flow diagram, ceramic can-in-canister at SRS using 221-F and DWPF.

Transfer Can Entry/Opening/Batching. A shipping drum containing a feed can will be brought to an entry hood from the plutonium storage vault. At this station, the feed can will be removed from the shipping drum and the serial number will be verified and entered into the accountability computer. The feed can will then be introduced into the feed preparation glove box through an airlock. The unopened feed can will be weighed. After the feed can is weighed, it will be opened and have a slip cover installed. Storage positions will be available to allow lag storage for oxide cans. The contents of one oxide transfer-can will be sized to ensure the oxide can be readily processed in the first stage melter. The feed cans will be transferred to the batching station where the contents will be emptied, blended with other materials as required, made up into the appropriate batch size, weighed, and bar coded. If oversized, grinding will be performed at this station. A weigh scale for accountability purposes and a vacuum system for any

cleanup that may be required is also included at this station. The oxide transfer can will be moved to the oxide lag storage.

Oxide Lag Storage Station. The oxide lag storage station is a multiposition critically safe lag storage area with locking features. Oxide transfer cans will be stored in the oxide lag storage station after being weighed having the bar code verified, and having the accountability computer updated.

CE-02 Calciner Feed Makeup. PuO₂ powder will be dry blended with ceramic precursors. Neutron absorber 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 & Calcine. The drying and calcining will be conducted in a rotating tank inside a high temperature furnace, i.e., rotary calciner. The tank is 30 cm (12 in.) diameter by 107 cm (42 in.) long. The tank will also have internal veins for proper mixing. The mixture will first be heated to around 150°C (300°F) to remove any residual moisture and adsorbed gases. 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-14 Milling and Granulation. Exact procedures in this step will depend to a large degree upon how fine or coarse the material is after *Dry and Calcine* (CE-03). The purpose of this step is to optimize size and morphology for the following pressing and sintering steps. If the material is dried in clumps, the material will be agitated or milled to recover the fine texture. A binder is added to granulate material, which then aids in the densification and sintering steps.

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 after cold-pressing will be about 8.9 cm (3.5 in.) diameter by 3.6 cm (1.4 in.) high. Pellets will be pressed at a load of about 27 tonnes (30 tons) and at an average rate of about 5 per minute. Pressed pellets will be transferred by a conveyer belt to the sintering oven. Cracked pellets will be conveyed to *Crushing & Milling* (CE-18).

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

CE-17 Sintering. The cold pressed pellets will be placed into a conveyer oven and heated to around 1300°C (2400°F) for several hours. To fully react material, longer reaction times may be used. After sintering, pellets will be approximately 6.4 cm (2.5 in.) in diameter by 2.5 cm (1 in.) high.

CE-18 Crushing and Milling. Pellets which have cracked after cold pressing or after sintering are crushed in a press and then ground in a milling device. After sufficient grinding, the powder is then returned to *Milling and Granulation* (CE-14).

CE-30 Dry Pretreatment Off-Gas Operation. The dry pretreatment off-gas system will reduce the quantity of radioactive particles in the vapors that evolve from the sizing/grinding step and melter before release to the ventilation exhaust system. Off gases will be drawn, quenched, and discharged into the off-gas condensate tank. The quenched gases from the off-gas condensate tank will be scrubbed in a steam atomized scrubber and cooled by a chilled water condenser. Gases from the condenser will then pass through the high-efficiency mist eliminator (HEME) and a set of HEPA filters before discharge into the exhaust tunnel and through a sand filter before the exhaust stack. Where the potential for plutonium and plutonium oxide dusting will exist, air flow will pass through filters before entering the ventilation ducts.

CE-33 Can Loading. Plutonium ceramic pellets are loaded into 12 cm (4.8 in.) diameter by 0.58 m (23 in) cans.

CE-06 Interim Can Storage. Cans loaded with the plutonium ceramic will be stored in storage racks in a 3rd level vault in the 221 F canyon building until they are ready to be placed in the DWPF canister.

For inventory and third party inspections, the individual cans can be moved to a surveillance station located in the canyon area where specific cans may be monitored and inspected as required.

CE-34 Place in Canister. The small plutonium-ceramic cans will be placed in a frame or holding rack, that will subsequently be placed inside an open DWPF canister. The canister head is then immediately welded into place. Refer to Figure 4 for a conceptual cut-away view of the DWPF canister containing plutonium cans. The final production rack has not yet been designed. A number of simple and quite feasible concepts are being considered to increase the intrinsic proliferation resistance of the container. For example, to prevent surgical extraction of cans by the use of linear shaped charges, the cans could be welded into sturdy cages which are welded to the internal holding rack. The base rack and cage would be constructed of a strong metal, perhaps stainless steel rebar—the size and strength of which would be determined by a threat risk analysis. An expanded metal shield could then be tack welded around the cage. The base rack would provide support and connect all of the cages into a single element. After the rack is placed into the canister it could be welded to the inside of the canister, then the top head would be welded onto the canister body. The loaded canister would be stored within 221-F until it is shipped to DWPF.

CE-08 New Canister Weld and Test . After the plutonium ceramic cans have been loaded into the canister, the head of the canister will then be welded to the body of the canister and the weld tested using procedures now used during off-site fabrication.

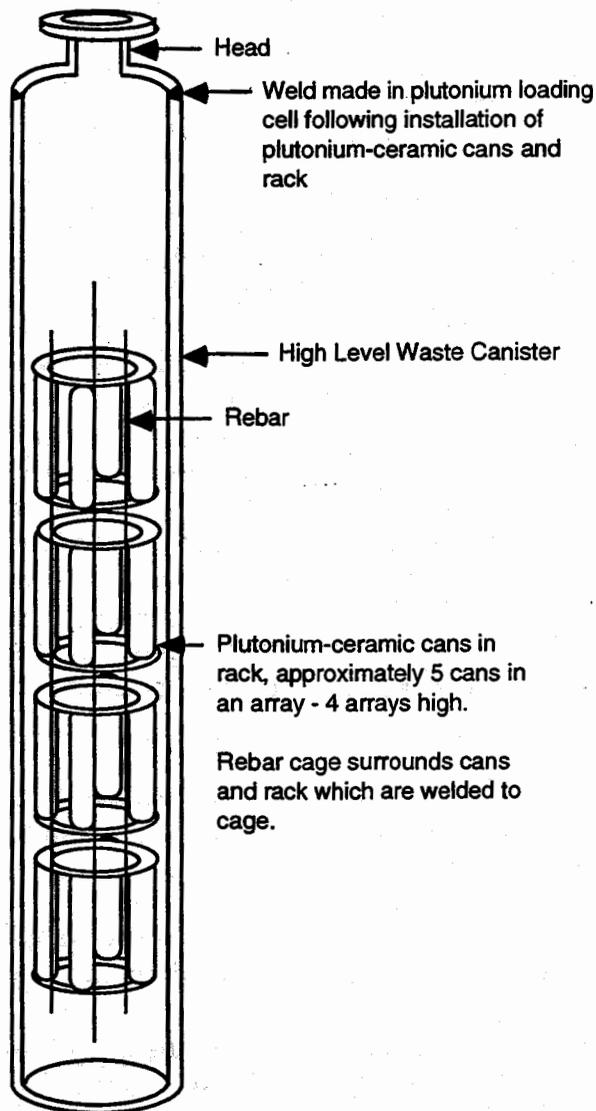


Figure 4. Conceptual cut-away of can-in-canister (not to scale).

Temporary storage may be provided in 221-F prior to shipment. Upon completion of the test, the canister will be placed in temporary storage until shipped by rail or truck to the DWPF.

1.3.3 Back-End Processing — HLW Vitrification

GL-26 Interim Canister Storage. A small can-in-canister storage vault will be constructed in the canister loading area of the DWPF Service Building. This cell will provide space for a special nuclear material vault with the capacity for about one week's supply of canisters containing plutonium ceramic cans. The cell will be shielded for ^{241}Am and will be provided with safeguards and security equipment commensurate with the material being handled.

The area between the small can-in-canister storage vault and the DWPF Vitrification Building canister airlock will be a controlled corridor during movement of the canisters into the melt cell. This corridor currently exists but will be provided with safeguards and security protection commensurate with the material being moved.

GL-14 Blend Tank. Inside the melter feed preparation cell will be the slurry mix evaporator, used borosilicate glass storage tank, blend tank, interconnecting piping, instrumentation, and remote control equipment.

GL-15 Canister Decon. Frit slurry blasting is used to remove contamination and metal oxides from the canister surface. As the canister rotates through a helical path in an enclosed chamber, jets blast all exposed surfaces with an aqueous slurry of glass frit. After canister decontamination, the used frit slurry (containing the contamination from the canister surface) is sent to the slurry mix evaporator (blend tank) for melter feed preparation.

GL-25 Canister Filling. Glass normally is removed from near the bottom of the DWPF melter through a rinser and pour spout. The canister (on the pour turntable) is connected to the melter by a bellows assembly, which seals the canister pour spout connection. Pouring is accomplished by drawing a vacuum on the pour spout relative to the melter. Canister filling is monitored by both infrared detection and weight systems. When the desired level of fill in the canister is achieved, pouring is stopped by equalizing the pressure between the melter and the pour spout.

Because the plutonium ceramic cans displace volume that would normally contain HLW-borosilicate glass in the DWPF canisters, additional DWPF canisters will be needed to process all of the HLW in the SRS Tank Farm. The number of additional DWPF canisters is directly proportional to the plutonium loading in the plutonium ceramic. The total number of DWPF canisters containing plutonium ceramic cans with 12 weight percent plutonium is expected to be approximately 1000. Assuming 20 cans of plutonium ceramic per DWPF canister, the volume of HLW glass displaced will be about 20%. The additional canisters produced by the DWPF as a result of this variant will be about 200.

GL-08 Weld and Test. The canister is sealed by upset-resistance welding a 12.7 cm (5 in.) diameter plug into the canister nozzle. After decontamination and drying, the temporary seal is pushed down in the canister neck, exposing clean metal for a permanent plug weld. The plug, which is slightly larger in diameter than the nozzle bore and has a tapered edge, is centered in the nozzle. The canister is supported by its flange on the welder bottom electrode, then the upper electrode is lowered onto the plug. As a force of 4×10^5 N (9×10^4 lb) is applied to the plug, a current of 250,000 A is passed through the plug and nozzle. The 40 cm (15.75 in.) line of contact is heated (but not melted), the plug is forced into the nozzle, and a 1-cm-thick, solid-state weld is made in 1.5 seconds.

1.3.4 Onsite Canister Storage

The Glass Waste Storage Building (GWSB) Unit 1 will store the DWPF glass waste containers until a HLW repository is available. The building has been constructed and is located near the DWPF. Glass Waste Storage Building Unit 1 has a capacity of 2286 canisters. Glass Waste Storage Building Unit 2 will be built as Glass Waste Storage Building Unit 1 fills with HLW-glass canisters or when plutonium ceramic-filled HLW glass canisters are ready for storage. This new facility will be built to Category I seismic requirements and will encompass safeguard (nonproliferation) controls. Because Glass Waste Storage Building Unit 2 is scheduled to be built in support of the DWPF mission, only the upgrades required to facilitate safeguards and security are considered as costs to this project.

Approximately 6000 canisters of HLW glass will be prepared within the DWPF to accomplish the high level waste mission. To accomplish the plutonium disposition mission for the assumed 50 tonnes (56 tonnes) of plutonium, approximately 1000 of these 6000 canisters would contain cans of plutonium ceramic. The present schedule indicates that the 1000 plutonium ceramic canisters can be produced periodically or randomly during the HLW glass canister productions without significant impact in the HLW mission. Additionally, the plutonium containing canisters could be stored randomly among the HLW canisters in the Glass Waste Storage Building (GWSB). Externally, the canisters with plutonium will appear identical to the HLW-canisters. The only markings to identify the plutonium ceramic canisters from the high level waste canisters will be the unique bar code number on the side of the canisters, which are not visible by looking down into the storage cells. Each individual storage cell is plugged with a 1410 kg (3,100 lb) reinforced concrete plug that requires a specially designed grapple to lift. There is no equipment in the GWSB with which the plug or a canister could be removed since removal can only be accomplished with equipment stored in DWPF.

The concrete vault area for the GWSBs is designed to contain glass waste canisters underground and protect personnel, the public, and the environment. The vault is an earthquake-resistant and tornado-resistant concrete structure. Radiation shielding protection will be provided by concrete walls, earth embedment, and a concrete deck that forms the floor of the operating area. The stored canisters will be protected against external damage and cooled to prevent internal heat buildup.

Radioactive decay heat from the canisters will be removed by the forced air exhaust system. The exhaust air will be passed through the HEPA filter ventilation system and then discharged to the atmosphere through a stack. No condensate is expected to accumulate in the ventilation system sump; however, if condensate accumulates, it will be drummed, monitored for radioactivity, and treated. Depending on radioactivity levels, the condensate will be released or sent to F- and H-Areas Effluent Treatment Facilities.

1.4 Facilities

This section describes the process areas and facilities available for this variant and explains the modifications to existing facilities that will be needed. This variant takes maximum advantage of existing buildings and processes. In this way, no completely new facilities will be required. Table 1 lists the physical locations at SRS for ceramic can-in-canister processes.

Front-end processing and pretreatment operations and ceramic immobilization take place in F-Area (see Fig. 5) where facilities are designed and built to handle large quantities of plutonium and have systems to maintain criticality control and safeguards systems to maintain accountability and security.

The floor area required for the front-end primary plutonium processing function and ceramic immobilization is approximately 2045 sq m (22,000 sq ft) for plutonium processing, 1485 sq m (16,000 sq ft) for direct plutonium processing support, and 6875 sq m (74,000 sq ft) for auxiliary support functions. The use of the available space in 221-F for this function is being evaluated.

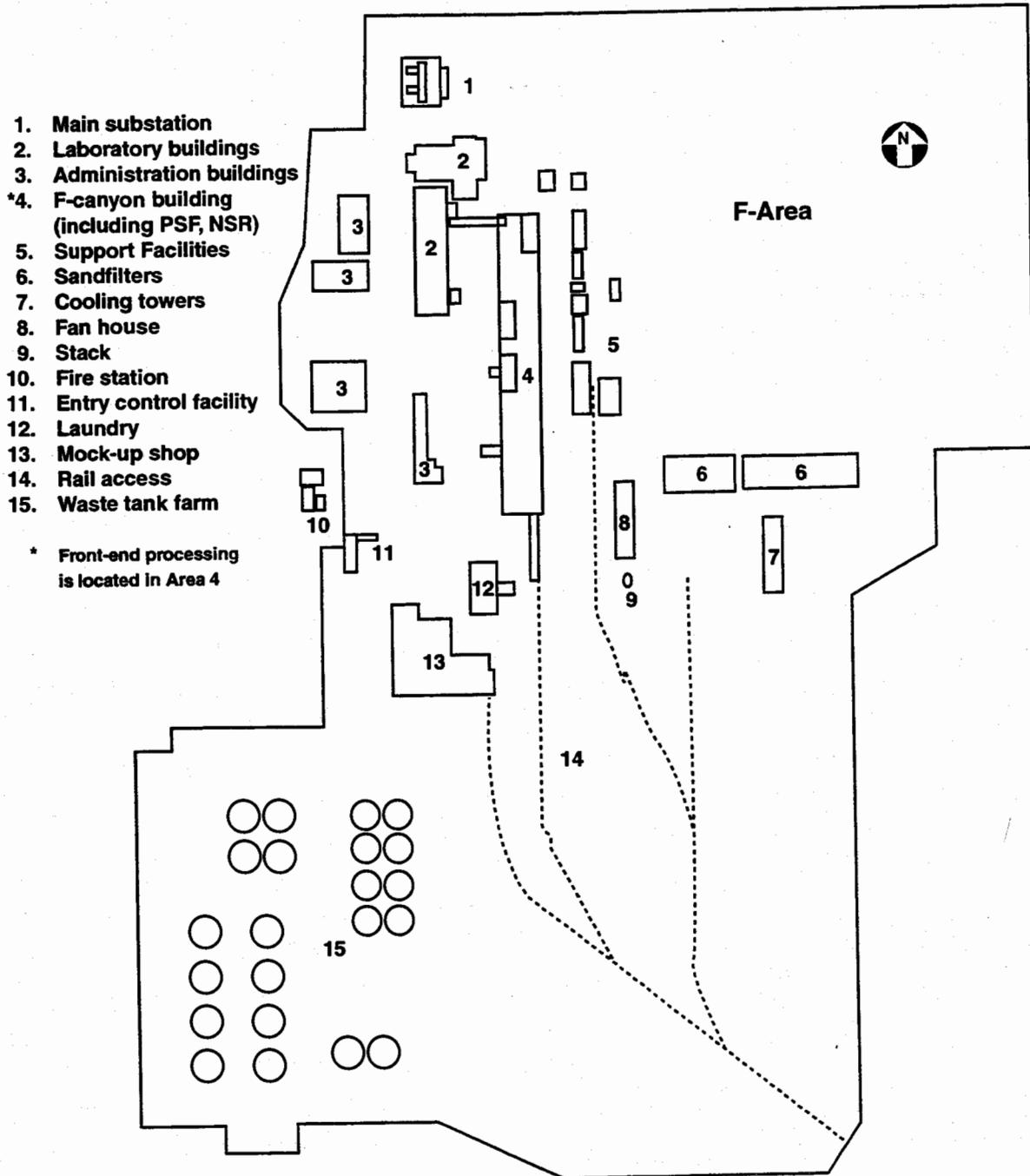
The addition of a high-level waste spike and final immobilization operations take place in S-Area (see Figure 6) where existing DWPF facilities will be upgraded and modified to support storage and handling of plutonium ceramic can-in-canisters through the entire immobilization process. Safeguards and security criteria will have to be upgraded in selected portions of the DWPF buildings.

Primary areas of the DWPF Service Building that are expected to need upgrades to accommodate the plutonium canisters are shown in Figure 7 and 8. Additionally, CCTVs will be needed in the DWPF Vitrification Building and possibly GWSB #2.

Safeguards and Security. Safeguards and Security upgrades are required in S-Area to accommodate the processing of special nuclear materials.

Protection of special nuclear material and vital equipment. Category I special nuclear material must be used or processed within material access areas requiring a material surveillance program to detect unauthorized material flows and transfers. The pretreatment facilities in F-Area meet the safeguards requirements established by DOE Order 5630.13A, *Master Safeguards and Security Agreements*.

The DWPF Vitrification Building and applicable portions of the Service Building and Glass Waste Storage Building Unit 2 will be upgraded to the criteria of DOE Order 5630.13A, as required for the attractiveness level of the material. The material stored in GWSB #2 is assumed to be Category IV-E with the addition of HLW to the canister containing the plutonium ceramic cans.



- 1. Main substation
 - 2. Laboratory buildings
 - 3. Administration buildings
 - *4. F-canyon building (including PSF, NSR)
 - 5. Support Facilities
 - 6. Sandfilters
 - 7. Cooling towers
 - 8. Fan house
 - 9. Stack
 - 10. Fire station
 - 11. Entry control facility
 - 12. Laundry
 - 13. Mock-up shop
 - 14. Rail access
 - 15. Waste tank farm
- * Front-end processing is located in Area 4

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Figure 5. F-Area layout.

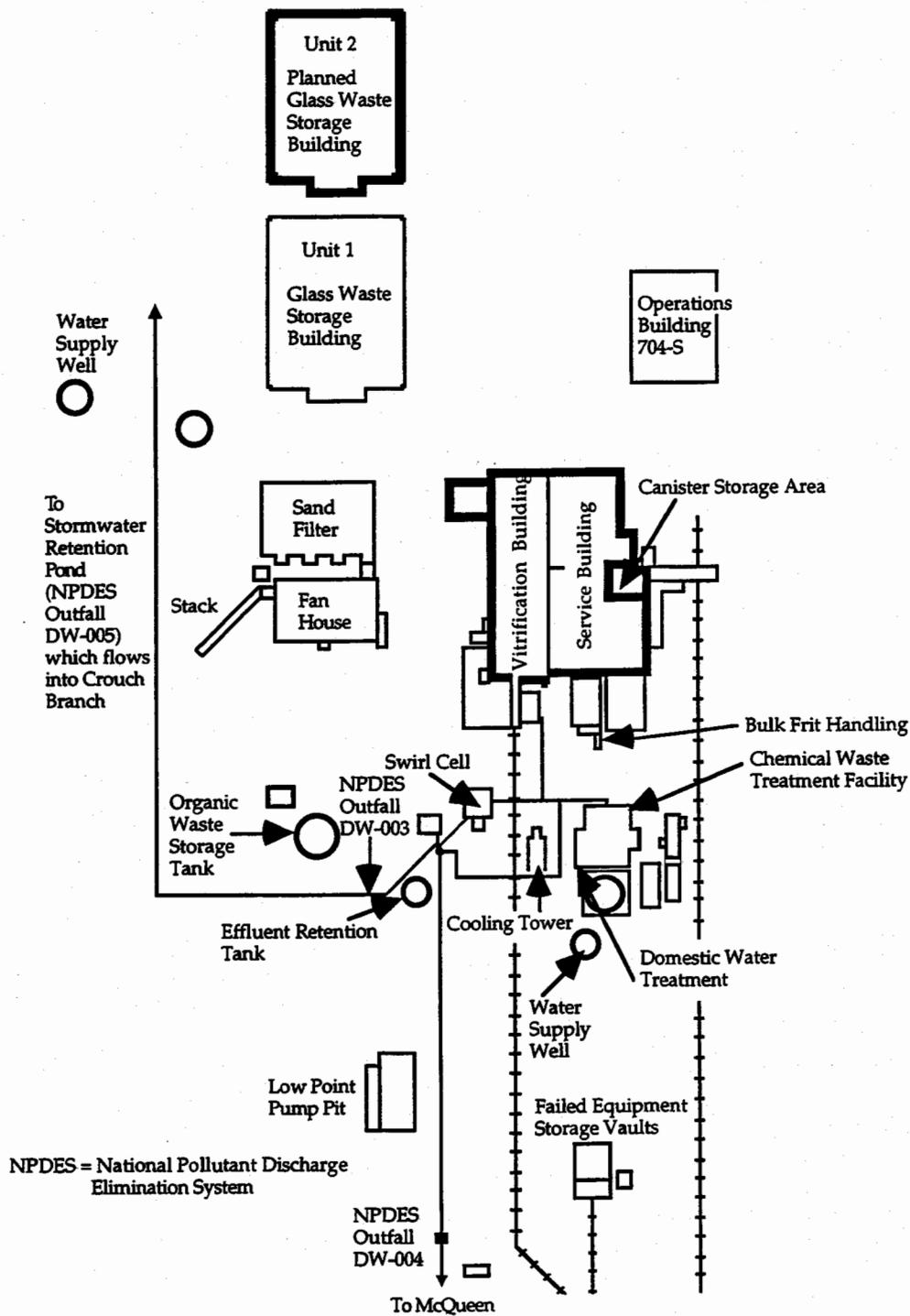
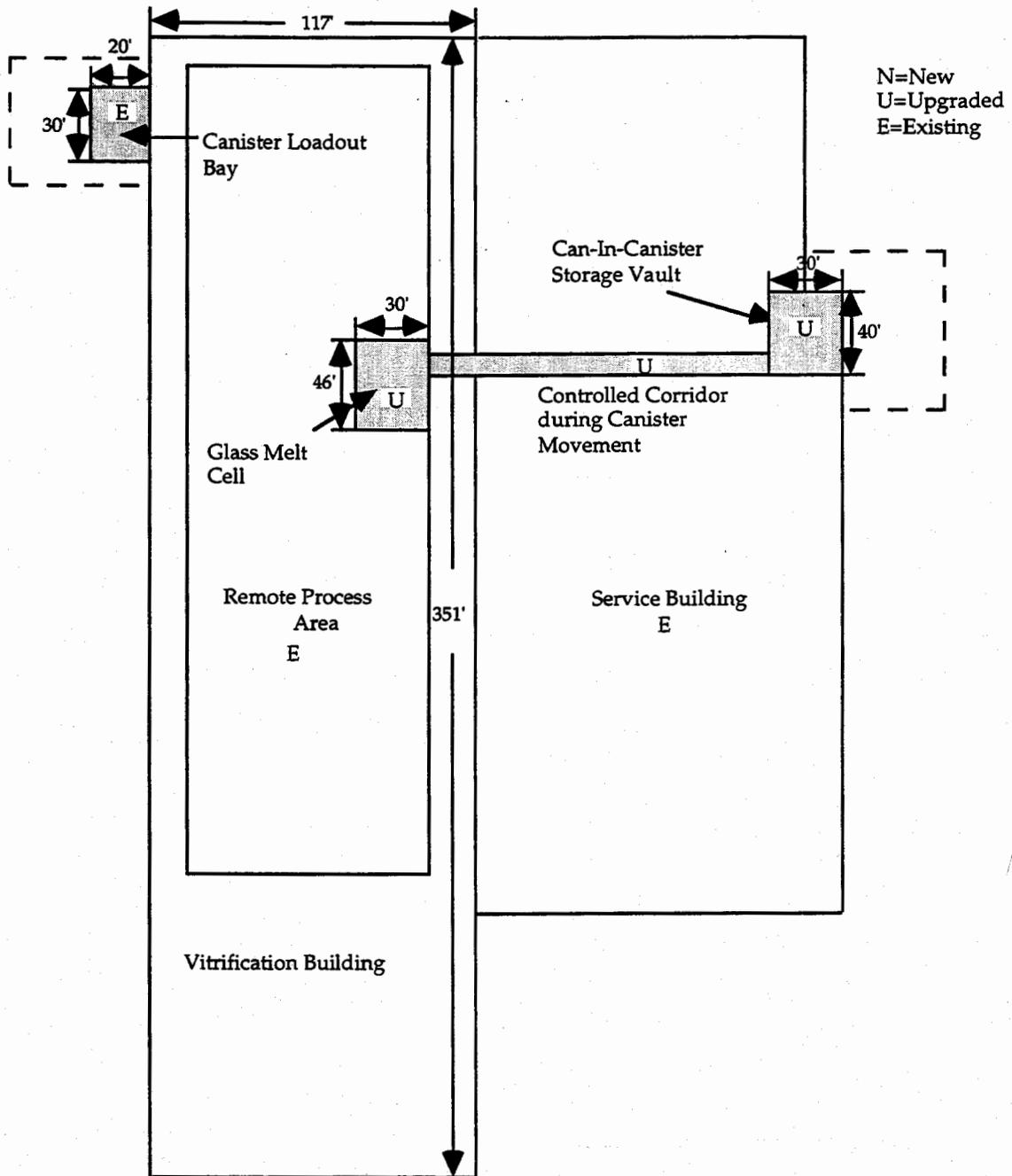
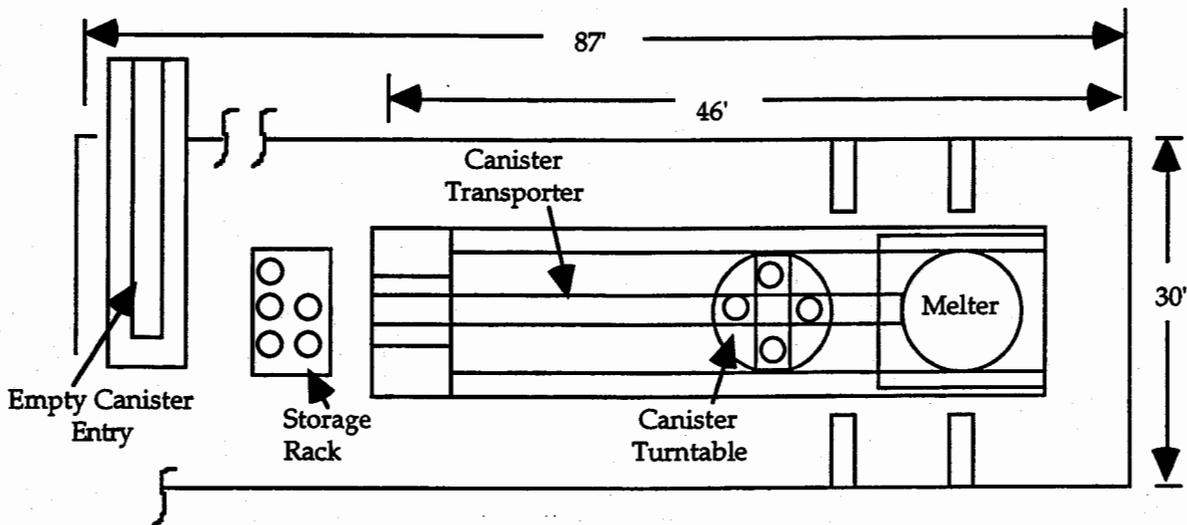


Figure 6. S-Area layout showing plutonium canister storage area at DWPF.



Note: Existing facility - Only upgrades are required

Figure 7. Plutonium canister interim storage vault and transfer corridor to DWPF.



Note: Existing Facility, upgrades will be required for safeguards and security only.

Figure 8. DWPF canister fill.

Third party inspection. A separate room will be provided in the 221-F canyon building for third party inspection. The room will include a separate area for processing records, studying reports, calibrating and repairing instruments, and loading and unloading cameras, etc. A camera will be located at the vault entry point for recording the entry and removal of containers from the vault and identifying them by bar code numbers. The cameras will be automatically triggered by the proximity of the material entering the vault. The equipment that is to be isolated from electrical surges will be provided with noninterruptible power, and other utilities.

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 from various DOE facilities to various other processing facilities to accomplish the immobilized disposal option. 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 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 flow depending upon which agency has authoritative control. An assumption for FMDP is that any new facility that is required to accomplish the immobilized option 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 the DNFSB.

The NRC regulation (10 CFR 71) establishes the requirements for packaging, preparation for shipment, and transportation of licensed material. This regulation also defines 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 depending upon if the movement of materials is considered onsite (intrasite) vs. 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 and uncontrolled access".

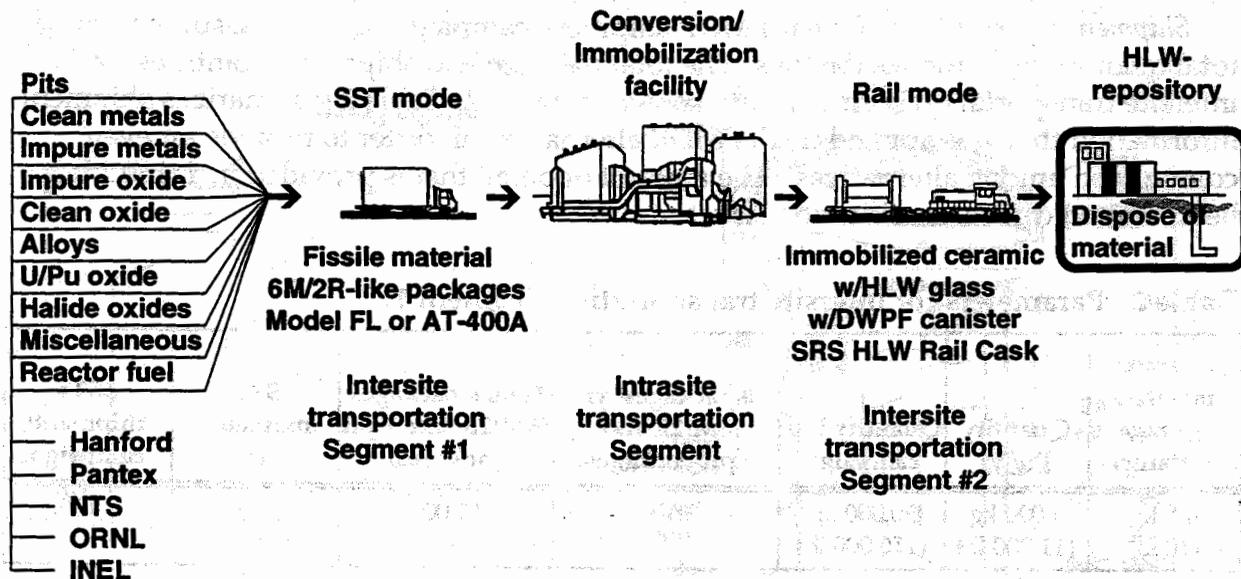
Transportation System. The transportation system is described below and shown graphically in Figure 9. There are two intersite transportation segments for the end-to-end immobilized option. The intrasite transportation occurs at the Savannah River Site (SRS) since the front-end processing and immobilization facility are co-located.

Intersite Transportation Segment #1

During this segment, fissile material located at various DOE facilities is transported to the onsite temporary storage at SRS. The materials requiring transport include: pits, clean metal, impure metal, impure oxide, clean oxide, alloys, U/Pu oxide, 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. Different 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 is assumed to meet *The Criteria for Safe Storage of Plutonium Metals and Oxides* stated in the DOE standard DOE-STD-3013-94, 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.



10.0.1195.2509pb09

Figure 9. Simplified flow chart showing transportation segments.

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 SAFREG 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 SST transport. A review of these variants 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 nonpit plutonium material when considering intersite transportation segment #1.

Shipment Information. 10-year FMDP shipment campaign has been assumed with a total quantity of 50 tonnes (56 tons) The total package and shipment quantities for intersite transportation segment 1 are shown in Table 2. Table 2 summarizes shipment information that was applied to all FMDP alternatives in order to provide an even comparison among alternatives. The amount of detail that is provided in Table 2 has been limited due to classification issues.

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 (10 lb)	5,000 kg (11,000 lb)	50,000 kg (110,000 lb)	3,100	31,000	110	1,100

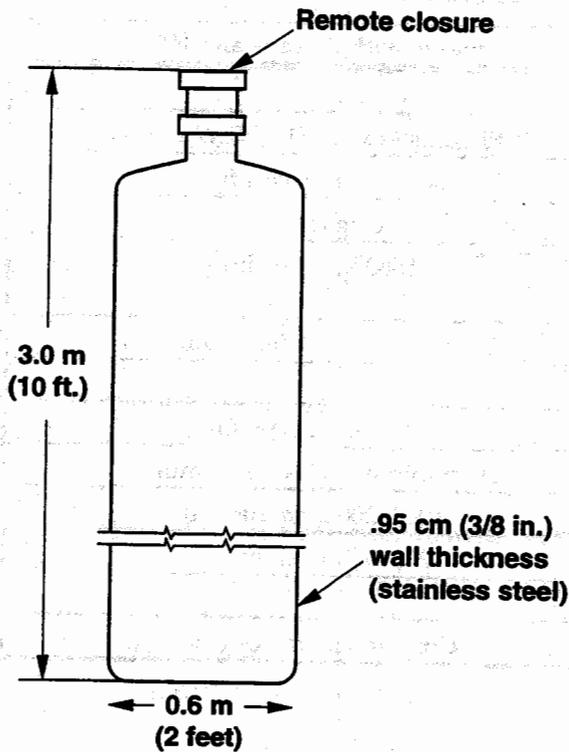
Intrasite Transportation. Canisters containing the plutonium-ceramic cans will be transported from 221-F to the DWPF Service Building via rail or truck, under heavy guard force protection.

Intersite Transportation Segment #2. During this segment, waste canisters loaded with up to 12 wt% weapons-grade plutonium ceramic in cans surrounded with HLW glass from SRS as a radiation barrier, are transported from SRS to the HLW repository.

Package Description. DOE is currently developing a stainless-steel canister for the Defense Waste Processing Facility (DWPF), shown in Fig. 10, for encapsulating plutonium ceramic glass for emplacement in HLW repository. The DWPF canister used at SRS, or a similar container, is expected to provide the primary containment boundary. Two variants of the DWPF canister have been tentatively selected for encapsulating immobilized plutonium forms depending on the waste form. The configuration shown in Figure 10 will be used for the ceramic can-in-canister option.

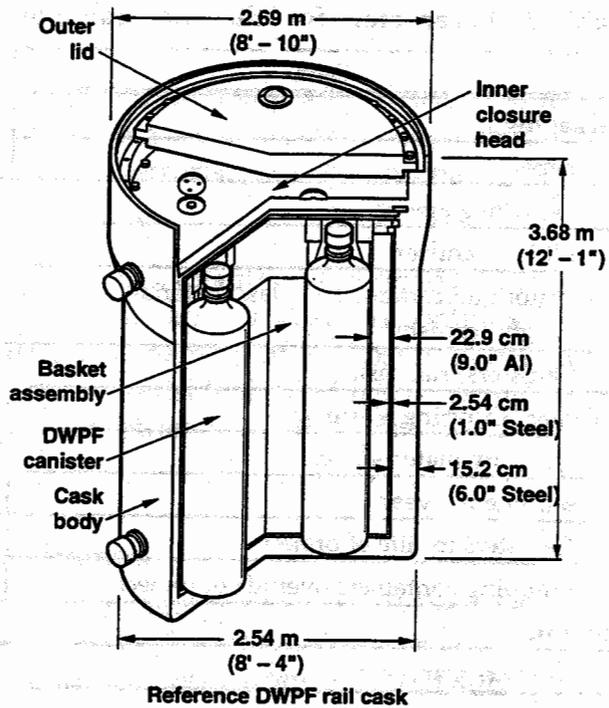
The additional packaging component required is a transportation cask which should also provide radiation shielding necessary for shipping the DWPF canisters to the HLW-repository. DOE is also developing a rail shipping cask for DWPF canisters. This SRS HLW rail cask, shown in Figure 11, will hold five DWPF canisters. After the SRS HLW rail cask is certified and approved by the NRC for DWPF canister transport, it can be certified and approved for shipping the immobilized plutonium forms to the HLW-repository.

The base case for the can-in-canister option assumes that plutonium will be contained in up to 1000 DWPF canisters. As the cans in these canisters will displace only 20% of the high-level waste-glass, an incremental increase in the number of canisters generated in the DWPF of 200 canisters over the life of the project. The increase in the number of shipping containers required by this option is 40.



10.0.0895.2070pb02

Figure 10. DWPF canister.



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

10.0.1195.2570pb03

Figure 11. SRS HLW rail cask.

Shipment Information. Table 3 details the packaging requirements and mode of transport for the immobilized glass material.

Current plans for shipping HLW glass canisters to the repository are to use a shipping cask that will hold five HLW canisters. The conceptual design would hold five DWPF canisters. Since the actual design has not been completed, it will be possible to design an expanded metal collar that would sit atop the canisters and prevent their easy extraction from the shipping cask.

Although the plutonium containing canisters could be shipped five to the shipping cask, probably only one canister per shipping cask will be shipped. This would allow the plutonium canisters to be positioned in the repository drifts at only one canister per disposal cask for ease of criticality control in the repository without requiring extended lag storage at the repository surface facility.

Table 3. Parameters for Intersite Transportation Segment 2

Data	Contents with Pu cans and HLW
Packaging	
Type	DWPF canister with SRS HLW rail cask
Certifying agency	not currently certified
Wt Pu/canister	50 kg (110 lb)
Plutonium ceramic and glass material weight/canister	1680 kg (3700 lb)
Canisters/rail cask	5 (maximum)/1 (minimum)
Average Shipping Volumes	
Quantity material/year	5000 kg (11,000 lb)
Shipments/year	20 (minimum)/100 (maximum)
Canisters for life of project	1000 (200 incremental)
Shipping containers over life of project	200 (40 incremental)
Routing	
Mode of transport	Commercial rail or truck

1.5.2 Domestic Safeguards

The FMDP has established two major Safeguards and Security (S&S) 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 is to protect and provide nonproliferation assurance 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, theft, and radiological and toxicological sabotage. Domestic safeguards primarily address unauthorized actions perpetrated by individuals and/or sub-national 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 nation's weapons complex), *diversion* (e.g., unauthorized removal of material by a member of the host nation's 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).

1.5.3 International Safeguards and Non-Proliferation

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

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 which may be affected by international and/or bilateral agreements to include areas which may be subject to the International Atomic Energy Agency (IAEA). International safeguards are composed of two subsystems, nuclear materials accountancy and materials containment and surveillance, 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 U.S.) 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 U.S. and agreed upon by the IAEA member states.

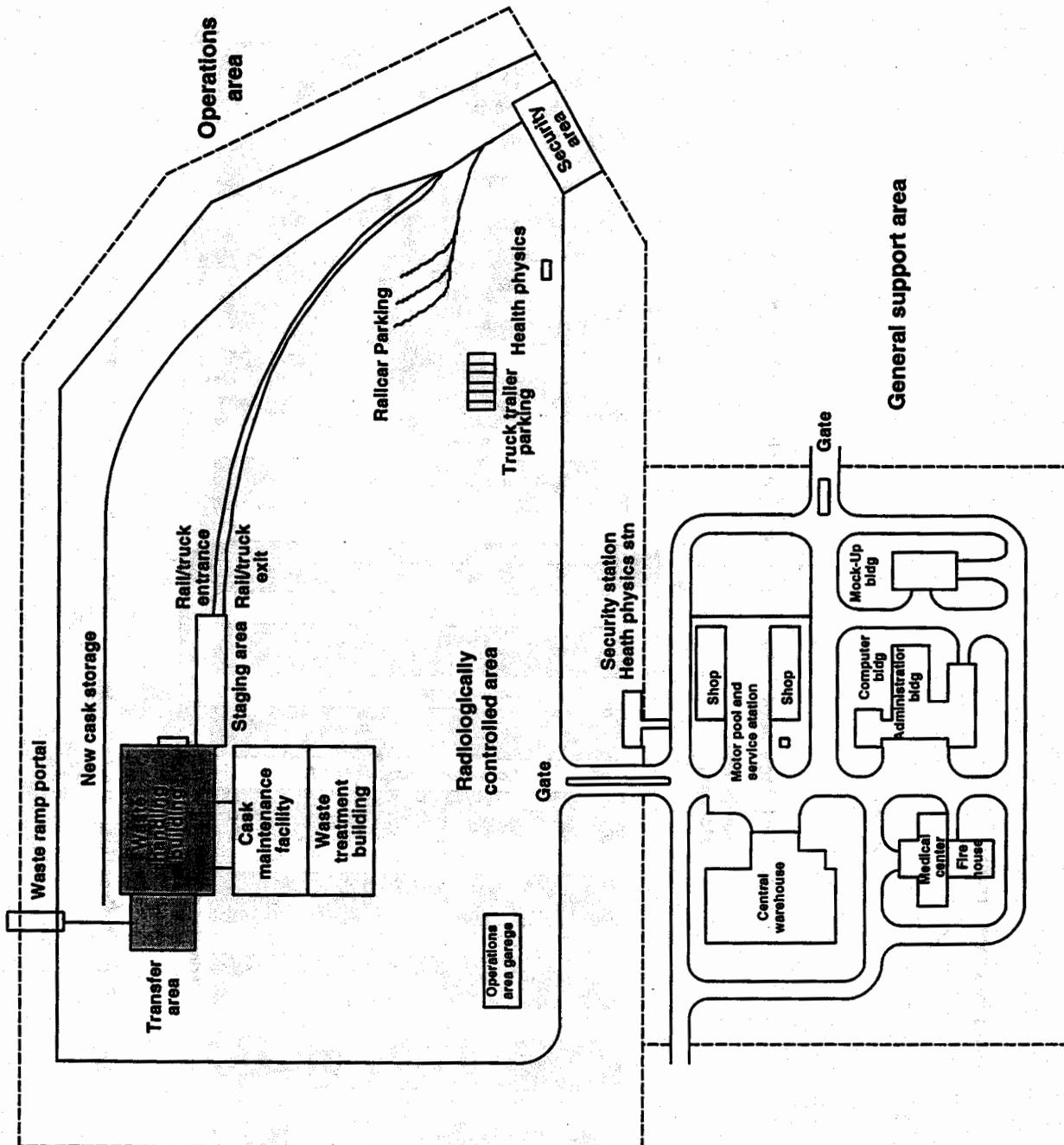
Domestically the DOE and NRC are the Safeguards and Security policing agencies depending upon jurisdiction. However, internationally there is no direct police organization for domestic safeguards and security. Specifically, the IAEA has no jurisdiction or obligation to oversee the measures taken by a state (or host nation) to address unauthorized access to special nuclear material (Criteria 1). In this variant 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 U.S. and the IAEA, part of the plutonium processing facility may, or may not, 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 for permanent disposal of plutonium waste forms consists of a surface facility (Fig. 12) for receipt and handling of wastes, and a subsurface facility (Fig. 13) for permanent isolation of the wastes from the accessible environment. The surface facility contains two separate areas: an operations area containing all the facilities for handling wastes that require radiological control; and a general support area consisting of "cold" facilities and the supporting infrastructure.

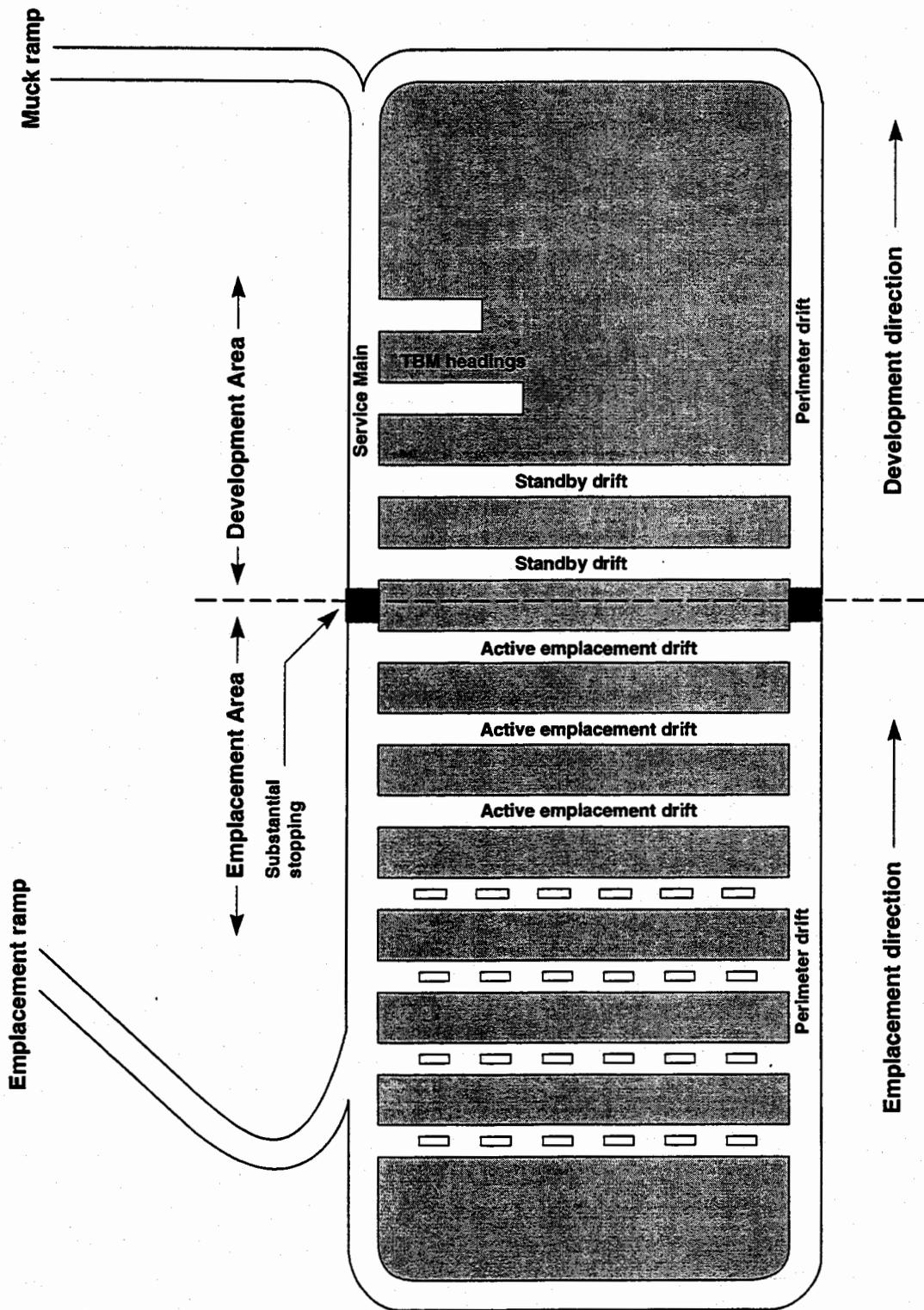
The disposal of immobilized waste forms in a repository is a solids handling process (Fig. 14). The loaded transportation casks containing immobilized plutonium forms are inspected at the repository boundary, and moved to a radiologically controlled area. The plutonium waste from casks will then enter 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.

The NRC requires two positive means of criticality control to be maintained. One method considered for the immobilized forms is the use of neutron absorber contained within the matrix of the immobilized forms. The second method being considered is placement of only one plutonium canister per disposal cask. Accordingly, only one plutonium canister would be placed in a shipping cask with the remaining canisters containing HLW. Otherwise extended lag-storage of the plutonium canisters would be required at the repository surface facility. The loading of only one plutonium canister per cask also has an safeguards and security benefit, posing a "shell game" problem to a theft attempt.



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Figure 12. Conceptual plan for repository surface facilities handling plutonium waste forms.



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Figure 13. Conceptual layout for isolation of plutonium waste forms.

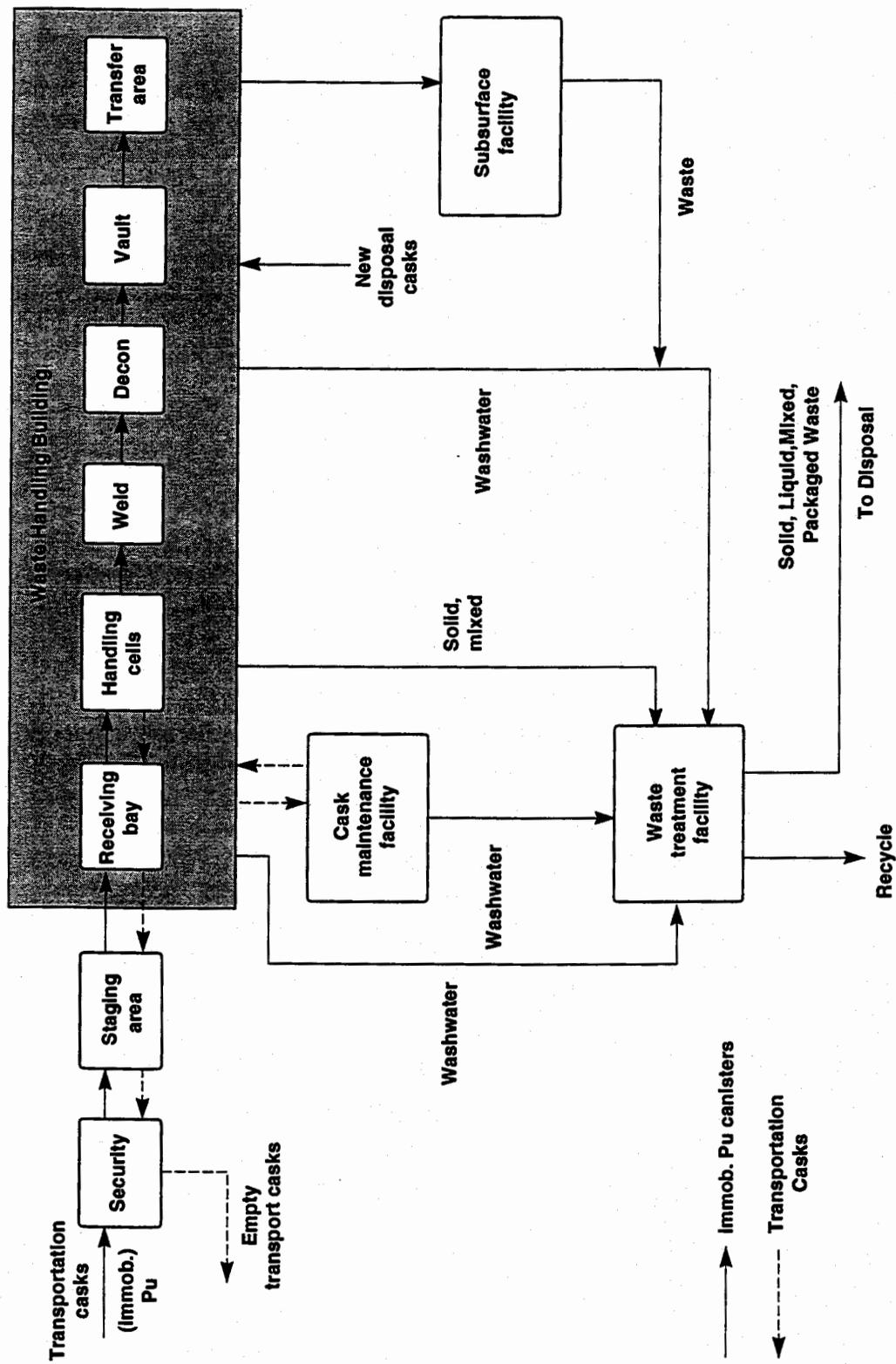


Figure 14. Conceptual process flow diagram for handling plutonium waste forms.

1.6 Other Approaches

1.6.1 Wet Pretreatment Feed Preparation Option

Another approach to using a dry-feed preparation process is a nitric acid wet process. Each wet-process step takes place in 221-F canyon building in F-Area at the SRS. The wet-feed preparation option is capable of dissolving plutonium forms other than oxides. Based upon further analysis and demonstration, this process may prove to significantly reduce the amount of DNFSB Recommendation 94-1 Remediation material requiring conversion to oxides in the front-end facility which could result in cost savings for this immobilization variant.

In this option the first- and second-level flow diagrams remain the same as shown in Figure 1-3. The processes that change are described below.

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 and 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 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 allow for better mixing. The process will also accommodate a stirrer blade in the center of the slurry tank.

CE-03 Dry & 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 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.

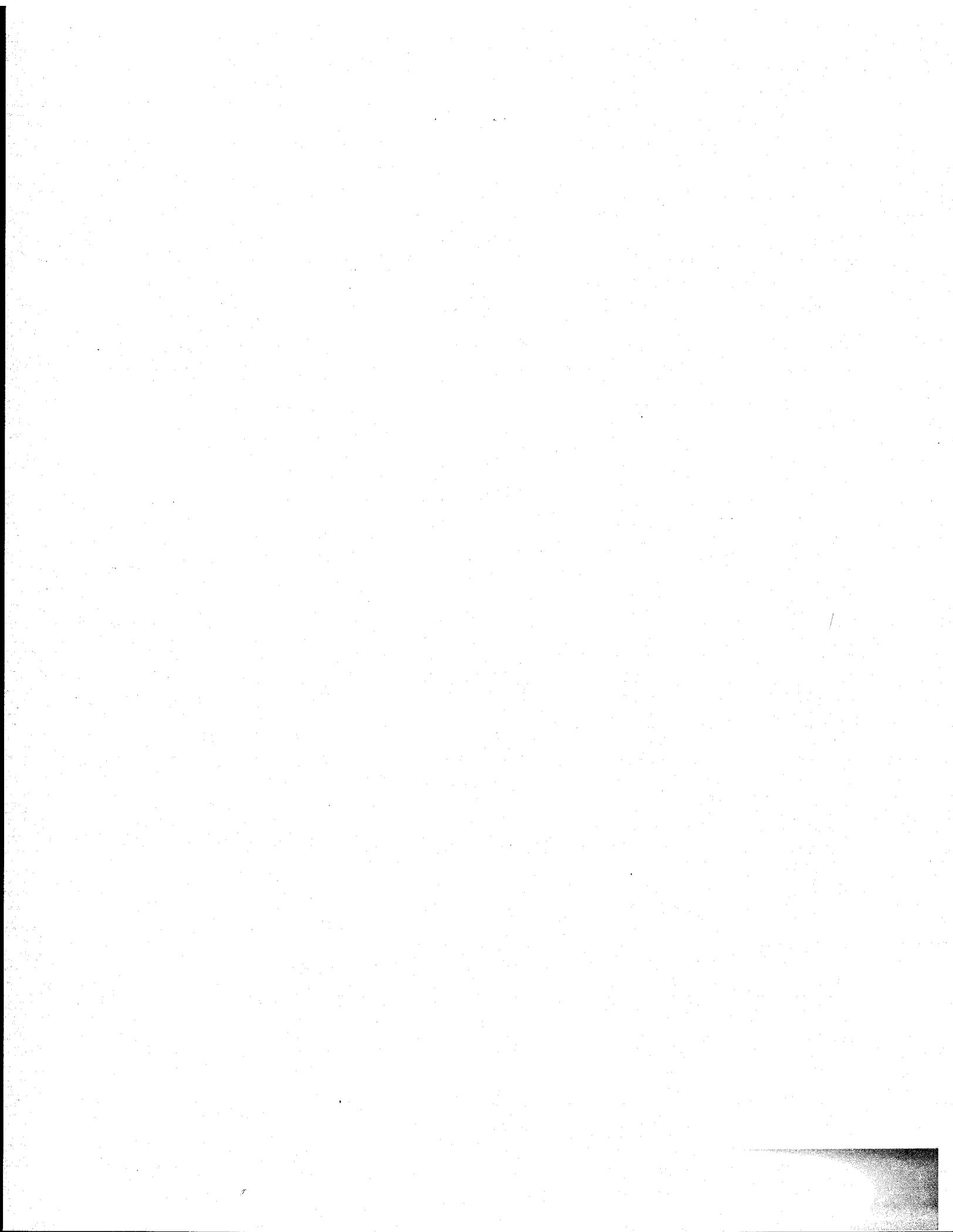
1.6.2 Hot Press in Bellows

Another approach to using cold pressing and sintering to fabricate the plutonium ceramic is to use a one step fabrication, namely hot pressing or hot isostatic pressing. This would be more costly than cold pressing and sintering, but would provide a denser and more uniform product. As a result, few if any pellet failures are expected thus eliminating the need for *Crushing and Milling* (CE-18).

In this option, the first-level flow diagram remains the same, but the second level flow diagram is revised. For the hot pressing in bellows option, the following changes are made to the baseline flow diagram (Fig. 3): *Bellows Filling and Closure* (CE-04) and *Hot Pressing* (CE-05) replace *Milling Granulation* (CE-14), *Pellet Pressing* (CE-15), *Screening/Inspection* (CE-16), and *Sintering* (CE-17). All other processes remain the same as discussed in Section 1.3.

CE-04 Bellows, Filling & Closure. The dried and calcined ceramic precursor material loaded with plutonium will be removed and transferred to the bellows with minimal or no contamination to the outside of the bellows. 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 about 1200°C (2200°F) and pressed at 14,000 k Pa (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. The muffle furnace will be held between 600°C and 800°C (1180–1470°F) until a number of 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. After hot pressing, the compressed bellows will be approximately 6.4 (2.5 in) diameter by 2.5 cm (1 in) high.



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 under way. 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. The use of existing facilities at SRS reduces the environmental impact from construction for both front-end and back-end processing because new facilities are not needed. The number of additional DWPF canisters required for this case is significantly less than for the greenfield cases.

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, sub-national 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

direct attack on a facility or they could involve covert measures that might utilize stealth and deception as well as possible help from an "insider." It is assumed that all facilities will meet the necessary safeguards and security requirements and that existing measures will help mitigate any risks. 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 variant, a brief discussion is presented below of the potential risks to theft.

The safeguards and security requirements for this variant 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 that 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 4 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 safeguards and security category of protection has its own requirements ranging from the highest level of protection, Category I, for assembled weapons, to Category IV for irradiated forms and less than 3 kg 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 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 must be made of a bullet resistant material. Duress alarms will be necessary at all manned 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 x-ray machines for hand-carried items.

Table 4. 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

2.2.2 Identification of Diversion, Theft, or Proliferation Risks

Tables 5-7 following this narrative provide information about the flow of plutonium through this variant, along with a description of the material and its changing attractiveness levels.

221-F-Area Facility. The 221-F facility is a safeguards 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 through II-D). Initially within this facility, most of the material is in a very attractive form with minimal intrinsic barriers. 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. Within the facility material will be changing form and concentration, decreasing the basic levels of protection category and attractiveness. At the ceramic fabrication area the oxide is mixed

Table 5. Safeguards and security environment.

Facility	Environment							
	Activity	Duration	Throughput	Waste streams	Lag storage	Max inventory	Intrasite transport	# proc steps
221-F Plutonium Processing and Immobilization	Feed processing and immobilization in a ceramic matrix	40 hrs.	5 tonnes (5.6 tons)/yr	Yes	Yes	~2 tonnes (2.2 tons)	Yes**	10
S-Area Facility DWPF	Plutonium/ ceramic can placed in HLW glass matrix	65	5 tonnes (5.6 tons)/yr	Yes	Yes	5 tonnes (5.6 tons)	Yes	0
Intersite Transport	DWPF Canisters in Transportation Casks to HLW Repository	TBD	5 tonnes (5.6 tons)/yr	No	No	N/A	N/A	0
High Level Waste Repository	Receiving, NDA*, transfer to emplacement canisters	TBD	5 tonnes (5.6 tons)/yr	No	Yes	5 tonnes (5.6 tons)	Yes, to drift emplacement	0
	Emplacement in repository	Permanent disposal	5 tonnes (5.6 tons)/yr	No	No	50 tonnes (56 tons)	No	0

* If required.
 ** F-Area to S-Area.

Table 6. Safeguards and security material form.

Facility	Activity	Material form					
		SNM input	SNM output	Conc. of pu	SNM category-attractiveness	Item mass/Dimensions	Self protecting
221-F Plutonium Processing and Immobilization	Feed processing and immobilization in a ceramic matrix	Metal and oxide	Ceramic	In - 90% Out - ≤12% by wt. of ceramic in cans	In - I-B Out - II-D	Various	No
Intrasite transport	Plutonium ceramic can to S-Area facility	Ceramic	Ceramic	≤12 wt.%	II-D	Can: 2.5 kg (5.5 lb) 12 cm (4.8 in) × 58 cm (23 in) Canister: 412 kg (906 lb) 60 cm (24 in) × 305 cm (10 ft)	No
S-Area Facility DWPF	Plutonium ceramic cans placed in a HLW glass matrix	Ceramic	Ceramic in HLW glass	12% (3% **by wt. in DWPF canisters)	In - II-D Out - IV-E	DWPF Canister 1680 kg (3700 lb) 60 cm (24 in.) × 305 cm (10 ft)	In - No Out - Yes/Rad.
Intersite Transport	DWPF Canisters in Transportation Casks to HLW Repository	Ceramic in HLW glass	Ceramic in HLW glass	3%**	IV-E	Cask 87 tonnes (96 tons) ~2.7 m (8 ft 10 in) × 3.7 m (12 ft 1 in)	Yes/Rad
High Level Waste Repository	Receiving, NDA*, hot cells, lag storage	Ceramic in HLW glass	Ceramic in HLW glass	3%**	IV-E	Emplacement Cask 22 tonnes (24 tons) ~1.6 m (5.2 ft) × 3.1 m (10 ft)	Yes/Rad.
	Emplacement in repository	Ceramic in HLW glass	Ceramic in HLW glass	3%**	IV-E	Emplacement packages	Yes/Rad.

* If required.
 ** Within inner can, concentration of plutonium is 12% in the plutonium bearing ceramic.

Table 7. Safeguards and security assurance.

Facility	Activity	S&S assurance				
		# of MBAs	Type of accounting	Nuclear measurement	Classified matter	Accessibility**
221-F Plutonium Processing and Immobilization	Feed processing and immobilization in a ceramic matrix	9	Bulk and item	Calorimetry, gamma, seg gamma neutron	in - yes out - no	THN
Intrasite transport	Plutonium ceramic can to S-Area facility	N/A	Item	N/A	No	CHY
S-Area Facility DWPF	High level waste (HLW) glass poured around cans	1	Item	Weight, neutron interrogation.	No	In - CHY Out - CRY
Intersite Transport	DWPF Canisters in Transportation Casks to HLW Repository	N/A	Item	N/A	No	CRY
High Level Waste Repository	Receiving, NDA*, transfer to emplacement casks	4	Item	N/A	No	CRY
	Emplacement in repository	TBD	Item	N/A	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.

with a matrix material, reducing the attractiveness level to a probable estimate of Category II-D. The final product is encased in a relatively small stainless steel can. The small cans are then emplaced within a larger canister that contains approximately 50 kg (110 lb) of plutonium, at a concentration of 12% or less. Since these forms/targets are still relatively accessible and transportable (prior to radiation spike) they are attractive targets for both covert and overt theft.

Overt theft attempt targets of greatest concern in this facility are the pits, pure metal, and oxides that are very transportable. However, these materials will be under significant protection so that the risk associated with an overt event would be acceptable.

The cans of vitrified plutonium will be loaded into the internal holding rack and then into the DWPF canister in the 221-F-Area facility. The welded cage structure surrounding each can will prevent removal of any can from the internal rack without first cutting the rebar cage. The internal rack will then be placed into the DWPF canister as a single element. The top of the canister will then be welded onto the body of the canister and the weld certified. At this point the twenty plutonium ceramic cans will be treated as one single unit for transport from F-Area to S-Area. The transport of the canisters, probably six or eight at a time, will be under significant protection so that the risk associated with an overt event would be acceptable.

S-Area Facility (DWPF). In the initial stages of handling and processing, S-Area facility is assumed to be a Category I facility. Within the facility material will be changing format concentration, decreasing the protection category and attractiveness. With the addition of a self-protecting property the material meets the definition for Category IV-E.

At DWPF the plutonium cans are surrounded by HLW glass reducing the attractiveness level. The final product is encased in a stainless steel canister and contains approximately 50 kg (110 lb) of plutonium, at an average plutonium concentration of 3% when the surrounding HLW glass is included.

Once the immobilized material has been given a self-protecting barrier by the introduction of HLW glass the safeguards and security requirements are significantly reduced as the Category is now that of IV-E (highly radioactive material, i.e., 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 (approximately 100 years) 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 can-in-canister variant is self-protecting and proliferation resistant with the high level waste glass in the canister which surrounds the plutonium ceramic cans. However, additional proliferation resistance measures are being investigated to potentially reduce the risk of theft and retrieval of the plutonium ceramic cans from the filled canisters by unauthorized outsiders such as terrorists and subnational groups. Potential proliferation resistance measures that are being investigated include, but are not limited to, the following:

- The cans could be encased inside a cage of steel re-enforcing bars (rebar) and the cans welded to the rebar. Steel plates will be on both the top and bottom of the cans, these plates could also be welded to the cans. The steel rebar cage could then be enclosed using a sheet of perforated metal. These welds will hold the cans in position within the canister. The welds will keep the cans attached to the rack during an activated explosive charge. The expanded metal will hold a quantity of high level waste loaded glass next to the cans. The cage structure would make the cans even more difficult to remove from the canister.
- A special coating could be developed which could be applied to the exterior of the cans and the perforated metal cage. This special coating would chemically bond to with the high-level waste glass when it contacts the cans and the expanded metal cage. As a result, some high level waste glass would remain surrounding the cans and the expanded metal following an activated explosive charge.

The implementation of such additional proliferation resistance measures must be evaluated against the technical viability and cost of those measures versus the additional proliferation resistance that would be provided. The degree of proliferation resistance would be declared adequate when it becomes more trouble for a terrorist group to separate the cans than it is for them to carry off the canister.

The DWPF plutonium canisters are filled and sealed. No further bulk processing is required. 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.

The canisters would be loaded into a SRS HLW rail cask for transport to the repository. The primary threat here is that a terrorist group could blow the lid off the shipping cask, drop a lifting ring around a DWPF canister and lift it from the shipping cask using a helicopter. Potential proliferation resistance measures that are being investigated include, but are not limited to, the following:

- A perforated metal collar that tops the canisters would prevent easy extraction of any one canister from the shipping cask.
- Approximately 1200 cask shipments, containing 5 canisters each are required to transport the DWPF HLW glass canisters to the repository. A minimum of 200 and a maximum of 1000 shipments would be necessary to transport the vitrified-plutonium canisters. A terrorist group would therefore have to have insider knowledge to determine which of the shipment contained one or more plutonium-containing canisters. As the shipping cask could contain from zero to five plutonium-containing canisters, the group would also have to have insider knowledge as to which canister contained plutonium if only one canister was to be hijacked. If only one plutonium canister was placed into a shipping cast, as probably will be required to maintain criticality control in the repository, then the terrorist group would have a 5 in 6 chance of hitting a shipment containing plutonium canister, but only a 1 in 5 chance of selecting the correct canister if the shipping cask contained a plutonium-containing canister.

The implementation of such additional proliferation resistance measures must be evaluated against the technical viability and cost of those measures versus the additional proliferation resistance that would be provided.

Risk Assessment. The measures identified for this criteria are the *environment, 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 of the facilities in this variant. Table 8 summarizes the potential risks. This assessment is highly qualitative and based on available data.

Environmental Conditions—The logistics, physical location, and the state during processing, transportation, or storage affect the opportunities for theft. The more complex the logistics (e.g., transfers and process locations), the more opportunities there are for theft. The more inaccessible the physical location (e.g., storage locations), the fewer opportunities for theft. Table 5 summarizes the safeguards and security environmental data.

221-F-Area Facility. The processing area in 221-F involves a large number of processing steps with a relatively high throughput. Based upon the quantity and attractiveness of the material this will be a Category I facility. Waste streams containing fissile material will be generated and thus require monitoring to prevent possible theft or use as a diversion path. There will be lag storage in an active vault. 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.

Safe secure trailer/transport will be used to deliver the material to 221F. There will be no intrasite transport movements until the large DWPF canisters are moved to the DWPF building.

Table 8. Relative Potential Risks for threats and criteria 1 & 2.

	Plutonium processing (Bldg. 221F)	Intrasite Transit	DWPF HLW Glass Pour S-Area Facility	Inter-Site Transit	High Level Waste Repository	After Repository Emplacement
Threat						
Covert Threat	High	Medium	Medium	Low	Low	Low
Overt Threat	Medium	Medium	Medium	Low	Low	Low
Diversion	High	Medium	Medium	Low	Low	Low
Criteria 1						
Material Form	High	Medium	Medium	Low	Low	Low
Environment	Medium Low	Medium	Medium	Low	Low	Low
Safeguards and Security	High	Medium	Medium	Low	Low	Low
Criteria 2						
Detection	High	Medium	Medium	Low	Low	Low
Irreversibility	High	Medium	Medium/Low	Low	Low	Low

Waste streams containing fissile material will be generated during processing activities.

S-Area Facility. The initial handling of the plutonium ceramic cans will be in a Category I Interim Canister Storage Vault (GL-26) until the cans in the DWPF canister enter the self protecting DWPF melter cell. No waste streams containing fissile material will be generated in the DWPF. 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 canisters from the storage area to the HLW 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 secures the drift and waste packages; final "securing" will not occur until; the end of the performance period (currently expected to be a 100 years from start of emplacement).

Material Form. Attractiveness is based on physical, chemical, or nuclear (isotopic and radiological) makeup of the fissile 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 content. Table 6 summarizes safeguards and security material form data.

221-F-Area Facility. The material received at the plutonium processing area is the most attractive material for this variant (e.g., pits, pure metal, and oxide) and can be up to Category I-B. The material has overall very low intrinsic barriers, and is transportable. It has a very low radiological barrier. It is in most cases 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.

Once the material has been blended and immobilized in the ceramic matrix, it is 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 produce a significant quantity. The Safeguards Category and Attractiveness has a probable determination of II-D, at this point. Once the material is placed into canisters its chemical, isotopic and radiological attributes would not change but its target mass and dimensions would increase (e.g., canisters) thus making it more difficult to move and easier to maintain surveillance, control, and accountancy.

S-Area Facility. The initial feed material, is comprised of very attractive material (I-C) within small, but sealed cans. With the addition of highly radioactive barrier material, the plutonium is safeguards categorized as IV-E.

Repository. The immobilized 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 an order of magnitude in 90 to 100 years.

Safeguards and Security Assurance. The effectiveness of safeguards and security protection depends on the materials 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 7.

221-F-Area Facility. Material received into this facility (e.g., pits and containers with tamper indicating devices) would utilize item accountancy. Once the material has been removed from the "container" bulk accountancy would be necessary. Much of the material is small and many operations involve hands-on activities. In addition to destructive assay other nondestructive assay (NDA) would be performed. As mentioned previously the pits and some other material will be classified. This may also apply to waste streams.

After the material is converted to a plutonium ceramic and sealed in a stainless steel can accountancy would revert to item count.

S-Area Facility. During all processing operations item accountancy would be conducted. Once the material is placed inside the canisters it is no longer accessible, and requires special remote handling equipment to be moved.

Item accountancy is used to account for canisters. Markings and seals on the canisters can also be used to verify material. Special handling equipment is required to move these canisters and once they have a radiation barrier remote handling is necessary. For immobilized-spiked material some non-destructive 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 variant 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 and 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 trailer/transport will be used to move the material between sites. A secure loading/unloading area must be available to ship/receive, verify, and store the Category I material. With respect to other transport activities (i.e. between processing and storage), there are inherently fewer 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 variant 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 world-wide 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 and 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 and 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 and therefore verification by the IAEA is not possible, until agreements between the IAEA and the U.S. can be accomplished. A number of different options are being considered which address this problem.

2.3.2 Possible Diversion, Reuse and Retrieval Risks

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 materials control and accountability, the IAEA will seek to independently verify material accounting.

Containment and surveillance are used to complement the material 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 variant there may be some differences. Because of inherent limitations on the accuracy of non-destructive assay measurements there is an increased risk of diversion at high throughput facilities. This is where containment and surveillance plays an important role in assuring material accountability. For each of the facilities in this variant a brief discussion is presented below of some of the potential risks to diversion. 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 materials control and accountability steps to be subverted in order to avoid detection.

221-F-Area Facility. The material received at the plutonium processing facility is the most attractive material for this variant (e.g., pits, pure metal and oxide). In the case of pit conversion the attractiveness goes from I-B to II-D. The material has overall very low intrinsic barriers, and is transportable. It is in most cases 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.

S-Area Facility. The primary initial feed material is comprised of relatively attractive material (II-D). Once the material is placed into canisters its chemical, isotopic and radiological attributes would not change. However, in S-Area target mass/dimensions would increase, and because of the presence of highly radioactive fission products chemical processing to convert into a weapons usable form is much more difficult, making it a Category IV-E material.

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 and 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.

Again 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 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.

221-F-Area Facility. The material received at the plutonium processing facility is the most attractive material for this variant (e.g., pits, pure metal and oxide). In the case of pit conversion the attractiveness goes from I-B to II-D. The material has overall very low intrinsic barriers, and is transportable. It is in most cases 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.

S-Area Facility. The primary initial feed material is comprised of relatively attractive material (II-D). The intrinsic attributes of this material are the same as described above. Once the material is placed into canisters its chemical, isotopic and radiological attributes would not change. However, target mass and dimensions would increase, and because of the presence of highly radioactive fission products chemical processing to convert into a weapons usable form is much more difficult, making it a Category IV-E material. 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 waste packages in a deep repository makes diversion very difficult, expensive,

and easily detected by containment and 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 & 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 non-destructive analysis 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

221-F-Area Facility. The material received at the plutonium processing facility is the most attractive material for this variant (e.g. pits, pure metal and oxide). In the case of pit conversion the attractiveness goes from I-B to II-D. The material has overall very low intrinsic barriers, and is transportable. It is in most cases 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.

S-Area Facility. The feed material, is comprised of relatively attractive material (II-D). The intrinsic attributes of this material are the same as described above. Once the material is placed into canisters its chemical, isotopic and radiological attributes would not change. However, target mass/dimensions would increase and because of the presence of highly radioactive fission products chemical processing to convert into a weapons usable form is much more difficult, making it a category IV-E material. After 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 waste packages will be sealed, item accountancy performed and containment and 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 and 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 SYNROC material. This is a titanate based waste form composed primarily of zirconolite, perovskite, hollandite, and rutile phases. Other phases have also been incorporated into the assemblage depending upon the stage of SYNROC

development and the composition of the waste to be immobilized. In a SYNROC waste form, 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 to name a few.

A significant strength 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. 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 in deionized water. Total dissolution rate of ceramic is also extremely low, around 0.15 nm (0.16 n yd) per day for SYNROC at 150°C (300°F) in deionized water.

Ceramics being crystalline in nature are sensitive to radiation damage effects which causes them to lose crystallinity thus 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 increased basicity 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 analogues in nature which 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 are expected to aid tremendously in the licensing process of a plutonium ceramic waste form.

For the nuclear material disposition application, a significant solid solubility of actinides 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. The pyrochlore phase can accommodate at least 30 wt% plutonium into its structure.

2.4.1 Technical Viability of Front-End Plutonium Processing—Disassembly and Conversion

The front-end consists of several different processes to convert plutonium storage forms to those needed for immobilization. Most of the processes used in the front-end are on the industrialization scale. The remaining technologies are in the engineering-scale testing or transitioning into the industrialization stage.

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 segmented 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 Lawrence Livermore National Laboratory.

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

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

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

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 grinding 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 of oxide will be similar to the vault storage techniques used in DOE complex facilities for many years.

2.4.2 Technical Viability of Front-End Ceramic Immobilization and Back-End HLW Glass Immobilization

The ceramic immobilization front-end process calcines the plutonium oxide feed, and cold presses sinters that product into a ceramic waste form suitable to send to the geologic repository. The major unit operations are *Feed Preparation (CE-01)*, *Dry and Calcine (CE-03)*, *Pellet Pressing (CE-15)*, *Sintering (CE-17)*, and *Canister Filling (GL-25)*

Feed Preparation (CE-01). Dry-feed processing includes the receipt of plutonium oxide containing cans and the feeding of oxide powder. The feed of dry calcine is an established operation.

Wet feed preparation has been demonstrated world wide on a production scale for a number of years. Dissolution of plutonium oxide in nitric acid solutions with hydrogen fluoride is a standard process in the DOE weapons complex.

For 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 10 μm or less. Obtaining good product homogeneity and density is not expected to be a problem. Obtaining complete reaction may require longer sintering times and well blended input material, 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.

Calciner Feed Makeup (CE-02) and Dry and Calcine (CE-03). These steps have been demonstrated at a production scale using surrogate HLW solutions. Ceramic waste forms developed at ANSTO and LLNL are generally fabricated by adsorption onto a high surface area precursor powder or granules using a nitrate solution of the waste elements. The slurry is then dried, calcined, and loaded into a stainless steel bellows and hot pressed at around 1300°C (2400°F). This process is known to yield a homogenous and dense product (>98% density) where the waste constituents are fully reacted with the immobilization matrix.

Pellet Pressing (CE-15) and Sintering (CE-17). For the cold press and sinter process, the precursor material will probably be relatively coarse. Precursor particle size will be optimized to obtain maximum product densities which will be probably between 90 and 95% of theoretical density but not greater than 98% as obtained when 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 Resource Conservation and Recovery Act (RCRA) metals and radioactive surrogates. This is similar to the process used in the nuclear fuel industry. The fabrication of plutonium loaded SYNROC ceramics by this method has been underway but only limited data on reaction time vs. PuO_2 input size is available. It is expected that ceramics made in this

manner will initially be slightly less durable than hot pressed ceramics, but after long time periods when the form has turned metamict, it is expected that the durability of the two forms will probably be about the same.

For the hot pressing variant, the ceramic will be fabricated (roughly the same size as cold press and sinter) by sintering under pressure. This process has been demonstrated at a production scale using surrogate 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 can-in-canister facility will be considerably smaller than 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 variant. Although ceramic immobilization has been demonstrated at full scale using surrogates, full scale demonstration of the process using plutonium and neutron absorbers is still needed.

Canister Filling (GL-25). Canister filling is an existing DWPF process which has been demonstrated through qualification tests and initial operations to date. The canisters containing the small ceramic cans are designed to be substantially transparent to the existing DWPF canister filling and handling process. The filling of canisters containing small cans of a surrogate glass (slightly larger than the proposed ceramic cans) was demonstrated in DWPF prior to the start of radioactive operations.

GL-26 Interim Canister Storage. Interim canister storage is the modification of the DWPF canyon building to provide vault storage of DWPF canisters containing plutonium glass cans. Construction and operation of vault storage of Category I material is a routine operation in the DOE complex.

Other DWPF Operations. GL-14 blend tank, GL-17 off-gas treatment, GL-15 canister decontamination, GL-08 weld and test are existing facilities that are not expected to be affected by the can-in-canister option.

2.4.3 Technical Viability—Repository (Ceramic Can-in-Canister)

Regulatory Risk. Any waste form accepted for disposal in a HLW repository must comply with the provisions of the Nuclear Waste Policy Act, as amended (NWPA). 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.

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 envelop 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 affects 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.

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

2.5.1 Front-End Plutonium Processing—Disassembly and Conversion

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

The pit disassembly, conversion, 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.

For this variant, all of the front-end processes will take place in the modified existing 221-F facility at SRS. No new facilities are to be constructed for the front-end which results in significant reductions from the base case environmental impacts for construction.

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; the plutonium contaminated uranium is fed directly to the immobilization process.

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.

2.5.2 Back-End HLW Glass Immobilization

Using SRS DWPF facilities for the addition of HLW glass uses existing hot cell facilities. Support facilities that would be needed are also existing. Thus, building of new facilities is minimal and considerably less than assumed in the PEIS.

Additionally, since only about 200 additional DWPF canisters will be required for this option, versus 600 additional canisters for the base case, significant reductions from the base case environmental impacts for operations will also result. No additional waste streams will be generated for the final immobilization process for this option, which also results in significant reductions from the base case environmental impacts for operations.

2.6 Costing Data—Ceramic Can-in-Canister Variant

The approach to costing the ceramic can-in-canister variant 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 variant schedule to provide constant dollar cash flows that can then be discounted at the appropriate real discount rate. The two major figures-of-merit for each variant are the constant dollar front-end costs, i.e., all LCCs prior to normal operation of each facility (this is what the Government must spend to develop, design, construct, and start up a given facility), and the discounted total LCC, 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 was 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 9 summarizes the lump sum constant dollar costs by facility based on use of SRS facilities. (Costs are in millions of 1996\$.) Operating assumptions and design basis for front-end and back-end costing are presented in Table 10. The estimated duration of the plutonium 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 operating year should be 200 days.

2.6.1 Front-End Operating Assumptions

Since front-end plutonium processing and ceramic immobilization facility operation is dominated by the shipping/receiving and recovery operations, our assumptions are that all nonremote handled operations for the end-to-end variant will be contained in a single plutonium facility. Specific examples include all plutonium recovery operations and all immobilization operations not involving the final pour high level waste glass. 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.

Table 9. Summary constant dollar life cycle costs for ceramic can-in-canister variant (\$M 1996).

Facility	Pu processing	Immobilization	Repository	Total end-to-end alt
Baseline				
Up front costs	342	222	—	564
Other life cycle (10 yrs of operations) plus D&D	981	167	100	1248
Total life cycle costs	1323	389	100	1812

Table 10. 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	SRS
Plant owner	U.S. Government (DOE)
Process building type	Seismic Category 1 for Pu handling areas
NEPA, safety, permitting	DOE
Feedstocks: Front-end Back-end	Pits and other surplus Pu forms Plutonium oxide
Plant operational lifetime/total Pu processed	10 years/50 tonnes (56 tons) Pu
Time from ROD to hot startup	10 years
Data source for cost information	DWPF, Bechtel, LANL and LLNL

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 which can be performed in a standard plutonium processing facility (e. g., no remote handled operations, only glove box operations). Post construction start-up costs are estimated as 1.5 years of operating costs based on the anticipated start-up 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 11 shows the summary of the front-end plutonium processing and ceramic immobilization LCC costs.

2.6.2 Back-End HLW Vitrification Cost Basis

Back-end and modification facility costs are estimated at a preconceptual level. The pricing level is based on 1996 dollars. Escalation is excluded. The estimates also assume a normal schedule without delays.

Noteworthy preoperational costs include R&D waste form 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 security upgrades for DWPF. The method of estimating is based on pre-conceptual quantity takeoffs, HVAC, special features (lined cells, etc.) or \$/ft² or \$/ft³ for the hardened receiving area and DWPF security upgrades.

Table 11. Plutonium processing and ceramic immobilization LCC Summary for ceramic can-in-canister at SRS (\$M 1996).

End to end variant	Cost	Basis
"Preoperational" "up-front" costs		Per SA model
Front-end costs:		
1. R&D	83	R & D estimate LANL/LLNL
2. NEPA, licensing, permitting	6	
3. Conceptual design	2	
4. Q/A, site qualification, S&S	0	
5. Postconstruction start-up	40	
6. Risk contingency	8	
Sub OPC	139	
"Capital" or "TPC" up-front costs (TEC)		
7. Title I, II, III engineering, design & inspection	20	
8a. Capital equipment	41	
8b. Direct & indirect construction/modification	39	
9. Construction management (% of category 8)	4	
10. Initial spares (technology dependent)	4	
11. Allowance for indeterminates (AFI) (% of Cats 7-10)	27	
12. Risk contingency	68	
Sub TEC	203	
Sub-total up-front cost	341	
Pu processing at LANL (Halides)	1	
Total up-front costs	342	
13. Operations & maintenance staffing	670	
14. Consumables including utilities	0	
15. Major capital replacements or upgrades (% of capital)	40	
16. Waste handling & disposal (TRU, mixed and LLW)	44	Unit costs from ORNL
17. Oversight—DOE or NRC	10	
18. M&O Contractor fees (2%)	15	
19. Payments-in-lieu-of-taxes to local communities (PILT) (1%)	8	
20. D&D	159	
21. Revenues (if applicable)	0	
22. Government subsidies or fees to private-owned facilities	0	
23. Transportation of Pu forms to facility	35	ORNL T & P estimate
24. Storage of Pu at existing 94-I site facility	0	
Sub of the LCCs	981	
Total LCC (front-end facilities)	1323	

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.

The operation and maintenance (O&M) cost estimate include costs for personnel wages, consumables, material and maintenance expenditures, and waste disposal.

Operation costs for personnel wages are based on the increase in DWPF facility manpower loading attributed to this mission. The cost for facility maintenance and spares is estimated based on percent of capital cost for increased operations and capital investment. Consumables items such as chemicals are based on data in the *Chemical Marketing Report* dated 1989. The cost for incremental DWPF 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.

Waste disposal is based on unit volume costs for disposal of 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.

Table 12 shows the summary of the back-end HLW glass processing LCC costs using DWPF at SRS.

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 DOE on August 20, 1987, and entitled *Civilian Radioactive Waste Management: Calculating Nuclear Fund Disposal Fees for DOE Defense Program Waste*. This document from the 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 this formula, the repository cost per canister of DHLW is approximately \$500K based on a total life cycle cost analysis completed in September 1996, "Analysis of the Total Life Cycle Cost of the Civilian Radioactive Waste Management Program," DOE/RW-0479, U.S. Department of Energy, Office of Civilian Radioactive Waste Management, September 1995.

Table 12. Back-end HLW glass immobilization LCC summary—ceramic can-in-canister at SRS (\$M 1996).

End-to-end variant	Cost 1995 \$M	Basis
"Preoperational" or "OPC" costs		
1. R&D	115	R&D estimate
2. NEPA, licensing, permitting • Core A/E and program team from end of Title II to issue of license	6	
3. Conceptual design	1	
4. Q/A site qualification, S&S	9	
5. Post-construction start-up	11	
6. Risk contingency	26	
Sub OPC	170	
"CAPITAL" OR "TPC" UP-FRONT COSTS (TEC)		
7. Title I, II, III engineering, design & inspection	8	Include Home Office Management
8a. Capital equipment	in 8b	
8b. Direct & indirect construction	23	
9. Construction management	0	
10. Initial Spares (technology dependent)	4	
11. Allowance for indeterminates (AFI)	0	
12. Contingency	17	
Sub TEC	52	
Sub-total up-front (TPC) for back-end facilities	222	
Total up-front (TPC) for back-end facilities	222	
Other life cycle costs		
13. Operations & maintenance Staff size (67 FTE)	73	
14. Consumables including utilities	31	Chem Marketing Prices Report
15. Major capital replacements or upgrades (% of capital)	44	
16. Waste handling & disposal	0	
17. Oversight—DOE or NRC	10	
18. M&O Contractor fees	5	
19. Payments-in-lieu-of-taxes to local communities(PILT) (1%)	2	
20. D&D	2	
21. Revenues (if applicable)	0	
22. Government subsidies or fees to private-owned facilities	0	
23. Transportation of Cs 137 forms to facility	0	
24. Storage of Pu at existing 94-I site facility	0	
Sub other LCC	167	
Total back-end LCC	389	

2.7 Schedule

2.7.1 Overall Schedule

Preliminary, estimated schedules to deploy, operate and decommission (or convert) the ceramic can-in-canister immobilization variant at SRS facilities have been developed by combining schedules for the front-end and immobilization facilities. These schedules are presented in tabular form in Tables 15 and 16 and in Gantt chart form in Figures 15 and 16 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 can-in-canister plutonium immobilization variant, which includes the design and construction of modifications to existing DOE SRS facilities for front-end and immobilization 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 variant.

A R&D program has been identified to develop and demonstrate the immobilized formulations and process equipment.

National Environmental Protection Act (NEPA) activities are included. For the ceramic can-in-canister with modifications to existing DOE SRS facilities for front end and immobilization facilities, it is assumed that a site-specific Environmental Impact Statement (EIS) will be required following the programmatic EIS. After the Final EIS and its ROD, Title II design for the front-end and immobilization facilities can begin.

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.

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. Since NRC licensing is only assumed for new facilities, the ceramic can-in-canister immobilization variant assumes DNFSB oversight. The same licensing activity duration will be used for modification of existing DOE facilities with DNFSB oversight. Licensing is a five-year long, key critical path activity. The schedule indicates nonsafety related construction starts a year prior to completion of this activity.

The schedule assumptions for NRC licensing are based on the Fluor-Daniel report, *Regulatory Plans for NRC Licensing of Fissile Materials Disposition Variants*, Draft Revision A, June 26, 1995.

For the ceramic can-in-canister immobilization variant, although NRC licensing for processing is not applicable, there are two other distinct license types each with distinct issues to be addressed during the NRC licensing process. The types are:

- 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.

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 variants 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 modifications to insure that the package criteria stated in DOE-STD 3013-94 are met. Further modifications would be required to insure that the packaging configuration incorporates the primary containment vessel, analysis/testing is performed to show the abnormal and normal accident scenarios, that 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 rule making or clarification in authorizing legislation for emplacing the immobilized forms in an 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 13 and 14 and in Gantt-chart form in Figures 15 and 16 is a logic network defined by activity durations and logical ties between them. As such, the logic 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. The same five year critical path activity for licensing has been assumed for both new facilities or use of existing facilities.

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 NEPA, 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 a variant will be identified early.

Table 13. 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	OY 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	3/26/97	5/13/03	
19	Preferred site selection	48w	1/1/97	12/2/97	2
20	NEPA/EIS and site selection	660d	12/21/98	6/29/01	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	900d	1/1/97	6/3/00	
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
26	Title I Des & PSAR	60w	4/21/99	6/13/00	3,22
27	Documentation to DNFSB, review process, Title II des., FSAR, DNFSB release for construction	1200d	6/13/00	1/18/05	
28	KD#2- Start Title II Design	0d	9/5/00	9/5/00	4,20,26
29	Submit documentation to DNFSB	0d	6/13/00	6/13/00	26
30	DNFSB oversight process	240w	6/14/00	1/18/05	29

Table 13. (continued).

Task no.	Task name	Duration	Start date	Finish date	Predecessors
31	NRC NEPA	104w	6/14/00	6/11/02	29
32	NRC issues	0d	6/11/02	6/11/02	31
33	Title II Design & FSAR	96w	7/2/01	8/23/02	28
34	NRC license	0d	1/18/05	1/18/05	30,20
35	DNFSB approval/KD#3/Release for Construction	0d	1/21/04	1/21/04	30FS-52w
36	Construction, equipment installation, startup, test, ORR	1320d	1/21/04	2/10/09	
37	Construction	240w	1/21/04	8/26/08	36
38	Procurement	138.4w	1/21/04	9/14/06	36
39	Equipment Installation	99.8w	1/6/06	12/5/07	39FS-36w
40	Startup, Preop testing, ORR	48w	3/12/08	2/10/09	38FS-24w,40
41	Operations	2400d	2/10/09	4/24/18	
42	KD#4 Commence Operation	0d	2/10/09	2/10/09	41
43	Operation	480w	2/11/09	4/24/18	43
44	D&D	720d	5/24/17	2/25/20	
45	D&D	144w	5/24/17	2/25/20	40FS-48w

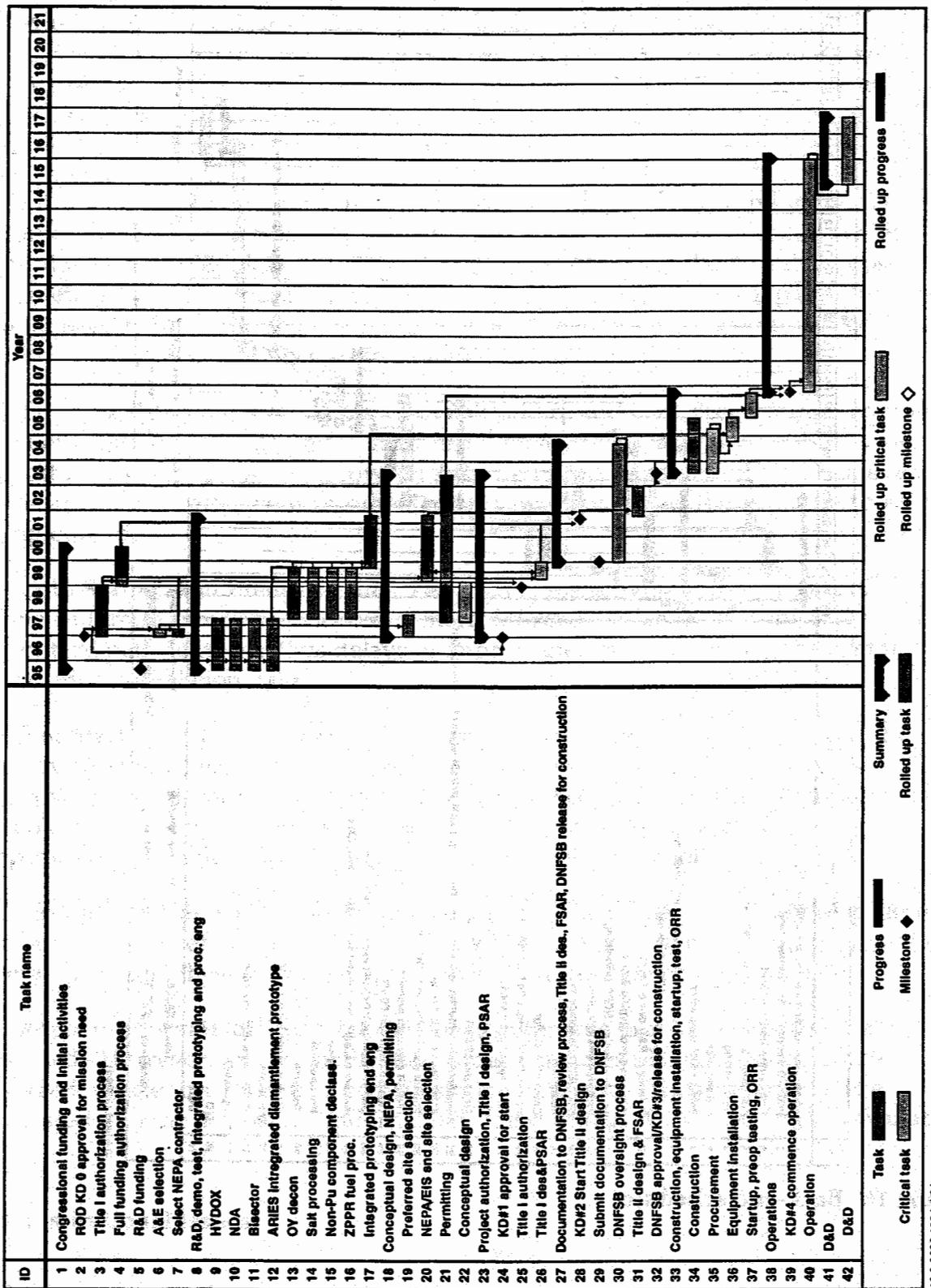
Table 14. Back-end facility schedule breakout.

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	2697d	10/2/95	1/3/06	
9	Formulation, proc. & long term perf	175d	10/1/96	6/1/96	5
10	Balance of R&D, demo & 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, permitting	1600d	3/26/97	5/13/03	
13	Preferred site selection	48w	1/1/97	12/2/97	2
14	NEPA/Support for license application	660d	4/21/99	6/13/00	7,15
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	900d	1/1/97	6/13/00	
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 & PSAR	60w	4/29/99	6/13/00	3,15
21	Documentation to DNFSB, review process, Title II des., FSAR, DNFSB 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
23	Submit documentation to DNFSB	0d	6/14/00	6/13/00	20,13
24	NRC licensing	240w	6/14/00	1/18/05	23
25	NRC NEPA				
26	NRC issues				
27	Title II Design & FSAR	96w	9/6/00	7/9/02	22
28	NRC license				
29	Approval to commence instruction				
30	DNFSB approval/KD#3/Release for Construction	0d	1/21/04	1/21/04	29

Table 14. (continued).

Task no.	Task name	Duration	Start date	Finish date	Predecessors
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.



10.0.0668.1994pb01

Figure 15. Front-end plutonium schedule.

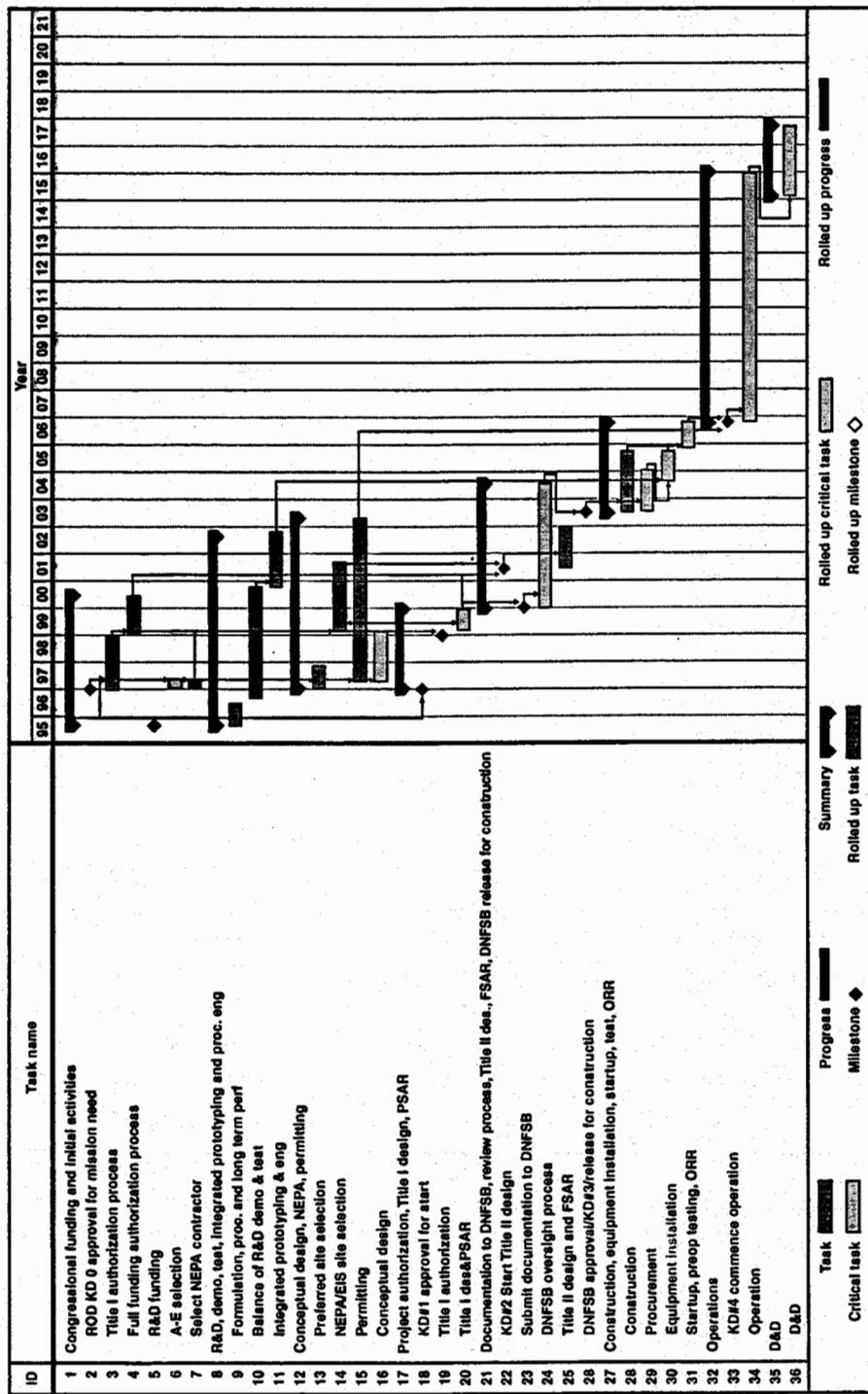


Figure 16. Back-end schedule.

Waste Form Certification and Qualification. Ceramic waste forms, similar to the form proposed for CCC, have been 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. For the non-NRC front-end and immobilization facilities, using existing SRS facilities, site specific NEPA and site selection activities are critical path activities, delays or improvements would impact the overall disposition completion date. 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 & II Design, Procurement, Construction, and SAR Preparation. For the front end and immobilization facilities, using existing SRS facilities, these activities offer opportunities to refine and improve on the schedule as more definition is achieved. Some are critical path activities, others may or may not 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 variant 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 U.S., 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 variants selected in the ROD. 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" variant 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 (or other variant disposal system). The radiation, level of 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:

- Western 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 has not 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 U.S. 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 U.S. 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 and to seek to minimize the civil use of highly enriched uranium.

Since it is assumed that the Disposition Program 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 element" 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 through out 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.

2.9 Hybrid Ceramic Options

There are a number of feasible hybrid options involving a combination of individual disposition alternatives or feed materials. The most logical hybrids are:

- A MOX Immobilization hybrid in which impure plutonium is immobilized and pure plutonium is made into MOX fuel for reactor irradiation.
- A hybrid in which low assay plutonium materials are blended with higher assay materials prior to immobilization, thereby allowing much higher levels of impurities to be immobilized without degrading the immobilized product.
- A hybrid combining plutonium and non-plutonium actinides that must be managed similarly as the excess plutonium.

2.9.1 MOX Ceramic Hybrid

Hybrid disposition approaches, in which different feed materials (e.g. pure plutonium oxide from pits versus impure plutonium feeds) are dispositioned by different approaches, open the possibility of utilizing existing facilities in creative ways to achieve FMDP objectives. As an example, the completed but never used New Special Recovery (NSR) Facility at SRS could be used as designed to directly support the immobilization portion of a hybrid variant with relative little modification. The pit recovery operations, which support the MOX fuel fabrication portion of the hybrid, could then be co-located with the MOX fuel fabrication operations with little impact because the required backup aqueous chemical operations would be available at the NSR facility at SRS. Other possible uses of existing facilities are also possible; these approaches need further evaluation.

The discussion presented below assumes that 32.5 tonnes (36.4 tons) of pure plutonium is converted to MOX fuel and the other 17.5 tonnes (19.6 tons) of the less pure plutonium are vitrified. This discussion also assumes that all plutonium coming to FMDP has been stabilized in accordance with the DNFSB Recommendation 94-1 and contains a plutonium concentration of ≥ 50 wt %.

2.9.1.1 Logic and Benefits of MOX- Ceramic Hybrid

Immobilization of surplus plutonium by ceramics has been studied in this report for all plutonium-bearing materials that could potentially become part of the disposition mission. By the use of blending, multiphase ceramics has the potential to convert ≥ 50 wt % plutonium stocks to ceramics without further separation of the plutonium from matrix materials. Much of the existing impure plutonium inventory exists because of economic and technical difficulties associated with separating plutonium from these materials. The flexibility of multiphase ceramics to incorporate these impurities could provide technical, economic, and institutional incentives to use multiphase ceramics for this portion of the inventory.

Potential benefits of the MOX-Ceramics Hybrid Option include:

- Hybrid approaches may provide better utilization of existing facilities, including fewer equipment modifications, thereby reducing start-up cost.
- Hybrid approaches could facilitate an earlier start of disposition through better utilization of existing facilities. Start-up of existing capability (especially in terms of installed equipment) and systems, such as NSR would reduce the time to complete pre-operational activities, such as funding appropriations, construction, start-up, and licensing.
- Because parallel processing paths would be utilized, the MOX-Ceramics hybrid approach could result in somewhat earlier completion of the plutonium disposition mission. For example, by reducing the quantity of plutonium to be processed into MOX fuel rods and burned in reactors by about 33%, the hybrid approach could result in a 6 year earlier completion of the LWR variant. Or it could reduce by one the number of reactors needed for the same program duration.
- *Russian Cooperation.* A hybrid option might facilitate better Russian cooperation. MINATOM has expressed strong opposition to disposition of pure plutonium as a waste because they prefer to use their pure plutonium materials as an energy resource. However, MINATOM may be responsive to vitrifying and disposing of their impure material.

Multiphase ceramics can readily accommodate the more problematic materials in the surplus plutonium inventory, such as plutonium alloys, alloy reactor fuel (unirradiated), oxide reactor fuels (unirradiated), uranium/plutonium oxide.

2.9.1.2 Plutonium Feed Materials

Plutonium alloys. Common alloys of plutonium include plutonium-gallium, plutonium-aluminum, plutonium-beryllium, plutonium-zirconium and plutonium-uranium. After conversion to oxide, all of these alloy constituents can be incorporated into multiphase ceramics. Beryllium oxide is easily incorporated into multiphase ceramics but incorporation of gallium oxide is not well characterized but would be expected to be about the same as aluminum oxide. Uranium oxides are also easily incorporated into multiphase ceramics.

Alloy Reactor Fuels (Unirradiated). Alloy reactor fuels are primarily the ZPPR plates located at ANL-W. These are plutonium-uranium alloys with a small amount of aluminum or molybdenum. As with the plutonium alloys, aluminum and uranium are readily accommodated into the multiphase ceramics. Molybdenum can be incorporated as oxide into the multiphase ceramics, but it is generally incorporated as metal.

Oxide Reactor Fuels (Unirradiated). These are primarily mixed oxide (uranium-plutonium) fuel pins located at ANL-W. As discussed above, uranium has a high solubility in multiphase ceramics.

Uranium/Plutonium Oxide. Uranium oxides are easily incorporated into multiphase ceramics.

2.9.1.3 Implementation

The hybrid analyzed is depicted in Figure 17. Approximately 32.5 tonnes (36.4 tons) of plutonium in the form of pits, clean metal, and clean oxide are converted to MOX fuel which is burned in existing LWRs. The remainder, about 17.5 tonnes (19.6 tonnes) of plutonium in various impure forms, would be vitrified through the can-in-canister variant.

Schedule. The schedule assumed in the analysis for this hybrid option is slightly changed from that presented in Figure 15; preparing ceramics in the small cans would begin in 2004. There may be an opportunity to further modify the schedule to optimize the hybrid option, if this is option were to be chosen in the upcoming ROD. Potentially, construction, start-up and processing could take place in a shorter period of time. However, it may be desirable to have the plutonium ceramics operations proceed in parallel with the fabrication of MOX fuel so that the plutonium-bearing scrap from MOX fuel fabrication operations could be fed into the ceramics process.

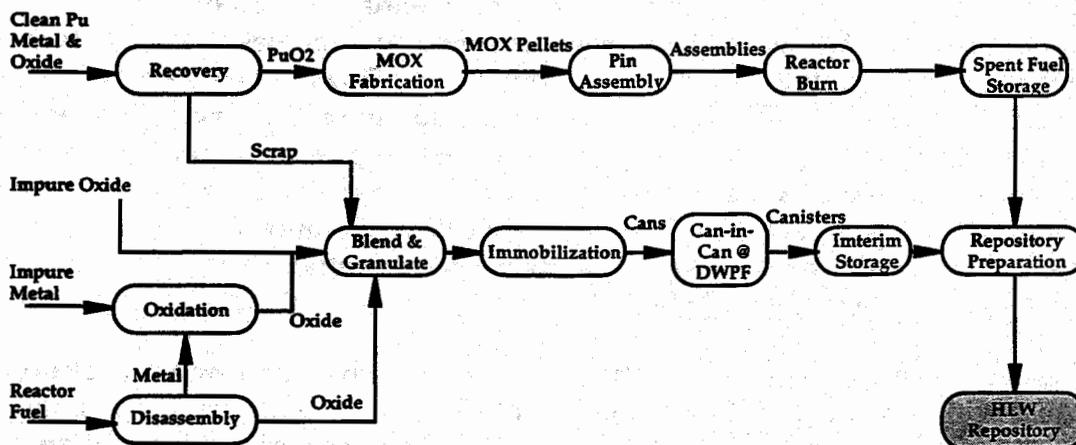


Figure 17. Hybrid option, ceramics can-in-canister with MOX fuel fabrication for reactor burn.

2.9.2 Low Assay Plutonium Immobilization

Hybrid disposition approaches, in which low assay feed materials (e.g. incinerator ash, etc.) are blended with higher assay materials prior to immobilization, open the possibility of utilizing existing facilities in different ways to achieve the objectives of both EM-60 Stabilization Program (DNFSB Recommendation 94-1) and FMDP objectives. As an example, DOE/EM-60 is considering transferring low assay materials to WIPP after treatment by a variety of methods including recovery of plutonium and

its and purification to MOX fuel requirements. These materials could be blended with higher grade plutonium materials without prior treatment and then immobilized in multiphase ceramics thereby avoiding much of the required processing. This would possibly allow an even wider range of existing DOE facilities to be utilized. Immobilization techniques in general require that any single tramp impurity be less than 1.0 wt % in the final immobilized product. However, non-proliferation and criticality concerns require that the plutonium content of the immobilized form be less than 10 wt%. Therefore, as a general statement, tramp impurities in the plutonium feed must be less than 10 wt % to give a final immobilized product containing less than 1 wt % of that individual tramp impurity. Many of the materials in the DOE stockpile could be blended to this level without any form of processing other than calcination.

The discussion presented below assumes that 32.5 tonnes (36.4 tons) of plutonium is converted to MOX fuel and the other 17.5 tonnes (19.6 tons) of the less pure plutonium are vitrified. This discussion also assumes that all plutonium coming to FMDFP has been stabilized in accordance with the DNFSB Recommendation 94-1, but that purification to a plutonium concentration of ≥ 50 wt % has not occurred.

2.9.2.1 Logic and Benefits of Low Assay Plutonium Ceramics Hybrid

Immobilization of surplus plutonium by ceramics has been studied in this report for all plutonium-bearing materials forms that could potentially become part of the disposition mission. The present MD program, however, assumes that all materials to be dispositioned will have a plutonium concentration ≥ 50 wt%. Since the composition, chemical, and isotopic characteristics of the U.S. plutonium inventory vary over a wide range, a variety of processing steps requiring varying degrees of chemical purification and final form processing will be required depending on the disposition route chosen. By combining and optimizing the plutonium treatment operations associated with unstable residues with ceramics, significantly processing efficiencies, cost reduction and schedule enhancements could be realized.

Multiphase ceramics has the potential to convert much of the low assay plutonium to ceramics without extensive separation of the plutonium from inert matrix materials. Much of the existing impure plutonium inventory exists because of economic and technical difficulties of separating plutonium from these materials. The flexibility of multiphase ceramics to incorporate these troublesome impurities up to 1 wt% in the final product could provide technical, economic, and institutional incentives to use ceramics for this portion of the inventory.

Benefits of the low assay hybrid approach include:

- It reduces the need to, and avoids the cost of, separating plutonium from much of the residue or scrap inventory.
- It offers the potential to reuse facilities developed for other plutonium missions to dispose of these more problematic materials, therefore providing the U.S. Government a much greater return-on-investment.

- It reduces storage costs for impure plutonium. Nuclear criticality safety in plutonium storage facilities is assured by geometric spacing of plutonium packages. The volumes of impure plutonium at sites such as Rocky Flats has resulted in such materials being stored in a large number of facilities including old production areas, with associated high cost. Conversion to an intermediate multiphase ceramics form with neutron absorbers incorporated in the multiphase ceramics matrix allows close packing and eliminates high-cost secondary storage areas.
- Preparing ceramics of impure plutonium to an intermediate multiphase ceramics form (without radioactive spike) at resident DOE sites solves transport difficulties because some of the impure plutonium materials are in chemical forms not suitable for transport to a central site for processing and disposition. Conversion to an intermediate multiphase ceramics creates a form which is readily transportable.
- Optimizing the plutonium treatment operations between the Stabilization and Disposition Programs and the utilizing existing facilities could result in significant cost savings for DOE.

2.9.2.2 Low Assay Plutonium Feed Materials

In general the impurities in low assay materials can be grouped into the following categories: halide salts, uranium, glass formers/modifiers, carbonaceous materials, and water. Carbonaceous materials, and water can be removed by calcination. If ceramics is the chosen form, then the glass formers/modifiers simply become a glass phase in the multiphase ceramic plutonium product.

Multiphase ceramics can readily accommodate the more problematic materials in the surplus plutonium inventory such as plutonium alloys alloy reactor fuel (unirradiated), oxide reactor fuels (unirradiated), uranium/plutonium oxide, plutonium chloride-oxides, low assay plutonium residues except for halide salt residues, halides salt residues after aqueous leaching to remove the bulk of the soluble halide salts.

In addition to the materials described above under the MOX ceramics hybrid, the following plutonium materials could be immobilized:

Plutonium Chloride Oxides. This group of materials in general contain >70 wt % plutonium or > 78 wt% plutonium oxide. The remaining 22 wt% of the material is a 50-50 by weight mixture of NaCl-KCl. Simple blending of the plutonium chloride oxide with an equal amount of low chloride feed stock would result in a feed containing < 10 wt% chloride and hence acceptable feed to ceramics.

Incinerator Ash. The bulk of this group of materials is made up of SiO₂ and Al₂O₃ from the incinerator firebrick and from clays in paper filler (individual cans range from ~10 to ~60 wt%), PbO from incineration of PbO lined gloves (0 to 50 wt%), unburned carbon materials (0 to 30 wt%), water (1 to 10 wt%) and plutonium (<2 to > 25 wt%) plus a host of other elements. The water and carbon materials could be removed by

calcination. The remaining elemental impurities easily can be blended to less than 10 wt%.

2.9.3 Non-Plutonium Feed Materials Hybrid

DOE owns other materials which are also expected to be declared excess. Multiphase ceramics is also particularly well suited for some of these non-plutonium surplus fissile materials. These include ^{233}U in the form of uranium oxide or a mixed thorium/uranium oxide.

About two tonnes of ^{233}U exists at various DOE sites. This isotope is weapons-usable and is part of the fissile materials disposition program, but is not a part of the plutonium disposition study. Most of it is located at ORNL and INEL. The material at ORNL is primarily impure uranium oxides. A significant fraction of this material contains other uranium isotopes and impurities such as CdO and Gd_2O_3 . A small portion of the inventory is metal and uranium fluoride with a LiF impurity. The material at INEL is exclusively unirradiated Th-uranium oxide fuel pellets. Material at other sites is primarily in the form of uranium oxides.

The uranium oxides containing ^{233}U behave chemically the same as the other isotopes of uranium. Thus, multiphase ceramics waste forms are well suited for incorporation of ^{233}U . The thorium-uranium oxides fuel pellets containing ^{233}U are also suitable feed to the multiphase ceramics waste form. Thorium can also be accommodated in the multiphase ceramics form with high solubilities.

3.0 Acronyms

ANL-W	Argonne National Laboratory-West
ALARA	As Low As Reasonably Achievable
ANSTO	Australian Nuclear Science and Technology Organization
BET	Brunauer-Emmett-Teller equation
CCC	Ceramic Can-in-Canister
C/S	Containment and Surveillance
CCTV	Closed Circuit Television
^{137}Cs	Cesium 137
CFR	Code of Federal Regulations
CGF	Ceramic Greenfield Facility
CRT	Container Restraint Transport
CRWMS	Civilian Radioactive Waste Management System
DHLW	Defense High-Level Waste
DNFSB	Defense Nuclear Facilities Safety Boards
DOE	Department of Energy
DOT	Department of Transportation
DP	Defense Programs
DWPF	Defense Waste Processing Facility
EM	Environmental Management
EPRI	Electric Power Research Institute
ET	Electrometallurgical Treatment
EIS	Environmental Impact Statement
FCF	Fuel Conditioning Facility @ ANL-W
FMDP	Fissile Materials Disposition Program
FMD PEIS	Fissile Materials Programmatic Environmental Impact Statement
FMF	Fuel Manufacturing Facility @ANL-W
GMODS	Glass Materials Oxidation Dissolution System
Gy	Gray
HEME	High-Efficiency Mist Eliminator
HEPA	High-Efficiency Particulate Air (filter)
HFEF	Hot-Fuel Examination Facility

HLW	High-Level Waste
HVAC	Heating, Ventilating, and Air Conditioning
IAEA	International Atomic Energy Agency
INEL	Idaho National Engineering Laboratory
ISG	International Safeguards
IWG	Interagency Working Group
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
MPC	Multi-Purpose Canister
MSO	Molten Salt Oxidation
NAS	National Academy of Sciences
NDA	Non-Destructive Analysis
NEPA	National Environmental Policy Act
NRC	Nuclear Regulatory Commission
NSR	New Special Recovery
NWPA	Nuclear Waste Policy Act
OCRWM	Office of Civilian Radioactive Waste Management
ORR	Operational Readiness Review
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
SRS	Savannah River Site
SST	Safe Secure Trailer/Transport
SYNROC	Synthetic Rock
TID	Tamper Indicator/Indication Device
TRU	Transuranic Waste
TLCC	Total Life-Cycle Cost
U	Uranium
VAM	Vitrification Adjunct Melter
VCC	Vitrification Can-in-Carister
VGf	Vitrification Greenfield Facility
WAO	Wet Air Oxidation
WIPP	Waste Isolation Pilot Plant
WSRC	Westinghouse Savannah River Company
ZPPR	Zero Power Physics Reactor