# K-Area Complex Plutonium Vitrification (Pu-Vit)

## Nuclear Criticality Safety Design Guidance Document

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ACRONYMS & ABBREVIATIONS

| | |
|---|---|
| APNMC | Active/Passive Neutron Multiplicity Counter |
| ANS | American Nuclear Society |
| ANSI | American National Standards Institute |
| CAAS | Criticality Accident Alarm System (Used synonymously with NIMS.) |
| CDS | Criticality Accident Detection System |
| CFR | Code of Federal Regulations |
| CIM | Cylindrical Induction Melter |
| CSC | Criticality Safety Committee |
| DCA | Double Contingency Analysis |
| DOE | US Department of Energy |
| DWPF | Defense Waste Processing Facility |
| FFTF | Fast Flux Test Facility |
| FPS | Feed Preparations System |
| Frit | Borated glass chips, used to blend down the fissile oxide and facilitate glass formation |
| GFDS | Green Fuel Disassembly System |
| HW/MW | Hazardous Waste/Mixed Waste (Implies the material does not contain Trans-Uranic Waste) |
| HEPA | High Efficiency Particulate Air [filter] |
| HEU | High Enriched Uranium |
| HLW | High Level Waste (Radioactive) |
| ISMS | Integrated Safety Management System |
| LLW | Low Level Waste; RM-LLW => from the Room; GB-LLW => from the glovebox |
| NCS | Nuclear Criticality Safety |
| NCSE | Nuclear Criticality Safety Evaluation |
| MAR | Material at Risk |
| MAA | Material Accountability Area |
| MC&A | Material Control and Accountability |
| NIMS | Nuclear Incident Monitoring System (Used synonymously with CAAS.) |
| PCV | Primary Containment Vessel |
| PFHA | Project Fire Hazards Analysis |
| Pu Vit | Plutonium Vitrification |
| SA | Staging Area (for a regulated Waste Stream) |
| SAA | Satellite Accumulation Area<br>(Also used to specify filled drums resulting from a SAA) |
| SNM | Special Nuclear Material |
| SRS | Savannah River Site |
| SWB | Standard Waste Box |
| TID | Tamper Indicating Device |
| TRU | Trans-Uranic (an element with an atomic number greater than Uranium of 92) |
| TRUW | Trans-Uranic Waste (Usually waste items, cans, gloves, etc. contaminated with Trans-Uranic elements) |
| WMAP | Waste Management Area Project |

## DEFINITIONS

| | |
|---|---|
| Consider | The use of consider denotes to include a design option in the initial set of design options for subsequent selection or rejection based on engineering judgment and other factors. It is not a requirement. |
| Nominal Fissile Mass | The expected operational fissile mass in a glovebox or workstation at this stage of the design. The nominal fissile mass is not a criticality safety limit. |
| Robust Control | A control is considered robust if it is unlikely to fail. The failure frequency associated with unlikely is qualitatively judged to be less than once in a hundred years. |
| Should | The use of should denotes a recommendation and not a requirement. |

## DIRECTIVES

Per WSRC customer request this document is being written under DOE Order 420.1B guidance. At this time, the SRS Site is under contract specifying DOE Order 420.1A.

## EXECUTIVE SUMMARY

The Plutonium Vitrification (Pu-Vit) facility will process scrap plutonium and/or enriched uranium left over from the cold war era into a stable glass. The facility will be able to handle a variety of feed materials, including scrap oxides and metals. The facility will utilize an assortment of dry processes, thus inherently assuring a high level of Nuclear Criticality Safety (NCS).

NCS design features and administrative controls are required to protect the operations in Pu-Vit from an inadvertent nuclear chain reaction. NCS features include: spacing between safe batch sizes, maintaining the material dry, safe floor configurations, and specific controls if unfavorable geometry equipment is required.

Specific evaluations, as approved by the Criticality Safety Committee (CSC), may be able to demonstrate that Nuclear Incident Monitors (NIMS) are not required for Pu-Vit. A specific evaluation is required to assure coverage and egress requirements of the final Pu-Vit layout.

Pu-Vit requires the use of a diverse and unique set of processes with fire, toxicological, radioactive, and criticality hazards, each of which requires special attention in the design stage. The processes will include Material Receipt & Storage, Feed Prep, Oxidation, Milling & Mixing, Vitrification, Bagless Transfer, Green Fuel, Waste Handling and Can-in-Canister Loading and Storage. These processes involve handling hazardous materials such as plutonium metals and oxide and green fuel plutonium & uranium oxide pellets. In addition, hazards typically involved in similar processes will also be present.

Pu-Vit will handle materials in sufficient quantities to require appropriate engineered and operational controls for criticality accident prevention. To ensure that Pu-Vit is designed, constructed, started, and operated while protecting the public, the worker, and the environment, the Pu-Vit requires that safety be systematically integrated into management and work practices at all levels.

The nuclear criticality safety design guidance is being developed at this time consistent with project schedule and needs. Early development of the nuclear criticality safety design guidance and requirements supports the implementation of a safety-by-design process by guiding design relative to safety goals and requirements. Additionally, this process ensures that cost and design impacts of nuclear criticality safety are included in the design, thereby minimizing the potential for late and costly nuclear criticality safety driven design changes.

Based on current needs of the project team, this document discusses the criticality safety philosophy for the Pu-Vit design and provides some high level guidance pertinent to the Pu-Vit process areas at this stage of design. Recognizing that the adequacy of the design will be based on application of the set of criteria within the context of the applicable standards and requirements, interaction between the design team and the nuclear criticality safety SME is essential for adequate implementation of these requirements.

# 1 Introduction

This criticality safety design guidance document is a communication tool for the Pu-Vit design team and is being developed early in the project conceptual design phase to provide a philosophical framework and high-level criticality safety guidance. This guidance is based on successful historical practices for similar activities. This document is not intended to be an all-encompassing requirements document, nor is it intended to replace in-depth discussions among the Pu-Vit designers and criticality safety specialists. As the Pu-Vit design evolves, such discussions will help establish operational procedures, specific equipment design, and corresponding criticality safety controls.

Developing the criticality strategy and providing early design guidance in conjunction with the Integrated Hazards Analysis effort ensures that criticality safety considerations are factored into the design at an early stage rather than retrofitted as an afterthought. This approach also ensures the cost and design impacts of criticality safety requirements are well understood and minimize the potential for late and costly criticality safety driven design changes. It also results in criticality strategy and design guidance specific to the needs of the Pu-Vit.

The Pu-Vit facility will accept feed material as oxide, metal or ceramic fuel pellets. The specific material types will be processed through a series of preparatory procedures, depending on the material type including incinerating metal to the required oxide. These processes are performed in a series of gloveboxes, a furnace, and stations and are protected with specific NCS mass limits. The final fissile oxide is separated into 2 kg batches and loaded into an enclosed hopper transport system.

The individual gloveboxes, furnace, and stations will have specific mass limits that account for potential double-batching and other scenarios. Individual automatic gas fire extinguishing systems will protect individual gloveboxes, the furnace, and workstations from fire, as determined in the Project Fire Hazards Analysis (PFHA). However, a standard water sprinkler system will protect the overall facility from fire.

The enclosed hopper system transfers the fissile oxide to one of the two attritor milling machines. Simultaneously charged into the attritor mill is a batch of borated glass chips, referred to as “frit.” The milling machines will mill the two materials, grinding them and thoroughly mixing them. The fissile oxide/frit milled mixture is a fine powder and is separated into batches.

An enclosed transport hopper moves the batches of milled powder to the melters. Currently, there are ten melters planned for Pu-Vit. The melters use inductive heating coils to heat the powder to approximately 1500 $^{\circ}$C to produce glass. There are no NCS requirements for these powders or the final glass. After cooling, the product cans are loaded into a storage cask and shipped for final burial.

# 2 Scope

The objective of this document is to provide high-level criticality safety design guidance for the CD-1 Pu-Vit design phase. This includes:

- Preliminary Safe parameters for use in the facility design,
- Specify additional NCS calculational needs,
- Preliminary Requirements for a Criticality Accident Alarm System (CAAS) also referred to as Nuclear Incident Monitoring System (NIMS),
- Process boundary for NCS Concerns, and
- Preliminary Double Contingency Analysis (Nuclear Criticality Safety Evaluations will include the final Double Contingency Analysis).

# 3 Design Philosophy/Policy

The Pu-Vit design approach is based on the application of modularized operations and building layout. This approach assures that operations within a module are clearly defined, and are performed on known materials. The Pu-Vit criticality safety philosophy is built upon and takes advantage of the inherent features of this modular approach to design. The criticality philosophy/policy is as follows:

> Criticality safety for the Pu-Vit mission and operations will be achieved with a balanced approach using engineered controls and/or administrative controls where appropriate. Engineered controls are preferred if practical and appropriate and should be considered in the earliest design phase to avoid significant re-work. If engineered controls are not practical or appropriate, administrative controls will be used to ensure criticality safety. A basis will be provided justifying the selected controls guided by the following elements:
>
> a) Processes shall remain subcritical ($k_{eff}$ +2*sigma < $k_{safe}$) under both normal and credible abnormal process conditions, preferably by incorporation of sufficient factors of safety to require at least two unlikely, independent, and concurrent changes in process conditions before a criticality accident is possible.
> b) The need to appropriately engage the operations staff in the nuclear criticality safety program and thus implement basic conduct of operations principles,
> c) The form and content of the material present in the module and the ability to control that form and content, and
> d) The ability to provide a passive criticality control.

Consistent with the principles of ISM, optimum design of the Pu-Vit facility will occur as a result of an iterative process involving people with a broad spectrum of knowledge and operational experience. Therefore, personnel with design, process operations, and criticality safety knowledge will be involved in the Pu-Vit design.

# 4 Criticality Safety Design Guidance for Pu-VIT

The guidance provided in this section was taken or derived from a number of sources including DOE Order 420.1B, DOE Guide 421.1-1 Criticality Safety Good Practices Guide for DOE Non-Reactor Facilities, and lessons learned. DOE Guide 421.1-1 provides additional criticality safety guidance for consideration in the designing a nuclear facility. Implementing the guidance provided in the following sections of this document does not necessarily satisfy all requirements derived from applicable CFRS, DOE Orders, and ANSI/ANS Standards.

## *4.1 General Guidance*

1. The Pu-Vit facility shall be designed so that all processes are sub-critical under both normal and credible abnormal conditions. This is a requirement of 10 CFR 830 Subpart B paragraph 202 and ANSI/ANS-8.1, Section 4.1.2 (Ref. 3). The preferred implementation method for this requirement is through application of the double contingency principle, i.e., process designs should incorporate sufficient factors of safety to require at least two unlikely, independent, and concurrent changes in process conditions before a criticality accident is possible. The preferred hierarchy for parameter control is by:
   - Passive engineered features (limited geometry, limited volume, racks, etc.),
   - Active engineered features (interlocks, etc.), and
   - Administrative requirements (mass check systems, etc.).

     Note: DOE approval is required if double contingency can not be met.

2. The Pu-Vit facility (processes, gloveboxes, workstations, and equipment) should be designed with human factors considerations so that it is easy for the operator to perform tasks as intended with respect to criticality safety. LA-3366, Criticality Control in Operations with Fissile Material states, “Criticality safety is enhanced by arrangements of material and equipment that tends to make proper operation convenient and maloperation inconvenient.” Consideration of human factors does not necessarily require a formal human factors analysis. (DOE G 421.1-1 Section 5.6.2.8)

3. Where administrative controls are used, engineered enhancements such as alarms to assist the operator should be considered. (DOE G 421.1-1, Section 5.7.5.1.3)

4. Where sprinkler systems are present, consideration should be given to the criticality safety implications of activation and appropriate measures should then be taken, e.g., minimize the potential for firewater intrusion into gloveboxes by design, as judged necessary. (ANSI/ANS-8.22 [Ref. 7], DOE G 421.1-1, Section 5.7.8.9)

5. Processes, gloveboxes, workstations, etc., should be designed to eliminate or minimize areas where fissile material can collect inadvertently. If wells/sumps are used, they should be designed to be inspected and cleaned. (DOE G 421.1-1, Section 7.4.2.1.1)

6. Wells/sumps, when necessary, should be designed with consideration to the process criticality safety implication (e.g., wells should be favorable for the amounts and types of fissile solutions that may inadvertently flow into them).

7. The design goal should be to eliminate glovebox drains due to contamination hazards. However, all risks should be considered in selecting the design solution and assure that these risks are adequately addressed in the design. If necessary from a criticality safety perspective they should be designed appropriately (e.g., preclude liquid accumulations to predetermined levels, visually verifiable as open) (DOE G 421.1, Section 5.7.4.2.1.2)

8. Room floors should be designed to limit the accumulation depth from sprinkler activation or leaks to acceptable levels (e.g., plutonium on the floor was found safe to a slab height of 2.0", Ref. 15). The firewater runoff collection system should be designed to preclude a criticality accident if it is credible for significant amounts of fissile material or solution to be collected or diverted to the system. (ANSI/ANS-8.7 [Ref. 8], Section 4.2.1, DOE Order 420.1B, Section 4.2.2.8)

9. Glovebox ventilation systems should be designed to minimize or eliminate accumulation of fissile material in ducts or other untoward areas.

10. Favorable geometry equipment for the processing of fissile or potentially fissile solutions should be used unless other considerations are overriding. (ANSI/ANS-8.1 [Ref. 3], Section 4.2.3, DOE O 420.1B, Section 4.3.2.d(2))

11. Radiation shielding and structural materials used for Pu-Vit may have some criticality safety impacts and should be evaluated (e.g., thickness and composition of walls may affect the placement of criticality accident alarm system detectors [ANSI/ANS-8.3 (Ref. 6), Section 5.8] or the allowable mass limits on storage vault shelves due to reflecting and moderating characteristics). Typical moderating shielding materials include concrete, acrylics, boron impregnated polyethylene, and Water-Extended Polyester.

12. The need for a Criticality Accident Alarm System (CAAS, also referred to as NIMS) should be addressed per ANSI/ANS-8.3 (Ref. 6) and DOE Order 420.1B (See Section 4.2.8). Personnel radiation exposure, emergency planning, and response should be considered in the facility design and addressed per ANSI/ANS-8.23 (Ref. 9).

Consistent with the principles of ISM, optimum design of the Pu-Vit will occur as a result of an iterative process involving people with a broad spectrum of knowledge and operational experience. Therefore, personnel with design, process, operations, and criticality safety knowledge will be involved with the Pu-Vit design.

## *4.2 Specific Guidance*

Operations at the Pu-Vit Facility will involve handling of fissile material in various forms. All of these forms are in a dry state. Although the fissile oxides will by nature absorb some humidity from the air when exposed, they remain relatively dry. Only under upset conditions could the fissile material become moderated with water, polyethylene or other potential moderator. In general, the relative risk of a criticality accident is lower in processes in which dry special nuclear material (SNM) is handled as part of the normal operation. The relative risk is increased for those operations that normally handle fissile solutions. To optimize the criticality safety control set for a module, the safety margin has to be evaluated for normal operations and credible abnormal conditions. The margin of safety for an operation will be determined by detailed criticality safety analyses for the specific module operation under normal operations and credible upsets. The following subsections provide high level guidance for criticality design/control for each major facility module and system.

### 4.2.1 Material Receipt and Storage System (MRSS)/Green Fuel

The feed material will be in various forms. Primarily, standard 3013 welded process cans (Ref. 2) will be received in 9975 shipping containers. The cans are unpacked, NDA measurements are taken, and the cans are stored in a storage vault. Alternatively, fuel pins may be received. For example, the FFTF Green Fuel (unirradiated) would be received in the form of sintered pellets contained inside stainless steel cladding making up a fuel pin, and the pins will be contained in fuel assemblies and transported and stored in a certified DOT Type B Package called a Hanford Unirradiated Fuel Package (HUFP). The Green Fuel Disassembly System (GFDS) glovebox will be used to manually cut and disassemble the fuel pins. The resulting fuel pellets will then be batched into screw-top (or other non-welded design) Pin Fuel cans with the same mass limits as the 3013 (4.4 kg of Metal or in most cases 5.0 kg of oxide [Ref. 2]). The Pin Fuel cans may also stored in the storage vault, with the same handling rules as the 3013 cans.

The cans (welded 3013s and/or non-welded Pin Fuel) will be transferred via a two-position shielded cart. The cart is equipped with borated shields. The shielding reduces the potential dose to the worker, and is not required for nuclear criticality safety reasons. Cans filled with metal (up to 4.4 kg, each) are delivered to the Oxidation System (DMO) and cans filled with oxide (up to 5.0 kg, each) are delivered to the Feed Preparations System (FPS).

Previous NCS analysis documents the two-position cart**.** Section 2.2.8 of WSMS-CRT-05-0070 (Ref. 5) provides a detailed description and photos of two-position carts used at SRS**.** Reference 5 also presents detailed Monte Carlo neutronics calculations with developed accident scenarios demonstrating the safety of the two-position cart interacting with additional carts and resident fissile material. The material-at-risk (MAR) for the two-position cart is limited to the contents of two cans with significant controls assuring they are a maximum of 4.4 kg of metal or 5.0 kg of oxide. At this time, it is not known if the existing cart will be re-used, or a new cart will be manufactured, while a NCS analysis is required to incorporate specific Pu-Vit scenarios (for example, the cart adjacent to storage Racks and NMC), no significant changes are expected.

Since the form of the oxide removed from fuel pins is sintered (very hard) pellets, there is no concern with uptake of atmospheric moisture, as there is with dry powders, which are stored in the welded 3013 cans.

Pin Fuel cans, or any unwelded can design including cans that may be intentionally vented to prevent build-up of radiolytic gasses may be introduced to the MRSS. Collectively, these alternate can designs are referred to as “non-3013” cans. The NCS concern with non-3013 cans is the potential for water to be introduced into the can due to sprinkler activation, or other loss of moderation control scenario. Calculations presented in N-CLC-K-00208 (Ref. 10) demonstrate that a can, the same size as a 3013, is geometrically favorable with complete water (or polyethylene) flooding and concrete reflection. Furthermore, interaction tables are presented for combinations (spacing violations) of moderated cans in N-CLC-K-00213 (Ref. 11). Therefore, with adequate spacing requirements any non-3013 can, with the same (or smaller) dimensions as standard 3013 cans are favorable geometry for the potential moderators in Pu-Vit. Double contingency is provided by adequate spacing of the cans, as provided for in a case specific NCSE.

Specific processing areas may not be assured of staying below a 2-inch water depth on the floor in the advent of sprinkler activation (Ref. 1). Therefore, specific NCSEs will have to address controls based on fully moderated and reflected conditions.

Criticality safety of the Pu-Vit process is maintained by:

- Limited batch sizes in the Cans.
- Spacing in the storage racks and transport cart.
- Moderation control of the material.

- Fuel pin receiving will be analyzed on case by case bases. NCS safe handling rules will cover disassembly and batching of material into the fuel pin cans.
- Routine inspections of the glovebox, HVAC, and filters prevent inadvertent fissile material accumulation.
- Facility construction assures that water spills on the floor cannot accumulate over 2 inches in depth. Areas that may not be shown to limit water on the floor to less than 2 inches will require NCS controls based on fully moderated and reflected conditions for spill scenarios.

Passive Engineered Features:

Can designs ensure the cans are favorable geometry.
Storage racks and transport cart provide the required spacing and can survive a design basis accident.
Glovebox and associated filters are designed to prevent significant accumulations.
Facility design limits the potential flooding depth on the floor.

Active Engineered Features: None Identified.

Administrative Controls:

Can loading limits are maintained.
Spacing requirements of individual cans are maintained.
Good housekeeping of gloveboxes and inspections of filters and HVAC prevent accumulations.
Limiting combustible materials and Operator response prevent/limit initiating fires.

### 4.2.2 Oxidation (DMO) System

Oxidation is a glovebox contained process where 3013 containers with Pu Metal (only) are opened, and dumped into a basket which will be fed into an oxidation furnace. The glovebox maintains an argon environment (around the exposed Pu), preventing the unintentional oxidation of the pyrophoric Pu metal.

The furnace operation converts the 4.4 kg (max.) of plutonium metal to a maximum of 5.0 kg plutonium oxide ($PuO_2$). It is expected that inspections of the resulting oxide will find unoxidized metal that will be reintroduced into the furnace until complete oxidation has occurred. The oxidized plutonium is batched into a transport can and moved to the Feed Preparation System.

Criticality safety of the furnace operation is maintained by:

- Limited batch sizes in the furnace hoppers.
- Spacing between the batches.
- Moderation control of the material.
- Routine inspections of the furnace, glovebox, HVAC, and filters prevent inadvertent fissile material accumulation.

- Facility construction assures that water spills on the floor cannot accumulate over 2 inches in depth.

Passive Engineered Features:

Glovebox design prevents introducing significant moderation during operations.
Hopper design is limited to a safe batch.
Hopper conveyor belt maintains safe spacing between the batches.
Associated glovebox, HVAC, and filters are designed to prevent accumulations.
Facility design limits the potential flooding depth on the floor.

Active Engineered Features: None Identified.

Administrative Controls:

Hopper loading limits are maintained.
Spacing requirements of individual hoppers are maintained.
Good housekeeping of gloveboxes and inspections of filters and HVAC prevent accumulations.
Limiting combustible materials and Operator response prevent/limit initiating fires.

### 4.2.3 Feed Preparations Systems (FPS)

The FPS is fully contained in a glovebox. The following functions are performed in the FPS glovebox.

- The incoming cans are unloaded from the transport cart into the input staging section lag storage positions.
- 3013's are punctured, vented, opened and the oxide is dumped into a crusher
- Pin Fuel cans from GFDS and transport cans from Oxidation are opened.
- Material from the Pin Fuel cans is processed through the crusher. The material from Oxidation, received in transfer cans, may already be of proper particle size and will only require dumping to split the material into 2 kg batch cans.

The resulting batch is a maximum of 5.0 kg of oxide. As required, the batch is fed into the crusher. After being crushed the material is sampled and separated into smaller 2.0 kg batches, and placed into "batch" cans. To facilitate the formation of even 2.0 kg batches from the odd masses of the incoming cans a "butt can" is required in the glove box. The butt can will have a maximum of 2.0 kg of fissile oxide at a given time, and is treated as resident material, along with projected High Efficiency Particulate Air (HEPA) filter hold-up, in the glove box NCSE.

Criticality safety of the FPS is maintained by:

- Limited batch sizes in the incoming cans, crusher, butt can, and exiting batch cans.
- Spacing between the various containers being processed and equipment containing Pu Oxide.
- Moderation control of the material.

- Routine inspections of the crusher, glovebox, HVAC, and filters prevent inadvertent fissile material accumulation.
- Facility construction assures that water spills on the floor cannot accumulate over 2 inches in depth.

Passive Engineered Features:

Can designs insure the cans are favorable geometry containers.
Crusher, glovebox, and associated filters are designed to prevent accumulations.
Facility design limits the potential flooding depth on the floor.

Active Engineered Features: None Identified.

Administrative Controls:

Can loading limits are maintained.
Spacing requirements of individual cans are maintained.
Good housekeeping of the crusher, gloveboxes, and inspections of filters and HVAC prevent accumulations.
Limiting combustible materials and Operator response prevent/limit initiating fires.

### 4.2.4 Attritor Mill, Milling & Mixing System (MIX)

The purpose of the Milling and Mixing System is for size reduction and uniform mixing of oxide with glass frit. MIX consists of three integrated subsystems to safely mix oxide with glass frit and deliver the resulting mixture to the Vitrification System. These subsystems include:

- Glass Frit Batching Subsystem
- Oxide/Frit Milling Mixing Subsystem
- Mix Collection and Batching Subsystem

The FPS delivers oxidized fissile material that has been ground to approximately 1 mm in size. A batch can containing up to 2.0 kg fissile oxide is transferred into Milling and Mixing. The batch can is emptied into one of two attritor mills along with glass frit (which is weighed from a hopper into the attritor mill) at a nominal 9:1 frit to oxide ratio (by weight). The attritor mill reduces the particle size of the material to less than or equal to 20 microns, and ensures that the frit and oxide are mixed into a homogeneous mixture suitable for vitrification. The material is dumped into a collection hopper and divided into 2 equal feed batches, each containing approximately 1 kg of bulk fissile material. A uniquely identified transport hopper will then take the melter feed batch to the Vitrification System for melting, via an automatic Material Handling System.

The attritor milling machines presents unique problems for NCS. Favorable geometry for 2.0 kg of plutonium oxide ($^{239}PuO_2$) is estimated by preliminary calculations as 5 liters; however,

current designs of the attritor mill are approximately 10 gallons or about 37.9 liters. Working properly, the fissile oxides will be blended down at approximately a 9:1 ratio with the nuclear poison, borated frit. However, failure of sequencing could lead to the scenario of fissile oxide being charged into an attritor mill, without the required poison. Given this single failure, no criticality event could occur. The fissile oxide powder would fall harmlessly to the milling media. However; given a second unlikely, independent, and consecutive failure of the attritor mill housing, water from the surrounding cooling jacket could spray into the hopper. Design features will assure protection from this concurrent event. Several design options are available; including the alternative design of an air-cooled jacket. An air cooled attritor mill would insure that the fissile material could not become moderated. In the event that design is forced to use a water-cooled jacket, two engineered barriers that prevent an accidental criticality are:

1. The charge mechanism assuring sequencing the fissile oxide with the borated frit, providing poison control.
2. The attritor mill housing engineered barrier provides moderation control.

These controls provide two engineered barriers, over two independent parameters.

In the event that the final attrition mill design requires both large mill housings (greater than 5 liters) and water-cooling jackets; two defense-in-depth precautions could be utilized. The milling media will consume about 1/3 of the volume, making a safe volume up to about 7 liters, additionally the milling media will be constructed from a mild nuclear poison. The current media design calls for zirconium with naturally occurring hafnium, or even if made from stainless steel, the media would be a mild poison.

In the event that design is forced to use a water-cooling jacket a precaution would be to add boron to the water cooling jacket. The likely hood of a criticality accident in the mill housing would be greatly reduced if borated water is used in the cooling jacket.

It would be difficult to take explicit credit for either of these defense-in-depth precautions, due to required surveillances. Maintaining them as defense-in-depth precautions would help assure criticality safety in the event of the failure of both engineered controls.

Given the controls in place on the sequencing of fissile oxide and borated frit along with the construction and inspection criteria of the attritor mills, it is believed that a specific NCSE will be able to demonstrate that a criticality in an attritor mill is beyond double contingency.

Criticality safety of Milling & Mixing is maintained by:

- Limited batch sizes in the incoming hoppers.
- Spacing between the individual hoppers.
- Moderation control of the feed material.

- Construction, acceptance inspection and follow-up maintenance assures the attritor mill housing is a robust engineered control preventing the cooling water from leaking into the milling chamber. This engineered barrier also contains the milling process; therefore, each cycle exposes the barrier to the milling media. The attritor mill housing providing the moderation barrier shall satisfy the conditions of ANSI/ANS 8.22, "Nuclear Criticality Safety based on Limiting and Controlling Moderators," Ref. 7. (Not required for an air cooled attritor mill.)
- Proper sequencing control assures that batches of fissile oxide are not introduced into an attritor mill, without the previous or simultaneous introduction of borated frit at the acceptable 9:1 weight ratio.
- An active system is required to notify operations in the event of a cooling water leak. (Not required for an air cooled attritor mill) For example: a pressure sensor in the cooling water system, or a level indicator depending on the selected design.
- Routine inspections of the attritor mills and associated equipment prevent inadvertent fissile material accumulation.
- Facility construction assures that water spills on the floor cannot accumulate over 2 inches in depth.

Defense-in-Depth Criticality Safety Mitigating Factors (Not credited in the DCA):

- The milling media in the attritor mills consumes some of the volume (~ 1/3) of the unfavorable geometry mill. Additionally, the media is manufactured with a mild poison. (Not required for a favorable geometry attritor mill)
- The cooling water (if required) circulated in the attritor mills will be borated. Given the scenario of a leak into the mill, simultaneously with a miss-batching of fissile oxide without sufficient borated frit, the likely hood of an inadvertent chain reaction with borated water is much less than with unborated water. (Not required for either a favorable geometry or an air cooled attritor mill.)

Passive Engineered Features:

Limited batch sizes in the incoming hoppers.
Spacing between the individual hoppers.
Moderation control of the feed material.
Construction, acceptance inspection and follow-up maintenance assures the attritor mill housing is a robust engineered control preventing the cooling water from leaking into the milling chamber. This engineered barrier also contains the milling process; therefore, each cycle exposes the barrier to the milling media. The attritor mill housing providing the moderation barrier shall satisfy the conditions of ANSI/ANS 8.22, "Nuclear Criticality Safety based on Limiting and Controlling Moderators," Ref. 7. (Not required for an air cooled attritor mill)

Active Engineered Features:

Proper sequencing control assures that batches of fissile oxide are not introduced into an attritor mill, with out the previous or simultaneous introduction of borated frit at the acceptable 9:1 weight ratio.

An active system is required to notify operations in the event of a cooling water leak. (Not required for an air cooled attritor mill) For example: a pressure sensor in the cooling water system, or a level indicator depending on the selected design.

Administrative Controls:

Routine inspections of the attritor mills and associated equipment prevent significant inadvertent fissile material accumulation.

### 4.2.5 Vitrification (VIT)

The purpose of the Vitrification System is to convert the blended glass frit/oxide powder received from the MIX system into a glass form that is acceptable for final disposition when encapsulated in a DWPF canister with HLW glass. The glass product is produced by feeding Pu and Lanthanide-Borosilicate (LaBS) glass frit into a Cylindrical Induction Melter (CIM). The CIM system consists of an inductively heated Platinum/Rhodium (Pt-Rh) containment vessel, an induction heating system, a control system, and a simple off-gas filtering system. The Pu oxide feed and frit are melted to incorporate the plutonium oxide into the glass. To discharge, the glass flows out the bottom of the melter by gravity through an inductively heated Pt-Rh drain tube into a stainless steel canister.

The Vitrification System receives melter feed batches from the two attritor mills in the MIX system. Each melter batch of approximately 10 kg bulk, consists of a glass frit and oxide mixture with a particle size less than or equal to 20 microns. This powder is fed directly to a CIM and is subjected to a melt cycle temperature of ~1500 $^{\circ}$C (2732 $^{\circ}$F). During the melt cycle, the plutonium oxide and glass become homogeneous, and substantial chemical processing would be required to separate out SNM after Vitrification. The melting cycle will take a maximum of 12 hours to complete, at which time the glass is emptied into a Vit can. The Vit can is then transferred to the Bagless Transfer System. After cooling, the bagless transfer cans are loaded into magazines and the magazines are loaded into special DWPF canisters. The canisters are staged prior to shipment. For anticipated throughput, a total of 10 melters are projected to complete the VIT system. Melter failure is an anticipated event during normal operations, and the design will account for routine maintenance removal of a failed melter.

The major components of the Vitrification System include the transport hopper handling equipment, melter(s), closed loop limited volume cooling water for melter(s), room air for melter cooling and glovebox atmosphere, mechanism for pouring glass into Vit Cans, cooling positions for the Vit Cans, monitoring equipment for holdup measurement of each melter, and internal material handling equipment.

Criticality safety of the Vitrification System is maintained by the physical form of the fissile material, once mixed with borated glass at a 9:1 ratio, there are no NCS concerns with the material. During the melt cycle, the plutonium oxide and glass become homogeneous chemically, and substantial chemical processing would be required to separate out SNM after vitrification (Ref. 12). No NCS controls are required on the position of transfer hoppers, Vit cans, water cooling system, or glass production.

### 4.2.6 Sampling and Inspection Work Stations

Multiple work stations will be required for sampling, inspections, and various auxiliary functions with the fissile material. In general, these fixed work stations provide neutronic isolation between the safe batches of material. Each station will process one batch at a time and no additional NCS controls will be required. Good housekeeping practices will assure that the stations that require access to the fissile powders will be regularly cleaned and routinely inspected for fissile material accumulations. Fume hoods, filter housings, and associated equipment will also be under routine surveillance to assure that accumulations of fissile material are found prior to ANSI/ANS 8.1 (Ref. 3) single parameter mass limits being exceeded.

Sample analysis equipment in the Feed Preparations glovebox will process samples of the Pu oxide. Accountability measurements will require use of various sources and standards which may contain small amounts of fissile isotopes. Individual NCSEs will insure the NCS safety of the stations prior to operations.

Calorimeters are used to measure the heat output due to isotopic radiation in the cans. This involves inserting the can into a device made of low-density styrofoam, without having to open the can. While this does increase the reflection of the cans, it is not significant compared to analyzed accident conditions for the cans, such as rolling into a concrete corner. In the event a water-cooled (or other refrigerant) Calorimeter is required for use with Pin Fuel cans or other non-3013 containers, a specific NCS calculation will be required to analyze upsets conditions involving loss of moderation control.

Pu Vit, as currently designated, does not have floor drains. In the event of sprinkler activation from an anticipated fire event, Reference 1 demonstrates that the expected number of sprinkler heads activated would result in less than 2 inches of standing water on the floor. Reference 10 demonstrates that 2 inches of water is critically safe for the expected batch sizes of Plutonium metal, and Plutonium/Uranium oxides. In the event design cannot maintain a safe slab depth in the event of an anticipated fire event, safe geometry water collection is required (per ANSI/ANS 8.7).

Criticality safety of Work Stations & Sample Equipment is maintained by:

- Limited batch sizes in the work stations.
- Spacing between the individual containers and equipment.
- Moderation control of the material.
- Sample Equipment will require individual NCSEs, particularly for processes that may involve dissolution of fissile materials.
- Routine inspections of hoods, filter housings, and all associated equipment to prevent inadvertent fissile material accumulation. Accumulations are to be maintained below 450 grams of $^{239}$Pu (ANSI.ANS 8.1, Section 5.2 [Ref. 3]).

- Facility construction assures that water spills/sprinkler activation maintain a favorable geometry (ANSI/ANS 8.7, 4.2.4). This guidance is met by maintaining the water on the floor below 2 inches in depth in the event of anticipated sprinkler activation (Ref. 1).
- If water-cooled (or other refrigerant) equipment is required, specific NCS evaluations will be required.

### 4.2.7 Waste Management

Multiple waste steams will be generated and/or processed through the Pu-Vit Waste Management system. The Pu-Vit Waste Management System consists of several rooms located throughout the facility. These rooms have various purposes to support the generation, transport, staging, assaying, loading/packaging, and shipping of waste. Listed below is each room with a short description of its purpose and room content. As the project matures and waste streams are defined, the room content with respect to number of waste containers for each may change. The information described below is a summary of the best available data to date.

1. Unassayed Container Staging Room:
   This room will be used to stage unassayed waste containers in critically safe arrays. The waste will include 5-gallon pails, small HEPA polyboxes, 55-gallon Trans-Uranic (TRU) drums, and large polyboxes. Final array sizes and spacing requirements will be established by NCSE.
2. TRU Waste Assay Room:
   This room will be used for the assay of waste containers including 5-gallon pails, HEPA polyboxes, drums, large items, etc. The equipment to be located in this room includes 2 scales, the Low Level Waste (LLW)/TRU Waste Assay System, the Active (for uranium) and/or passive (for plutonium) Nuclear Multiplication Counter (APNMC), and a Portable Waste Assay System.
3. Assayed Pail Staging Room:
   This room will be used for staging 5-gallon pails after they have been assayed. Space for up to 60 pails will be allocated, which includes an area for “high” pails while awaiting relocation to GFDS for repackaging. The pails may be staged on shelving up to two high.
4. TRU Waste Loading:
   This room will be used for loading assayed 5-gallon pail waste into 55-gallon TRU waste drums. Pails will be opened, the bagged waste removed and placed directly into the designated drum. A ventilation hood will be available for use during waste loading as required for safe handling.

5. Standard Waste Box (SWB) Loading Area:
   This room will be used for loading SWBs and small polyboxes with assayed waste such as HEPA filter polyboxes or large items. Shelving for staging the assayed polyboxes (to fit both the small and large), and associated equipment will be provided.
6. Outgoing Waste Staging Area:
   This room will be used for staging pallet(s) to collect TRU Waste Drums.
7. Failed Equipment Staging Room:
   This room will be used for staging SWBs containing failed equipment from the gloveboxes (e.g., melter, furnace, and attritor) with various amounts of MAR. These items will require staging while characterization and Material Control and Accountability (MC&A) issues are resolved for their final disposition.
8. LLW Staging Room:
   This room will be used for staging bags of room low level waste (RM-LLW) from the various process rooms and containers for glovebox low level waste (GB-LLW) until time to package into the B12s/B25s.
9. LLW Loading Room:
   This room will be used for loading the LLW into the B12s/B25s. Once all information from the RM-LLW bags and/or GB-LLW pails is obtained, the LLW will be added to the B12s/B25s. Once full, the B12/B25 will be sealed, weighed and a Tamper Indication Device (TID) is installed. The pail is then removed from the Material Accountability Area (MAA).
10. Waste Staging Room:
    This room will be used for temporarily staging LLW.
11. Hazardous Waste/Mixed Waste (HW/MW) (Non-TRU) Staging:
    This room will be used for the establishment of Satellite Accumulation Areas (SAA) if needed. Once a SAA drum is full, it will be relocated, within the same room, to a Staging Area (SA) and the 90-day clock initiated. Once the drum is characterized and cleared through SNM checks, it will be removed from the MAA.
12. Waste Staging:
    This room/building will be used for the staging for full, characterized waste containers awaiting shipment to Waste Management Area Project (WMAP). The container will consist of drums, SWBs, and B12/B25s. Fork truck access and hoisting equipment will also be required. Shelving may be utilized for TRU drum and SWB staging if needed. TRU drums and SWBs shall not be stacked directly on top of each other. B12s/B25s may be stacked two (2) high.

All storage units (shelving, racks, cabinets, etc.) designed for fissile material (or material pending resolution) shall meet all design basis events and contain essentially no combustible materials. (ANSI/ANS 8.7, Ref. 8)

Final location and waste specifications are subject to change. Each waste handling room/ defined area will have its own NCSE written per WSMS NCS Manual, Ref. 4, the NCSE will

define the allowed mass limits, inventory, and spacing requirements of each allowed storage array, shelving and stacking arrangement.

### 4.2.8 Criticality Accident Alarm System (CAAS)/(NIMS)

ANSI/ANS 8.3, Reference 6 provides the guidance for the use of Criticality Accident Alarm systems. CAAS coverage shall be evaluated for all activities in which the inventory of fissionable materials in individual unrelated areas exceeds 450 grams of any combination of $^{235}U$, $^{233}U$, or $^{239}Pu$. The mass limit of 4.4 kg of metal (5.0 kg of oxide) in a single container is above this guideline. ANSI/ANS 8.3 also states that the installation of an alarm system implies a nontrivial risk of criticality. Additionally, testing and inadvertent activation of a CAAS/NIMS system is a concern for industrial safety. ANSI/ANS 8.3 requires specific evaluations to justify the installation of CAAS/NIMS systems.

DOE Order 420.1B specifically allows an exception from having CAAS/NIMS for approved shipping containers. The majority of material handling will be in approved shipping containers, or the inner containers of the package with additional safe handling rules. Areas with opened containers involving material processing require specific evaluations for the need of CAAS/NIMS systems.

WSRC NCS Manual, Ref. 13, currently interprets a nontrivial risk as having a probability of a criticality greater than $10^{-6}$/y (odds of an uncontrolled nuclear criticality accident are greater than 1 in a million years, based on projected operating conditions). This interpretation requires a detailed analysis and complete NCS scenario development. However, the WSRC NCS Manual interpretation was based on specific guidance from DOE 420.1A (see Directive section). This document is addressing the guidance of DOE Order 420.1B, which removes the specific exemptions from ANS/ANSI 8.3 for engineering judgment and probabilistic study. Therefore, documented evaluations must clearly state the criteria used for exempting a particular facility from requiring CAAS/NIMS. The local Criticality Safety Committee (CSC) is responsible for the final determination of the risk from a nuclear criticality accident, based on the controls elected and the process evaluated (Ref. 14).

If CAAS/NIMS are required to protect personnel, additional modeling of the final Pu Vit design will be required for a layout of alarms that insure coverage and provide exit routes for evacuating personnel.

In keeping with the recent efforts by DOE to increase and promote safety in design and inclusion of robust engineered controls earlier in project development (DOE Interim Guidance), it would appear prudent at the early design stages of a project which will be handling significantly more than a critical mass of fissile material to assume that the facility will need CAAS/NIMS until it can be demonstrated that the need is no longer necessary at which time the project costs may be reduced (Ref. 14). At this point in the project, based on the lack of maturity of the design, the uncertainties associated with the implementation of the proposed

controls and the long term mission of the Pu-Vit there is judged to be a non-trivial risk of a criticality. Based on this evaluation, it is recommended that NIMS be included in the project baseline for the Pu-Vit project.

# 5 Conclusions

Application of the general design guidance presented in Section 4 to the structures, systems and components involved in the Plutonium Vitrification project will ensure safe handling of the fissile material. Specifically:

- Safe parameters for use in the facility design:
  - The safe mass limits on individual containers per DOE 3013 (Ref. 2) assures safety in the Pu Vit Facility.
  - The 2-inch height limit for solutions on the floor has been demonstrated as safe for specific mass and isotopic distributions (Ref. 15).
- Additional NCS calculational needs:
  - Individual Pu-bearing material types, prior to acceptance,
  - The attritor mills, two-position cart, work stations,
  - Specific processing areas with the potential of greater than 2-inch water depth,
  - Demonstrate the criticality safety margin achieved by blending the fissile oxide with borated frit at a 9:1 ratio.
  - Waste streams as identified in Section 7 (on-going).
- Preliminary Requirements for a Criticality Accident Alarm System (CAAS) also referred to as Nuclear Incident Monitoring System (NIMS):
  - Specific evaluations, as approved by the CSC, may be able to demonstrate that NIMS are not required for Pu-Vit.
  - Alarm performance criteria are in ANSI/ANS-8.3-1997 (Reaffirmed 2002).
  - A specific Monte Carlo calculation is required to assure coverage and egress requirements of the final Pu-Vit layout.
- Process boundary for NCS Concerns:
  - Areas include Green Fuel process and all fissile storage areas up to and including the attritor mills. Waste streams will also require specific NCSE evaluations.
- Preliminary Double Contingency Analysis (NCSEs will include the final Double Contingency Analysis).
  - Above Sections 4.2.1-6 justify that NCSEs can be developed to demonstrate The Double Contingency Principle in the final Pu-Vit design.

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