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# CSER 99-007: CRITICALITY SAFETY EVALUATION REPORT FOR PFP GLOVEBOX HA-21I MUFFLE FURNACE OPERATION FOR PLUTONIUM STABILIZATION

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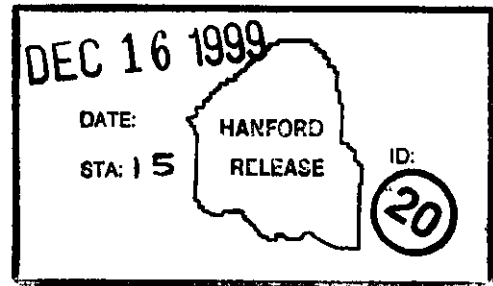
**Key Words:** HA-21I, PFP, Criticality Safety, Fissile Material, Plutonium, Moderation, glovebox, furnace

**Abstract:** Criticality Safety Evaluation Report for operation of PFP Glovebox HA-21I muffle furnace for plutonium stabilization. Glovebox limits are specified for processing metal and oxide fissile materials.

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**CSER 99-007:**  
**Criticality Safety Evaluation Report for PFP**  
**Glovebox HA-21I Muffle Furnace Operation for**  
**Plutonium Stabilization**

December 1999

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For  
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In Support of  
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## **Executive Summary**

**Glovebox HA-21I is located in Room 235B of the 234-5Z Building at the Plutonium Finishing Plant. This enclosure contains three muffle furnaces used to thermally stabilize plutonium and uranium in the form of metal or oxide. This criticality safety evaluation includes these materials with a hydrogen to fissile atom ratio (H/X)  $\leq$  20 for the oxide. Glovebox HA-21I is classified as a dry glovebox, meaning it has no internal liquid lines, and no free liquids or solutions in excess of 50 ml of lubricants are allowed.**

**Two glovebox limit sets are supported by this document. If any plutonium or uranium metal is present, then the metal limit set applies and 4.65 kg of plutonium or fissile equivalent is allowed in up to six boats, sweeps container, and sieve pan assembly. This limit set applies for any combination of metal or oxide. For oxide only, then 8.0 kg of plutonium or fissile equivalent in up to six boats and a sweeps container is allowed. Sieve pan assembly must be removed or made into a noncontainer in the oxide limit set. These mass limits include glovebox and filter holdup.**

**Evaluation of this glovebox operation included normal, base case, and contingencies. The base case took the normal operation and added the likely off-normal events. Each contingency is evaluated assuming the unlikely event happens to the conservative base case. A hazards assessment was conducted to assure that each credible unlikely event or set of correlated unlikely events was included in this analysis. 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 Manuals, HNF-PRO-334, HNF-PRO-537, and HNF-PRO-539, ANSI standards, and DOE Order 5480.24. This CSER also follows Fluor Federal Services, Inc. Practice 134.290.1121.**

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**List of Terms**

<b>AIChE</b>	<b>American Institute of Chemical Engineers</b>
<b>CSER</b>	<b>Criticality Safety Evaluation Report</b>
<b>ID</b>	<b>Identification Number</b>
<b>NC</b>	<b>no controls</b>
<b>PHA</b>	<b>Preliminary Hazards Analysis</b>
<b>Pu</b>	<b>Plutonium</b>
<b>U</b>	<b>Uranium</b>

## 1.0 INTRODUCTION AND SUMMARY

### 1.1 INTRODUCTION

The plutonium stabilization program at the Plutonium Finishing Plant (PFP) includes high temperature firing of plutonium-bearing materials in muffle furnaces. Such heat treatments have been conducted in two furnaces in Glovebox HC-21C situated in Room 230A. Glovebox HA-21I in Room 235B has three muffle furnaces to be used to stabilize plutonium and uranium metal or oxide. This criticality safety evaluation supports operation under two limit sets, one for material containing metal and/or oxide and a second for oxide only. In both sets, the maximum moderation is a hydrogen-to-fissile (H/X) ratio of 20. This is a dry glovebox so no liquids are allowed in excess of 50 ml of lubricants. Operationally, 25.4 cm (10 in.) spacing will be required between containers of fissile material. The base case, however, will include one spacing violation to preclude the argument over whether it is likely or unlikely two containers will be brought closer than 25.4 cm (10 in.) from each other. A second 25.4 cm (10 in.) violation is considered a contingency. Stacking is strictly prohibited, as it is throughout the PFP. The limits and controls of Section 3 provide the basis for the Criticality Prevention Specifications for the operations in this glovebox.

The fixed glovebox equipment includes three furnaces and their off-gas filters. The sump located near the southern end of the glovebox must be removed and a criticality drain must be installed such that in the unlikely case of liquids entering this glovebox, the liquid level will not exceed 5.08 cm (2 in.) in depth. The tank located on the mezzanine just above and to the east of this glovebox must remain empty of any liquid. An empty tank falling on the glovebox would not be worse than the seismic analysis of Section 5.3.1. However, if this tank contained a liquid, then it could be a source of moderation that could be introduced in a manner that may move or stir fissile material not considered by this CSER. A barrier is required so that a fissile material transport wagon cannot roll under the glovebox.

Only muffle furnace boats, sieve pan assembly (metal processing only), and a 0.5 L container for cleanup are allowed as primary containers for plutonium or uranium-bearing material. From the standpoint of the criticality safety analysis, the 0.5 L container is any 0.5 L container. Off-gas filter cartridges do not contain fissile material and the HEPA filters are changed using their own CSER (Altschuler 1981) after unloading the fissile material containers from the glovebox. Any holdup of fissile material on the filters, floors or walls must be counted towards the glovebox mass limits. Glovebox HA-21I is periodically non-destructive assayed (NDA) to establish the fissile material holdup. Each of the containers used to fill the boats were NDA in the past and those fissile values are used to determine the inventory of the glovebox. After being fired in the furnaces, the boats are taken to Glovebox 18M where their material is canned and NDA before transporting to a vault, thus providing a check of the fissile quantity assigned. Careful material balances are performed for each container movement for safeguards reasons.

## 1.2 DOUBLE CONTINGENCY DOCUMENTATION

### 1.2.1 Metal

This section presents a summary description of expected operations, expected normal conditions, base case of normal condition plus anticipated off-normal conditions for metal feed in Table 1-1, and results of the contingency analyses in Table 1-2. If metal is present, the limit set of this section applies. For oxide, see the limit set of Section 1.2.2.

#### **Expected Operation:**

Receive furnace boats with metal pieces, buttons or pieces of buttons. There may be oxide present. Heat in muffle furnaces to oxidize the metal and then allow to cool. Sieve the resultant fired material and heat in muffle furnaces again, if metal pieces remain. Transfer the material to other gloveboxes to place in containers for storage.

#### **Expected Normal Conditions:**

Glovebox HA-21I may contain plutonium and/or uranium in metal, alloy, or oxide form. The fissile mass is limited to 4.65 kg plutonium or fissile equivalent with the uranium  $^{235}\text{U}$  enrichment less than or equal to 50%. Containers are limited to six boats, a 0.5 L container sweeps container, a 3.3 L sieve pan assembly, and lubricant containers not to exceed 50 ml. The fissile mass may be present in any of the boats or the container or as holdup with each container limited to a maximum of 2.5 kg of plutonium or fissile equivalent and spaced a minimum of 25.4 cm (10 in.) from each other and other fissile material. Any spill will be cleaned up prior to continued operation. There is 1.27 cm (0.5 in.) of lead shielding around the lower sides of the glovebox. Any glovebox holdup, such as in the HEPA filter, must be counted towards the glovebox mass limit.

#### **Base Case Model:**

The base case encompasses the normal and worst-case likely off-normal events. This includes 4.7 kg of Pu in the most reactive combination of metal and oxide conservatively modeled in two boats with another 2.5 kg of Pu in boat on HA-28 conveyor (CPS 1997). The Pu is 100%  $^{239}\text{Pu}$  with  $H/X = 20$  for the oxide and one spacing violation is included. There is full reflection on all sides of glovebox and nominal reflection around each group of containers, the most conservative likely arrangement. Structural materials and their neutron absorption is ignored. The metal base case (case c9007bml) had a calculated  $k_{\text{eff}}$  of  $0.8556 \pm 0.0011$ , which is less than the allowable  $k_{\text{eff}}$  of 0.932 for MCNP calculations of plutonium metal systems.

**Table 1-1. Glovebox HA-21I – Base Case Metal Limits Summary**

<b>Controlled Parameter</b>	<b>Limit</b>	<b>Abnormal but anticipated conditions (conservatism for analysis)</b>
Mass	Maximum 4.65 kg Pu & fissile equiv., glovebox total Maximum 2.5 kg Pu & fissile equiv./boat or sieve pan assembly	4.7 kg Pu with all fissile modeled as <sup>239</sup> Pu
Volume	Maximum 2.2 L/boat, six boats Maximum 0.5 L container; 3.3 L sieve pan assembly, 50 ml lubricant	
Moderation	H/X ≤ 20 Dry Glovebox, except 50 ml lubricants	
Interaction	Minimum 25.4 cm (10-in.) surface to surface spacing of fissile containers in glovebox and to fissile material in HA-28; transportation and storage spacing around glovebox, no stacking of containers	One spacing error included
Reflection	Dry glovebox Criticality drain visibly unobstructed	Full reflection around glovebox and 2.54 cm (1-in.) reflection around each group of containers
Geometry	Pu in boats, container, or sieve pan assembly	Holdup is included in the boat mass
Isotopics	NA	100% <sup>239</sup> Pu
Enrichment	Maximum 50% <sup>235</sup> U in U	<sup>235</sup> U treated as <sup>239</sup> Pu fissile equivalent
Density	NA	
Concentration	NA	
Poisons	NA	

**Contingency Summary:**

Table 1-2 summarizes the analyses of the unlikely, independent, off-normal events (contingencies). Each event is assumed to occur with the glovebox configured as the described base case with the contingency added. The resultant computed reactivity is compared to the subcriticality target  $k_{\text{eff}}$  of 0.932 for MCNP calculations of plutonium metal systems, explained in Section 4.0. This table summarizes the results of the contingency evaluation found in Section 5. Specific  $k_{\text{eff}}$  calculations were not made for contingencies in Table 1.2 that were bounded by other analyzed contingencies.

**Table 1-2. Glovebox HA-21I – Metal Contingency Summary**

<b>Contingency Description</b>	<b>Affected Parameter(s)</b>	<b>Barriers that make contingency unlikely</b>	<b><math>k_{eff}</math> bounding contingency (case ID)</b>
Seismic event with flooding causes fissile material to accumulate in corner	Reflection Moderation Interaction Geometry	Seismic event unlikely; Requires severe damage to glovebox, fissile material accumulation in a corner, and concurrent sprinkler flooding.	$0.9314 \pm 0.0013$ (py16)
Fire with sprinkler soaking of containers	Reflection Moderation	Major building fire that melts glovebox panels is unlikely; interspersed water density above 0.03 g/cc in glovebox is unlikely with density above 0.2 g/cc not credible	$0.9306 \pm 0.0013$ (c9007fm8)
Extra boat with 2.5 kg Pu as metal in glovebox, stacked	Volume Mass Interaction	Operator training/procedure/inventory posted limits	$0.9316 \pm 0.0011$ (c9007sm2b)
Boat with 2.5 kg Pu as oxide spilled on boat with 2.5 kg Pu button	Mass Interaction	Operator training/procedure/inventory	$0.8833 \pm 0.0017$ (c9007so2)
Two buttons in one boat	Mass	Operator training/procedure/inventory	Covered by base case-two buttons together
Container with 2.5 kg Pu brought too close to glovebox	Interaction	Operator training/procedure	Less reactive than extra boat stacked
Excess holdup exceeding glovebox mass limit	Mass	Operator training/procedure/inventory control	Less reactive than extra boat stacked
Container too large	Volume	Operator training/procedure	Less reactive than fire analysis
Extra oil or plastic	Moderation	Operator training/procedure	Less reactive than fire analysis

The hazards assessment determined that it is not credible to have uranium with  $^{235}\text{U}$  enrichment exceeding 50% in this glovebox. Therefore, no contingency was evaluated for enrichment.

### 1.2.2 Oxide

This section presents a summary description of expected operations, expected normal conditions, base case of normal condition plus anticipated off-normal conditions for oxide feed material in Table 1-3, and results of the contingency analyses in Table 1-4. This limit set is for oxide only. If metal is present, then the metal limit set of Section 1.2.1 applies.

#### **Expected Operation:**

Receive furnace boats with plutonium or uranium oxide. Heat in muffle furnaces to drive off moisture and then allow to cool. Transfer the material to other gloveboxes to place in containers for storage.

#### **Expected Normal Conditions:**

Glovebox HA-21I may contain plutonium and/or uranium oxide. The fissile mass is limited to 8 kg plutonium or fissile equivalent with the uranium  $^{235}\text{U}$  enrichment less than 50%. Containers are limited to six boats, a 0.5 L container sweeps container, and lubricant containers not to exceed 50 ml. Fissile material may be present in any of the boats or the container or as holdup with each container limited to a maximum of 2.5 kg plutonium or fissile equivalent with a minimum of 25.4 cm (10 in.) spacing between each other and other fissile material. Any spill will be cleaned up prior to continued operation. There is 1.27 cm (0.5 in.) of lead shielding around the lower sides of the glovebox.

#### **Base Case Model:**

The base case encompasses the normal and worst-case likely off-normal events. This includes 8 kg of Pu in the most reactive arrangement of allowed containers modeled as three boats and sweeps container with another 2.5 kg of Pu in a boat spaced a minimum of 25.4 cm (10 in.) on the HA-28 conveyor (CPS 1997). The Pu is 100%  $^{239}\text{Pu}$  with H/X = 20 and one spacing violation as two boats adjacent, is included. There is full reflection on all sides, above and below the glovebox and nominal reflection around each group of containers. Structural materials and their neutron absorption is ignored. The oxide base case (case c9007b01) had a calculated  $k_{\text{eff}}$  of  $0.7873 \pm 0.0014$ , which is less than the allowable  $k_{\text{eff}}$  of 0.942 for MCNP calculations of plutonium non-metal systems.

**Table 1-3. Glovebox HA-21I – Base Case Oxide Limits Summary**

<b>Controlled Parameter</b>	<b>Limit</b>	<b>Abnormal but anticipated conditions (conservatism for analysis)</b>
Mass	Maximum 8.0 kg Pu & fissile equiv. Oxide, glovebox total Maximum 2.5 kg Pu & fissile equiv./boat	Pu and fissile U modeled as <sup>239</sup> Pu
Volume	Maximum 2.2 L/boat, six boats Maximum 0.5 L container; 50 ml lubricant	
Moderation	H/X ≤ 20 Dry Glovebox, except 50 ml lubricants	
Interaction	A minimum of 25.4 cm (10 in.) surface to surface spacing between fissile material containers and to fissile material in HA-28; transportation and storage spacing around glovebox; no stacking of containers	One spacing error included
Reflection	Dry glovebox Criticality drain visibly unobstructed	Full reflection around glovebox and 2.54 cm (1in.) reflection around each group of containers
Geometry	Pu in boats or container	
Isotopics	NA	100% <sup>239</sup> Pu
Enrichment	Maximum 50% <sup>235</sup> U in U	<sup>235</sup> U treated as <sup>239</sup> Pu fissile equivalent
Density	NA	
Concentration	NA	
Poisons	NA	

**Contingency Summary:**

Table 1-4 summarizes the analyses of the unlikely, independent, off-normal events (contingencies). Each event is assumed to occur with the glovebox configured as the described base case with the contingency added. The resultant computed reactivity is compared to the subcriticality target  $k_{\text{eff}}$  of 0.942 for MCNP calculations of non-metal systems, explained in Section 4.0. The table summarizes the analysis found in Section 5 in this CSER. Specific  $k_{\text{eff}}$  calculations were not made for contingencies in Table 1-4 that were bounded by other analyzed contingencies.

**Table 1-4. Glovebox HA-21I – Oxide Contingency Summary**

<b>Contingency Description</b>	<b>Affected Parameter(s)</b>	<b>Barriers that make contingency unlikely</b>	<b><math>k_{eff}</math> bounding contingency (case ID)</b>
Seismic with flooding causes fissile material to accumulate in corner	Reflection Moderation Interaction Geometry	Seismic event is unlikely and is unlikely to empty boats. Requires severe damage to glovebox and concurrent sprinkler flooding	$0.9377 \pm 0.0018$ (pyr3)
Fire with sprinkler soaking of containers	Reflection Moderation Interaction	Major building fire that melts glovebox panels is unlikely	$0.8775 \pm 0.0014$ (c9007fo1)
Extra boat with 2.5 kg Pu as oxide in glovebox, stacked	Volume Mass Interaction	Operator training/procedures/inventory	$0.9385 \pm 0.0016$ (c9007so1)
Button in one boat	Mass	Operator training/procedure/inventory	$0.8833 \pm 0.0017$ (c9007so2)
Overloaded boat	Mass	Operator training/procedures/inventory	Less reactive than extra boat stacked
Container brought too close to glovebox	Interaction	Operator training/procedure	Less reactive than extra boat stacked
Excess holdup exceeding glovebox limit	Mass	Operator training/procedure/inventory control	Less reactive than extra boat stacked
Container too large	Volume	Operator training/procedure	Less reactive than extra boat stacked
Sieve pan assembly left in glovebox	Volume	Operator training/procedure	Less reactive than fire analysis
Extra oil or plastic	Moderation	Operator training/procedure	Less reactive than fire analysis

The hazards assessment determined that it is not credible to have uranium with  $^{235}\text{U}$  enrichment greater than 50% in this glovebox. Therefore, no contingency was evaluated for enrichment.

### 1.3 SUMMARY

This criticality safety evaluation report (CSER) documents the criticality safety of operation using three muffle furnaces to thermally stabilize plutonium and uranium in the form of metal or oxide in Glovebox HA-21I. An oxide is formed with very low moisture content that can meet long term storage requirements. This criticality safety evaluation includes introduction of materials with a hydrogen-to-fissile atom ratio ( $H/X$ )  $\leq 20$  for the oxide. Glovebox HA-21I is classified as a dry glovebox, meaning it has no internal liquid lines, and no free liquids or solutions in excess of 50 ml of lubricants are allowed.

Two glovebox limit sets are supported by this document. If any plutonium or uranium metal is present, then the metal limit set applies allowing 4.65 kg of plutonium or fissile equivalent in up to six boats, sweeps container, or sieve pan assembly. This limit set applies for any combination of metal or oxide. For oxide only, then 8.0 kg of plutonium or fissile equivalent (uranium is less than 50%  $^{235}\text{U}$ ) in up to six boats or sweeps container is allowed. Sieve pan assembly must be removed or made into a noncontainer in the oxide limit set.

Evaluation of this glovebox operation 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. A hazards analysis was conducted to assure that each credible unlikely event or set of correlated unlikely events was included in this analysis. Demonstrating that each contingency has a calculated  $k_{\text{eff}}$  less than the subcritical safety limit shows that this operation meets 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 Manuals, HNF-PRO-334 (FDH 1997), HNF-PRO-537 (FDH 1997a), and HNF-PRO-539 (FDH 1997b), ANSI/ANS-8 series Standards (ANSI 1998), and DOE Order 5480.24(DOE 1992). This CSER also follows Fluor Federal Services, Inc. Practice 134.290.1121.

It is required that the sump located in the southern end of the glovebox be removed and that a criticality drain be installed. It is also required that the tank, located on the mezzanine just above and to the east of this glovebox, remains empty of any liquid. During a seismic event, this not seismically qualified tank could fall on the glovebox and not cause  $k_{\text{eff}}$  to exceed that calculated in Section 5.3.1. However, if this tank contains liquid, then another source of moderator could be introduced in a manner that may move or stir fissile material in a manner not considered here. A physical barrier is required to prevent a fissile material transport wagon from rolling under the glovebox.

## **2.0 SYSTEM DESCRIPTION AND NORMAL OPERATIONS**

Glovebox HA-21I will be used to process metallic plutonium, plutonium oxide or other plutonium or uranium compounds by thermal stabilization in the muffle furnaces. The normal operational sequence relating to criticality safety is given in Section 2.1 below.

The following sections describe the facilities, fissionable materials, and technical practices and process features of the handling processes.

### **2.1 OPERATIONAL SEQUENCE**

Furnace boats containing either plutonium or uranium in metal or oxide form will be prepared for thermal stabilization in another glovebox such as HC-21A or 235-B-5, with that operation evaluated in other CSERs. The oxide material will have an H/X less than or equal to 20 and a plutonium or fissile equivalent mass less than or equal to 2.5 kg plutonium. The boats will be covered while in transit and be handled one at a time, maintaining 183 cm (6 ft) spacing on conveyors and 25.4 cm (10 in.) edge-to-edge spacing in Glovebox HA-21I.

Up to six boats, a 0.5 L sweeps container, and sieve pan assembly (fissile metal processing) is allowed in HA-21I, at one time. Up to three boats are staged for muffle furnace operation and up to three furnaces are operated in unison. Only one boat can fit into a furnace at a time. Upon completion of a heating cycle, boats are removed to their cooling stands using a boat handling tool because boats are too hot to handle with gloves. Other boats can be staged in the south end of Glovebox HA-21I, but not close to the hot furnaces or cooling boats.

For fissile metal stabilization, a sieve pan assembly is used to separate metal pieces from the resultant oxide for reheating in the furnaces. If metal pieces are still present after the first heating, the contents of the boat are poured into the sieve pan assembly. The pieces are sufficiently separated and poured back into the boat for a second heating that usually completely oxidizes the plutonium. When the material is completely oxidized, boats are covered and transferred to Glovebox HC-18M for loss-on-ignition sampling and canning.

### **2.2 FACILITY AND EQUIPMENT DESCRIPTION**

The glovebox and the equipment within it are described in this section.

#### **2.2.1 Glovebox HA-21I Description**

Glovebox HA-21I is located in room 235B in the main PFP Building 234-5Z. Figure 1 shows a sketch of the approximate layout of the glovebox in relation to the other gloveboxes and conveyors used for thermal stabilization activities. HA-21I is 109.2 cm (43 in.) deep, 102.2 cm (40.25 in.) high, 396.2 cm (156 in.) long, and supported 91.4 cm (36 in.) above the room floor by a table frame. The floor plan arrangement of the glovebox is shown in Figure 2. Note that this

glovebox has gloveports on both sides. This sketch shows the approximate layout of operations in the glovebox. The south end of HA-21I connects to conveyor HA-28. The north end view of Glovebox HA-21I in Figure 3 illustrates the tilted configuration of the off-gas filters adopted to be able to accommodate the furnace installations within the narrow confines of the box walls. The 22.9 cm (9-in.) deep by 25.4 cm (10 in.) diameter pot-sump shown under the box floor in Figure 3, and near the south end of the box in Figure 2, will be replaced with a criticality drain that will prevent liquids from exceeding a 5.08 cm (2 in.) depth in this glovebox. Near the south end of the glovebox a section of the floor is lower than the rest of the floor by 5.08 cm (2 in.).

A summary of the process equipment and containers expected in Glovebox HA-21I for operations is given below.

The equipment available in Glovebox HA-21I are:

- muffle furnace (3)
- off-gas filter (3)

The containers available in Glovebox HA-21I are:

- Furnace boats (2.2 L max.)(6),
- Furnace boat covers,
- Polyjar or similar container with 0.5 L nominal volume for floor sweeps (if needed),
- Containers of MgO<sub>2</sub> sand in the glovebox in case of fire (2.2 L max.),
- Sieve Pan Assembly (3.3 L max.), metal processing only

Other materials available in Glovebox HA-21I are:

- Damp rag (limited to 6 sq. ft. total) for cleaning.

Glovebox HA-21I does not have any internal water lines or water fire protection. It does have a dry chemical 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 Design Basis Earthquake (DBE).

### **2.2.2 Furnaces and Other Equipment**

A general view of the muffle furnace design in Glovebox HA-21I is given in Figure 4. The cut-away diagram in Figure 4 illustrates the orientation of the furnace chamber and the piping for off-gas extraction. Specification literature from the furnace manufacturer gives overall dimensions for the unit as a width of 39.4 cm (15.5 in.), a height of 45.7 cm (18 in.), and a length of 61 cm (24 in.), including the door and appendages. Also, according to the manufacturer’s data, the heating chamber width is 14 cm (5.5 in.), its height is 12.7 cm (5.0 in.), and its length is 33 cm (13 in.) (these are also the cavity dimensions reported by CSER 94-007 [Altschuler 1994] for the furnaces in HC-21C).

Figure 1. Approximate Layout for Gloveboxes and Conveyors Utilized for Thermal Stabilization Activities

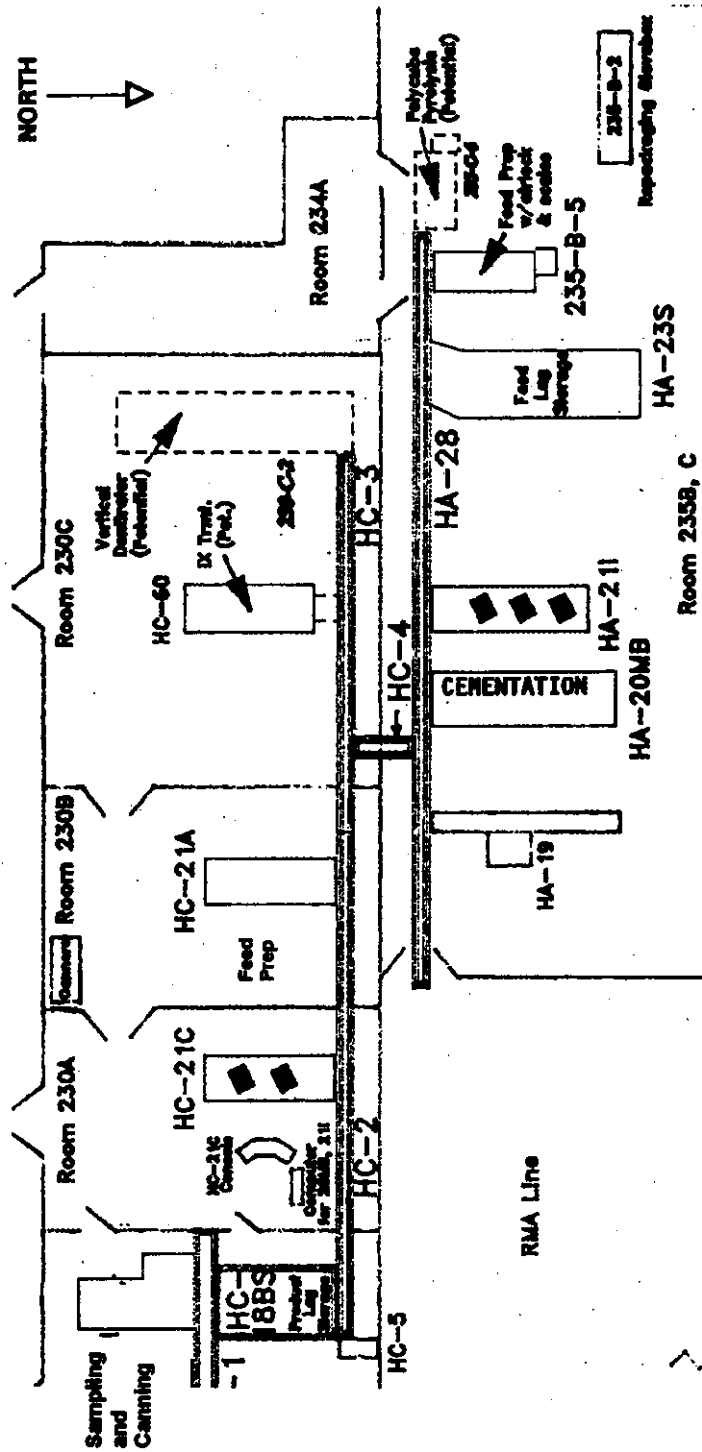
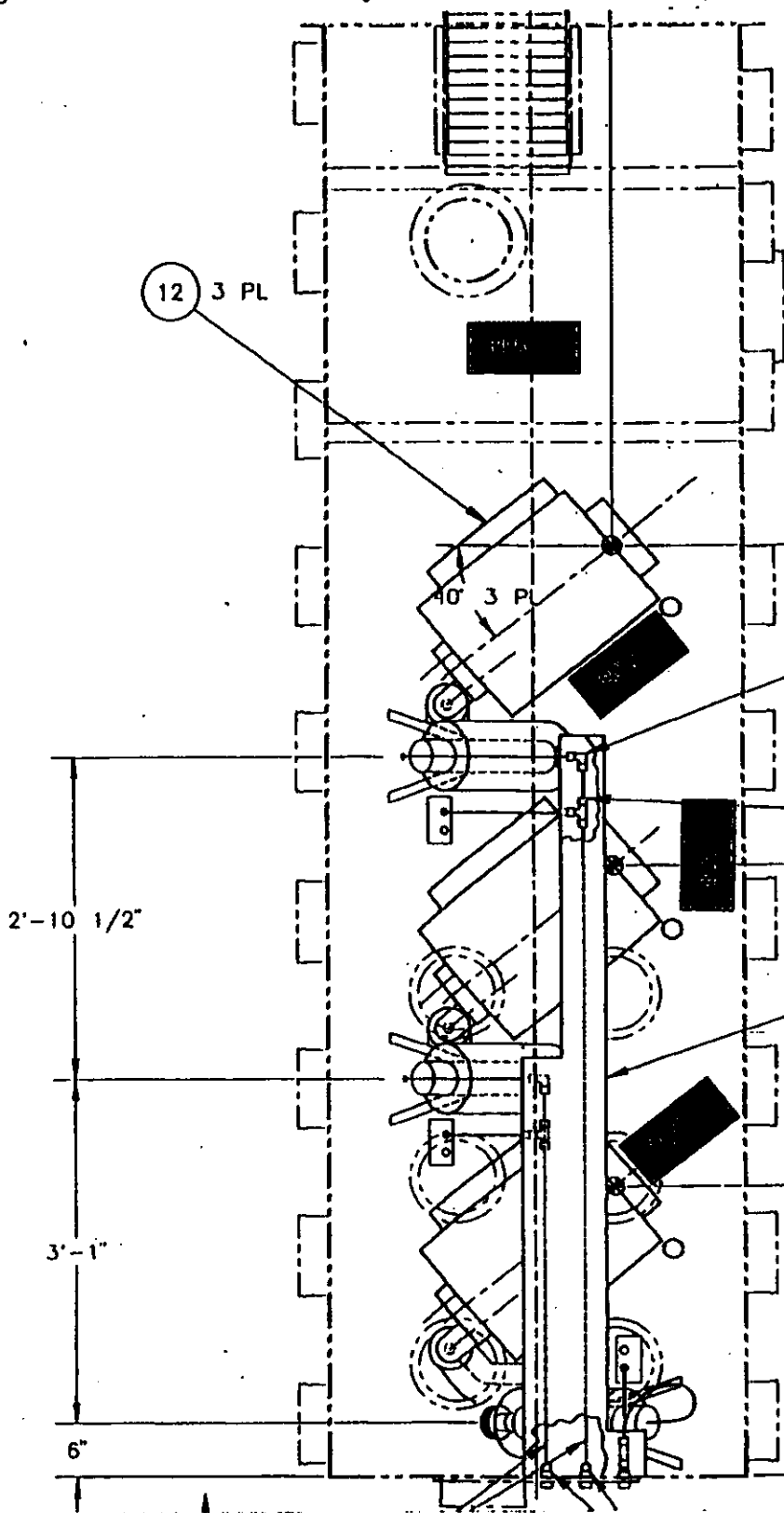
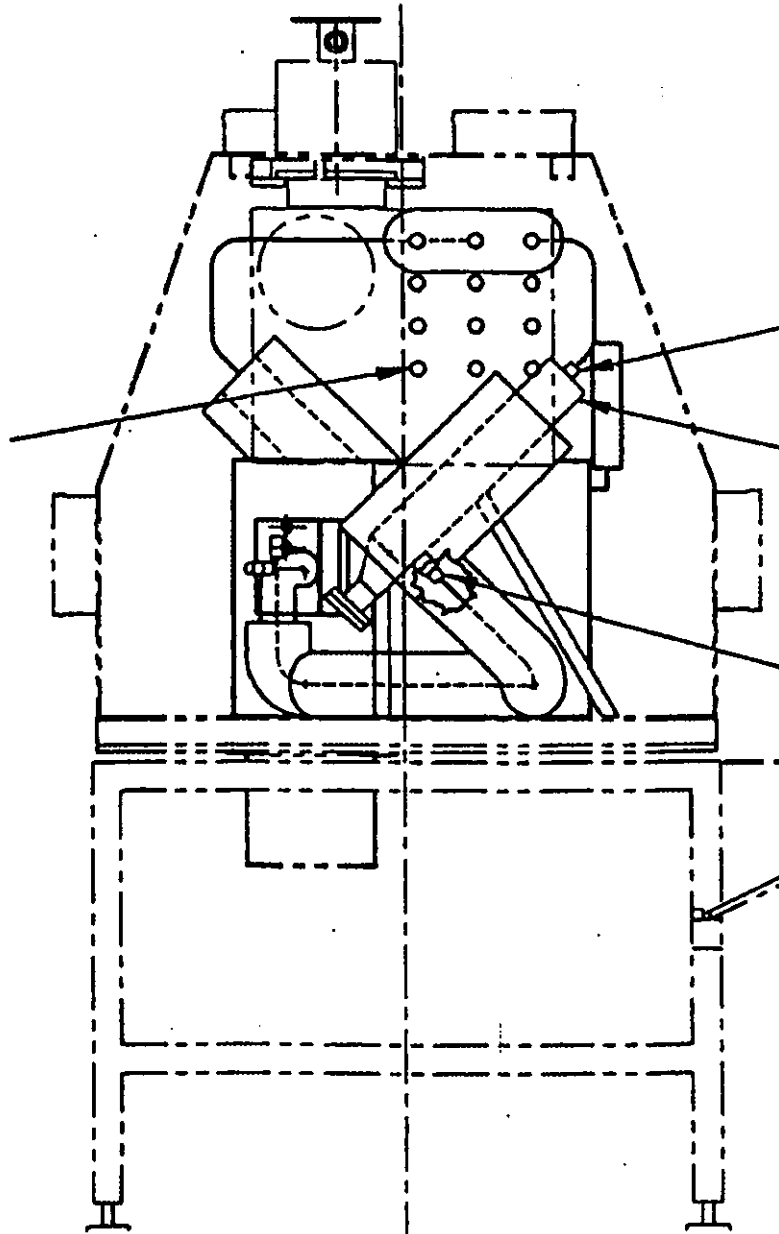


Figure 2. Glovebox HA-21I Layout for Muffle Furnace Operations

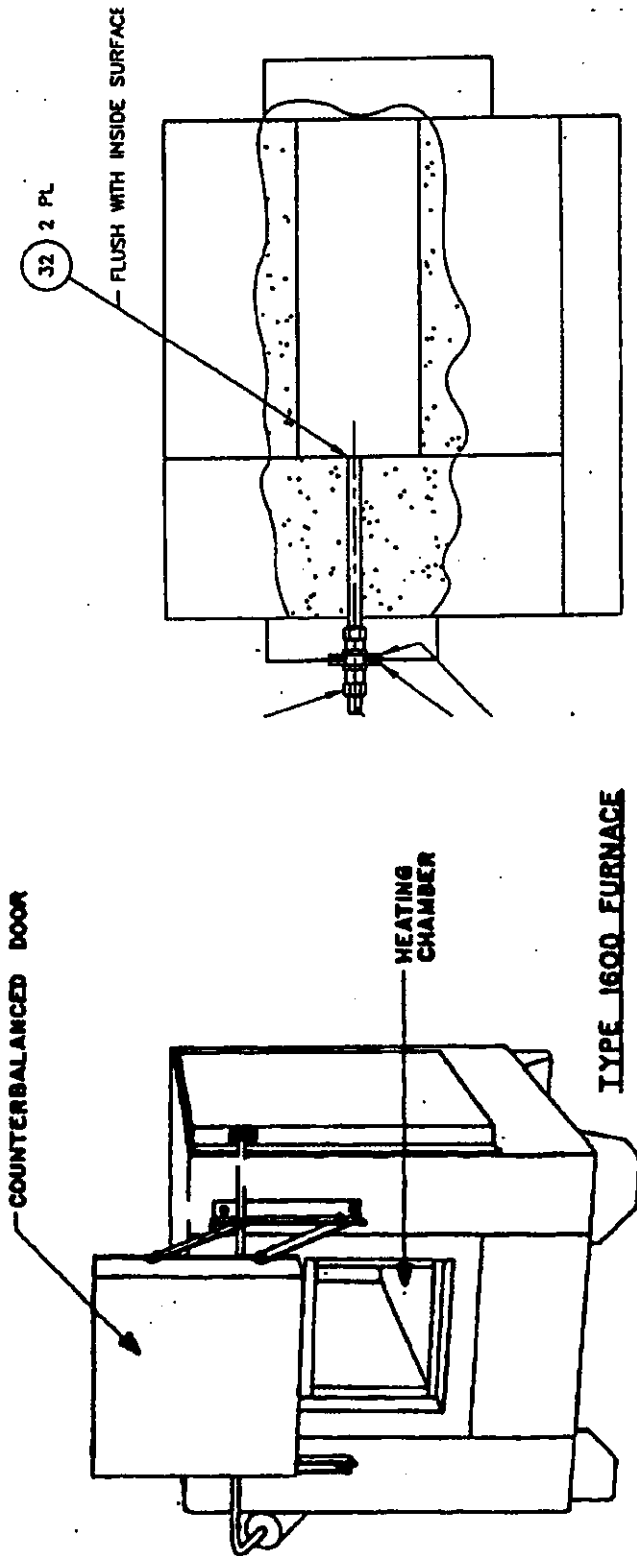


**Figure 3. End View of Muffle Furnace Glovebox HA-21I**



**A: HA-21I**

Figure 4. Muffle Furnace Basic Design



Based upon scaling estimates from the layout drawing in Figure 2 and perspective drawing in Figure 4, the main insulated body of the furnace consists of a 39 cm (15.4 in.) wide by 42.2 cm (16.6 in.) high by 50.5 cm (19.9 in.) long block. The heating chamber is centered in the front face and has a swing-away door of about 6.0 cm thickness to cover the chamber at the front. This block is then supported about 5.08 cm (2 in.) above the floor by four stout legs.

The scale of the drawings also indicate that the off-gas filter assemblage for each furnace has a 19 cm (7.5 in.) outer diameter insulation jacket surrounding a 8.9 cm (3.5 in.) diameter by 45.7 cm (18 in.) long filter casing. These units contain replaceable 5.08 cm (2 in.) diameter sintered silicon carbide filter cartridges.

Boat stands are also utilized in this glovebox. A boat stand is a 15.2 x 17.8 cm (6 x 7 in.) steel plate platform. These stands have three 20.3 cm (8 in.) legs which elevate a boat so its bottom surface will be even with the bottom of the heating cavity of a furnace. In this way, a just-fired boat may be withdrawn from the furnace a short distance out onto a boat stand using the boat handling tools. This is necessary because the boats are too hot to handle with gloves. The boat cools on the stand unit until it may be handled.

A boat rack may optionally be used in the glovebox to help maintain the 25.4 cm (10 in.) spacing requirement between fissile containers.

### 2.2.3 Muffle Furnace Boat

The furnace boat is made from 0.32 cm (1/8 in.) thick Hastelloy-X<sup>1</sup> sheet stock shaped into a "cake pan", with an outside width of 13.34 cm (5.25 in.) and an outside length of 28.58 cm (11.25 in.). Inside, the bottom of the pan has an area of 354.84 cm<sup>2</sup>. A measured brim-full volume of 2.2 L equates to an inside height of 6.20 cm (2.44 in.). The total pan height of 6.5 cm (2.57 in.) thus does not allow stacking of two such boats inside a 12.7 cm (5 in.) muffle furnace heating chamber. Two 0.79 cm (5/16 in.) diameter holes were located at an outside height of 4.45 cm (1.75 in.) in each end plate. The holes were centered at a distance of 5.08 cm (2.0 in.) center-to-center. The boat has a cover used to minimize dispersion of PuO<sub>2</sub> powder when transported. Only one boat can fit in a muffle furnace at a time. Magnesium oxide liners, approximately 0.32 cm (0.125 in.) thick, may be used in the boats to prevent burn through of the boat pan when metal items are processed.

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<sup>1</sup> Hastelloy is a trademark of Stellite Rod Division, Stoodly Deloro Stellite, Inc., Industry, Ca.

### 2.2.4 Sieve Screen Assembly

The sieve screen is 7.30 cm (2-7/8 in.) high with 5.08 cm (2 in.) above the screen and 2.22 cm (7/8 in.) below the screen. The sieve pan and sieve screen both have 20.32 cm (8 in.) diameters. The sieve pan and sieve screen, when fully engaged, each make up 5.08 cm (2 in.) of the 10.16 cm (4 in.) height that gives a nominal total volume of 3.3 L. The sieve screen is only used when processing metal, and will be removed or made into a noncontainer when processing oxide.

## 2.3 FISSIONABLE MATERIALS DESCRIPTION

The fissionable material handled in Glovebox HA-21I is plutonium in the forms of metal, oxide and other compounds as well as mixed oxides of plutonium and uranium. The  $^{235}\text{U}$  is counted as an equivalent mass of plutonium as specified in PFP CPS-Z-165-80010 and analyzed by CSER 99-003 (Marusich 1999) for calculating the total plutonium mass to compare to a mass limit. The fissionable isotope content and physical forms are discussed below.

### 2.3.1 Fissionable Isotopes

The plutonium used in the models in this CSER is all  $^{239}\text{Pu}$ . This simplification is conservative for the plutonium with more  $^{240}\text{Pu}$  than  $^{241}\text{Pu}$ , which is the case for the reactor produced plutonium at PFP. This also includes any depleted or natural uranium or mixed oxides of plutonium and uranium that may be present. Uranium enriched up to 50%  $^{235}\text{U}$  is conservatively modeled as  $^{239}\text{Pu}$  as demonstrated by the analysis in CSER 99-003 (Marusich 1999). The fissile material may contain a nominal 10 wt% or less of carbon. Table 11 of the Nuclear Criticality Safety Guide, LA-12808, (Pruvost and Paxton 1996) shows that as carbon is increased from C/U = 0 to C/U = 20, the minimum critical mass increases by over a factor of three. At 10 wt% (C/U ~ 2) carbon in highly enriched uranium (93.5 wt%  $^{235}\text{U}$ ), the carbon has a negligible effect, but the effect would decrease the reactivity. Plutonium is similar enough to highly enriched uranium to assume that 10 wt% would have negligible effect on its reactivity, especially compared to H/Pu of 20.

### 2.3.2 Metallic Plutonium

Metallic plutonium introduced into Glovebox HA-21I will generally be in the form of 2.5 kg or smaller buttons or scrap pieces from clean out operations. A density of 19.48 g/cm<sup>3</sup> for metallic plutonium was used for this evaluation. This value is in the range of densities found in actual metal systems in Paxton (1987). The glovebox mass limit was established by the non-physical combining of more than one button into a sphere of this high density. Also, the metal base case and contingencies bring metal buttons closer than is physically possible because the steel of the boats was ignored. Metallic plutonium may form corrosion products of hydrides, oxides,

and nitrides. CSER 98-008 (Greenberg 1999) shows that mass limits for plutonium metal are adequate for metal with corrosion products.

### **2.3.3 Plutonium Oxide**

Plutonium compounds or other forms (e.g., MOX with a limit of  $^{235}\text{U}$  enrichment of 50 wt%), is hereafter referred to as plutonium oxide ( $\text{PuO}_2$ ). The plutonium oxide will be in furnace boats or the sweeps container. The allowable H/X ratio for operations in this glove box will be less than or equal to 20. The criticality mass limits are given for plutonium and the analysis has been done using plutonium oxide. CSER 98-008 (Greenberg 1999) has shown that other plutonium compounds are less reactive than plutonium oxide. The limit set derived from analyses for plutonium oxide bound other plutonium compounds.

CSER 99-003 (Marusich 1999) shows that plutonium and water mixtures are more reactive than uranium enriched to 50wt%  $^{235}\text{U}$  and water mixtures. This result allows 50 wt% enriched uranium to be mixed with or substituted for plutonium and still use the mass limits set for plutonium. PFP CPS-Z-165-80010 requires 1 g of  $^{235}\text{U}$  to be counted as 1 g of  $^{239}\text{Pu}$ . Natural or depleted uranium does not make a positive contribution to reactivity and may be included without adding to the plutonium mass.

## **2.4 FISSIONABLE MATERIAL HANDLING**

Fissionable materials will be handled as a safe batch so that the limits and controls for criticality safety will be easier to implement. These 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. The multiple levels of protection will assure that criticality safety will not be jeopardized by the inadvertent failure of a single control.

In addition, processing will be stopped as necessary to clean up visible accumulations of fissionable materials from spills or processing.

The following is a description of the handling of fissionable materials in this glovebox.

### **2.4.1 Receipt of Fissionable Material**

Material will be received in Glovebox HA-21I in muffle furnace boats of  $\leq 2.5$  kg Pu with an  $\text{H/X} \leq 20$ . The maximum container mass will be  $\leq 2.5$  kg plutonium or its equivalent in other fissionable materials. The glovebox mass limits are 4.65 kg Pu for metal and 8.0 kg Pu for oxide.

### 2.4.2 Process Description

Figure 1 illustrates the layout of the area encompassing the Pu stabilization activities on the first floor of the PFP. Preparation of the furnace boat charges is done in Glovebox HC-21A in Room 230B, or a future glovebox attached near the west end of HA-28. Product is handled in glovebox HC-18M. Loaded boats are transferred to the furnace glovebox HA-21I in Room 235B via the conveyor gloveboxes HC-2, HC-3, HC-4, and HA-28. Thus, the furnace glovebox HA-21I only receives prepared boats, and boats of fired material are output from HA-21I for transfer to other gloveboxes for further processing.

The gloveboxes involved in the processes for preparation, firing, and product packaging for the furnace operations are designated as dry gloveboxes, so that free water is not allowed (except for damp cleanup rags per usual restrictions). Also, there are no water lines for processes or fire fighting within the gloveboxes.

### 2.4.3 Waste Packages

Glovebox waste is generated from PFP plutonium stabilization operations. It is placed into plastic bags, transferred to Isolated Transport Containers, assayed, then placed into waste drums. This waste consists of gloves, bags, rags, containers used to port-in items, etc. Prior to bagging, all noticeable fissile material is shaken or brushed from these items and no fissile item is intentionally placed in these packages. Inspection of historical assay data shows that normally these packages contain only 1 or 2 grams of fissile material. Appendix F documents this inspection and supports the conclusion that it is not credible for the packages to contain more than a few tens of grams of fissile material except for the upset of a fissile item in the waste package, which is bounded by other upset conditions (reflection).

Waste packages are allowed in Glovebox HA-21I and would result from glovebox cleaning operations. Waste packages created in this glovebox would only contain the fissile material already inventoried and resultant neutron reflection/moderation is already conservatively modeled by water in the base calculations.

It is unlikely that a waste package containing fissile material from another glovebox would be transferred to HA-21I because it is not a destination glovebox for waste packages. This event is not forbidden and is bounded by the analysis of upset conditions for Glovebox HA-21I.

### 3.0 LIMITS AND CONTROLS

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

**Table 3-1. Controls on Parameters Related to Criticality in Glovebox HA-21I**

Parameter	Controlled	Discussion (Limit or Process Control if Yes, Reason if No)
Mass	Yes	8.0 kg plutonium total glovebox mass for oxide processing, 4.65 kg plutonium total glovebox mass for metal processing, consisting of: 1) Maximum 2.5 kg plutonium per container, and 2) Glovebox holdup.
Volume or Geometry	Yes	A limit of six 2.2 L furnace boats, one 0.5 L container sweeps container, and 3.3 L sieve pan assembly for the metal limit set.
Spacing	Yes	25.4 cm (10 in.) edge-to-edge minimum spacing between containers of fissile material, including containers on conveyor HA-28. Two containers can be brought together to pour contents of one into the other provided the combined mass of plutonium is not greater than 2.5 kg. No fissionable material in excess of 15 grams is allowed underneath the glovebox.
Moderator	Yes	Maximum allowed H/X = 20.
Reflector	Yes	No free liquids or solutions are allowed in the glovebox except 50 ml of lubricants.
Poisons	No	Poisons were not used in this analysis.
Concentration	No	Worst credible concentrations were analyzed.
Enrichment	Plutonium, no; Uranium, yes	Plutonium was assumed to be 100 wt% <sup>239</sup> Pu. This conservatively encompasses all allowed fissionable materials including depleted or natural uranium and uranium enriched to 50% <sup>235</sup> U.
Density	No	Maximum credible densities were used for all materials.
Other	N/A	No other parameters affecting criticality were identified.

### 3.1 LIMITS

The operations in Glovebox HA-21I are defined in Section 2. Operations are performed in the main glovebox area. The fissionable material mass limits specified for these operations are under the constraints of the overall fissionable material mass limits of the glovebox. There will be two glovebox limit sets. One for metal and/or oxide and one for oxide-only operations. If any metal is present, then the metal limit set must be used.

**Metal limit set:**

- 4.65 kg plutonium or fissile equivalent including holdup in glovebox,
- 2.5 kg plutonium or fissile equivalent per container,
- Container volume limited to a maximum of six boats of 2.2 L, each; a maximum of one 0.5 L sweeps container; a maximum of one 3.3 L sieve pan assembly, 50 ml of lubricants, a maximum of 2.2 L MgO<sub>2</sub> sand
- Minimum 25.4 cm (10 in.) edge-to-edge spacing between containers of fissile material, including containers on conveyor HA-28. Two containers can be brought together to pour contents of one into the other provided the combined mass of plutonium is not greater than 2.5 kg.
- No liquids other than 50 ml of lubricants,
- Maximum H/X = 20,
- Stacking of containers and/or boats is prohibited,
- Maximum uranium enrichment 50% <sup>235</sup>U.

**Oxide limit set:**

- 8.0 kg plutonium or fissile equivalent including holdup in glovebox,
- 2.5 kg plutonium or fissile equivalent per container,
- Container volume limited to a maximum of six boats of 2.2 L, each; a maximum of one 0.5 L sweeps container; 50 ml of lubricants, a maximum of 2.2 L MgO<sub>2</sub> sand
- Minimum 25.4 cm (10 in.) edge-to-edge spacing between containers of fissile material, including containers on conveyor HA-28. Two containers can be brought together to pour contents of one into the other provided the combined mass of plutonium is not greater than 2.5 kg.
- No liquids other than 50 ml of lubricants,
- Maximum H/X = 20,
- Stacking of containers and/or boats is prohibited,
- Maximum uranium enrichment 50% <sup>235</sup>U.

### **3.2 PROCESS CONTROLS**

To assure continued criticality safety during operations, several process controls are required. They are:

- One 0.5 L nominal volume container for floor sweepings is allowed.
- Rags (maximum 6 sq. ft. total) allowed for cleaning.
- One can of MgO<sub>2</sub> sand for fire fighting is allowed (2.2 L maximum volume).
- Noticeable accumulations of fissionable materials, such as from spills, are not allowed to remain in Glovebox HA-21I, and are to be cleaned up before continuing operating.
- During HEPA filter change out, all loaded containers shall be removed from the glovebox.
- No fissionable materials > 15 g are permitted underneath the glovebox at any time.

- Fire fighting category C.
- Waste packages minimized to those required for cleanup of HA-21I.

### **3.3 ENGINEERED CONTROLS**

Engineered controls are the primary means of preventing a criticality in the Glovebox HA-21I. These controls include the following:

- Eliminating of water sources or other moderator sources inside the glovebox such as fire sprinkler systems.
- Minimizing of structural materials such as plastics that moderate neutrons.
- Criticality drain installed and has no visible obstructions.
- Blocking the area below the glovebox to prevent entry of the transport wagon containing fissionable materials.
- Eliminate the sump in the floor of the glovebox.
- Size of muffle furnace allows only one boat at a time.
- Size of furnace boat and sweeps container
- Tank on mezzanine above Glovebox HA-21I blanked to prevent liquid accumulation.

### **3.4 ADMINISTRATIVE CONTROLS**

Criticality Prevention Specifications (CPS), postings and procedures provide limits and controls for handling fissionable materials, moderators, and other conditions that will assure criticality safety. These controls will address the following:

- Fissionable material interaction,
- Masses of fissionable materials,
- Elimination or minimization of moderator materials,
- Volumes of fissionable material containers.

The criticality analysis in this document demonstrates that a single failure of any administrative control will not result in a  $k_{eff}$  that will exceed the criticality prevention criterion.

### **3.5 SUPPORTING INFORMATION**

Operations within Glovebox HA-21I require:

Fire Fighting Category: C.

This allows mists or fogs during fire fighting, but no directed solid streams of water are allowed (that may move or upset containers of fissionable materials).

**3.6 CONTROLLED DIMENSIONS AND ASSUMPTIONS**

No additional equipment dimension controls are required.

## 4.0 METHODOLOGY

### 4.1 ANALYSIS PHILOSOPHY

The statement of work for this safety evaluation required the allowable glovebox fissile mass to be maximized. Handbook analyses were first consulted to obtain the approximate masses that could be accommodated given the normal operation and the off-normal events that could occur. Based upon ARH-600 (Carter 1968) it was apparent that during the seismic event when the glovebox collapses on one corner and the fissile material accumulates in one corner and fire suppression water creates neutron reflection, any fissile metal would limit the glovebox mass relative to an all-oxide case. Therefore, two limit sets were evaluated in order to maximize the oxide allowed. Also, ARH-600 provided a starting point for the maximum mass determination by showing that 5 kg of plutonium or fissile equivalent is approximately the limit for metal and 8 kg for oxide. The actual criticality evaluation was then performed using the Monte Carlo computer code MCNP, described below.

### 4.2 MCNP CODE

The Monte Carlo Code MCNP Version 4B, was certified (Schwinkendorf 1998) and validated (Erickson 1998a and Lan 1999) for plutonium systems such as the operation in this glovebox. Room temperature cross sections were used for the MCNP calculations. Some experimental data indicate that  $^{239}\text{Pu}$  may have a very small positive (on the order of  $10^{-5}$  to  $10^{-6}$   $\Delta k/k/\text{kg}$ ) reactivity response to increasing temperature (Hummel 1978). This is insignificant compared with the typical statistical uncertainty of 0.002 for the MCNP calculations. Only under normal conditions are the furnace boats heated to 1000 °C in the furnaces. The heating in the furnace drives off water, reducing the H/X ratio to less than 2 after firing. The heating also slightly expands the physical dimensions of the fissile material according to the temperature coefficient of expansion. Both of these phenomena decrease reactivity, but were not included in the analyses. Therefore, room temperature cross sections and material densities are the most appropriate to compare with safety limits.

A summary of the validation of MCNP4B is included in Appendix B, MCNP 4B Computer Code Validation, which determines a maximum allowable  $k_{\text{eff}}$  value of 0.942 for non-metal and 0.932 for metal system calculations. These values are for calculations with statistical uncertainties  $\leq \pm 0.002$  and assure subcriticality with an acceptable margin, including the uncertainties in the analytical methods and benchmark experimental data.

### 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 ( $k_{\text{eff}}$ ) shall not exceed 0.95 (i.e.,  $k_{\text{eff}} \leq 0.95$ ) 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 standards, and HNF-PROs. The subcriticality criterion is used to judge the acceptability of a calculated  $k_{\text{eff}}$  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.

#### **4.4 APPLICATION OF DOUBLE CONTINGENCY PRINCIPLE**

This analysis must meet the requirements of HNF-PRO-334, *Criticality Safety General Requirements*, (FDH 1997) HNF-PRO-537, *Criticality Safety Control of Fissionable Material*, (FDH 1997a) and HNF-PRO-539, *Criticality Safety Evaluations* (FDH 1997b). HNF-PRO-539 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 demonstrate the Double Contingency Principle is satisfied, this CSER must show that there are sufficient factors of safety in the operation of Glovebox HA-21I such that at least two unlikely, independent, and concurrent changes in process conditions are required before a criticality accident is possible.

#### **4.5 HAZARDS ASSESSMENT**

Identification of the contingencies for the operation described in Section 2 and evaluated in Section 5 used a hazards assessment technique called a Preliminary Hazard Assessment (PHA). The goal of this effort is to identify deviations from the planned operation that may pose a challenge to criticality safety. Analysis is done as necessary to demonstrate that each identified condition satisfies the criticality safety criteria.

In a PHA, an interdisciplinary team uses a disciplined, systematic approach to identify hazards and deviations that could lead to undesirable consequences. Because the criticality safety concerns usually arise from deviations from the process design, an experienced team leader systematically guides the team through the planned operation. Off-normal events are identified and separated into likely and unlikely to happen during the duration of the operation. The likely events become part of the base case and the unlikely events are the contingencies of Section 5. The detailed results of this assessment are presented in Appendix D.

## 5.0 EVALUATION AND RESULTS

### 5.1 NORMAL CASE

This section presents the standard model of the HA-21I Glovebox with Muffle Furnaces under normal conditions of operations. The following assumptions were used to model the normal conditions for fissionable materials and geometry of equipment in the glovebox. Conservatism was used to represent the normal conditions in the most limiting credible forms with respect to fissionable material arrangements and modeling conventions.

The normal case is described in detail in the sections below. The items modeled within the glovebox are the furnaces, the furnace boats, and the cleanup can. Details of the normal oxide case and the normal metal case models are summarized in Tables 5-1 and 5-2, respectively.

The oxide normal case model for the glovebox had a  $k_{\text{eff}}$  of  $0.6732 \pm 0.0014$  (case c9007no1), and the metal normal case model for the glovebox had a  $k_{\text{eff}}$  of  $0.7093 \pm 0.0011$  (case c9007nm1). These values are well below the allowable  $k_{\text{eff}}$  of 0.942 for plutonium oxide systems and 0.932 for plutonium metal systems.

**Table 5-1. Normal Oxide Case Model**

Glovebox Assumptions	Glovebox is surrounded with a minimum of 30.48 cm (12 in.) of water for neutron reflection. Rectangular transverse cross-section instead of actual slanted-side outlines. 2.54 cm (1in.) water reflection representing hands around each container Pu holdup in glovebox included in total glovebox mass limit
Glovebox dimensions	109.2 cm (43 in.) deep, 102.2 cm ( 40.25 in.) high, 442.0 cm (174 in.) long.
Furnaces	14 cm (5.5 in.) x 33.0 cm (13.0 in.) x 12.7 cm (5.0 in.) chamber 39 cm (15.4 in.) x 42.2 cm (16.6 in.) x 56.5 cm (22.2 in.) block of insulation (W x H x L) (including door) Full density firebrick. Furnace legs, off-gas piping, and electrical junction box ignored. Full face furnace doors.
Off-gas Filters	Not included in model since covered by water reflection.

Furnace boats	Inside dimensions used, metal container and liner ignored. 12.7 cm (5 in.) wide by 27.94 cm (11 in.) long by 6.20 cm (2.44 in.) high 3 boats with 2.5 kg Pu per boat H/X = 20 25.4 cm (10 in.) edge-to-edge spacing
Maintenance fluids	Not explicitly modeled since covered by water reflection.
Sweeps container	One 0.5 L container 0.5 kg Pu, H/X = 20 8.89 cm (3.5 in.) diameter 25.4 cm (10 in.) edge-to-edge spacing
Room Assumptions	One boat containing 2.5 kg Pu as oxide at H/X = 20 on conveyor HA-28 modeled at 25.4 cm (10 in.) spacing (vertical) from other boats.

Table 5-2. Normal Metal Case Model

Glovebox Assumptions	Glovebox is surrounded with a minimum of 30.48 cm (12 in.) of water for neutron reflection. Rectangular transverse cross-section instead of actual slanted-side outlines. 2.54 cm (1in.) water reflection representing hands around each container Pu holdup in glovebox included in total glovebox mass limit
Glovebox dimensions	109.2 cm (43 in.) deep, 102.2 cm (40.25 in.) high, 442.0 cm (174 in.) long.
Furnaces	14 cm (5.5 in.) x 33.0 cm (13.0 in.) x 12.7 cm (5.0 in.) chamber 39 cm (15.4 in.) x 42.2 cm (16.6 in.) x 56.5 cm (22.2 in.) block of insulation (W x H x L) (including door) Full density firebrick. Furnace legs, off-gas piping, and electrical junction box ignored. Full face furnace doors.
Off-gas Filters	Not included in model since covered by water reflection.
Furnace boats	Inside dimensions used, metal container and liner ignored. 12.7 cm (5 in.) wide by 27.94 cm (11 in.) long by 6.20 cm (2.44 in.) high 2 boats with 2.35 kg Pu in sphere per boat H/X = 0 25.4 cm (10 in.) edge-to-edge spacing

Maintenance fluids	Not explicitly modeled since covered by water reflection.
Sweeps container	Not included since more reactive to have all Pu in boats
Room Assumptions	One boat containing 2.5 kg Pu as oxide at H/X = 20 on conveyor HA-28 modeled at 25.4 cm (10 in.) spacing (vertical) from other boats.

### 5.1.1 Glovebox HA-21I

Glovebox HA-21I was modeled as a box that is 109.2 cm (43 in.) deep, 102.2 cm (40.25 in.) high, and 442.0 cm (174 in.) long. The end of the glovebox opening on HA-28 conveyor was extended 45.7 cm (18 in.) beyond the actual end of the glovebox to include the HA-28 conveyor. The glovebox walls are not included (except for a check of the effect of the lead shielding on the walls described in Section 5.2) and the sides, top, and bottom are surrounded with a minimum of 30.48 cm (12 in.) of water for neutron reflection representing operators. The glovebox was modeled with a rectangular transverse cross-section instead of actual slanted-side outlines. Nominal water reflection of 2.54 cm (1 in.) representing hands was included around each container. Plutonium holdup in the glovebox was included in total glovebox masses modeled in containers. The normal cases included the maximum quantity of fissionable materials allowed in the glovebox. This model represents the most limiting situation that could credibly occur in the glovebox. The interacting units and the reflection surrounding the model adequately cover all situations of fissionable material brought into close proximity to the glovebox, such as a transport wagon on the floor, material on conveyor HA-28, and the reflection from the glovebox walls, windows, gloves and personnel.

The glovebox has a mass limit of 8.0 kg of plutonium for oxide and 4.65 kg of plutonium for metal. The 8.0 kg of plutonium oxide was conservatively modeled in three boats of 2.5 kg plutonium each and 0.5 kg plutonium in a 0.5 L sweeps container. The 4.65 kg glovebox limit for plutonium metal was conservatively modeled as a 4.7 kg quantity of plutonium metal in two boats of 2.35 kg plutonium each. Dispersing the material into more boats reduces reactivity.

### 5.1.2 Modeling Assumptions of Plutonium Metal Buttons and Pieces

Several different buttons will be handled in Glovebox HA-21I, however there are no limitations on the shapes of the metal pieces to be thermally stabilized. The metal representing buttons or pieces was modeled as spheres or cuboids to maximize reactivity. The plutonium metal was modeled as 100 wt% <sup>239</sup>Pu with a density of 19.48 g/cm<sup>3</sup> and up to 2.5 kg per container as explained in Section 2.3.2.

### 5.1.3 Modeling Assumptions of Plutonium Oxide

The H/X ratio of plutonium oxide was modeled at the upper allowed limit of 20. At theoretical densities of 11.46 g/cm<sup>3</sup> for PuO<sub>2</sub> particles (Carter 1968) and 1.0 g/cm<sup>3</sup> for water, the components of material densities in the PuO<sub>2</sub> models are listed in Table 5-3. The 2.2 L modeled boat volume filled with this PuO<sub>2</sub>/water mixture at H/X=20 results in 2.58 kg Pu per boat, which conservatively represents the 2.5 kg Pu limit. This water content is more reactive than any higher density and lower water content up to the 11.46 g/cm<sup>3</sup>, as explained in Section 5.3.1.1 where the glovebox oxide mass limit was established. The plutonium of the plutonium oxide was modeled as 100% <sup>239</sup>Pu.

For metal, the most reactive boat is to have the 2.5 kg of Pu metal in one low neutron leakage lump. For the oxide, the most reactive boat is 2.5 kg of Pu with a water content of H/X = 20. For H/X > 20, plutonium mass is displaced from the boat as the water is added and the reactivity is less as shown in CSER 98-003 (Erickson, 1998b). For H/X < 20, reactivity also decreases as shown by the previous HA-21I glovebox CSER 96-008 (Hess, 1996) based upon ARH600 handbook information (Carter, 1968). The present CSER evaluation checked this trend by calculating H/X=0 with maximum plutonium oxide density and found it to be less reactive than 2.5 kg H/X=20 in these containers.

**Table 5-3. Densities Assumed in Modeling of Plutonium Oxide for Normal Condition Analysis**

Description	H/X = 0	H/X = 20
PuO <sub>2</sub> Volume Fraction	1.00	0.116
Water / Void Volume Fraction	0.0	0.884
PuO <sub>2</sub> Density (g/cm <sup>3</sup> )	11.46	1.330
Pu Density (g/cm <sup>3</sup> )	10.11	1.173
Water Density (g/cm <sup>3</sup> )	0.0	0.884
Total Density (g/cm <sup>3</sup> )	11.46	2.214

### 5.1.4 Muffle Furnace Boat

The muffle furnace boat was modeled as a box. The dimensions are 27.94 cm (11.00 in.) length, 12.70 cm (5.0 in.) width, and 6.20 cm (2.44 in.) height. These correspond to the inside dimensions for the furnace boat. The volume of the boat filled level to the top is 2.2 l. The mass of plutonium in a boat fully filled with plutonium oxide is 2.5 kg at an H/X ratio of 20. The plutonium oxide was modeled as a mixture with water at a H/X ratio of 20 that fills the boat. The metal representing buttons or pieces was modeled as a full density metal sphere in a corner of each boat. The material in the boat walls and floor was not included in the model for conservatism and simplicity and to account for any effects due to corrosion. The structural materials act mainly as a neutron poison. The magnesium oxide liner that may optionally be used

in the boats also was not included in the model. The liner would slightly reduce the available volume in a boat.

### **5.1.5 Sweeps Container**

One 0.5 L container is allowed in the glovebox for cleaning up spills. The 0.5 L container is a cylinder with a diameter of 8.89 cm (3.5 in.) and a height of 8.89 cm (3.5 in.). For the normal oxide case the sweeps container was modeled as containing 0.5 kg of plutonium as PuO<sub>2</sub>, water with a H/X of 20 and was located in the model with 25.4 cm (10 in.) edge-to-edge spacing from the furnace boats. For the normal metal case the sweeps container was empty since it was more reactive to have the glovebox mass limit located in the two boats.

### **5.1.6 Muffle Furnaces**

There are three muffle furnaces in glovebox HA-21I. Each muffle furnace was modeled as a full density firebrick 39 cm x 42.2 cm x 56.5 cm block of insulation (W x H x L) (including door) with a 14 cm x 33.0 cm x 12.7 cm chamber. The furnace legs, off-gas piping, and electrical junction box were ignored. The furnace doors were simplified in the model as full face furnace doors.

### **5.1.7 HA-28 Conveyor Fissile Movement Past HA-21I Glovebox**

Glovebox HA-21I is open to the HA-28 conveyor, providing a path for fissile material movement to, from, and past HA-21I. The PFP conveyor CPS (CPS-Z-165-80608) requires an edge-to-edge spacing limit of 25.4 cm (10 in.) between a container on a conveyor and a loaded container in a connecting glovebox. This separation isolates fissile material on the conveyor from fissile material in the glovebox for normal operations. One boat containing 2.5 kg Pu as plutonium oxide and water at H/X = 20 on conveyor HA-28 was modeled inside the glovebox with 25.4 cm (10 in.) spacing from other boats. It was positioned vertically above the other boats in the calculation for conservatism.

### **5.1.8 Glovebox Filter Holdup for HEPA Filter Replacement Operation**

PFP gloveboxes have in-place High Efficiency Particulate Air (HEPA) filters in the exhaust lines to remove plutonium dust and other particulate. The nominal 20.3 cm x 20.3 cm x 15.2 cm (8 in. x 8 in. x 6 in.) filter is normally located in a recess in the glovebox roof. A glovebox would only have one significantly contaminated filter since experience has shown that even if there are two filters in sequence, only the first is contaminated with sufficient fissile material to be of any concern for criticality safety. The second filter will be contaminated but only with milligram quantities of plutonium (unless the first filter has been physically broken through).

CSAR 80-014 shows that over the credible range of plutonium particle densities, criticality in an optimally moderated filter is not credible at either full or nominal water reflection. In

Glovebox HA-21I with no water lines and the introduction of water prohibited, nominal reflection is considered normal. Per CSAR 80-014, dozens of filters are needed to approach criticality at low plutonium densities; at higher densities, tens of kg of plutonium are needed; and in between, both the number and mass required for criticality is incredible. Clearly the HEPA filter alone is not a threat to criticality safety.

The HEPA filter is made of material that is considered a moderator, so the HEPA filter is classified as having unrestricted moderation. CSER 80-014 shows that for a critical configuration at an optimal moderation of 30 g Pu/L and full water reflection, the 111 g of plutonium contained in the 3.72 L media volume of the 20.3 cm x 20.3 cm x 15.2 cm (8 in. x 8 in. x 6 in.) HEPA filter at 30 g/L is about 21% of the minimum critical mass. As the plutonium particle density is increased, the percent of the critical mass increases to about 50% at an upper limit density of 5 g Pu/cc on the filter at 240 g Pu/l. If the remaining plutonium in a glovebox is restricted to less than a quarter of a minimum critical configuration, then criticality would not be possible during HEPA filter change out. By removing all loaded containers from the glovebox, only the holdup on the floor needs to be considered. Figure III.A.5(100)-3 in ARH-600 (Carter 1968) shows that a slab less than a 1.27 cm (0.5 in.) thick of <sup>239</sup>Pu-water fully water reflected is less than a quarter of the critical slab thickness. No containers of fissionable material are allowed in the glovebox while removing a HEPA filter. Floor accumulations are minimized by the requirement to expeditiously clean up spills. Therefore, reactivity would not be increased significantly above that for the filter by itself, which is well within allowables for credible accumulations in the filter.

### 5.1.9 Normal Cases Results

Normal case evaluations were conservatively modeled to represent the operations defined in Section 4.4. The results for all of the normal evaluations are given in Table 5-4. These  $k_{\text{eff}}$ s are all significantly less than the criticality safety limit. The criticality safety criterion has been met for the normal situation.

**Table 5-4. MCNP Calculational Results of Normal Cases in Glovebox HA-21I**

<b>Case</b>	<b>Description</b>	<b>k<sub>calc</sub></b>	<b>1σ</b>
c9007nm1	Two 2.35 kg plutonium metal spheres in boats, 25.4 cm separation, nominal reflection on boats, one extra boat with 2.5 kg Pu as PuO <sub>2</sub> with H/X = 20 representing boat on HA-28 conveyor, nominal reflection on all containers, 10 in. spacing on all containers.	0.709	0.001
c9007no1	Three boats with 2.5 kg Pu each as PuO <sub>2</sub> with H/X = 20, One sweeps container with 0.5 kg Pu as PuO <sub>2</sub> with H/X = 20, One extra boat with 2.5 kg Pu as PuO <sub>2</sub> with H/X = 20 representing boat on HA-28 conveyor, nominal reflection on all containers, 10 in. spacing on all containers.	0.673	0.001

Note: All normal cases represent glovebox mass limits, including holdup, along with one unit mass (2.5 kg Pu) more than is allowed inside glovebox HA-21I by the limits in Section 3.1, to account for interaction with a unit mass on the HA-28 conveyor.

## 5.2 BASE CASE

This section presents the standard model of the HA-21I Glovebox with Muffle Furnaces under base conditions of operations. The base case is composed of the normal operation with all parameters to their limiting values and expected abnormal conditions. The main difference between the base case and the normal case is the inclusion of one spacing violation as an expected abnormal condition. The following assumptions were used to model the base conditions for fissionable materials and geometry of equipment in the glovebox. Conservatism was used to represent the base conditions in the most limiting credible forms with respect to fissionable material arrangements and modeling conventions. The last paragraph of Section 5.3.3.2 discusses the conservatism of the selected modeling.

The base case is described in detail in the sections below. The items modeled within the glovebox are the furnaces, the furnace boats, and the cleanup can. Details of the base oxide case and the base metal case models are summarized in Tables 5-5 and 5-6, respectively. The description of the normal case in sections 5.1.1 through 5.1.7 also apply to the base case, with the exceptions described in the following sections.

The oxide base case model for the glovebox had a  $k_{\text{eff}}$  of  $0.7873 \pm 0.0014$  (case c9007bo1), and the metal base case model for the glovebox had a  $k_{\text{eff}}$  of  $0.8556 \pm 0.0011$  (case c9007bm1). These values are well below the allowable  $k_{\text{eff}}$  of 0.942 for plutonium oxide systems and 0.932 for plutonium metal systems.

**Table 5-5. Base Oxide Case Model**

<b>Glovebox Assumptions</b>	Glovebox is surrounded with a minimum of 30.48 cm (12 in.) of water for neutron reflection. Rectangular transverse cross-section instead of actual slanted-side outlines. 2.54 cm (1 in.) water reflection representing hands around each container Pu holdup in glovebox included in total glovebox mass limit
<b>Glovebox dimensions</b>	109.2 cm (43 in.) deep, 102.2 cm (40.25 in.) high, 442.0 cm (174 in.) long.
<b>Furnaces</b>	14 cm (5.5 in.) x 33.0 cm (13.0 in.) x 12.7 cm (5.0 in.) chamber 39 cm (15.4 in.) x 42.2 cm (16.6 in.) x 56.5 cm (22.2 in.) block of insulation (W x H x L) (including door) Full density firebrick. Furnace legs, off-gas piping, and electrical junction box ignored. Full face furnace doors.
<b>Off-gas Filters</b>	Not included in model since covered by water reflection.
<b>Furnace boats</b>	Inside dimensions used, metal container and liner ignored. 12.7 cm (5 in.) wide by 27.94 cm (11 in.) long by 6.20 cm (2.44 in.) high 3 boats with 2.5 kg Pu per boat H/X = 20 2 boats touching sides, 1 boat with 25.4 cm (10 in.) edge-to-edge spacing
<b>Maintenance fluids</b>	Not explicitly modeled since covered by water reflection.
<b>Sweeps container</b>	One 0.5 L container 0.5 kg Pu, H/X = 20 8.89 cm (3.5 in.) diameter 25.4 cm (10 in.) edge-to-edge spacing
<b>Room Assumptions</b>	One boat containing 2.5 kg Pu as oxide at H/X = 20 on conveyor HA-28 modeled at 25.4 cm (10 in.) spacing (vertical) from other boats.

**Table 5-6. Base Metal Case Model**

<b>Glovebox Assumptions</b>	Glovebox is surrounded with a minimum of 30.48 cm (12 in.) of water for neutron reflection. Rectangular transverse cross-section instead of actual slanted-side outlines. 2.54 cm (1 in.) water reflection representing hands around each container Pu holdup in glovebox included in total glovebox mass limit
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Glovebox dimensions	109.2 cm (43 in.) deep, 102.2 cm (40.25 in.) high, 442.0 cm (174 in.) long.
Furnaces	14 cm (5.5 in.) x 33.0 cm (13.0 in.) x 12.7 cm (5.0 in.) chamber 39 cm (15.4 in.) x 42.2 cm (16.6 in.) x 56.5 cm (22.2 in.) block of insulation (W x H x L) (including door) Full density firebrick. Furnace legs, off-gas piping, and electrical junction box ignored. Full face furnace doors.
Off-gas Filters	Not included in model since covered by water reflection.
Furnace boats	Inside dimensions used, metal container and liner ignored. 12.7 cm (5 in.) wide by 27.94 cm (11 in.) long by 6.20 cm (2.44 in.) high 2 boats with 2.35 kg Pu in cuboid per boat H/X = 0 Boats touching with Pu metal touching
Maintenance fluids	Not explicitly modeled since covered by water reflection.
Sweeps container	Not included since more reactive to have all Pu in boats
Room Assumptions	One boat containing 2.5 kg Pu as oxide at H/X = 20 on conveyor HA-28 modeled at 25.4 cm (10 in.) spacing (vertical) from other boats.

### 5.2.1 Base Case Model Differences from Normal Case

For the metal base case the 4.7 kg plutonium metal representing buttons or pieces was modeled in two adjacent boats as two 2.35 kg plutonium cuboids in intimate contact in adjacent corners of each boat, together approximating a cube. This represents a violation of the 25.4 cm (10 in.) spacing requirement. All other aspects of the model were identical to the normal metal case.

For the oxide case the 8.0 kg plutonium oxide was represented the same as in the normal oxide case, in three boats, at 2.5 kg plutonium in each boat, and 0.5 kg in a sweeps container, as a mixture of plutonium oxide and water with H/X of 20. The only difference was that for the base oxide case two of the three boats were located side by side so that the boat contents were touching. This represents a violation of the 25.4 cm (10 in.) spacing requirement. All other aspects of the model were identical to the normal oxide case.

### 5.2.2 Base Cases Results

Base case evaluations were conservatively modeled to represent the operations defined in Section 4.4. The results for all of the base case evaluations are given in Table 5-7. These  $k_{eff}$ s are

all significantly less than the criticality safety limit. The criticality safety criterion has been met for the base situation.

**Table 5-7. MCNP Calculational Results of Base Cases in Glovebox HA-21I**

Case	Description	$k_{calc}$	$1\sigma$
c9007bm1	Two 2.35 kg plutonium metal cuboids in boats, no separation, nominal reflection on boats, one extra boat with 2.5 kg Pu as PuO <sub>2</sub> with H/X = 20 representing boat on HA-28 conveyor, nominal reflection on all containers with 10 in. spacing from other boats.	0.8556	0.0011
c9007bm1pb	Same as c9007bm1 except lead in glovebox walls included in model.	0.8557	0.0011
c9007bo1	Three boats with 2.5 kg Pu each as PuO <sub>2</sub> with H/X = 20, One sweeps container with 0.5 kg Pu as PuO <sub>2</sub> with H/X = 20, One extra boat with 2.5 kg Pu as PuO <sub>2</sub> with H/X = 20 representing boat on HA-28 conveyor, nominal reflection on all containers, 10 in. spacing on all containers except two boats touching.	0.7873	0.0014

Note: All base cases represent glovebox mass limits, including holdup, along with one unit mass (2.5 kg Pu) more than is allowed inside glovebox HA-21I by the limits in Section 3.1, to account for interaction with a unit mass on the HA-28 conveyor.

The metal and oxide base cases did not include the effect of the lead in parts of the glovebox walls. The impact of the 1.27 cm (0.5 in.) lead in parts of the glovebox walls on the glovebox reactivity was investigated by making a separate calculation including the lead walls for the metal base case. This case (case c9007bm1pb) had the same  $k_{eff}$  within statistical uncertainties as the metal base case neglecting the lead (case c9007bm1).

### 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.

Mass is controlled administratively by measurement. The total fissile mass of the glovebox is limited to 8.0 kg when processing oxide and 4.65 kg when processing metal. These mass limits were determined by the maximum mass that would satisfy the criticality safety limits on  $k_{eff}$  for the limiting conditions of the seismic contingency analysis. Sections 5.3.3 and 5.3.7 address the contingency of exceeding the glovebox mass limit. Each container is limited to 2.5 kg Pu. Sections 5.3.3, 5.3.4, 5.3.5, and 5.3.10 address the contingency of exceeding container mass limits.

**Volume and Geometry** are physically controlled by restrictions on container numbers and volumes. There is a limit of six 2.2 L furnace boats, a 0.5 L container sweeps container, and a sieve pan assembly (metal processing only) in the glovebox. Sections 5.3.3 and 5.3.8 address the contingency of exceeding the volume limits.

**Density** is not controlled. The most reactive credible densities were used for all materials.

**Moderation and reflection** are controlled for hydrogenous materials, such as water, carbon, and other low atomic number elements, mixed with plutonium compounds or surrounding the plutonium bearing containers. Moderation and reflection are also controlled by prohibiting free liquids and solutions in this glovebox. Section 5.3.2 addresses the contingency of water increasing the H/X ratio and moderation between the plutonium bearing containers.

**Interaction** is controlled by a minimum 25.4 cm (10 in.) spacing requirement between containers and limits on the numbers and types of containers. Section 5.3.3 addresses the contingency of container stacking. A single violation of the 25.4 cm (10 in.) spacing requirement is included in the base cases, and is not considered a contingency. Firefighting Category C is specified to restrict solid streams of water. Stacking bounds a second spacing violation.

**Enrichment, Concentration, and Isotopes** are not controlled for plutonium which was assumed to be 100 wt%  $^{239}\text{Pu}$ . This conservatively encompasses all allowed fissionable materials including depleted or natural uranium and uranium enrichment which is restricted to 50%  $^{235}\text{U}$ . The hazards assessment, Appendix D, states that it isn't credible to exceed this uranium enrichment in Glovebox HA-21I.

**Neutron Absorption** is not controlled.

The off-normal situations of fissionable material handling for the operations in Glovebox HA-21I are listed in Tables 1-2 and 1-4. The following discussions in this section give a description of the off-normal conditions and the calculational results. Each of the unlikely off-normal events results from a loss of one or more controls, and is therefore considered to be a contingent condition.

Fissionable material in the form of either metallic plutonium or plutonium oxide was evaluated in Section 5.2 for the base case situation in the glovebox. The model assumed the most limiting allowed conditions for criticality controls of mass, moderator, volume, and separation distance including likely off-normal events. A contingency is an unlikely situation where a control is inadvertently lost. A contingency may involve multiple losses of controls if a common mode of failure is identified. The following cases are evaluations of the unlikely off-normal situations where one or more of these controls are violated.

### 5.3.1 Seismic Event

The following sections describe the seismic criticality safety evaluation. This contingency is the limiting event for setting the glovebox fissile mass limits. The metal and oxide limit sets are analyzed separately.

The Plutonium Finishing Plant Final Safety Analysis Report (FDH 1999) states that Glovebox HA-21I is not seismically qualified, and neither is the fire suppression water piping overhead. Therefore, this glovebox could incur structural damage and the fire water piping could break during an earthquake. From a criticality safety viewpoint, the worst situation is for one corner of the glovebox to drop to the floor and the windows break allowing fire suppression water to enter. For this analysis, it is assumed that the corner distant from the criticality drain drops, the maximum allowed fissile loading of the glovebox accumulates in that corner outside of the containers, and the fire suppression water covers the fissile material. The maximum credible saturation of oxide is assumed to be  $H/X = 20$  which corresponds to 88% water by volume and a plutonium oxide density of 1.33 g/cc. This happens to be the maximum allowed normal glovebox moderation and in effect means that the material accumulates in the collapsed corner and water from the sprinklers sits on top adding reflection. It is not considered reasonable to assume that the water could stir this material or that it could be more saturated. Also, any non fissile objects, such as muffle furnaces, tools, and containers are conservatively assumed not to fall and displace the fissile material and add neutron absorption. Such objects would reduce the reactivity.

#### 5.3.1.1 Metal Seismic Analysis

If any fissile metal is present then the metal limit set applies for any combination of metal or oxide. The seismic event is assumed to occur with the maximum allowed loading in the glovebox. Normally the boats are covered except when placed into the furnace and when sitting on the cooling tray after being fired. Because up to 2.5 kg Pu is allowed in a boat and three boats could be fired at a time or be cooling at one time, then up to 7.5 kg Pu could be sitting in uncovered boats. This mass could then spill into the collapsed corner of the glovebox during an earthquake and be reflected with water from the fire suppression system. However, a quick check of handbook analyses (Carter 1968), shows that in reality, only about 5 kg of plutonium metal would remain subcritical if reflected and in the form of a sphere. Because the statement of work directed that the glovebox allowable fissile mass limit be maximized, the following analysis searches for the greatest mass for the metal limit set that can be in present in Glovebox HA-21I, regardless of whether it is oxide or metal.

The collapsed corner of the glovebox was modeled as an inverted pyramid of fissile material with its point resting on the concrete floor. Steel of the glovebox was ignored and the fissile material was surrounded by 1 in. of water on the sides, representing nominal neutron reflection and 1 foot on the top representing full reflection by the water entering the glovebox. Fissile metal was modeled as a sphere within the pyramid. Eight MCNP calculations were performed to determine the effect on the reactivity of combinations of metal and oxide with  $H/X = 20$  in this geometry. The results of those calculations are shown in Table 5-8.

**Table 5-8. Seismic Analysis of Metal Limit Set<sup>a</sup>**

Case	Description	$k_{eff}$	1-sigma
pyr8	3.5 kg metal sphere surrounded by pyramid of 1.13 kg Pu as oxide H/X = 20	0.9193	0.0016
pyr9	3.0 kg metal sphere surrounded by pyramid of 1.63 kg Pu as oxide H/X = 20	0.9020	0.0020
py10	3.6 kg metal sphere surrounded by pyramid of 1.03 kg Pu as oxide H/X = 20	0.9202	0.0018
py11	3.7 kg metal sphere surrounded by pyramid of 0.93 kg Pu as oxide H/X = 20	0.9188	0.0015
py12	3.8 kg metal sphere surrounded by pyramid of 0.83 kg Pu as oxide H/X = 20	0.9212	0.0018
py13	3.93 kg metal sphere surrounded by pyramid of 0.83 kg Pu as oxide H/X = 20	0.9302	0.0017
py14	4.75 kg metal sphere surrounded by pyramid of water	0.9390	0.0012
py15	4.7 kg metal sphere surrounded by pyramid of water	0.9343	0.0015
py16	4.65 kg metal sphere surrounded by pyramid of water	0.9314	0.0013

a) Neutron reflection for all cases was modeled as concrete below the point of the fissile material pyramid, one in. of water on each side, and one foot of water on top of the fissile material.

Comparison of cases pyr8 and pyr9 shows that changing metal to oxide with H/X = 20, holding fissile mass constant, reduces the reactivity. For cases pyr8, py10, py11, and py12, changing oxide to metal, holding fissile mass constant increased reactivity. Then for case py13, the metal mass was increased to obtain a  $k_{eff}$  close to the 0.932 limit for metal calculations as explained in Section 4. The oxide mass remained the same. Then that mass was converted to all metal surrounded by water which is the most reactive arrangement. Because this mass is too reactive, as demonstrated by case py14, the mass was reduced until  $k_{eff}$  dropped below 0.932. These calculations thus established the glovebox metal limit set mass at 4.65kg with a calculated  $k_{eff}$  of  $0.9314 \pm 0.0013$ .

### 5.3.1.2 Oxide Seismic Analysis

As observed for the metal/oxide calculations described above, as metal is converted to oxide with H/X=20, the reactivity decreases for a constant fissile mass. Therefore, for the all oxide case, one would expect the allowed mass to be greater. Three MCNP calculations were used to find the maximum fissile mass if it were all plutonium oxide. The above model was used with the entire pyramid region consisting of plutonium oxide with H/X = 20. For Cases pyr1 through pyr3, summarized in Table 5-9, the plutonium loading was reduced from 8.312 kg, to 8 kg to drop below the  $k_{eff}$  limit of 0.942 for oxide calculations as explained in Section 4. The 8 kg plutonium glovebox mass limit was established by Case pyr3 with a calculated  $k_{eff}$  of  $0.9377 \pm 0.0018$ . To check the assumption that this was the most reactive density, an additional calculation with the maximum theoretical plutonium oxide density was performed. From the drop in reactivity of this case, py17, and from figure III.A.9(100)-4 of Carter 1968, any displacement of

the water and subsequent increase in density of the oxide between  $H/X = 20$  and  $H/X = 0$  will reduce reactivity compared to case pyr3.

**Table 5-9. Seismic Analysis of Oxide Limit Set**

<b>Case</b>	<b>Description</b>	<b><math>k_{eff}</math></b>	<b>1-sigma</b>
pyr1	8.3 kg plutonium as oxide with $H/X = 20$ in pyramid	0.9509	0.0017
pyr2	8.2 kg plutonium as oxide with $H/X = 20$ in pyramid	0.9443	0.0018
pyr3	8.0 kg plutonium as oxide with $H/X = 20$ in pyramid	0.9377	0.0018
py17	8.0 kg plutonium as oxide with $H/X = 0$ and maximum theoretical density of 11.46 g/cc	0.8067	0.0014

### 5.3.2 Fire Event

Glovebox HA-21I is designated as a dry glovebox. There are no liquid lines running into or through the glovebox and no free liquids or solutions are allowed. Three ways moderator or reflector material can be introduced are 1) introduction of objects that can cause a moderating or reflecting effect, such as human hands and arms inside rubber gloves, 2) introduction of containers with moderating liquids, and 3) breakage or burn through of plastic glovebox panels concurrently with water sprinkler activation or other water sources introducing water until flooding is possible. Water could then collect in containers in the glovebox. Only firefighting category C, such as mists or fogs are allowed. It was assumed that the fissile material is not moved by the water, and therefore for firefighting no solid streams of water are allowed. The criticality drain will limit the accumulation of water to no more than 5.08 cm (2 in.).

The normal and base case models included partial neutron reflection from operator hands inside rubber gloves around every fissile container. The entire glovebox was also modeled as surrounded by 30.48 cm (12 in.) of water to represent operator bodies or other external reflectors.

The main containers in the glovebox are flat open top boats. Therefore, there is the potential for water dilution of the fissile-bearing material. If the water ingress occurs as a spray or overhead "rain", the fissile material is not expected to be disturbed, and will occupy its original volume fraction. The introduction of water into the glovebox was analyzed by filling the fissile containers with water and flooding the glovebox floor to the height of the boats, 6.20 cm (2.44 in.). The oxide material at  $H/X = 20$  was already modeled at the maximum water content for the 2.5 kg Pu limit per boat, so any water added to the boats would displace Pu. A separate oxide case was analyzed where the 8.0 kg Pu was distributed among six boats mixed with enough water to fill the volume of the six boats. The introduction of mist in the glovebox atmosphere was analyzed by increasing the interspersed water density above the flooded floor and containers from no water to full flooding.

#### 5.3.2.1 Oxide Processing

The results of the fire contingency cases for oxide material are shown in Table 5-10. The

base case oxide results are also shown for comparison. The separate case (case c9007fo2) where the 8.0 kg Pu was distributed among six boats mixed with enough water to fill the volume of the boats had a lower  $k_{\text{eff}}$  ( $0.7029 \pm 0.0014$ ) than the base case that had the 8.0 kg Pu distributed in three boats ( $0.7873 \pm 0.0014$ ). Therefore further studies on glovebox water introduction were modifications of the oxide base case. The oxide results in Table 5-10 show that reactivity increases with increasing interspersed water density, but that even the incredible event of full flooding of the glovebox is less than the criticality safety limit of 0.942 for oxide systems.

**Table 5-10. MCNP Calculational Results of Fire Contingency Cases for Oxide Processing**

Case	Description	$k_{\text{calc}}$	$1\sigma$
c9007bo1	Oxide Base Case. Three boats with 2.5 kg Pu each as $\text{PuO}_2$ with $H/X = 20$ . One sweeps container with 0.5 kg Pu as $\text{PuO}_2$ with $H/X = 20$ . One extra boat with 2.5 kg Pu as $\text{PuO}_2$ with $H/X = 20$ representing boat on HA-28 conveyor, nominal reflection on all containers, 10 in. spacing on all containers except two boats touching.	0.7873	0.0014
c9007fo2	Six boats with 1.33 kg Pu each as $\text{PuO}_2$ , mixed with water to fill boat volume ( $H/X = 41$ ). 0.5 kg Pu as $\text{PuO}_2$ with $H/X = 20$ in sweeps container. One extra boat with 2.5 kg Pu as $\text{PuO}_2$ with $H/X = 20$ representing boat on HA-28 conveyor, nominal reflection on all containers, 10 in. spacing on all containers except two boats touching.	0.7029	0.0014
c9007fo3	Same as oxide base case c9007bo1 except glovebox flooded to height of boats (6.20 cm). Interspersed water density = $0.0 \text{ g/cm}^3$	0.7987	0.0014
c9007fo4	Same as c9007fo3 except interspersed water density = $0.01 \text{ g/cm}^3$	0.8008	0.0015
c9007fo5	Same as c9007fo3 except interspersed water density = $0.03 \text{ g/cm}^3$	0.8017	0.0015
c9007fo6	Same as c9007fo3 except interspersed water density = $0.10 \text{ g/cm}^3$	0.8221	0.0015
c9007fo7	Same as c9007fo3 except interspersed water density = $0.50 \text{ g/cm}^3$ .	0.8612	0.0015
c9007fo1	Same as c9007fo3 except interspersed water density = $1.00 \text{ g/cm}^3$ (fully flooded)	0.8775	0.0014

These calculations show that the criticality safety limit of 0.942 for oxide is met for the fire contingency. A second unlikely and unrelated contingency would have to occur in order to exceed the safety limits. The double contingency criterion has been met.

### 5.3.2.2 Metal Processing

The results for the metal material in Table 5-11 show that reactivity increases with increasing interspersed water density, but that even at interspersed water densities of up to 0.20 g/cm<sup>3</sup> the glovebox reactivity is less than the criticality safety limit of 0.932 for metal systems. The criticality drain will limit the water depth to 5.08 cm (2 in.). Therefore full flooding of the glovebox is not credible. Achieving an interspersed water density of even 0.20 g/cm<sup>3</sup> is not credible, since sprinklers and fire mist systems are typically in the range less than 0.03 g/cm<sup>3</sup> as explained in Appendix G.

**Table 5-11. MCNP Calculational Results of Fire Contingency Cases for Metal Processing**

Case	Description	k <sub>calc</sub>	1σ
c9007bm1	Base Metal Case. Two 2.35 kg plutonium cuboids in boats, no separation, nominal reflection on boats, one extra boat with 2.5 kg Pu as PuO <sub>2</sub> with H/X = 20 representing boat on HA-28 conveyor, nominal reflection on all containers with 10 in. spacing from other boats.	0.8556	0.0011
c9007fm2	Same as metal base case c9007bm1 except glovebox flooded to height of boats (6.20 cm) and interior of boats flooded. Interspersed water density = 0.0 g/cm <sup>3</sup>	0.9238	0.0013
c9007fm3	Same as c9007fm2 except interspersed water density = 0.01 g/cm <sup>3</sup>	0.9242	0.0013
c9007fm4	Same as c9007fm2 except interspersed water density = 0.03 g/cm <sup>3</sup>	0.9252	0.0013
c9007fm5	Same as c9007fm2 except interspersed water density = 0.10 g/cm <sup>3</sup>	0.9272	0.0013
c9007fm8	Same as c9007fm2 except interspersed water density = 0.20 g/cm <sup>3</sup> .	0.9306	0.0013
c9007fm7	Same as c9007fm2 except interspersed water density = 0.30 g/cm <sup>3</sup> .	0.9342	0.0012
c9007fm6	Same as c9007fm2 except interspersed water density = 0.50 g/cm <sup>3</sup> .	0.9396	0.0013
c9007fm1	Same as c9007fm2 except interspersed water density = 1.00 g/cm <sup>3</sup> (fully flooded)	0.9451	0.0013

These calculations show that the criticality safety limit of 0.932 for metal systems is met for the fire contingency provided Category C fire fighting is used and the criticality drain functions. A second unlikely and unrelated contingency would have to occur in order to exceed the safety limits. The double contingency criterion has been met.

### 5.3.3 Extra Boat in Glovebox Stacked on Other Boats

#### 5.3.3.1 Oxide Processing

The normal situation for oxide processing is to have up to 8.0 kg of Pu at a  $H/X \leq 20$  in up to six boats and one 0.5 L container, with a minimum 25.5 cm (10 in.) edge-to-edge spacing, and no more than 2.5 kg Pu in any container. The base case for the oxide processing included a violation of the 25.4 cm (10 in.) spacing limit between fissile containers as a not-unlikely event. However, a stacking violation is considered an unlikely event and therefore a contingency that must be evaluated. Similarly, the oxide base case included a 2.5 kg Pu unit mass on the HA-28 conveyor at the 25.4 cm (10 in.) spacing limit as a not-unlikely event. Bringing this unit mass into the glovebox and stacking it on an existing boat in the glovebox would violate both the glovebox mass limit of 8.0 kg Pu with a total of 10.5 kg Pu and the no-stacking restriction in a single event. Therefore, rather than performing analyses for separate stacking violation and mass limit violations, a single analysis was performed to represent the limiting event of bringing a 2.5 kg Pu loaded boat from the HA-28 conveyor into the glovebox and stacking it on an existing boat in the glovebox, with the glovebox already at the total Pu mass limit.

The MCNP model of the oxide contingency case (case c9007so1) for this event was the same as the oxide base case c9007bo1 except that the extra boat with 2.5 kg Pu at  $H/X = 20$  representing a unit mass on the HA-28 conveyor was moved so that it was stacked (centered) on top of the two adjacent boats. This resulted in a compact arrangement of 7.5 kg of Pu at  $H/X = 20$ , with another 2.5 kg of Pu in a boat and 0.5 kg Pu in a sweeps container at a distance of 25.5 cm (10 in.). Nominal water reflection (1 in.) was included around the combined mass and other containers, with full reflection on the bottom, sides, and top of the glovebox. The result of the MCNP calculation of this extra boat stacking contingency for the oxide material was a  $k_{\text{eff}}$  of  $0.9385 \pm 0.0016$ , as shown in Table 5-12. This is less than the criticality safety limit of 0.942 for MCNP calculations of non-metal systems.

**Table 5-12. MCNP Calculational Results of Extra Boat Stacking Cases for Oxide**

Case	Description	$k_{\text{calc}}$	$1\sigma$
c9007so1	Same as oxide base case c9007bo1 except extra boat with 2.5 kg Pu at $H/X = 20$ representing unit mass on HA-28 conveyor stacked (centered) on top of two adjacent boats	0.9385	0.0016

#### 5.3.3.2 Metal Processing

The normal situation for metal processing is to have up to 4.65 kg of Pu in up to six boats and one 0.5 L container, with a minimum 25.5 cm (10 in.) edge-to-edge spacing, and no more than 2.5 kg Pu in any container. The base case for the metal processing modeled a total of 4.7 kg in two adjacent boats since it included a violation of the 25.4 cm (10 in.) spacing limit between fissile containers as a not-unlikely event. Similarly, the metal base case included a 2.5 kg Pu unit mass on the HA-28 conveyor at the 25.4 cm (10 in.) spacing limit as a not-unlikely event.

Bringing this unit mass into the glovebox and stacking it on an existing boat in the glovebox could violate both the glovebox mass limit of 4.65 kg Pu with a total mass of 7.2 kg Pu and the no-stacking restriction in a single event. Therefore, rather than performing analyses for separate stacking violation and mass limit violations, a single analysis was performed to represent the limiting event of bringing a 2.5 kg Pu loaded boat from the HA-28 conveyor into the glovebox and stacking it on an existing boat in the glovebox, with the glovebox already at the total Pu mass limit.

The MCNP model of the metal contingency case (case c9007sm1) for this event was the same as metal base case c9007bm1 except that the extra boat with 2.5 kg Pu at H/X = 20 representing a unit mass on the HA-28 conveyor was moved so that it was stacked (centered) on top of the two adjacent boats. This resulted in a nearly cubic arrangement of 4.7 kg Pu metal with a cuboid mass 2.5 kg of Pu in the form of PuO<sub>2</sub> and water at H/X of 20 directly on top, with nominal (1 in.) water reflection on the sides and top of the combined mass and full reflection on the bottom, sides, and top of the glovebox. The result of the MCNP calculation of this extra boat stacking contingency case for the metal material was a  $k_{\text{eff}}$  of  $0.9007 \pm 0.0015$ , as shown in Table 5-13. A second metal case for this contingency (case c9007sm2b) was used to evaluate metal in the extra boat. This case modeled the extra 2.5 kg Pu unit mass as a single piece of plutonium metal that was stacked on top of the glovebox boats so that the metal mass was in direct contact with the two adjacent metal masses in the boats. This effectively formed a single piece of plutonium metal with a combined mass of 7.15 kg Pu in a compact arrangement. The actual limit of 4.65 kg Pu was used for the two adjacent boats. This is a much more compact arrangement of Pu metal than could be realistically achieved in three boats. The spacing and poisoning effect of the boat walls and floor were ignored and it is very unlikely for the Pu metal to achieve the compact mass modeled. The result of the MCNP calculation of this extra boat stacking contingency for the metal material (case c9007sm2b) was a  $k_{\text{eff}}$  of  $0.9316 \pm 0.0011$ , as shown in Table 5-13. Both cases were less than the criticality safety limit of 0.932 for MCNP calculations of metal systems.

**Table 5-13. MCNP Calculational Results of Extra Boat Stacking Cases for Metal**

Case	Description	$k_{\text{calc}}$	$1\sigma$
c9007sm1	Same as metal base case c9007bm1 except extra boat with 2.5 kg Pu at H/X = 20 representing unit mass on HA-28 conveyor stacked (centered) on top of two adjacent boats	0.9007	0.0015
c9007sm2b	Same as c9007sm1 except 4.65 kg Pu in two adjacent boats, stacked extra boat contains 2.5 kg Pu metal in cuboid centered on top of other Pu masses	0.9316	0.0011
c9007sm2d	Same as c9007sm2b except fissile material spaced by the width of the adjacent boat walls and the thickness of the boat floor for the extra boat	0.8803	0.0011
c9007sm2e	Same as c9007sm2d except the boats are adjacent to full-height water reflector	0.8944	0.0011

Upon reviewing the first two entries of Table 5-13, the independent reviewer asked how the calculated  $k$ -effectives of Tables 5-12 and 5-13 would change if the boats were adjacent to full height water-reflected walls. Modeling placed the boats next to the 2-inch high step in the floor of the glovebox that extends the water reflection from under the glovebox up along side the boat.

Does the conservatism of ignoring the spacing between fissile masses by the 1/8-inch walls of the boats overshadow the fact that they are not sitting right next to the wall having a line of people on the other side? The second two entries of Table 5-13 show that the  $k$ -effective drops by 0.051 when the plutonium buttons are separated by the width of the boat walls and only rises 0.014 when moved adjacent to the side water reflection. Therefore, the computer modeling for this evaluation is conservative.

### 5.3.3.3 Summary

These calculations show that the criticality safety limits of 0.942 for oxide and 0.932 for metal systems are met for the stacking and extra boat contingency. A second unlikely and unrelated contingency would have to occur in order to exceed the safety limits. The double contingency criterion has been met.

### 5.3.4 Button in One Boat While Processing Oxide

The normal situation for oxide processing is to have up to 8.0 kg of Pu at a  $H/X \leq 20$  in up to six boats and one 0.5 L container, with a minimum 25.5 cm (10 in.) edge-to-edge spacing, and no more than 2.5 kg Pu in any container. If any metal is present when processing oxide, the more restrictive metal mass limit of 4.65 kg Pu must be used. A contingency would involve discovering that there was metal in a boat, when it was assumed to be oxide, with the oxide mass limit of 8.0 kg Pu in the glovebox. The glovebox would thus contain up to 2.5 kg of Pu metal, or Pu metal and oxide, in one boat with 5.5 kg of oxide in the remaining boats and sweep container. This contingency was analyzed by staying within the 8.0 kg Pu glovebox limit for oxide but including a 2.5 kg Pu metal button in a boat that already contained 2.5 kg of Pu as  $\text{PuO}_2$  at  $H/X = 20$ . The button was modeled as a 2.5 kg Pu metal sphere centered in a boat on the glovebox floor, with the remainder of the boat volume filled with the 2.5 kg Pu oxide. The height of the oxide material was increased beyond the height of the boat to compensate for the displaced volume of the metal sphere. The spacing violation assumed in the base case was thus represented by the more reactive situation of combining the contents of two boats. The mass of Pu in the glovebox boats and sweeps container was maintained at the oxide limit of 8.0 kg Pu as in the oxide base case. The extra boat representing a unit mass on the HA-28 conveyor was maintained at 25.4 cm (10 in.) vertical spacing from the combined boat. The calculation for the button in boat contingency provided a  $k_{\text{eff}}$  of  $0.8833 \pm 0.0017$  (case c9007so2) for oxide processing. This  $k_{\text{eff}}$  satisfies the criticality limit of 0.932 for MCNP calculations of metal systems. A second unlikely and unrelated contingency would have to occur in order to exceed the safety limits. The double contingency criterion has been met.

**Table 5-14. MCNP Calculational Results of Button in Boat Case for Oxide**

Case	Description	$k_{calc}$	$1\sigma$
c9007so2	Same as oxide base case c9007bo1 except 2.5 kg Pu metal sphere surrounded by 2.5 kg Pu as $PuO_2$ at $H/X = 20$ in one boat	0.8833	0.0017

### 5.3.5 Two Buttons in One Boat While Processing Metal

The normal situation for metal processing is to have up to 4.65 kg of Pu in up to six boats and one 0.5 L container, with a minimum 25.5 cm (10 in.) edge-to-edge spacing. Two metal buttons could be in the glovebox in separate boats under normal conditions, as long as the 4.65 kg Pu total mass limit was met. A contingency would be to have a spill or operator error where these two buttons ended up in contact in a single boat. The base case for the metal processing modeled the 4.65 kg Pu in two adjacent boats since it included a violation of the 25.4 cm (10 in.) spacing limit between fissile containers as a not-unlikely event. This base case model placed the Pu metal in each boat as approximately one half of a cube, with the sides touching to complete the cube. The contingency of having two buttons in one boat is therefore covered under the metal base case calculated  $k_{eff}$  of  $0.8556 \pm 0.0011$  (case c007bml), which satisfies the criticality limit of 0.932 for MCNP calculations of metal systems. A second unlikely and unrelated contingency would have to occur in order to exceed the safety limits. The double contingency criterion has been met.

### 5.3.6 Container Outside Glovebox Brought too Close

The normal situation for oxide processing is to have up to 8.0 kg of Pu at a  $H/X \leq 20$  in up to six boats and one 0.5 L container, with a minimum 25.5 cm (10 in.) edge-to-edge spacing, and no more than 2.5 kg Pu in any container. The normal situation for metal processing is to have up to 4.65 kg of Pu in up to six boats and one 0.5 L container, with 25.5 cm (10 in.) edge-to-edge spacing, and no more than 2.5 kg Pu in any container. Normal operation allows fissile containers within 46 cm (18 in.) of the outside of the glovebox while in transit. A contingency would be through operator error to place a fissile container with no more than 2.5 kg Pu against the glovebox wall. The extra boat stacking contingency described in Section 5.3.3 covers a more reactive configuration than any arrangement of this metal or oxide outside of the glovebox. The calculations for this contingency in Section 5.3.3 provided a  $k_{eff}$  of  $0.9007 \pm 0.0015$  (case c9007sm1) for an extra boat of oxide and  $0.9316 \pm 0.0011$  (case c9007sm2b) for an extra boat of metal for metal processing and  $0.9385 \pm 0.0016$  (case c9007so1) for oxide processing. These  $k_{eff}$ s satisfy the criticality limit of 0.932 for MCNP calculations of metal systems and 0.942 for MCNP calculations of oxide systems. A second unlikely and unrelated contingency would have to occur in order to exceed the safety limits. The double contingency criterion has been met.

### 5.3.7 Holdup Exceeding Glovebox Mass Limits

The normal situation for oxide processing is to have up to 8.0 kg of Pu at a  $H/X \leq 20$  in up to six boats and one 0.5 L container, with a minimum 25.5 cm (10 in.) edge-to-edge spacing, and no more than 2.5 kg Pu in any container. The normal situation for metal processing is to have up to 4.65 kg of Pu in up to six boats and one 0.5 L container, with a minimum 25.5 cm (10 in.) edge-to-edge spacing, and no more than 2.5 kg Pu in any container. Any glovebox holdup must be subtracted from the total mass limit to determine the maximum fissile mass allowed in containers. Normal operation allows holdup in a variety of forms, such as a layer on the floor or furnaces, piles of material on the floor, or filter accumulations. However, noticeable accumulations of fissionable materials, such as from spills, are not allowed to remain in the glovebox and must be cleaned up as soon as practical. A contingency would be through operator error to exceed the glovebox mass limits by not accounting correctly for the amount of holdup in the glovebox. It is not credible for any unaccounted glovebox holdup to exceed a single unit mass of 2.5 kg Pu. Therefore, the extra boat stacking contingency described in Section 5.3.3 covers a more reactive configuration than any arrangement of this metal or oxide holdup. The calculations for this contingency in Section 5.3.3 provided a  $k_{\text{eff}}$  of  $0.9007 \pm 0.0015$  (case c9007sm1) for an extra boat of oxide and  $0.9316 \pm 0.0011$  (case c9007sm2b) for an extra boat of metal for metal processing and  $0.9385 \pm 0.0016$  (case c9007so1) for oxide processing. These  $k_{\text{eff}}$ s satisfy the criticality limit of 0.932 for MCNP calculations of metal systems and 0.942 for MCNP calculations of oxide systems. A second unlikely and unrelated contingency would have to occur in order to exceed the safety limits. The double contingency criterion has been met.

### 5.3.8 Container Too Large

The normal situation for both metal and oxide processing allows one 0.5 L container for a sweeps container. Through operator error, a larger container could be brought in to the glovebox in place of the 0.5 L container. The fire contingency described in Section 5.3.2 covers flooding of the glovebox with water up to the top of the boats and the entire glovebox volume filling with water mist at various densities. These analyses conservatively bound any contingency of larger containers in the glovebox. For the oxide processing, even fully flooding the glovebox with water provided a  $k_{\text{eff}}$  of  $0.8775 \pm 0.0014$  (case c9007fo1), which satisfies criticality safety limit of 0.942 for oxide systems. For the metal processing, flooding the glovebox with water to the top of the boats and filling the glovebox air with water at a density of  $0.20 \text{ g/cm}^3$  provided a  $k_{\text{eff}}$  of  $0.9306 \pm 0.0013$  (case c9007fm8), which satisfies the criticality safety limit of 0.932 for metal systems.

### 5.3.9 Extra Oil or Plastic

The normal situation for both metal and oxide processing allows a 0.5 L container, a damp rag for cleaning, a lubricant container not to exceed 50 ml, and waste packages that may contain gloves, rags, containers used to port-in items, etc. Extra oil or plastic could be introduced into the glovebox by bringing in a larger container of lubricant or other liquid, or allowing an accumulation of excess plastic such as gloves or bags. The fire contingency described in Section

5.3.2 covers flooding of the glovebox with water up to the top of the boats and the entire glovebox volume filling with water mist at various densities. These analyses conservatively bound any contingency of extra oil or plastic in the glovebox. For the oxide processing, even fully flooding the glovebox with water provided a  $k_{\text{eff}}$  of  $0.8775 \pm 0.0014$  (case c9007fo1), which satisfies criticality safety limit of 0.942 for oxide systems. For the metal processing, flooding the glovebox with water to the top of the boats and filling the glovebox air with water at a density of  $0.20 \text{ g/cm}^3$  provided a  $k_{\text{eff}}$  of  $0.9306 \pm 0.0013$  (case c9007fm8), which satisfies the criticality safety limit of 0.932 for metal systems.

### 5.3.10 Overloaded Boat

The normal situation for oxide processing is to have up to 8.0 kg of Pu at a  $H/X \leq 20$  in up to six boats and one 0.5 L container, with a minimum 25.5 cm (10 in.) edge-to-edge spacing, and no more than 2.5 kg Pu in any container. The normal situation for metal processing is to have up to 4.65 kg of Pu in up to six boats and one 0.5 L container, with a minimum 25.5 cm (10 in.) edge-to-edge spacing, and no more than 2.5 kg Pu in any container. A contingency would be through operator error, such as a spill, to exceed the container mass limit by overloading a boat with oxide or metal material. It is not credible to overload a boat by more than a single unit mass of 2.5 kg Pu, or for this overloaded material to have an  $H/X$  greater than 20. Therefore, the extra boat stacking contingency described in Section 5.3.3 covers a more reactive configuration than any arrangement of this metal or oxide overload. The calculations for this contingency in Section 5.3.3 provided a  $k_{\text{eff}}$  of  $0.9007 \pm 0.0015$  (case c9007sm1) for metal processing and  $0.9385 \pm 0.0016$  (case c9007so1) for oxide processing. These  $k_{\text{eff}}$ s satisfy the criticality limit of 0.942 for MCNP calculations of oxide systems and 0.932 for MCNP calculations of metal systems. A second unlikely and unrelated contingency would have to occur in order to exceed the safety limits. The double contingency criterion has been met.

### 5.3.11 Oxide Boat Spilled on Metal Boat While Processing Metal

The normal situation for metal processing is to have up to 4.65 kg of Pu in up to six boats and one 0.5 L container, with a minimum 25.5 cm (10 in.) edge-to-edge spacing. Oxide material can, and will, be present in the glovebox when processing metal, as long as the 4.65 kg Pu total mass limit is met. A contingency would be to have a spill or operator error where an oxide boat is spilled on a metal boat. The glovebox could therefore contain a single boat with up to 4.65 kg of some combination of Pu metal and oxide. This contingency is covered by the button in boat analysis for oxide processing described in Section 5.3.4. The analysis in Section 5.3.4 included a 2.5 kg Pu metal sphere in a boat that already contained 2.5 kg of Pu as  $\text{PuO}_2$  at  $H/X = 20$ . The button was modeled as a 2.5 kg Pu metal sphere centered in a boat on the glovebox floor, with the remainder of the boat volume filled with the 2.5 kg Pu as Pu oxide. The height of the oxide material was increased beyond the height of the boat to compensate for the displaced volume of the metal sphere. The spacing violation assumed in the base case was thus represented by the more reactive situation of combining the contents of two boats. The mass of Pu in the glovebox boats and sweeps container was at the oxide limit of 8.0 kg Pu, which is more reactive than the

4.65 kg Pu metal mass limit. The calculation for the button in boat contingency provided a  $k_{\text{eff}}$  of  $0.8833 \pm 0.0017$  (case c9007so2). This  $k_{\text{eff}}$  satisfies the criticality limit of 0.932 for MCNP calculations of metal systems. A second unlikely and unrelated contingency would have to occur in order to exceed the safety limits. The double contingency criterion has been met.

### **5.3.12 Sieve Pan Assembly Left in Glovebox While Processing Oxide**

The sieve pan assembly can be used when processing metal or mixed metal and oxide material to separate any combined oxide and metal materials under the metal limit set. The sieve pan assembly is removed or made a noncontainer in the glovebox when processing only oxide material under the oxide limit set. A contingency would be for the sieve pan assembly to be a container in the glovebox when processing oxide material under the oxide limit set. The sieve pan assembly provides a larger volume, 3.3 L, than a boat. Having 2.5 kg of oxide material in the sieve pan assembly rather than a boat is covered by the extra boat stacking contingency described in Section 5.3.3. The other impact of the sieve pan assembly is it provides additional volume that could be filled with water in the event that fire sprinklers introduce water into the glovebox. The fire contingency analysis described in Section 5.3.2 showed that for oxide processing the fully flooded glovebox had a  $k_{\text{eff}}$  of  $0.8775 \pm 0.0014$ , which satisfies the criticality limit of 0.942 for MCNP calculations of oxide systems. A second unlikely and unrelated contingency would have to occur in order to exceed the safety limits. The double contingency criterion has been met.

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**APPENDIX A**

**INDEPENDENT REVIEW COMMENTS AND CHECKLIST**

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## Peer Review Comments

D. G. Erickson, a qualified Criticality Safety Specialist of the Criticality and Shielding group in FDNW Safety Analysis and Nuclear Engineering, carried out an independent, technical review of HNF-5450, Rev. 0, *CSER 99-007: Criticality Safety Evaluation Report for the PFP Glovebox HA-21I Muffle Furnace Operation for Plutonium Stabilization*, for which the following comments were provided.

The technical arguments given in the report were found to be sound for qualifying the criticality safety of PFP glovebox HA-21I for use in receiving muffle furnace boats filled with a maximum of 2.5 kg of plutonium as metal and/or oxide and thermally stabilizing the material. All credible contingencies resulted in  $k_{eff}$ s that are within the subcriticality limit of  $k_{eff} = 0.95$  including the code bias and calculational uncertainties.

The review of this CSER showed that the normal condition analyses adequately and conservatively modeled the actual conditions that would be found in the glovebox. The base case model conservatively included the effects of any anticipated off-normal operating conditions. Some of the conservatisms in the base case were: 1) assuming all material was  $^{239}\text{Pu}$ , 2) not including any of the structural metal for the boats, 3) nominal (2.54 cm) water reflection on all containers, 4) assuming maximum moderation for all oxides cases, and 5) combining plutonium metal pieces into worst possible geometry. For the oxide cases, the boats actually contained 2.58 kg of plutonium when filled to the maximum volume of 2.2  $\ell$  at the maximum H/X of 20.

The review of the unlikely off-normal condition analysis (contingencies) also incorporated all of the above mentioned conservatisms, as well as including additional conservatisms that bound any credible off-normal operation. The analysis shows that even if the glovebox were to be flooded, containers were to be overbatched, or spacing between containers was lost, the system is still subcritical.

The plutonium densities, including all or part of a plutonium metal button, between the theoretical density of  $\text{PuO}_2$  (11.46  $\text{g}/\text{cm}^3$ ) at an H/Pu of 0 up to the maximum H/Pu (lowest density) possible with the available container volume is analyzed and shown to be acceptable. In all cases adequate margins of safety exist to assure that the operations to be performed in glovebox HA-21I will not pose any criticality concerns.

The analysis of the postulated seismic event also very conservatively models any credible rearrangement of the materials and containers in glovebox HA-21I. The model used either a spherical geometry for the metal contingency or an inverted pyramid in the corner of the glovebox for the oxide contingency with at least nominal (2.54 cm) water reflection surrounding the entire model. It is incredible to believe that any event could cause the materials contained in the glovebox to even approach the modeled geometry.

The report was reviewed for technical accuracy, consistency, coverage of all credible contingencies, and adequacy of limits. Discrepancies, inconsistencies, and significant editorial

presentation issues were raised and have been adequately resolved.

The input and output files from all computer calculations were also reviewed. The input files were checked for material densities, material masses, geometry, and container volumes. During the course of that review several modeling discrepancies and non-conservatisms were noted, and those cases were corrected/revised and recalculated. The output files were checked for convergence. The  $k_{\text{eff}}$  values reported in the report were verified against the results in the output files.

This reviewer affirms that based on the analysis contained in CSER 99-007, the operations proposed for PFP glovebox HA-21I are safe from a criticality standpoint.

FLUOR DANIEL NORTHWEST

**TECHNICAL PEER REVIEWS**

**CHECKLIST FOR TECHNICAL PEER REVIEW**

Document Reviewed: HNF-5450 Rev.0  
 Title: CSER 99-007: Criticality Safety Evaluation Report PFP Glovebox HA-21I Muffle Furnace Operation for Plutonium Stabilization  
 Author: K. D. Dobbin, D. W. Wootan  
 Date: December 9, 1999  
 Scope of Review: Full Document

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

David G. Erickson David G. Erickson 12-10-99  
 Reviewer: (Printed and Signed) Date

\* All "NO" responses must be explained below or on an additional page.  
 \*\* 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 intelligible to a technically qualified third party.

# **MOHR AND ASSOCIATES**

## **ENGINEERING - ANALYSIS - CONSULTING**

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509-846-0841  
509-846-2340  
FAX 509-846-4385

December 9, 1999

To: Kenneth D. Dobbin, Fluor Daniel Northwest

From: Warner A. Blyckert

Subject: Review of CSER99-007: Criticality Safety Evaluation Report for PFP Glovebox HA-211 Muffle Furnace Operation for Plutonium Stabilization (HFN-5450 Rev 0)

Document HNF-5450, Rev. 0, *CSER 99-007: Criticality Safety Evaluation Report for PFP Glovebox HA-211 Muffle Furnace Operation for Plutonium Stabilization*, was given an independent technical review. The approach to analyzing the proposed operations, technique used, and computer calculation inputs were checked for suitability, accuracy and completeness. The results indicate that the operation may be safely operated under the constraints of the analysis.

The material which was reviewed consisted of the draft of the final report. The output files of the computer calculations were not reviewed so that no assessment was made of accuracy, convergence, or any other parameter of the results. The correctness and results of the validation effort was not reviewed so that the limits used in the CSER were not checked for accuracy nor applicability other than the narrative account of the approach which is reported in an appendix. The referenced CSERs and CSARs were not reviewed and the statements concerning their results were accepted without verification.

Responses to the reviewer's comments have been incorporated into the final report and adequately address the comments.

The reviewer agrees with the conclusion of the report that the proposed stabilization operations may be safely operated with the postulated material under the limiting conditions of operation.

Very truly yours,



Warner A. Blyckert

**FLUOR DANIEL NORTHWEST**

**TECHNICAL PEER REVIEWS**

**CHECKLIST FOR TECHNICAL PEER REVIEW**

Document Reviewed: HNF-5450 Rev.0  
 Title: CSER 99-007: Criticality Safety Evaluation Report PFP Glovebox HA-21I Muffle Furnace Operation for Plutonium Stabilization  
 Author: K. D. Dobbin, D. W. Wootan  
 Date: December 9, 1999  
 Scope of Review: Full Document

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

Wagner Blycker Wagner Blycker 12-10-1999  
 Reviewer: (Printed and Signed) Date

\* All "NO" responses must be explained below or on an additional page.

\*\* 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 intelligible to a technically qualified third party.

**NUCLEAR ENGINEERING**

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**APPENDIX B**  
**MCNP COMPUTER CODE VALIDATION**

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**B.1 VALIDATION PROCEDURE**

Validation of the computer code methods in this analysis consisted of testing the code and neutron cross sections on calculations of known critical configurations. These benchmark experiments have fissile isotopes in systems similar to that evaluated by this CSER. The computed and measured  $k_{eff}$ s for the benchmark configurations were compared to establish a bias that includes the uncertainty in the calculational methods. A bias-adjusted  $k_{eff}$  for the benchmark systems was defined to include both the deviations of the calculated from the measured  $k_{eff}$ 's, and experimental and calculational uncertainties along with the spread in the ability of the computer code to calculate similar systems. In addition, criticality safety criteria require that the bias-adjusted  $k_{eff}$  for CSER analysis calculations not exceed the established  $k_{eff}$  safety limit at the 95% confidence level.

This method is illustrated in Figure B.1. Critical is defined as a  $k_{eff}$  of unity, adjusted by the bias established from the comparison of calculations with benchmarks. The bias is combined with the safety margin of 0.05 (a safety limit that  $k_{eff}$  must be less than or equal to 0.95) to compare with the calculated value and statistical uncertainty of the computer calculated  $k_{eff}$ 's of this CSER analysis. The calculated target  $k_{eff}$  is established by adding the bias, 0.05, and 1.645 times the one-sigma uncertainty of the calculated  $k_{eff}$  for the particular CSER analysis and subtracting that value from 1.0. For the analyses in this CSER, all the computer statistical uncertainties were less than  $\pm 0.002$ , so this value was used to set the target  $k_{eff}$ 's as described in Section B.2.

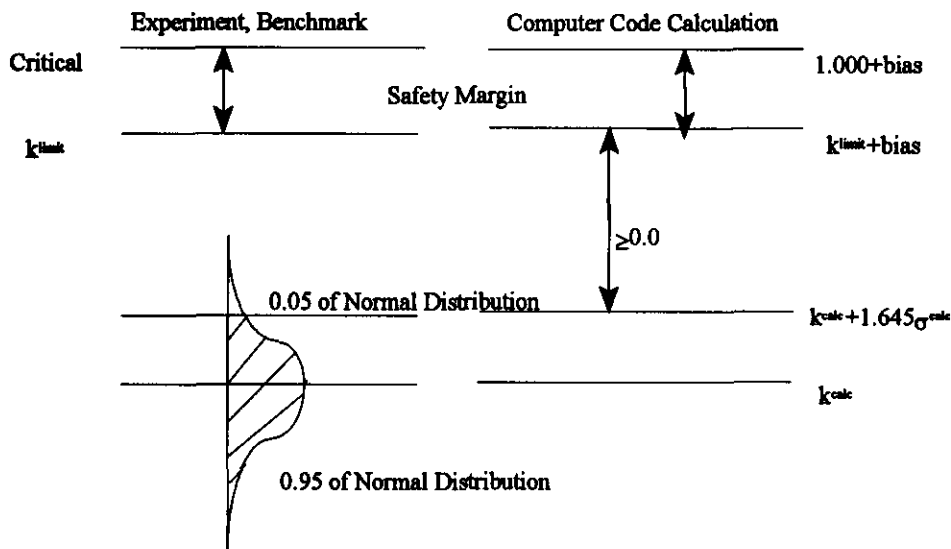


Figure B.1. Logic of Validation Procedure

## B.2 GENERIC VALIDATION FOR PLUTONIUM SYSTEMS

A report by J. S. Lan, *MCNP Version 4B Approval For Use Documentation & Authorized User List* (Lan 1999), presents the results of calculations to determine a generic bias for plutonium configurations, as encountered in the Plutonium Finishing Plant. One hundred and forty three benchmark experiments were calculated. There were different material types that were considered in the plutonium validation calculations:

- Plutonium metal,
- Plutonium oxide,
- Plutonium solutions,
- Plutonium solutions with cadmium (a neutron poison),
- Water and polystyrene moderators, and
- Water, plexiglass, paraffin, polyethylene, and steel and concrete reflectors

The lower tolerance limit  $b_L$  was calculated for the benchmark experiments such that there is 95% confidence that 95% of the benchmark calculated  $k_{eff}$ 's is above that limit. This is expressed by the following formula:

$$b_L = k_{avg} - K_b * \sigma_{avg}$$

- where:  $b_L$  = lower tolerance limit for 95% confidence that 95% of the benchmark calculated  $k_{eff}$ 's is above this limit,
- $k_{avg}$  = the average of the  $k_{eff}$ 's calculated by MCNP 4B,
- $K_b$  = a multiplier found from statistical tables for non-central t-distribution, and depends on number of degrees of freedom, and
- $\sigma_{avg}$  = standard deviation of the MCNP  $k_{eff}$ 's.

Bias is calculated by the following formula:

$$\text{bias} = b_L - k_{crit}$$

where:

- $k_{crit}$  = the average of the  $k_{eff}$ 's for the critical experiments; for the plutonium experiments  $k_{crit} = 1.000$ .

The bias for the plutonium metal group was significantly different than for all other groups. For this reason, it was concluded that separate bias values for metal and non-metal groupings would be appropriate. The lower tolerance limit for the metal group (17 benchmark critical experiments) calculated to be 0.9884. The lower tolerance limit for the non-metal group (126 benchmark critical experiments) calculated to be 0.9991. These lower tolerance limits yielded the bias appropriate for each material category:

- Plutonium metal                      bias is -0.0116,
- Plutonium non-metal                bias is -0.0009.

For conservatism, these calculated biases were recommended to be increased to:

- Plutonium metal recommended bias is -0.0150,
- Plutonium non-metal recommended bias is -0.0050.

The safety criteria for future calculations on undetermined systems requires that the bias-adjusted  $k_{\text{eff}}$  does not exceed 0.95 at the 95% confidence level. This is expressed by the following formula:

$$k_{\text{eff}} = k_{\text{calc}} - \text{bias} + 1.645 * \sigma_{\text{calc}} \leq k_{\text{limit}}$$

- where:
- $k_{\text{calc}}$  = k value given by MCNP 4B calculation for system in question,
  - bias = -0.015 for Pu metal, and -0.005 for Pu non-metal systems,
  - 1.645 = a constant number of standard deviations for .95 of the distribution for a one-sided standard normal distribution
  - $\sigma_{\text{calc}}$  = standard deviation given by MCNP 4B calculation for system in question, and
  - $k_{\text{limit}}$  = 0.95 for plutonium systems, generally.

$k_{\text{limit}}$  is generally taken to be 0.95 for plutonium systems.

For a standard deviation ( $\sigma_{\text{calc}}$ ) of 0.002 or less, the  $k_{\text{eff}}$  value for plutonium metal systems is:

$$k_{\text{calc}} - (-0.015) + 1.645 * 0.002 \leq 0.95, \text{ or}$$

$$k_{\text{calc}} \leq 0.95 + (-0.015) - 1.645 * 0.002 = 0.932.$$

On this basis, it is determined that the true  $k_{\text{eff}}$  of an analyzed configuration with plutonium will not exceed 0.95 with a 95% confidence level for plutonium metal systems if the calculated value ( $k_{\text{calc}}$ , and  $\sigma \leq 0.002$ ) is limited to a maximum value of 0.932.

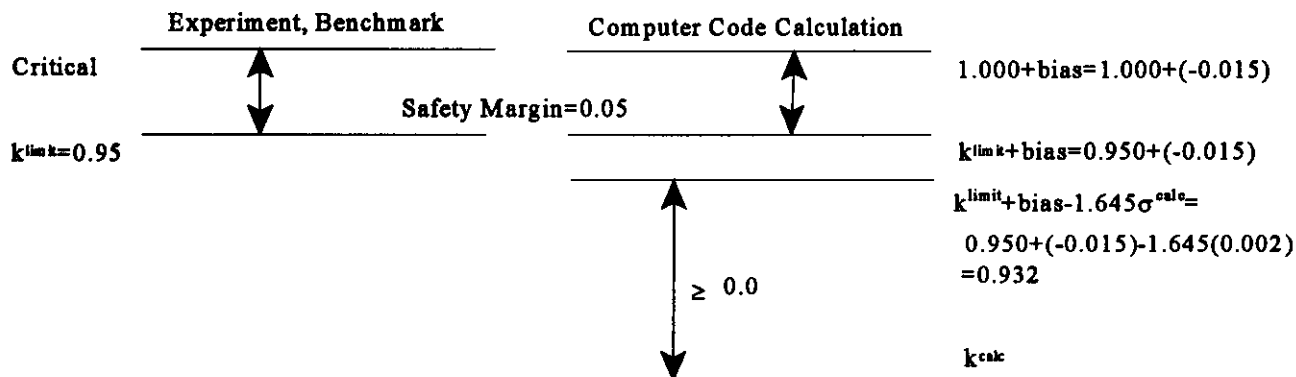


Figure B.2. Implementation of Validation Procedure

For a standard deviation ( $\sigma_{\text{calc}}$ ) of 0.002 or less, the  $k_{\text{eff}}$  value for non-metal systems is:

$$k_{\text{calc}} - (-0.005) + 1.645 * 0.002 \leq 0.95, \text{ or}$$

$$k_{\text{calc}} \leq 0.95 + (-0.005) - 1.645 * 0.002 = 0.942.$$

On this basis, it is determined that the true  $k_{\text{eff}}$  of an analyzed configuration with plutonium will not exceed 0.95 with a 95% confidence level for plutonium non-metal systems if the calculated value ( $k_{\text{calc}}$ , and  $\sigma \leq 0.002$ ) is limited to a maximum value of **0.942**.

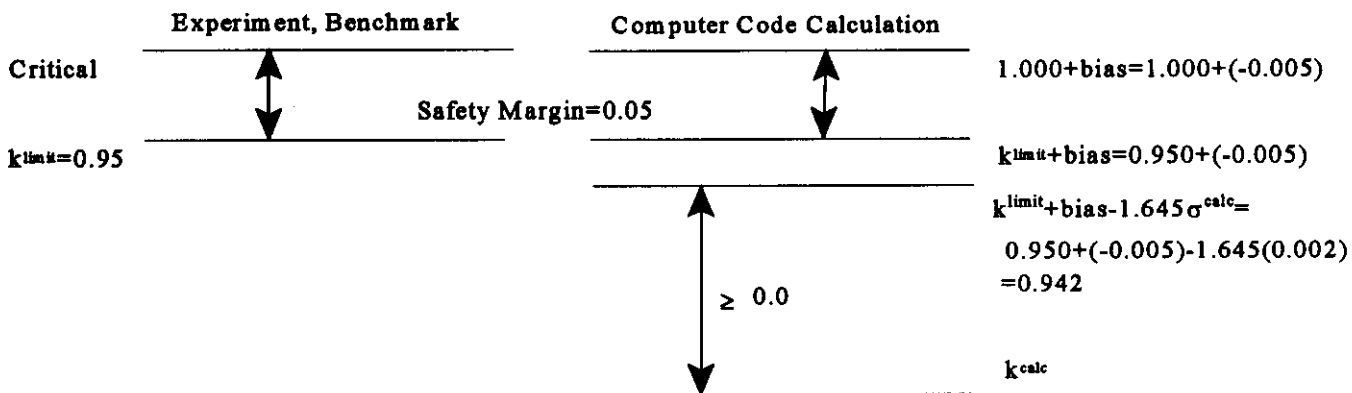


Figure B.3 Implementation of Validation Procedure

### B.3 VALIDATION OF MCNP 4B

The validation of the MCNP4B code on the new computing system, Intergraph™, 400/450 MHz Pentium II, personal computers was documented in Lan, 1999. The essence of the validation was cross-correlation of calculational results obtained with this code version and results of critical experiments, as reported in *MCNP Version 4B Approval for Use Documentation & Authorized User List* (Lan 1999).

**APPENDIX C**  
**MCNP INPUT FILES**

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## MCNP Input Files for Base Cases and Seismic Model and Diff Files for Others

py16.txt  
diff py16.txt py15.txt  
diff py16.txt py14.txt  
diff py16.txt py13.txt  
diff py16.txt py12.txt  
diff py16.txt py11.txt  
diff py16.txt py10.txt  
diff py16.txt pyr9.txt  
diff py16.txt pyr8.txt  
pyr3.txt  
diff pyr3.txt pyr2.txt  
diff pyr3.txt pyr1.txt  
diff pyr3.txt py17.txt  
c9007bo1.i  
diff c9007bo1.i c9007no1.i  
diff c9007bo1.i c9007fo2.i  
diff c9007bo1.i c9007fo3.i  
diff c9007fo3.i c9007fo4.i  
diff c9007fo3.i c9007fo5.i  
diff c9007fo3.i c9007fo6.i  
diff c9007fo3.i c9007fo7.i  
diff c9007fo3.i c9007fo1.i  
diff c9007bo1.i c9007so1.i  
diff c9007bo1.i c9007so2.i  
c9007bm1.i  
diff c9007bm1.i c9007nm1.i  
diff c9007bm1.i c9007bm1pb.i  
diff c9007bm1.i c9007fm2.i  
diff c9007fm2.i c9007fm3.i  
diff c9007fm2.i c9007fm4.i  
diff c9007fm2.i c9007fm5.i  
diff c9007fm2.i c9007fm6.i  
diff c9007fm2.i c9007fm7.i  
diff c9007fm2.i c9007fm8.i  
diff c9007fm2.i c9007fm1.i  
diff c9007bm1.i c9007sm1.i  
diff c9007bm1.i c9007sm2b.i  
diff c9007sm2b.i c9007sm2d.i  
diff c9007sm2d.i c9007sm2e.i

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py16.txt

```
seismic contingency for metal/PuO2 H/X = 20 in pyramid with 12" h2o on top
1 5 -1.00 1 2 3 -4 11 imp:n=1 $ inside pu
2 5 -1.00 (-1:-2:-3: 4) 5 6 7 -8 9 imp:n=1 $ 1" h2o
3 3 -2.37 -9 -10 imp:n=1 $ concrete floor
4 4 -0.00129 (-5:-6:-7: 8) 9 -10 imp:n=1 $ air
5 0 10 imp:n=0 $ outside world
6 6 -19.48 -11 imp:n=1 $ metal sphere
```

```
c ----- boat -----
1 px 0.00
2 py 0.00
3 pz 0.00
4 p 19.55 0 0 0 19.55 0 0 0 19.55
5 px -2.54
6 py -2.54
7 pz -2.54
8 p 50.03 0 0 0 50.03 0 0 0 50.03
9 p 0.707107 0.707107 0.707107 0.0
10 so 80.0 $ outside world
11 s 4.0 4.0 4.0 3.84769
```

```
mode n
m1 94239.55c 1.00 8016.50c 12.0 1001.50c 20.0 $ rho=2.2124, boat
mt1 lwtr.01t
m4 7014.50c 0.790000 8016.50c 0.210000 $ rho=0.00129 ar, air
m5 1001.50c 0.66667 8016.50c 0.3333 $ rho=1.00 , h2o
mt5 lwtr.01t
m3 1001.50c 0.0642 8016.50c 0.5916 14000.50c 0.2405 $ rho=2.37
20000.50c 0.0738 26000.55c 0.0299 $ concrete
mt3 lwtr.01t
m6 94239.55c 1.00
kcode 3000 1.0 10 100
ksrc 3.64 3.64 3.64
prdmp j -300 1 3
totnu
print
ctme 40
```

diff py16.txt py15.txt

```
20c20
< 11 s 4.0 4.0 4.0 3.84769
---
> 11 s 4.0 4.0 4.0 3.86143
```

diff py16.txt py14.txt

```
20c20
< 11 s 4.0 4.0 4.0 3.84769
---
> 11 s 4.0 4.0 4.0 3.8765
```

diff py16.txt py13.txt

```
2c2
< 1 5 -1.00 1 2 3 -4 11 imp:n=1 $ inside pu
---
> 1 1 -2.2124 1 2 3 -4 11 imp:n=1 $ inside pu
13c13
< 4 p 19.55 0 0 0 19.55 0 0 0 19.55
---
> 4 p 17.55 0 0 0 17.55 0 0 0 17.55
17c17
< 8 p 50.03 0 0 0 50.03 0 0 0 50.03
---
> 8 p 48.03 0 0 0 48.03 0 0 0 48.03
20c20
< 11 s 4.0 4.0 4.0 3.84769
---
> 11 s 3.6416 3.6416 3.6416 3.64
```

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**diff py16.txt py12.txt**

```
2c2
< 1 5 -1.00 1 2 3 -4 11 imp:n=1 $ inside pu
---
> 1 1 -2.2124 1 2 3 -4 11 imp:n=1 $ inside pu
13c13
< 4 p 19.55 0 0 0 19.55 0 0 0 19.55
---
> 4 p 17.55 0 0 0 17.55 0 0 0 17.55
17c17
< 8 p 50.03 0 0 0 50.03 0 0 0 50.03
---
> 8 p 48.03 0 0 0 48.03 0 0 0 48.03
20c20
< 11 s 4.0 4.0 4.0 3.84769
---
> 11 s 3.6416 3.6416 3.6416 3.597
```

**diff py16.txt py11.txt**

```
2c2
< 1 5 -1.00 1 2 3 -4 11 imp:n=1 $ inside pu
---
> 1 1 -2.2124 1 2 3 -4 11 imp:n=1 $ inside pu
13c13
< 4 p 19.55 0 0 0 19.55 0 0 0 19.55
---
> 4 p 18.06 0 0 0 18.06 0 0 0 18.06
17c17
< 8 p 50.03 0 0 0 50.03 0 0 0 50.03
---
> 8 p 48.54 0 0 0 48.54 0 0 0 48.54
20c20
< 11 s 4.0 4.0 4.0 3.84769
---
> 11 s 3.6416 3.6416 3.6416 3.565
```

**diff py16.txt py10.txt**

```
2c2
< 1 5 -1.00 1 2 3 -4 11 imp:n=1 $ inside pu
---
> 1 1 -2.2124 1 2 3 -4 11 imp:n=1 $ inside pu
13c13
< 4 p 19.55 0 0 0 19.55 0 0 0 19.55
---
> 4 p 18.55 0 0 0 18.55 0 0 0 18.55
17c17
< 8 p 50.03 0 0 0 50.03 0 0 0 50.03
---
> 8 p 49.03 0 0 0 49.03 0 0 0 49.03
20c20
< 11 s 4.0 4.0 4.0 3.84769
---
> 11 s 3.6416 3.6416 3.6416 3.533
```

**diff py16.txt pyr9.txt**

```
2c2
< 1 5 -1.00 1 2 3 -4 11 imp:n=1 $ inside pu
---
> 1 1 -2.2124 1 2 3 -4 11 imp:n=1 $ inside pu
13c13
< 4 p 19.55 0 0 0 19.55 0 0 0 19.55
---
> 4 p 21.0 0 0 0 21.0 0 0 0 21.0
17c17
< 8 p 50.03 0 0 0 50.03 0 0 0 50.03
```

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```

---
> 8 p 51.48 0 0 0 51.48 0 0 0 51.48
20c20
< 11 s 4.0 4.0 4.0 3.84769
---
> 11 s 3.9416 3.9416 3.9416 3.325
33c33
< ksrc 3.64 3.64 3.64
---
> ksrc 3.94 3.94 3.94

```

diff py16.txt pyr8.txt

```

2c2
< 1 5 -1.00 1 2 3 -4 11 imp:n=1 $ inside pu
---
> 1 1 -2.2124 1 2 3 -4 11 imp:n=1 $ inside pu
13c13
< 4 p 19.55 0 0 0 19.55 0 0 0 19.55
---
> 4 p 19.0 0 0 0 19.0 0 0 0 19.0
17c17
< 8 p 50.03 0 0 0 50.03 0 0 0 50.03
---
> 8 p 49.48 0 0 0 49.48 0 0 0 49.48
20c20
< 11 s 4.0 4.0 4.0 3.84769
---
> 11 s 3.9416 3.9416 3.9416 3.5
33c33
< ksrc 3.64 3.64 3.64
---
> ksrc 3.94 3.94 3.94

```

pyr3.txt

seismic contingency for PuO2 H/X = 20 in 7.0 liter pyramid with 12" h2o on top

```

1 1 -2.2124 1 2 3 -4 imp:n=1 $ inside pu
2 5 -1.00 (-1:-2:-3: 4) 5 6 7 -8 9 imp:n=1 $ 1" h2o
3 3 -2.37 -9 -10 imp:n=1 $ concrete floor
4 4 -0.00129 (-5:-6:-7: 8) 9 -10 imp:n=1 $ air
5 0 10 imp:n=0 $ outside world

```

```

c ----- boat -----
1 px 0.00
2 py 0.00
3 pz 0.00
4 p 34.4810 0 0 0 34.4810 0 0 0 34.4810
5 px -2.54
6 py -2.54
7 pz -2.54
8 p 64.9610 0 0 0 64.9610 0 0 0 64.9610
9 p 0.707107 0.707107 0.707107 0.0
10 so 80.0 $ outside world

```

```

mode n
m1 94239.55c 1.00 8016.50c 12.0 1001.50c 20.0 $ rho=2.2124, boat
mt1 lwtr.01t
m4 7014.50c 0.790000 8016.50c 0.210000 $ rho=0.00129 ar, air
m5 1001.50c 0.66667 8016.50c 0.3333 $ rho=1.00 , h2o
mt5 lwtr.01t
m3 1001.50c 0.0642 8016.50c 0.5916 14000.50c 0.2405 $ rho=2.37
20000.50c 0.0738 26000.55c 0.0299 $ concrete
mt3 lwtr.01t
kcode 3000 1.0 10 100
ksrc 5.0 5.0 5.0
prdmp j -300 1 3
totnu
print
ctme 40

```

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diff pyr3.txt pyr2.txt

```

12c12
< 4 p 34.4810 0 0 0 34.4810 0 0 0 34.4810
---
> 4 p 34.6936 0 0 0 34.6936 0 0 0 34.6936
16c16
< 8 p 64.9610 0 0 0 64.9610 0 0 0 64.9610
---
> 8 p 65.1736 0 0 0 65.1736 0 0 0 65.1736
30c30
< ksrc 5.0 5.0 5.0
---
> ksrc 9.0 9.0 9.0

```

diff pyr3.txt pyr1.txt

```

1c1
< seismic contingency for PuO2 H/X = 20 in 7.0 liter pyramid with 12" h2o on top
---
> seismic contingency for PuO2 H/X = 20 in 7.2 liter pyramid with 12" h2o on top
12c12
< 4 p 34.4810 0 0 0 34.4810 0 0 0 34.4810
---
> 4 p 34.92501 0 0 0 34.92501 0 0 0 34.92501
16c16
< 8 p 64.9610 0 0 0 64.9610 0 0 0 64.9610
---
> 8 p 65.40501 0 0 0 65.40501 0 0 0 65.40501

```

diff pyr3.txt py17.txt

```

2c2
< 1 1 -2.2124 1 2 3 -4 imp:n=1 $ inside pu
---
> 1 1 -11.46 1 2 3 -4 imp:n=1 $ inside pu
12c12
< 4 p 34.4810 0 0 0 34.4810 0 0 0 34.4810
---
> 4 p 16.808 0 0 0 16.808 0 0 0 16.808
16c16
< 8 p 64.9610 0 0 0 64.9610 0 0 0 64.9610
---
> 8 p 47.29 0 0 0 47.29 0 0 0 47.29
21c21
< m1 94239.55c 1.00 8016.50c 12.0 1001.50c 20.0 $ rho=2.2124, boat
---
> m1 94239.55c 1.00 8016.50c 2.0 $ rho=2.2124, boat

```

c9007bol.1

```

glovebox ha21i muffle furnace model - base oxide - c9007bol
c base case oxide 8 kg pu total
c glovebox - full water reflection on all sides
c furnaces - empty
c boats - 3 boats on floor
c 2 boats touching sides, 1 boat 10" spacing
c 1.173 g pu/cc oxide
c 2.5 kg pu/boat
c h/x = 20
c 1 inch water reflection on boats
c sides, top, bottom of boats not included
c containers - 1 0.5 liter polyjar 10" spacing from boats
c 1.173 g pu/cc oxide
c h/x=20
c 500g pu
c 1 inch water reflection on polyjar
c ha28 conveyor - 1 boat 10 inch spacing from boats in glovebox
c 2.5 kg pu
c h/x = 20
c 1 inch water reflection

```

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```

c
c  glovebox
1  0      1 -2 3 -4 20 -6
      #10 #11 #12 #13
      #20 #21 #22 #23
      #30 #31 #32 #33
      (-211:9:-210:212:213)
      (-211:9:-224:214:213)
      (-307:308:-309:310:-311:312)
      (402:404)
c  glovebox floor depression
2  0      3 -2 7 -5 8 -9
      (-211:9:-210:212:213)
      (-211:9:-224:214:213)
      (402)
c  glovebox lead sidewall and window
3  1 -1.0 (-1:2:-3) (10 -11 12 -4 5 -19)
4  1 -1.0 7 -5 8 -9 12 -3
5  1 -1.0 7 -5 8 -9 -11 2
6  1 -1.0 (-1:2:-3) (10 -11 12 -4 19 -6)
c  full water reflection
7  1 -1.0 ((-10:11:-12:4:6)(13 -14 15 -16 5 -18)):
      (13 -14 15 -16 -5 17 (-8:-7:9:-12:11))
c  outside world
8  0      -13:14:-15:16:-17:18
c  floor layer
9  0      1 -2 3 -4 5 -20
      (-211:9:-210:212:213)
      (-211:9:-224:214:213)
      (402:404)
c  furnace 1
10 2 -2.1 (101 -102 105 -106 -103 104)
      (-108:109:-110:111:112)
c  furnace cavity
11 0      108 -109 110 -111 -112 104
      (-113:114:125:-115:116)
c  boat in furnace cavity
12 0      113 -114 -125 123 115 -116
c  furnace door
13 2 -2.1 101 -102 -104 107 105 -106
c  furnace 2
20 like 10 but trcl=2
c  furnace cavity
21 like 11 but trcl=2
c  boat in furnace cavity
22 like 12 but trcl=2
c  furnace door
23 like 13 but trcl=2
c  furnace 3
30 like 10 but trcl=3
c  furnace cavity
31 like 11 but trcl=3
c  boat in furnace cavity
32 like 12 but trcl=3
c  furnace door
33 like 13 but trcl=3
c  3 boats, 1 with 10" spacing on floor with 1" water
201 3 -2.214 202 -203 204 -205 7 -201
202 3 -2.214 223 -206 204 -205 7 -201
204 1 -1.0 (201:-202:203:-204:205)
      210 211 -212 -213 -9 7
205 1 -1.0 (201:-223:206:-204:205)
      224 211 -214 -213 -9 7
c  polyjar
207 3 -2.214 -401 7 -403
208 1 -1.0 (-402 7 -404) (401:403)
c  1 boat with 10" spacing from others
301 3 -2.214 301 -302 303 -304 305 -306
302 1 -1.0 (-301:302:-303:304:-305:306)
      307 -308 309 -310 311 -312
1  px 0.0
2  py 109.20
3  py 0.0
4  px 441.96

```

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5	pz	0.0
6	pz	102.24
7	pz	-5.08
8	px	283.21
9	px	358.14
10	px	-1.27
11	py	110.47
12	py	-1.27
13	px	-30.48
14	py	139.68
15	py	-30.48
16	px	472.44
17	pz	-30.48
18	pz	132.72
19	pz	41.91
20	pz	2.54
c	furnace	
101	pz	-21.1
102	pz	21.1
103	py	50.5
104	py	0.0
105	px	-19.50
106	px	19.50
107	py	-6.035
108	pz	-6.35
109	pz	6.35
110	px	-6.985
111	px	6.985
112	py	33.02
113	pz	-6.20
114	pz	0.0
115	px	-6.35
116	px	6.35
117	py	-2.54
118	py	-30.48
119	pz	-8.74
120	pz	2.54
121	px	-8.89
122	px	8.89
123	py	0.0
124	py	-33.02
125	py	27.94
c	boats	
201	pz	1.12
202	py	86.35
203	py	99.05
204	px	327.66
205	px	355.60
206	py	60.95
207	py	48.25
208	py	22.85
209	py	10.15
210	py	83.81
211	px	325.12
212	py	101.59
213	pz	3.66
214	py	63.49
215	py	45.71
216	py	25.39
217	py	7.61
223	py	35.55
224	py	33.01
c	boat with 10" spacing from other boats (conveyor)	
301	px	327.66
302	px	355.60
303	pz	26.52
304	pz	32.72
305	py	48.25
306	py	60.95
307	px	325.12
308	px	358.14
309	pz	23.98
310	pz	35.26
311	py	45.71
312	py	63.49

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```

c      polyjar
401   c/z 297.815 54.60 4.445
402   c/z 297.815 54.60 6.985
403   pz  1.787
404   pz  4.327

m1    1001.5 2 8016.5 1                $water
mt1   lwtr.01
m2    8016.50 0.03930 12000.50 0.00063 13027.50 0.00994 $firebrick
      14000.50 0.01135 20000.50 0.00022 26000.55 0.00032
m3    94239.55 1.00      8016.50 12 1001.50 20                $pu oxide h/x=20
mt3   lwtr.01
*tr1  78.74 34.29 26.18 40 50 90 130 40 90 90 90 0          $furnace 1
*tr2  166.37 34.29 26.18 40 50 90 130 40 90 90 90 0          $furnace 2
*tr3  254.00 34.29 26.18 40 50 90 130 40 90 90 90 0          $furnace 3
ksrc  341 54 -2
      341 16 -2
      341 92 -2
      298 54 -2
      341 54 30
kcode 1000 1.0 10 400
ctme 300
print 10 40 50
prdmp j j j 3

```

**diff c9007bol.1 c9007noi.1**

```

1,2c1,2
< glovebox ha21i muffle furnace model - base oxide - c9007bol
< c      base case oxide 8 kg pu total
---
> glovebox ha21i muffle furnace model - normal oxide - c9007noi
> c      normal case oxide 8 kg pu total
6c6
< c                2 boats touching sides, 1 boat 10" spacing
---
> c                10" spacing
28c28,29
<                (-211:9:-224:214:213)
---
>                (-211:9:-215:214:213)
>                (-211:9:-217:216:213)
34c35,36
<                (-211:9:-224:214:213)
---
>                (-211:9:-215:214:213)
>                (-211:9:-217:216:213)
49c51,52
<                (-211:9:-224:214:213)
---
>                (-211:9:-215:214:213)
>                (-211:9:-217:216:213)
77c80
< c      3 boats, 1 with 10" spacing on floor with 1" water
---
> c      3 boats, with 10" spacing on floor with 1" water
79c82,83
< 202  3  -2.214  223 -206 204 -205 7 -201                imp:n=1
---
> 202  3  -2.214  207 -206 204 -205 7 -201                imp:n=1
> 203  3  -2.214  209 -208 204 -205 7 -201                imp:n=1
82,83c86,89
< 205  1  -1.0    (201:-223:206:-204:205)
<                224 211 -214 -213 -9 7                    imp:n=1
---
> 205  1  -1.0    (201:-207:206:-204:205)
>                215 211 -214 -213 -9 7                    imp:n=1
> 206  1  -1.0    (201:-209:208:-204:205)
>                217 211 -216 -213 -9 7                    imp:n=1

```

**diff c9007bol.1 c9007fo2.1**

1,2c1,2

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```

< glovebox ha211 muffle furnace model - base oxide - c9007bol
< c    base case oxide 8 kg pu total
----
> glovebox ha211 muffle furnace model - fire case oxide - c9007fo2
> c    base case oxide 8 kg pu total, boats flooded
5,9c5,8
< c    boats - 3 boats on floor
< c    2 boats touching sides, 1 boat 10" spacing
< c    1.173 g pu/cc oxide
< c    2.5 kg pu/boat
< c    h/x = 20
----
> c    boats - 6 boats 10" spacing on floor, 2 boats touching
> c    0.5783 g pu/cc oxide + water
> c    1.33 kg pu/boat
> c    h/x = 41
13c12
< c    1.173 g pu/cc oxide
----
> c    1.173 g pu/cc oxide + water
15c14
< c    500g pu
----
> c    500 g pu
26,28c25,30
<      #30 #31 #32 #33
<      (-211:9:-210:212:213)
<      (-211:9:-224:214:213)
----
>      #30 #31 #32 #33
>      (-211:9:-210:212:213:-5)
>      (-211:9:-224:214:213:-5)
>      (-219:222:-210:212:213:-5)
>      (-219:222:-215:214:213:-5)
>      (-219:222:-217:216:213:-5)
32,35c34
< 2 0    3 -2 7 -5 8 -9
<      (-211:9:-210:212:213)
<      (-211:9:-224:214:213)
<      (402)
----
> 2 0    3 -2 7 -5 8 -9
48,49c47,51
<      (-211:9:-210:212:213)
<      (-211:9:-224:214:213)
----
>      (-211:9:-210:212:213:-5)
>      (-211:9:-224:214:213:-5)
>      (-219:222:-210:212:213:-5)
>      (-219:222:-215:214:213:-5)
>      (-219:222:-217:216:213:-5)
77,83c79,94
< c    3 boats, 1 with 10" spacing on floor with 1" water
< 201 3 -2.214 202 -203 204 -205 7 -201
< 202 3 -2.214 223 -206 204 -205 7 -201
< 204 1 -1.0    (201:-202:203:-204:205)
<      210 211 -212 -213 -9 7
< 205 1 -1.0    (201:-223:206:-204:205)
<      224 211 -214 -213 -9 7
----
> c    6 boats 10" spacing on floor with 1" water
> 201 4 -1.627 202 -203 204 -205 218 -201
> 202 4 -1.627 223 -206 204 -205 218 -201
> 204 4 -1.627 202 -203 220 -221 218 -201
> 205 4 -1.627 207 -206 220 -221 218 -201
> 206 4 -1.627 209 -208 220 -221 218 -201
> 207 1 -1.0    (201:-202:203:-204:205:-218)
>      210 211 -212 -213 -9 5
> 208 1 -1.0    (201:-223:206:-204:205:-218)
>      224 211 -214 -213 -9 5
> 210 1 -1.0    (201:-202:203:-220:221:-218)
>      210 219 -212 -213 -222 5
> 211 1 -1.0    (201:-207:206:-220:221:-218)
>      215 219 -214 -213 -222 5
> 212 1 -1.0    (201:-209:208:-220:221:-218)

```

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```

> 217 219 -216 -213 -222 5 imp:n=1
85,86c96,97
< 207 3 -2.214 -401 7 -403 imp:n=1
< 208 1 -1.0 (-402 7 -404) (401:403) imp:n=1
---
> 213 3 -2.214 -401 218 -403 imp:n=1
> 214 1 -1.0 (-402 5 -404) (401:403:-218) imp:n=1
111c122
< 20 pz 2.54
---
> 20 pz 1.12
139c150
< 201 pz 1.12
---
> 201 pz 8.74
151c162
< 213 pz 3.66
---
> 213 pz 11.28
155a167,171
> 218 pz 2.54
> 219 px 378.46
> 220 px 381.00
> 221 px 408.94
> 222 px 411.48
161,162c177,178
< 303 pz 26.52
< 304 pz 32.72
---
> 303 pz 34.14
> 304 pz 40.34
167,168c183,184
< 309 pz 23.98
< 310 pz 35.26
---
> 309 pz 31.60
> 310 pz 42.88
174,175c190,191
< 403 pz 1.787
< 404 pz 4.327
---
> 403 pz 9.407
> 404 pz 11.947
182a199,200
> m4 94239.55 -0.6059 8016.50 -0.9167 1001.50 -0.1045 $pu oxide flooded
> mt4 lwtr.01
186,189c204,210
< ksrc 341 54 -2
< 341 16 -2
< 341 92 -2
< 298 54 -2
---
> ksrc 341 54 3
> 341 16 3
> 341 92 3
> 298 54 3
> 395 54 3
> 395 16 3
> 395 92 3

```

diff c9007bo1.i c9007fo3.i

```

1,2c1,2
< glovebox ha21i muffle furnace model - base oxide - c9007bo1
< c base case oxide 8 kg pu total
---
> glovebox ha21i muffle furnace model - base oxide - c9007fo3
> c base case oxide 8 kg pu, flooded to top of boats, int. water=0
32c32
< 2 0 3 -2 7 -5 8 -9
---
> 2 1 -1 3 -2 7 -5 8 -9
47c47

```

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```

< 9 0 1 -2 3 -4 5 -20
---
> 9 1 -1 1 -2 3 -4 5 -20
111c111
< 20 pz 2.54
---
> 20 pz 1.12

```

**diff c9007fo3.1 c9007fo4.1**

```

1,2c1,2
< glovebox ha211 muffle furnace model - base oxide - c9007fo3
< c base case oxide 8 kg pu, flooded to top of boats, int. water=0
---
> glovebox ha211 muffle furnace model - base oxide - c9007fo4
> c base case oxide 8 kg pu, flooded to top of boats, int. water=0.01
23c23
< 1 0 1 -2 3 -4 20 -6
---
> 1 1 -0.01 1 -2 3 -4 20 -6
32c32
< 2 1 -1 3 -2 7 -5 8 -9
---
> 2 1 -1.0 3 -2 7 -5 8 -9

```

**diff c9007fo3.1 c9007fo5.1**

```

1,2c1,2
< glovebox ha211 muffle furnace model - base oxide - c9007fo3
< c base case oxide 8 kg pu, flooded to top of boats, int. water=0
---
> glovebox ha211 muffle furnace model - base oxide - c9007fo5
> c base case oxide 8 kg pu, flooded to top of boats, int. water=0.03
23c23
< 1 0 1 -2 3 -4 20 -6
---
> 1 1 -0.03 1 -2 3 -4 20 -6
32c32
< 2 1 -1 3 -2 7 -5 8 -9
---
> 2 1 -1.0 3 -2 7 -5 8 -9

```

**diff c9007fo3.1 c9007fo6.1**

```

1,2c1,2
< glovebox ha211 muffle furnace model - base oxide - c9007fo3
< c base case oxide 8 kg pu, flooded to top of boats, int. water=0
---
> glovebox ha211 muffle furnace model - base oxide - c9007fo6
> c base case oxide 8 kg pu, flooded to top of boats, int. water=0.10
23c23
< 1 0 1 -2 3 -4 20 -6
---
> 1 1 -0.10 1 -2 3 -4 20 -6
32c32
< 2 1 -1 3 -2 7 -5 8 -9
---
> 2 1 -1.0 3 -2 7 -5 8 -9

```

**diff c9007fo3.1 c9007fo7.1**

```

1,2c1,2
< glovebox ha211 muffle furnace model - base oxide - c9007fo3
< c base case oxide 8 kg pu, flooded to top of boats, int. water=0
---
> glovebox ha211 muffle furnace model - base oxide - c9007fo7
> c base case oxide 8 kg pu, flooded to top of boats, int. water=0.50
23c23
< 1 0 1 -2 3 -4 20 -6
---

```

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```
> 1 1 -0.50 1 -2 3 -4 20 -6
32c32
< 2 1 -1 3 -2 7 -5 8 -9
---
> 2 1 -1.0 3 -2 7 -5 8 -9
```

**diff c9007fo3.1 c9007fo1.1**

```
1,2c1,2
< glovebox ha21i muffle furnace model - base oxide - c9007fo3
< c base case oxide 8 kg pu, flooded to top of boats, int. water=0
---
> glovebox ha21i muffle furnace model - base oxide - c9007fo1
> c base case oxide 8 kg pu total interstitial water density =1
23c23
< 1 0 1 -2 3 -4 20 -6
---
> 1 1 -1.0 1 -2 3 -4 20 -6
32c32
< 2 1 -1 3 -2 7 -5 8 -9
---
> 2 1 -1.0 3 -2 7 -5 8 -9
111c111
< 20 pz 1.12
---
> 20 pz 2.54
194a195
>
```

**diff c9007bo1.1 c9007so1.1**

```
1,2c1,2
< glovebox ha21i muffle furnace model - base oxide - c9007bo1
< c base case oxide 8 kg pu total
---
> glovebox ha21i muffle furnace model - base oxide - c9007so1
> c base case oxide 8 kg pu boat from conveyor stacked
17c17
< c ha28 conveyor - 1 boat 10 inch spacing from boats in glovebox
---
> c ha28 conveyor - 1 boat no spacing from boats in glovebox
28,29c28
< (-211:9:-224:214:213)
< (-307:308:-309:310:-311:312)
---
> (-211:9:-224:214:(213 -228):(213 227):302)
79c78,79
< 202 3 -2.214 223 -206 204 -205 7 -201 imp:n=1
---
> 202 3 -2.214 (223 -206 204 -205 7 -201):
> (201 -301 -225 226 204 -205) imp:n=1
82,83c82,83
< 205 1 -1.0 (201:-223:206:-204:205)
< 224 211 -214 -213 -9 7 imp:n=1
---
> 205 1 -1.0 ((201 -226):(201 225):301:-223:206:-204:205)
> 224 211 -214 (-213:228) (-213:-227) -302 -9 7 imp:n=1
87,90d86
< c 1 boat with 10" spacing from others
< 301 3 -2.214 301 -302 303 -304 305 -306 imp:n=1
< 302 1 -1.0 (-301:302:-303:304:-305:306)
< 307 -308 309 -310 311 -312 imp:n=1
157a154,157
> 225 py 54.60
> 226 py 41.90
> 227 py 57.14
> 228 py 39.36
159,170c159,160
< 301 px 327.66
< 302 px 355.60
< 303 pz 26.52
< 304 pz 32.72
```

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```
< 305 py 48.25
< 306 py 60.95
< 307 px 325.12
< 308 px 358.14
< 309 pz 23.98
< 310 pz 35.26
< 311 py 45.71
< 312 py 63.49
---
> 301 pz 7.32
> 302 pz 9.86
194a185
>
```

**diff c9007bol.1 c9007so2.1**

```
1,2c1,2
< glovebox ha21i muffle furnace model - base oxide - c9007bol
< c base case oxide 8 kg pu total
---
> glovebox ha21i muffle furnace model - base oxide - c9007so2
> c base case oxide 8 kg pu total with metal and oxide boats combined
6c6,7
< c 2 boats touching sides, 1 boat 10" spacing
---
> c 1 boat with 2.5 kg metal combined with 1 boat 2.5 kg oxide,
> c 1 boat 10" spacing
28c29
< (-211:9:-224:214:213)
---
> (-211:9:-215:214:226)
34c35
< (-211:9:-224:214:213)
---
> (-211:9:-215:214:226)
49c50
< (-211:9:-224:214:213)
---
> (-211:9:-215:214:226)
79c80,81
< 202 3 -2.214 223 -206 204 -205 7 -201 imp:n=1
---
> 202 3 -2.214 207 -206 204 -205 7 -225 501 imp:n=1
> 203 5 -19.48 -501 imp:n=1
82,83c84,85
< 205 1 -1.0 (201:-223:206:-204:205)
< 224 211 -214 -213 -9 7 imp:n=1
---
> 205 1 -1.0 (225:-207:206:-204:205)
> 215 211 -214 -226 -9 7 imp:n=1
157a160,161
> 225 pz 1.4817
> 226 pz 4.0217
161,162c165,166
< 303 pz 26.52
< 304 pz 32.72
---
> 303 pz 26.8817
> 304 pz 33.0817
167,168c171,172
< 309 pz 23.98
< 310 pz 35.26
---
> 309 pz 24.3417
> 310 pz 35.6217
175a180,181
> c metal sphere
> 501 s 341.63 54.60 -1.79915 3.129
182a189
> m5 94239.55 1.00 $pu metal h/x=0
```

**c9007bol.1**

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```

glovebox ha211 muffle furnace model - base metal - c9007bm1
□
c   base case metal 4.7 kg pu total
□
c   glovebox - full water reflection on all sides
□
c   furnaces - empty
□
c   boats - 2 boats on floor
□
c       2 boats touching sides
□
c       19.48 g pu/cc pu metal
c       2.35 kg pu/boat
c       h/x = 0
c       1 inch water reflection on boats
c       sides, top, bottom of boats not included
c   containers - 1 0.5 liter polyjar 10" spacing from boats
c       0 g pu/cc
c       h/x=0
c       0 g pu
c       0 inch water reflection on polyjar
c   ha28 conveyor - 1 boat 10 inch spacing from boats in glovebox
c       2.5 kg pu
c       h/x = 20
c       1 inch water reflection
c
c   glovebox
1   0       1 -2 3 -4 20 -6
       #10 #11 #12 #13
       #20 #21 #22 #23
       #30 #31 #32 #33
       {-211:9:-210:212:213}
       {-211:9:-224:214:213}
       {-307:308:-309:310:-311:312}
       (402:404)                                     imp:n=1
c   glovebox floor depression
2   0       3 -2 7 -5 8 -9
       {-211:9:-210:212:213}
       {-211:9:-224:214:213}
       (402)                                         imp:n=1
c   glovebox lead sidewall and window
3   1 -1.0  (-1:2:-3) (10 -11 12 -4 5 -19)          imp:n=1
4   1 -1.0  7 -5 8 -9 12 -3                        imp:n=1
5   1 -1.0  7 -5 8 -9 -11 2                       imp:n=1
6   1 -1.0  (-1:2:-3) (10 -11 12 -4 19 -6)        imp:n=1
c   full water reflection
7   1 -1.0  {(-10:11:-12:4:6)(13 -14 15 -16 5 -18)}:
       (13 -14 15 -16 -5 17 (-8:-7:9:-12:11))      imp:n=1
c   outside world
8   0       -13:14:-15:16:-17:18                    imp:n=0
c   floor layer
9   0       1 -2 3 -4 5 -20
       {-211:9:-210:212:213}
       {-211:9:-224:214:213}
       (402:404)                                     imp:n=1
c   furnace 1
10  2 -2.1  (101 -102 105 -106 -103 104)
       (-108:109:-110:111:112)                    trcl=1    imp:n=1
c   furnace cavity
11  0       108 -109 110 -111 -112 104
       (-113:114:125:-115:116)                    trcl=1    imp:n=1
c   boat in furnace cavity
12  0       113 -114 -125 123 115 -116            trcl=1    imp:n=1
c   furnace door
13  2 -2.1  101 -102 -104 107 105 -106            trcl=1    imp:n=1
c   furnace 2
20  like 10 but  trcl=2
c   furnace cavity
21  like 11 but  trcl=2
c   boat in furnace cavity
22  like 12 but  trcl=2
c   furnace door
23  like 13 but  trcl=2
c   furnace 3

```

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```

30 like 10 but trcl=3
c furnace cavity
31 like 11 but trcl=3
c boat in furnace cavity
32 like 12 but trcl=3
c furnace door
33 like 13 but trcl=3
c 3 boats, 1 with 10" spacing on floor with 1" water
201 0 202 -203 204 -205 7 -201 imp:n=1
202 0 223 -206 204 -205 7 -201 (503:-502:-501) imp:n=1
204 0 (201:-202:203:-204:205)
210 211 -212 -213 -9 7 imp:n=1
205 1 -1.0 (201:-223:206:-204:205)
224 211 -214 -213 -9 7 imp:n=1
501 4 -19.48 501 502 -503 -205 7 -201 imp:n=1
c polyjar
207 0 -401 7 -403 imp:n=1
208 0 (-402 7 -404) (401:403) imp:n=1
c 1 boat with 10" spacing from others
301 3 -2.214 301 -302 303 -304 305 -306 imp:n=1
302 1 -1.0 (-301:302:-303:304:-305:306)
307 -308 309 -310 311 -312 imp:n=1

```

```

1 px 0.0
2 py 109.20
3 py 0.0
4 px 441.96
5 pz 0.0
6 pz 102.24
7 pz -5.08
8 px 283.21
9 px 358.14
10 px -1.27
11 py 110.47
12 py -1.27
13 px -30.48
14 py 139.68
15 py -30.48
16 px 472.44
17 pz -30.48
18 pz 132.72
19 pz 41.91
20 pz 2.54
c furnace
101 pz -21.1
102 pz 21.1
103 py 50.5
104 py 0.0
105 px -19.50
106 px 19.50
107 py -6.035
108 pz -6.35
109 pz 6.35
110 px -6.985
111 px 6.985
112 py 33.02
113 pz -6.20
114 pz 0.0
115 px -6.35
116 px 6.35
117 py -2.54
118 py -30.48
119 pz -8.74
120 pz 2.54
121 px -8.89
122 px 8.89
123 py 0.0
124 py -33.02
125 py 27.94
c boats
201 pz 1.12
202 py 86.35
203 py 99.05
204 px 327.66
205 px 355.60

```

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```

206 py 60.95
207 py 48.25
208 py 22.85
209 py 10.15
210 py 83.81
211 px 325.12
212 py 101.59
213 pz 3.66
214 py 63.49
215 py 45.71
216 py 25.39
217 py 7.61
223 py 35.55
224 py 33.01
c boat with 10" spacing from other boats (conveyor)
301 px 327.66
302 px 355.60
303 pz 26.52
304 pz 32.72
305 py 48.25
306 py 60.95
307 px 325.12
308 px 358.14
309 pz 23.98
310 pz 35.26
311 py 45.71
312 py 63.49
c polyjar
401 c/z 297.815 54.60 4.445
402 c/z 297.815 54.60 6.985
403 pz 1.787
404 pz 4.327
c metal buttons in boats
501 py 45.131
502 px 349.36
503 py 51.369

m1 1001.5 2 8016.5 1 $water
mt1 lwtr.01
m2 8016.50 0.03930 12000.50 0.00063 13027.50 0.00994 $firebrick
14000.50 0.01135 20000.50 0.00022 26000.55 0.00032
m3 94239.55 1.00 8016.50 12 1001.50 20 $pu oxide h/x=20
mt3 lwtr.01
m4 94239.55 1.00 $pu metal
*tr1 78.74 34.29 26.18 40 50 90 130 40 90 90 90 0 $furnace 1
*tr2 166.37 34.29 26.18 40 50 90 130 40 90 90 90 0 $furnace 2
*tr3 254.00 34.29 26.18 40 50 90 130 40 90 90 90 0 $furnace 3
ksrc 352 48 -2
352 54 30
kcode 1000 1.0 10 400
ctme 300
print 10 40 50
prdmp j j j 3

```

**diff c9007bm1.i c9007nm1.i**

```

1,2c1,2
< glovebox ha21i muffle furnace model - base metal - c9007bm1
< c base case metal 4.7 kg pu total
---
> glovebox ha21i muffle furnace model - normal metal - c9007nm1
> c normal case metal 4.7 kg pu total
5,6c5
< c boats - 2 boats on floor
< c 2 boats touching sides
---
> c boats - 2 boats on floor 10" spacing
28c27,28
< (-211:9:-224:214:213)
---
> (-211:9:-215:214:213)
> (-211:9:-217:216:213)
34c34,35

```

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```

< (-211:9:-224:214:213)
---
> (-211:9:-215:214:213)
> (-211:9:-217:216:213)
49c50,51
< (-211:9:-224:214:213)
---
> (-211:9:-215:214:213)
> (-211:9:-217:216:213)
77c79
< c 3 boats, 1 with 10" spacing on floor with 1" water
---
> c 2 boats, with 10" spacing on floor with 1" water
79c81,82
< 202 0 223 -206 204 -205 7 -201 (503:-502:-501) imp:n=1
---
> 202 0 207 -206 204 -205 7 -201 501 imp:n=1
> 203 0 209 -208 204 -205 7 -201 502 imp:n=1
82,84c85,90
< 205 1 -1.0 (201:-223:206:-204:205)
< 224 211 -214 -213 -9 7 imp:n=1
< 501 4 -19.48 501 502 -503 -205 7 -201 imp:n=1
---
> 205 1 -1.0 (201:-207:206:-204:205)
> 215 211 -214 -213 -9 7 imp:n=1
> 206 1 -1.0 (201:-209:208:-204:205)
> 217 211 -216 -213 -9 7 imp:n=1
> 501 4 -19.48 -501 imp:n=1
> 502 4 -19.48 -502 imp:n=1
178,180c184,185
< 501 py 45.131
< 502 px 349.36
< 503 py 51.369
---
> 501 s 352.534 51.316 -2.014 3.0652
> 502 s 352.534 19.784 -2.014 3.0652

```

**diff c9007bml.1 c9007bmlpb.1**

```

1,3c1,3
< glovebox ha21i muffle furnace model - base metal - c9007bml
< c base case metal 4.7 kg pu total
< c glovebox - full water reflection on all sides
---
> glovebox ha21i muffle furnace model - base metal - c9007bmlpb
> c base case metal 4.7 kg pu total 0.5 inch lead walls
> c glovebox - full water reflection on all sides 0.5 inch lead walls
37,39c37,39
< 3 1 -1.0 (-1:2:-3) (10 -11 12 -4 5 -19) imp:n=1
< 4 1 -1.0 7 -5 8 -9 12 -3 imp:n=1
< 5 1 -1.0 7 -5 8 -9 -11 2 imp:n=1
---
> 3 5 -11.4 (-1:2:-3) (10 -11 12 -4 5 -19) imp:n=1
> 4 5 -11.4 7 -5 8 -9 12 -3 imp:n=1
> 5 5 -11.4 7 -5 8 -9 -11 2 imp:n=1
188a189
> m5 82000.50 1.00 $lead metal

```

**diff c9007bml.1 c9007fm2.1**

```

1,2c1,2
< glovebox ha21i muffle furnace model - base metal - c9007bml
< c base case metal 4.7 kg pu total
---
> glovebox ha21i muffle furnace model - base metal fire - c9007fm2
> c base case metal 4.7 kg pu total, flooded to top of boat
32c32
< 2 0 3 -2 7 -5 8 -9
---
> 2 1 -1 3 -2 7 -5 8 -9
47c47
< 9 0 1 -2 3 -4 5 -20

```

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```

---
> 9 1 -1 1 -2 3 -4 5 -20
78,80c78,80
< 201 0 202 -203 204 -205 7 -201 imp:n=1
< 202 0 223 -206 204 -205 7 -201 (503:-502:-501) imp:n=1
< 204 0 (201:-202:203:-204:205)
---
> 201 1 -1 202 -203 204 -205 7 -201 imp:n=1
> 202 1 -1 223 -206 204 -205 7 -201 (503:-502:-501) imp:n=1
> 204 1 -1 (201:-202:203:-204:205)
86,87c86,87
< 207 0 -401 7 -403 imp:n=1
< 208 0 (-402 7 -404) (401:403) imp:n=1
---
> 207 1 -1 -401 7 -403 imp:n=1
> 208 1 -1 (-402 7 -404) (401:403) imp:n=1
112c112
< 20 pz 2.54
---
> 20 pz 1.12

```

**diff c9007fm2.1 c9007fm3.1**

```

1,2c1,2
< glovebox ha21i muffle furnace model - base metal fire - c9007fm2
< c base case metal 4.7 kg pu total, flooded to top of boat
---
> glovebox ha21i muffle furnace model - base metal fire - c9007fm3
> c base case metal 4.7 kg pu total, flooded to top of boat, 0.01 above
23c23
< 1 0 1 -2 3 -4 20 -6
---
> 1 1 -0.01 1 -2 3 -4 20 -6
197a198
>

```

**diff c9007fm2.1 c9007fm4.1**

```

1,2c1,2
< glovebox ha21i muffle furnace model - base metal fire - c9007fm2
< c base case metal 4.7 kg pu total, flooded to top of boat
---
> glovebox ha21i muffle furnace model - base metal fire - c9007fm4
> c base case metal 4.7 kg pu total, flooded to top of boat, 0.03 above
23c23
< 1 0 1 -2 3 -4 20 -6
---
> 1 1 -0.03 1 -2 3 -4 20 -6
197a198
>

```

**diff c9007fm2.1 c9007fm5.1**

```

1,2c1,2
< glovebox ha21i muffle furnace model - base metal fire - c9007fm2
< c base case metal 4.7 kg pu total, flooded to top of boat
---
> glovebox ha21i muffle furnace model - base metal fire - c9007fm5
> c base case metal 4.7 kg pu total, flooded to top of boat, 0.1 above
23c23
< 1 0 1 -2 3 -4 20 -6
---
> 1 1 -0.1 1 -2 3 -4 20 -6
197a198
>

```

**diff c9007fm2.1 c9007fm6.1**

```

1,2c1,2
< glovebox ha21i muffle furnace model - base metal fire - c9007fm2
< c base case metal 4.7 kg pu total, flooded to top of boat

```

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---

```
> glovebox ha21i muffle furnace model - base metal fire - c9007fm6
> c    base case metal 4.7 kg pu total, flooded to top of boat, 0.5 above
23c23
< 1  0      1 -2 3 -4 20 -6
---
```

```
> 1  1 -0.5      1 -2 3 -4 20 -6
197a198
>
```

**diff c9007fm2.1 c9007fm7.1**

```
1,2c1,2
< glovebox ha21i muffle furnace model - base metal fire - c9007fm2
< c    base case metal 4.7 kg pu total, flooded to top of boat
---
```

```
> glovebox ha21i muffle furnace model - base metal fire - c9007fm7
> c    base case metal 4.7 kg pu total, flooded to top of boat, 0.3 above
23c23
< 1  0      1 -2 3 -4 20 -6
---
```

```
> 1  1 -0.3      1 -2 3 -4 20 -6
197a198
>
```

**diff c9007fm2.1 c9007fm8.1**

```
1,2c1,2
< glovebox ha21i muffle furnace model - base metal fire - c9007fm2
< c    base case metal 4.7 kg pu total, flooded to top of boat
---
```

```
> glovebox ha21i muffle furnace model - base metal fire - c9007fm8
> c    base case metal 4.7 kg pu total, flooded to top of boat, 0.2 above
23c23
< 1  0      1 -2 3 -4 20 -6
---
```

```
> 1  1 -0.2      1 -2 3 -4 20 -6
197a198
>
```

**diff c9007fm2.1 c9007fm1.1**

```
1,2c1,2
< glovebox ha21i muffle furnace model - base metal fire - c9007fm2
< c    base case metal 4.7 kg pu total, flooded to top of boat
---
```

```
> glovebox ha21i muffle furnace model - base metal fire - c9007fm1
> c    base case metal 4.7 kg pu total all flooded
23c23
< 1  0      1 -2 3 -4 20 -6
---
```

```
> 1  1 -1      1 -2 3 -4 20 -6
112c112
< 20  pz  1.12
---
```

```
> 20  pz  2.54
```

**diff c9007bm1.1 c9007sm1.1**

```
1,2c1,2
< glovebox ha21i muffle furnace model - base metal - c9007bm1
< c    base case metal 4.7 kg pu total
---
```

```
> glovebox ha21i muffle furnace model - spacing metal - c9007sm1
> c    base case metal 4.7 kg pu, conveyor boat on other boats
17c17
< c    ha28 conveyor - 1 boat 10 inch spacing from boats in glovebox
```

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```

---
> c    ha28 conveyor - 1 boat no spacing from boats in glovebox
28,29c28
<          (-211:9:-224:214:213)
<          (-307:308:-309:310:-311:312)
---
>          (-211:9:-224:214:(213 -228):(213 227):302)
79a79
> 203    3  -2.214  (201 -301 -225 226 204 -205)          imp:n=1
82,83c82,83
< 205    1  -1.0    (201:-223:206:-204:205)
<          224 211 -214 -213 -9 7          imp:n=1
---
> 205    1  -1.0    ((201 -226):(201 225):301:-223:206:-204:205)
>          224 211 -214 (-213:228) (-213:-227) -302 -9 7  imp:n=1
88,91d87
< c    1 boat with 10" spacing from others
< 301    3  -2.214  301 -302 303 -304 305 -306          imp:n=1
< 302    1  -1.0    (-301:302:-303:304:-305:306)
<          307 -308 309 -310 311 -312          imp:n=1
158a155,158
> 225    py    54.60
> 226    py    41.90
> 227    py    57.14
> 228    py    39.36
160,171c160,161
< 301    px    327.66
< 302    px    355.60
< 303    pz    26.52
< 304    pz    32.72
< 305    py    48.25
< 306    py    60.95
< 307    px    325.12
< 308    px    358.14
< 309    pz    23.98
< 310    pz    35.26
< 311    py    45.71
< 312    py    63.49
---
> 301    pz    7.32
> 302    pz    9.86
197a188
>

```

**diff c9007bml.i c9007sm2b.i**

```

< glovebox ha21i muffle furnace model - base metal - c9007bml
< c    base case metal 4.7 kg pu total
---
> glovebox ha21i muffle furnace model - spacing metal - c9007sm2b
> c    base case metal 4.65 kg pu, conveyor boat on other boats
8c8
< c          2.35 kg pu/boat
---
> c          2.325 kg pu/boat
17c17
< c    ha28 conveyor - 1 boat 10 inch spacing from boats in glovebox
---
> c    ha28 conveyor - 1 boat no spacing from boats in glovebox
19c19
< c          h/x = 20
---
> c          h/x = 0
28,29c28
<          (-211:9:-224:214:213)
<          (-307:308:-309:310:-311:312)
---
>          (-211:9:-224:214:(213 -228):(213 227):302)
79a79
> 203    0          (201 -301 -225 226 204 -205) (503:-502:-501:506)  imp:n=1
82,83c82,84
< 205    1  -1.0    (201:-223:206:-204:205)
<          224 211 -214 -213 -9 7          imp:n=1
---

```

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```

> 205 1 -1.0 ((201 -226):(201 225):301:-223:206:-204:205)
> 224 211 -214 (-213:228) (-213:-227) -302 -9 7 imp:n=1
> c metal pieces
84a86
> 502 4 -19.48 501 502 -503 -205 201 -506 imp:n=1
88,91d89
< c 1 boat with 10" spacing from others
< 301 3 -2.214 301 -302 303 -304 305 -306 imp:n=1
< 302 1 -1.0 (-301:302:-303:304:-305:306)
< 307 -308 309 -310 311 -312 imp:n=1
158a157,160
> 225 py 54.60
> 226 py 41.90
> 227 py 57.14
> 228 py 39.36
160,171c162,163
< 301 px 327.66
< 302 px 355.60
< 303 pz 26.52
< 304 pz 32.72
< 305 py 48.25
< 306 py 60.95
< 307 px 325.12
< 308 px 358.14
< 309 pz 23.98
< 310 pz 35.26
< 311 py 45.71
< 312 py 63.49
---
> 301 pz 7.32
> 302 pz 9.86
178,180c170,175
< 501 py 45.131
< 502 px 349.36
< 503 py 51.369
---
> 501 py 45.148
> 502 px 349.395
> 503 py 51.353
> 504 py 46.59
> 505 py 49.91
> 506 pz 4.453
192c187
< ksrc 352 48 -2
---
> ksrc 352 48 0
197a193
>
diff c9007sm2b.i c9007sm2d.i

1c1
< glovebox ha211 muffle furnace model - spacing metal - c9007sm2b
---
> glovebox ha211 muffle furnace model - spacing metal - c9007sm2d
85,86c85,89
< 501 4 -19.48 501 502 -503 -205 7 -201 imp:n=1
< 502 4 -19.48 501 502 -503 -205 201 -506 imp:n=1
---
> 501 4 -19.48 501 502 -504 -205 7 -201 imp:n=1
> 502 4 -19.48 505 502 -503 -205 7 -201 imp:n=1
> 503 4 -19.48 501 502 -503 -205 507 -506 imp:n=1
> 504 0 504 502 -505 -205 7 -201 imp:n=1
> 505 0 501 502 -503 -205 201 -507 imp:n=1
170c173
< 501 py 45.148
---
> 501 py 44.830
172,175c175,179
< 503 py 51.353
< 504 py 46.59
< 505 py 49.91
< 506 pz 4.453
---
> 503 py 51.670

```

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```
> 504 py 47.9325
> 505 py 48.5675
> 506 pz 4.4375
> 507 pz 1.4375
187,188c191,193
< ksrc 352 48 0
<      352 54 30
---
> ksrc 352 46 -2
>      352 50 -2
>      352 50 3
```

**diff c9007sm2d.i c9007sm2e.i**

```
lcl
< glovebox ha21i muffle furnace model - spacing metal - c9007sm2d
---
> glovebox ha21i muffle furnace model - spacing metal - c9007sm2e
97c97
< 4 px 441.96
---
> 4 px 358.141
109c109
< 16 px 472.44
---
> 16 px 388.621
```

**APPENDIX D**  
**PRELIMINARY HAZARDS ANALYSIS**

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## **1.0 HA-21I Glovebox Criticality Preliminary Hazards Analysis**

### **1.1 PURPOSE**

The purpose of this Preliminary Hazard Analysis (PHA) is to identify the important process parameters and conditions that could impact the potential for the occurrence of a criticality in the PFP HA-21I Glovebox. The results of this PHA will be used for input into the HA-21I Criticality Safety Evaluation Report (CSER).

### **1.2 HAZARDS EVALUATION**

A PHA is a technique derived from the U.S. Military Standard System Safety Program Requirements (MIL-STD-882). A PHA focuses on the hazardous materials and major process areas of a facility. Because of its military heritage, the PHA technique is useful for reviewing process areas where energy can be released in an uncontrolled manner. In general, the PHA formulates a list of hazards and hazardous situations by considering the following process characteristics:

- Raw materials, intermediate and final products, and their reactivity
- Plant equipment
- Facility layout
- Operating environment
- Operational activities (testing, maintenance, etc.)
- Interfaces among system components.

The American Institute of Chemical Engineers (AIChE) recognizes the PHA process as a creditable method of hazard evaluation. AIChE describes this process in their publication titled "Guidelines for Hazard Evaluation Procedures" (AIChE 1992) A multi-disciplinary team records the results of the PHA process using a tabular format.

The depth of a PHA is directly related to the experience and knowledge of the participants. A short resume of each team member is included (Section 3.0) to document the experience and knowledge of the PHA team.

### **1.3 PHA EVALUATION STRUCTURE**

Criticality events are prevented by establishing limits for specific parameters. These parameters are referred to as controlled parameters. This PHA was structured to address the following controlled parameters:

- Mass
- Volume

- Geometry
- Moderation
- Reflection
- Interaction
- Enrichment
- Density
- Concentration
- Poisons

#### 1.4 PHA TABLE DESCRIPTION

The PHA table (Appendix B, Table B-1) was structured to ensure a systematic and thorough evaluation of the controlled parameters. The PHA table captured the following information:

**ID:** Item Identification; used to record a unique identifier for the hazardous condition

**Hazardous Condition:** Hardware failures, operational faults, or conditions that have the potential for causing a criticality in the HA-21I glovebox

**Controlled Parameter:** Parameters that are controlled to prevent the occurrence of criticality events. Ten parameters are used: **mass, volume, moderation, interaction, reflection, geometry, enrichment, density, concentration, and poisons.**

**General Cause:** The general cause leading to the hazardous condition. In many cases, multiple hardware or operational faults are required to produce the hazardous condition. This column, in conjunction with the following column, identifies the sequence of hardware or operational faults postulated to produce the hazardous condition.

**Detailed Causes:** Specific causes within the general group of causes identified in the preceding column that can lead to the hazardous condition. This column is used to capture important details that may be important in the analysis that will define the controls to prevent a criticality.

**Existing Eng Safety:** Hardware items identified by the PHA team that have the potential to mitigate or prevent the hazardous condition of concern

**Existing Admin Safety:** Administrative controls such as facility worker training and safety procedures identified by the PHA team that have the potential to mitigate or prevent the hazardous condition

**Freq Cat NC: Frequency Category, No controls** – The frequency ranking is a qualitative estimate of whether the hazardous condition is considered credible or not. Conditions considered not credible will not be evaluated further.

**Remarks:** Miscellaneous observations or clarifying comments for a given item. This column is also used to capture criticality analysis requirement decisions of the PHA team.

## 1.5 PHA RESULTS

The results of this PHA are in the form of information to be considered as part of the Criticality Safety Evaluation Report (CSER). The raw data is presented in Table A1.

The following data was derived from the PHA:

### Fissile Material Considerations

- Planned material to be thermally stabilized are metals, alloys, pure metal, product quality oxide (>85% Pu), high-grade oxide (50%-85% Pu), “junk” low grade oxide (30%-50% Pu), defective buttons, pieces of buttons, and filtrate from the magnesium hydroxide process if  $H/X \leq 20$
- Activities not planned for thermal stabilization in HA-21I are processing of button ash, reactive ash, or sludge
- Materials:
  - MOX (Mixed Oxide)
  - Plutonium-Uranium ( $\leq 50\%$  U235; not credible to have higher enriched uranium in Glovebox HA-21I)
  - Metal
  - Alloys
- PFP has Mixed Oxide material (MOX) which consists of U/Pu - up to 50%  $^{235}\text{U}$  enriched. Accidental introduction of this material into HA-21I needs to be considered.
- Precipitate of the magnesium hydroxide process will be addressed in calculations as H/X unlimited (<450 g/L) which is beyond the scope of this CSER
- Liquid present in  $\text{Mg}(\text{OH})_2$  filtrate (potentially “soupy” consistency)
- For calculational purposes assume density of fissile material to be ~2.7 g/cc to 11g/cc  $\text{PuO}_2$ . Density of material to be confirmed by PFP.

**Material Handling Considerations**

- Assume the normal operation situation is glovebox has three loaded furnace boats staged in HA-21I, with three furnaces loaded and operating (one boat each)
- Furnace boats are handled/moved ( $\leq 2500$  gm loading) **ONE AT A TIME**
- For metal material calculations assume 2 boats in boat dock, 1 boat being sieved, 1 boat containing metal, three boats cooling after thermal stabilization complete
- Assume that sieving and sampling will be performed in glovebox HA-21I
- Assume pieces of a button or a defective button may be processed in glovebox HA-21I
- Assume the presence of furnace boats, sweep cans (containers) – 0.5 L, sieve/pan assembly. Do not assume both loaded furnace boat and loaded sieve pan assembly present and adjacent. If sieve pan assembly used, contents of furnace boat transferred to sieve pan assembly, then transferred back to furnace boat.
- Assume furnace boats are not staged on conveyors
- 3 operators are required to be involved in the process of loading a furnace boat, one operator in Room 230-A and two in Room 235-B.
- Potential fissile material that can move past HA-21I: Cement billets, waste packages, sludges, lard can wagons
- Assume maintenance activities will occur in glovebox HA-21I in CSER analysis e.g. plastic introduced in glovebox

**Facility Configuration Considerations**

- Mezzanine hangs over HA-21I. A tank is on mezzanine just above the HA-21I glovebox and has the potential to impact the glovebox.
- HA 28 conveyor higher than floor of HA-21I
- Criticality drain will be installed in HA-21I
- Sump will be removed from HA-21I
- Flooding of room containing glovebox HA-21I not considered credible – doors will not hold water in room

- Glovebox HA-21I is not seismically qualified.
- Fire system piping is not seismically qualified.
- Tank on mezzanine is not seismically qualified. It was not determined whether it can be filled and whether it is isolated.
- Hardware will be installed to prevent wagons from going under HA-21I
- Glovebox HA-21I shell - 42 in. Wide x 39 in. height x 156 in. length
- Furnaces are assumed to stay shut during DBE
- Furnace off-gas vacuum system up on mezzanine: vacuum pump pulls maximum of 6 in. Hg
- A furnace boat racking structure (boat dock) for staging furnace boats should be considered as part of the glovebox equipment.

## **2.0 PHA TEAM MEMBER BIOGRAPHIES**

Janice R Billingsley, B&W Hanford Company, PFP Operations – Ms. Billingsley has nine years of experience as a Nuclear Chemical Operator at the Plutonium Finishing Plant. She is certified in Thermal Stabilization Operations and the Cementation process. She also, has four years of experience in Solid Waste Operations and currently holds certifications for that group.

Ken Dobbin - Fluor Federal Services, Inc, Criticality Safety Engineer - Mr. Dobbin has 25 years experience as a nuclear engineer, 20 of these years analyzing reactor physics and fuel management and 5 years in criticality safety. He is qualified as a Criticality Safety Engineer at the Plutonium Finishing Plant and has 20 months experience with PFP systems. During his PFP tenure, he contributed criticality safety expertise for the successful completion of an Operational Readiness Review to resume thermal stabilization of plutonium. Mr. Dobbin has both undergraduate and masters degrees in nuclear engineering.

Joe Estrellado, Jr, Fluor Federal Services, Inc – Scribe for PHA. Mr. Joe Estrellado has over 30 years of combined engineering and management experience in the nuclear and chemical industries. He has successfully completed assignments in the safety analysis and process engineering arenas and has taken a number of HazOp-related training courses at the University of Texas, Austin. Mr. Estrellado has a bachelor degree in Chemical Engineering from the University of Washington.

Alan Ramble - B&W Hanford Company, PFP Facility Engineering - Mr. Ramble is currently the Criticality Safety Representative, the cognizant engineer for the Safety Analysis Report, and project manager for the Solution Stabilization Project at the Plutonium Finishing Plant. As Criticality Safety Representative, Mr. Ramble has responsibility for implementation of the criticality safety program at PFP, including approval of Criticality Safety Evaluation Reports, Criticality Prevention Specifications, operating procedures, initial training and annual retraining of fissile material handlers, and inspection for compliance with criticality safety requirements of PFP.

H. Rees Risenmay – Fluor Daniel Hanford Inc., Engineer, PFP Thermal Stabilization Team, Solids Stabilization Cognizant Engineer – Mr. Risenmay has 16 years experience at the Hanford site. His experience has been in the Chemical Engineering Laboratory, the PUREX plant, the UO<sub>3</sub> plant, and the PFP plant. His experience is mostly in process engineering with detailed knowledge of the processes and safety aspects for each plant. Mr. Risenmay has a Bachelor of Science Degree in Chemistry from Brigham Young University and a Bachelor of Science Degree in Engineering with chemical engineering emphasis from the University of Washington.

Milton V. Shultz, Jr. – Fluor Federal Services Inc., Safety Analysis and Risk Assessment. B.S. Nuclear Engineering Technology. Facilitator for Glovebox HA-21I PHA. More than twenty-four years experience in a broad range of engineering and technical assignments at the Hanford Site. Experience includes leading PHAs and HAZOPs for a variety of TWRS projects, including several for the TWRS FSAR and BIO efforts, contributor to the hazards analysis work for the TWRS BIO. Has performed independent Nuclear Safety evaluations of reactor plant design and operation at Hanford's N Reactor.

Dwayne R. Speer, Project Manager, Materials Stabilization Project, Plutonium Finishing Plant B&W Hanford Company – Mr. Speer has over 20 years of experience and is currently Project Manager for Materials Stabilization at the Plutonium Finishing Plant. Prior to moving to PFP he was Manager of the B Plant/WESF Baseline Control group. He has been the Program Manager for the Liquid Effluents Interim Compliance and Miscellaneous Streams Programs, Manager of Decommissioning Engineering for Westinghouse Hanford, Activity Manager responsible for the Decontamination and Decommissioning Program and the Effluent and Environmental Surveillance Programs for Rockwell Hanford Operations. He has been a Senior Health Physicist for Rockwell, and worked for Eberline Instruments Company in Santa Fe, NM. Before joining Eberline, he worked for Battelle-Northwest, the State of North Carolina, the State of Nebraska, and Princeton University. He has a B.S. Engineering Technology, Oklahoma State University and an A.A. Radiation and Nuclear Technology, Oklahoma State University.

David W. Wootan, Fluor Federal Services, Inc, Criticality Safety Engineer, – Mr. Wootan has a B.S. Nuclear Engineering and M.S. Nuclear Engineering. He has twenty years experience at Hanford performing nuclear engineering analyses in the areas of reactor physics, shielding, and characterizing radiation environments, with 4 years experience in criticality safety.

**References**

AICHE, 1992, *Guidelines for Hazard Evaluation Procedures*, American Institute of Chemical Engineers, New York, New York.

MIL-STD-882B, 1977, *System Safety Program Requirements*, Department of Defense, Washington, DC

Table D1. PFP GLOVEBOX CRITICALITY PRELIMINARY HAZARDS ANALYSIS

Total Pages: 11

Date: November 4, 1999  
 Controlled Parameters: MASS, VOLUME, MODERATION, INTERACTION, REFLECTION, GEOMETRY, ENRICHMENT, DENSITY, CONCENTRATION, POISONS

Note: *Fuel* material is assumed to be present for all controlled parameters

ID	HAZARDOUS CONDITION	CONTROLLED PARAMETER	GENERAL CAUSE	DETAILED CAUSES	ENGINEERED SAFETY FEATURES	ADMINISTRATIVE SAFETY FEATURES	FRBQ CAT NC	REMARKS
HA21I-01	Criticality in HA-21I	Mass	More mass than limit/intended	Overloaded boat (human error)	Boat volume limits maximum mass	- Administrative limit on boat loading - Boat weighed during loading - Operator procedure - MBA custodian check	C	1. Human error 2. Measuring equipment error 3. Error in Pu/feed item value - Human error in reading - Labeling error (small errors only) - Larger errors are considered to be Not Credible (NC). Operational experience indicates NDA adequate to prevent large errors.
HA21I-02	Criticality in HA-21I	Mass	More mass than limit/intended	Too many boats (human error)	Glovebox volume	- Administrative limit on mass in glovebox - Administrative limit on volume of containers in glovebox	C	1. Human error potential cause 2. Boats cannot make themselves 3. Boats will not float
HA21I-03	Criticality in HA-21I	Mass	More mass than limit/intended	Box holdup as a result of stabilization operations (e.g. failure to clean up spills, buildup of fugitive material)	None identified	- NDA requirements for glovebox - Glovebox holdup tracking	C	1. NDA done on management request 2. Required to be accounted for in glovebox total mass requirements/limits 3. A factor to be considered in evaluation of other mass conditions

Table D1. PFP GLOVEBOX CRITICALITY PRELIMINARY HAZARDS ANALYSIS

Date: November 4, 1999

Total Pages: 11

Controlled Parameters: MASS, VOLUME, MODERATION, INTERACTION, REFLECTION, GEOMETRY, ENRICHMENT, DENSITY, CONCENTRATION, POISONS

Note: Fusible material is assumed to be present for all controlled parameters

ID	HAZARDOUS CONDITION	CONTROLLED PARAMETER	GENERAL CAUSE	DETAILED CAUSES	ENGINEERED SAFETY FEATURES	ADMINISTRATIVE SAFETY FEATURES	FREQ CAT NC	REMARKS
HA21I-04	Criticality in HA-21I	Mass	More mass than limit/intended	Sweeps container mass concerns: - too much mass in a container (human error) - too large a jar (human error)	Container size	- Only 1 container allowed in glovebox - Jar is required to be 0.5 l	C	1. Rule of plant: only 1 container in glovebox 2. Sweeps jar is 0.5 l 3. Concern only when combined with other mass
HA21I-05	Criticality in HA-21I	Mass	More mass than limit/intended	Sieve pan assembly - too much mass (human error)	None identified	- Mass limits for sieve pan - Procedures for loading sieve pan - Placard travels with sieve as in 18M - Operator turnover sheets	C	1. Human error 2. Sieve pan has large volume (3.3L) 3. Don't have to start w/4.4 kg for upset condition. Procedure allows only 1 container dumped at a time into sieve 4. Sieve pan mass can interact w/other glovebox mass
HA21I-06	Criticality in HA-21I	Volume & Geometry (combined) of fissile material	Exceed safe limits	Wrong container (other than currently allowed due to human error)	Use of approved containers Basis built to approved specifications	- Administrative requirements on volume and mass - Administrative requirements on number of containers - Administrative requirements on permitted containers	C	

Table D1. PFP GLOVEBOX CRITICALITY PRELIMINARY HAZARDS ANALYSIS

Total Pages: 11

Date: November 4, 1999

Controlled Parameters: MASS, VOLUME, MODERATION, INTERACTION, REFLECTION, GEOMETRY, ENRICHMENT, DENSITY, CONCENTRATION, POISONS

Note: Fissile material is assumed to be present for all controlled parameters

ID	HAZARDOUS CONDITION	CONTROLLED PARAMETER	GENERAL CAUSE	DETAILED CAUSES	ENGINEERED SAFETY FEATURES	ADMINISTRATIVE SAFETY FEATURES	FREQ CAT NC	REMARKS
HA211-07	Criticality in HA-211	Volume & Geometry (combined) of fissile material	Exceed safe limits	Stacking of containers containing fissile material (human error)	None identified	- Administrative requirements for container stacking	C	Stacking is not currently allowed
HA211-08	Criticality in HA-211	Volume & Geometry (combined) of fissile material	Exceed safe limits	Sieve screen placed on glovebox floor forming a container (upside down sieve lid) coupled with conditions that deposit fissile material in sieve screen	None identified	- Administrative control regarding sieve placement	C	1. Requirement to set sieve on side to prevent becoming a container *Calculation assumption: Remember button plus full pan with powder and concern for interacting with other masses  Note: - Liners may be present in boat to process various materials at different temperatures. Liners may affect neutron interactions - Without liner, processing metal in furnace could cut hole in boat bottom.

Table D1. PFP GLOVEBOX CRITICALITY PRELIMINARY HAZARDS ANALYSIS

Total Pages: 11

Date: November 4, 1999

Controlled Parameters: MASS, VOLUME, MODERATION, INTERACTION, REFLECTION, GEOMETRY, ENRICHMENT, DENSITY, CONCENTRATION, POISONS

Note: Fissile material is assumed to be present for all controlled parameters

ID	HAZARDOUS CONDITION	CONTROLLED PARAMETER	GENERAL CAUSE	DETAILED CAUSES	ENGINEERED SAFETY FEATURES	ADMINISTRATIVE SAFETY FEATURES	FREQ CAT NC	REMARKS
HA21I-09	Criticality in HA-2II	Moderation	Water presence in glovebox	Glovebox water source and conditions resulting in water distribution in glovebox	- Stored volume of water in various gloveboxes not sufficient to flow to HA-2II - Criticality drain in magnesium hydroxide gloveboxes - Criticality drain in HA-2II - Conveyors elevation combined with limited volume prevent water movement to HA-2II	Administrative Control	C	Introduction from other gloveboxes due to conveyor connection.  Sources: external water - HA20-MB glovebox 5 gallons - 227-S glovebox 3 tanks - Mg(OH) wash precipitation tanks (3); Jay Lan evaluated - 230-C small NaOH tank
HA21I-10	Criticality in HA-2II	Moderation	Water presence	Roof leaks	NA	NA	N/C	The glovebox of concern is several floors below the roof. Leaks from roof not considered credible source of moderator
HA21I-11	Criticality in HA-2II	Moderation	Water presence	Firewater from system actuation or failure	Fire suppression is dry chemical inside gloveboxes	None identified	C	Only firewater scenarios to get large quantities of water into glovebox: Fire Seismic Explosion

Table D1. PFP GLOVEBOX CRITICALITY PRELIMINARY HAZARDS ANALYSIS

Date: November 4, 1999

Total Pages: 11

Controlled Parameters: MASS, VOLUME, MODERATION, INTERACTION, REFLECTION, GEOMETRY, ENRICHMENT, DENSITY, CONCENTRATION, POISONS

Note: Fissile material is assumed to be present for all controlled parameters

ID	HAZARDOUS CONDITION	CONTROLLED PARAMETER	GENERAL CAUSE	DETAILED CAUSES	ENGINEERED SAFETY FEATURES	ADMINISTRATIVE SAFETY FEATURES	FREQ CAT NC	REMARKS
HA21I-12	Criticality in HA-2II	Moderation	Plastic (presence)	Waste packaging present in glovebox during thermal stabilization (human error)	None identified	Plastic not allowed in glovebox during furnace operation  Administrative control for plastic mixing with Pu  Container not allowed near furnace	C	- Waste not allowed in glovebox during furnace operation  - Depends on how Pu is distributed in plastic waste packaging
HA21I-13	Criticality in HA-2II	Moderation	Presence of oil	Maintenance activities introduce too much oil (human error)	None identified	Administrative control of oil quantity	C	Oils would be present if furnace components needed to be lubricated
HA21I-14	Criticality in HA-2II	Interaction	Material Movement	Material on conveyor moves past fully loaded HA-2II (consider spacing and quantity)	None identified	Administrative requirements for spacing	C	1. This is an allowed condition as far as being able to transfer material past this glovebox at any time.  2. Only place of concern is boat on platform with material being moved past - HA-2II  3. Project will consider - A Boat Rack in glovebox design which should be included in crit calculations

**Table D1. PFP GLOVEBOX CRITICALITY PRELIMINARY HAZARDS ANALYSIS**

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**Date: November 4, 1999**

**Controlled Parameters: MASS, VOLUME, MODERATION, INTERACTION, REFLECTION, GEOMETRY, ENRICHMENT, DENSITY, CONCENTRATION, POISONS**

**Note: Fissile material is assumed to be present for all controlled parameters**

ID	HAZARDOUS CONDITION	CONTROLLED PARAMETER	GENERAL CAUSE	DETAILED CAUSES	ENGINEERED SAFETY FEATURES	ADMINISTRATIVE SAFETY FEATURES	FREQ CAT NC	REMARKS
HA21I-15	Criticality in HA-21I	Interaction	Material Movement	Fissile material passes beside or under glovebox exterior	Feature to prevent movement under glovebox (e.g. bars, screens)	Administrative control of fissile material near glovebox Control limits posted	C	1. Assume glovebox is loaded 2. Facility plans installation of preventer (Guard rail to be installed) 3. Distance limits assume material being moved conforms to applicable criticality specifications
HA21I-16	Criticality in HA-21I	Interaction	Material Movement	Boat to boat and boat to other items: Interaction of material to glovebox (human error)	None identified	Administrative control  Operator training  Criticality training	C	1. Stacking 2. Side spacing 3. Container on top of boat 4. Spill of 1 boat over another 5. Spills without clean out
HA21I-17	Criticality in HA-21I	Reflection	Presence of people (high H2O content)	People standing next to or under glovebox	None identified	TBD	C	1. Analyst to run full reflection case
HA21I-18	Criticality in HA-21I	Reflection	Presence of people (high H2O content)	Limbs inside glovebox	None identified	TBD	C	1. Analyst to run container reflection case (fully reflected)

Table D1. PFP GLOVEBOX CRITICALITY PRELIMINARY HAZARDS ANALYSIS

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Controlled Parameters: MASS, VOLUME, MODERATION, INTERACTION, REFLECTION, GEOMETRY, ENRICHMENT, DENSITY, CONCENTRATION, POISONS

Note: Flammable material is assumed to be present for all controlled parameters

ID	HAZARDOUS CONDITION	CONTROLLED PARAMETER	GENERAL CAUSE	DETAILED CAUSES	ENGINEERED SAFETY FEATURES	ADMINISTRATIVE SAFETY FEATURES	FREQ CAT NC	REMARKS
HA211-19	Criticality in HA-211	Reflection	Other reflectors present	Other materials present	None identified	TBD	C	1. Lead 2. Silicon Carbide 3. Plastic  Note: Room full of water not credible.  Calculations will consider the presence of various reflectors.
HA211-20	Criticality in HA-211	Enrichment	Higher due to unidentified causes	NA	NA	NA	NA	Enrichment is determined by the material available in the PFP facility. Calculations will be based on currently available enrichment levels.
HA211-21	Criticality in HA-211	Density	Material distribution	Addressed under external phenomena considerations	NA	NA	NA	1. Need to establish feed materials density 2. External phenomena are fire, flood, explosion 3. For metal, use full density including alloy
HA211-22	Criticality in HA-211	Concentration	Greater than expected	Unexpected metal in oxide powder Presence of liquids	None identified	TBD (determined by calculations)	C	Contingencies to consider: 1. H/X unlimited 2. H/X ≤ 20 3. Metal

**Table D1. PFP GLOVEBOX CRITICALITY PRELIMINARY HAZARDS ANALYSIS**

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**Controlled Parameters: MASS, VOLUME, MODERATION, INTERACTION, REFLECTION, GEOMETRY, ENRICHMENT, DENSITY, CONCENTRATION, POISONS**

**Note: Fissile material is assumed to be present for all controlled parameters**

ID	HAZARDOUS CONDITION	CONTROLLED PARAMETER	GENERAL CAUSE	DETAILED CAUSES	ENGINEERED SAFETY FEATURES	ADMINISTRATIVE SAFETY FEATURES	FREQ CAT NC	REMARKS
HA21F-23	Criticality in HA-211	Poison	NA	NA	NA	NA	NA	1. Calculations will assume no poisons presence for conservatism

Table D1. PFP GLOVEBOX CRITICALITY PRELIMINARY HAZARDS ANALYSIS

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Controlled Parameters: MASS, VOLUME, MODERATION, INTERACTION, REFLECTION, GEOMETRY, ENRICHMENT, DENSITY, CONCENTRATION, POISONS

Note: Fissile material is assumed to be present for all controlled parameters

ID	HAZARDOUS CONDITION	CONTROLLED PARAMETER	GENERAL CAUSE	DETAILED CAUSES	ENGINEERED SAFETY FEATURES	ADMINISTRATIVE SAFETY FEATURES	FREQ CAT NC	REMARKS
HA21I-24	Criticality in HA-21I	Various (the events being considered impact multiple controlled parameters)	External event	Seismic	None identified	TBD based on criticality evaluation	C	<ol style="list-style-type: none"> <li>1. Geometry changes interaction, change in reflection</li> <li>2. Glovebox not qualified</li> <li>3. Building mezzanine is seismically qualified</li> <li>4. Tanks on mezzanine not qualified</li> <li>5. Fire piping not qualified</li> <li>6. Assume 3 boats out of furnaces to cool for 1 hour without cover</li> <li>7. Assume that material in furnace not released during seismic event (doors remain shut)</li> <li>8. Postulated seismic event has low potential to cause vacuum system to draw material into HEPA filter (requires water introduced to glovebox) Vacuum system only pulls 6 in. Hg - Height from glovebox to vacuum system greater than lift capability of vacuum system, therefore, not considered credible and will be excluded from analysis</li> </ol>

Table D1. PFP GLOVEBOX CRITICALITY PRELIMINARY HAZARDS ANALYSIS

Total Pages: 11

Date: November 4, 1999

Controlled Parameters: MASS, VOLUME, MODERATION, INTERACTION, REFLECTION, GEOMETRY, ENRICHMENT, DENSITY, CONCENTRATION, POISONS

Note: Fissile material is assumed to be present for all controlled parameters

ID	HAZARDOUS CONDITION	CONTROLLED PARAMETER	GENERAL CAUSE	DETAILED CAUSES	ENGINEERED SAFETY FEATURES	ADMINISTRATIVE SAFETY FEATURES	FREQ CAT NC	REMARKS
HA21I-25	Criticality in HA-2II	Various (the events being considered impact multiple controlled parameters)	External event	Fire	Fire suppression system	TBD based on criticality evaluation	C	1. Glovebox gloves/windows fail 2. Fire system puts water in glovebox 3. Containers filled with water 4. Criticality drain works 5. Interstitial moderation to be considered. 6. Fire is considered Category C; no material movement to be assumed based on fire suppression system action
HA21I-26	Criticality in HA-2II	Various (the events being considered impact multiple controlled parameters)	External event	Explosion in glovebox	None identified	TBD based on criticality evaluation	C	Sec analysis in HC-21C CSER
HA21I-27	Criticality in HA-2II	Various (the events being considered impact multiple controlled parameters)	External event	Tornado & Aircraft crash	NA	NA	N/C	Not credible because glovebox is interior room (3 walls separation)

Table D1. PFP GLOVEBOX CRITICALITY PRELIMINARY HAZARDS ANALYSIS

Total Pages: 11

Date: November 4, 1999

Controlled Parameters: MASS, VOLUME, MODERATION, INTERACTION, REFLECTION, GEOMETRY, ENRICHMENT, DENSITY, CONCENTRATION, POISONS

Note: Fissile material is assumed to be present for all controlled parameters

ID	HAZARDOUS CONDITION	CONTROLLED PARAMETER	GENERAL CAUSE	DETAILED CAUSES	ENGINEERED SAFETY FEATURES	ADMINISTRATIVE SAFETY FEATURES	FREQ CAT NC	REMARKS
HA21I-28	Criticality in HA-21I	Various (the events being considered impact multiple controlled parameters)	External event	Pressurized gas bottles	NA	NA	N/C	Not allowed in area
HA21I-29	Criticality in HA-21I	Various (the events being considered impact multiple controlled parameters)	External event	Small tank falls on glovebox	None identified	None identified	C	Covered by seismic evaluation

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**APPENDIX E**  
**MCNP MODEL FIGURES**

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Figure E-1. Normal Oxide Case Horizontal Cross Section Through Boats and Sweeps Container.

```
11/24/99 11:08:06
glovebox ha211 muffle furnace
metal - normal oxide - c1907mol

prebid = 11/24/99 11:05:03
basis:
( 1.000000, 0.000000, 0.000000)
( 0.000000, 1.000000, 0.000000)
origin:
( 220.00, 54.00, 0.50)
extent = ( 295.00, 235.00)
```

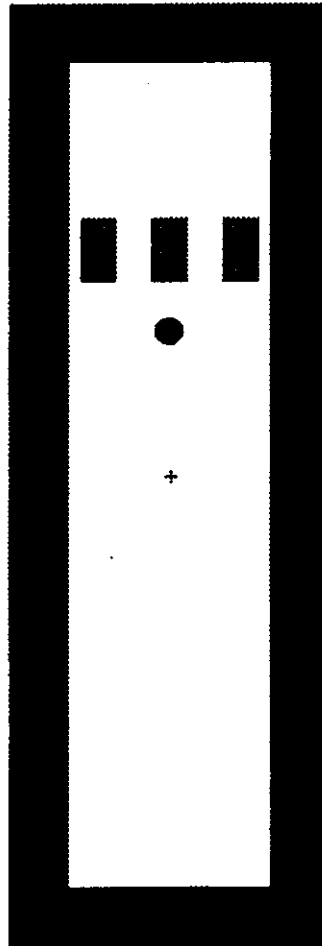


Figure E-2. Normal Oxide Case Vertical Cross Section Through Boats, Sweep Container, and Furnaces

```
11/24/99 11:18:14  
glowbox h211 muffle furnace  
model - normal oxide - 09007mel  
  
probid = 11/24/99 11:16:35  
basis:  
( 1.000000, 0.000000, 0.000000)  
( 0.000000, 0.000000, 1.000000)  
origin:  
( 220.00, 54.00, 40.00)  
extent = ( 255.00, 255.00)
```

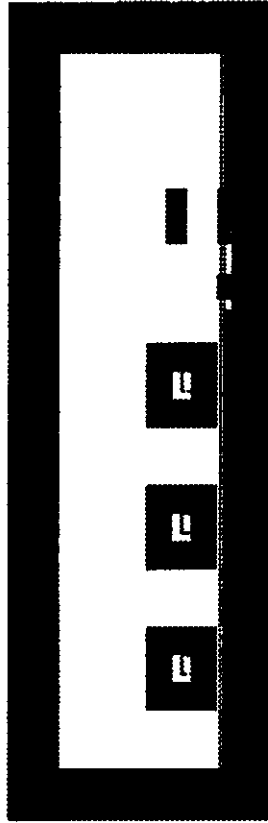


Figure E-3. Normal Oxide Case Horizontal Cross Section Showing Muffle Furnaces and Boat.

```
11/24/99 11:24:34  
glovebox ha211 muffle furnace  
modal ~ normal oxide ~ c9007mol  
  
prebid = 11/24/99 11:22:19  
basis:  
{ 1.000000, 0.000000, 0.000000}  
{ 0.000000, 1.000000, 0.000000}  
origin:  
{ 220.00, 54.00, 27.00}  
extent = { 255.00, 255.00}
```

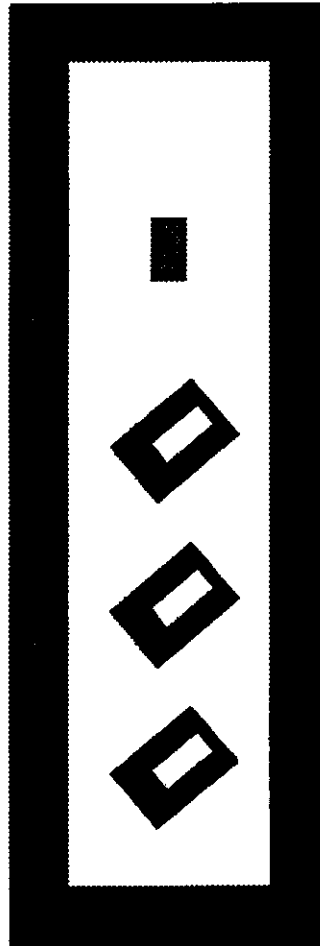
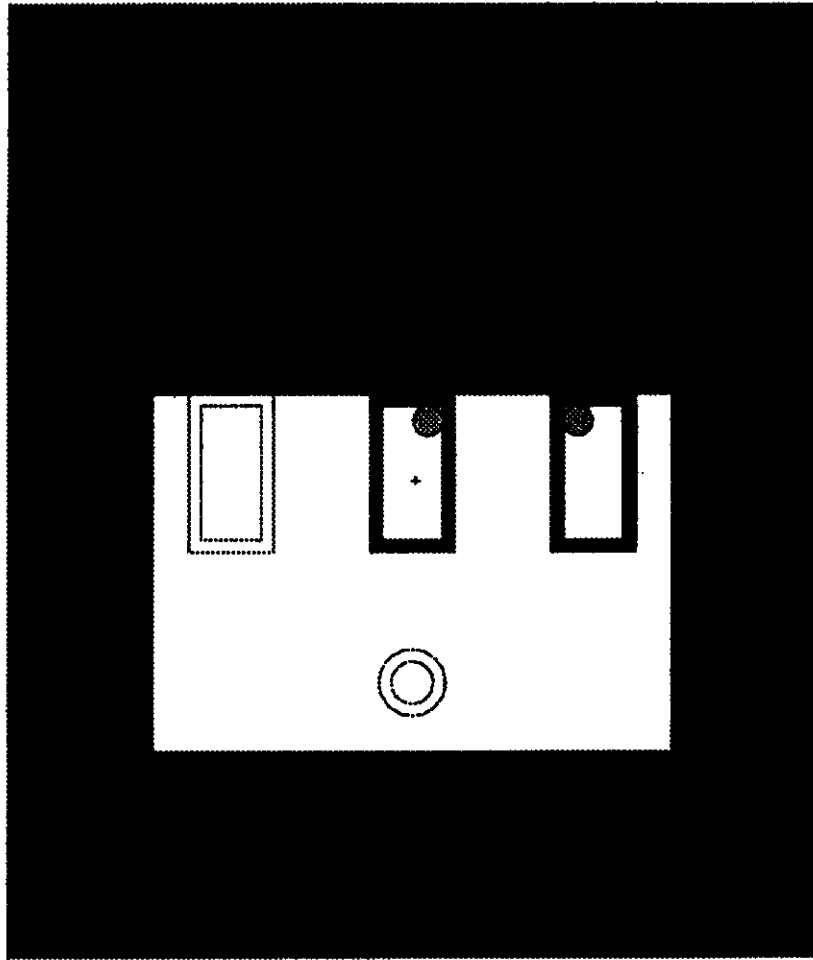


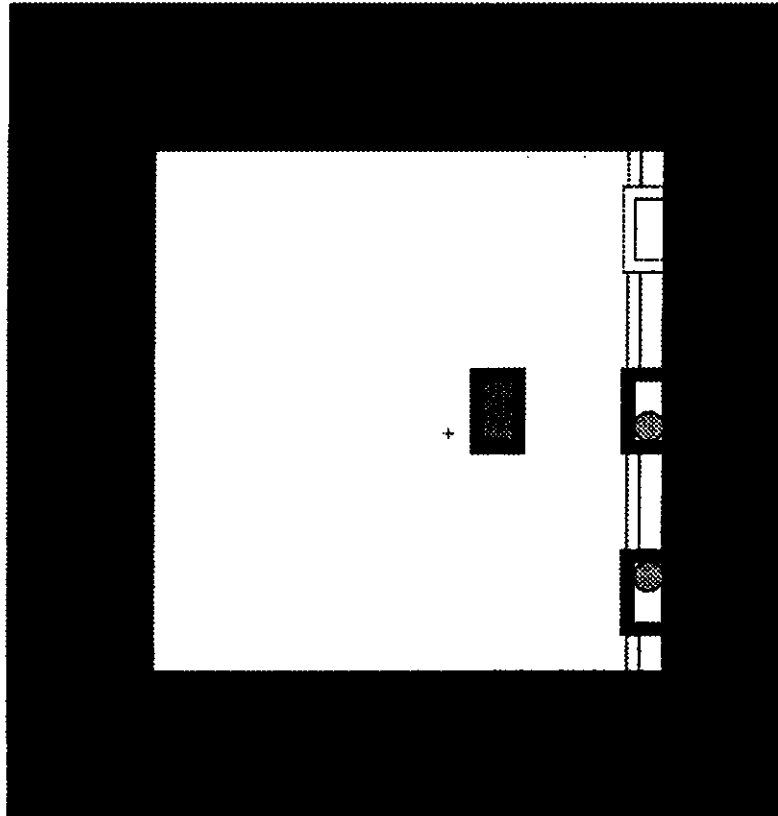
Figure E-4. Normal Metal Case Horizontal Cross Section Showing Metal Sphere in Boats.



```
11/24/99 11:53:39
glovebox ba21i missile furnace
model - normal metal - c1907mm1

prebid = 11/24/99 11:50:46
basis:
( 1.000000, 0.000000, 0.000000, 0.000000)
( 0.000000, 1.000000, 0.000000, 0.000000)
origin:
( -340.00, 54.00, -2.00)
entent = ( 100.00, 100.00)
```

Figure E-5. Normal Metal Case Vertical Cross Section.



```
11/24/99 12:02:10
glovebox ba21i wuffle furnace
model - normal metal - c9007mm1

probid = 11/24/99 12:01:00
basis:
( 0.000000, 1.000000, 0.000000)
( 0.000000, 0.000000, 1.000000)
origin:
( 352.50, 49.50, 40.00)
extent = ( 100.00, 100.00)
```

Figure E-6. Normal Metal Case Vertical Cross Section.

```
11/24/99 12:20:06  
glovebox ha21a muffle furnace  
model - normal metal - c9007mal  
  
prebid = 11/24/99 12:17:34  
basis:  
( 1.000000, 0.000000, 0.000000)  
( 0.000000, 0.000000, 1.000000)  
origin:  
( 352.50, 49.90, 50.00)  
extent = ( 80.00, 80.00)
```

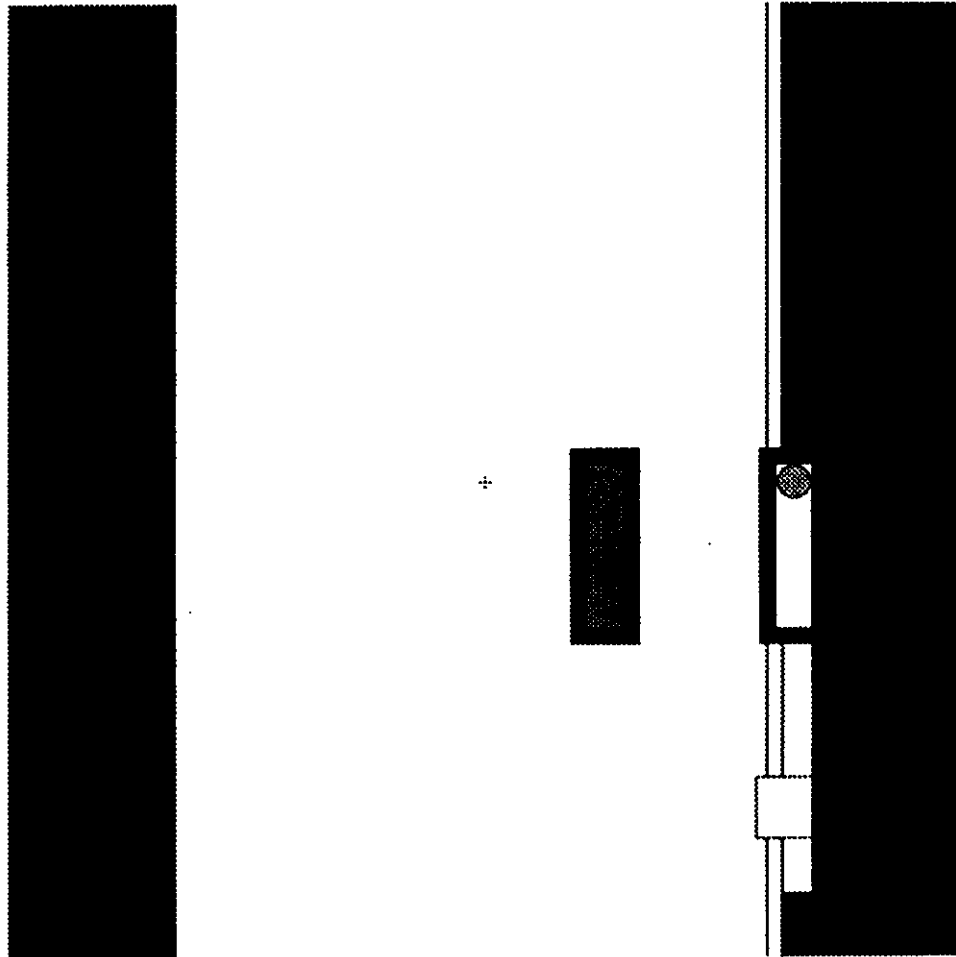
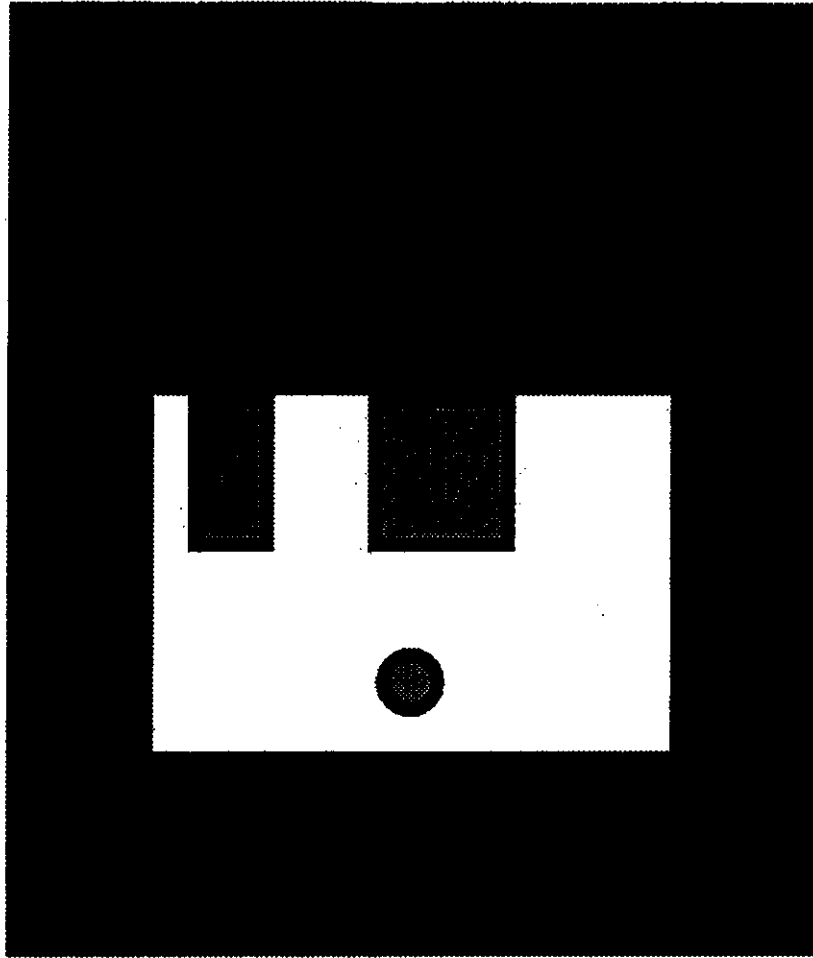


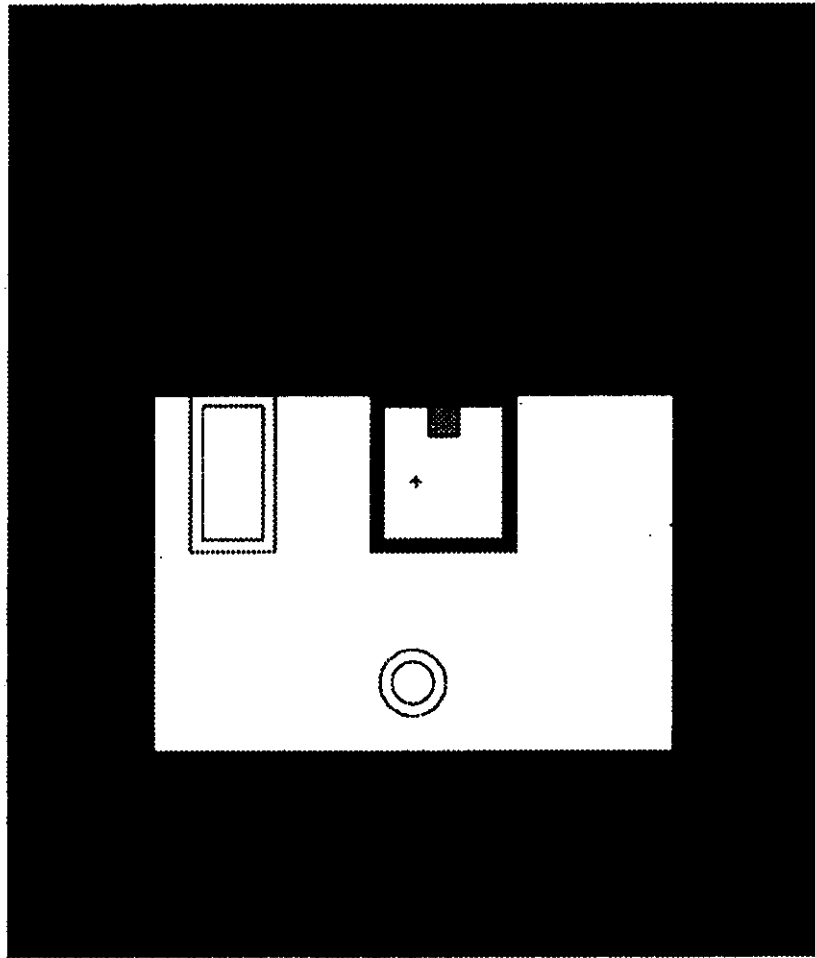
Figure E-7. Base Oxide Case Horizontal Cross Section.



```
11/24/99 12:24:50
glovebox ba2li muffle furnace
model - base oxide - c1907b01

probid = 11/24/99 12:23:56
basis:
( 1.000000, 0.000000, 0.000000, 0.000000)
( 0.000000, 1.000000, 0.000000, 0.000000)
origin:
( 340.00, 54.00, -2.00)
extent = ( 100.00, 100.00)
```

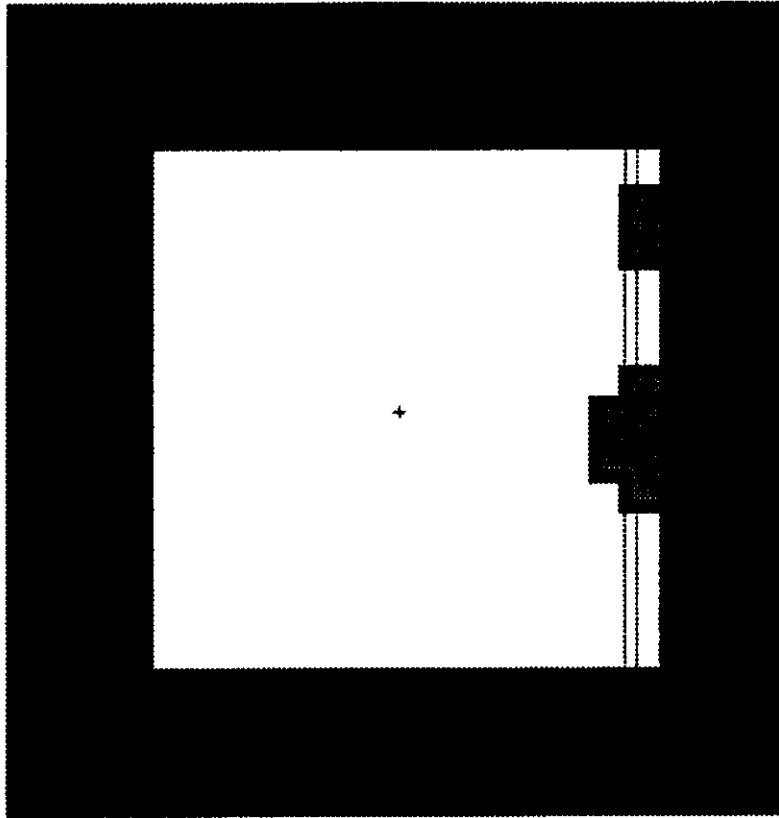
Figure E-8. Base Metal Case Horizontal Cross Section Showing Two Adjacent Boats.



```
11/24/99 12:28:50
glovebox hazli missile furnace
model - base metal - c9007ba1

probid = 11/24/99 12:27:57
basis:
( 2.000000, 0.000000, 0.000000, 0.000000)
( 0.000000, 1.000000, 0.000000, 0.000000)
origin:
( 340.00, 54.00, -2.00)
extent = ( 100.00, 100.00)
```

Figure E-9. Oxide Stacking Contingency Case Vertical Cross Section.



```
11/24/99 12:35:14
glovebox hazli shuffle furnace
model -- base oxide - c9007sol

probid = 11/24/99 12:34:20
basis:
( 0.000000, 1.000000, 0.000000)
( 0.000000, 0.000000, 1.000000)
origin:
( 340.00, 54.00, 50.00)
extent = ( 100.00, 100.00)
```

Figure E-10. Metal Stacking Contingency Case With Oxide Boat Vertical Cross Section.

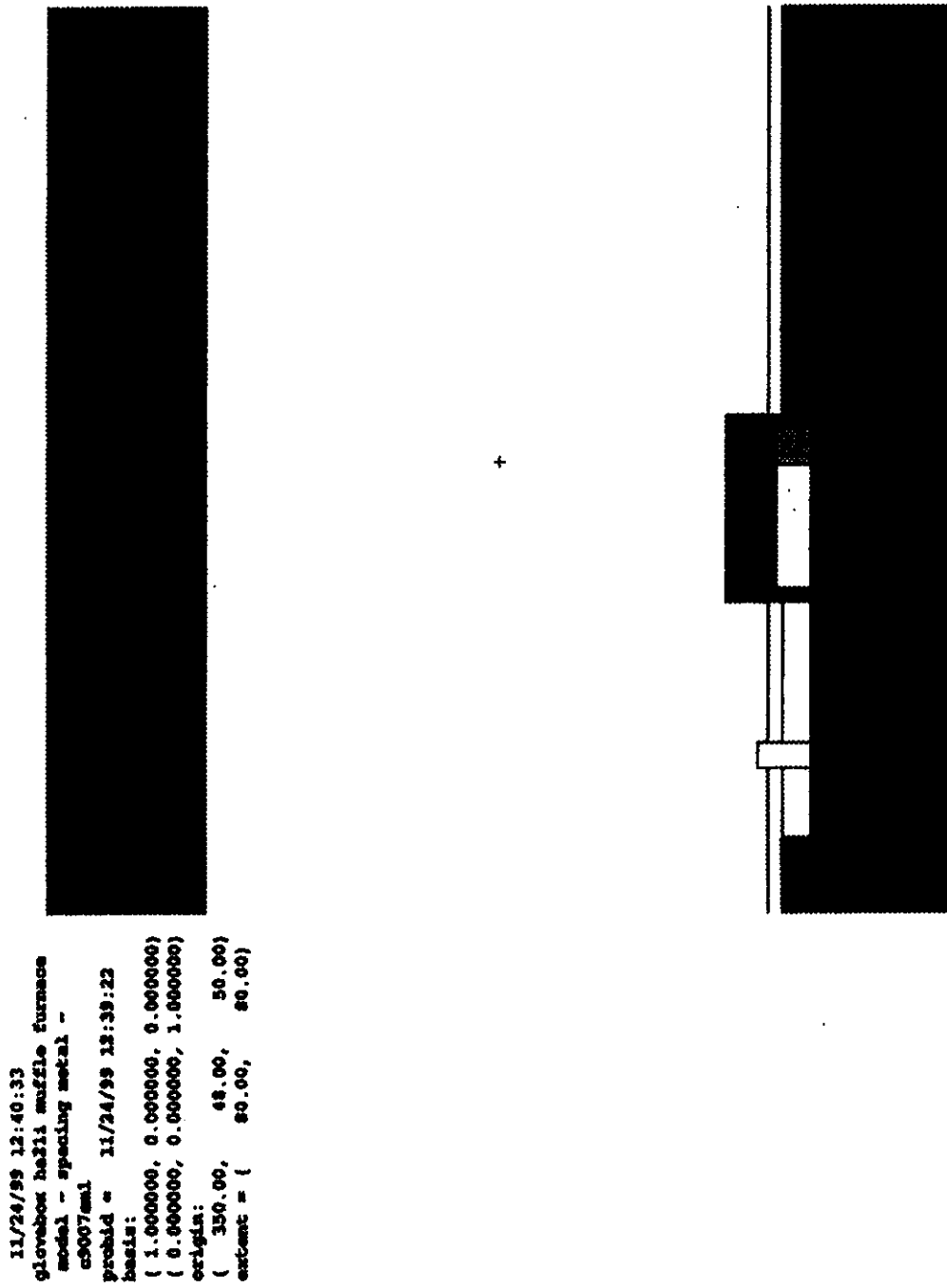


Figure E-11. Metal Stacking Contingency With Metal Boat Vertical View.

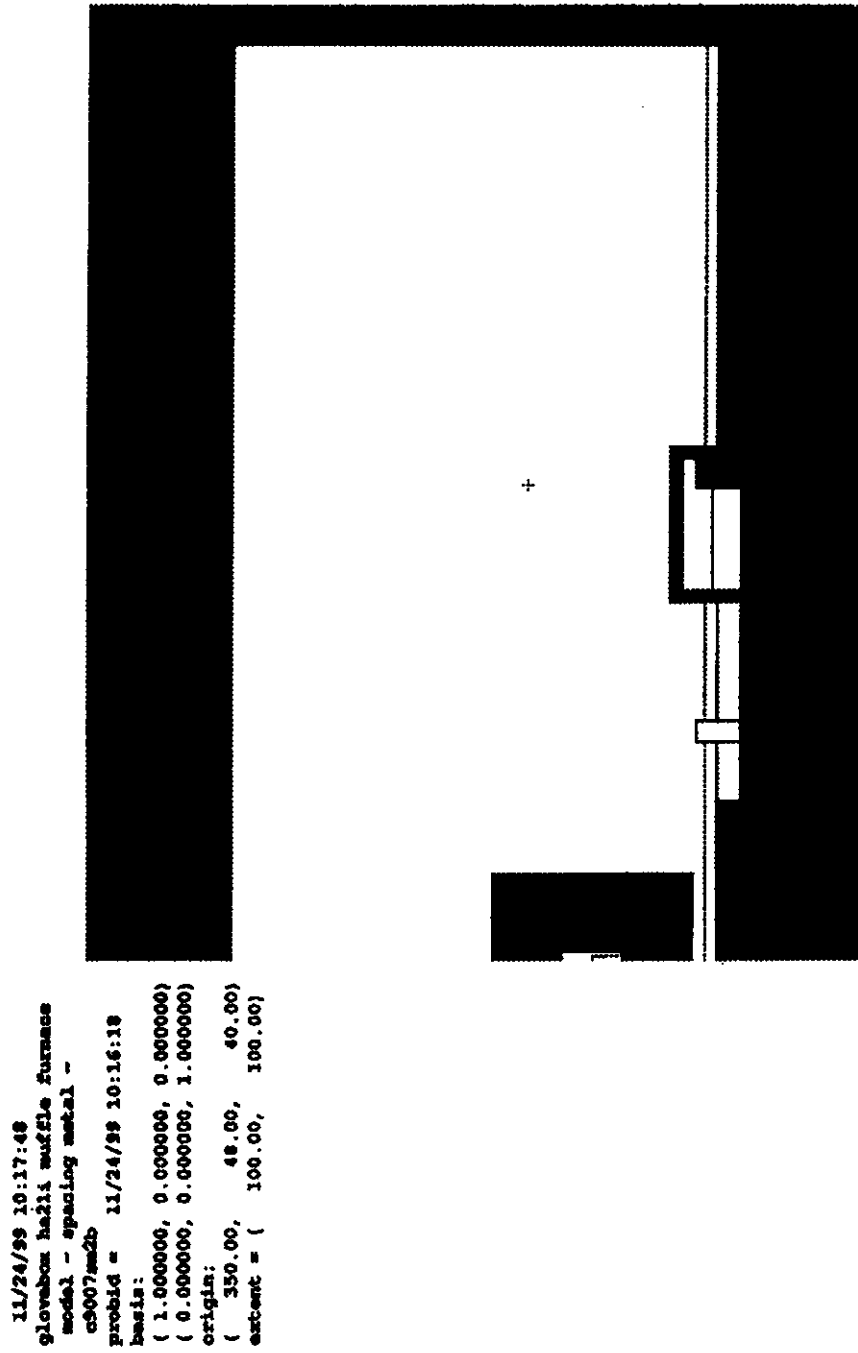
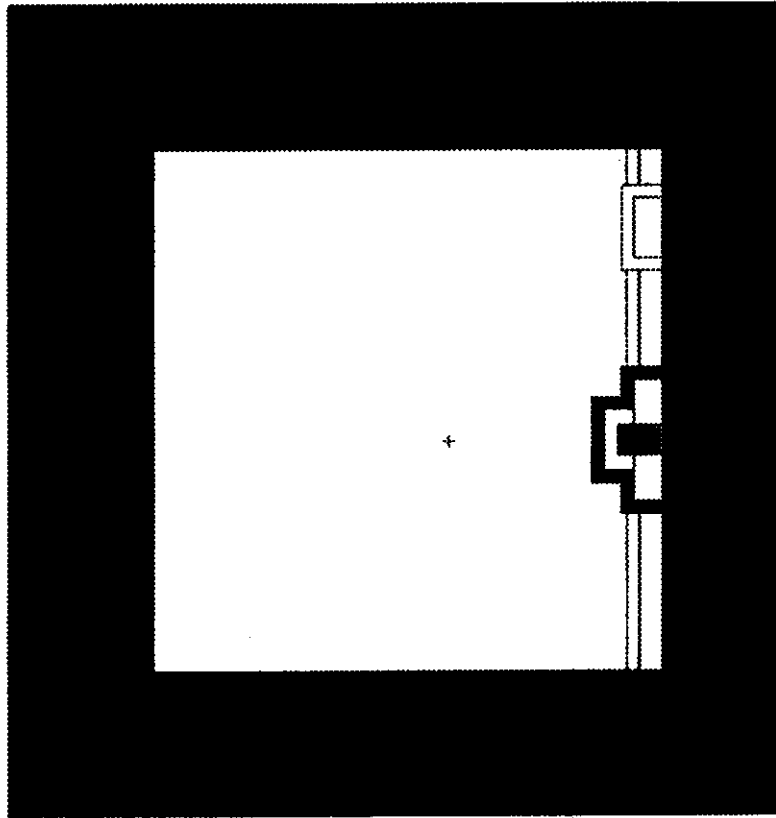


Figure E-12. Metal Stacking Contingency With Metal Boat Vertical Cross Section.



```
11/23/99 15:15:23  
glovebox ha211 snifle furnace  
model - spacing metal -  
n9007sm2  
probid = 11/23/99 15:14:24  
basis:  
{ 0.000000, 1.000000, 0.000000}  
{ 0.000000, 0.000000, 1.000000}  
origin:  
( 350.00, 48.00, 40.00)  
extent = ( 100.00, 100.00)
```

Figure E-13. Oxide Fire Contingency Vertical Cross Section.

```
11/24/99 12:49:25
glovebox ka211 muffla furnace
model - base oxide - c9007fc3

probid = 11/24/99 12:48:04
basis:
( 1.000000, 0.000000, 0.000000)
( 0.000000, 0.000000, 1.000000)
origin:
( 350.00, 54.00, 50.00)
extent = { 80.00, 80.00}
```

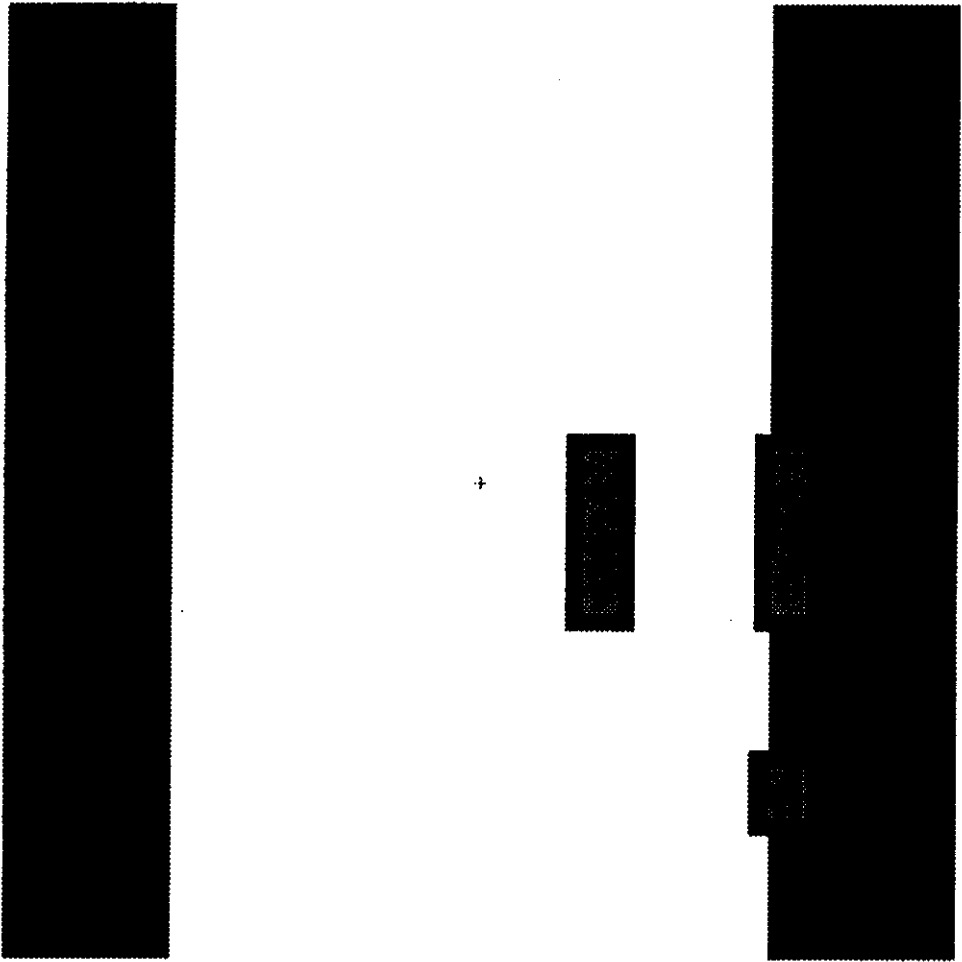


Figure E-14. Metal Fire Contingency Vertical Cross Section.

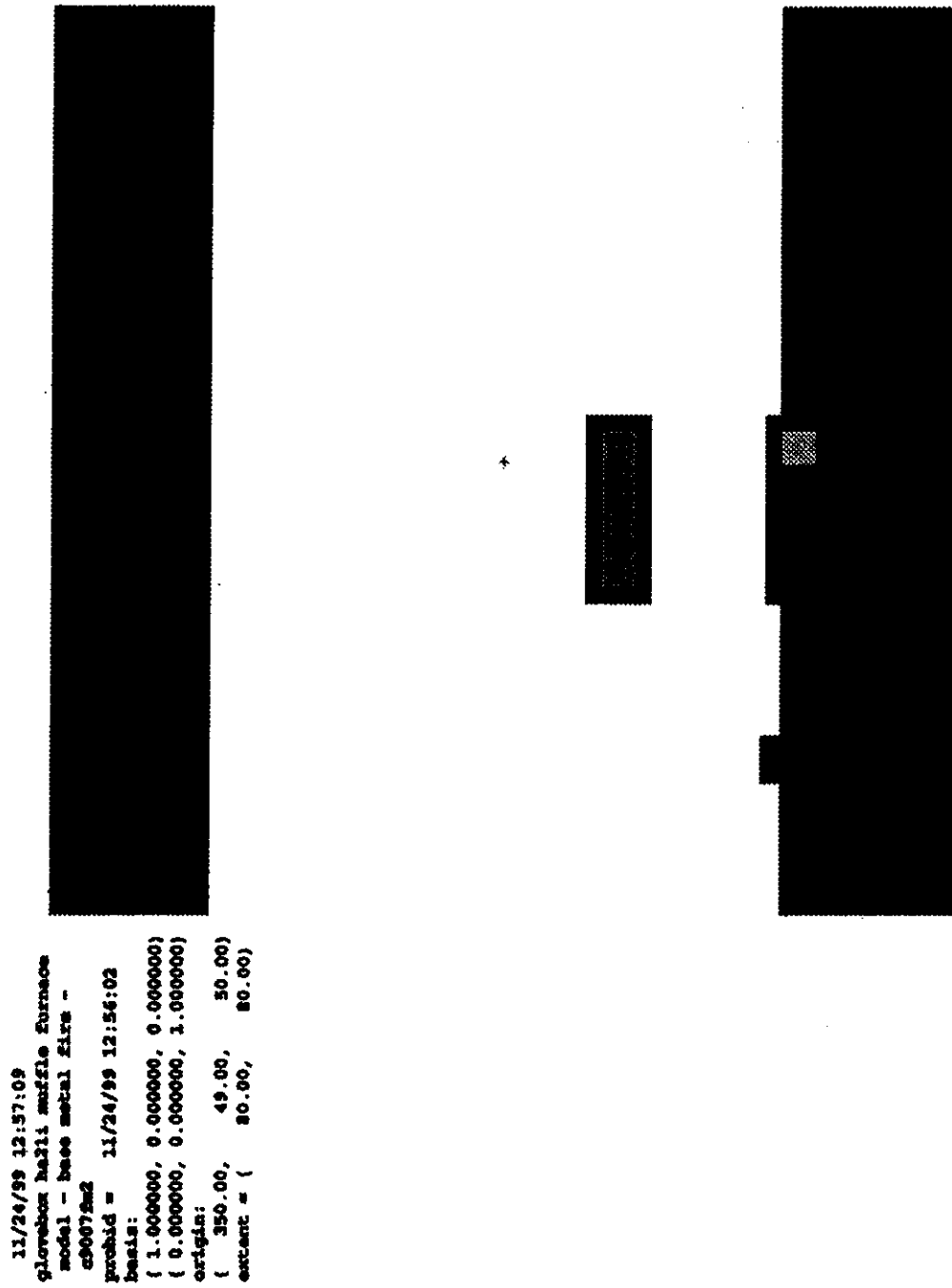
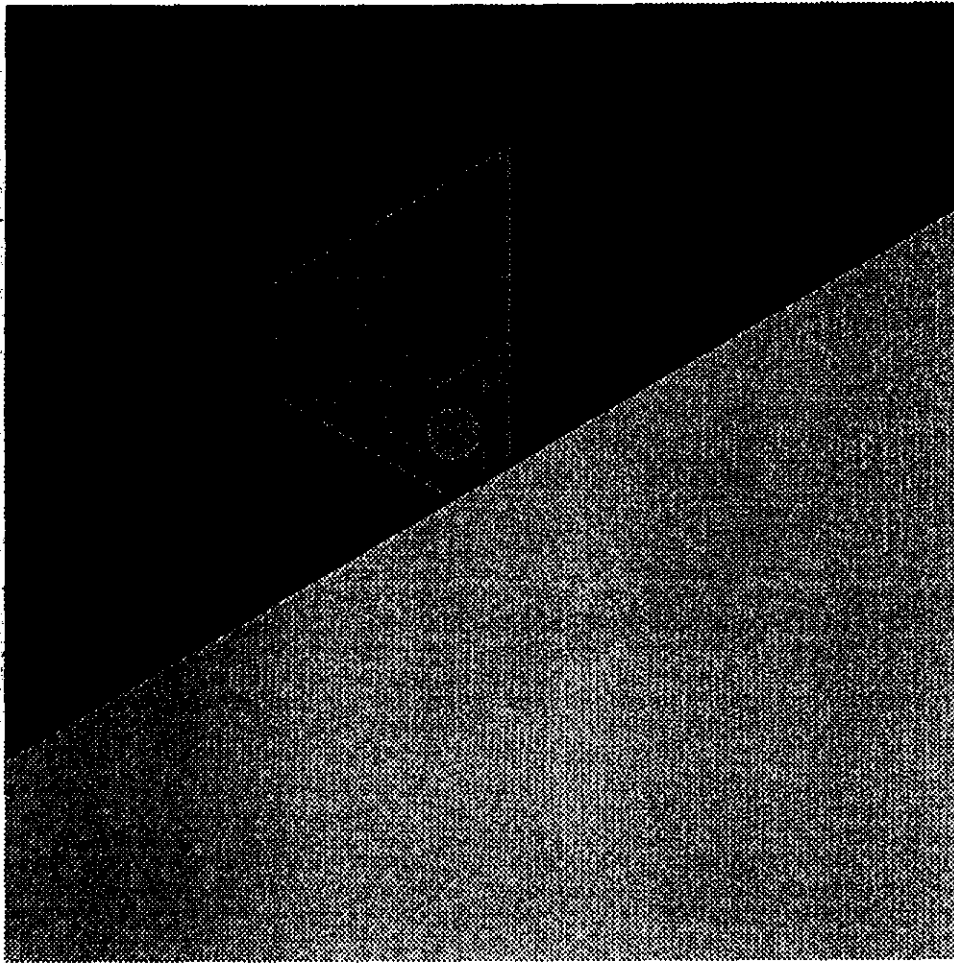
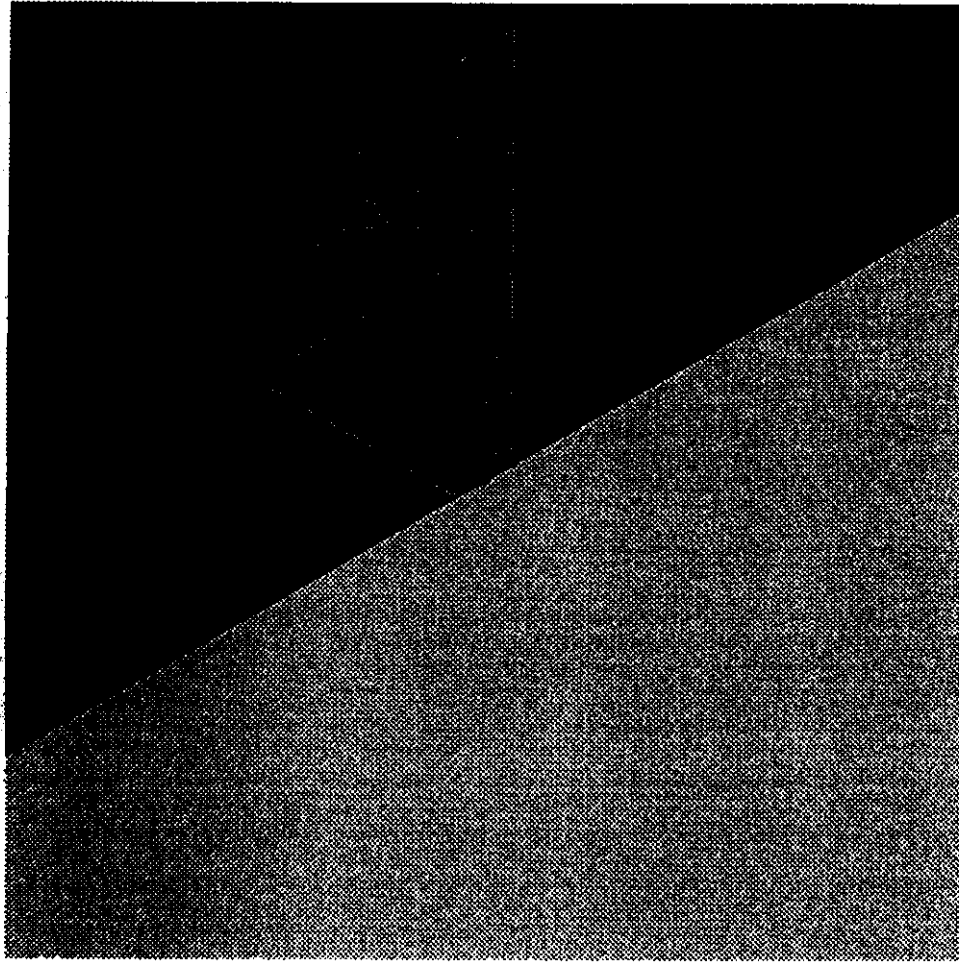


Figure E-15. Metal Seismic Case Cross Section Showing Glovebox Corner Pyramid Resting on Concrete Floor.



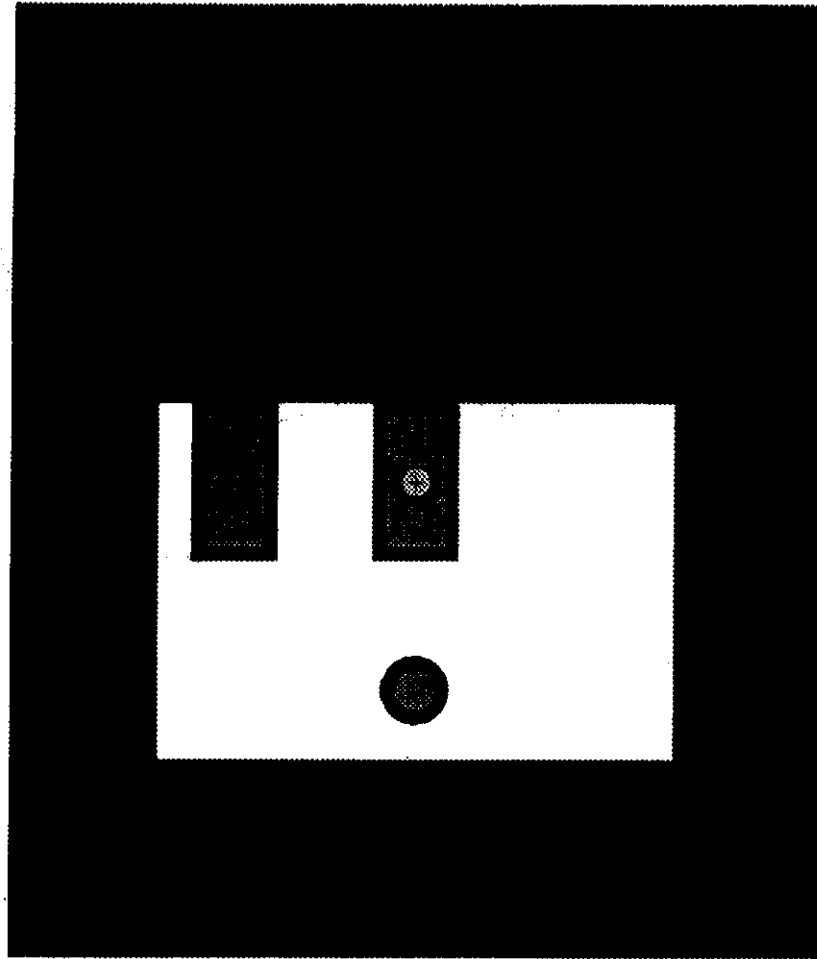
11/24/99 13:13:23  
seismic contingency for  
metal/Pw02 R/X = 20 in pyramid  
with 12" h2o on top  
probid = 11/24/99 13:13:11  
basis:  
( 0.707107, 0.707107, 0.000000)  
(-0.408260, 0.408260, 0.816485)  
origin:  
( 0.00, 0.00, 0.00)  
extent = ( 50.00, 50.00)

Figure E-16. Seismic Case Cross Section.



11/24/99 13:21:47  
seismic contingency for PuO2 H/X  
= 20 in 7.0 liter Pyramid with  
12" h2o on top  
probid = 11/24/99 13:20:30  
basis:  
( 0.707107, 0.707107, 0.000000)  
(-0.408248, 0.408248, 0.816497)  
origin:  
( 0.00, 0.00, 0.00)  
extent = ( 50.00, 50.00)

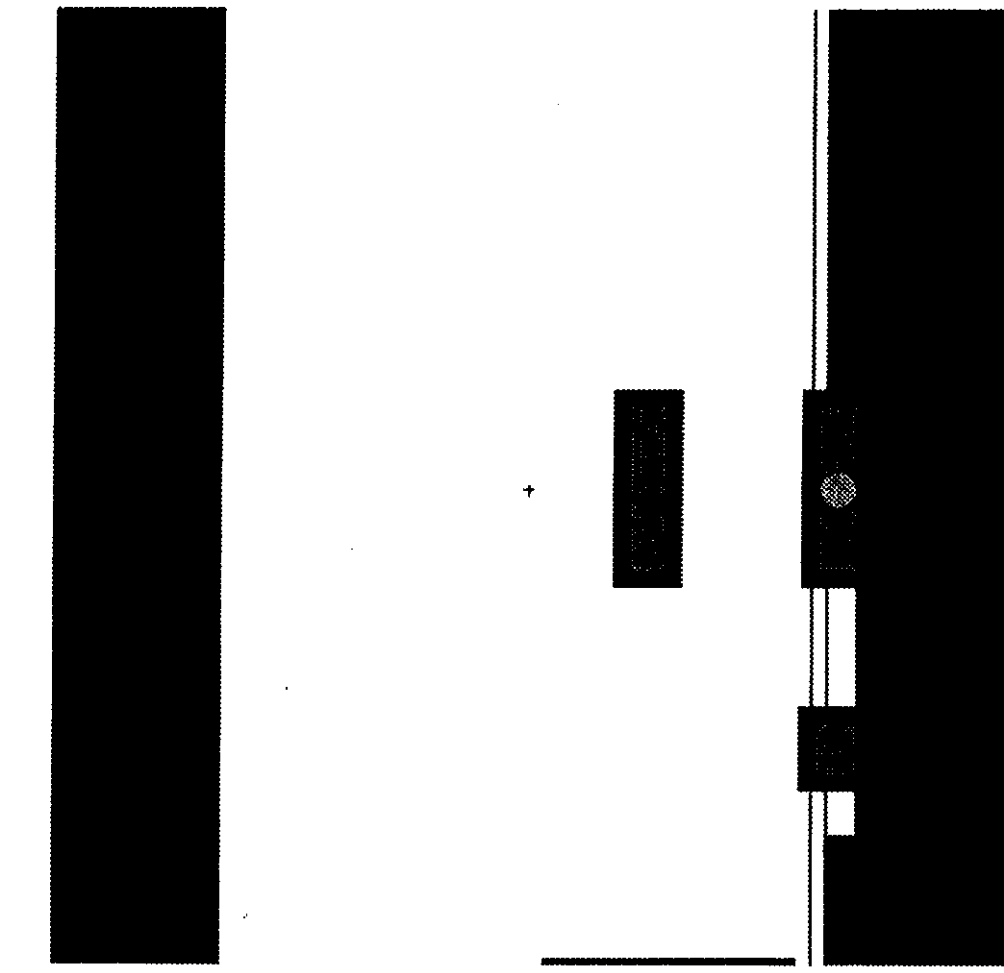
Figure E-17. Button in Boat Contingency Oxide Case Horizontal Cross Section.



```
11/24/99 13:02:13
glovebox bn211 waffle furnace
model - base oxide - c9007so2

prebid = 11/24/99 13:01:19
basis:
( 1.000000, 0.000000, 0.000000)
( 0.000000, 1.000000, 0.000000)
origin:
( 341.60, 54.60, -1.80)
extent = ( 100.00, 100.00)
```

Figure E-18. Button in Boat Contingency Oxide Case Vertical Cross Section.



```
11/24/99 13:06:42
glovebox hazli muffle furnace
mod1 - base oxide - c9007so2

probid = 11/24/99 13:05:32
base:
( 1.000000, 0.000000, 0.000000, 0.000000)
( 0.000000, 0.000000, 1.000000, 0.000000)
origin:
( 341.60, 54.60, 50.00)
extent = ( 80.00, 80.00)
```

Figure E-19. Metal Stacking Contingency with Metal Boat, Full Water Reflection One Side, and Boat Wall Spacing

```
12/02/99 15:29:13
glovebox h2li suffle furnace
model - spacing metal -
c9007m2e
probid = 12/02/99 15:27:46
basis:
( 1.000000, 0.000000, 0.000000, 0.000000)
( 0.000000, 0.000000, 1.000000, 0.000000)
origin:
( 330.00, 47.00, 0.00)
extent = ( 30.00, 30.00)
```

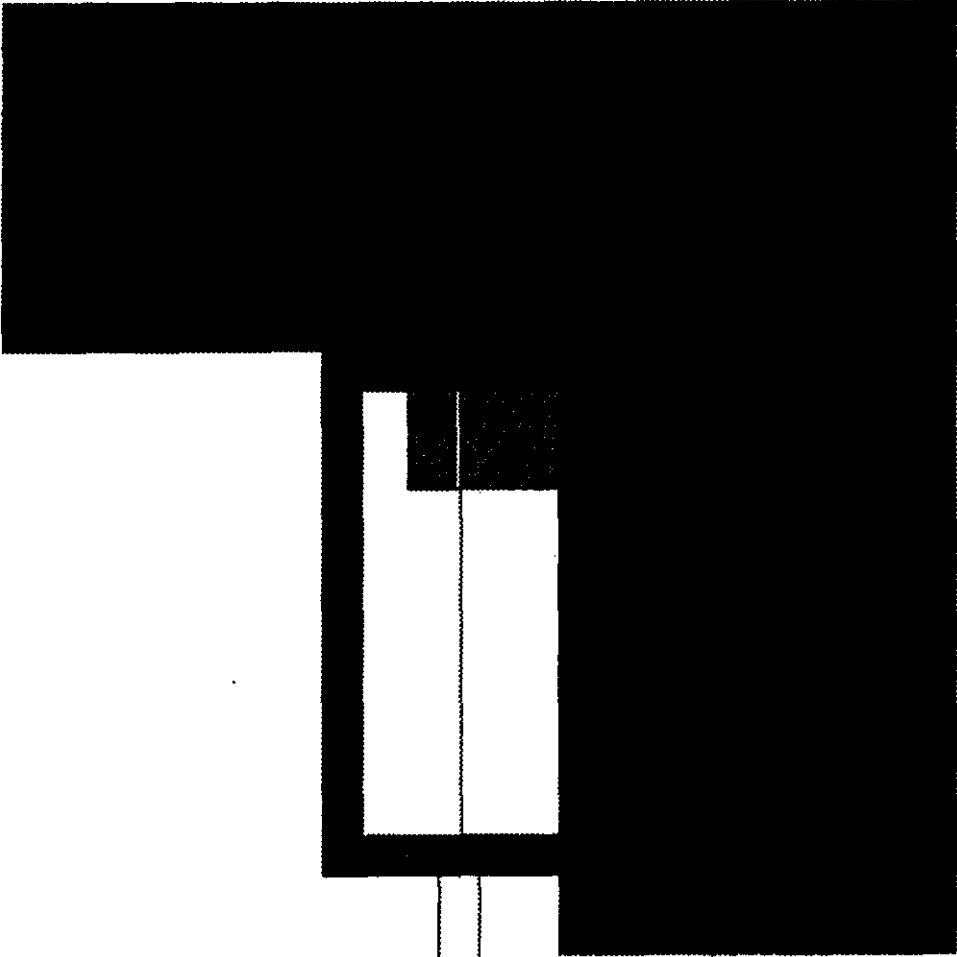
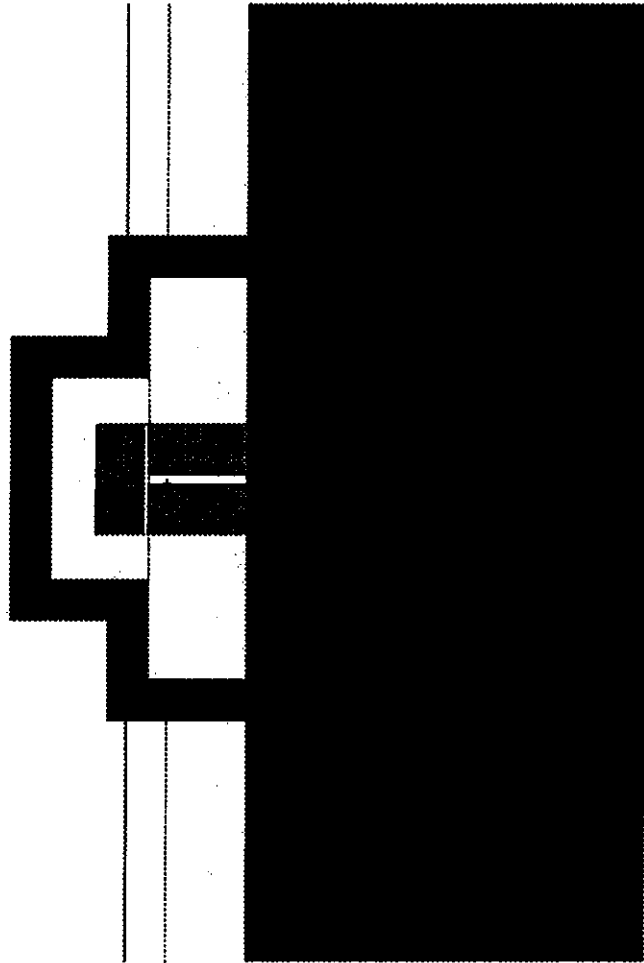


Figure E-20. Metal Stacking Contingency With Metal Boat, Full Reflection One Side, and Boat Wall Spacing

```
12/02/99 15:30:54
glevebox ha2li muffle furnace
model - spacing metal -
c7007sm2a
probid = 12/02/99 15:29:44
basis:
( 0.000000, 1.000000, 0.000000)
( 0.000000, 0.000000, 1.000000)
origin:
( 350.00, 48.00, 0.00)
extent = ( 30.00, 30.00)
```



**APPENDIX F**  
**WASTE PACKAGE DATA**

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**Dobbin, Kenneth D**

**From:** Ramble, Alan L  
**Sent:** Friday, November 19, 1999 3:09 PM  
**To:** Dobbin, Kenneth D  
**Cc:** Shaw, Maria E; Ramble, Alan L  
**Subject:** FW: G Pu in Waste Packages

Ken, some data. More to follow. AJ

-----Original Message-----

**From:** Baker, Eugene S (Scott)  
**Sent:** Wednesday, November 17, 1999 9:53 AM  
**To:** Baker, Eugene S (Scott); Fazzari, Dennis M; Westsik, George A  
**Cc:** Ramble, Alan L  
**Subject:** RE: G Pu in Waste Packages

AJ has asked for a little more information on what I have mentioned below in my earlier message.

There are two calibration curves that everything in ITC's are counted on.

- < 25 lbs., low density, both combustible and non-combustible (#1)
- dense items or ITC's > 25 lbs. (#2)

Looking at the data below, and classifying the 100 analyses (down from 102 due to some confusion in classification), the information can be grouped as follows:

<u>Pu Content</u>	<u># of items counted by #1</u>	<u># of items counted by #2</u>
0-2 grams	53	15
2-10 grams	15	9
10-20 grams	1	2
20-30 grams	0	1
30-40 grams	1	1
40+ grams	0	3
Average value	2.16	9.82
High value	35.43	68.53

Based on this information, if you make the assumption that all of the items that would be considered "waste packages" are less than 25 lbs. and do not contain any dense metal items, your CSER evaluation of a waste package containing 2 grams as the "normal and base case condition" would be valid. You would also be correct in pointing out the 30 gram item identified as a contingency. I would feel a little uncomfortable in stating that item to be the "only contingency identified ....in assay data history," however.

Scott

-----Original Message-----

**From:** Baker, Eugene S (Scott)  
**Sent:** Monday, November 15, 1999 1:22 PM  
**To:** Fazzari, Dennis M; Westsik, George A  
**Cc:** Ramble, Alan L  
**Subject:** RE: G Pu in Waste Packages

I agree with the comments Dennis makes. I have also looked at the ITC results from the NaI counter for 6/1/99 to the present, and can make the following observations:

<u>Pu content</u>	<u># of items</u>
0-2 grams	69
2-10 grams	24
10-20 grams	3
20-30 grams	1
30-40 grams	2
40+ grams	3
<b>Total</b>	<b>102</b>

Average gram Pu value, all items - 4.5 grams  
 Average gram value, 0 - 10 gram items (93 items) - 1.7 grams  
 Highest value for a single item - 68.53 grams

If you look only at items counted 9/1/99 to the present, the numbers change to:

Pu content	# of items
0-2 grams	21
2-10 grams	15
10-20 grams	1
20-30 grams	1
30-40 grams	2
40+ grams	1
<b>Total</b>	<b>41</b>

Average gram Pu value, all items - 6.0 grams  
 Average gram value, 0 - 10 gram items (36 items) - 2.4 grams  
 Highest value for a single item - 45.29 grams

Scott

-----Original Message-----

From: Fazzari, Dennis M  
 Sent: Monday, November 16, 1999 7:56 AM  
 To: Wozniak, George A  
 Cc: Rambis, Alan L; Baker, Eugene S (Scott)  
 Subject: RE: G Pu in Waste Packages

There is no way I can determine what items were waste, scrap, sludge, etc... and, for that matter, what the average or maximum gram quantity might be. Operations does not identify items well and, as a result, the information you requested cannot be easily identified. Most waste items are assayed on the NaI counter - which is Scott's (Baker) responsibility.

I'm not sure where the 30 gram maximum came from. Based upon the measurement results I've reviewed, I doubt any reasonable statement can be made regarding average or maximum quantities.

Similar comments below.

Dennis

-----Original Task-----

Subject: G Pu in Waste Packages  
 Priority: Normal  
  
 Start date: Mon 11/15/1999  
 Due date: Mon 11/15/1999  
  
 Status: Not Started  
 % Complete: 0%  
  
 Total work: 0 hours  
 Actual work: 0 hours

-----  
 Please look in your vast memories or backlog of papers and let Al Ramble (with a copy to me) know by COB 11/15 if the average package quantity and the upper limit quantity are reasonable. Thank you.

George

George could you confirm the 30 gram number. Mike this is the process upset for waste packages we are considering in glovebox 211.

Al Ramble

-----Original Message-----

From: Debbin, Kenneth D  
 Sent: Wednesday, November 10, 1999 7:52 AM  
 To: Erickson, David G; Miller, Edward M; Rambis, Alan L; Richard, Robert F; Shaw, Maria E; Toffer, Hans; Wilkinson, Alan D; Wooten, David W  
 Cc: Debbin, Kenneth D  
 Subject: Waste Package Definition

Yesterday afternoon, we agreed upon the definition of a waste package to be used for CSERs associated with plutonium stabilization. The purpose of this message is to put that definition in writing and allow meeting participants a chance to comment. Unless I hear back today, the following definition will be used in these CSERs.

Glovebox waste is generated from PFP plutonium stabilization operations. It is placed into plastic bags, transferred to isolated Transport Containers, assayed, then placed into waste drums. This waste consists of gloves, rags, containers used to port-in items, etc. Prior to bagging, all noticeable fissile material is brushed from these items [Fazzari, Dennis M] I doubt this is true. I suspect the items are bagged and removed without brushing, and no fissile item is intentionally placed

in these packages. Inspection of historical assay data show that normally these packages contain only 1 or 2 grams of fissile material. [Fazzari, Dennis M] No. I don't believe there is any technical basis for this statement. The greatest quantity found was one package that contained 30 grams of plutonium. [Fazzari, Dennis M] Where did this value come from?

This CSER evaluation includes a waste package containing 2 grams as the normal and base case conditions. For this fissile loading, the package acts as a reflector and possibly adds interspersed moderation between containers, however, no more so than already modeled in the base case. The only contingency identified is the excess fissile mass condition of 30 grams that was found once in the assay data history. [Fazzari, Dennis M] ??? Errors associated with loading fissile objects into the waste package are not included because if loaded in this glovebox they would be already covered by evaluation, and if the loading error occurs in other gloveboxes and transferred to this glovebox, then two errors would be required. Waste packages are not normally brought from other gloveboxes to this one.

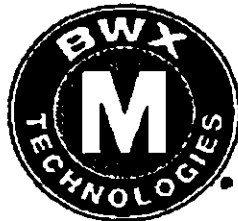
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**APPENDIX G**  
**FIREFIGHTING WATER DENSITY**

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**B & W Hanford Co.**

a McDermott company

<b>To</b>	A. L. Ramble, Engineer PFP Facility Engineering	T5-54	
<b>From</b>	R. D. Pickett, Cognizant Engineer PFP Facility Systems Engineering	T4-20	
<b>Subj</b>	FIRE FLOODING AND SPRAY ANALYSIS FOR ROOM 638		Date: May 17, 1999

Reference: Telephone Request for Fire Water Flooding and Spray Analysis, dated May 7, 1999.

**ASSUMPTIONS**

- Fire department on scene within 40 minutes (see FSAR section 9.2.2A).
- 120 psi at each sprinkler head (this is very conservative since line losses and operation of other sprinkler heads would decrease this pressure).
- Fight a fire with two hoses for a total of 400 gpm (one hose at 100 gpm and second hose at 300 gpm per information provided by the fire department). Note: these hoses are variable stream types so the pattern and flows are adjustable.
- For flooding, assume all sprinkler heads operate (this is worse than a shear of a 1 1/2" water line).
- 1 second of flow from a sprinkler head or hose will suspend the amount of water to achieve the maximum density.
- Assume 3 sprinkler heads worth of flow into the cage area.
- No leakage out of the room.
- There is 8 lb. Water in 1 gallon.
- Exclude floor space and volume of room 639 and 640.

**BACKGROUND**

- Area of the room floor = 130 ft<sup>2</sup>.
- 14 sprinkler heads in the room (see CVI 21097)
- Sprinklers have a 1/2" orifice with a 5.62 K-factor.
- There are 7.481 gallons per ft<sup>3</sup>.
- Occupational Classification is Ordinary Hazard (see CVI 21097).
- Caged area has two sprinkler heads.
- Ceiling height is 9' 6".
- Floor dimensions of caged area 7' x 18' 3"
- Probability of fire not being noticed and the fire department being delayed 30 minutes is discussed in section 9.2.2A of the FSAR.
- Flooding cannot occur when a fire hose is used since the doors to the room have to be open along the hose route all the way to the outside of the building. There are no hose connections inside 2736-ZB or 2736-Z.

A. L. Ramble, et. al.  
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May 17, 1999

15510-99-RDP-038

**CALCULATIONS**

Flow per sprinkler head =  $Q = K \sqrt{P} = 5.62 \cdot \sqrt{120} = 61.56 \text{ gpm}$

Sprinkler flow into cage area =  $3 \cdot 61.56 = 185 \text{ gpm}$

Sprinkler flow into the whole room =  $14 \cdot 61.56 = 862 \text{ gpm}$

Volume of cage area =  $7' \cdot 18' \cdot 9.5' = 1200 \text{ cu. ft.}$

**CAGE DENSITY CALCULATIONS**

Cage Density during fire fighting in cage area = 185 gpm from sprinklers + 400 gpm from fire hoses = 585 gpm total flow.

Water released in 1 second of sprinklers and hoses =  $585 \text{ gpm} \cdot (1 \text{ min}/60 \text{ sec}) \cdot 1 \text{ sec} = 9.75 \text{ gal.}$

Water density in cage area =  $9.75 \text{ gal}/1200 \text{ cu. ft.} = 0.0081225 \text{ gal/cu. ft.}$

**FLOODING CALCULATIONS**

Volume of water release in 40 minutes =  $40 \text{ min} \cdot 862 \text{ gpm} \cdot (1 \text{ cu. ft.}/7.481 \text{ gal}) = 4609 \text{ cu. ft.}$

Water level after 40 min. =  $4609 \text{ cu. ft.}/1340 \text{ sq. ft. floor area} = 3.44 \text{ ft.}$

**CONCLUSIONS**

After 40 minutes of sprinkler flow, the water level in room 638 will be 3.44 feet. The maximum density of water suspended in the cage area is 0.008-gal/cu. ft.

klm

Distribution

Floor Daniel Northwest

K. D. Dobbin	B4-44
J. S. Lan	B4-44
J. A. Miller	B4-44
RDP File/LB	