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1	/	Design Agent	A. L. Ramble	4-27-99	T5-54	1	/	CSE:	K. D. Dobbin	K. D. Dobbin	B4-44
1	/	Cog. Eng.	J. S. Lan	4/23/99	B4-44	1	/	Contributor:	R. F. Richard	R. F. Richard	B4-44
1	/	Cog. Mgr.	J. P. Estrellado, Jr	4/26/99	B4-44	1	/	Tech. Review:	D. G. Erickson	D. G. Erickson	B4-44
1	/	Safety	S. E. Nunn	4/27/99	T5-11	1	/	Operations:	T. A. Brown	T. A. Brown	T5-15

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## CSER 99-002: CSER for Unrestricted Moderation of Sludge Material with Two-Boat Operations in Gloveboxes HC-21A and HC21-C

Jay S. Lan

Fluor Daniel Northwest, Inc., Richland, WA 99352  
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Abstract: This Criticality Safety Evaluation Report was prepared by Fluor Daniel Northwest under contract to BWHC. This document establishes the criticality safety parameters for unrestricted moderation of sludge material with two-boat operations in gloveboxes HC-21A and HC-21C.

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**CSER 99-002: Criticality Safety Evaluation Report for Unrestricted Moderation of Sludge Material with Two-Boat Operations in Gloveboxes HC-21A and HC-21C**

Prepared by: J. S. Lan Date: 4-26-99  
J. S. Lan, Criticality and Shielding

Prepared by: R. F. Richard Date: 4-27-99  
R. F. Richard, Criticality and Shielding

Reviewed by: D. G. Erickson Date: 4-26-99  
D. G. Erickson, Criticality and Shielding

Approved by: J. P. Estrellado Date: 4/26/99  
J. P. Estrellado, Jr., Manager, Criticality and Shielding

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**CSER 99-002: Criticality Safety Evaluation Report for Unrestricted Moderation of Sludge Material with Two-Boat Operations in Gloveboxes HC-21A and HC-21C****1.0 INTRODUCTION**

The plutonium stabilization process at the Plutonium Finishing Plant (PFP) converts scrap plutonium into dry powder that is chemically stable for long term storage. Gloveboxes HC-21A and HC-21C are enclosures where trays (furnace boats) holding plutonium bearing materials are prepared prior to thermal stabilization in the muffle furnaces. HC-21A is a furnace boat preparation glovebox, and HC-21C is a heat treatment glovebox containing 2 muffle furnaces.

Existing Criticality Safety Evaluation Reports (CSERs) have addressed fissile materials of various forms to be processed in HC-21A [Erickson, 1998 (CSER 98-003), Altschuler, 1994 (CSER 94-008)] and HC-21C [Altschuler, 1994 (CSER 94-007)]. Those analyses have restricted applications, i.e., only to those materials having hydrogen to fissile atom ratios (H/Pu) of  $\leq 20$ . There are other fissile materials existing in the form of sludge that may have H/Pu  $> 20$ . This material is referred to as having unlimited moderation which must also be thermally stabilized for long term storage. This CSER addresses the feasibility of putting such unrestricted material through Gloveboxes HC-21A and HC-21C to cover a wider range of existing sludge inventories that have various quantities of moderation.

At the early planning stage, it was intended only to process one furnace boat at a time (CSER 98-011) with a glovebox mass limit of 2 kg and container volume limit of 4.6 l in either HC-21A or HC-21C. Later, the PFP operations realized the need to allow two boats and a 0.5 l sweeps container in each glovebox at a time and to increase the mass limit of each glovebox to 2.5 kg (including holdup) and total container volume limit to 7.1 l. FDNW was directed to extend the analysis for the two-boat operation. The Statement Of Work for this CSER is attached in Appendix D.

The following outline characterizes the upgraded loading approach and its normal operation conditions for modeling guidelines:

**Available Containers:**

- 2 boats (each boat – 2.3 l, 2.5"  $\times$  5"  $\times$  11" nominal)
- 4 canisters (0.5 l polyjar or slip-lid can, incoming materials)
- 1 container (0.5 l for sweeps)

**Planned Operation:**

Receive canisters from other gloveboxes or storage vaults; open canisters; load furnace boats in HC-21A with plutonium sludge for processing in HC-21C furnaces.

Normal Conditions:

$\leq 1.0$  kg Plutonium unit mass(es) in  $4.3 \ell$  maximum unit volume,  $25.4 \text{ cm}$  (10 in.) between unit masses,  $2.5$  kg glovebox total including holdup.  
Major neutron reflection occurs from operator's torso and palms.

Abnormal But Anticipated Conditions:

Loss of spacing between 2 unit masses is considered to be an abnormal but anticipated condition.

Table 1.1 summarizes the base case control parameters, their limits and abnormal but anticipated conditions. Table 1.2 summarizes the contingencies to comply with the requirements for a Double Contingency Documentation (DCD) form for PFP under Section 3.3 of FSP-PFP-5-8 (Shaw, Letter of Instruction, Task Order 915-003, 1998).

Table 1.1 Gloveboxes HC-21A and HC-21C – Base Case Summary

Control Parameter	Limit	Credible Abnormal Conditions (Conservative for Analysis)
Mass	$1.0$ kg fissionable/unit volume, $2.5$ kg fissionable/glovebox, $1.0$ kg in section of HC-2 conv. next to HC-21A or HC-21C	less than actual Pu-240 content
Volume	$2.3 \ell$ boat, $0.5 \ell$ sweeps container $4.3 \ell$ unit volume, $7.1 \ell$ glovebox	NA
Interaction	$\geq 24.5 \text{ cm}$ (10 in.) spacing between unit masses	$< 25.4 \text{ cm}$ (10 in.) of spacing
Reflection	Dry glovebox	Conservative reflection
Geometry	$2.3 \ell$ boat $27.94 \text{ cm} \times 12.7 \text{ cm} \times 6.35 \text{ cm}$ ( $2.5" \times 5" \times 11"$ ) $0.5 \ell$ polyjar or slip-lid can	$2.3 \ell$ per boat
Density	NA	NA
Concentration	NA	NA
Homogeneity	NA	NA
Moderation	NA	NA
Enrichment	NA	NA

The base case comprises one boat (1.0 kg Pu) adjacent to a second boat (1.0 kg Pu, no spacing) in the glovebox plus a 0.5 l sweeps container (500 g Pu) in the glovebox and one boat

(1.0 kg Pu) on the conveyor; 25.4 cm (10 in.) spacing between boat on conveyor and boats in glovebox. Nominal 2.54 cm (1 in.) water reflection around containers, full water reflection (30.48 cm all sides) around model (Figure 5.4),  $H/Pu = 58.4145$  in boats and  $H/Pu = 23.913$  in sweeps container. Total mass = 3.5 kg of Pu (Table 5.4), and 7.687 kg of mixture (sludge) (Table 5.2). The base case  $k_{\text{eff}} = 0.7672$  (inp22).

Table 1.2 Gloveboxes HC-21A and HC-21C – Contingency Summary			
Contingency Description	Affected parameter(s)	Barriers that make contingency unlikely	$k_{\text{eff}}$ bounding contingency (case ID)
Stacking containers (stack second boat on a boat in glovebox, 4.5 kg Pu total)	Interaction Mass Volume	Operator training	0.9012 (inp22db)
Over batched container (4.5 kg Pu total)	Mass Interaction	Operator training, mass control on process for loading containers, inventory control	Two stacked boats bound a double batched single boat or overbatched polyjar.
Fire with flooding (flooded glovebox)	Reflection	Requires severe fire, concurrent sprinkler flooding, and glovebox breaking or parts melting	0.8474 (inp22f)
Seismic (inverted pyramid, nominal water on sides, full water on top. 2.5 kg Pu in 7.1 $\ell$ volume)	Reflection Geometry	Requires severe damage from seismic event, concurrent sprinkler flooding of the damaged glovebox, and material rearrangement	0.8957 (pyr12)

## 2.0 CONCLUSION

This CSER shows that a two-boat operation with sludge material in a glovebox with unrestricted moderation, controlled to the limits listed in Section 3.0, is acceptable in either HC-21A or HC-21C glovebox. No single credible event causes the  $k_{\text{eff}}$  criticality safety limit of 0.95 to be exceeded. A calculational limit of  $k_{\text{eff}} = 0.942$  specified in Appendix B is used to account for bias and computational uncertainty. Therefore, this CSER meets the requirements of the Double Contingency Principle for a criticality safety analysis specified in the Hanford Site Nuclear Criticality Safety Manual (HNF-PRO-539).

### 3.0 LIMITS AND CONTROLS

The limits required by this CSER for the control of the sludge material with unrestricted moderation are:

- 1) Glovebox total mass inventory is limited to 2.5 kg of plutonium including glovebox holdup.
- 2) Unit mass is limited to 1kg of plutonium.
- 3) No metal button is allowed in this operation.
- 4) Container volumes in a glovebox are limited to 2.3 l for furnace boats and 0.5 l (nominal) each for all other containers (i.e. canisters or sweeps).
- 5) The maximum total volume of any grouping of containers (unit volume, without spacing limit) is 4.3 l. Total volume of containers in a glovebox (with spacing restriction) is limited to 7.1 l (see Table 5.3).
- 6) Minimum edge-to-edge spacing of 25.4 cm (10 in.) is required between unit masses or other fissionable material including containers on conveyor HC-2.
- 7) Stacking of fissionable material-bearing containers is prohibited.
- 8) Processing is to be stopped to clean up debris of fissionable materials from spills or processing dust.
- 9) Gloveboxes HC-21A and HC-21C are to have a criticality firefighting category of C. This allows water to be used as mists or fogs in the gloveboxes, but not as directed solid streams of water.
- 10) Glovebox depressions are to be filled, sealed or made into a non-container in order to prevent accumulation of fissinable materials.

### 4.0 SYSTEM DESCRIPTION

Glovebox HC-21C is located on the west side of Room 230A and Glovebox HC-21A is located on the west side of Room 230B in the 234-5Z building of PFP. Both gloveboxes are 325.12 cm (10 ft 8 in.) long with an inside working floor width of 106.7 cm (42 in.). Conveyor Glovebox, HC-2, is attached at the north end of HC-21A and HC-21C. Each glovebox is supported by a stand, placing the working floor 137.2 cm (54 in.) above the room floor (Altschuler CSER 94-007, Altschuler CSER 94-008). The gloveboxes have a depression in one corner with approximate dimensions of 12.7 cm (5 in.)  $\times$  13.14 cm (5.175 in.)  $\times$  58.42 cm (23 in.). The depression in HC-21A is filled with blocks to reduce the available volume to less than 2.3 l. The depression in HC-21C is sealed to prevent fissile material entering. Two figures

in this section are reproduced from CSER 98-003 for characterization and modeling (Section 5.0) purposes. Figure 4.1 provides a sketch showing the location of the gloveboxes in question in relation to the other gloveboxes and conveyors used for thermal stabilization activities. The sketch of glovebox HC-21A is shown in Figure 4.2. Note that this glovebox has gloveports on both sides. The sketches also show the approximate arrangement for sludge transfer operations in the glovebox.

Unrestricted moderation material (sludge) is introduced into Glovebox HC-21A in canisters or polyjars and transferred into a furnace boat. The furnace boat has inside dimensions of 27.94 cm (11 in.) by 12.7 cm (5 in.) with a height of 6.35 cm (2.5 in.). The glovebox will have up to two loaded furnace boats plus a 0.5 l sweeps container. A loaded furnace boat is transferred from HC-21A to HC-21C via the conveyor, HC-2. HC-21C contains two muffle furnaces. Each muffle furnace can accommodate one furnace boat. In addition to the boats in the muffle furnaces, a 0.5 l sweeps container is also located in HC-21C. The heating and cooling cycle in the two muffle furnaces in HC-21C lasts several hours. Upon completion, each boat is transferred to HC-18BS via the conveyor, HC-2.

The major operation in the thermalization process includes: receive canisters from other gloveboxes or vault storage to Glovebox HC-21A; open canisters; load furnace boats with sludge and transfer to Glove HC-21C for processing in the muffle furnaces. The base case outlined in Table 1.1 includes all modeling assumptions used to bound the normal intended operating conditions. The base case also includes off-normal conditions expected during the lifetime of the system such as multiple container handling, or a spacing error that is likely to occur at some point.

## 5.0 COMPUTER MODELING AND ANALYSIS

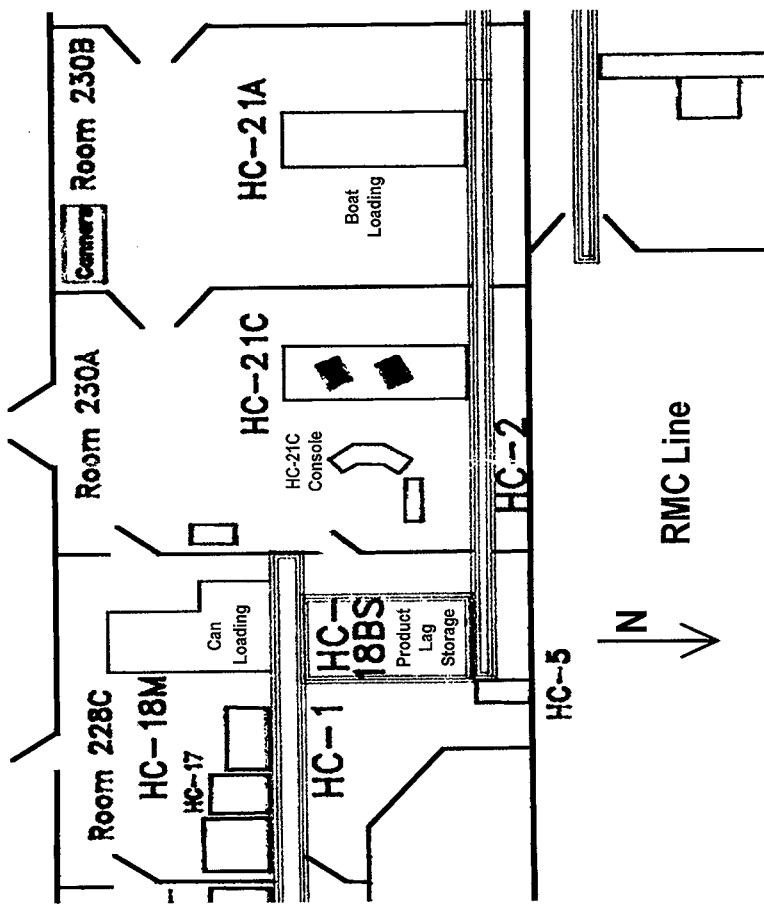
### 5.1 MODELING ASSUMPTIONS

The following assumptions are used to model the fissionable material and geometry of equipment in the glovebox. Normal and off-normal credible conditions are conservatively modeled.

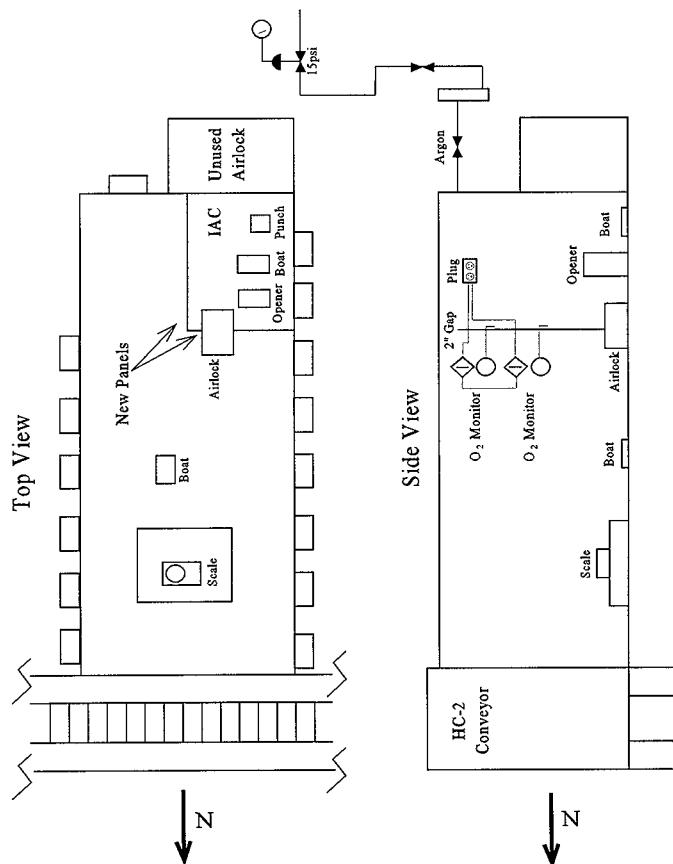
#### 5.1.1 Materials

The sludge material will be brought into glovebox HC-21A in 0.5 l canisters. These canisters are typically brought in 4 at a time. Most of the material will be in the form of sludge. In some cases a small amount of liquid supernatant will be associated with the sludge. Each group of canisters may have up to a unit mass of plutonium (1.0 kg) in the mixture. For this

Figure 4.1 Approximate Layout for Gloveboxes and Conveyors Utilized for Thermal Stabilization Activities



**Figure 4.2 Sketch of Glovebox HC-21A**



CSER the phrase “unrestricted moderation” refers to a wet, saturated sludge. Small amounts of low concentration plutonium nitrate solution may also be associated with the sludge. A solution is defined as 450 g Pu/l or less, and sludge is assumed to be 2.0 kg Pu/l. At a concentration of 450 g/l the H/Pu = 57 (Carter 1980). This CSER uses the maximum hydrogen to plutonium atom ratio according to the capacity of each individual container.

Using the boat as an example, mixing plutonium oxide ( $\text{PuO}_2$ , having 1 kg net of plutonium) with water in a 2.3 l volume (a boat) or container will have maximum H to Pu atom ratio of 58.4145. This gives the  $\text{H}_2\text{O}$  volume fraction in  $\text{PuO}_2$ -water mixture of 0.957 and the Pu density of 0.435 g/cc. The sludge material is modeled as a mixture of plutonium and water with the plutonium being entirely  $^{239}\text{Pu}$  in the form of  $\text{PuO}_2$ . The sludge material densities used in the calculation are given in Table 5.1 which shows the similar results for other types of containers as well.

Table 5.1 Mixture Material Densities

	sweeps	canisters*	boats	sphere
Maximum H/Pu	23.913	50.455	58.415	72.745
Pu density (g/cc)	1.00000	0.50000	0.43478	0.35211
$\text{PuO}_2$ density (g/cc)	1.13386	0.56690	0.49298	0.39924
$\text{H}_2\text{O}$ density (g/cc)	0.90106	0.95053	0.95698	0.96516
Total (g/cc)	2.03492	1.51743	1.44996	1.36440

\* boat data was used instead, see Table 5.2.

### 5.1.2 Unit Geometry

#### Boats

The 2.3 l furnace boats having nominal inner dimensions of 27.94 cm×12.7 cm×6.35 cm (11"×5"×2.5") were assumed to contain 1.0 kg of Pu in sludge with the maximum calculated H/Pu = 58.41. The boat (container) material was conservatively ignored in the calculations so that each boat modeled consists only of the sludge with the boat inside dimensions. At an H/Pu of 58.41, 1.0 kg of plutonium requires a 2.3 l volume to accommodate the entire plutonium mass. The boat height was deliberately increased to 6.482 cm (2.552 in.) to model a full 2.3 l volume. 2.54 cm (1 in.) of water reflection around and on top of each boat was included in the model. In an actual boat, 1.0 kg of Pu in sludge would be confined to a smaller volume with a lower hydrogen to plutonium atom ratio. Therefore, the modeling is conservative with respect to reality.

#### Canisters

250 g of plutonium in a 0.5 l canister was conservatively modeled as a cylinder of volume 0.575 l. This cylinder was modeled with the height (9.02 cm) equal to the diameter (9.02 cm). This single canister volume (0.575 l) allows the total volume of the

4 canisters to be equivalent to that of a boat. Therefore, the hydrogen to plutonium atom ratio, the mixture density, and the mixture mass in the canisters are the same as the boat. The actual 0.5 l volume with 250 g of plutonium will have a lower H/Pu ratio, so the model is conservative. Table 5.2 shows the adjusted parameters in parenthesis used for canister modeling. Four canisters with 2.54 cm (1 in.) water reflection are grouped together and adjacent to a boat.

### Sweeps

A 0.5 l cylinder model is used for a sweeps container for collecting up to 500 g of plutonium. It is modeled as a cylinder with height (8.602 cm) equal to diameter (8.602 cm). At 1 g/cc Pu density, the maximum hydrogen to plutonium atom ratio was calculated to be 23.913. Although 25.4 cm (10 in.) spacing is required (item 5 of Section 3), the sweeps container was intentionally placed next to a boat in the base case model to account for conservative contribution from water reflection. 2.54 cm (1 in.) of water reflection is also modeled around the sweeps container.

### Sphere

For the seismic contingency analysis, a sphere was used as a conservative model to bound any possible geometry. At H/Pu=58.41, sludge with 2.5 kg of plutonium occupies a volume of 5.75 l. Even when spilled, the plutonium bearing sludge will maintain this H/Pu ratio. To increase the H/Pu ratio the sludge would have to expand in volume. This is not credible. However, to account for and fill the allowed 7.1 l container volume, for the seismic analysis the H/Pu ratio was conservatively increased. Therefore, a 7.1 l sphere with an 11.923 cm radius was conservatively used. The sphere has 2.54 cm (1 in.) of nominal water reflection. In a volume of 7.1 l, 2.5 kg of plutonium has a density of 0.352 g/cc, the H/Pu is 72.75 and the mixture density (sludge) is 1.36440 g/cc (Table 5.2).

### Pyramid

A more realistic, credible geometry representing a collapsed glovebox following a seismic event is an inverted pyramid. This represents a spill of all the fissile material into a low corner of the glovebox resting on the concrete floor. Nominal water reflection is modeled on the sides of the pyramid with up to full water reflection on top (base of inverted pyramid). As with the sphere, described above, the pyramid was conservatively modeled with a volume of 7.1 l with 2.5 kg of plutonium at H/Pu = 72.75.

### Glovebox

Figures 5.1 to Figure 5.7 are MCNP plots showing various container arrangements. All the figures are top views (x-y plane) except Figure 5.5 which is a side view (x-z plane) to show a stacking violation and Figure 5.7 to show the pyramid shape. Figure 5.1 is a schematic that represents a normal configuration of canisters, boats, sweeps container inside or nearby a glovebox. The boat with 4 adjacent canisters represents a unit mass/volume. The other boat represents a second one in the glovebox or on the conveyor.

Figure 5.1 MCNP Model of Gloveboxes HC-21A & HC-21C Fissile Material Layout

```
01/28/99 07:15:25
gloveboxes hc-21a, hc-21c caer
for unrestricted moderation

probid = 01/28/99 07:14:25
basis:
( -1.000000, 0.000000, 0.000000)
( 0.000000, 1.000000, 0.000000)
origin:
(
 50.00, 150.00, 5.00)
extent = (
 180.00, 180.00)
```

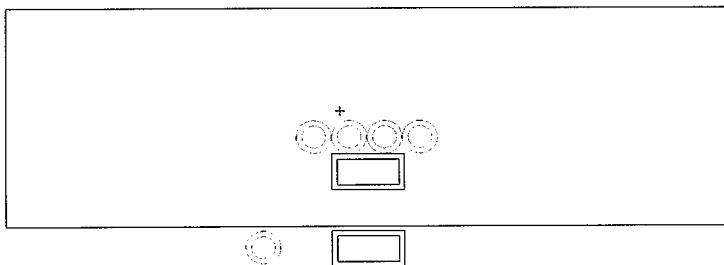


Figure 5.2 MCNP Base Case Test Model I

```
01/28/99 07:59:13
gloveboxes hc-21a, hc-21c cser
for unrestricted moderation
probid = 01/28/99 07:57:42
basis:
( 1.000000, 0.000000, 0.000000)
( 0.000000, 1.000000, 0.000000)
origin:
( 30.00, 30.00, 5.00)
extent = (
```

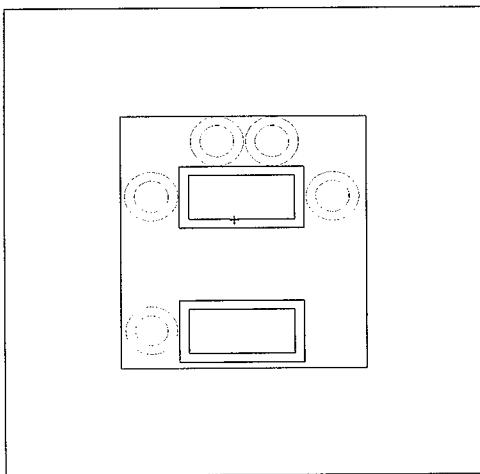


Figure 5.3 MCNP Base Case Test Model II

```
02/15/99 09:49:31
gloveboxes hc-11a, hc-21c case
for unrestricted moderation
probid = 02/15/99 09:49:03
basis:
( 1.000000, 0.000000, 0.000000)
( 0.000000, 1.000000, 0.000000)
origin:
( 30.00, 30.00, 5.00)
extent = ( 100.00, 100.00)
```

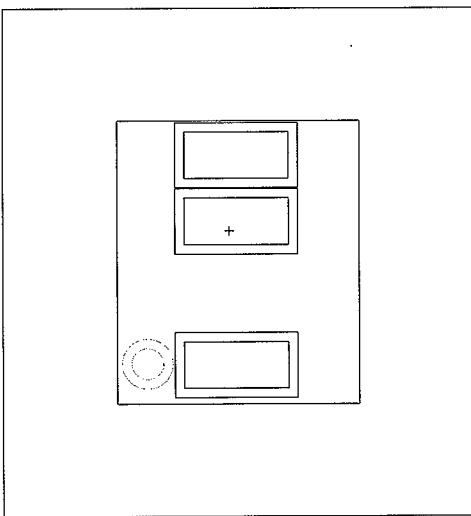


Figure 5.4 MCNP Model for Gloveboxes HC-21A & HC-21C Base Case & Flooding Case

```
02/15/99 11:07:31
gloveboxes hc-21a, hc-21c cser
for unrestricted moderation
probid = 02/15/99 11:06:20
basis:
( 1.000000, 0.000000, 0.000000)
( 0.000000, 1.000000, 0.000000)
( 0.000000, 0.000000, 1.000000)
origin:
( 30.00, 30.00, 5.00)
extent = ( 100.00, 100.00)
```

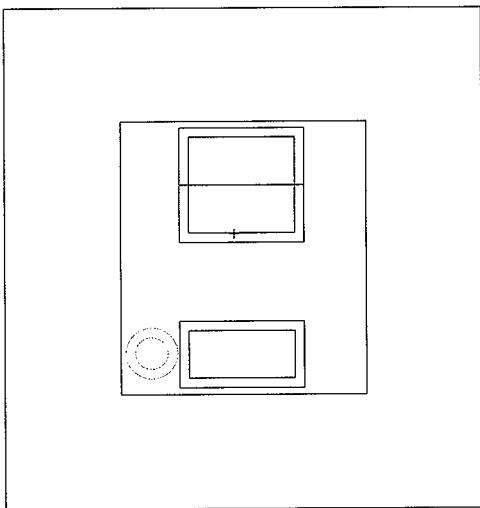


Figure 5.5 MCNP Model for Gloveboxes HC-21A & HC-21C Double Batching Case

```
02/16/99 12:30:34
gloveboxes hc-21a, hc-21c cser
for unrestricted moderation
probid = 02/16/99 12:29:41
basis:
( 1.000000, 0.000000, 0.000000)
( 0.000000, 0.000000, 1.000000)
origin:
( 40.00, 26.00, 8.00)
extent = ( 100.00, 100.00)
```

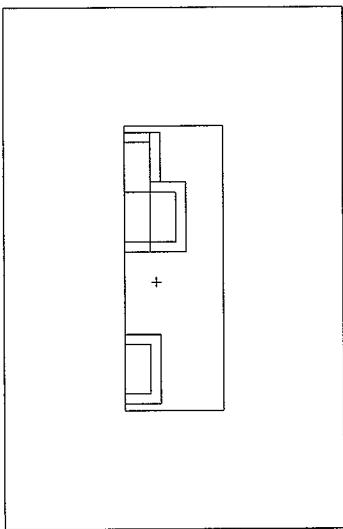


Figure 5.6 MCNP Model for Gloveboxes HC-21A & HC-21C Seismic Case

```
01/28/99 12:29:15
seismic contingency by a 2500 gm
in 7.2 liter sphere with 1" h2o
surrounding
probid = 01/28/99 12:28:19
basis:
( 1.000000, 0.000000, 0.000000)
( 0.000000, 1.000000, 0.000000)
origin:
(
  0.00,    0.00,    0.00)
extent = ( 30.00, 30.00)
```

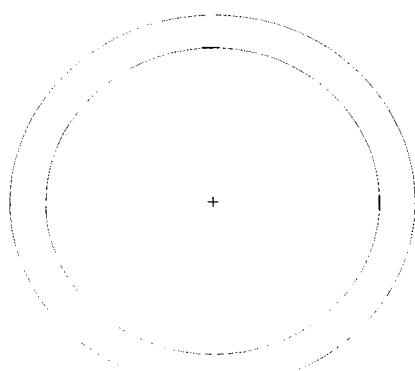
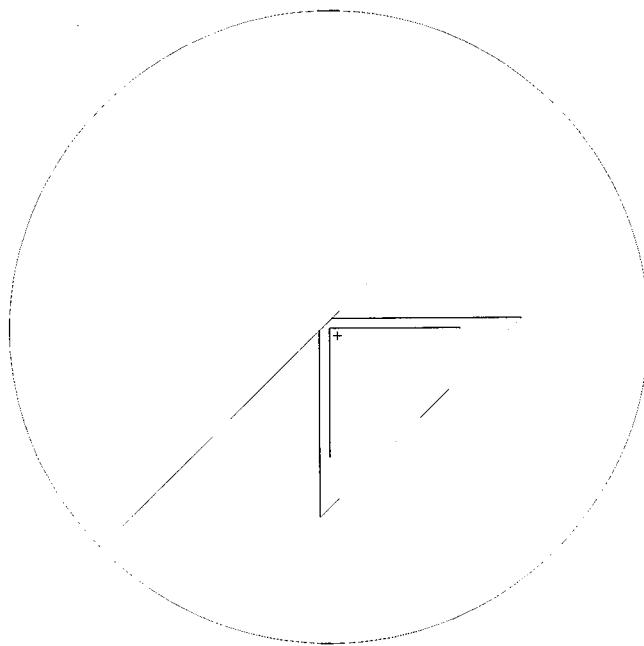


Figure 5.7 Collapsed Glovebox (Pyramid) Model for Seismic Analysis

```
02/11/99 12:35:27
seismic contingency by a 2500 gm
Pu in 7.2 liter pyramid with 5"
hd on top
probid = 02/11/99 12:32:18
basis:
( 1.000000, 0.000000, 0.000000)
( 0.000000, 0.000000, 1.000000)
origin:
( 2.00, 2.00, 2.00)
extent = ( 90.00, 90.00)
```



The two boats are separated 25.4 cm (10 in.) apart edge-to-edge. A sweeps container is also required to be 25.4 cm (10 in.) from a boat.

The normal operation configuration was modified and tested to create the base case to eliminate lengthy and unnecessary calculations. Two of the 4 canisters next to the first boat were moved closer to the boat for better neutron interaction, and the sweeps container was moved adjacent to the second boat. This arrangement also allows for better neutron reflection from the 30.48 cm (12 in.) of water that encloses the model. The 4 canisters next to a boat operation (Figure 5.2) was later replaced by two adjacent boats (Figure 5.3) inside a glovebox. This model was further extended from having 2.54 cm (1 in.) water reflection around all sides of each boat to a model which has water between the adjacent sides of the two boats taken away (Figure 5.4). The result shows that former cases are less reactive than the last case which was then chosen to be the base case (Table 5.3). This base case bounds any normal as well as abnormal but anticipated conditions for the two-boat operation in the glovebox with a loaded boat 24.5 cm (10 in.) away on HC-2 conveyor. This base case configuration was also used for the flooding scenario by replacing the central atmosphere region with water. Figure 5.5 shows the double batch contingency condition of boat stacking or overbatching. Figure 5.6 is the 7.1  $\ell$  sphere containing 2.5 kg of plutonium with 2.54 cm (1 in.) of water reflection to simulate the seismic condition. Figure 5.7 is the pyramid model for the seismic case.

### 5.1.3 Model Summary

Table 5.2 summarizes the parameters and provides a comparison between the expected condition and the actual computational condition. The third column of the table includes the nominal material parameters for 250 g of Pu in a 0.5  $\ell$  canister and the conservative material parameters used (in parentheses). Using these more conservative values assures that the 1.0 kg of Pu occupying the four 0.5  $\ell$  containers is equivalent to one boat worth of sludge.

Modeled cell volume (row 10) and modeled cell mass (row 11) are numbers from MCNP outputs for various containers. Those numbers indicate the accuracies of both geometries and materials provided for the code calculations.

## 5.2 ANALYSES AND RESULTS

Calculations were done for both normal and contingency conditions. All the calculational parameters are listed in Table 5.2. This table includes model input assumptions and parameters from MCNP outputs. The results of these calculations are presented in Tables 5.4 and 5.5.

Table 5.2 Comparison of Assumed and Modeled Parameters

Items	Glovebox			Seismic
	Boats	Canisters	Sweeps	Sphere/ Pyramid
Container Capacity (liter)	2.30	0.50	0.50	7.10
Pu Mass (kg)	1.00	0.25	0.50	2.50
Pu Density (g/cc)	0.434800	0.50000	1.00000	0.352113
Optimum Moderation (H/Pu)	58.41	50.46 (58.41)	23.913	72.75
Mixture Density (g/cc)	1.44996	1.51743 (1.44996)	2.03492	1.36441
Mixture Mass (grams)	3334.94	758.76 (833.74)	1017.46	9687.31
Modeled Cell Volume (cm <sup>3</sup> )	2.300e+3	5.00e+2 (5.75e+2)	5.00e+2	7.10e+3
Modeled Cell Mass (grams)	3.33494e+3	7.5876e+2 (8.3374e+2)	1.0175e+3	9.6873e+3
Modeled Mixture Content (Pu:O:H)	1:31.21:58.41	1:27.23:50.46 (1:31.21:58.41)	1:13.96:24.00	1:38.37:72.75
Modeled Pu Content (% Pu-239)	100	100	100	100
Modeled Container (unit)	2	4	1	1
Modeled Configuration (relative distance)	25.4 cm (10 in.) apart	packed and adjacent to first boat	adjacent to second boat	isolated
Total Pu Mass (kg)	normal:2.5, base case:3.5, double batch: 4.5			2.5
Water Reflection	2.54 cm (1 in.) around containers, 30.48 cm (1 ft.) surrounding glovebox			2.54 cm (1 in.) around

### Base Case

Three normal condition arrangements were evaluated to determine the bounding base case. One normal arrangement has four 0.5 l canisters (250 g Pu, each) adjacent to a loaded boat, plus a 0.5 l sweeps container (500 g Pu) next to a boat on the conveyor (Figure 5.2). Each boat contains 1.0 kg of plutonium. Nominal water reflection is 2.54 cm (1 in.) around all containers,

full water reflection 30.48 cm (12 in. all sides) around model,  $H/Pu = 58.4145$  for boats and  $0.5 \ell$  canisters,  $H/Pu = 23.913$  for the sweeps container. Total mass of 3.5 kg of Pu, and 7.687 kg of mixture (sludge) with air in the central region of the model. This represents the process of bringing plutonium into the glovebox. The  $k_{\text{eff}}$  for this arrangement is 0.6895 (inp2).

A second arrangement (Figure 5.3) models a boat (1.0 kg Pu) adjacent to a second boat (1.0 kg Pu) in a glovebox, plus a  $0.5 \ell$  sweeps container (500 g Pu) next to a third boat (1.0 kg Pu) on the conveyor. There is 25.4 cm (10 in.) spacing between the boats in the glovebox and the boat on the conveyor. Nominal water reflection is 2.54 cm (1 in.) around all containers, full water reflection 30.48 cm (12 in. all sides) around model,  $H/Pu = 58.4145$  for boats and  $H/Pu = 23.913$  for the sweeps container. Total mass of 3.5 kg of Pu, and 7.687 kg of mixture (sludge) with air in the central region of the model. This arrangement has  $k_{\text{eff}} = 0.7306$  (inp21).

A third arrangement is similar to the second except that there is no nominal water reflection between the adjacent boats. Instead the boats are touching with 2.54cm (1 in.) nominal water reflection around the pair of boats (Figure 5.4). The  $k_{\text{eff}}$  for this case is 0.7672 (inp22). This arrangement is the most conservative and bounds the normal operation scenario. It is designated as the base case to be used as the basis for the contingency calculations.

Table 5.3 provides a summary of of container volumes and masses for the normal condition models. A summary of the results for the normal condition cases are shown in Table 5.4.

Table 5.3 Container Volume and Mass in Normal Condition Models

		Case inp2	Cases inp21 & inp22	
Container type	Volume ( $\ell$ )	Mass (kg)	Volume ( $\ell$ )	Mass (kg)
boats	2.3	1.0	4.6 (2 boats)	2.0
canisters	2.0 (4 canisters)	1.0	0	0
boat on conveyor	2.3	1.0	2.3	1.0
sweeps can	0.5	0.5	0.5	0.5
Total	7.1	3.5	7.4	3.5

Table 5.4 Normal Condition Case Summary

Case ID	Description	$k_{\text{eff}}$	$\sigma$
inp2	4 0.5 $\ell$ canisters adjacent to a boat, 1" water around each unit	0.6895	0.0017
inp21	4 canisters replaced by a boat, 1" water around each boat	0.7306	0.0019
inp22	1" water around 2 boats, no water between adjacent sides	0.7672	0.0016

### **Flooding Case**

The flooding case has exactly the same configuration (Figure 5.4) as that of the base case except with the central atmospheric region replaced by water. All the calculational parameters remain the same as that of the base case except the exchange of air density to water density. The fully flooded case has  $k_{\text{eff}} = 0.8474$  (inp22f).

### **Double Batching Case**

The double batching case has one additional boat with 1.0 kg of plutonium placed on top of the existing boat of the base case model as shown in Figure 5.5. All the calculational parameters remain the same as that of the base case except the total plutonium mass has been increased from 3.5 kg to 4.5 kg. The double batching case has  $k_{\text{eff}} = 0.9012$  (inp22db).

### **Seismic Case**

Two models were used for the seismic analysis. A spherical model that bounds any possible geometry, and an inverted pyramid that represents a bounding credible geometry for the fissile material in a collapsed glovebox. Both models have a 7.1  $\ell$  volume (allowed container volume in glovebox) and 2.5 kg of plutonium (glovebox mass limit). They are described in the following paragraphs.

For the first model, a 7.1  $\ell$  volume was conservatively modeled as a sphere (11.923 cm radius) with 2.5 kg of plutonium mass inside and H/Pu of 72.75 to represent the maximum water moderation. The sphere also has 2.54 cm (1 in.) nominal water reflection around the surface (Figure 5.6). This bounding spherical seismic case has  $k_{\text{eff}} = 0.9102$  (inp2s).

The second model had the more credible pyramid geometry. This represents a low corner of a collapsed glovebox resting on a concrete floor. The sides of the inverted pyramid have 2.54 cm (1 in.) of nominal water reflection. Water accumulates on the base of the pyramid to a depth of 30.48 cm (12 in.) (Figure 5.7). The  $k_{\text{eff}}$  for this geometry is 0.8957 (pyr12.i)

Table 5.5 Calculational Results

Case Names	Description	$k_{\text{eff}}$	$\sigma$
inp22	base case	0.7672	0.0016
inp22f	flooding	0.8474	0.0016
inp22db	double batch	0.9012	0.0021
inp2s	seismic (sphere)	0.9102	0.0017
pyr12.i	seismic (pyramid)	0.8957	0.0018

### 5.3 MCNP4B VERIFICATION & VALIDATION

The criticality prevention criterion requires that the effective neutron multiplication factor ( $k_{\text{eff}}$ ) shall not exceed 0.95 ( $k_{\text{eff}} \leq 0.95$ ), including allowances for bias and uncertainties. This criterion is in accordance to HNF-PRO-537 Rev. 0, Criticality safety Control of Fissionable Material, Chapter 2, section 1.4.1.2, *Acceptable Margin of Subcriticality*, and section 1.4.1.3, *Maximum Calculated K-Effective*.

The validation of the methods used in the analysis consists of testing the ability of the code and neutron cross-sections in calculations of known critical configurations, which are various benchmark experiments with the fissile material in question. Such analyses determine calculational bias (the deviations of calculated  $k_{\text{eff}}$  values from unity for the benchmark cases) and the uncertainties culminating from the experimental and calculational errors.

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

$$k_{\text{eff}} = k_{\text{calc}} - \text{bias} + (U_b^2 + U_c^2)^{1/2} \leq 0.95$$

where

$k_{\text{eff}}$  = the effective multiplication constant corrected for bias and uncertainties,

$k_{\text{calc}}$  =  $k$  value by calculation for system in question,

bias = mean difference ( $k_{\text{calc}} - 1.0$ ) for benchmark criticals,

$U_b$  = 95% confidence level uncertainty in the bias determination,

$U_c$  = 95% confidence level uncertainty in new calculation.

All calculations used to verify compliance with the 0.95  $k_{\text{eff}}$  limit will be performed using the Monte Carlo computer code MCNP (Breismester 1993). MCNP is used internationally and has been extensively tested with the ENDF/B-V-based cross sections. The code development group at Los Alamos National Laboratory has a set of 25 calculational benchmarks that extensively test various options within the code. These benchmarks are used to confirm that new versions of the code give the same answer as before and that executables for users at other sites give the same answer. Analyses performed will also account for operator error contingencies to ensure that the criticality criteria are not violated by those contingencies.

Appendix B provides a standardized summary for the documentation of the verification and validation (Lan, 1999) carried out for the MCNP4B code, and its predecessor versions, as applicable to plutonium materials encountered at PFP. With the cross section library supplied, the MCNP4B validation calculations indicate an allowed maximum  $k_{\text{eff}}$  value of 0.95

$(k_{\text{calc}} \leq 0.942)$  for new system calculations to assure subcriticality with an acceptable margin, including the uncertainties in the analytical methods and benchmark experimental data. This limit requires the standard deviation of the new calculation be less than 0.002.

## 6.0 NORMAL CONDITION

### Normal Operation

Under normal operating conditions, sludge will be brought into the glovebox in canisters, such as the 0.5 l polyjars from glovebox HA-23S, and transferred to the 2.3 l furnace boats. Minimum edge-to-edge spacing between unit masses should be at least 25.4 cm (10 in.). Empty canisters are removed from the glovebox or made into non-containers by crushing or placing lids on them.

Except at the very beginning of the operation when 4 canisters of sludge with 1.0 kg of plutonium are loaded into the first empty boat, under the normal two-boat operation condition, a glovebox will have up to a maximum of 2.5 kg of plutonium which includes a loaded boat with up to 1.0 kg of Pu, with another 1.0 kg of Pu between 4 canisters and the second boat, and a sweeps container with up to 500 g of Pu. This defines the maximum allowable sludge arrangement inside a dry glovebox. For this CSER the phrase “dry glovebox” means that there are no water lines or other moderator paths into the glovebox.

Since part of the allowed glovebox inventory will be holdup material, actual plutonium mass in the containers will be less than 2.5 kg. This would be less reactive than the previously discussed condition. The holdup material would be distributed randomly around the glovebox and, therefore, there would be less interaction between this material and the reduced sludge mass in the containers.

### Base Case

The bounding base case, as described in Section 5.2, includes the normal operation condition and abnormal but anticipated conditions. This base case scenario has one boat (1.0 kg Pu) adjacent to a second boat (1.0 kg Pu, no spacing) in a glovebox, plus a 0.5 l sweeps container (500 g Pu) adjacent to a boat (1.0 kg Pu) on the conveyor. There is 25.4 cm (10 in.) spacing between the first pair of boats and the sweeps container and boat. The sweeps container is modeled next to the boat on the conveyor to allow for closer, conservative reflection around the arrangement of containers. The actual positioning of the sweeps container would be in the glovebox and 25.4 cm (10 in.) away from any unit volume. Each container has 2.54 cm (1 in.) nominal water reflection around. There is also full water reflection of 30.48 cm (12 in.) around the model with  $H/Pu = 58.4145$  in the boats and  $H/Pu = 23.913$  in sweeps container. The total Pu mass is 3.5 kg, the mixture (sludge) mass is 7.687 kg.

The base case contains the maximum fissile material that would be expected inside the glovebox or nearby the HC-2 conveyor during normal operations. It also includes the abnormal but anticipated event of loss of spacing. This base case  $k_{\text{eff}} = 0.7672$  (inp22, Table 5.4)

## 7.0 CONTINGENCY ANALYSES

The following discussion in this section gives a description of beyond-base-case off-normal conditions and the calculational results. Each of the conditions results from a loss of control on one or more of the parameters given in Section 3.0, and is therefore considered to be a contingency condition.

The double contingency criterion requires at least two unlikely, independent, and concurrent or sequential events to occur before a criticality is possible. A contingency is a possible but unlikely change in a condition or control identified as an important barrier factor in preventing a nuclear criticality accident. For any single contingency, the system will still be acceptably safe (i.e.,  $k_{\text{eff}}$  less than 0.95, or  $k_{\text{calc}} \leq 0.942$ ).

### 7.1 GLOVEBOX MASS LIMIT, SPACING LIMIT AND STACKING

The glovebox mass limit is 2.5 kg including holdup. Both overbatching the glovebox or a single boat is represented by Case inp22db (Table 5.5). A single contingency would be the introduction of an additional boat with a unit mass or have double the mass in an allowed boat. Case inp22db ( $k_{\text{eff}} = 0.9012$ ) has four 2.3  $\ell$  boats (two stacked, Figure 5.5), each with 1.0 kg of sludge for a glovebox total of 4.5 kg. This case is subcritical, and conservatively represents overbatching the glovebox, loss of spacing and stacking of containers. It is clear that loss of any one of these contingencies does not result in a criticality.

### 7.2 SPILL

An upset of a sludge filled furnace boat or container could result in all the sludge spilling onto the glovebox floor. Even if the entire 2.5 kg of sludge were to form a sphere, criticality is not possible (case inp2s,  $k_{\text{eff}} = 0.9102$ , Table 5.5). This case represents a sphere with 2.5 kg of  $^{239}\text{Pu}$  at an H/Pu of 72.75. The sphere volume is 7.1  $\ell$ , and has nominal 2.54 cm (1in.) water reflection. The most likely scenario would have the sludge spread out over the glovebox to form a thin slab geometry. A portion of the sludge could flow out of the opening into the conveyor HC-2. As the sludge spreads to form the slab, the sludge would become more subcritical as the slab thickness decreases. Sludge could flow into the unoccupied volume of the depression but could be no more reactive than the modeled sphere. For any spill scenario  $k_{\text{eff}}$  is bounded by Case inp2s (Table 5.5) and criticality is not possible.

### 7.3 MIST ATMOSPHERE

Gloveboxes HC-21A and HC-21C are dry gloveboxes, as defined in Section 6.0. A saturated atmosphere, achieved by steam displacing air in the glovebox would be a very unlikely event. Sprinklers, mist, and foam have densities much lower than full water density used in the analyses. And although the opening to HC-2 conveyor precludes flooding, this analysis was done to show that reduced water density between containers in Gloveboxes HC-21A and HC-21C is acceptable. As the water density increases,  $k_{\text{eff}}$  increases. The maximum  $k_{\text{eff}}$  is for full water density.

Table 7.1 shows how  $k_{\text{eff}}$  varies with water densities. The conservative base case configuration was used again as the starting point of this analysis. The model includes two 2.3 l furnace boats spaced 25.4 cm (10 in.) apart. Each boat contains 1.0 kg of sludge with  $H/\text{Pu} = 58.41$ . Between the boats the water density is varied up to a maximum of 1.0 g/cm<sup>3</sup>. The boats and mist are enclosed by 30.48 cm (12.0 in.) nominal water reflection. The maximum  $k_{\text{eff}}$  case is for full water density and 30.48 cm (12 in.) reflection ( $k_{\text{eff}} = 0.8474$ , inp2f), which matches with the glovebox flooding case (Table 5.5).

These results show that a mist atmosphere, of any density, in the glovebox will not cause a criticality.

Table 7.1 Mist Atmosphere

case	water density (%)	$k_{\text{eff}}$	$\sigma_c$
inp22m00	0	0.7667	0.0018
inp22m02	2	0.7670	0.0019
inp22m05	5	0.7709	0.0017
inp22m10	10	0.7815	0.0016
inp22m20	20	0.7963	0.0017
inp22m40	40	0.8221	0.0018
inp22m50	50	0.8236	0.0021
inp22m80	80	0.8391	0.0017
inp22m100	100	0.8474	0.0016

#### 7.4 WATER INGRESS BY FIRE OR OTHER MEANS

Gloveboxes HC-21A and HC-21C are both dry gloveboxes as defined in Section 6.0, and therefore contain no water lines and have no means of water ingress, unless damaged. However, even if water flooding is assumed,  $k_{\text{eff}}$  is subcritical as shown from case inp22f ( $k_{\text{eff}} = 0.8474$ ) of Table 5.5. Addition of water outside the containers represents one contingency and it does not cause criticality.

A fire would not increase the probability of a criticality. It may cause dispersion of the material which would result in a more subcritical condition. Moderation provided by the addition of fire fighting water would result in a higher  $k_{\text{eff}}$  but the system would remain subcritical. The moderation effect as a result of fire fighting water is demonstrated in Section 7.3. Full water flooding results in the highest  $k_{\text{eff}}$  of 0.8474 (Table 7.1, inp22m100). If sludge were to spill out of the containers a less reactive geometry would result as the material forms a thin slab.

## 7.5 SEISMIC EVENT

Both Gloveboxes HC-21A and HC-21C are classified, in the PFP Safety Analysis Report, Table 9.2.4-1, (Shapley 1995) are not “seismically qualified”. As such, these gloveboxes could incur structural damage from the effect of a Design Basis Earthquake (DBE). It is conceivable that these gloveboxes could be damaged in such a manner that one corner may end up as a low point on the floor for sludge accumulation.

Gloveboxes HC-21A and HC-21C are dry gloveboxes as defined in Section 6.0. A DBE could breach the gloveboxes in such a way to allow a water path into the glovebox. However, in conjunction with the breached glovebox a water source must be provided. This could possibly be a broken water line from a fire suppression sprinkler system. Whatever the water source is, it would have to be precisely aimed at the breached area of the glovebox in order for water entry to occur. It is likely that if the DBE has caused a water entry path, it would also be just as likely that a water exit path was created.

Following a DBE, two scenarios are possible. The first scenario would involve the two boats and the sweeps container, each boat containing 1.0 kg of Pu and a sweeps containing 500 g of Pu in the form of sludge. They could all slide to the low point of the glovebox under a DBE with one boat flipping on top of the other. The sludge would be contained by the 5.1  $\ell$  volume formed by the boats and the sweeps container.

In the second scenario, the sludge material is not contained by the containers. In this case the sludge could spill out of the containers and into the glovebox. The spill would tend to disperse rather than form a single unit. Any unlikely addition of water would collect on top of the sludge or leak out through the breaches in the glovebox. The total sludge volume would remain unchanged. This also would not create a criticality and is bounded by the nominally reflected spherical 7.1  $\ell$  calculation. The small amount of solution material associated with the sludge is covered by the sludge or would leak out of the glovebox. A 7.1  $\ell$  volume was conservatively modeled (inp2s) as a sphere containing 2.5 kg of plutonium with H/Pu of 72.75 to represent a maximum water moderation for that volume. The sphere has 2.54 cm (1 in.) of nominal water reflection around the surface. This seismic case has  $k_{\text{eff}} = 0.9102$  (inp2s) as shown in Table 5.5. A sphere is used for this analysis because it bounds any credible geometry of a given volume with a given mass. Formation of this sphere is not considered credible.

A credible and conservative geometry following a DBE, is an inverted pyramid formed in the lower corner of the glovebox as it collapses onto the floor. Most likely any breaching of the glovebox that allows water to enter would also provide a path for fissile material to leak out onto the floor. However, assuming no fissile leakage out of the glovebox an inverted pyramid could form in the low corner (Figure 5.7). The 2.5 kg of plutonium allowed in the glovebox could accumulate in this pyramid shape. As water entering the glovebox accumulates on the top (base of inverted pyramid)  $k_{\text{eff}}$  increases to a maximum with full water reflection. The results are tabulated in Table 7.2. Criticality does not occur, the maximum  $k_{\text{eff}}$  is 0.8957.

In order for a criticality to approach plausibility, water leaking into the glovebox must mix intimately with the 2.5 kg of plutonium in sludge to create a homogenous  $^{239}\text{Pu}$  - water mixture contained within a credible geometry of much larger volume. A sphere bounds any

credible geometry and would have to expand to 16.5  $\ell$  before criticality is possible with no reflection. With 2.54 cm (1 in.) of water reflection, expansion to an 11  $\ell$  sphere is required, and with full reflection a 7.2  $\ell$  sphere is required. (Chart III.A.9(100)-4, Carter 1968). These configurations are not credible. The worst credible shape would be a pyramid in the lower corner. This shape provides more neutron leakage and therefore is more subcritical than a sphere. Also, homogeneity of the sludge-water mixture is required and is unlikely. Water entering the glovebox would more likely settle around the sludge rather than mix intimately with it.

Table 7.2 Water Accumulation on Top of a Pyramid

Case	Water on top of pyramid	$k_{\text{eff}}$	Uncertainty (1 $\sigma$ )
pyr01	2.54 cm (1")	0.8131	0.0021
pyr02	5.08 cm (2")	0.8471	0.0020
pyr03	7.62 cm (3")	0.8708	0.0016
pyr04	10.16 cm (4")	0.8875	0.0019
pyr05	12.70 cm (5")	0.8860	0.0020
pyr06	15.24 cm (6")	0.8943	0.0019
pyr07	17.78 cm (7")	0.8958	0.0018
pyr08	20.32 cm (8")	0.8983	0.0018
pyr09	22.86 cm (9")	0.8955	0.0019
pyr10	25.40 cm (10")	0.8958	0.0020
pyr11	27.94 cm (11")	0.8954	0.0020
pyr12	30.48 cm (12")	0.8957	0.0018

The results show that  $k_{\text{eff}}$ 's increases quickly from first 2.5 cm (inch) of water accumulation to about 12.7 cm (5 inch). After that, the reflection effect begins to level off. The

highest value of  $k_{\text{eff}}=0.896$  is less than that of the sphere case ( $k_{\text{eff}}=0.910$ ) which verifies the bounding presumption.

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**APPENDIX A**  
**INDEPENDENT REVIEW COMMENTS AND CHECKLIST**

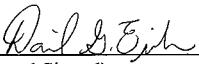
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## CHECKLIST FOR TECHNICAL PEER REVIEW

**Document Reviewed:** CSER 99-002:Criticality Safety Evaluation Report for Unrestricted Moderation of Sludge Material with Two-Boat Operation in Gloveboxes HC-21A and HC-21C

Yes No\* NA

- [ ] [ ] Problem completely defined.
- [ ] [ ] Necessary assumptions explicitly stated and supported.
- [ ] [ ] Computer codes and data files documented.
- [ ] [ ] Data used in calculations explicitly stated in document.
- [ ] [ ] Data checked for consistency with original source information as applicable.
- [ ] [ ] Mathematical derivations checked including dimensional consistency of results.
- [ ] [ ] Models appropriate and used within range of validity or use outside range of established validity justified.
- [ ] [ ]  Hand calculations checked for errors. Spreadsheet results should be treated exactly the same as hand calculations.
- [ ] [ ] Software input correct and consistent with document reviewed.
- [ ] [ ] Software output consistent with input and with results reported in document reviewed.
- [ ] [ ] Limits/criteria/guidelines applied to analysis results are appropriate and referenced. Limits/criteria/guidelines checked against references.
- [ ] [ ] Safety margins consistent with good engineering practices.
- [ ] [ ] Conclusions consistent with analytical results and applicable limits.
- [ ] [ ] Results and conclusions address all points required in the problem statement.
- [ ] [ ] \*\*Review calculations, comments, and/or notes are attached.
- [ ] [ ] **Document approved (i.e., the reviewer affirms the technical accuracy of the document).**
- [ ] [ ] Traceability

D. G. Erickson   
Reviewer: (Printed and Signed)

2-19-99

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.

## Technical Peer Review Comments

D. G. Erickson of the Criticality and Shielding group in FDNW Specialty Engineering carried out the technical peer review of HNF-4025, Rev. 0, CSER 99-002, *Criticality Safety Evaluation Report for Unrestricted Moderation of Sludge Material with Two-Boat Operation in Gloveboxes HC-21A and HC-21C*, for which the following comments are provided.

The technical arguments given in the report were found to be sound for qualifying the criticality safety of Gloveboxes HC-21A and HC-21C for operations involving two furnace boats and unrestricted moderation sludges. The glovebox mass limit of 2.5 kg and glovebox volume limit of 7.1 l are both significant limits that help assure the criticality safety of the operation. All credible contingencies resulted in  $k_{eff}$ s that are within allowables.

The review of this CSER showed that the normal conditions were analyzed adequately and very conservatively modeled the actual conditions that would be found in the glovebox. Some of the conservatisms were: maximum H/X ratio based on exceeding the actual container volumes, nominal reflection on all containers, and full water reflection of the glovebox.

Analysis of the off-normal conditions also incorporated most if not all of the above mentioned conservatisms, as well as including additional conservatisms that bound any credible off-normal conditions (i.e. nominally reflected 7.1 l sphere for the seismic analysis). The analysis shows that even if the glovebox were to be flooded, additional materials were brought into the glovebox, or container spacing were lost, the system is still subcritical. In all cases adequate margins of safety exist to assure that the operations to be performed in the gloveboxes does not pose any criticality concerns. For the fire analysis, a non-credible scenario that had full flooding was postulated, and was shown to be acceptable.

The analysis of the postulated seismic event, also, very conservatively modeled any credible rearrangement of the materials and containers in the glovebox. The model used a sphere of excessively moderated  $PuO_2$  with nominal water reflection surrounding the spherical model. It is not credible to believe that any event could cause the materials contained in the glovebox to even approach the modeled geometry. A more realistic inverted pyramid model was also created to show how conservative the spherical model was.

The report was reviewed for technical accuracy, consistency, coverage of all credible contingencies, and adequacy of limits, and found to be sound. Extensive comments regarding the document format and content were made and have been adequately resolved. All editorial comments have also been adequately resolved. A different model for the base case was suggested, and found to be more limiting than the original base case, therefore, all analyses other than seismic were rerun to assure they were bounding.

The input and output files from all computer calculations were also reviewed. The input files were checked for model adequacy, material densities, geometry, and container volumes. The  $k_{eff}$  values given in the report were verified against the results in the output files, and the outputs were reviewed for adequate convergence.

This reviewer affirms that based on the analysis contained in CSER 99-002, the operations proposed for Gloveboxes HC-21A and HC-21C with unrestricted moderation sludges are safe from a criticality standpoint.

## CHECKLIST FOR INDEPENDENT PEER REVIEW

**Document Reviewed:** CSER 99-002:Criticality Safety Evaluation Report for Unrestricted Moderation of Sludge Material with Two-Boat Operation in Gloveboxes HC-21A and HC-21C

Yes No\* NA

- [ ] [ ] Problem completely defined.
- [ ] [ ] Necessary assumptions explicitly stated and supported.
- [ ] [ ] Computer codes and data files documented.
- [ ] [ ] Data used in calculations explicitly stated in document.
- [ ] [ ] Data checked for consistency with original source information as applicable.
- [ ] [ ] Mathematical derivations checked including dimensional consistency of results.
- [ ] [ ] Models appropriate and used within range of validity or use outside range of established validity justified.
- [ ] [ ] Hand calculations checked for errors. Spreadsheet results should be treated exactly the same as hand calculations.
- [ ] [ ] Software input correct and consistent with document reviewed.
- [ ] [ ] Software output consistent with input and with results reported in document reviewed.
- [ ] [ ] Limits/criteria/guidelines applied to analysis results are appropriate and referenced. Limits/criteria/guidelines checked against references.
- [ ] [ ] Safety margins consistent with good engineering practices.
- [ ] [ ] Conclusions consistent with analytical results and applicable limits.
- [ ] [ ] Results and conclusions address all points required in the problem statement.
- [ ] [ ] \*\*Review calculations, comments, and/or notes are attached.
- [ ] [ ] **Document approved (i.e., the reviewer affirms the technical accuracy of the document).**
- [ ] [ ] Traceability

A. D. Wilcox

*Austin D. Wilcox*

3/16/99

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 changes to this CSER were  
editorial and didn't impact the technical  
analysis. Austin Wilcox 3/23/99*

# MOHR AND ASSOCIATES

ENGINEERING-ANALYSIS-CONSULTING

1440 AGNES STREET  
RICHLAND, WA 99352  
509-946-0943  
FAX 509-946-4395

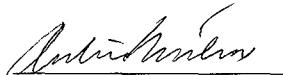
February 23, 1999

To: J. Lan  
From A.D. Wilcox

Subj: Review of CSER 99-002: Criticality Safety Evaluation Report for Unrestricted Moderation of Sludge Material with Two-Boat Operations in Gloveboxes HC-21A and HC-21C

The subject CSER was reviewed. The analyses shows that two boats may be allowed in the gloveboxes during normal and off-normal operations and are sufficiently conservative to show an adequate margin of safety. Several editorial comments were transmitted informally to you and have been incorporated into the CSER.

Sincerely,



Archie D. Wilcox

The subsequent editorial changes to this CSER were reviewed and found to not impact the technical conclusions.



**APPENDIX B**

**MCNP4B COMPUTER CODE VALIDATION**

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## B.1 VALIDATION PROCEDURE

The validation of the computer code methods used in this analysis consisted of testing that the code and neutron cross-sections calculations on known critical configurations, benchmark experiments, that have the fissile isotopes in systems being studied match the benchmark cases  $k_{\text{eff}}$ . Such analyses determine a calculational bias (the deviations of calculated  $k_{\text{eff}}$  values from unity for the benchmark cases) and the uncertainties culminating from the experimental and calculational errors and spread in the values calculated for benchmark cases.

The safety criteria for future calculations on undetermined systems requires that the bias-adjusted  $k_{\text{eff}}$  does not exceed  $k_{\text{limit}}$  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 MCNP4B calculation for the system in question,

bias = mean difference ( $k_{\text{calc}} - 1.0$ ) for benchmark criticals plus the product of the standard deviation of this mean difference times a multiplier for incorporating 95% of the population at the 95% confidence level for the number of degrees of freedom in the validation with benchmark criticals,

1.645 = number of standard deviations in standard normal distribution required to yield 95% of the distribution (95% confidence) of a one-sided distribution,

$\sigma_{\text{calc}}$  = standard deviation given by MCNP4B calculation for system in question, and

$k_{\text{limit}}$  = 0.95 for plutonium systems, generally.

Thus, the bias-adjusted  $k_{\text{eff}}$  includes the statistical uncertainties in both the particular MCNP4B calculation and the validation calculations to benchmark experiments.

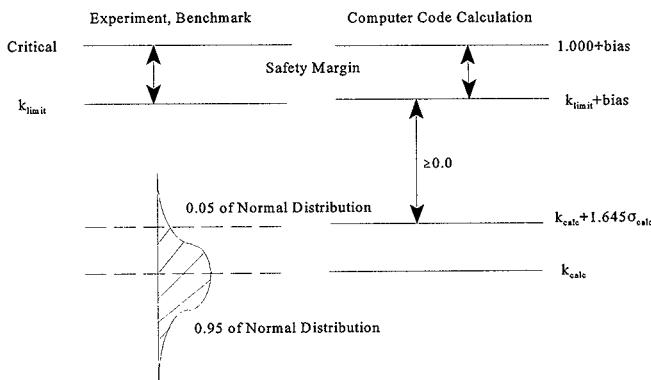


Figure B.1 Logic of Validation Procedure

## 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

A  $k_{\text{limit}}$  of 0.95 is used when the cases to be calculated are predominately composed of these bench marked material. For materials which are analyzed, but not benchmarked, a lower  $k$  limit is to be used (usually  $k_{\text{limit}} = 0.90$ ) per HNF-PRO-537.

The safety criteria for future calculations on undetermined systems requires that the lower tolerance limit  $b_L$  is calculated such that there is 95% confidence that 95% of the population is above that limit. This is expressed by the following formula:

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

where  $b_L$  = lower tolerance limit for 95% confidence that 95% of population is below this limit,  
 $k_{\text{avg}}$  = the average of the  $k_{\text{eff}}$ '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  
 $\sigma_{\text{avg}}$  = standard deviation of the MCNP  $k_{\text{eff}}$ 's.

Bias is calculated by the following formula:

$$\text{bias} = b_L - 1.000$$

where bias = mean difference ( $k_{\text{calc}} - 1.0$ ) for benchmark criticals plus the product of the standard deviation of this mean difference times a multiplier for incorporating 95% of the population at the 95% confidence level for the number of degrees of freedom in the validation with benchmark criticals,  
 $b_L$  = lower tolerance limit for 95% confidence that 95% of population is below this limit, and  
1.000 = the average of the  $k_{\text{eff}}$ 's for the critical experiments.

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, but,  $k_{\text{limit}}$  of 0.90 may be used if the moderator or reflector in the system being analyzed were not included in the materials evaluated in the MCNP 4B criticality code validation.

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

$$k_{\text{calc}} - (-0.005) + 1.645 * 0.002 \leq 0.95, \text{ or [Plutonium non-metal]}$$

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

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**.

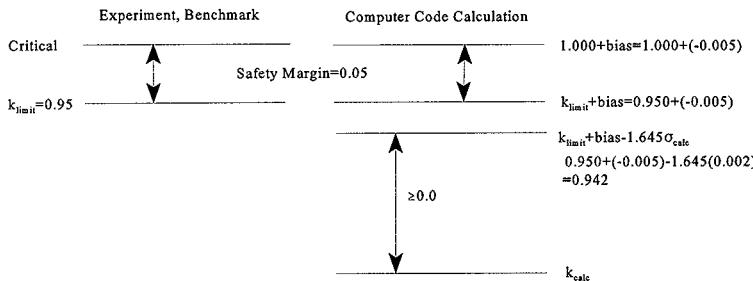


Figure B.2 Implementation of Validation Procedure

### 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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INP2

gloveboxes hc-21a, hc-21c cser for unrestricted moderation

c normal base case, 2 boats, 4 cans, 1 sweep, total of 3500 gm of pu

1	0	31	imp:n=0 \$ outside world
2	4 -0.00129	(-19: 20:-21: 22:-23: 24) -31	imp:n=1 \$ outside glovebox
3	5 -1.00	19 -20 21 -22 23 -24	
		(-13: 14:-15: 16:-17: 18)	imp:n=1 \$ 12" of water
4	4 -0.00129	13 -14 15 -16 17 -18	
		#7 #10 #13 #16 #19 #22 #25	imp:n=1 \$ inside glovebox

c boat 1 model

5	1 -1.449958	1 -2 3 -4 5 -6	u=1 imp:n=1 \$ pu in boat 1
6	5 -1.00	(-1: 2: -3: 4: -5: 6)	u=1 imp:n=1 \$ 1" of water
7	0	7 -8 9 -10 5 -12	trcl=1 fill=1 imp:n=1 \$

c boat 2 model

8	1 -1.449958	1 -2 3 -4 5 -6	u=2 imp:n=1 \$ pu in boat 2
9	5 -1.00	(-1: 2: -3: 4: -5: 6)	u=2 imp:n=1 \$ 1" of water
10	0	7 -8 9 -10 5 -12	trcl=2 fill=2 imp:n=1 \$

c canister 1 model

11	1 -1.449958	-27 -26 25	u=3 imp:n=1 \$ pu in can 1
12	5 -1.00	(27: 26:-25)	u=3 imp:n=1 \$ 1" of water
13	0	-30 -29 25	trcl=3 fill=3 imp:n=1 \$

c canister 2 model

14	1 -1.449958	-27 -26 25	u=4 imp:n=1 \$ pu in can 2
15	5 -1.00	(27: 26:-25)	u=4 imp:n=1 \$ 1" of water
16	0	-30 -29 25	trcl=4 fill=4 imp:n=1 \$

c canister 3 model

17	1 -1.449958	-27 -26 25	u=5 imp:n=1 \$ pu in can 3
18	5 -1.00	(27: 26:-25)	u=5 imp:n=1 \$ 1" of water
19	0	-30 -29 25	trcl=5 fill=5 imp:n=1 \$

c canister 4 model

20	1 -1.449958	-27 -26 25	u=6 imp:n=1 \$ pu in can 4
21	5 -1.00	(27: 26:-25)	u=6 imp:n=1 \$ 1" of water
22	0	-30 -29 25	trcl=6 fill=6 imp:n=1 \$

c sweep model

23	3 -2.034923	-33 -32 25	u=7 imp:n=1 \$ pu in a sweep
24	5 -1.00	(33: 32:-25)	u=7 imp:n=1 \$ 1" of water
25	0	-35 -34 25	trcl=7 fill=7 imp:n=1 \$

c ----- boat -----

1	px 0.0001		
2	px 12.7000	\$ 5"	
3	py 0.0001		
4	py 27.9400	\$ 11"	
5	pz 0.0001		
6	pz 6.4821	\$ 2.5"=6.35, this dim. is for 2.3 liter	

c ----- 1" h2o -----

7	px -2.5400		
8	px 15.2400	\$ 5" + 1" water	
9	py -2.5400		
10	py 30.4800	\$ 11" + 1" water	
11	pz -2.5400		
12	pz 9.0221	\$ 2.5"=6.35, this dim. is for 2.3 liter + 1" water	

c ----- glovebox -----

13	px 0.0000		
14	px 73.0000	\$ 42" wide of glovebox	
15	py 0.0000		
16	py 65.0000	\$ 128" long of glovebox	

```

17      pz      0.0000
18      pz      25.0000      $ 42" deep of glovebox
c      ----- 12" h2o -----
19      px      -30.4800
20      px      103.4800      $ 42" wide of glovebox + 12" of water
21      py      -30.4800
22      py      95.4800      $ 128" long of glovebox + 12" of water
23      pz      -30.4800
24      pz      55.4800      $ 42" deep of glovebox + 12" of water
c      -----
25      pz      0.0020
26      cz      4.5100      $ 0.5 liter canister
27      pz      9.0200
c      -----
28      pz      -2.5400
29      cz      7.0500      $ 0.5 liter canister + 1" of water
30      pz      11.5600
c      -----
31      so      500.0000      $ sphere for outside world boundary
c      -----
32      cz      4.30127      $ 0.55 liter canister
33      pz      8.60254
c      -----
34      cz      6.84127      $ 0.55 liter canister + 1" of water
35      pz      11.14254

tr1    17.00    18.00    0.01      $ boat 1 inside glovebox
tr2    56.00    18.00    0.01      $ boat 2 outside glovebox
tr3    23.00    8.00     0.01      $ canister 1
tr4    7.10     25.40    0.01      $ canister 2
tr5    7.10     40.00    0.01      $ canister 3
tr6    23.00    56.00    0.01      $ canister 4
tr7    62.00    8.00     0.01      $ sweep 1

mode n
m1    94239.55c  1.00      8016.50c 31.20725  1001.50c  58.4145  $ rho=1.449958, boat
mt1   1wtr.01t
m2    94239.55c  1.00      8016.50c 27.22750  1001.50c  50.455   $ rho=1.517430, cans
mt2   1wtr.01t
m3    94239.55c  1.00      8016.50c 13.9600   1001.50c  23.91    $ rho=2.034923, sweep
mt3   1wtr.01t
m4    7014.50c  0.790000  8016.50c  0.210000   $ rho=1.00129 ar, air
m5    1001.50c  0.66667   8016.50c  0.3333    $ rho=1.00   , h2o
mt5   1wtr.01t

c      m6    26000.55c  0.05536  24000.50c  0.01641  28000.50c  0.01122  $ ss
c      25055.50c  0.00155   42000.50c  0.00126  6000.50c  0.0002003 $ ss
c      m7    1001.50c  -0.0031   8016.50c  -0.4407  11023.50c  -0.0182   $ Concrete
c      12000.50c  -0.0376   13027.50c  -0.0607  14000.50c  -0.2157   $ concrete
c      15031.50c  -0.0009   16032.50c  -0.0009  36084.50c  -0.0066   $ concrete
c      20000.50c  -0.1306   22000.50c  -0.0049  26000.55c  -0.0788   $ concrete
c      mt7   1wtr.01t

kcode 3000 1.0 10 100
ksrc  17.00    18.00    0.01      $ boat 1 inside glovebox
      56.00    18.00    0.01      $ boat 2 outside glovebox
      23.00    8.00     0.01      $ canister 1
      7.10     25.00    0.01      $ canister 2
      7.10     40.00    0.01      $ canister 3
      23.00    56.00    0.01      $ canister 4
      62.00    8.00     0.01      $ sweep 1

```

```
prdmp j -300 1 3
totnu
print
ctme 100
```

## INP21

```
gloveboxes hc-21a, hc-21c cser for unrestricted moderation
c normal base case, 2 boats, 4 cans, 1 sweep, total of 3500 gm of pu
  1 0 31 imp:n=0 $
outside world
  2 4 -0.00129 (-19: 20:-21: 22:-23: 24) -31 imp:n=1 $ outside glovebox
  3 5 -1.00 19 -20 21 -22 23 -24 (-13: 14:-15: 16:-17: 18) imp:n=1 $ 12" of water
  4 4 -0.00129 13 -14 15 -16 17 -18 #7 #10 #13 #25 imp:n=1 $ inside glovebox
c boat 1 model
  5 1 -1.449958 1 -2 3 -4 5 -6 u=1 imp:n=1 $ pu in boat 1
  6 5 -1.00 (-1: 2: -3: 4: -5: 6) u=1 imp:n=1 $ 1" of water
  7 0 7 -8 9 -10 5 -12 trcl=1 fill=1 imp:n=1 $
c boat 2 model
  8 1 -1.449958 1 -2 3 -4 5 -6 u=2 imp:n=1 $ pu in boat 2
  9 5 -1.00 (-1: 2: -3: 4: -5: 6) u=2 imp:n=1 $ 1" of water
  10 0 7 -8 9 -10 5 -12 trcl=2 fill=2 imp:n=1 $
c boat 3 model
  11 1 -1.449958 1 -2 3 -4 5 -6 u=3 imp:n=1 $ pu in boat 2
  12 5 -1.00 (-1: 2: -3: 4: -5: 6) u=3 imp:n=1 $ 1" of water
  13 0 7 -8 9 -10 5 -12 trcl=3 fill=3 imp:n=1 $
c sweep model
  23 3 -2.0349 23 -33 -32 25 u=7 imp:n=1 $ pu in a sweep
  24 5 -1.00 (33: 32:-25) u=7 imp:n=1 $ 1" of water
  25 0 -35 -34 25 trcl=7 fill=7 imp:n=1 $
c ----- boat -----
  1 px 0.0001
  2 px 12.7000 $ 5"
  3 py 0.0001
  4 py 27.9400 $ 11"
  5 pz 0.0001
  6 pz 6.4821 $ 2.5"=6.35, this dim. is for 2.3 liter
c ----- 1" h2o -----
  7 px -2.5400
  8 px 15.2400 $ 5" + 1" water
  9 py -2.5400
  10 py 30.4800 $ 11" + 1" water
  11 pz -2.5400
  12 pz 9.0221 $ 2.5"=6.35, this dim. is for 2.3 liter + 1" water
c ----- glovebox -----
  13 px 0.0000
  14 px 77.0000 $ 42" wide of glovebox
  15 py 0.0000
  16 py 65.0000 $ 128" long of glovebox
  17 pz 0.0000
  18 pz 25.0000 $ 42" deep of glovebox
c ----- 12" h2o -----
  19 px -30.4800
  20 px 107.4800 $ 42" wide of glovebox + 12" of water
```

```

21      py   -30.4800
22      py   95.4800      $ 128" long of glovebox + 12" of water
23      pz   -30.4800
24      pz   55.4800      $ 42" deep of glovebox + 12" of water
c -----
c      25      pz   0.0020
c      26      cz   4.5100      $ 0.5 liter canister
c      27      pz   9.0200
c -----
c      28      pz   -2.5400
c      29      cz   7.0500      $ 0.5 liter canister + 1" of water
c      30      pz   11.5600
c -----
c      31      so   500.0000      $ sphere for outside world boundary
c -----
c      32      cz   4.30127      $ 0.55 liter sweeps
c      33      pz   8.60254
c -----
c      34      cz   6.84127      $ 0.55 liter sweeps + 1" of water
c      35      pz   11.14254

tr1  21.00  18.00  0.01      $ boat 1 inside glovebox
tr2  60.00  18.00  0.01      $ boat 2 outside glovebox
tr3  3.00   18.00  0.01      $ boat 3 represent 4 canisters
tr7  66.00  8.00   0.01      $ sweep 1

mode n
m1  94239.55c 1.00      8016.50c 31.20725  1001.50c 58.4145  $ rho=1.449958, boat
mt1  lwtr.01t
m2  94239.55c 1.00      8016.50c 27.22750  1001.50c 50.455   $ rho=1.517430, cans
mt2  lwtr.01t
m3  94239.55c 1.00      8016.50c 13.9600   1001.50c 23.91   $ rho=2.034923, sweep
mt3  lwtr.01t
m4  7014.50c 0.790000  8016.50c 0.210000   $ rho=1.00129 ar, air
m5  1001.50c 0.66667   8016.50c 0.3333   $ rho=1.00   . h20
mt5  lwtr.01t
kcode 3000 1.0 10 100
ksrc  21.00  18.00  0.01      $ boat 1 inside glovebox
      60.00  18.00  0.01      $ boat 2 outside glovebox
      3.00   18.00  0.01      $ canister 1
      66.00  8.00   0.01      $ sweep 1
prdmpr  j -300 1 3
totnus
print
ctme  100

```

## inp22

```

gloveboxes hc-21a, hc-21c cser for unrestricted moderation
c      normal base case, 2 boats, 4 cans, 1 sweep, total of 3500 gm of pu
      1      0                                         31      imp:n=0 $
outside world
      2      4 -0.00129 (-19: 20:-21: 22:-23: 24) -31      imp:n=1 $ outside glovebox
      3      5 -1.00      19 -20 21 -22 23 -24
                  (-13: 14:-15: 16:-17: 18)      imp:n=1 $ 12" of water
      4      4 -0.00129      13 -14 15 -16 17 -18
                  #7 #10 #13 #25      imp:n=1 $ inside glovebox
c      boat 1 model

```

```

5   1 -1.449958   1 -2  3 -4  5 -6      u=1 imp:n=1 $ pu in boat 1
6   5 -1.00      (-1: 2: -3: 4: -5: 6)      u=1 imp:n=1 $ 1" of water
7   0            37 -8  9 -10  5 -12 trcl=1 fill=1 imp:n=1 $
c   boat 2 model
8   1 -1.449958   1 -2  3 -4  5 -6      u=2 imp:n=1 $ pu in boat 2
9   5 -1.00      (-1: 2: -3: 4: -5: 6)      u=2 imp:n=1 $ 1" of water
10  0            7 -8  9 -10  5 -12 trcl=2 fill=2 imp:n=1 $
c   boat 2 model
11  1 -1.449958   1 -2  3 -4  5 -6      u=3 imp:n=1 $ pu in boat 3
12  5 -1.00      (-1: 2: -3: 4: -5: 6)      u=3 imp:n=1 $ 1" of water
13  0            7 -38 9 -10  5 -12 trcl=3 fill=3 imp:n=1 $
c   sweep model
23  3 -2.0349   23 -33 -32 25           u=7 imp:n=1 $ pu in a sweep
24  5 -1.00      (33: 32:-25)           u=7 imp:n=1 $ 1" of water
25  0            -35 -34 25 trcl=7 fill=7 imp:n=1 $

c ----- boat -----
1   px  0.0001
2   px  12.7000   $ 5"
3   py  0.0001
4   py  27.9400   $ 11"
5   pz  0.0001
6   pz  6.4821    $ 2.5"=6.35, this dim. is for 2.3 liter
c ----- 1" h2o -----
7   px  -2.5400
8   px  15.2400   $ 5" + 1" water
9   py  -2.5400
10  py  30.4800   $ 11" + 1" water
11  pz  -2.5400
12  pz  9.0221    $ 2.5"=6.35, this dim. is for 2.3 liter + 1" water
c ----- glovebox -----
13  px  0.0000
14  px  73.0000   $ 42" wide of glovebox
15  py  0.0000
16  py  65.0000   $ 128" long of glovebox
17  pz  0.0000
18  pz  25.0000   $ 42" deep of glovebox
c ----- 12" h2o -----
19  px  -30.4800
20  px  103.4800  $ 42" wide of glovebox + 12" of water
21  py  -30.4800
22  py  95.4800   $ 128" long of glovebox + 12" of water
23  pz  -30.4800
24  pz  55.4800   $ 42" deep of glovebox + 12" of water
c ----- canister -----
25  pz  0.0020
c   26  cz  4.5100   $ 0.5 liter canister
c   27  pz  9.0200
c ----- canister -----
c   28  pz  -2.5400
c   29  cz  7.0500   $ 0.5 liter canister + 1" of water
c   30  pz  11.5600
c ----- outside world boundary -----
31  so  500.0000  $ sphere for outside world boundary
c ----- canister -----
32  cz  4.30127   $ 0.55 liter canister
33  pz  8.60254
c -----
```

```

34      cz      6.84127      $ 0.55 liter canister + 1" of water
35      pz      11.14254
37      px      -.00001
38      px      12.70001      $ 5" + 1" water

tr1    17.00  18.00  0.01      $ boat 1  inside  glovebox
tr2    56.00  18.00  0.01      $ boat 2  outside glovebox
tr3     4.20  18.00  0.01      $ boat 3  replace 4 canisters
tr7    62.00   8.00  0.01      $ sweep    1

mode  n
m1    94239.55c  1.00      8016.50c 31.20725  1001.50c  58.4145  $ rho=1.449958, boat
mt1   lwtr.01t
m2    94239.55c  1.00      8016.50c 27.22750  1001.50c  50.455   $ rho=1.517430, cans
mt2   lwtr.01t
m3    94239.55c  1.00      8016.50c 13.9600   1001.50c  23.91   $ rho=2.034923, sweep
mt3   lwtr.01t
m4    7014.50c   0.790000  8016.50c 0.210000
m5    1001.50c   0.66667   8016.50c 0.3333   $ rho=1.00129 ar, air
m6    1001.50c   0.66667   8016.50c 0.3333   $ rho=1.00      . h20
mt5   lwtr.01t
kcode 3000 1.0 10 100
ksrc   17.00  18.00  0.01      $ boat 1  inside  glovebox
      56.00  18.00  0.01      $ boat 2  outside glovebox
      4.20   18.00  0.01      $ boat 3  replace 4 canisters
      62.00   8.00  0.01      $ sweep    1

prdmp
totnu
print
ctme  100

```

## inp22db

```

gloveboxes hc-21a, hc-21c cser for unrestricted moderation
c      normal base case. 2 boats, 4 cans, 1 sweep. total of 3500 gm of pu
      1      0                                         31          imp:n=0 $
outside world
      2      4 -0.00129 (-19: 20:-21: 22:-23: 24) -31      imp:n=1 $ outside glovebox
      3      5 -1.00          19 -20 21 -22 23 -24
                  (-13: 14:-15: 16:-17: 18)      imp:n=1 $ 12" of water
      4      4 -0.00129   13 -14 15 -16 17 -18
                  #7 #10 #13 #16 #25 #17      imp:n=1 $ inside glovebox
c      boat 1 model
      5      1 -1.449958   1 -2 3 -4 5 -6      u=1 imp:n=1 $ pu in boat 1
      6      5 -1.00          (-1: 2: -3: 4: -5: 6)      u=1 imp:n=1 $ 1" of water
      7      0      37 -8 9 -10 5 -6 trcl=1 fill=1 imp:n=1 $
c      boat 2 model
      8      1 -1.449958   1 -2 3 -4 5 -6      u=2 imp:n=1 $ pu in boat 2
      9      5 -1.00          (-1: 2: -3: 4: -5: 6)      u=2 imp:n=1 $ 1" of water
      10     0      7 -8 9 -10 5 -12 trcl=2 fill=2 imp:n=1 $
c      boat 3 model
      11     1 -1.449958   1 -2 3 -4 5 -6      u=3 imp:n=1 $ pu in boat 3
      12     5 -1.00          (-1: 2: -3: 4: -5: 6)      u=3 imp:n=1 $ 1" of water
      13     0      7 -38 9 -10 5 -6 trcl=3 fill=3 imp:n=1 $
      17     5 -1.00          7 -48 9 -10 6 -12 trcl=3      imp:n=1 $ 1" water on top
c      sweep model
      23     3 -2.0349          23 -33 -32 25      u=7 imp:n=1 $ pu in a sweep
      24     5 -1.00          (33: 32:-25)      u=7 imp:n=1 $ 1" of water
      25     0      -35 -34 25 trcl=7 fill=7 imp:n=1 $

```

```

c  boat 4 model
14    1 -1.449958  1  -2   3  -4   5  -6      u=8 imp:n=1 $ pu in boat 4
15    5 -1.00    (-1: 2: -3: 4: -5: 6)   u=8 imp:n=1 $ 1" of water
16    0          7  -8   9 -10  5 -12 trcl=8 fill=8 imp:n=1 $

c ----- boat -----
1   px    0.0001
2   px    12.7000   $ 5"
3   py    0.0001
4   py    27.9400   $ 11"
5   pz    0.0001
6   pz    6.4821   $ 2.5"=6.35, this dim. is for 2.3 liter
c ----- 1" h2o -----
7   px    -2.5400
8   px    15.2400   $ 5" + 1" water
9   py    -2.5400
10  py    30.4800   $ 11" + 1" water
11  pz    -2.5400
12  pz    9.0221   $ 2.5"=6.35, this dim. is for 2.3 liter + 1" water
c ----- glovebox -----
13  px    0.0000
14  px    73.0000   $ 42" wide of glovebox
15  py    0.0000
16  py    65.0000   $ 128" long of glovebox
17  pz    0.0000
18  pz    25.0000   $ 42" deep of glovebox
c ----- 12" h2o -----
19  px    -30.4800
20  px    103.4800  $ 42" wide of glovebox + 12" of water
21  py    -30.4800
22  py    95.4800   $ 128" long of glovebox + 12" of water
23  pz    -30.4800
24  pz    55.4800   $ 42" deep of glovebox + 12" of water
c ----- -----
25  pz    0.0020
c  26  cz    4.5100   $ 0.5 liter canister
c  27  pz    9.0200
c ----- -----
c  28  pz    -2.5400
c  29  cz    7.0500   $ 0.5 liter canister + 1" of water
c  30  pz    11.5600
c ----- -----
31  so    500.0000   $ sphere for outside world boundary
c ----- -----
32  cz    4.30127   $ 0.55 liter canister
33  pz    8.60254
c ----- -----
34  cz    6.84127   $ 0.55 liter canister + 1" of water
35  pz    11.14254
37  px    -0.0001
38  px    12.70001  $ 5" + 1" water
48  px    10.1500   $ 5" + 1" water

tr1  17.00  18.00  0.01   $ boat 1 inside glovebox
tr2  56.00  18.00  0.01   $ boat 2 outside glovebox
tr3  4.20   18.00  0.01   $ boat 3 replace 4 canisters
tr7  62.00  8.00   0.01   $ sweep 1
tr8  17.00  18.00  6.51   $ boat 4 for double batching

```

```

mode n
m1 94239.55c 1.00     8016.50c 31.20725 1001.50c 58.4145 $ rho=1.449958, boat
mt1 lwtr.01t
m2 94239.55c 1.00     8016.50c 27.22750 1001.50c 50.455 $ rho=1.517430, cans
mt2 lwtr.01t
m3 94239.55c 1.00     8016.50c 13.9600 1001.50c 23.91 $ rho=2.034923, sweep
mt3 lwtr.01t
m4 7014.50c 0.790000 8016.50c 0.210000 $ rho=1.00129 ar, air
m5 1001.50c 0.66667 8016.50c 0.3333 $ rho=1.00 , h20
mt5 lwtr.01t
kcode 3000 1.0 10 100
ksrc 17.00 18.00 0.01 $ boat 1 inside glovebox
      56.00 18.00 0.01 $ boat 2 outside glovebox
      4.20 18.00 0.01 $ boat 3 replace 4 canisters
      62.00 8.00 0.01 $ sweep 1
      17.00 18.00 6.51 $ boat 4 for double batching
prdmp j -300 1 3
totnu
print
ctme 100

inp22f

gloveboxes hc-21a, hc-21c cser for unrestricted moderation
c normal base case, 2 boats, 4 cans, 1 sweep, total of 3500 gm of pu
      1 0                                     31           imp:n=0 $
outside world
      2 4 -0.00129 (-19: 20:-21: 22:-23: 24) -31           imp:n=1 $ outside glovebox
      3 5 -1.00          19 -20 21 -22 23 -24
      (-13: 14:-15: 16:-17: 18)           imp:n=1 $ 12" of water
      4 5 -1.00          13 -14 15 -16 17 -18
      #7 #10 #13 #25           imp:n=1 $ inside glovebox
c boat 1 model
      5 1 -1.449958      1 -2 3 -4 5 -6 u=1 imp:n=1 $ pu in boat 1
      6 5 -1.00          (-1: 2: -3: 4: -5: 6) u=1 imp:n=1 $ 1" of water
      7 0          37 -8 9 -10 5 -12 trcl=1 fill=1 imp:n=1 $
c boat 2 model
      8 1 -1.449958      1 -2 3 -4 5 -6 u=2 imp:n=1 $ pu in boat 2
      9 5 -1.00          (-1: 2: -3: 4: -5: 6) u=2 imp:n=1 $ 1" of water
      10 0          7 -8 9 -10 5 -12 trcl=2 fill=2 imp:n=1 $
c boat 2 model
      11 1 -1.449958      1 -2 3 -4 5 -6 u=3 imp:n=1 $ pu in boat 3
      12 5 -1.00          (-1: 2: -3: 4: -5: 6) u=3 imp:n=1 $ 1" of water
      13 0          7 -38 9 -10 5 -12 trcl=3 fill=3 imp:n=1 $
c sweep model
      23 3 -2.0349      23 -33 -32 25 u=7 imp:n=1 $ pu in a sweep
      24 5 -1.00          (33: 32:-25) u=7 imp:n=1 $ 1" of water
      25 0          -35 -34 25 trcl=7 fill=7 imp:n=1 $
c ----- boat -----
      1 px 0.0001
      2 px 12.7000 $ 5"
      3 py 0.0001
      4 py 27.9400 $ 11"
      5 pz 0.0001
      6 pz 6.4821 $ 2.5"=6.35, this dim. is for 2.3 liter
c ----- 1" h20 -----
      7 px -2.5400

```

8        px    15.2400        \$ 5" + 1" water  
 9        py    -2.5400  
 10      py    30.4800        \$ 11" + 1" water  
 11      pz    -2.5400  
 12      pz    9.0221        \$ 2.5"=6.35, this dim. is for 2.3 liter + 1" water  
 c ----- glovebox -----  
 13      px    0.0000  
 14      px    73.0000        \$ 42" wide of glovebox  
 15      py    0.0000  
 16      py    65.0000        \$ 128" long of glovebox  
 17      pz    0.0000  
 18      pz    25.0000        \$ 42" deep of glovebox  
 c ----- 12" h2o -----  
 19      px    -30.4800  
 20      px    103.4800        \$ 42" wide of glovebox + 12" of water  
 21      py    -30.4800  
 22      py    95.4800        \$ 128" long of glovebox + 12" of water  
 23      pz    30.4800  
 24      pz    55.4800        \$ 42" deep of glovebox + 12" of water  
 c -----  
 25      pz    0.0020  
 c        cz    4.5100        \$ 0.5 liter canister  
 c        pz    9.0200  
 c -----  
 c        28      pz    -2.5400  
 c        29      cz    7.0500        \$ 0.5 liter canister + 1" of water  
 c        30      pz    11.5600  
 c -----  
 31      so    500.0000        \$ sphere for outside world boundary  
 c -----  
 32      cz    4.30127        \$ 0.55 liter canister  
 33      pz    8.60254  
 c -----  
 34      cz    6.84127        \$ 0.55 liter canister + 1" of water  
 35      pz    11.14254  
 37      px    -0.00001  
 38      px    12.70001        \$ 5" + 1" water  
  
 tr1    17.00    18.00    0.01        \$ boat 1 inside glovebox  
 tr2    56.00    18.00    0.01        \$ boat 2 outside glovebox  
 tr3    4.20    18.00    0.01        \$ boat 3 replace 4 canisters  
 tr7    62.00    8.00    0.01        \$ sweep 1  
 mode n  
 m1    94239.55c 1.00    8016.50c 31.20725    1001.50c 58.4145    \$ rho=1.449958, boat  
 mt1    lwtr.01t  
 m2    94239.55c 1.00    8016.50c 27.22750    1001.50c 50.455    \$ rho=1.517430, cans  
 mt2    lwtr.01t  
 m3    94239.55c 1.00    8016.50c 13.9600    1001.50c 23.91    \$ rho=2.034923, sweep  
 mt3    lwtr.01t  
 m4    7014.50c 0.790000    8016.50c 0.210000  
 m5    1001.50c 0.66667    8016.50c 0.3333    \$ rho=1.00129 ar, air  
 mt5    lwtr.01t  
 kcode 3000 1.0 10 100  
 ksrc    17.00    18.00    0.01        \$ boat 1 inside glovebox  
 56.00    18.00    0.01        \$ boat 2 outside glovebox  
 4.20    18.00    0.01        \$ boat 3 replace 4 canisters  
 62.00    8.00    0.01        \$ sweep 1  
 prdimp j -300 1 3

```
totnu
print
ctme 100
```

I22M10

The following MCNP input file is for a mist atmosphere case with 10% water density (cell 4). All other mist cases are identical except that the water density is changed.

```
gloveboxes hc-21a, hc-21c cser for unrestricted moderation
c   normal base case, 2 boats, 4 cans, 1 sweep, total of 3500 gm of pu
    1    0                                31      imp:n=0 $ outside world
    2    4 -0.00129 (-19: 20:-21: 22:-23: 24) -31      imp:n=1 $ outside glovebox
    3    5 -1.00   19 -20  21 -22  23 -24
                      (-13: 14:-15: 16:-17: 18)      imp:n=1 $ 12" of water
    4    5 -0.10000 13 -14  15 -16  17 -18
                      #7 #10 #13 #25      imp:n=1 $ inside glovebox
c   boat 1 model
    5    1 -1.449958 1 -2  3 -4  5 -6      u=1 imp:n=1 $ pu in boat 1
    6    5 -1.00   (-1: 2: -3: 4: -5: 6)      u=1 imp:n=1 $ 1" of water
    7    0      37 -8  9 -10  5 -12 trcl=1 fill=1 imp:n=1 $
c   boat 2 model
    8    1 -1.449958 1 -2  3 -4  5 -6      u=2 imp:n=1 $ pu in boat 2
    9    5 -1.00   (-1: 2: -3: 4: -5: 6)      u=2 imp:n=1 $ 1" of water
   10    0      7 -8  9 -10  5 -12 trcl=2 fill=2 imp:n=1 $
c   boat 3 model
   11    1 -1.449958 1 -2  3 -4  5 -6      u=3 imp:n=1 $ pu in boat 3
   12    5 -1.00   (-1: 2: -3: 4: -5: 6)      u=3 imp:n=1 $ 1" of water
   13    0      7 -38 9 -10  5 -12 trcl=3 fill=3 imp:n=1 $
c   sweep model
   23    3 -2.034923 -33 -32  25      u=7 imp:n=1 $ pu in a sweep
   24    5 -1.00   (33: 32:-25)      u=7 imp:n=1 $ 1" of water
   25    0      -35 -34 25      trcl=7 fill=7 imp:n=1 $
c   ----- boat -----
   1    px    0.0001
   2    px    12.7000      $ 5"
   3    py    0.0001
   4    py    27.9400      $ 11"
   5    pz    0.0001
   6    pz    6.4821      $ 2.5"=6.35, this dim. is for 2.3 liter
c   ----- 1" h2o -----
   7    px    -2.5400
   8    px    15.2400      $ 5" + 1" water
   9    py    -2.5400
  10    py    30.4800      $ 11" + 1" water
  11    pz    -2.5400
  12    pz    9.0221      $ 2.5"=6.35, this dim. is for 2.3 liter + 1" water
c   ----- glovebox -----
  13    px    0.0000
  14    px    73.0000      $ 42" wide of glovebox
  15    py    0.0000
  16    py    65.0000      $ 128" long of glovebox
  17    pz    0.0000
  18    pz    25.0000      $ 42" deep of glovebox
c   ----- 12" h2o -----
```

```

19      px  -30.4800
20      px  103.4800      $ 42" wide of glovebox + 12" of water
21      py  -30.4800
22      py  95.4800      $ 128" long of glovebox + 12" of water
23      pz  -30.4800
24      pz  55.4800      $ 42" deep of glovebox + 12" of water
c -----
c      25      pz  0.0020
c      26      cz  4.5100      $ 0.5 liter canister
c      27      pz  9.0200
c -----
c      28      pz  -2.5400
c      29      cz  7.0500      $ 0.5 liter canister + 1" of water
c      30      pz  11.5600
c -----
c      31      so  500.0000      $ sphere for outside world boundary
c -----
c      32      cz  4.30127      $ 0.55 liter canister
c      33      pz  8.60254
c -----
c      34      cz  6.84127      $ 0.55 liter canister + 1" of water
c      35      pz  11.14254
c      37      px  -.00001
c      38      px  12.70001      $ 5" + 1" water

tr1  17.00  18.00  0.01      $ boat 1  inside glovebox
tr2  56.00  18.00  0.01      $ boat 2  outside glovebox
tr3  4.20   18.00  0.01      $ boat 3  replace 4 canisters
tr7  62.00  8.00   0.01      $ sweep   1

mode  n
m1  94239.55c 1.00      8016.50c 31.20725  1001.50c  58.4145  $ rho=1.449958, boat
mt1  lwtr.01t
m2  94239.55c 1.00      8016.50c 27.22750  1001.50c  50.455   $ rho=1.517430, cans
mt2  lwtr.01t
m3  94239.55c 1.00      8016.50c 13.9600   1001.50c  23.91    $ rho=2.034923, sweep
mt3  lwtr.01t
m4  7014.50c  0.790000  8016.50c  0.210000
m5  1001.50c  0.66667   8016.50c  0.3333   $ rho=1.00129 ar, air
mt5  lwtr.01t
kcode 3000 1.0 10 100
ksrc  17.00  18.00  0.01      $ boat 1  inside glovebox
      56.00  18.00  0.01      $ boat 2  outside glovebox
      4.20   18.00  0.01      $ boat 3  replace 4 canisters
      62.00  8.00   0.01      $ sweep   1

prdmp
totnru
print
ctme  100

```

## pyr01

The following MCNP input file is of an inverted pyramid for the seismic analysis. This case has 2.54 cm (1 in.) of water accumulation on top (surface 8). Higher water levels are obtained by adjusting surface 8.

seismic contingency by a 2500 gm Pu in 7.2 liter pyramid with 1" h2o on top

```

1   1 -1.364406      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   34.92501 0 0  0 34.92501 0  0 0 34.92501
5   px  -2.54
6   py  -2.54
7   pz  -2.54
8   p   37.46501 0 0  0 37.46501 0  0 0 37.46501
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 38.3725    1001.50c 72.745 $ rho=1.364406, boat
mt1  lwtr.01t
m4  7014.50c 0.790000 8016.50c 0.210000      $ rho=0.00129 ar, air
m5  1001.50c 0.666667 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 240

INP2S

seismic contingency by a 2500 gm in 7.2 liter sphere with 1" h2o surrounding
1   1 -1.364406      -1      imp:n=1 $ inside pu
2   5 -1.00          1 -2      imp:n=1 $ 1" h2o
3   4 -0.00129        2 -3      imp:n=1 $ air
4   0                 3      imp:n=0 $ outside world

c ----- boat -----
1   so   11.92312    $ 7.1 liter
2   so   14.46312    $ 1" of h2o
c -----
3   so   500.00000    $ sphere for outside world boundary

mode n
m1  94239.55c 1.00      8016.50c 38.3725    1001.50c 72.745 $ rho=1.364406, boat
mt1  lwtr.01t
m4  7014.50c 0.790000 8016.50c 0.210000      $ rho=0.00129 ar, air
m5  1001.50c 0.666667 8016.50c 0.3333      $ rho=1.00      , h2o
mt5  lwtr.01t
kcode 3000 1.0 10 100
ksrc  0 0 0
prdmp j -300 1 3

```

totnu  
print  
ctme 240

**APPENDIX D**  
**STATEMENT OF WORK**

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## STATEMENT OF WORK

CSER FOR UNRESTRICTED MODERATION  
IN GLOVEBOX HC-21A AND HC-21C

January 5, 1999

## INTRODUCTION

CSER 98-011 was written to allow handling of 2 kg of sludge (unrestricted moderation) in containers totaling 4.6 liters in gloveboxes HC-21A and HC-21C. This CSER was based upon the plan to load sludge in one furnace boat at a time. During the signoff process, the PFP discovered the need for the flexibility to load two boats at a time using 2.5 kg in 7.1 liters in each glovebox. FDNW is directed to redo the analysis for two-boat operation.

## SCOPE

FDNW will perform an evaluation to demonstrate subcriticality for operation with unrestricted H/X in HC-21A and HC-21C gloveboxes at 2.5 kg of plutonium as plutonium oxide in 7.1 liters. Unit mass and unit volume limits of 1 kg and 4.3 liters along with 10-inch spacing will be maintained. Assume the plutonium is all Pu-239. Contingencies will be calculated as unlikely upsets from the base case. The work will involve the following activities:

- Calculate the base case with the highest reactivity. Load 1 kg Pu at H/X =60 in a boat and 250 g plutonium at H/X=60 in each of four 0.5 liter containers without spacing. A 0.5 liter sweeps container with 500 g plutonium and the rest of the volume water and second boat (in adjacent conveyor and containing 1 kg plutonium at H/X=60) are spaced 10 inches from the other containers. Model one inch water reflection around each boat and container and 12 inches of water around the glovebox; sides, ends, under, and over. The 12 inches of water simulating operators around the glovebox can be conservatively modeled just outside of the region that encompasses the containers described above. Find the arrangement of containers that would be the highest reactivity allowed by these limits (ie. 2.5 kg in glovebox in 4.8 liters and 1 kg in 2.3 liters on conveyor at 10 inches).
- calculate the overbatch/spacing/volume upset condition by adding one additional 2.3 liter boat containing 1000 g on top of the one in the glovebox (ie. 3.5 kg plutonium in glovebox in 7.1 liters and 1 kg in 2.3 liters on conveyor at 10 inches).
- calculate flooding initiated by fire by adding 2.5 inches of water on the floor around containers in the base case to simulate reflection of flooded second boat that is ready to be filled from the 0.5 liter containers.
- calculate the seismic contingency by simulating the dumping of the 2.5 kg plutonium H/X=60 in 7.1 liters in a corner of the glovebox with 1 inch nominal reflection. A spherical calculation would be acceptable if

it does not too conservatively show a k-effective above the subcriticality limit. If it does, then more accurately model the corner of the glovebox. If the reactivity is still to high, then reduce the base case to 2.5 kg plutonium in 6.6 liters, where the sweeps container must be one of the first four 0.5 liter containers.

- Follow the requirements of the Reference with the exception that a hazards review for this simple change of analysis is not required.
- Submit the results as an Supporting Document transmitted by EDT

#### COST

FDNW will provide the schedule for the above work by 1/11/99.

#### SCHEDULE

FDNW will provide the schedule for the above work by 1/11/99.

#### REFERENCE

Letter, M. E. Shaw to D. S. Leach, "Letter of Instruction, Task Order 915-003," BWHC-9860620, December 22, 1998.

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		ECN No. N/A

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