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# CSER 01-008: Canning of Thermally Stabilized Plutonium Oxide Powder in PFP Glovebox HC-21A

Prepared for the U.S. Department of Energy
Assistant Secretary for Environmental Management
Project Hanford Management Contractor for the
U.S. Department of Energy under Contract DE-AC06-96RL13200

**Fluor Hanford**
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**Richland, Washington**

HNF-8560
Revision 0
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# CSER 01-008: Canning of Thermally Stabilized Plutonium Oxide Powder in PFP Glovebox HC-21A

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Fluor Federal Services

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August 2001

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# CSER 01-008: Canning of Thermally Stabilized Plutonium Oxide Powder in PFP Glovebox HC-21A

**Key Words:** HC-21A, BTCC, Room 228C,

**Abstract:** This document presents the analysis performed to support the canning operation in HC-21A. Most of the actual analysis was performed for the operation in HC-18M and HA-20MB, and is documented in HNF-2707 Rev 1a (Erickson 2001a). This document will reference Erickson (2001a) as necessary to support the operation in HC-21A.

# CSER 01-008: Canning of Thermally Stabilized Plutonium Oxide Powder in PFP Glovebox HC-21A

August 2001

Prepared by
Fluor Federal Services
Richland, Washington

For
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## EXECUTIVE SUMMARY

The plutonium stabilization program at the Plutonium Finishing Plant (PFP) uses heat to convert plutonium-bearing materials into dry powder that is chemically stable for long term storage. The stabilized plutonium is transferred into one of several gloveboxes for the canning process. Gloveboxes HC-18M in Room 228C, HA-20MB in Room 235B, and HC-21A in Room 230B are to be used for this process.

This document presents the analysis performed to support the canning operation in HC-21A. Most of the actual analysis was performed for the operation in HC-18M and HA-20MB, and is documented in HNF-2707 Rev 1a (Erickson 2001a). This document will reference Erickson (2001a) as necessary to support the operation in HC-21A.

Evaluation of this operation included normal, base cases, and contingencies. The base cases took the normal operations for each type of feed material and added the likely off-normal events. Each contingency is evaluated assuming the unlikely event happens to the conservative base case. Each contingency was shown to meet the double contingency requirement. That is, at least two unlikely, independent, and concurrent changes in process conditions are required before a criticality is possible. Therefore, this CSER meets the requirements for a criticality evaluation contained in the Hanford Site Nuclear Criticality Safety Program, HNF-7098 (FH, 2001), ANSI /ANS-8 series standards (ANSI 1998), and DOE Order 5480.24, *Nuclear Criticality Safety* (DOE 1992). This CSER also follows Fluor Hanford Criticality Safety Desk Instruction 6, Rev. 0, *Criticality Safety Evaluation Reports* (FH 2000).

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## List of Terms

| | |
|---|---|
| AIChE | American Institute of Chemical Engineers |
| ANSI | American National Standards Institute |
| ANS | American Nuclear Society |
| BTCC | Bagless Transfer Convenience Can |
| BTS | Bagless Transfer System |
| CPS | Criticality Prevention Specification |
| CSER | Criticality Safety Evaluation Report |
| DBE | Design Basis Earthquake |
| DOE | United States Department of Energy |
| FGE | Fissile Gram Equivalent |
| HCC | Hanford Convenience Can |
| ID | Identification Number |
| JEF | Joint European File |
| MCNP | Monte Carlo-n-Particle |
| NC | No Controls |
| PFP | Plutonium Finishing Plant |
| PHA | Preliminary Hazards Analysis |
| UKAEA | United Kingdom Atomic Energy Authority |
| UKNDL | United Kingdom Nuclear Data Library |

## List of Definitions

Contingency – A possible but unlikely change in a condition or control that could influence the nuclear criticality safety of a fissionable material operation and that would, if the change were to occur, reduce the number of barriers (either administrative or physical) that prevent an accidental nuclear criticality.

# 1.0 INTRODUCTION AND SUMMARY

## 1.1 INTRODUCTION

The plutonium stabilization program at the Plutonium Finishing Plant (PFP) uses heat to convert plutonium-bearing materials into dry powder that is chemically stable for long term storage. The stabilized plutonium is transferred into one of several gloveboxes for the canning process. Gloveboxes HC-21A in Room 230B, HC-18M in Room 228C, and HA-20MB in Room 235B may be used for this process. The operation includes sieving, grinding, canning, sampling, and weighing of the thermally stabilized material. The material is transferred into the glovebox in cans or boats.

The analysis performed for Gloveboxes HC-18M and HA-20MB (Erickson 2001a) restricts operations to oxides having an H/Pu ≤ 2 except for one furnace boat may be allowed to contain H/ Pu ≤ 20 for processing, but not for storage in the glovebox. The Bagless Transfer Convenience Container (BTCC) and sieve stack have a mass limit of 4.4 kg, while other containers have a mass limit of 2.5 kg. The gloveboxes have a total mass limit of 10.0 kg. Finally, material from the magnesium hydroxide process will be canned in these gloveboxes.

Neither of the previously analyzed gloveboxes [HC-18M or HA-20MB (Erickson 2001a)] is postulated to collapse during a design basis earthquake (DBE), however HC-21A is not seismically qualified, and is postulated to sustain damage, including collapsing, during a DBE. Therefore, a glovebox total mass limit of 7.5 kg (7.1 kg operating limit plus 0.4 kg 'fixed' holdup) is required for this operation in HC-21A.

The evaluation shows that under the controls specified in Section 3, assurance of subcriticality under normal and credible upset conditions is provided which satisfies the double contingency criterion. That is, at least two unlikely, independent, and concurrent changes in process conditions are required before a criticality is possible. Therefore, this CSER meets the requirements for a criticality evaluation contained in the Hanford Site Criticality Safety Program, HNF-7098 (FH, 2001), ANSI/ANS-8 series standards (ANSI 1998), and DOE Order 5480.24 (DOE 1992). This CSER also follows Fluor Hanford Criticality Safety Desk Instruction 6, Rev. 0, *Criticality Safety Evaluation Reports* (FH 2000).

## 1.2 DOUBLE CONTINGENCY DOCUMENTATION

This section presents a summary description of expected operations, expected normal conditions, and base cases for normal conditions plus anticipated off-normal conditions for the operations performed in HC-21A. Table 1-1 lists the criticality limits and base case conditions for each criticality parameter. Table 1-2 summarizes the bounding contingency cases.

### 1.2.1 Expected Operations for Glovebox HC-21A

Glovebox HC-21A is expected to receive furnace boats of thermally stabilized material ($H/X \leq 2$). The operations of sieving, grinding, canning, sampling, weighing, and sealing of cans is performed in Glovebox HC-21A. Other than the lower total glovebox mass limit, this operation is expected to be the same as allowed in HC-18M and HA-20MB (Erickson 2001a).

### 1.2.2 Expected Normal Conditions

"Normal operation" is considered the most reactive condition that could occur under allowed (non-upset) conditions, with maximum fissile material in the containers in the most reactive composition and configuration allowed. This glovebox may contain plutonium and/or uranium in oxide or hydroxide or other compound forms. Although it is expected that the material in the glovebox will be oxide having an $H/Pu \leq 2$ as a result of the thermal stabilization operations that typically produce the material, normal operation conditions consider both metal and oxide with other moderation conditions. No fissionable material solutions are allowed. The fissile mass is limited to 4.4 kg plutonium or plutonium fissile equivalent for the BTCC and sieve stack and 2.5 kg plutonium or plutonium fissile equivalent for all other containers. The resulting $k_{eff}$ for the normal case (Erickson 2001a) was $0.765 \pm 0.004$ (hc18m07).

Fissile equivalent $^{235}U$ may be present (gram-for-gram in place of $^{239}Pu$) in any enrichment, providing the material is insoluble and fissile bulk density is at least 1 g/cm$^3$. Otherwise, uranium enrichment is limited to 50 wt% $^{235}U$. Muffle furnace oxidation of plutonium and uranium metal and alloys produces oxide of bulk density in the range of 3 to 5 g/cm$^3$ (Greenborg 2001). Non-metal plutonium and uranium materials may have lower densities. Some materials to be processed may have densities less than 1 g Pu/cm$^3$.

### 1.2.3 Base Case Model

Adding any anticipated off-normal conditions to the above "normal operation" conditions produces the "base case" model. Thus, the base case encompasses the normal case with the worst-case likely off-normal conditions added. Table 1-1 summarizes the limits for normal conditions for each criticality parameter. The combination of normal conditions allowed by limits plus anticipated off-normal conditions is used to evaluate the criticality safety of normal operations as the base case. Analysts evaluate abnormal conditions and contingencies by adding an unlikely event to the base case. The base case adds the condition of 0.32 cm (1/8 in.) of oxide on the floor of the glovebox to the normal case. The resulting $k_{eff}$ for the base case model (Erickson 2001a) was calculated to be $0.775 \pm 0.004$ (hc18m15).

Table 1-1. Glovebox HC-21A – Base Case Limits Summary

| **Controlled Parameter** | **Limit** | **Abnormal but anticipated conditions** |
|---|---|---|
| Mass | Maximum 2.5 kg Pu or fissile equivalent per container, except BTCC or sieve stack maximum 4.4 kg Pu or fissile equivalent. Maximum 7.5 kg Pu (7.1 kg operating limit plus 0.4 kg 'fixed' holdup) or fissile equivalent limit in glovebox. | BTCC with 5.0 kg Pu, which is larger than the container mass limit. |
| Volume | Maximum 3.3 liter container volume limit (sieve stack).<br>Container grouping Limits:<br>1) Max 5.0 kg, max 7.0 L<br>2) Max 6.5 kg, max 6.5 L | No anticipated volume upsets. |
| Fissile Form | Oxide, or other compounds. One quarter of a metal button(625 g) included. | No anticipated upsets. |
| Moderation | H/Pu $\leq$ 2, one container with H/Pu $\leq$ 20. HC-21A is a dry glovebox, and no solutions are allowed. | H/Pu = 20 in sieve stack, H/Pu = 2 elsewhere. |
| Interaction | 25.4 cm (10 in.) minimum spacing between unit masses and/or unit volumes including containers on the conveyor. | A 0.32 cm thickness of $PuO_2$ (H/Pu = 20) modeled on the floor. One spacing violation modeled. |
| Reflection | Dry or drained glovebox. | Full water reflection on glovebox sides, nominal water reflection on top and bottom of glovebox, and a nominal 2.54 cm (1 in.) water reflector around each container. |
| Geometry | Pu only in designated containers. | Worst case geometry assumed. |
| Isotopics | N/A | None (fissile equivalent 100% $^{239}$Pu). |
| Enrichment | Maximum 50 wt% $^{235}$U in uranium if material is soluble or bulk density is less than 1.0 g/cm$^3$ but greater than 0.1 g/cm$^3$. | None ($^{235}$U treated as $^{239}$Pu). |
| Density | N/A | Most reactive credible densities used for fissile materials. |
| Concentration | N/A | Plutonium in the most reactive arrangement among the containers. |
| Poisons | N/A | No anticipated abnormal poison upsets. |

### 1.2.4 Contingency Summary

Table 1-2 summarizes the analyses of the independent, non-concurrent off-normal events (contingencies). The resultant computed reactivity is compared to the subcriticality target $k_{eff}$ of 0.942 for MCNP calculations of non-metal, 0.932 for MCNP calculations of metal plutonium systems, or 0.935 for MONK calculations as explained in Section 4.0. This table summarizes the results of the contingency evaluation found in Section 5.3 of this CSER. Specific $k_{eff}$ calculations were not made for contingencies in Table 1-2 that were bounded by other analyzed contingencies.

Table 1-2. Glovebox HC-21A – Contingency Summary

| **Contingency Description** | **Affected Parameter(s)** | **Barriers that make contingency unlikely** | **$k_{eff}$ bounding contingency (case ID)** |
|---|---|---|---|
| Mass limits of glovebox exceeded | Mass | Procedures and Training. | 0.917 ± .004 (hc18m13a) |
| Mass limit of container exceeded | Mass | Procedures and Training. | 0.917 ± .004 (hc18m13a) |
| 2.5 kg metal button introduced into glovebox | Density, Moderation | Procedures and Training. | 0.815 ± .004 (hc18m24) |
| Spacing limits violated | Interaction | Procedures and Training. | 0.910 ± .002 (btcc3_775) |
| Fire with Water Ingress into containers | Moderation, Reflection | Fire with sprinkler activation is unlikely. | 0.920 ± .002 (wet) |
| Spilled Plutonium dioxide (all containers) | Volume, Geometry, Spacing | Procedure and Training. | 0.917 ± .004 (hc18m13a) |
| Mist Atmosphere | Reflection | Fire with sprinkler activation is unlikely. | 0.824 ± .004 (hc18m23) |
| Seismic event | Interaction, Moderation, Reflection | Seismic event unlikely; requires severe damage to glovebox and fire suppression system. | 0.938 ± .002 (seism41) |
| Neutron Reflection under glovebox | Reflection | Procedure and Training, Glovebox has braces and steps that make storing things under the glovebox inconvenient. | 0.917 ± 0.004 (hc18m13a) |

## 1.3 SUMMARY

This criticality safety evaluation report (CSER) documents the criticality safety of the canning operation of thermally stabilized plutonium with an $H/X \leq 2$ within Glovebox HC-21A. Evaluation of these operations included normal, base case, and contingencies. The base case took the normal operation and added the likely off-normal events, so that each contingency is evaluated upon the worst likely situation. Demonstrating that each contingency has a calculated $k_{eff}$ less than the subcritical safety limit, shows that this operation meets the double contingency requirement, provided the recommended limits are observed. That is, at least two unlikely, independent, and concurrent changes in process conditions are required before a criticality is possible.

This CSER meets the requirements for a criticality evaluation contained in the Hanford Site Criticality Safety Program, HNF-7098 (FH, 2001), ANSI/ANS-8 series Standards (ANSI 1998), and DOE Order 5480.24(DOE 1992). This CSER also follows Fluor Hanford Criticality Safety Desk Instruction 6, Rev. 0, *Criticality Safety Evaluation Reports* (FH 2000).

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# 2.0 SYSTEM DESCRIPTION AND NORMAL OPERATIONS

Glovebox HC-21A is located in Room 230B, in PFP building, 234-5Z, which is located in the 200 west area of the Hanford site. This facility was historically used to process plutonium into oxide or metal forms. It is currently undergoing operations to stabilize the different forms of plutonium still located there.

## 2.1 OPERATIONAL SEQUENCE

Plutonium stabilization activities take place on the first floor of the PFP. The furnace boat charges are prepared in several different gloveboxes in PFP. The loaded boats are then transferred via conveyor Gloveboxes HC-2, HC-3, HC-4, and HA-28 to the furnace gloveboxes (HC-21C in Room 230A and HA-21I in Room 235B) for thermal stabilization. Furnace gloveboxes receive only prepared furnace boats. The thermally stabilized material is transferred to Gloveboxes HC-21A, HC-18M, or HA-20MB for further processing and canning.

In Glovebox HC-21A, the stabilized plutonium (most likely in the form of $PuO_2$) is sieved. Any chunks are ground as necessary until they can pass through the sieve. A sample is taken for moisture content determination and the remaining $PuO_2$ is placed into a metal can. Once a can is filled, it is weighed and a solid lid is attached to the can. These cans may then be sent to Glovebox HC-18BS for temporary storage until the moisture content results are returned. After the moisture content results are available (4 - 8 hrs), the cans would then be returned to one of the canning gloveboxes. If the results indicate that the contents of the can are within allowable limits, the solid lids will be replaced with vented lids and the can may be transferred out of the subject gloveboxes.

## 2.2 FACILITY AND EQUIPMENT DESCRIPTION

### 2.2.1 Glovebox HC-21A

Glovebox HC-21A is located in room 230B in the main PFP Building 234-5Z. Figure 2-1 shows a sketch of the approximate layout of the glovebox in relation to the other gloveboxes and conveyors used for thermal stabilization activities. Glovebox HC-21A is 106.7 cm (42 inches) deep, 91.4 cm (36 inches) high, and 322.6 cm (127 inches) long. It is supported 137.2 cm (54 inches) above the room floor by a table frame. This glovebox has gloveports on both sides.

The north end of HC-21A connects to conveyor HC-2. The height of the glovebox floor and the HC-2 conveyor are approximately the same (the glovebox floor is slightly above the level of the conveyor) whereby the HC-2 conveyor connection acts as a criticality drain for the glovebox, thus eliminating the concern for the main section of the glovebox holding water and flooding. The table frame supporting the Glovebox HC-21A has horizontal members that do not allow a transport wagon to roll underneath the glovebox from any side.

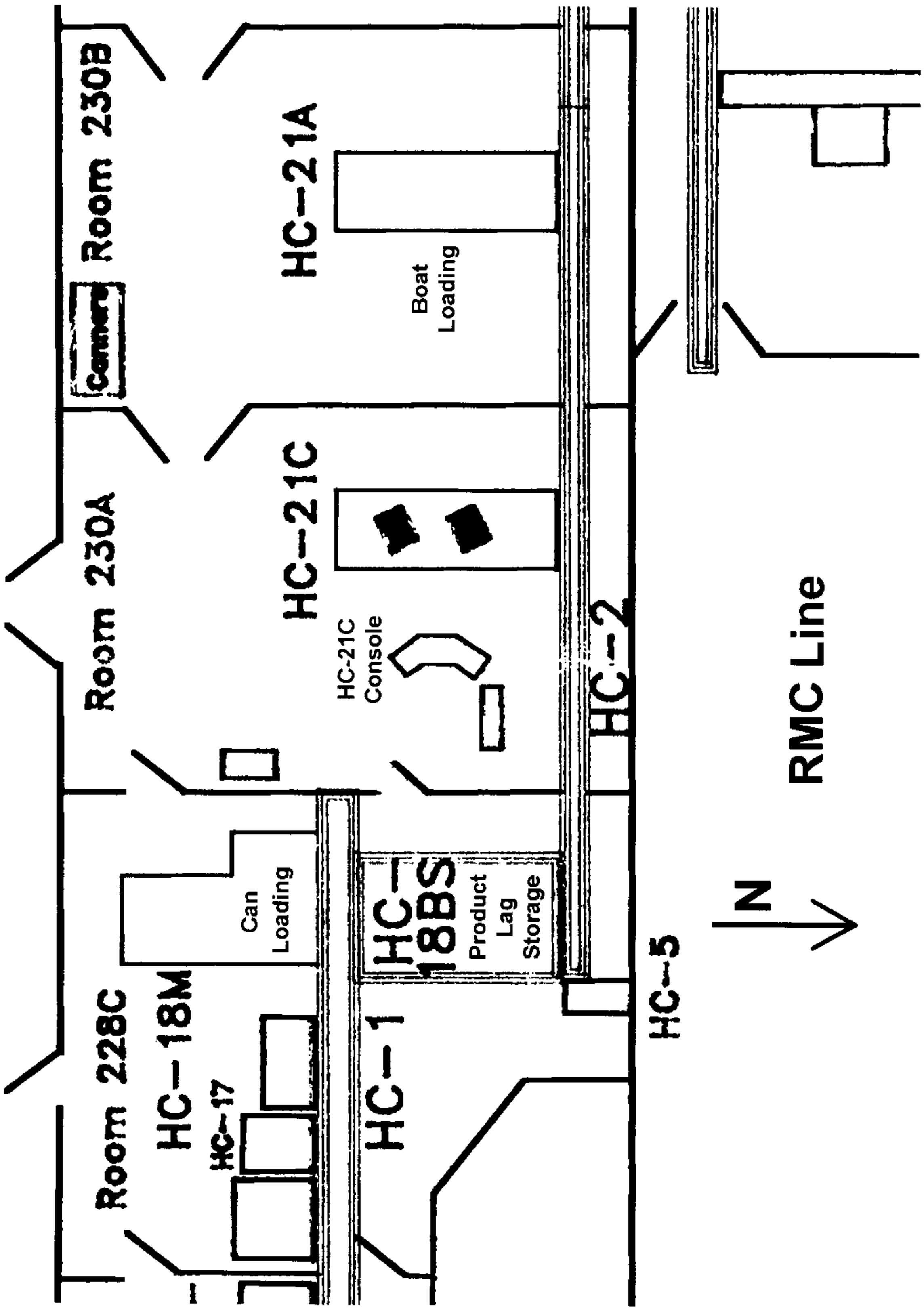


Figure 2-1 Layout for Gloveboxes and Conveyors Utilized for Thermal Stabilization Activities

Glovebox HC-21A does not have any internal water lines or water fire protection. It does have a Halon fire suppression system. The glovebox is listed as a "seismically unqualified" glovebox. Such gloveboxes could incur structural damage as a result of stresses from a DBE.

### 2.2.2 Glovebox Equipment

A summary of typical process equipment and containers expected in Glovebox HC-21A for the canning operation is listed below (this list is not all inclusive).

#### 2.2.2.1 Process Equipment

- Sieve Stack with one sieve pan (1.65 ℓ) and one sieve screen (3.30 ℓ total volume): The sieve stack diameter is 20.32 cm (8 in.). The combination of the sieve pan and sieve screen, with sieve screen fully inserted into pan, has a nominal height of 10.16 cm (4 in.) and a nominal volume of 3.3 ℓ (201 $in.^3$). The sieve screen has a 2.22 cm (7/8 in.) high reduced diameter section below the screen to insert into the sieve pan. If the screen is not fully inserted into the pan, the maximum volume would be 4.0 ℓ (245 $in.^3$).
- Electronic Scale
- Mortar and Pestle (≤1.1 ℓ )
- Mill/Grinder (≤1.1 ℓ )
- Electric can opener
- Electric canner and associated equipment
- Funnel, tongs, tools, and other non-container equipment

#### 2.2.2.2 Containers

- Furnace Boats and covers: The furnace boat is made from 0.32 cm (⅛ in.) thick Hastelloy X sheet stock shaped into a "cake pan", with an outside width of 13.3 cm (5.25 in.) and an outside length of 28.6 cm (11.25 in.). Inside, the bottom of the pan has an area of 354.8 $cm^2$. A measured brim-fill volume of 2.2 ℓ equates to an inside brim height of 6.2 cm (2.4 in.). Two 0.79 cm (5/16 in.) diameter holes are centered 4.5 cm (1.8 in.) above the boat inside bottom at each end. If the boat can only hold liquid up to the center of the hole, the capacity of the boat is 1.61 ℓ. The boat may have a cover to minimize dispersion of $PuO_2$ powder.
- PUREX slip lid can: The PUREX slip lid can has a nominal volume of 0.8 ℓ with an outside diameter and height of 8.7 cm (3 7/16 in.) and 13.7 cm (5 3/8 in.), respectively, and is sealed by taping the edge of the slip lid to the can. The cans have a wall thickness of approximately 0.023 cm (0.009 in.)

- PFP slip lid can:
  The PFP slip lid can has a nominal volume of 0.9 ℓ with an outside diameter and height of 9.2 cm (3 5/8 in.) and 14.3 cm (5 5/8 in.), respectively, and is sealed by taping the edge of the slip lid to the can
- Food Pack Can
- BTCC:
  The BTCC has a nominal volume of 1.65 ℓ with a diameter and height of 10.6 cm (4.17 in.) and 18.7 cm (7.34 in.), respectively. The wall thickness is approximately 0.05 cm (0.127 in.). The can is sealed by the addition of a screw top lid. When the can is open the screw threads add an additional 1.3 cm (0.5 in.) to the volume. See Section 2.2.3.3 for more discussion of the BTCC and its lids.
- BTCC with funnel has a nominal volume of 2.4 ℓ
- 0.5 ℓ slip lid can or poly jar
- 15 mℓ - 50 mℓ screw-cap glass or plastic sample vials
- Container for floor sweeps (≤ 0.5 ℓ)
- Container up to 2.3 ℓ as authorized by the CSR

#### 2.2.2.3 BTCC Lids

BTCCs have a volume of ~1.7 L assuming they are filled all the way to the top. Under normal circumstances, the BTCC is only to be filled (procedurally) to within approximately 3.8 cm (1.5 in.) of the top. This is to assure that no product gets into the internal threads, and prevents the lid from being properly seated.

The BTCCs may have several different types of lids available. These lids all have external screw threads to mate up with the BTCC's internal threads. The first lid type fits into the BTCC, is vented, and will be used for most purposes (i.e., for placement of the BTCC into the BTC). This lid is inset, and therefore, reduces the available internal volume of the BTCC. A second lid type is not vented, and in fact has a seal to prevent anything from entering or leaving the BTCC, or fouling the threads. This lid will be used to seal the BTCC after the product sample has been taken, while awaiting the moisture content results, or in the W-460 project where it allows a larger internal volume so combined batches of product can be homogenized more effectively for more accurate sampling.

Though the second lid increases the internal volume of the BTCC it only does so after the BTCC has already been filled appropriately. Due to the robust nature of the BTCC, and the seal of this second lid, it is not considered credible for anything to enter or leave the BTCC once the lid is screwed on. This lid is not to be used to increase the quantity of product that a BTCC will hold. Due to the larger diameter of this lid, the BTCC with this lid on, will not fit into the BTC.

There are also other lid types to be used for closing the BTCC. One has a T-handle welded to it, to assist with the open, closing, and moving of the BTCC, as well as a seal. Another will have magnetically coupled pressure sensors on it to measure the internal pressure of the BTCC. None of these lids are used to increase the useable volume of the BTCC.

Due to the above discussion about the nature of the different lid types, it is not necessary to perform or revise any criticality analysis to account for additional product in a BTCC or increased moderation beyond that which the analysis already accounts for. Any BTCC lid that is NOT used to increase the volume of material placed into the BTCC is acceptable from a criticality standpoint.

#### 2.2.2.4 Other Materials

- 6 $ft^2$ of damp rags for cleaning operations

## 2.3 FISSIONABLE MATERIALS DESCRIPTION

### 2.3.1 Fissile Isotopes

Each container is labeled with the mass of plutonium or fissile material. In this analysis, the fissile material is assumed to be $^{239}$Pu. This assumption is conservative for plutonium with more $^{240}$Pu than $^{241}$Pu, which is the case for plutonium produced in reactors at Hanford or elsewhere. The assumption of $^{239}$Pu is also conservative with respect to fissile material consisting of depleted or natural uranium or mixed oxides of plutonium and uranium where the uranium is less than 20% of the mixture.

### 2.3.2 Uranium Enrichment

It has been shown (Greenborg 2001) that uranium/water mixtures between 0.1 g/cm$^3$ and 1 g/cm$^3$ fissile concentration can be more reactive than similar concentrations of plutonium/water if the uranium is enriched to greater than 50 wt% $^{235}$U. Fissile equivalent $^{235}$U (substituted gram-for-gram with $^{239}$Pu) is allowed if the material is insoluble and the fissile density is less than 0.1 g/cm$^3$ or greater than 1 g/cm$^3$ (e.g. metal (alloy) thermal stabilization materials, corrosion products, oxidized metal, and product quality oxide) or the uranium is enriched to $\leq$ 50 wt%. Otherwise, uranium enriched to > 50 wt% is not allowed.

### 2.3.3 Non-Oxide Content

The subject gloveboxes will normally receive thermally stabilized (burned) fissile material compounds. These will generally be in the oxide form. However, some carbon compounds may survive the process. In addition some hydroxides may be present. Since plutonium hydroxide will oxidize at 70 °C not much of this form is expected to survive the furnace. In either case the oxide form at theoretical density is the most reactive and will be used to bound all other forms.

Inclusion of up to 625 g of plutonium metal (¼ of a button) in the oxide was analyzed by Cise (Cise 2000) and found to have negligible effect on the reactivity of the system. Thus, metal was only analyzed as a contingency of including an intact button in the glovebox.

### 2.3.4 Material Density and Associated Moderation

The majority of the materials to be processed through this glove box come from the thermal stabilization process. These materials are expected to have a density that exceeds 1 g Pu/cm$^3$ and are not soluble. In the case of water ingress to the glovebox, material of this type is not expected to be stirred up. Therefore, a reasonable maximum H/Pu ratio, without changing the material density, of 23.9 is assumed.

It is possible that other materials with a lower plutonium density could be brought into this glovebox for canning. In the case of water ingress to the glovebox with these lower density materials, the behavior of the material is not as well known. Therefore, the total volume of the fissionable material is controlled. The volume control will in turn limit the total mass of this material allowed in the glovebox.

## 2.4 FISSIONABLE MATERIAL HANDLING

Fissionable material will be inventoried as containers enter and leave, with the type of container controlled by the posted limit set. Controls include multiple levels of protection of a safe batch such as limits on fissionable mass, maximum container volume, elimination of moderation, and separation distance from other fissionable materials.

### 2.4.1 Glovebox Holdup in Glovebox HC-21A

Processing operations may result in fissionable materials being spread throughout the gloveboxes. Periodically the gloveboxes are cleaned of this material, and an NDA measurement is made to determine the glovebox holdup. For glovebox HC-21A, these NDA measurements were reviewed and a conservative value of 400 grams of the holdup were determined to be 'fixed' and therefore, unavailable for accumulation during upset conditions. An email documenting the results of the NDA analyses that was used to set this value has been received, and is included as Appendix C of Addendum 3 to CSER 99-007 (Erickson 2001b) for reference. All other holdup from the most recent controlling value, beyond the 400-gram value is to be included in the accounting for the total glovebox allowed mass.

# 3.0 LIMITS AND CONTROLS

Table 3-1 lists each of the parameters of concern for criticality safety, and discusses whether controls on these parameters are necessary.

These limits define an envelope of allowed masses and volumes that have been analyzed as meeting criticality safety requirements. The criticality prevention specifications (CPS) for Glovebox HC-21A implementing these requirements can be more restrictive than the limits specified in this CSER. The CPSs do not have to repeat these requirements verbatim. Any CPS requirement that is more restrictive, e.g., lower mass, smaller volume, or fewer containers, will have a larger margin of criticality safety and will meet the goal of ensuring a critically safe operation.

**Table 3-1. Controlled Parameters Related to Criticality in Glovebox HC-21A**

| Parameter | Controlled | Associated Limits |
|---|---|---|
| Mass | Yes | Maximum 7.5 kg plutonium or fissile equivalent in glovebox. |
| Volume | No | Volume is not controlled. |
| Density | Yes | Minimum 1 g Pu/cm$^3$. |
| **OR** | | |
| Mass | Yes | Maximum 7.5 kg plutonium or fissile equivalent in glovebox. |
| Volume | Yes | Maximum 7.1 liters of fissionable material in containers in glovebox. |
| Density | No | Density is not controlled. |
| | | |
| Moderator | Yes | H/Pu $\leq$ 2, except for a single container H/Pu $\leq$ 20 with authorization of CSR. |
| Spacing | Yes | 25.4 cm edge-to-edge minimum spacing between approved groupings. |
| Reflector | No | Worst credible reflection was used. |
| Poisons | No | Poisons were not used in this analysis. |
| Concentration | No | Worst credible concentrations were analyzed. |
| Enrichment | Yes | Plutonium was assumed to be 100 wt% $^{239}$Pu. $^{235}$U enriched to > 50 wt% is excluded if the fissile material is soluble or the bulk fissile density is less than 1 g/cm$^3$ but greater than 0.1 g/cm$^3$. |
| Geometry | Yes | Plutonium in designated containers with a maximum container volume of 3.3 $\ell$. |

## 3.1 ADMINISTRATIVE LIMITS AND CONTROLS

This analysis requires limits for control of fissile material in Glovebox HC-21A when the glovebox is used for the process defined in Section 2. When Glovebox HC-21A is used for a different process, criticality limits based on an approved CSER for that process are to be used. The limits for the process described in Section 2 are:

1) Glovebox total mass inventory limit is 7.5 kg of plutonium or fissile equivalent including holdup in glovebox (this includes 400 g of 'fixed' holdup).

2) If fissionable material density is less than 1.0 g/cc, the combined volume of fissionable material in containers in the glovebox is limited to 7.1 L.

3) Furnace boat or other container, except the BTCCs or sieve receiver pan, fissile mass limit is 2.5 kg of plutonium as a plutonium compound, per item.

4) BTCCs or sieve receiver pan mass limit is 4.4 kg of plutonium as a plutonium compound, per item.

5) Fissile material is limited to:

   a) Plutonium oxide and other plutonium compounds. MAXIMUM 625 g of unreacted plutonium or uranium metal is allowed. However the CSR must be notified if any plutonium or uranium metal is in the glovebox.

   b) $^{239}Pu$ may be substituted for $^{235}U$, gram-for-gram following the General Limits (CPS-Z-165-80010)

6) H/Pu is limited to a maximum of two (2).

   **EXCEPTION:** The CSR must be notified before processing a single furnace boat of H/Pu $\leq$ 20, but the material may not be stored in the glovebox.

7) Allowed groupings of containers fit into two categories of limits. These categories are:

   a) 5.0 kg maximum mass of plutonium, 7.0 $\ell$ maximum volume, or

   b) 6.5 kg maximum mass of plutonium, 6.5 $\ell$ maximum volume.

   The above volumes are the sums of the volumes of all of the fissile material bearing containers in each group of containers spaced less than 25.4 cm (10.0 in.) edge-to-edge at any one time. This allows containers to be brought together for material transfer operations.

8) Spacing limits:

   a) Each fissionable material bearing container or allowed container grouping is to be spaced 25.4 cm (10 in.) or more edge-to-edge from any other fissionable material bearing container or container grouping.

b) Each container or container grouping must be spaced at least 25.4 cm (10 in.) edge-to-edge from fissionable material containers on the conveyor.

c) A single plutonium bearing sample vial with a volume ≤ 30 mℓ may be moved anywhere without spacing requirements.

d) Spacing of 25.4 cm (10 in.) must be maintained between in-place high-efficiency particulate air (HEPA) exhaust filters and any fissionable material of more than 100 g.

9) A maximum of one sieve screen and one sieve pan (nominal 3.3 ℓ combined) are allowed in the glovebox.

10) A maximum volume of 1.0 ℓ of sample vials (30 mℓ maximum for each sample vial) are allowed in the glovebox. The vials are to be capped except for a maximum of three being open to take samples.

11) A maximum of one nested BTCC and sieve funnel (nominal 2.4 ℓ) is allowed.

12) Maximum of one floor sweeps container with a maximum 0.6 ℓ volume.

## 3.2 PROCESS CONTROLS

1) Stacking of plutonium bearing containers other than a sieve screen and sieve receiver pan or BTCC and sieve funnel is prohibited.

2) Noticeable accumulations of fissionable material are not allowed to remain. Spills are to be cleaned up as soon as practicable.

3) Free liquids or solutions other than maximum 50ml non-fissile liquid are not allowed in the glovebox.

4) Damp rags (6 square feet maximum area) may be present for glovebox cleaning purposes.

5) Glovebox HC-21A is to have a criticality fire fighting category of C. This allows water to be used as mists or fogs in the glovebox, but not as directed solid streams of water.

6) Storage of significant neutron reflecting materials, such as plastic, drums, equipment, etc. under the glovebox, is prohibited.

7) Before doing any operation to move or replace an in-place HEPA exhaust filter, remove any loaded containers of fissionable material from the glovebox and limit glovebox floor

accumulations to less than 0.3175 cm (⅛ in.) thickness of fissionable material. Other limits of CPS-Z-165-80250 for glovebox 8 x 8 x 6 size in-place HEPA exhaust filters are to apply.

8) The sieve screen is to be fully inserted into the sieve pan when stacked.

## 3.3 ENGINEERED SAFETY FEATURES

None

## 3.4 SUPPORTING INFORMATION

None

## 3.5 EVALUATION ASSUMPTIONS

All fissile material is assumed to be $^{239}Pu$.

# 4.0 METHODOLOGY

## 4.1 ANALYSIS PHILOSOPHY

The computer code, MCNP was used to calculate the $k_{eff}$ of specific limits for the operation in HC-21A. MCNP and MONK were used in CSER 98-005 (Erickson 2001a). Validation of these codes was performed by evaluating benchmark experiments involving the materials that will be used in these containers. See Section 4 of Erickson (2001a) for additional discussion of the code validation for both MCNP and MONK

## 4.2 MODELING ASSUMPTIONS FOR THE GLOVEBOX ARRANGEMENT

The normal operation of moving the plutonium from furnace boats to cans uses a sieve, grinder, boat, and can. A compact grouping of these containers on the glovebox floor is used to make up a conservative assembly of containers for normal operations. The model presented in Erickson (2001a) includes a 0.635 cm (0.25 in.) steel floor and a minimum 2.54 cm (1 in.) of water around and above the containers to simulate workers hands, gloves, rags, and other equipment. This water thickness between containers decreases when the distance between the containers is less than one inch. The mist analysis (Section 5.3.8 of Erickson 2001a) shows that the reflected cases are the most reactive. A one inch thick water reflector around containers is a conservative model of hands holding a container. The clusters of containers are modeled as being in a corner of the glovebox. The glovebox is modeled as being constructed of 0.635 cm (0.25 in.) thick steel, one foot of water from the concrete floor to the height of the glovebox top on all sides to model personnel, and a thick concrete floor beneath the glovebox. Top reflection is included over each container, and is not a part of the glovebox model. The model includes an extra can and an extra boat to be used in evaluation of contingencies.

## 4.3 SUBCRITICALITY LIMIT

For the purposes of this report, the principal criticality prevention criterion or parameter is that the effective neutron multiplication (or criticality) factor ($k_{eff}$) shall not exceed 0.95 for all permitted normal configurations of materials, containers, etc., and for any credible off-normal event. This criterion is based on implementing the applicable DOE Orders, ANSI /ANS-8 series standards, and the Hanford Criticality Safety Program. The subcriticality criterion is used to judge the acceptability of a calculated $k_{eff}$ value for fissionable material configuration. This criterion must account for the bias inherent in the code and cross sections used, any uncertainties in the physical problem being analyzed, and the uncertainties in both the bias determination (the experimental basis) and the calculational methods.

With the cross-section library supplied, the MONK6A/6B validation calculations indicate an allowed maximum $k_{eff}$ value of 0.935 for new system calculations to assure subcriticality with an acceptable margin, including the uncertainties in the analytical methods and benchmark experimental data. This limit requires the standard deviation of the new calculation be less than 0.01.

With the computer code MCNP a maximum allowable $k_{eff}$ value of 0.942 was established for calculations of non-metal systems, and a maximum allowable $k_{eff}$ value of 0.932 was established for calculations of metal systems. These values are for calculations with relative statistical uncertainties $\leq 0.002$ and assure subcriticality with an acceptable margin, including the uncertainties in the analytical methods and benchmark experimental data. See Appendix C of Erickson (2001a) for additional discussion.

## 4.4 APPLICATION OF DOUBLE CONTINGENCY PRINCIPLE

This analysis must meet the requirements of HNF-7098 (FH, 2001). HNF-7098 states that for all new operations and changes pertinent to criticality safety issues in existing operations, the CSER is required to demonstrate that there is an acceptable margin of subcriticality for all normal and credible abnormal conditions to meet the Double Contingency Principle. To demonstrate the Double Contingency Principle is satisfied, this CSER must show that there are sufficient factors of safety in the operation of Glovebox HC-21A such that, at least two unlikely, independent, and concurrent changes in process conditions are required before a criticality accident is possible.

# 5.0 EVALUATION AND RESULTS

## 5.1 NORMAL CASE

The normal case model from Erickson (2001a) has 2.5 kg Pu in a furnace boat, a conservative 5.0 kg Pu in a BTCC or HCC, 2.5 kg Pu in the sieve stack, 0.6 kg Pu in another container, for a total of 10.6 kg Pu and 7.7 ℓ. This mass is greater than the 7.1 kg Pu glovebox HC-21A limit. The containers inside the glovebox have close fitting water reflection, consisting of a minimum of 2.54 cm (1 in.) water reflection on the top and four sides. The container collection is placed adjacent to one corner of the glovebox for maximum reflection from the glovebox walls. The glovebox walls are modeled with 30.00 cm (11.8 in.) of water reflection on all glovebox sides up to the glovebox roof. This water reflector is a conservative model of people standing outside the glovebox.

The normal condition discussion and results are presented in Section 5.1 and Table 5.1 of Erickson (2001a), respectively. One case with plutonium at H/Pu = 20 only in the boat (hc18m06) had a calculated $k_{eff} = 0.736 \pm 0.003$. Another case with plutonium at H/Pu = 20 only in the sieve pan (hc18m07) had a calculated $k_{eff} = 0.765 \pm 0.004$, and a final case with plutonium at H/Pu = 0 at theoretical density (hc18m26) had a calculated $k_{eff} = 0.699 \pm 0.003$. The $k_{eff}$s of the normal condition models are all within allowable limits.

The normal cases include conservatisms such as excess mass and the ignoring of container spacing. As such, any allowed arrangement of fissile material is sufficiently bounded by the calculations. In addition, the results show that $k_{eff}$ is less than 0.77 during normal operations.

## 5.2 BASE CASE

Section 6.2 of Miller (1998) presents analysis used as the base case conditions of operations. The base case is composed of the normal operation with all parameters at their limiting values and likely abnormal conditions. Fissionable, moderating, and reflecting materials are modeled in the most conservative arrangement to represent the highest neutron multiplication for the system.

The base case model, is the same as the normal case model, except that 0.32 cm (1/8 in.) of oxide is modeled on the floor of the glovebox. This case [hc18m15 (Table 6.3 of Miller {1998})] has 2.5 kg in a boat with an H/Pu = 2, 2.5 kg in the sieve stack with an H/Pu = 20, 5.0 kg in a can with H/Pu = 2, 0.6 kg in another container with H/Pu = 2, and 0.32 cm (1/8 in.) oxide on the glovebox floor. This is a total of 10.6 kg (plus oxide on the floor) and a container volume of ~7.7 ℓ. The $k_{eff}$ for this base case is $0.775 \pm 0.004$. Since the total glovebox mass limit for HC-21A is 7.1 kg the analysis presented in Erickson (2001a) and Miller (1998) utilizing a 10.0 kg total glovebox mass limit is bounding. This volume also exceeds the limiting volume used when lower density material is present, and therefore, will bound that scenario as well.

An alternate scenario for the base case is to have 625 g plutonium as metal in the glovebox (instead of an equivalent amount of oxide). This situation is analyzed in the seismic analysis (Section 5.3.1) that provides the bounding mass limits and is shown to be acceptable. This is also bounded by the analysis for all other conditions in that they were performed for a glovebox mass limit of 10 kg and the limit for the operation in this glovebox is only 7.1 kg. The additional 2.9 kg of plutonium above the limit in this CSER adequately covers the inclusion of 625 g of plutonium metal in the base case.

The containers involved in this model are representative of those that would be used in this process, and adequately represent the maximum loading of the containers in a representative worst case configuration. The BTCC filled with 4.4 kg of plutonium at an H/X of 2 has an H/D of about 1. Results presented in Table 5.2 in Section 5.3.6 bounds having 4.4 kg in the 3.3 L and 20 cm (8. in) diameter sieve pan and sieve screen.

## 5.3 CONTINGENCY ANALYSIS

The contingency analysis section addresses the effect of various unlikely, off-normal events on the critical parameters and their associated controls to confirm the double contingency criterion has been met.

The off-normal situations of fissionable material handling for the subject gloveboxes are discussed in this section. These discussions give a description of the off-normal conditions and the calculational results. Each of the off-normal events results from a loss of one or more controls, and is therefore considered to be a contingency. For each contingency, the model assumed the most limiting allowed conditions for criticality controls shown in Section 3 including likely off-normal events. Each of these events is described below.

### 5.3.1 Seismic Event

The normal situation for canning of thermally stabilized material in HC-21A is to have up to 7.1 kg plutonium as oxide at an $H/X \leq 2$ in any number of unit masses spaced a minimum of 25.4 cm (10 in.) edge-to-edge from each other and from a unit mass on the HC-2 conveyor. The glovebox holdup is included in the total mass of plutonium. The Plutonium Finishing Plant Final Safety Analysis Report (Shapley, 1995) states that Glovebox HC-21A is not seismically qualified. In the event of an unlikely DBE, the structure supporting the glovebox could collapse allowing all fissionable material to collect in one corner of the glovebox. It is assumed that with a DBE that collapses the structural support of the glovebox, there will be damage to the glovebox itself. It is also assumed that the fire suppression piping overhead will not remain intact. Under these conditions, water ingress to the damaged glovebox is likely.

It is assumed that water entering the glovebox will not be in the form of a solid stream that could disperse the fissionable material in the water resulting in a lower effective plutonium density. It has been noted that for plutonium densities less than 5 g/cm$^3$, a mixture will become more reactive as the H/X ratio increases (e.g. water is added). Water entering the glovebox, could, however, saturate the fissionable material. Except for plutonium hydroxide, the product resulting from processing magnesium hydroxide, it is anticipated that fissionable material being introduced into Glovebox HC-21A will have a plutonium density ≥ 1 g/cm$^3$. Fully moderated material at this plutonium density, as in the event of water ingress, will have a maximum H/X ratio of 23.9. Because water ingress is likely during a seismic event, oxide was modeled with an H/X = 23.9.

To show that this contingency will remain subcritical, the glovebox mass limit of 7.1 kg plutonium as oxide having an H/X = 23.9 (plutonium density = 1 g/cm$^3$) was modeled as a regular pyramid in the corner of the glovebox. A regular pyramid is the most realistic and compact geometry and therefore the most reactive. In a collapsed glovebox, there will not be large reflectors along the outside windows of the glovebox but there will be a collection of water from sprinklers above the fissionable material. Therefore, nominal water reflection 2.5 cm (1 in.) was applied to the faces of the pyramid and full water reflection 30.5 cm (12 in.) was applied to the base of the pyramid. It is assumed that a corner of the collapsed glovebox will rest on the concrete floor of the room. Therefore, a thick 30.5 cm (12 in.) concrete reflector was modeled at the point of the pyramid. The results of MCNP calculations for seismic events are given in Table 5-1. The calculational result of this case which modeled only $PuO_2$ indicated a $k_{eff}$ of 0.938 ± 0.002. This result is less than the criticality safety limit of 0.942 for MCNP calculations of non-metal systems.

Material introduced into Glovebox HC-21A may have plutonium densities as low as 0.2 g/cm$^3$ for the case of plutonium from various precipitation processes. At that density, the largest possible H/X ratio in the material under water ingress will be approximately 130. It was found through analysis of the seismic contingency that the system reactivity for 7.1 kg plutonium at an H/X ratio greater than 23.9 (plutonium density of 1 g/cm$^3$) was unacceptable. Noting that critical volume increases with decreasing plutonium density below 1 g/cm$^3$ on Figures III.A.9(100)-4 and III.A.9(100)-5 in ARH-600, a volume limit of 7.1 liters will ensure a subcritical system at any plutonium density below 1 g/cm$^3$. Therefore, material having a low plutonium density, such as plutonium hydroxide, may be present in the glovebox if the limit set restricting total volume of fissile material is used. Alternately, if plutonium density is restricted to ≥ 1 g/cm$^3$, no limit on total fissile material volume in the glovebox is required (it is self limiting). Note that at a plutonium density of 1 g/cm$^3$, 7.1 kg plutonium occupies 7.1 liters. Therefore, this analysis is applicable for both sets of limits as presented in Section 3.

Because there is the possibility of metal pieces being interspersed in the oxide that is to be canned, the above seismic model was modified to include 625 g plutonium metal (¼ button) as part of the glovebox mass. The metal was modeled as a sphere and placed within a pyramid of $PuO_2$ having the balance of 6.475 kg plutonium. To determine the most reactive location, the sphere was modeled at the point of the pyramid, in the middle of the pyramid, and on the base of the pyramid. The results of these calculations are given in Table 5-1 and indicate that, although statistically insignificant at the 95% confidence level, modeling the metal sphere in the middle or on the base of the pyramid may result in a more reactive system than oxide alone. To determine the effect of the modeled shape of the metal (one sphere of 625 g) on the reactivity of the system, case ***seism43*** was modified to include a grouping of 5 plutonium metal spheres each having a mass of 125 g in place of the one sphere having a mass of 625 g. The results of this case show that dividing the plutonium metal mass into smaller pieces will reduce reactivity. Although the result of this case, ***seism43b***, and the other cases with metal have a $k_{eff}$ greater than the criticality safety limit of 0.932 for MCNP calculations of metal systems, it is concluded that if the mass of plutonium metal was further subdivided such that the resulting pieces had a diameter/thickness less than 0.625 cm (0.25 inches), the size of openings in the sieve screen, the reactivity of the system would be reduced to below the acceptable criticality safety limit.

Table 5-1 Results of MCNP Calculations for a Seismic Event

| Case | Description | $k_{calc}$ | 1 σ |
|---|---|---|---|
| ***Seism41*** | 7.1 kg plutonium as oxide pyramid located in corner of the glovebox nominally reflected (1 inch) on the faces and fully reflected (12 inches) on the base | 0.9380 | 0.0017 |
| ***Seism42*** | ***seism41*** with a 625 g plutonium metal sphere modeled at the point of the pyramid | 0.9212 | 0.0015 |
| ***Seism43*** | ***seism41*** with a 625 g plutonium metal sphere modeled in the middle of the pyramid | 0.9396 | 0.0015 |
| ***Seism43b*** | ***seism43*** with a 625 g plutonium metal sphere modeled as five 125 g plutonium metal spheres grouped in the middle of the pyramid | 0.9363 | 0.0015 |
| ***Seism44*** | ***seism41*** with a 625 g plutonium metal sphere modeled at the base of the pyramid | 0.9398 | 0.0017 |

### 5.3.2 Water Ingress and Fire

The analysis presented in Section 5.3.2 of Erickson (2001a) utilized a glovebox total mass limit of 10.0 kg. This is significantly more mass than the 7.1 kg allowed for the operation in HC-21A. Therefore, that analysis will bound the contingency of water ingress and fire in HC-21A. Case ***wet***, with water filling each container and mixed with the plutonium, gave a $k_{eff}$ of 0.920 ± 0.002. The additional 2.9 kg of plutonium above the limit in this CSER also covers the inclusion of 625 g of plutonium metal as discussed in the base case, Section 5.2.

### 5.3.3 Mass Limit of Glovebox Exceeded

The analysis presented in Section 5.3.3 of Erickson (2001a) utilized a glovebox total mass limit of 10.0 kg, and then exceeded the glovebox mass limit to analyze more than 14 kg of plutonium in the glovebox. This is significantly more mass than the 7.1 kg allowed for the operation in HC-21A. Therefore, that analysis will bound the contingency of exceeding the total glovebox mass limit in HC-21A. Case ***hc18m13a*** added an HCC with 5.0 kg for a bounding glovebox total of 15.6 kg. The $k_{eff}$ for this case was 0.917 ± 0.004. The additional 2.9 kg of plutonium above the limit in this CSER also covers the inclusion of 625 g of plutonium metal as discussed in the base case, Section 5.2.

### 5.3.4 Mass limit of Container Exceeded

The analysis presented in Section 5.3.4 of Erickson (2001a) utilized a glovebox total mass limit of 10.0 kg, and then exceeded the container mass limits. The container mass limits for Glovebox HC-21A are the same as the gloveboxes analyzed in Erickson (2001a). Since that analysis utilizes significantly more mass than the 7.1 kg allowed for the operation in HC-21A, that analysis will bound the contingency of exceeding the container mass limits in HC-21A. Case ***hc18m13a*** with a can containing 5.0 kg of plutonium laying down in a boat that already contains 2.5 kg and one inch of close fitting water under the glovebox floor had a bounding $k_{eff}$ of 0.917 ± 0.004. The additional 2.9 kg of plutonium above the limit in this CSER also covers the inclusion of 625 g of plutonium metal as discussed in the base case, Section 5.2.

### 5.3.5 2.5 kg Metal Button Introduced into the Glovebox

The analysis presented in Section 5.3.5 of Erickson (2001a) utilized a glovebox total mass limit of 10.0 kg, and analyzed plutonium metal being introduced into the glovebox. Since the analysis in Erickson (2001a) utilizes significantly more mass than the 7.1 kg allowed for the operation in HC-21A, that analysis will bound the contingency of introducing plutonium metal into HC-21A. Case ***hc18m24*** for introduction of a 2.5 kg plutonium metal item into the glovebox in a boat is bounding and has a $k_{eff}$ of 0.815 ± 0.004. The additional 2.9 kg of plutonium above the limit in this CSER also covers the inclusion of 625 g of plutonium metal as discussed in the base case, Section 5.2.

### 5.3.6 Spacing Limits Violated

The normal situation in the glovebox is to separate controlled quantities of plutonium oxide in their respective container groupings by a separation distance between surfaces of at least 25.4 cm (10 in.). The loss of spacing control among plutonium oxide containers to be used in the glovebox was investigated in Section 5.3.6 of Erickson (2001a). The arrangement of plutonium containers in the model discussed in Section 5.1, Normal Conditions, describes the cluster of containers modeled. In this model the containers were in intimate contact. This model adequately bounds any actual grouping of containers that may be used. These cases had $k_{eff}$'s less than an alternate model of three BTCC's with 4.5 kg of plutonium mixed with water at an H/X of 7.75 and close fitting water reflection. This case, ***btcc3_775***, had a $k_{eff}$ of 0.910 ± 0.002.

The volume of a quantity of plutonium oxide is controlled by limits on container volume and volume of containers in an allowed grouping. In addition to the above limits, a controlled separation distance of at least 25.4 cm (10 in.) is maintained between the surfaces of the containers and/or groups of containers. One could consider that groups of containers in close proximity constitute a composite volume.

A conservative analysis was performed to bound possible groupings of containers, and provides some general mass/volume limits for operations in the glovebox. The model used was a simplified model of the glovebox consisting of a 90 cm (35.4 in.) cube. The four sides had 30cm (11.8 in.) of water reflection and the top and bottom each had 6 cm (2.4 in) of water reflection. In the middle of the box, on the floor was a hemisphere, to model the container grouping, with 2.54 cm (1.0 in.) close water reflection. Two different hemisphere volumes were considered, 6.5 ℓ and 7.0 ℓ, to give two associated mass limits. The plutonium was homogeneously mixed with water to generate the necessary volumes. This very conservative model represents the situation of bringing multiple containers of dry ($H/X \leq 2$) thermally stabilized plutonium together and having an added contingency of water addition to the container. Table 5-2 lists the H/X ratio utilized for each case.

Parametric analyses were performed to verify that the highest reactivity in either case was with the higher mass. The results of the parametric analyses are presented in Table 5.2. For the 6.5 ℓ volume a mass of 6.5 kg is acceptable and for the 7.0 ℓ volume a mass of 5.0 kg is acceptable. These allowable mass/volume limit sets are actually bounded by the base analysis performed in Erickson (2001a) for the base case with 10.6 kg and ~ 7.7 ℓ. The over mass or over volume contingencies also bound this operation do to the significantly larger mass analyzed and the compact grouping of containers. These limits provide an acceptable margin of safety even if low density material from the magnesium hydroxide process were to be brought into the glovebox and then flooded. The analysis is conservative since the actual glovebox dimensions and materials are not utilized, and none of the individual containers are modeled. Both of these conservatisms would provide additional absorption and leakage, reducing the $k_{eff}$ of the system. These conservatisms and Table 5.2 indicate that the contingency of an added container meets the double contingency criteria.

Table 5.2. Mass/Volume Parametric for HC-21A

| Case Name | H/X Ratio | Mass (kg) | Volume (ℓ) | $k_{eff} \pm \sigma$ |
|---|---|---|---|---|
| h-65-22 | 22.0 | 7.0 | 6.5 | 0.939 ± 0.0015 |
| h-65-24 | 23.9 | 6.5 | 6.5 | 0.932 ± 0.0016 |
| h-65-26 | 26.1 | 6.0 | 6.5 | 0.930 ± 0.0015 |
| h-65-29 | 28.7 | 5.5 | 6.5 | 0.927 ± 0.0015 |
| | | | | |
| h-231 | 31.2 | 5.5 | 7.0 | 0.940 ± 0.0016 |
| h-235 | 34.5 | 5.0 | 7.0 | 0.936 ± 0.0015 |
| h-239 | 38.7 | 4.5 | 7.0 | 0.930 ± 0.0015 |
| h-244 | 43.4 | 4.0 | 7.0 | 0.925 ± 0.0014 |

### 5.3.7 Spilling of $PuO_2$

The analysis presented in Section 5.3.7 of Erickson (2001a) utilized a glovebox total mass limit of 10.0 kg, and analyzed spilling $PuO_2$ on the floor of the glovebox. Since the analysis in Erickson 2001a utilizes significantly more mass than the 7.1 kg allowed for the operation in HC-21A, that analysis will bound the contingency of spilling $PuO_2$ in HC-21A. Case ***hc18m13a*** is bounding for a spill condition and has a $k_{eff}$ of 0.917 ± 0.004. The additional 2.9 kg of plutonium above the limit in this CSER also covers the inclusion of 625 g of plutonium metal as discussed in the base case, Section 5.2.

### 5.3.8 Mist Atmosphere

The analysis presented in Section 5.3.8 of Erickson (2001a) utilized a glovebox total mass limit of 10.0 kg, and a mist atmosphere as interspersed moderation possibly due to sprinklers or fire fighting efforts. Since the analysis in Erickson 2001a utilizes significantly more mass than the 7.1 kg allowed for the operation in HC-21A, that analysis will bound the contingency of a mist atmosphere in HC-21A. Case ***hc18m23*** with full density water filling the glovebox had a $k_{eff}$ of 0.824 ± 0.004. The additional 2.9 kg of plutonium above the limit in this CSER also covers the inclusion of 625 g of plutonium metal as discussed in the base case, Section 5.2.

### 5.3.9 Neutron Reflecting Materials Underneath Glovebox

The analysis presented in Section 5.3.9 of Erickson (2001a) utilized a glovebox total mass limit of 10.0 kg, and analyzed additional reflecting materials under the glovebox. Since the analysis in Erickson (2001a) utilizes significantly more mass than the 7.1 kg allowed for the operation in HC-21A, that analysis will bound the contingency of additional reflecting materials under HC-21A. Case ***hc18m13a*** has the bounding $k_{eff}$ of 0.917 ± 0.004 for the conservative arrangement of grouped containers with added neutron reflecting material below the glovebox floor. The additional 2.9 kg of plutonium above the limit in this CSER also covers the inclusion of 625 g of plutonium metal as discussed in the base case, Section 5.2.

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# APPENDIX A - INDEPENDENT REVIEW COMMENTS AND CHECKLIST

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Desk Instruction 2.0, Rev. 1

## CHECKLIST FOR TECHNICAL PEER REVIEW

Document Reviewed - HNF-8560, Rev. 0

Title: Canning of Thermally Stabilized Plutonium Oxide Powder in PFP Glovebox HC-21A

Author: D. G. Erickson

Date: 15 AUG 2001

Reviewed complete Document

| Yes | No* | NA | | |
|---|---|---|---|---|
| [X] | [ ] | [ ] | | Referenced analyses appropriate. |
| [X] | [ ] | [ ] | | Problem completely defined and all potential configurations considered. |
| [X] | [ ] | [ ] | | Accident scenarios developed in a clear and logical manner. |
| [X] | [ ] | [ ] | | Necessary assumptions explicitly stated and supported. |
| [ ] | [ ] | [X] | | Computer codes and data files documented. |
| [X] | [ ] | [ ] | | Data used in calculations explicitly stated in document. |
| [X] | [ ] | [ ] | | Data checked for consistency with original source information as applicable. |
| [X] | [ ] | [ ] | | Mathematical derivations checked including dimensional consistency of results |
| [X] | [ ] | [ ] | | Models appropriate and used within range of validity, or use outside range of established validity justified. |
| [X] | [ ] | [ ] | | Hand calculations checked for errors. Spreadsheet results should be treated exactly the same as hand calculations. |
| [ ] | [ ] | [X] | | Software input correct and consistent with document reviewed. |
| [ ] | [ ] | [X] | | Software output consistent with input and with results reported in document reviewed. |
| [X] | [ ] | [ ] | | Limits/criteria/guidelines applied to analysis results are appropriate and referenced. Limits/criteria/guidelines checked against references. |
| [X] | [ ] | [ ] | | Safety margins consistent with good engineering practices. |
| [X] | [ ] | [ ] | | Conclusions consistent with analytical results and applicable limits. |
| [X] | [ ] | [ ] | | Results and conclusions address all points required in the problem statement. |
| [X] | [ ] | [ ] | | Format consistent with applicable guides or other standards. |
| [ ] | [ ] | [X] | ** | Review calculations, comments, and/or notes are attached. |
| [X] | [ ] | [ ] | | Document approved (for example, the reviewer affirms the technical accuracy of the document). |

E. M. Miller *Edward M. Miller* — 15 AUG 2001

Technical Peer Reviewer (printed name and signature) — Date

* All "no" responses must be explained below or on an additional sheet.

** Any calculations, comments, or notes generated as part of this review should be signed, dated and attached to this checklist. The material should be labeled and recorded in such a manner as to be understandable to a technically qualified third party.

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# APPENDIX B – LIMITS/CONTROLS AND BASES

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**ADMINISTRATIVE LIMITS AND CONTROLS**

1) Glovebox total mass inventory limit is 7.5 kg of plutonium or fissile equivalent including holdup in glovebox (this includes the 400 g of 'fixed' holdup).

   **BASIS:** The Seismic Contingency, section 5.3.1, allows a maximum of glovebox loading of 7.1 kg of mobile plutonium. The fixed loading of 400 grams added to the mobile value gave a total glovebox loading of 7.5 kg.

2) If fissionable material density is less than 1.0 g/cm$^3$, the combined volume of fissionable material in containers in the glovebox is limited to 7.1 L

   **BASIS:** The Seismic Contingency, section 5.3.1, demonstrates that with a fissionable material volume limit of 7.1 L, the system will remain subcritical even with material with a fissile density less than 1.0 g/cm$^3$.

3) Furnace boat or other container, except the BTCCs or sieve receiver pan, fissile mass limit is 2.5 kg of plutonium as a plutonium compound, per item.

   **BASIS:** This mass is the allowed mass in these containers for normal operations. Larger masses were not used in the models for these containers. This mass is a normal loading for a furnace boat or other container in other PFP operations.

4) BTCCs or sieve receiver pan mass limit is 4.4 kg of plutonium as a plutonium compound, per item.

   **BASIS:** This mass is the allowed mass in these containers for normal operations. This is the largest unit mass of plutonium presently allowed in PFP. Larger masses are not allowed in these containers.

5) Fissile material is limited to:

   a) Plutonium oxide and other plutonium compounds. MAXIMUM 625 g of unreacted plutonium metal or uranium metal is allowed. However the CSR must be notified if any plutonium or uranium metal is in the glovebox.

   **BASIS:** The analyses use plutonium densities of compounds, not metal, in the base case.

   b) $^{239}$Pu may be substituted for $^{235}$U, gram-for-gram following the General Limits (CPS-Z-165-80010).

   **BASIS:** Greenborg (2001) provides the discussion and justification of the gram-for-gram control as implemented in the General Limits CPS.

6) H/Pu is limited to a maximum of two (2).

**EXCEPTION:** The CSR must be notified before processing a single furnace boat of H/Pu ≤ 20, but the material may not be stored in the glovebox.

**BASIS:** The base case analysis used an H/Pu = 2, except for one container of H/Pu = 20. This glovebox will receive stabilized material, which has been heated. All water and hydrocarbons should have been driven off. However, material presently in PFP has an H/Pu ratio of up to a possible value of 20. A boat with H/Pu ≤ 20 may need to be put in another container or the moisture test may find a filled container with an H/Pu > 2. Since such a situation could arise it has been allowed and analyzed.

7) Allowed groupings of containers fit into two categories of limits. These categories are:

a) 5.0 kg maximum mass of plutonium, 7.0 ℓ maximum volume, or

b) 6.5 kg maximum mass of plutonium, 6.5 ℓ maximum volume.

The above volumes are the sums of the volumes of all of the fissile material bearing containers in each group of containers spaced less than 25.4 cm (10.0 in.) edge-to-edge at any one time. This allows containers to be brought together for material transfer operations.

**BASIS:** This limit is an auxiliary limit to the spacing limits. It covers the situation where a cluster of containers might be equivalent to a larger volume. The limits are based on a conservative analysis of a hemispherical volume presented in Section 5.3.6. The values given are also conservative based on bounding analyses.

8) Spacing limits:

a) Each fissionable material bearing container or allowed container grouping is to be spaced 25.4 cm (10 in.) or more edge-to-edge from any other fissionable material bearing container or container grouping.

b) Each container or container grouping must be spaced at least 25.4 cm (10 in.) edge-to-edge from fissionable material containers on the conveyor.

c) A single plutonium bearing sample vial with a volume ≤ 30 mℓ may be moved anywhere without spacing requirements.

d) Spacing of 25.4 cm (10 in.) must be maintained between in-place high-efficiency particulate air (HEPA) exhaust filters and any fissionable material of more than 100 g.

**BASIS:** This distance is based on past analyses and is accepted as good practice in fissile material handling facilities.

9) A maximum of one sieve screen and one sieve pan (nominal 3.3 ℓ combined) are allowed in the glovebox.

**BASIS:** Only one sieve screen and sieve pan were utilized in the analysis, and that is all that is required for the operation.

10) A maximum volume of 1.0 ℓ of sample vials (30 mℓ maximum for each sample vial) are allowed in the glovebox. The vials are to be capped except for a maximum of three being open to take samples.

**BASIS:** This grouping would result in a grouping that is less reactive than a container analyzed and is within criticality safety limits.

11) A maximum of one nested BTCC and sieve funnel (nominal 2.4 ℓ) is allowed.

**BASIS:** Only one sieve funnel is necessary for the operation in the glovebox. With this grouping, if additional material was inadvertently placed into the BTCC/funnel combination, the resulting mass and volume have been shown to be acceptable.

12) Maximum of one floor sweeps container with a maximum 0.6 ℓ volume.

**BASIS:** This volume limit allows the 0.5 ℓ nominal volume polyjar to be used without concern for its exact volume. The analysis base case included a 0.6 ℓ container in addition to the process items.

**PROCESS CONTROLS**

1) Stacking of plutonium bearing containers other than a sieve screen and sieve receiver pan or BTCC and sieve funnel is prohibited.

**BASIS:** This limit is based on good fissionable material practices. The worst case stacking scenario, an HCC stacked on top of a boat, has been analyzed in section 5.3.4 as part of the investigation of exceeding the mass of a container.

2) Noticeable accumulations of fissionable material are not allowed to remain. Spills are to be cleaned up as soon as practicable.

**BASIS:** This limit is based on good fissionable material practices. Accumulation of unaccountable material makes it easier to inadvertently exceed the glovebox mass limit.

3) Free liquids or solutions other than maximum 50ml non-fissile liquid are not allowed in the glovebox.

**BASIS:** Control of liquids while handling fissile materials is extremely important. The saturation of the material with water and the wetting of the atmosphere between cans has been treated as a contingency. Increasing the probability of such an occurrence could cause these situations to be classified as expected off-normal events, and thus removing one barrier to a possible unsafe condition. 50 ml of non-fissile liquid (such as lubricants) is useful for routine maintenance activities on the equipment in the box, and is such a small quantity as to not be a concern during glovebox operations.

4) Damp rags (6 square feet maximum area) may be present for glovebox cleaning purposes.

**BASIS:** The amount of water in such rags has been accounted for by the 2.5 cm (1 in.) of water around containers included in the base case analysis.

5) Glovebox HC-21A is to have a criticality fire fighting category of C. This allows water to be used as mists or fogs in the glovebox, but not as directed solid streams of water.

**BASIS:** Solid streams of water will stir up the fissile material and facilitate the mixing of the plutonium and the water. While such a situation has been analyzed, it has been treated as a contingency.

6) Storage of significant neutron reflecting materials, such as plastic, drums, equipment, etc. under the glovebox, is prohibited.

**BASIS:** The presence of such materials was treated as a contingency in the analysis.

7) Before doing any operation to move or replace an in-place HEPA exhaust filter, remove any loaded containers of fissionable material from the glovebox and limit glovebox floor accumulations to less than 0.3175 cm (⅛ in.) thickness of fissionable material. Other limits of CPS-Z-165-80250 for glovebox 8 x 8 x 6 size in-place HEPA exhaust filters are to apply.

**BASIS:** The removal of a HEPA filter was analyzed with an empty glovebox.

8) The sieve screen is to be fully inserted into the sieve pan when stacked.

**BASIS:** The sieve was analyzed with its nominal volume with the screen inserted.

## ENGINEERED SAFETY FEATURES

None

## SUPPORTING INFORMATION

None

## EVALUATION ASSUMPTIONS

All fissile material is assumed to be $^{239}Pu$.

**BASIS:** This is a conservative assumption for the materials to be processed through the thermal stabilization process..

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# APPENDIX C – MCNP INPUT FILES

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```
Hemisphere - h/x=22.018 h-65-22.i
c  7.0 kg, 6.5 L
c
   1  1 -2.1145      -1 15                              imp:n=1 $ PuO2
   2  3 -1.00        -2 15 (1:-15)                      imp:n=1 $ reflector
   3  2 -0.0013      11 -12 13 -14 15 -16  (2:-15)     imp:n=1 $ air
   4  3 -1.00        21 -22 23 -24 25 -26
                   (-11: 12:-13: 14:-15: 16)           imp:n=1 $ reflector
   5  0            (-21: 22: -23: 24: -25: 26)         imp:n=0 $ outside

   1  so     14.587
   2  so     17.127
c
  11  px    -45.0
  12  px     45.0
  13  py    -45.0
  14  py     45.0
  15  pz      0.0
  16  pz     90.0
c
  21  px    -75.0
  22  px     75.0
  23  py    -75.0
  24  py     75.0
  25  pz     -6.0
  26  pz     96.0
c

kcode  1000  1.0  50 450
ksrc     0.00     0.00     1.00      $ source centered
         5.00     0.00     5.00
        -5.00     0.00     5.00
         0.00     5.00     5.00
         0.00    -5.00     5.00
m1    $ PuO2 in Water
      94239.55c    1
       8016.50c   13.009
       1001.50c   22.018
mt1   lwtr.01t
m2    $ Water for air
       8016.50c    2
       1001.50c    1
mt2   lwtr.01t
m3    $ Water for reflector
      1001.50c     2
      8016.50c     1
mt3   lwtr.01t
```

```
Hemisphere - h/x=23.913 h-65-24.i
c  6.5 kg, 6.5 L
c
   1  1 -2.0349      -1 15                              imp:n=1 $ PuO2
   2  3 -1.00        -2 15 (1:-15)                      imp:n=1 $ reflector
   3  2 -0.0013      11 -12 13 -14 15 -16  (2:-15)     imp:n=1 $ air
   4  3 -1.00        21 -22 23 -24 25 -26
                   (-11: 12:-13: 14:-15: 16)           imp:n=1 $ reflector
   5  0            (-21: 22: -23: 24: -25: 26)         imp:n=0 $ outside

   1  so     14.587
   2  so     17.127
```

```
c
  11  px    -45.0
  12  px     45.0
  13  py    -45.0
  14  py     45.0
  15  pz      0.0
  16  pz     90.0
c
  21  px    -75.0
  22  px     75.0
  23  py    -75.0
  24  py     75.0
  25  pz     -6.0
  26  pz     96.0
c

kcode  1000  1.0  50 450
ksrc     0.00     0.00     1.00      $ source centered
         5.00     0.00     5.00
        -5.00     0.00     5.00
         0.00     5.00     5.00
         0.00    -5.00     5.00
m1   $ PuO2 in Water
     94239.55c    1
      8016.50c   13.957
      1001.50c   23.913
mt1  lwtr.01t
m2   $ Water for air
      8016.50c    2
      1001.50c    1
mt2  lwtr.01t
m3   $ Water for reflector
     1001.50c     2
     8016.50c     1
mt3  lwtr.01t
```

```
Hemisphere - h/x=26.125 h-65-26.i
c  6.0 kg, 6.5 L
c
   1  1 -1.9553      -1 15                         imp:n=1 $ PuO2
   2  3 -1.00        -2 15 (1:-15)                 imp:n=1 $ reflector
   3  2 -0.0013      11 -12 13 -14 15 -16  (2:-15) imp:n=1 $ air
   4  3 -1.00        21 -22 23 -24 25 -26
                    (-11: 12:-13: 14:-15: 16)      imp:n=1 $ reflector
   5  0             (-21: 22: -23: 24: -25: 26)    imp:n=0 $ outside

   1  so     14.587
   2  so     17.127
c
  11  px    -45.0
  12  px     45.0
  13  py    -45.0
  14  py     45.0
  15  pz      0.0
  16  pz     90.0
c
  21  px    -75.0
  22  px     75.0
  23  py    -75.0
  24  py     75.0
```

```
  25  pz      -6.0
  26  pz      96.0
c

kcode  1000  1.0  50 450
ksrc     0.00     0.00     1.00       $ source centered
         5.00     0.00     5.00
        -5.00     0.00     5.00
         0.00     5.00     5.00
         0.00    -5.00     5.00
m1    $ PuO2 in Water
      94239.55c    1
       8016.50c   15.062
       1001.50c   26.125
mt1   lwtr.01t
m2    $ Water for air
       8016.50c    2
       1001.50c    1
mt2   lwtr.01t
m3    $ Water for reflector
      1001.50c     2
      8016.50c     1
mt3   lwtr.01t
```

```
Hemisphere - h/x=28.738 h-65-29.i
c  5.5 kg, 6.5 L
c
   1  1 -1.8757      -1 15                             imp:n=1 $ PuO2
   2  3 -1.00        -2 15 (1:-15)                     imp:n=1 $ reflector
   3  2 -0.0013      11 -12 13 -14 15 -16  (2:-15)     imp:n=1 $ air
   4  3 -1.00        21 -22 23 -24 25 -26
                  (-11: 12:-13: 14:-15: 16)            imp:n=1 $ reflector
   5  0           (-21: 22: -23: 24: -25: 26)          imp:n=0 $ outside

   1  so      14.587
   2  so      17.127
c
  11  px    -45.0
  12  px     45.0
  13  py    -45.0
  14  py     45.0
  15  pz      0.0
  16  pz     90.0
c
  21  px    -75.0
  22  px     75.0
  23  py    -75.0
  24  py     75.0
  25  pz     -6.0
  26  pz     96.0
c

kcode  1000  1.0  50 450
ksrc     0.00     0.00     1.00       $ source centered
         5.00     0.00     5.00
        -5.00     0.00     5.00
         0.00     5.00     5.00
         0.00    -5.00     5.00
m1    $ PuO2 in Water
      94239.55c    1
```

```
      8016.50c   16.369
      1001.50c   28.738
mt1  lwtr.01t
m2   $ Water for air
      8016.50c    2
      1001.50c    1
mt2  lwtr.01t
m3   $ Water for reflector
     1001.50c     2
     8016.50c     1
mt3  lwtr.01t



Hemisphere - h/x=31.151 h-231.i
c  5.5 kg, 7.0 L
c
   1  1 -1.8131      -1 15                           imp:n=1 $ PuO2
   2  3 -1.00        -2 15 (1:-15)                   imp:n=1 $ reflector
   3  2 -0.0013      11 -12 13 -14 15 -16  (2:-15)   imp:n=1 $ air
   4  3 -1.00        21 -22 23 -24 25 -26
                    (-11: 12:-13: 14:-15: 16)        imp:n=1 $ reflector
   5  0             (-21: 22: -23: 24: -25: 26)      imp:n=0 $ outside

   1  so      14.951
   2  so      17.491
c
  11  px     -45.0
  12  px      45.0
  13  py     -45.0
  14  py      45.0
  15  pz       0.0
  16  pz      90.0
c
  21  px     -75.0
  22  px      75.0
  23  py     -75.0
  24  py      75.0
  25  pz      -6.0
  26  pz      96.0
c

kcode  1000  1.0  50 450
ksrc     0.00     0.00     1.00      $ source centered
         5.00     0.00     5.00
        -5.00     0.00     5.00
         0.00     5.00     5.00
         0.00    -5.00     5.00
m1   $ PuO2 in Water
     94239.55c    1
      8016.50c   17.576
      1001.50c   31.151
mt1  lwtr.01t
m2   $ Water for air
      8016.50c    2
      1001.50c    1
mt2  lwtr.01t
m3   $ Water for reflector
     1001.50c     2
     8016.50c     1
mt3  lwtr.01t
```

```
Hemisphere - h/x=34.53 h-235.i
c  5 kg, 7.0 L
c
   1  1 -1.7392       -1 15                           imp:n=1 $ PuO2
   2  3 -1.00         -2 15 (1:-15)                   imp:n=1 $ reflector
   3  2 -0.0013       11 -12 13 -14 15 -16  (2:-15)   imp:n=1 $ air
   4  3 -1.00         21 -22 23 -24 25 -26
                     (-11: 12:-13: 14:-15: 16)        imp:n=1 $ reflector
   5  0              (-21: 22: -23: 24: -25: 26)      imp:n=0 $ outside

   1  so      14.951
   2  so      17.491
c
  11  px     -45.0
  12  px      45.0
  13  py     -45.0
  14  py      45.0
  15  pz       0.0
  16  pz      90.0
c
  21  px     -75.0
  22  px      75.0
  23  py     -75.0
  24  py      75.0
  25  pz      -6.0
  26  pz      96.0
c

kcode  1000  1.0  50 450
ksrc     0.00     0.00     1.00      $ source centered
         5.00     0.00     5.00
        -5.00     0.00     5.00
         0.00     5.00     5.00
         0.00    -5.00     5.00
m1    $ PuO2 in Water
     94239.55c    1
      8016.50c   19.265
      1001.50c   34.53
mt1  lwtr.01t
m2    $ Water for air
      8016.50c    2
      1001.50c    1
mt2  lwtr.01t
m3    $ Water for reflector
     1001.50c     2
     8016.50c     1
mt3  lwtr.01t
```

```
Hemisphere - h/x=38.657 h-239.i
c  4.5 kg, 7.0 L
c
   1  1 -1.6653       -1 15                           imp:n=1 $ PuO2
   2  3 -1.00         -2 15 (1:-15)                   imp:n=1 $ reflector
   3  2 -0.0013       11 -12 13 -14 15 -16  (2:-15)   imp:n=1 $ air
   4  3 -1.00         21 -22 23 -24 25 -26
                     (-11: 12:-13: 14:-15: 16)        imp:n=1 $ reflector
   5  0              (-21: 22: -23: 24: -25: 26)      imp:n=0 $ outside
```

```
   1  so     14.951
   2  so     17.491
c
  11  px    -45.0
  12  px     45.0
  13  py    -45.0
  14  py     45.0
  15  pz      0.0
  16  pz     90.0
c
  21  px    -75.0
  22  px     75.0
  23  py    -75.0
  24  py     75.0
  25  pz     -6.0
  26  pz     96.0
c

kcode  1000  1.0  50 450
ksrc     0.00    0.00    1.00      $ source centered
         5.00    0.00    5.00
        -5.00    0.00    5.00
         0.00    5.00    5.00
         0.00   -5.00    5.00
m1   $ PuO2 in Water
     94239.55c    1
      8016.50c   21.329
      1001.50c   38.657
mt1  lwtr.01t
m2   $ Water for air
      8016.50c    2
      1001.50c    1
mt2  lwtr.01t
m3   $ Water for reflector
     1001.50c     2
     8016.50c     1
mt3  lwtr.01t
```

```
Hemisphere - h/x=43.817 h-244.i
c  4.0 kg, 7.0 L
c
   1  1 -1.5914      -1 15                           imp:n=1 $ PuO2
   2  3 -1.00        -2 15 (1:-15)                   imp:n=1 $ reflector
   3  2 -0.0013      11 -12 13 -14 15 -16  (2:-15)   imp:n=1 $ air
   4  3 -1.00        21 -22 23 -24 25 -26
                   (-11: 12:-13: 14:-15: 16)         imp:n=1 $ reflector
   5  0            (-21: 22: -23: 24: -25: 26)       imp:n=0 $ outside

   1  so     14.951
   2  so     17.491
c
  11  px    -45.0
  12  px     45.0
  13  py    -45.0
  14  py     45.0
  15  pz      0.0
  16  pz     90.0
c
  21  px    -75.0
```

```
  22  px      75.0
  23  py     -75.0
  24  py      75.0
  25  pz      -6.0
  26  pz      96.0
c

kcode  1000  1.0  50 450
ksrc     0.00     0.00     1.00       $ source centered
         5.00     0.00     5.00
        -5.00     0.00     5.00
         0.00     5.00     5.00
         0.00    -5.00     5.00
m1    $ PuO2 in Water
      94239.55c    1
       8016.50c   23.909
       1001.50c   43.817
mt1   lwtr.01t
m2    $ Water for air
       8016.50c    2
       1001.50c    1
mt2   lwtr.01t
m3    $ Water for reflector
      1001.50c     2
      8016.50c     1
mt3   lwtr.01t
```

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