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Project Hanford Management Contractor for the
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CSER 01-009: PFP 241-Z Waste Tanks 900 Gram Mass Limit

Key Words: PFP, 241-Z waste tanks, plutonium, CSER, criticality, D8, D5

Abstract: This CSER raises the fissile mass limit for the PFP 241-Z Waste Tanks from 400 to 900 grams. This increase is allowed by increased control of the amount and location of fissile material waste sources to Tank TK-D8. The input of waste to TK-D8 is limited to 150 g or less per addition. The fissile mass in additions, the mass in the tank heel, and the tank inventory book keeping are done and then checked. The tank inventories are calculated conservatively by adding inputs of fissile mass but not subtracting outputs. After a tank is emptied, the tank fissile mass inventory is rebaselined to be equal to a conservatively measured NDA value for the tank.

CSER 01-009: PFP 241-Z WASTE TANKS

900 GRAM MASS LIMIT

October 2001

Prepared by
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1.0 INTRODUCTION AND SUMMARY

1.1 INTRODUCTION

The 241-Z waste tanks at PFP are large and geometrically unfavorable for criticality safety. Historically, these tanks have had a 400-gram fissile mass limit on each tank and conservative accounting rules for maintaining records on tank fissile inventory. This tank inventory includes the initial NDA value plus the tank throughput. Further, a transfer from one tank to another adds the entire transferring tank inventory to the tank receiving the transfer.

With this accounting system, the fissile mass inventory approaches the mass limit rapidly. Upon reaching the limit, the tanks can no longer receive additional liquids, shutting down liquid transfers while tank contents are sampled and analyzed. After the tank contents are transferred, NDA on the empty tank is required to set the heel fissile content as the reinitialized inventory value. The operation of the waste tanks under these rules is expensive and inefficient. When PFP was in production, the waste to these tanks had a large volume but small amounts of fissile material because of the incentive to recover all fissile material possible. PFP is now in a clean up mode. Volumes of waste liquids are smaller and may contain more fissile material because there is less incentive to recover plutonium from the waste streams. This new operating mode requires revised limits to permit efficient operation.

PFP has all sources that drain to the waste tanks in 241-Z controlled and limits each discharge to a maximum of 150 grams of fissile material. This CSER uses this control and the properties of the solutions in the tanks and their agitators to show that a larger mass limit is permissible for more efficient safe operation of the waste tanks.

1.2 DOUBLE CONTINGENCY DOCUMENTATION

This section presents a summary of the expected operations, the expected normal conditions, and the base case for normal conditions plus anticipated off-normal conditions for the 241-Z Waste Tanks. The hazards assessment in the quick screen for CSAR 79-044 (Wilkinson 2000) was considered adequate for this revised criticality assessment of the 241-Z waste system, since there are no new events introduced and raising the limit from 400 grams of plutonium per tank to 900 grams does not alter the likelihood of the events considered. The normal conditions with likely upset conditions constitute the base case. Table 1-1 lists the criticality limits and base case conditions for each criticality parameter. Table 1-2 summarizes the bounding contingencies.

1.2.1 Expected Operations

Discharges from PFP now accumulate in Tank TK-D8 prior to transfer to Tank TK-D5. The material in TK-D5 is treated and subsequently transferred to the 244-TX facility (tank farms). The fissile mass in each of these PFP discharges is recorded and a running total kept to determine the Tank TK-D8 and TK-D5 fissile inventory. This inventory includes any fissile

mass in the tank heel. The tank heel is the NDA value for the tank after the contents have been emptied.

1.2.2 Base Case Conditions

Based on the expected operations described above in Section 1.2.1, the base case for a tank vault includes a tank with 900 g plus an overbatch of 50 grams of fissile material in it and lard cans, a 55-gallon drum, and fissile material in the sump. Table 1-1 below summarizes the limits for normal conditions and the anticipated abnormal conditions used for each criticality parameter. This CSER uses the normal conditions allowed by limits and anticipated abnormal conditions to evaluate the criticality safety of operations in the base case. Section 5.0 of this CSER presents the analysis for the 241-Z waste system.

Table 1-1. Summary of Base Case Limits

Controlled Parameter	Limit	Abnormal but Anticipated Conditions
Mass	900 g of total plutonium per tank. 150 g of plutonium per addition to Tank TK-D8. Only one waste addition at a time. Tank inventory includes all additions until rebaselined. Sampling for mass of tanks done to double contingency standards (See Section 3.2, Item 6). Mass of all inputs to tanks determined to double contingency standards (See Section 3.2, Item 7). Record keeping of the mass in tanks and inputs to tanks done to double contingency standards (See Section 3.2, Item 9). Maximum of 400 g of plutonium on a vault floor and in a vault sump. Maximum of 400 g of plutonium in the overflow tank in vault for TK-D7. Lard can mass per CPS-Z-165-80100. 55-gallon drum mass per CPS-Z-165-80100.	950 g in tank
Volume	Lard can volume per CPS-Z-165-80100.	None[1]
Moderation	No organics allowed.	None[1]
Interaction	Maximum of 3 lard cans per vault. Maximum of 1 55-gallon drum per vault. Container spacing per CPS-Z-165-80100.	None
Reflection	None	None
Geometry	Tank NDA done on empty tanks.	None[1]
Isotopics	None	None
Enrichment	None	None

Controlled Parameter	Limit	Abnormal but Anticipated Conditions
Density	None	None
Concentration	None	None
Poisons	None	None

[1] All operations to add to or measure material in the waste tanks are done by procedure to meet double contingency requirements.

1.2.3 Contingency Conditions

This CSER reviewed conceivable off-normal conditions to determine contingencies, where a contingency is defined as a base case plus a single, independently, unlikely event. Contingencies are considered unlikely because each addition to Tank TK-D8 is strictly limited to a maximum 150 g of fissionable material and more than one person is required to track mass inventories in tanks and check them prior to fissile solution transfer. Table 1-2 summarizes the analyses of the unlikely, independent, non-concurrent off-normal events considered in Section 5.0 of this CSER.

The sequence of unlikely events that led to the smallest fissile mass configuration is used to set a minimum fissile mass limit for TK-D8. In this event, numerous waste additions of 35 g Pu/L are added to the tank ten feet above the tank bottom. This dilute mixture or solution reaches the tank bottom and adds to other additions of dilute material and is assumed to form a squat cone even though the added material does not have the viscosity to form a cone, at an optimal concentration of 35 g Pu/L. The required mass for criticality of the water and concrete reflected cone is 1288 g ± 10. This means more than two additions of 150 g each are needed to go from the fissile mass limit of 900 g or the base case tank inventory of 950 g to reach the fissile mass required for an unsafe quantity of fissile material in a squat cone. Therefore, the contingency of one 150 g fissile addition is bounded by the analysis shown in Section 5.1.

This scenario is applicable to TK-D8 where additions from drains are made and the additions are limited to 150 g per addition. TK-D5 can receive transfers from TK-D8 of more than 150 g per transfer, but no more than the TK-D8 inventory limit of 900 g. An overbatch contingency could add another 900 grams to Tank TK-D5. Since the material from TK-D8 has been mixed, the transferred material has a concentration less than 7 g Pu/L and can not make a 35 g Pu/L cone. The minimum fissile mass configuration would be a shallow slab of greater than 7 g Pu/L configuration. For this configuration, approximately 19 kg of fissile material is needed to form a critical configuration. Because of the number of transfers to TK-D5 to make this amount of fissile material, the tank is more than double contingent. If the other tanks in the waste system are used, the scenario for TK-D8 or for TK-D5 would apply.

Table 1-2. Contingencies

Geometry	Affected Criticality Parameter(s)	Barriers that Make Contingency unlikely or Criticality Incredible	Double Contingent Basis
150 gram overbatch of TK-D8	Mass	Double samples taken on solution transfer from 234-5Z and requirement for more than one person to keep inventory. The cone model used to set mass limit is overly conservative because it is an unlikely geometry for waste added to tank. Operator training/procedure	More than two additions of 150 grams Pu required to reach minimum critical mass (Section 5.1)
900 gram overbatch of Pu from transfer from TK-D8 to TK-D5	Mass	Sample analysis of fissile mass prior to tank transfers Mixing tank contents required before transfer Operator training/procedure	Multiple 900 g additions to reach 19 kg of Pu required for criticality in stirred waste. (Sections 5.5 and 5.9)
Organic solvent added and agitator draws added organic solvent into compact configuration	Moderation	Sample analysis for organics of additions and tank contents Minimum of 11 L in spherical shape Operator training/procedure	Criticality with organics is not credible (Section 5.3)
Tank leak of more than the allowed 400 grams Pu in sump	Geometry	Significant leak of more than 400 grams Pu is unlikely Sump liquid detector	Less reactive than 900 grams in tank (Section 5.14.1)
Sump to tank overbatch	Mass	Operator training/procedure	Less reactive than double batching TK-D5 (Section 5.9)
Overbatch of 55-gallon drum and lard can in vault areas	Mass	Operator training/procedure	Evaluated in the CSAR supporting the array storage (Sections 5.14.2 and 5.14.3)
Loss of spacing of 55-gallon drum and lard can	Interaction	Operator training/procedure	Less reactive than infinite array of lard cans (Sections 5.14.2 and 5.14.3)

1.3 SUMMARY

This CSER has investigated all identified credible configurations of fissile material. Most require too much fissile material to be credible with the controls on fissile material addition to the tanks. Additions to the tanks from drains and other sources are restricted to a maximum of 150 g per disposal. The mass addition is controlled by sampling and procedures that meet double contingency requirements.

This CSER shows that the storage of waste in the 241-Z tanks according to the limits and controls listed in Section 3 is acceptable. No single credible event causes the fissionable material to exceed limits specified by HNF-7098 (FH 2001) and ANS standards. Therefore, the CSER meets the requirements of the Double Contingency Principle for a criticality safety analysis specified in the Hanford Site Nuclear Criticality Safety Program, HNF-7098.

2.0 SYSTEM DESCRIPTION

2.1 241-Z WASTE RETENTION FACILITY

The 241-Z Waste Retention Facility is located south of 234-5Z Building. A 290-foot long underground piping trench connects the 241-Z Waste Retention Facility with the 234-5Z Building, the only remaining source of waste streams to the facility. Five nominal 5000-gallon tanks are in a line in 241-Z, each in its own vault as shown in Figure 1 at the end of Section 2.0. The vaults are 17-ft square and 22-ft high with 1-ft thick concrete walls, floor, and ceiling. Each tank rests on a 6-in. high raised, concrete octagonal base, centered in its vault. A sump is located in the north west corner of each of the five vaults and has dimensions of 2-ft by 2-ft by 1.5-ft. Liquid collected in sumps can be pumped into the waste tanks. The tanks are designated TK-D4 thru TK-D8. Moving from east to west the order is TK-D5, -D4, -D6, -D7, and –D8. The top of the tanks is 12 ft below the top deck of the vaults, which is just above grade. The top deck of each vault has a 4-ft diameter access hatch. A grating deck is located 13 ft below the top deck and nine feet above the floor of the vault. TK-D6 is inactive. Each active tank overflow nozzle connects to the overflow tank in the TK-D7 vault. The overflow tank has a nominal capacity of 200 gallons, has a level alarm, and a 2-inch vent to an exhaust filter.

Discharges from PFP now accumulate in Tank TK-D8 prior to transfer to Tank TK-D5 for treatment and subsequent transfer to the 244-TX facility (tank farms). The fissile mass in each of these PFP discharges is recorded and a running total kept to determine the Tank TK-D8 fissile inventory. This inventory includes any fissile mass in the tank heel. The tank heel is the NDA value for the tank after the contents have been transferred.

2.2 TANKS

The waste retention tanks are flat bottomed, 10-ft in outside diameter, and 8-ft vertical cylindrical section topped by a dished head about two feet high. The nominal tank capacity is 18,000 liters, the working capacity is 12,000 liters, and the tank over flows at 15,478 liters. The tank material is AISI type 347 stainless steel and the wall thickness is 3/8 in. The tank bottom pitches 3-3/8 in. from north to south. The top of the flanges on the vertical tank nozzles are ten feet above the vault floor. The waste inlet nozzles to the Tanks TK-D8 and TK-D5 project vertically up from the surface of the tanks dished tops at a distance from the agitator at the center line of the tank and inboard of the tank vertical cylindrical outside wall. These inlet pipes have no down-comer extending into the tanks. The agitator is composed of four paddles at 90 degrees to each other within a 23-in. diameter circle. The bottom of the paddles are 33 inches above the bottom of the tank as shown in Figure 2 at the end of Section 2.0.

The cylindrical overflow tank outside dimensions are 30 in. (76.2 cm) diameter and 6-ft (182.9 cm) tall as shown in Drawing H-2-27584. This tank is located in the southeast corner of the TK-D7 vault.

2.3 TANK CONNECTIONS

The inlet flow of waste enters TK-D8 thru the inlet pipes. The waste is stored in TK-D8 as-is. The waste is not normally chemically treated in TK-D8. The fissionable waste is normally in solution in TK-D8. The waste is jetted (transfer by steam powered ejectors) to TK-D5 for preparation for transfer to Tank Farms. Prior to 1993, waste from different sources and buildings was piped to different tanks. TK-D4 and TK-D7 are available to store waste if TK-D8 reaches its storage capacity before TK-D5 is available to receive the waste. TK-D6 is not in service because it was found to be leaking. Tanks TK-D5 and TK-D4 over flow from side nozzles at an elevation of about 8-ft above the vault floor, TK-D7 and TK-D8 over flow from top nozzles at about 10.3 ft above the vault floor as shown in Drawings H-2-27583 and H-2-27597.

The waste flow from PFP is routed to TK-D8 only. TK-D8 has only one outlet line for transfers to the other large tanks and it allows transfers to TK-D5 only. TK-D5 collects the waste for chemical adjustment and transfers the waste to Tank Farms. Figure 3 at the end of Section 2.0 shows major tank connections and input sources.

The contents in the overflow tank in TK-D7 vault can be jetted to TK-D4. The sumps in vaults with TK-D4, -D6, -D7, and –D8 can be jetted into TK-D4. TK-D4 can collect the tank and vault overflows or sump liquids. The contents of TK-D4 can be jetted to TK-D7 or TK-D8. The TK-D4 line to TK-D7 is the only input to TK-D7. TK-D7 has only one outlet line and it allows transfers to TK-D5. These connections allow sump and overflow to be put into the collection tank TK-D8 or the chemical adjustment outlet tank TK-D5. The sump in the vault with TK-D5 can only be emptied into TK-D5. Drawing H-2-80102, Engineering Flow Diagram, shows the tank piping connections.

2.4 WASTE SOURCES

Tank TK-D8 may receive aqueous waste from, or is connected to, (1) the Analytical Labs (A-Labs), (2) the Plutonium Process Support Laboratories (PPSL) including the PPSL Laboratory Prototype Calciner in Glovebox HC-188-1, (3) process areas of PFP 234-5Z building, (4) periodic flushes and seal water from the 26-inch vacuum system, (5) filtrate from the plutonium precipitation process in Glovebox HC-230C-4, (6) Production Vertical Denitration Calciner in Glovebox HC-60, and (7) the Plutonium Reclamation Facility (PRF).

In the past, the piping was routed from sources in the 234-5Z Building through the floor into pipe trenches. Pipe trenches are located just under the floor of the main level of PFP and are wide and deep enough to contain several pipes. The pipes in the pipe trenches are connected to the main drain headers located in the tunnels under the 234-5Z Building. The main drain headers are now connected to Tank TK-D8.

Washington State law now requires that these waste pipes be visually inspected. However, operations could not visually inspect the pipes in the enclosed pipe trenches in 234-5Z building. Several years ago, the pipes leading from the waste sources to the main drain header pipes in the tunnel below the first floor of 234-5Z Building were replaced. The piping from these waste sources is made of kynar, and is routed above the floor to just above the tunnels. No

active waste pipes are routed through the pipe trenches. By routing the waste piping above the floor, they can be visually inspected. The pipes are routed through the floor above the tunnels and connected to the main drain headers in the tunnels. The piping in the tunnels can also be visually inspected. The pipes from Building 234-5Z to Tank TK-D8 are double encased steel pipes with leak detection, and do not have any low points or p-traps. The pipes in the tunnels are made of stainless steel. All of the drain headers were also reconfigured to drain into Tank TK-D8.

The quick screen for Revision 1a to CSAR 79-044 (Wilkinson 2000) identified fifty-seven potential sources from building drawings, discussions with the Cognizant Engineer of the 241-Z tanks, and with representatives from the labs and process areas. These potential sources are listed in the following tables (Tables 2-1, 2-2, and 2-3). The existence of these sources, along with the fissile mass limits, holdup, and the potential for fissionable material to enter these sources was investigated in walkdowns and subsequent discussions with the PFP criticality safety representative (CSR) and operations. The walkdowns found that seven of the potential sources, as noted in Tables 2-1, 2-2, and 2-3, are no longer capable of draining to the 241-Z waste tanks.

For the quick screen, several walkdowns were performed with operations personnel to identify all of the sources available to Tank TK-D8. Representatives from A-Labs, PPSL, and Stabilization were present when their respective areas were walked down. Additional walkdowns were performed in the tunnels. The CSR was also present for some of these walkdowns.

These walkdowns determined that the 46 existing sources located in Building 234-5Z lead to Tank TK-D8. Visual inspections of sources at Building 234-5Z determined that 12 of them are blocked or covered. Two of the open sources are sinks and floor drains in the two decontamination rooms. Most of the PFP sources are open sinks in A-Labs and PPSL both inside and outside hoods. A list of the potential sources examined in this document is provided in the tables below. All of the sinks listed were found to be connected to drain headers D4, D5, and D6. There are also multiple sources located in PRF (see Section 2.4.7).

The quick screen considered that all the potential sources are connected to Tank TK-D8, unless the source is permanently blocked or is not a credible source. The sources not considered credible are the condensate traps connected to Glovebox 552 in Room 152, the hydraulic pump system for the glovebox in Room 145, and the floor drains in Room 191.

2.4.1 Analytical Lab

Table 2-1 lists all credible sources of waste streams to TK-D8 from the Analytical Laboratory. N/A means not available.

Table 2-1. Potential Sources in Analytical Laboratory at PFP.

Source	Exists?	Holdup	Criticality Limit	Operation Active?	Blocked?	Notes
Room 133 Sink	Yes	N/A	N/A	No	No	a
Room 134 Sink	Yes	N/A	N/A	No	Yes	b
Room 143, Hood 2 Sink	Yes	No	150 g	Yes	No	i
Room 143, Hood 3 Sink	Yes	No	150 g	Yes	No	i
Room 143, Hood 5 Sink	Yes	No	150 g	Yes	Yes	b, i, j
Room 144, Hood 9 Sink	No					
Room 145, Glovebox Hydraulic	Yes	103 g	None	No	No	c
Room 146 Sink	Yes	N/A	N/A	Yes	No	
Room 148 Sink	Yes	N/A	N/A	Yes	Yes	d
Room 149, Hood 3	Yes	N/A	None	No	No	e
Room 152, Glovebox 552	No					
Room 152, Steam Condensate Traps	Yes	N/A	N/A	Yes	No	f
Room 153 Sink	No					
Room 153 Condensate Drain	Yes	N/A	None	No	Yes	g
Room 155 Sink	Yes	N/A	N/A	No	Yes	b
Room 221C, Hood 221C-1 Sink	Yes	N/A	150 g	Yes	No	
Room 221C, Hood 221C-2 Sink	Yes	N/A	150 g	Yes	No	
Room 221D, Hood 221D-2 Sink	Yes	N/A	150 g	Yes	Yes	
Room 221D, Hood 221D-3&4 Sink	Yes	N/A	250 g	Yes	Yes	
Room 221E, Hood 221E-1 Sink	Yes	N/A	150 g	Yes	No	
Room 221E, Dishwasher	Yes	N/A	None	No	No	h
Safety Shower Drain, Column H3, Corridor 4B	Yes	N/A	N/A	Yes	Yes	
Eyewash Station Outside Room 156	Yes	N/A	N/A	Yes	No	

a) A-labs, dark room; no fissile material; currently used for chemical storage.
b) Sink is covered.
c) Glovebox is not in use. Hydraulic system is not a viable source. Listed as connected to the D-1 header system in the SAR.
d) The sink is covered by Plexiglas, and is used as a 90-day pad and chemical storage.
e) Offgas scrubber. This hood has never been used.
f) Condensate drain line for Glovebox 552. Not a viable source. Listed as connected to the D-3 header system in the SAR. Piping goes directly into the floor; not routed above the floor.
g) Nothing is connected to the line.
h) Dishwasher has never been used.
i) Access to this room will be controlled, and the sinks in this room will not require plugging.
j) The vent line in hood 5 Room 143 is not considered to be a credible source.

2.4.2 Plutonium Process Support Laboratories

Table 2-2 lists the sources of waste streams to TK-D8 from the Plutonium Process Support Laboratory. N/A means not available.

Table 2-2. Potential Sources in the Plutonium Process Support Laboratory at PFP.

Source	Exists?	Holdup	Criticality Limit	Active?	Blocked?	Notes
Room 179, Glovebox 4	Yes	119 g	400 g	Yes	No	a
Room 179, Glovebox 6	Yes	24 g	400 g	Yes	No	a
Room 179, Glovebox 9	Yes	32 g	400 g	Yes	No	a
Room 179, Glovebox 10	Yes	19 g	2500 g	Yes	No	f
Room 179, Glovebox 12	Yes	33 g	2500 g	Yes	No	f
Room 179 Sink	No					
Room 180, Floor Drain	Yes	N/A	N/A	Yes	Yes	
Room 182 Sink	Yes	N/A	N/A	Yes	Yes	b
Room 187 Sink	Yes	N/A	N/A	Yes	No	
Room 187, Hood 3	Yes	N/A	150 g	Yes	No	
Room 187, Hood 5	Yes	N/A	150 g	Yes	No	
Room 188, Glovebox 1	Yes	c	14,000 g	Yes	No	c
Room 188, Glovebox 1 Off-gas Scrubber	Yes	N/A	See GB 1	Yes	No	g
Room 188, Glovebox 1 Phase Disengaging Tanks	Yes	N/A	See GB 1	Yes	No	g
Room 191, Hood 2 Sink	Yes	N/A	None	Yes	No	d
Room 191, Sink, North Wall	Yes	N/A	N/A	Yes	Yes	d, e
Room 191, 2 floor drains	Yes	N/A	N/A	Yes	No	d

a) Currently posted to allow 250 grams.
b) Sink is covered.
c) Material inside the calciner is considered holdup. The glovebox has a CPS posting of 14 kilograms for criticality, but only a 7-kilogram SAR limit of dispersible plutonium.
d) Room 191 is a cold room. No fissionable material is allowed.
e) Sink Drain is plugged.
f) Active criticality drain exists.
g) Only one valve exists between source and Tank TK-D8. Will require two valves prior to restart of the calciner, or the evaluation must be revised to address double-batching of Tank TK-D8 from these sources

2.4.3 Process Areas of 234-5Z Building

Table 2-3 lists the sources of waste streams to Tank TK-D8 from process areas in the 234-5Z Building. N/A means not available.

Table 2-3. Potential Sources in the Process Areas at PFP.

Source	Exists?	Holdup	Criticality Limit	Active?	Blocked?	Notes
Room 125/126, DeCon Room	Yes	N/A	N/A	Yes	No	
Room 196, DeCon Room	Yes	N/A	N/A	Yes	No	
Room 228C, Sink	Yes	N/A	N/A	Yes	No	a
Room 228A, B, C Drip Header	No					b
Room 230C, Glovebox HC-60	Yes	232 g	None	No	No	c, i
Room 230C, Glovebox HC-230C-2	No					d
Room 230C, Glovebox HC-230C-4	Yes			Yes	Yes	e, j
Room 235B, Hydraulic Pump	Yes	N/A	N/A	No	No	f
Room 235A-2, Hydraulic Pump	Yes	N/A	N/A	No	No	f
Room 235A-3, Glovebox HA-9A	Yes	2,821 g	None	No	No	g, i
Duct Level Sink	No					
Off Gas Scrubber, Room 232	Yes	N/A	None	No	No	h

a) Sink is partially covered. Sink may be removed.
b) No visible connections found in Rooms 228A, B, or C.
c) Inactive glovebox, pipe opening leading to Tank TK-D8 is about 1' above the glovebox floor.
d) Piping exists, but is not connected to the glovebox.
e) Magnesium hydroxide process. Sources are blocked until tank TK-D8 becomes available.
f) Hydraulic system for pump does not connect to any fissile sources. Not a valid source.
g) Could not visually verify piping inside of the glovebox. This glovebox has been inactive for several years. There is inadequate lighting in the room and in the glovebox. The glovebox is covered with lead shroud due to high radiation.
h) Could not access. Airborne radioactive area and high contamination area.
i) Inactive criticality drain exists.
j) Active criticality drain exists.

2.4.4 26-inch Vacuum System Flushes and Seal Water

The 26-inch Hg vacuum system is connected to several fissile solutions tanks, such as those in Glovebox HC-227S and the phase disengaging tanks in Glovebox 188. Vacuum traps prevent fissile solution from entering the 26-inch Hg vacuum system. A series of interlocks in the 26-inch Hg vacuum system also prevents the introduction of fissile solutions. Any solution that is found in the vacuum system is sampled prior to transfer to Tank TK-D8. These multiple barriers make the inadvertent introduction of fissile material into Tank TK-D8 incredible.

The 26-in. Hg vacuum seal water system would not allow fissile solutions to drain to Tank TK-D8. The HEPA filters filter out dust to prevent fissile contamination of the 26-in. Hg vacuum system and the interlocked system prevents liquids from entering the 26-in. Hg vacuum system.

2.4.5 Plutonium Precipitation Process Filtrate

Glovebox HC-230C-4 in Room 230C has three pairs of 25 liter tanks. The waste filtrate can be routed to TK-D8. The filtrate solution is to be sampled for plutonium content and organics prior to transfer to Building 241-Z for disposal. The out-of-spec filtrate is to be returned to the precipitators, filters, or blended to reduce the fissile material concentration to allowable values acceptable to 241-Z. The piping has two valves in the path from Glovebox HC-230C-4 to TK-D8. The control panel operates the first valve. The second valve is a manual valve that is to be locked except when making transfers.

2.4.6 PPSL Laboratory Prototype Calciner

PPSL Laboratory Prototype Calciner in Glovebox HC-188-1 is not normally connected to a drain to the waste tanks. During disassembly of this lab calciner, the drain line may be connected to dispose of liquids per a written procedure and disconnected after each disposal. Each batch is to have the amount of fissile material in it documented and added to the tank inventory.

2.4.7 Plutonium Reclamation Facility

Tank TK-D8 has connections to the Plutonium Reclamation Facility (PRF). PRF has four tanks connected to the waste system. They are Tanks 19, 21, 43, and WM1. These sources have been flushed and drained and are no longer in service. These sources are operationally empty, and have no liquid sources available.

PRF has other connections to the drain system, but there are no sources of fissile material in PRF except holdup. PRF was serviced by the D6 drain header and is connected to the 234-5Z Building drain header near manhole Z4. The piping from each source to the D6 drain header goes through an electronically operated motor valve and is key locked. There is another valve downstream on the D6 drain header that separates and further isolates the PRF sources.

2.5 PROXIMITY OF INLET TO OVERFLOW IN TK-D8

The overflow pipe from TK-D8 is attached to a vertical nozzle on the dished head of the tank, not a side nozzle as on tanks TK-D5 and TK-D4. This arrangement precludes inlet flow channeling to the overflow tank without mixing in TK-D8 first. The piping arrangement is shown in Drawing H-2-27597. The possibility that high concentration fissile input liquids could be diverted to the overflow tank is precluded by the piping arrangement on Tanks TK-D7 and TK-D8.

2.6 PROXIMITY OF PERSONNEL TO TANKS

This section describes the distance and shielding between the tanks and occupied areas for personal taking samples and doing NDA on the tanks. Drawing H-2-28853 shows the 241-ZA Building for sampling the tanks to be at grade level and to be to the east of the tank vaults sunken 22 feet deep in the ground below grade. The sample room floor is at an elevation of 675 ft, grade level. The top of the tanks are at an elevation of 663 ft. The closest wall of the 241-ZA building is on a concrete slab on grade over 10 ft east of the nearest tank. A person taking samples would be at least 16 ft from a tank. This spacing, a foot or more of concrete, and some feet of dirt would reduce the radiation from the tanks.

Personnel walking over the tank vaults at grade level or doing NDA would be 12 feet above the top of the tanks and 22 feet above the bottom of the tanks.

2.7 HISTORY OF TANKS AND PIPING

Building 234-5Z and PRF had several drain header systems to channel liquid waste to the tanks in 241-Z Building. Originally each header drained to a dedicated tank. Drain headers were labeled TK-D4 through TK-D8. Drain header D4 serviced PPSL and emptied into Tank TK-D4; drain header D5 serviced A-Labs and emptied into Tank TK-D5; drain header D6 serviced the process areas of 234-5Z Building and emptied into Tank TK-D6. PRF is serviced by the D6 drain header and is connected to the 234-5Z Building drain header near manhole Z4. Drain headers D7 and D8 are no longer in service.

Any pipe that is not routed above the floor in Building 234-5Z process areas to one of the main corridors before going into the floor is an inactive drain line. The D4, D5, and D6 main drain header lines have recently been scanned and no significant holdup was found.

The only credible contingency that could lead to an inadvertent criticality in the 241-Z facility is mass overbatch in the tanks. The piping is too small a diameter to support a criticality for waste streams in the 241-Z facility and the concentration of fissile material is too low.

Care must be exercised to limit fissionable material entrance into the waste system because when PFP was engaged in production, any significant plutonium in waste solutions was extracted before the solution was transferred to 241-Z Building waste tanks. Thus, little plutonium was transferred to 241-Z Building waste tanks. During production about 100,000 gallons of solution per year was transferred to the waste tanks in 241-Z. When the plant went from production to plutonium stabilization, only about 3,000 gallons of solution per year was transferred to the waste tanks in 241-Z (primarily low-level salt wastes from the laboratories). Waste liquids are now transferred to Tank TK-D8 without extracting plutonium, except for the plutonium precipitation process in Glovebox HC-230C-3. More plutonium may be transferred to the 241-Z tanks than in the past.

Figure 1. Plan and Elevation Views of Building 241-Z Tanks and Cells

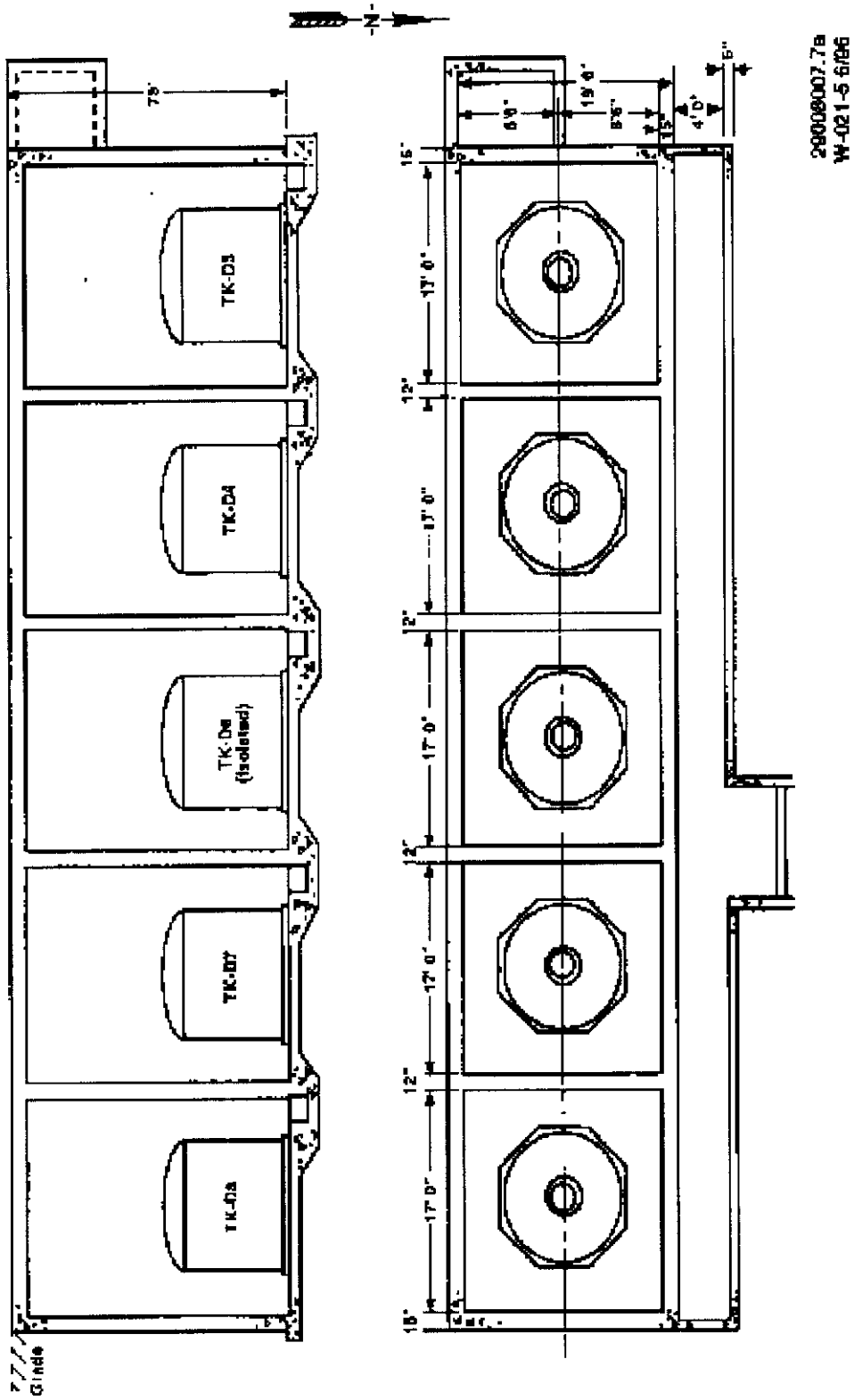
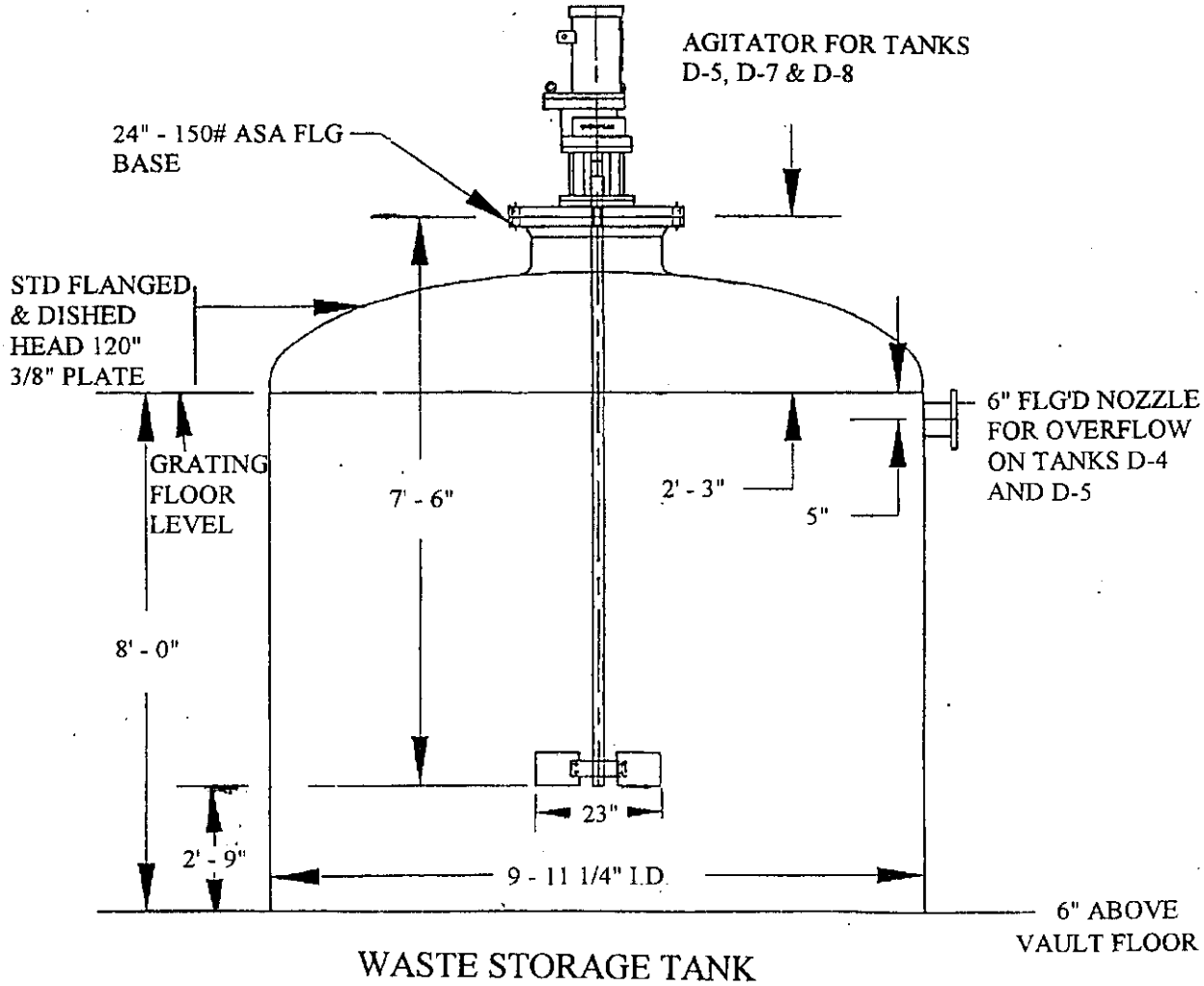
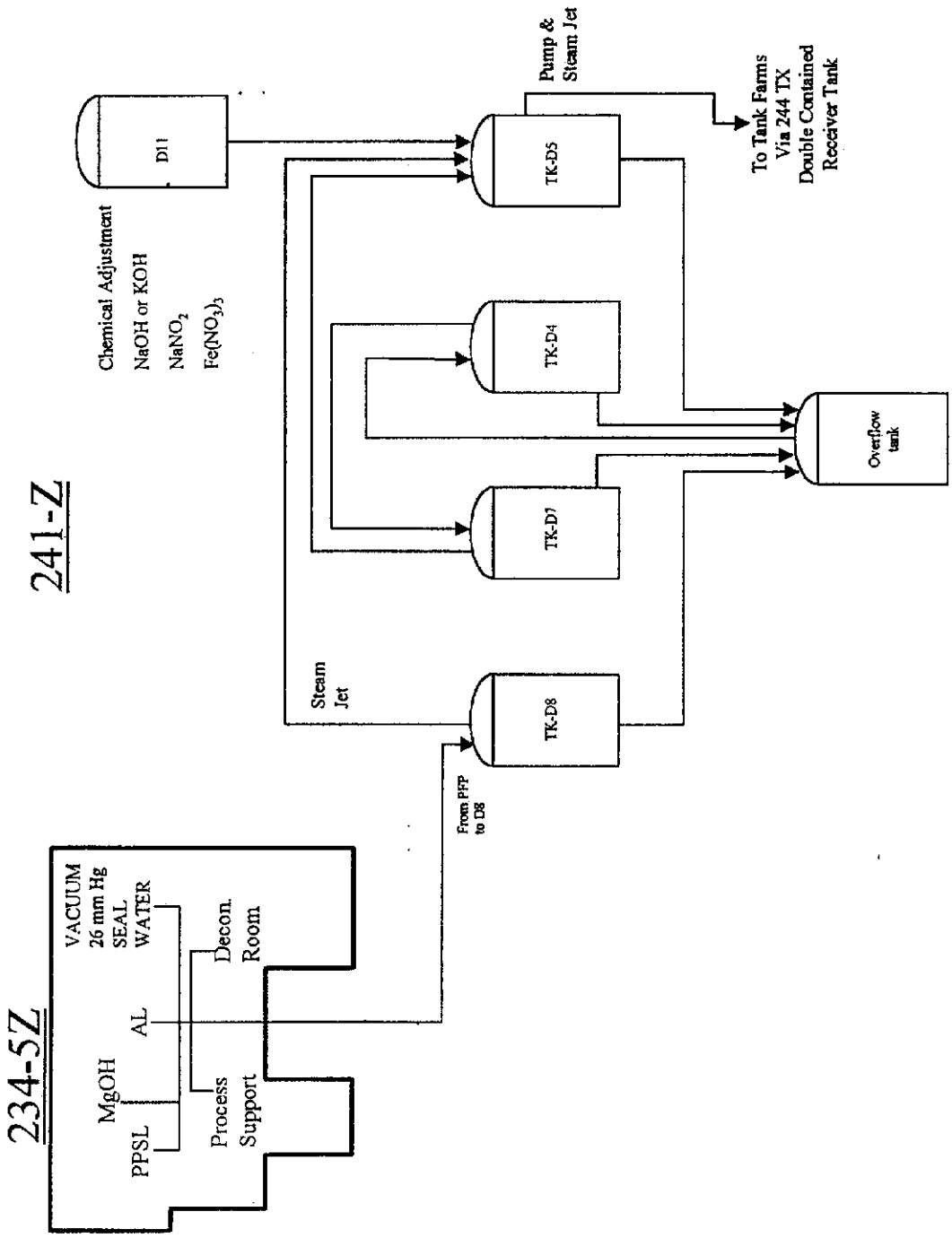


Figure 2. 241-Z Waste Storage Tank



PIPE DOWNCOMERS AND RELATED NOZZLES LEFT OUT

Figure 3. Schematic of Radioactive Liquid Waste Flows



3.0 LIMITS AND CONTROLS

This section identifies the controlled parameters and their associated limits. These limits and controls are needed for nuclear criticality safety. The bases for the limits or controls are presented directly below each limit in italic.

3.1 LIMITS

1. Maximum mass of plutonium or equivalent fissile material allowed in each tank, Tanks TK-D4, TK-D5, TK-D7, and TK-D8, including holdup, is 900 grams.

   Mass limit based on the minimum critical mass of an accumulation of fissile material on the floor of the tank below the inlet. (Section 5.1, Fissile Material Cone on Tank Bottom, presents the basis for the 900 g tank mass limit.)

2. Maximum of 150 g of plutonium or equivalent fissile material per addition of waste to Tank TK-D8.

   The use of the 0.75 factor for determining the allowed mass from the critical mass requires that an overbatch not double the mass in the tank. The amount of mass that is allowed to be added in an addition needs to be smaller than the 900 g allowed in the tank. (The third from the last paragraph on Section 5.1, Fissile Material Cone on Tank Bottom, presents the basis for the 150 g mass limit per addition to Tank TK-D8.)

3. Only one addition of waste may be added to a tank at a time.

   To prevent overbatching, only one batch of waste is allowed to be added to a tank at a time. (Section 5.2, Optimally Moderated Fissile Sphere, gives the basis for this restriction on the number of additions to a tank at a time.)

4. Maximum of 400 grams of plutonium or equivalent fissile material is allowed on the vault floor and sump in each 241-Z tank vault. The mass limit for the 200-gallon over flow tank in the TK-D7 vault is also 400 g of plutonium or equivalent fissile material.

   This is the mass limit for the floor and sump in each 241-Z vault and for a separate limit on the overflow tank in the vault for TK-D7. This limit of 400 grams keeps the mass to less than a minimum critical mass. (Section 5.14.1, Vault Floor and Sump, provides the basis for this limit.)

5. Maximum of one 55-gallon drum per vault loaded and spaced per CPS-Z-165-80100.

   PFP General Limits, CPS-Z-165-80100, impose mass and spacing requirements for 55-gallon drums. (Section 5.14.2, 55-Gallon Drum, provides the basis for this limit.)

6. Maximum of 3 lard cans per vault loaded and spaced per CPS-Z-165-80100.

   PFP General Limits, CPS-Z-165-80100, impose mass and spacing requirements for lard cans. (Section 5.14.3, Lard Can, provides the basis for this limit.)

3.2 PROCESS CONTROLS

1. The Cognizant Engineer for 241-Z shall approve any transfer of fissile material into Tank TK-D8.

   A central control person is needed to review and coordinate additions to the tanks to prevent simultaneous additions. (Section 5.7, Single Additions or Transfers to Tank TK-D8, and Section 5.12.1, Work Plan, provide the basis for this process control.)

2. Tank inventory is the initial NDA mass plus all additions to the tank without subtracting transfers out of the tank. Transfers between tanks are assumed to move all of the fissile material, including holdup, from one tank to another.

   The unfavorable geometry of the waste tanks requires that a conservative accounting be used to compare with the tank mass limit. (Section 5.12.3, Tank Transfers, provides the basis for this process control.)

3. NDA for the rebaselining of the fissile mass inventory in a tank is to be done when the tank is empty. (Tank is empty if ejector pumping has removed all the fluid it can.)

   NDA measurements are more accurate when the tank is empty. (Section 5.12.4, NDA Tank Measurements, provides the basis for this process control.)

4. NDA measurements shall determine tank holdup (the heel) before an estimated 900 grams minus the last tank NDA value (the heel) of plutonium or equivalent fissile material has passed through or been added to a tank.

   This control makes overbatching a tank unlikely from documented transfers and additions. (Section 5.12.3, Tank Transfers, provides the basis for this process control.)

5. Operations is to ascertain that transfers to active waste tanks (e.g., TK-D5, TK-D8) do not have an organic phase by testing or by process knowledge.

   An organic phase can reduce the minimum critical mass of a geometry and can preferentially concentrate the acidic plutonium nitrate in the organic phase. (Section 5.3, Organic Solvent, provides the basis for this process control.)

6. Operations is to ensure that the sampling of additions to be transferred to 241-Z tanks, or the sampling of the contents of the 241-Z tanks, is double contingent to the limits on mass by implementing the following or equivalent process controls on sampling:

a. Two independent samples shall be taken to determine the concentration of plutonium or equivalent fissile material in liquids that are to be transferred to Tank TK-D8 or between 241-Z tanks. To be independent, the samples must be taken at different times in a sample system or at different places in the batch. Knowledge of the operational process from which the liquid originated shall dictate which isotopes are to be measured. The mass concentration in samples is to be reported with a measured uncertainty of one sigma or better. The following are Exemptions:

   i. For a liquid waste batch with a total volume of one liter or less, sampling is not required if the fissile mass is known and well documented to be below 150 g.

   ii. An addition of up to 300 ml containing aqueous liquid is exempt from this two-sample requirement.

   iii. Any volume of known, non-fissile, aqueous liquid, such as flush water, may be introduced into Tank TK-D8 or Tank TK-D5 without sampling with the approval of the 241-Z Cognizant Engineer.

b. An instrument standard shall be run and documented at the beginning of a shift and at some other time during the shift (this may include a holdover to the next shift) before reporting the sample results. The instrument standards test results must be determined to be within the Analytical Laboratory Quality Control (QC) acceptance criteria before waste samples are measured. The scientist or lab supervisor shall review and approve both samples and measurement control results before data is reported.

c. The highest mass value from the two analyzed samples shall be used to ensure compliance with the given mass limits. The mass value shall include measurement uncertainty at 2 sigma (95% confidence level) or better.

   To control the fissile mass in the tanks, sampling must meet a double contingency standard. The exceptions to item (a) above are based on the item having a small volume or being known not to contain fissile material. (Section 5.12.7, Tank TK-D8 Sampling, and 5.12.8, Sampling Requirements, provide the basis for these process controls.)

7. Operations is to ensure that the additions to be transferred to the 241-Z tanks are double contingent to the tank limits on mass by implementing the following or equivalent process controls:

   a. Each addition to a tank must be controlled by a work plan, procedure, or JCS work package that lists all containers to be emptied into a drain to Tank TK-D8. The container to be dumped must be labeled with an ID number and fissile mass. Sample vials and small containers up to one liter do not have to be labeled. However, documentation of the fissile mass of each vial and container must be readily available at the drain site.

To control the fissile mass in the tanks, additions to tanks must meet a double contingency standard. (Section 5.8.5, Logbook, and Section 5.12.1, Work Plan, provide the basis for this process control.)

b. Fissile material can only be emptied into the drain headers in sinks, hoods, or gloveboxes with a posted maximum of 150-gram limit for the glovebox. Exemptions are as follows:

   i. Liquid used to condition the ion exchange columns in Glovebox 179-9, which are posted to allow up to a maximum of 400 grams.

   ii. Effluent from bench top scale magnesium hydroxide testing in Glovebox 179-4 posted to allow up to a maximum of 400 grams.

   iii. The vertical denitration calciner in Glovebox 188 or other glovebox being cleaned where drains are secured so inadvertent drainage to the waste tanks is not possible.

   The 150-gram limit prevents the overbatching of Tank TK-D8 from a single event. (Section 5.12.2, 150 Gram Limit, and Section 5.13.4, PPSL and Process Gloveboxes, provide the basis for this process control and exemptions.)

c. Before the contents of a fissile material container are emptied into the drain headers in sinks, hoods, or gloveboxes leading to Tank TK-D8, two people must verify that the container to be dumped is the one specified in the work plan or procedure.

   These verification controls, along with the sampling controls, track the plutonium mass in the tanks to make it unlikely that greater than 150 grams of plutonium would be dumped into a tank. (Section 5.12.2, 150 Gram Limit, and Section 5.8.5, Logbook, provide the basis for this process control.)

d. Transfers of effluents to Tank TK-D8 from the vertical denitration calciner in Glovebox 188 or other gloveboxes containing fissile material that are being cleaned up may discharge liquid waste to tank TK-D8 in accordance to a work plan or work package that limits fissile material to 150 g or less per discharge. The work plan or work package shall include a section that establishes the mass to be transferred to Tank TK-D8. The work plan or work package and actual discharge must have two sign offs each. Drains must be secured so inadvertent discharge to the waste tanks is not possible.

   If the inadvertent introduction of fissile material into Tank TK-D8 from unplanned discharges to a drain in a process area were possible, then the 150-gram limit could be violated. (Section 5.8.2, Process Area Drains, and Section 5.12.2, 150 Gram Limit, provide the basis for this process control.)

e. Transfers of fissile material from Tank TK-D8 to Tank TK-D5 are to be sampled and mixed.

Sampling of Tank TK-D8 contents provides a check on the plutonium mass transfer to TK-D5 in waste transfers. (Section 5.12.7, Tank TK-D8 Sampling, provides the basis for this process control.)

f. Fissile material mass transferred to Tank TK-D5 during sampling of Tank TK-D8 is determined by multiplying the volume of liquid that is transferred as a result of sampling times the concentration of fissile material found in the samples times 10. This value for the fissile mass transfer added to the total fissile mass inventory of the tank receiving the transfer, TK-D5, is to have a sum less than 900 grams.

The sampling process itself involves the transfer of significant material between Tank TK-D8 and TK-D5. (Section 5.12.7, Tank TK-D8 Sampling, provides the basis for this process control.)

8. Two valves are required to be verified in the closed position between any active process tanks and the 241-Z tanks. One valve must be locked closed by administrative programs or engineered feature such as a key interlock on a control panel.

Flow paths to the waste system must have two barriers. (Section 5.12.5, Valves for Process Waste Tanks, provides the basis for this process control.)

9. All potential sources of fissionable material listed below are required to have one of the following: (1) to be blocked by a plug, (2) to be blanked off, (3) to be covered by Plexiglas inserts, (4) to be covered for contamination control purposes, (5) to be physically disconnected from the main drain headers leading to Tank TK-D8, or (6) to restrict access to a sink by lock and key. Access to the process drains may be restricted by a locked door with the key controlled by the managing organization. This door is to be posted with instructions that liquids may not be dumped into the sink without permission. Decontamination rooms are exempt from these controls. If plugs are used, then the expandable neoprene plugs are to be used. These plugs shall be of sufficient design and integrity to prevent liquids from entering the process drain for one shift. (Any liquid that is spilled into an open sink or laboratory hood would not remain in the sink but would be cleaned up due to Rad-Con concerns.) These sources listed below may only be unblocked for the authorized dumping of fissile material per approved work plan or work package, except the off gas scrubber in Room 232 is not to be unblocked to be used as a drain.

   i. All sinks connected to D4, D5, and D6 drain headers.

   ii. Floor drains in Room 191.

   iii. Drain header entrances in Gloveboxes 4, 6, 9, 10, and 12 in Room 179.

   iv. All drain header entrances in Glovebox 188-1 in Room 188.

   v. Drain header entrances in Gloveboxes HC-60 and HC-230C-2 if these gloveboxes become active, or an evaluation must show that excessive fissile material entrance to a header drain is double contingent.

vi. Off gas scrubber in Room 232.

The unfavorable geometry of the waste tanks requires that the inlets to the tanks be controlled to prevent overbatching and unrecorded additions to the tanks. (Section 5.12.2, 150 Gram Limit, Section 5.8.2, Process Area Drains, and the subsections under Section 5.13, Fissile Material Sources, provide the basis for this process control.)

10. The dishwasher in Room 221E shall not be used.

The dishwasher drains to TK-D8. (Section 5.13.2, Dishwasher in Room 221E, presents the basis for this process control.)

11. The criticality drains in Gloveboxes 10 and 12 in Room 179 and Glovebox 188-1 in Room 188 must be operable when the process drains in their respective gloveboxes are plugged.

Drains must be available to limit the depth of fissile liquid in these gloveboxes. (The second paragraph in Section 5.13.4, PPSL and Process Gloveboxes, presents the basis for this process control.)

12. Before the lead shroud around Glovebox HA-9A is removed, the criticality drain must be activated or the pipe in the glovebox leading to Tank TK-D8 must be blocked or disconnected from the drain headers leading to Tank TK-D8.

The lead shroud is preventing water entrance into the glovebox that could flow to the waste system. Actions to prevent flow to the waste system are necessary before the shroud is removed. (The last paragraph in Section 5.13.4, PPSL and Process Gloveboxes, expands the reasons for this process control.)

13. The concentration of plutonium or fissile equivalent in solution transferred to tank farms from the 241-Z tanks shall meet the tank farm acceptance criteria.

When tanks contents are to be sent to another jurisdiction, the transfer must meet the requirements of the receiving organization. (This basis is self-contained and requires no additional analysis in Section 5.0.)

14. Operations is to test transfers to tank farms for an organic phase immiscible in water.

An organic phase can reduce the minimum critical mass of a geometry and can preferentially concentrate acidic plutonium nitrate in an organic phase. A test of the liquid in TK-D5 can ascertain that the active 241-Z waste tanks (e.g. TK-D5, TK-D8) do not have a build up of an organic layer. (Section 5.3, Organic Solvent, presents the basis for controls on organic solvents.)

15. Operations is to ensure that the record keeping for the fissile mass transferred to 241-Z tanks meet the mass limits by implementing the following or equivalent process controls that meet double contingent requirements:

a. Before fissile material is emptied into the drain headers that feed Tank TK-D8 or transferred to Tank TK-D5, the sum of the fissile inventory (initial NDA fissile mass plus throughput fissile mass) of the tank plus the fissile mass to be added is to be determined to be less than the tank mass limit of 900 g.

b. The mass of plutonium or fissile equivalent transferred to a 241-Z tank shall be recorded in a log for each transfer. Two people shall initial each entry.

c. The NDA measured mass value shall include measurement uncertainty at 2 sigma (95% confidence level) or better. This rebaselined value shall be considered resident in the tank until a new NDA measurement is made.

To control the fissile mass in the tanks, record keeping must meet a double contingency standard. (Section 5.12.2, 150 Gram Limit, and Section 5.8.5, Logbook, provide the basis for this process control.)

16. A single plutonium source, not to exceed 150 g plutonium, may be brought next to any vessel for the purpose of checking nondestructive assay monitors. After the check is complete, the spacing limits shall be reestablished.

    An addition to a tank can be up to 150 g. (Section 5.12.2, 150 Gram Limit, allows 150 gram additions to the TK-D8.)

17. A single container may be brought next to a process vessel or other container for the purpose of transferring material within the container plutonium mass limits. After the transfer is complete, the spacing limits shall be reestablished.

    This necessary process separates mass into two containers that reduces reactivity. The process increases the volume that could hold water, but the operator protects against water addition and separates the two containers. (This basis is self-contained and requires no additional analysis in Section 5.0.)

18. A vault sump with liquid or solid accumulations greater than 0.5 inches are treated as containing more than 100 g.

    The fissile mass in a sump may not be known and needs to have spacing from other fissile material. By defining the sump as containing more than 100 g, the General Limits, CPS-Z-165-80010, specifies the spacing from other fissile material. (This basis is self-contained and requires no additional analysis in Section 5.0.)

3.3 ENGINEERED DESIGN FEATURES

None

4.0 ANALYSIS APPROACH

4.1 ANALYSIS COMPUTER CODE

The Monte Carlo code MCNP4B (Lan 1999) is used to model and calculate the mass required for a critical 140° cone at optimal or moderated conditions. The code was certified (Schwinkendorf 1998) and validated (Erickson 1998 and Lan 1999) for plutonium such as the fissile material in this tank.

A summary of the validation of MCNP4B is included in Appendix B, MCNP4B Computer Code Validation, which determines a total bias of 0.008 for non-metal system calculations. This value is for calculations with statistical uncertainties of $< \pm 0.002$ and assures subcriticality with an acceptable margin, including the uncertainties in the analytical methods and benchmark experimental data.

4.2 HAZARDS ANALYSIS

Identification of the contingencies for the operation of the 241-Z tanks and their sources was done during the Hazards Assessment. The goal of this effort was to identify deviations from planned operation that may pose a challenge to criticality safety. Analysis identifies the necessary controls to demonstrate that for each identified condition, the criticality safety criteria are satisfied.

In a Hazards Assessment, an interdisciplinary team uses a disciplined, systematic approach to identify hazards and deviations that could lead to undesirable consequences. Off-normal events are identified and separated into events that are likely and unlikely during the duration of the operation at the facility. The hazards analysis for this document can be found in Revision 1a to HNF-SD-SQA-CSA-20213 (Wilkinson 2000).

5.0 EVALUATION AND ANALYSIS

The following analysis shows that a criticality is incredible within conditions that are possible given the equipment and operating conditions. The case of a cone shaped pile of 35 g Pu/L material is developed as a contingency case because it sets the minimum mass for a criticality of any of the possible configurations. The other configurations are sketched out to show how much larger a minimum critical mass would be necessary for other critical configurations. All cases are shown to be double contingent. Table 5-1 summarizes the conceivable critical geometries and the barriers that make a criticality incredible. The term incredible is used to indicate a process that is more unlikely than one that is double contingent and has barriers in addition to those of being double contingent.

Table 5-1. Conceivable Critical Geometries

Geometry	Affected Criticality Parameter(s)	Barriers that Make Criticality Incredible
Fissile cone on bottom of tank from additions (See Section 5.1)	Mass Geometry	Inconsistency of concentration and shape 900 g fissile material limit Operator training/procedure
Overbatch of 30 g Pu/L liquid into tank as a sphere (See Section 5.2)	Mass Concentration	Sample analysis of fissile mass in additions to tanks Additions limited to 150 g per addition Operator training/procedure
Organic solvent added (See Section 5.3)	Concentration Moderation	Sample analysis for organics of additions and tank contents Minimum of 11 L in spherical shape Operator training/procedure
Critical slab of fissile material on tank bottom (See Section 5.4)	Geometry	900 g fissile material limit (Minimum of 40 kg for critical slab) Operator training/procedure
Tank contents at critical concentration (See Section 5.5)	Concentration	900 g fissile material limit (Minimum of 21 kg for tank at critical concentration) Operator training/procedure
Agitator sweeping fissile solids into vortex (See Section 5.6)	Concentration Geometry	23 inch diameter agitator 33 inches off floor in a 120 inch diameter tank (Agitator startup affects only small part of floor solids at a time)

5.1 FISSILE MATERIAL CONE ON TANK BOTTOM

To determine allowable mass limit for the tank, several geometries were investigated. A sphere would be the most reactive shape for the material but it is not considered credible for more than 500 g of plutonium at approximately 35 g Pu/L to accumulate in that shape. The next most reactive shape is postulated to be a hemisphere, however, creating a pile of material with this shape at the bottom of a ten-foot tall tank is also not considered credible. A cone is postulated, this shape does have some credibility of being generated, although it is considered to be quite small. A slab is also a credible shape, but it takes at least 40 kg of plutonium to create the critical slab in this tank. Therefore, since the cone shape is considered to be a possible shape with the lowest mass for a critical configuration, it is further investigated to determine the acceptable mass.

The materials to be transferred into the tank are expected to be in the form of a solution, however, fissionable particulates may also be disposed of. For a solution, no mechanism is identified that would increase the concentration up to a level that would cause a criticality concern over the tank volume.

The fissile material must be mixed with water. Any other moderator would form a less reactive unit. Organics could form a more reactive unit, but organics are excluded by testing samples of inputs to tanks. A 35 g Pu/L mixture of plutonium and water is or acts like a solution. Plutonium solids would have to have a density of 0.035 g/cm^3 for particulate to form a cone at 35 g Pu/L. No process at PFP makes plutonium solids of that low a density by a factor of ten. A solution would not form a cone or maintain that shape between plutonium additions to the tank. A hemisphere would be a more reactive shape but it is not credible that a solution adding 150 grams of plutonium at a time could maintain the steep sides of a hemisphere between additions.

The tank inlet nozzle is about 10 feet above the bottom of the tank. If the liquid level in the tank is high, the inlet flow has to drop in air about 3 feet, hit the water, and then drift through water for 7 feet. To postulate that the material remains in a compact mass is not credible. If the liquid level is low, the material falls 9 feet into 1 foot of water. Again the energy of impact would mix the material with surrounding liquid diluting the fissile far below a concentration that can be critical. For any tank liquid level in between these two extremes, a combination of splashing into the water in the tank and then drifting down thru water in the tank (a total distance from inlet to tank bottom of about 10 feet) would dilute the inlet material to a concentration less than can be made critical.

For the particulates, the only credible form of material that is of concern for criticality, the density would have to be extremely low (on the order of 35 g Pu/L) to have the minimum critical mass. For material of such low density, it is not expected that a steep sided cone would be generated. Therefore, it is postulated that a rather flat cone is the worst credible shape. The previous CSAR analysis (Wilkinson 2000) assumed a 140 degree cone to be a reasonable shape to evaluate. Based on this review of inlet flow to the tank, postulating a cone with an angle of 140 degrees is a conservative assumption. No smaller angle is credible, and larger angles are less reactive. Therefore, a 140 degree cone is used in this analysis to evaluate the allowable tank plutonium mass.

Dense solutions (> 450 g Pu/L) or slurries of particulate that are viscous enough to form cones or hemispheres on the tank bottom, require much more plutonium than a minimum critical concentration of 35 g Pu/L of solution or particulate. This low density shape is bounding because of the low mass required for that critical system. Appendix C shows that as the concentration of plutonium in water increases or decreases from 35 g Pu/L, the minimum critical mass of an optimally moderated cone sphere water and concrete reflected increases. Figure III.A.9(100)-4 in ARH-600 (Carter 1968) shows the MCM increasing from 530 g to over 3000 g of plutonium for an increase from 30 g Pu/L, a solution, to 500 g Pu/L, a loose slurry for a sphere. The MCM of the cone would increase at least as rapidly as the sphere. Getting the 1288 g into the tank for the MCM of the cone is considered improbable, but getting two, three, or more kilograms of plutonium into the tank is not an expected event.

The minimum critical mass is postulated to be the accumulation of multiple transfers into the tank of 150 g or less that accumulate as an obtuse cone. This shape is the most reactive that is postulated for material composed of 35 g Pu/L plutonium and water. The agitator could not have been operated between additions as it would spread the material out over the tank bottom. Eight additions would have to have been made to the tank to have enough plutonium for a critical system. The last three in violation of the 900 g limit for the tank. The solution or

particulate must be at about 35 g Pu/L to be optimally moderated so the mass needed for a critical configuration is minimized.

This analysis includes 3 wt% ^{240}Pu without a limit on plutonium isotopics because PFP has too small an amount to get a critical mass in the tanks with plutonium of less than 3 wt% ^{240}Pu. PFP has less than 1400 grams of plutonium containing less than 3 wt% ^{240}Pu as ten items. If 10% of all the less than 3 wt% ^{240}Pu, a conservative value, were sent at one time to TK-D8, the total mass of less than 3 wt% ^{240}Pu would be less than 140 grams. With just 140 g of 4 wt% ^{240}Pu, the average ^{240}Pu percentage would be over 3 wt% since no plutonium has less than 2 wt% ^{240}Pu. Even at twice the total amount of less than 3 wt% of ^{240}Pu, the higher ^{240}Pu material would average out with the lower to above 3 wt% ^{240}Pu.

The analysis for this model is presented in Appendix C. The model used a cone with a 140 degree apex on thick concrete and the remainder is water reflected. The cone is composed of 35 g Pu/L plutonium metal mixed with water, where the plutonium has 3 wt% ^{240}Pu. The minimum critical mass is calculated to be 1288 g. This value is the lower of reading the plot and linearly interpolating between the 1100 g and 1300 g MCNP runs in Appendix C. A conservative estimate of a one sigma error on the value is 10 grams.

HNF-7098 (HF 2001) allows a mass limit of 0.75 of MCM if double batching is not credible for normal operations. This fraction of the above calculated MCM is 966 g. If the tank limit is set at a value of 900 g for conservatism, and all additions to TK-D8 are limited to 150 grams, an overbatch results in a maximum of 1050 g. Two more additions to the tank in violation of the tank limit would be necessary to reach an idealized critical configuration. The dispersal of most of the fissile material and inclusion of 5 wt% or more of the ^{240}Pu isotope in the plutonium would increase the actual minimum mass needed.

Additional conservatism is incorporated by the requirements on calculating the tank inventory for additions and transfers. Process control: Inventory of TK-D8 = last NDA value + all additions to tank since last NDA. (Conservative by any transfers out of the tank) AND Process control: Mass transfer to TK-D5 from TK-D8 equals the total mass inventory of source tank. (Conservative by (1) any transfers out of tank and (2) by each transfer including the latest and all previous transfers since the last source tank NDA, since the source tank inventory is not decreased when transfers from the source tank are made.)

To check on the reasonableness of the 900 g limit, we can compare it to the mass of the cone at a k_{eff} of 0.942 for non-metal plutonium systems. This k_{eff} value is the normal limit for base and contingent configurations. The curve for 35 g Pu/L with 3 wt% ^{240}Pu shows that over 1000 g of plutonium is required to reach a k_{eff} of 0.94. A linear interpolation of the data gives a mass of 1025 g. The 900 g mass limit is comfortably less than the value found for a k_{eff} of 0.05 and the MCNP bias less than the critical value of 1.0.

A mass overbatch of 150 grams in TK-D8 was identified as a contingency. The TK-D8 mass limit of 900 grams is unlikely to be exceeded because of the stringent controls on the drains that feed this tank. These controls also make the addition of more than a 150 gram overbatch incredible. Since it requires the addition of more than two 150 gram mass additions to a tank at the mass limit to reach criticality, a tank is double contingent. It takes more than two unlikely events to reach the mass for a critical configuration. The presence of other allowed containers in

this 17 by 17 foot vault such as 55-gallon drums or lard cans properly spaced would not significantly increase the reactivity of the vault. Therefore, the overbatch contingency in Tank TK-D8 meets the double contingency principle.

5.2 OPTIMALLY MODERATED FISSILE SPHERE

In the large water filled waste tanks, 530 g of plutonium could theoretically form a critical configuration. The addition, if at a concentration greater than 30 g Pu/L, could dilute to that optimal concentration and be fully water reflected by the water in a large tank. It is considered incredible that 530 or more grams of plutonium solution or particulate could be introduced into the tank in one addition because of the controls on inputs to the tanks. These controls limit each addition to 150 grams of plutonium. It is also physically improbable. The inlet nozzle is ten feet above the tank bottom. The material has to fall to the liquid surface, dispersing and gaining energy in the fall, then the energy of the fall and any difference in density would mix the addition with the material in the tank to less than 30 g Pu/L and into a non-spherical shape before all the addition entered the tank. The material in the tank receiving additional transfers has to be at a low concentration if the agitator has mixed the tank contents or to have spread out to be a thin slab at the bottom of the tank, since the mass limit for the tank is 900 g and the tank is 10 feet in diameter. To get the addition to the tank through the piping from the drain to the tank nozzle, additional rinse water would be needed that would dilute and add to the time needed to get all the fissile material into the tank.

5.3 ORGANIC SOLVENT

Introduction of an immiscible liquid into the waste tank TK-D8 can make a criticality more likely in two ways. The organic solvent could preferentially collect the plutonium nitrate in the organic phase, and the organic may also decrease the mass needed for a critical configuration. In a worst case, 11 liters of 35 g Pu/L as a reflected sphere could be critical (Thompson 1976). In the waste tank, immiscible organic liquids are prohibited, tested for, and additions checked. No floor drain is open to channel an organic solvent spill to the waste tanks. It is unlikely that a tank would contain an immiscible phase. Since a volume of at least 11 liters is needed for a critical sphere, double that amount is needed for a cone or other shapes that could be engendered by the start of the agitator in the tank. This 22 liters (5.8 gallons) is too large an amount to be inadvertently included in a waste item, and spills are prevented by sealing floor drains.

The double contingent control of inputs to the tank makes having a significant amount of immiscible liquid in a waste tank unlikely. It is considered incredible that a non-aqueous solvent could be spilled down a drain to TK-D8 because organics and other materials are controlled (tested for) before transfer to TK-D8. Feed to Glovebox HC-230C-3 is sampled and tested for organics by the analytical lab. Filtrate in Glovebox HC-230C-4 is tested for organics before transferring waste solvent to TK-D8. Material to be transferred to TK-D8 is to be reviewed/tested for organic solvents and organics. The transfers from TK-D5 to Tank Farms are tested for organics immiscible in water. An accidental buildup of organics in the 241-Z tanks would be detected.

To ensure that these determinations are continued, a process control requires that no organic liquids immiscible in water be allowed in the 241-Z waste tanks or be transferred to TK-D8. Glovebox HC-230C-4 filtrate and other material to be transferred to TK-D8 are to be reviewed/tested for immiscible organic liquids or certified as only aqueous by process knowledge.

Even if an immiscible phase got into a waste tank, the material would be in a thin layer on the top or at the bottom of the water. Only when the agitator started, would the surfaces be deformed to make possible a thicker configuration of the organic. As discussed in Section 5.6, the size and placement of the agitator paddles makes the mixing expand from a volume around the agitator to larger volumes until the entire liquid in the tank is mixed. This expanding mixing volume restricts the amount of the top or bottom layer pulled into the agitator to an expanding torus. Thus, only part of any organic layer would be pulled into the agitator at a time. Getting a critical amount of fissile/organic into the center of the tank before being mixed for a critical configuration is considered incredible.

5.4 FISSILE SLAB ON TANK FLOOR

A criticality is considered incredible by a layer of fissile material on the floor of the tank because the amount of fissile mass required is larger than could credibly be put in a tank with the present controls on additions and transfers.

Figure III.A.8(100)-3 in ARH-600 (Carter 1968) shows that plutonium as metal has the minimum critical thickness. The minimum critical thickness increases as the density of plutonium decreases. A maximum density of plutonium from PFP as settled solids on the tank bottom would be 3 g Pu/cm^3. For plutonium with zero ^{240}Pu, fully water reflected, and interstitial water moderated, the critical plutonium infinite slab thickness is 3.6 cm (1.4 in.) at 3 g Pu/cm^3 for plutonium/water mixtures. Conservatively assuming an infinite slab has 5% neutron leakage from the edges of a circular slab, the slab radius would be twenty times the thickness. For a 3.6 cm (1.4 in.) thick slab, an "infinite" slab radius would be 71 cm (28 in.). (A slab with only one percent leakage at the sides would have a radius of 356 cm (140 in.). The mass of plutonium for this 3.6 cm (1.4 in.) thick slab is 170 kg.

At the other extreme of plutonium density, a plutonium concentration of about 15 g Pu/L (0.015 g Pu/cm^3) has a critical slab thickness of 17.8 cm (7 in.). For 5% leakage at the edge, the slab radius is 356 cm (140 in.). This slab would have 106 kg of plutonium.

At the optimum moderation of 30 g Pu/L, the critical slab thickness is 10.2 cm (4 in.). Using a radius of 203 cm (80 in.) for 5% edge leakage, gives a slab plutonium mass of about 40 kg. The optimal moderation case would give the minimal required mass case. This amount of fissile material required for a slab criticality in a closely watched tank is so large as to make a criticality incredible.

5.5 TANK CONCENTRATION

A criticality is considered incredible due to the tank contents reaching a concentration over 7 g Pu/L because the amount of fissile mass required is larger than could credibly be put in a tank with the present controls on additions and transfers.

The tank agitator would mix a solution in the tank evenly so the 900 g of plutonium would have a concentration much lower than the minimum critical concentration of 7 g Pu/L for plutonium in water. At this concentration, an infinite volume is needed for a critical configuration. To estimate a conservative lower plutonium mass needed for a critical configuration in the waste tank, the author used the 302.9 cm (119.25 in.) inside diameter and conservatively assumed a concentration of 7 g Pu/L (0.007 g Pu/cm^3) and a tank liquid level of 38.1 cm (15 in.) per Figure III.A.8(100)-3 in ARH-600 (Carter 1968). The mass needed is approximately 19 kg, which is too large an amount to consider credible for a tank with a 900 g plutonium mass limit and close surveillance.

The overbatch of TK-D5, TK-D4, and TK-D7 with an additional 900 grams of plutonium was identified as a contingency. Due to operator training and procedures for keeping tank fissile inventory, an inadvertent tank-to-tank transfer above allowed limits is unlikely. Two such transfers to one tank is not credible. For an inadvertent transfer, the resultant 1800 grams of plutonium would be thoroughly mixed by the method of transfer from one tank to another. The resultant uniformly distributed 1.8 kg of plutonium is much less fissile mass than the conservatively calculated 19 kg for a criticality in a tank of uniform fissile material calculated in this section. Therefore, the overbatch by transfer of one tank to another meets the double contingency principle.

5.6 AGITATOR

A criticality is considered incredible by the agitator stirring up the solids from the bottom of the tank into a spherical shape because the stirring pattern does not sweep all the material into a center vortex at the same time, but draws only part of the settled solids into the mixing pattern at a time.

The agitator is composed of four radial paddles at 90° to each other with an outer diameter of 23 inches as shown in Figure 1. The 24-inch diameter flange on the tanks top head limits the diameter of the agitator. The bottom of the flat paddles are 33 inches above the tank floor, three times further than the paddle outer radius. Upon starting, the paddles push fluid outward and pull it in from above and below along the shaft centerline. The paddle rotation initiates a circulation above and below the plane of the paddles. These circulations would begin close to the paddles and expand as the paddles transfer more momentum to the tank fluid. The circulation at first would not impinge on the tank bottom because of the limited diameter of the paddles and spacing to the tank bottom specified in ECN 641494 for drawing H-2-16418, Sht. 1, Rev.8. As the circulation increases in size, it will include part of the tank bottom, but not all. Some of the material settled on the tank bottom would be swept up into the circulation and brought into the center of the tank and mixed with the tank fluids. As the circulation grows, more of the bottom at greater diameters (and larger areas) will be added to the circulation. This pattern brings in settled solids in a piecemeal process because of the relatively small size of the

paddles in relation to the size of the tank. Only fractional amounts of the settled solids would be brought to the tank centerline before being mixed with the tank fluids. This process would not sweep all the solids at one time into a central vortex at the agitator. Since the agitators are to mix the tank contents, both fluid and fine solids in the tanks, the settled solids can be assumed to be spread over the tank bottom between agitations, with some concentration in the area below the inlet flange from additions to the tank between agitations.

This description shows that the agitator is sized such that it will mix the material in a tank in stages during startup and not all at once. This means that only a small fraction of fissile solids on the floor of the tank would be swept into a central vortex at a time before being mixed with the fluid. The agitator would not be a credible means of assembling a critical configuration from solids in a tank unless the tank had tens of kilograms of fissile material in addition to that allowed.

5.7 SINGLE ADDITIONS OR TRANSFERS TO TANK TK-D8

This CSER uses the limit that a maximum of 150 g of fissile material is transferred to Tank TK-D8 in one operation. If two transfers are allowed to send waste material to TK-D8 at the same time, the tank could get 150 g above the tank mass limit because both transfers checked and found that their addition was under the limit. If there was an error in the tank inventory or the mass in the transfer, the tank could have accumulated even more than 150 g excess. For these reasons, there is a limit of only one transfer to, from, or between 241-Z waste tank TK-D8 at a time and a process control to require a cognizant engineer sign off on each transfer.

If waste material was poured down a drain without sufficient flush water following the waste to wash it thru the piping to TK-D8, then two or more waste additions could be added to the tank simultaneously or to the tank after it has been emptied. The process control for no simultaneous additions includes flushing the addition into the tank as part of the work plan or work package.

5.8 SYSTEM CONNECTED TO TK-D8

The following events do not pose a credible threat to criticality safety.

5.8.1 26-inch Hg Vacuum System

The 26-inch Hg vacuum system is connected to several fissile solution tanks, such as those in Glovebox HC-227S and the phase disengaging tanks in Glovebox 188. Vacuum traps prevent fissile solution from entering the 26-inch Hg vacuum system. A series of interlocks in the 26-inch Hg vacuum system also prevents fissile solutions reaching geometrically unfavorable down stream HEPA filter locations in the vacuum system. Any solution that is found in the vacuum system is sampled prior to transfer to Tank TK-D8. These multiple barriers make the inadvertent introduction of fissile material into Tank TK-D8 incredible. The HazOp, also, found that the vacuum system is not a credible source of fissile material to Tank TK-D8.

5.8.2 Process Area Drains

Introduction of fissile material into Tank TK-D8 from unplanned discharges to a drain in process areas is incredible. No fissile material is present that can spill into a drain connected to Tank TK-D8, except at the magnesium hydroxide process and the vertical calciner gloveboxes. The contingency of overbatching Tank TK-D8 by a spill from the magnesium hydroxide process is addressed in CSER 00-004 (Lan 2000), CSER for PFP Magnesium Hydroxide Filtrate Storage for Plutonium Stabilization Glovebox 4. The vertical calciner evaluation must be revised to address the contingency of overbatching Tank TK-D8 before this inactive process is restarted.

5.8.3 Decontamination Drains

Personnel decontamination rooms have drains to Tank TK-D8. However, decontamination of one or more persons would introduce such a small amount of fissile material that these drains are not controlled. The amount of fissile material from personnel decontamination would not create an overbatch in Tank TK-D8. That the amount could cause a criticality is considered incredible.

5.8.4 PRF

The introduction of significant amounts of fissile material into Tank TK-D8 from an unplanned discharge of water in PRF is incredible. This water can reach Tank TK-D8 thru PRF pipe trenches, but the only fissile material in PRF that could be entrained in the water is plutonium contamination on PRF equipment, walls, and floor.

The PRF is now isolated from all liquid effluent streams. The pipes from the PRF are capped off. The hazards analysis, also, determined that it is incredible that solutions containing significant mass of fissile material could enter Tank TK-D8 from the process tanks in PRF. PRF has no fissile solutions. All of the tanks in PRF have been emptied of fissile solutions and rinsed. PRF is an inactive facility. New operations at PRF will require a new criticality safety analysis. The new analysis shall have controls to prevent the inadvertent transfer of fissile material into Tank TK-D8.

5.8.5 Logbook

A logbook error or an improperly dumped bottle that could cause a criticality in Tank TK-D8 is also not credible. Only containers whose combined mass is less than 150-grams of plutonium or equivalent fissile material are allowed to be dumped into a drain to Tank TK-D8. All drains must be posted with a 150-gram limit before the contents of any container is poured into a drain to Tank TK-D8. Also, the 241-Z Cognizant Engineer must approve any dumping of fissile material into a drain to Tank TK-D8. A written work plan or work package is required for each dumping activity. The PFP 5.8 manual requires approval by the CSR and CSE of any work plan or work package involving the movement of fissile material. Three separate introductions of the posted maximum limit of 150 grams of plutonium are required before a criticality in Tank TK-D8 (900 grams in Tank TK-D8 plus 3 times 150 grams to exceed 1288 grams) is possible.

This limitation, along with the controls for sampling, and the two-person rule, make it incredible to get a criticality in Tank TK-D8 due to a logbook error.

5.9 TK-D5 TRANSFERS

The transfer of fissile material from Tank TK-D8 to Tank TK-D5 is allowed to move up to 900 g of fissile material. Transfers from Tank TK-D8 are required to be mixed. These transfers and any transfers from other tanks would be well mixed by pumping the material thru pipes and dropping the material into TK-D5. This mixing eliminates the possibility that a cone of 35 g Pu/L could be formed. To mix the contents of a tank, the liquid level needs to be over 33 inches high to cover the agitator. Section 5.5 shows that 900 grams in 33-inch deep tank liquid would have a concentration of about 0.15 g Pu/L. This concentration is too low to form a critical configuration or to allow settling out in a specific spot to form a cone. Even if the transfer had a small volume of liquid, transferring the material into a ten foot high and ten-foot diameter tank would spread and mix the material in the tank to a thin slab. This tank could have a larger mass limit than TK-D8, but to have only one tank mass limit, TK-D5 is also limited to 900 g for operational convenience.

TK-D5 could conceivably be double batched by a second transfer from TK-D8. This event would require more than one mistake because the sum of transferred mass plus tank mass or other checked book keeping value is doubly checked. Also, an actual transfer requires multiple actions (e.g., opening valves), not just operating one switch. Also, even a double batch of 1800 g would be at most at a concentration of 0.3 g Pu/L for a transfer from a tank that was mixed. This again is too low a concentration to be a concern. Sections 5.4-5.5 show that tens of kilograms are required for a critical configuration in a tank that has been mixed by the agitator or by pumping from one tank to another. Large diameter tanks need large amounts of fissile material for a critical configuration as a slab of settled solids or as a mass of liquid. The TK-D5 would be double contingent by both book keeping requirements and by margin to the mass required for a critical configuration.

It is incredible that fissile waste from the tank farms could get into Tank TK-D5 to threaten criticality safety. The lines from Tank TK-D5 to Tank Farms slope away from Tank TK-D5. The TK-D5 transfer pump is controlled by Tank Farms and the TK-D5 steam supply valve that supplies the power to move the waste from TK-D5 to Tank Farms is locked closed with a Tank Farm controlled lock.

5.10 AGGREGATION OF POLYMERIZED PLUTONIUM

The chemistry in the 241-Z waste tanks is not controlled. Plutonium could precipitate or polymerize in a tank. Polymerized plutonium attaches to surfaces and metal ions in the liquid, but does not self adhere or build up to a marble size aggregations (Barney 2001). The size of the aggregations are too small to be a concern of criticality. The material coating surfaces is the same as a slab of precipitate or particulate on the tank bottom that has been shown to require tens of kilograms of fissile material to reach a critical configuration. Polymerized plutonium does not form large enough aggregates of plutonium to approach a critical configuration. No controls are required on the chemistry of the tanks.

5.11 241-Z WASTE TANK PIPING

The piping is too small a diameter to support a criticality for waste streams in the 241-Z facility. Figure III.A.4(97)-3 in ARH-600 (Carter 1968) shows that for a plutonium water mixture with 3 wt% ^{240}Pu and one inch of water reflection, criticality is not possible in an eight inch diameter or smaller pipe. And at less than 30 g Pu/L, a ten-inch diameter pipe is too small for a criticality. For additions of 150 g per disposal and the concentrations of the waste, the 4, 6 and 8 inch piping sizes used in the 241-Z waste facility are geometrically favorable.

5.12 NEW CONTROLS

5.12.1 Work Plan

An approved work plan or work package is required before any fissile material is introduced into the drain headers that feed Tank TK-D8. This work plan or work package will require that all of the fissile material containers that will be emptied into a drain header be listed with the container ID number and fissile mass.

5.12.2 150 Gram Limit

Any sink, hood, or glovebox used to introduce fissile material into the drain headers that feed Tank TK-D8 shall be posted with a 150-gram limit. This control will prevent the overbatching of Tank TK-D8 from a single event. Procedure ZSP-002 requires verification that a container meets posted limits before entry into a hood. Bottles to be dumped are labeled with a container ID number and plutonium and uranium mass. Procedures require two people verify that the correct container is to be dumped.

To make the dumping of more than 150 grams of plutonium into a tank unlikely, two independent checks are made on waste additions to 241-Z tanks. The checks begin with preparation of a work package for dumping the waste container and continue with a double check on the fissile mass in a waste container. Before the contents of the fissile material container is introduced into Tank TK-D8, operations is to sum the fissile mass in Tank TK-D8 plus the fissile mass to be introduced and check that the result is less than the Tank TK-D8 mass limit. For the actual dumping, the container identity is double-checked. Finally, the fissile mass addition to Tank TK-D8 fissile mass inventory is double-checked. The fissile mass in the tank is the sum of transfers to the tank plus additions and the tank holdup determined at the last NDA. Implementation of these controls that track the plutonium mass in the tanks make it unlikely that greater than 150 grams would be dumped into a tank. To make transfers between tanks of more than 900 grams of plutonium unlikely, two independent checks are made on transfers. A log must be maintained that tracks the changes to tank inventory, including NDA initializing, additions, and transfers to a tank. Because people could make incorrect entries in logbooks, two people will be required to review and sign each entry.

The liquid used to condition ion exchange columns in Glovebox 179-9 are allowed to be dumped in gloveboxes not posted with the maximum 150-gram limit. These liquids are assumed

to be low-level liquids. Effluents from benchmark magnesium hydroxide testing in Glovebox 179-4 are also allowed to be dumped in gloveboxes not posted with the maximum 150-gram limit. These effluents are assumed to be less than 10^{-1} grams per liter of plutonium. These effluents are sampled to determine the fissile concentration. If the concentration is more than 0.1 g Pu/L, procedures require that the transfer be signed off by the CSR and the responsible managers for the sending and receiving organizations. This procedure applies to the production precipitation process also. Gloveboxes HC-230C-3 and –4 have disposal blocked by two valves. A normal disposal of a pair of 20 L tanks from HC-230C-4 at a high concentration of 3 g Pu/L would add 120 g to TK-D8. This is within the 150 g per disposal mass limit.

5.12.3 Tank Inventory Transfer Rules

Tank transfers are assumed to move all of the fissile material, including holdup, from one tank to another. Tank transfers also assume that none of the fissile material in the source tank transferred out of the tank. The fissile material in the source tank is assumed to be in the heel until an NDA is done on the tank. An NDA is scheduled after the beginning plutonium inventory in the heel plus the cumulative plutonium in the transfers and additions to the tank reaches the limiting value or a lesser operational value. This inventory check is required to increase assurance that the fissile mass in a waste tank is less than the allowed 900 g. This control makes overbatching a tank unlikely from documented transfers and additions. The new NDA result becomes the new starting mass of fissile material to use in calculating the fissile mass transferred through and added to the tank.

5.12.4 NDA Tank Measurements

The tank is emptied before an NDA is done to find the plutonium mass value of the heel because the most accurate measurement can be made on an empty tank. A tank is "empty" when the pumping system has removed all the liquid that it can. NDA on a tank that is not empty can have a larger uncertainty on the plutonium mass due to self attenuation. NDA reports the measured mass of fissile material plus at least two sigma of the uncertainty in the mass at a 95% confidence level as the "MOST" value. The MOST value is also conservative because it is calculated assuming that all the fissile isotopes are at the bottom of the tank since the detectors are placed at the top of the tank.

5.12.5 Valves For Process Waste Tanks

The only operation processes with a glovebox configured to send wastes to the TK-D8 tank are the plutonium precipitate filtrate glovebox and the vertical calciner. The filtrate from the plutonium precipitate process would be transferred to the TK-D8 tank thru two valves in series with one controlled from a key locked control panel. Waste fluids that reside in process tanks, like the plutonium precipitate filtrate, exerts pressure on the closed outlet valves from the filtrate tanks. Valve leaks are likely. However, for two closed valves in series to leak is unlikely. Leaking valves is not a concern with piping connections to PRF since these tanks have been drained. All other sources, which requires double valve isolation, the valve leaking scenario has been addressed in their respective evaluations.

If at least one of the two valves is locked either through a key interlock on a control panel or the use of a program such as Controlled Equipment, Lock-Out/Tag-Out (LO/TO) program, etc., the inadvertent opening of the two valves is unlikely.

Operation of the vertical calciner will not resume until the overbatching of Tank TK-D8 is addressed in its evaluation.

5.12.6 Uranium Enrichment

Some of the waste introduced into the tanks will contain uranium. For the tanks, the limit on the plutonium mass is adequate for ^{235}U. There need be no limit on the amount of ^{238}U since this isotope of uranium isn't fissile. The mass limit is set for plutonium at optimal moderation, 30 g Pu/L. Uranium is more reactive than plutonium in the range of 100 to 800 g/L. A sphere is critical at 530 g of plutonium at 30 g Pu /L while at 100 g Pu/L the critical mass is 850 g, more than a 50 % increase. The percentage increase would be comparable for a cone. Uranium decreases the critical mass by only 10% in the middle of the 100 to 800 g U/L range. The 900 g limit is conservative for the range where uranium is more reactive than plutonium, because the largest decrease in critical mass for ^{235}U over ^{239}Pu is about 10% while changing from 30 g/L to 100 g/L increases the critical mass by 50%. Going to 800 g /L continues to increase the percentage of critical mass needed over that at 30 g/L.

5.12.7 Tank TK-D8 Sampling

Sampling of liquid inside Tank TK-D8 in the 241-Z Building is required before the waste is transferred to Tank TK-D5 for treatment and eventual transfer to tank farms. The sampling process is started by first activating the stirrer in Tank TK-D8. After the contents inside of the tank have been stirred, the solution is transferred to a sampling glovebox. To get an adequate sample at least fifty liters of solution must go through the sampling glovebox. The solution that enters the sample glovebox flows into Tank TK-D5 instead of back into Tank TK-D8. Sampling results in a sizeable quantity of fissile material being transferred into Tank TK-D5 before the concentration of the solution is known. There are two options available to correct this. The first option is to change the sampling configuration so the solution is returned to Tank TK-D8. The second option is to leave the sampling configuration the way it is and track the fissile material that is transferred into Tank TK-D5. The tracking is done by taking the volume of solution that is transferred to Tank TK-D5 and multiplying by the density of the solution obtained from samples to obtain the mass, and multiplying the mass by a factor of 10. This will result in a conservative value for the amount of fissile material that is transferred into Tank TK-D5 during the sampling process. One of these options will be required for the continued operation of Tank TK-D5.

5.12.8 Sampling Requirements

Before fissile material is transferred, two independent samples shall be taken. To be independent the samples must be taken at different times in a sample system or at different places in a batch. The fissile isotope that will be measured from these samples is based on the

operational process from where the fissile material originated. The sample value is required to be added to the tank (i.e., greater value of the two samples reported at 95% CL).

Analysis of transfer samples provides the fissile mass value to enter into the logbook for each transfer to a tank. Uncertainties in the mass in a transfer could be from errors in volume and in concentration. Errors in volume are unlikely because the volume of a batch can be easily quantified (e.g., a known number of 4-liter bottles or a maximum tank volume of 20 liters). The concentration relies on assay equipment and calculations that are more prone to errors. When samples are independently acquired and analyzed and the instrumentation is calibrated, an incorrect sample result is considered unlikely. A measurement control standard must be run on the instrument at the beginning of the shift and at some later time during the shift (this may include a holdover to the next shift). This prevents results from being reported that could be in error due to instrument drift or errors before they are detected.

The scientist/supervisor shall review the instrument calibration, samples acquisition, and measurement before the results are reported. Reported results shall include measurement uncertainty. The sample result having the highest mass with measurement uncertainty applied at 2 sigma (95% confidence level) shall be used to ensure compliance with the tank mass limits. The error in the results of one sample will not result in an incorrect fissile concentration for transfer to a tank because the results of a second sample are needed for a transfer. Two unlikely events are necessary before excessive fissile mass could be transferred into a tank. Requiring two independent results maintains double contingency.

There are three exceptions to the sampling requirement, based on the small volume to be added to the waste tanks or the known fissile content. 300 ml or less volume are exempted because they could not add more than 150 g of fissile material in that volume when 450 g Pu/L is the maximum fissile concentration of liquids at PFP. Waste batches of one liter or less whose fissile mass is known or documented is exempt from sampling based on the limited mass that a one liter of waste can contain. Process knowledge has shown that rinse solutions from cleaned tanks carries only a nominal amount of fissile material. The CSR may approve non-fissile liquids, such as flush water, to be exempt from sampling because the CSR can judge when a liquid would not have been exposed to significant amounts of fissile material.

5.13 FISSILE MATERIAL SOURCES

The paragraphs below specify the action taken for each source to the 241-Z tanks and the basis for that action for each entry in Tables 2-1, 2-2, 2-3, and 2-4 that list all the sources to 241-Z drain headers that flow to Tank TK-D8.

5.13.1 Sinks

The sinks listed in the tables in Section 2 are connected to drain headers D4, D5, or D6 and then lead to Tank TK-D8. To prevent accidental introduction of unknown amounts of fissile material into Tank TK-D8, all of these sinks are required to have one of the following: to be blocked by a plug, to be blanked off, to be covered by a Plexiglas insert, to be covered for contamination control purposes, to be physically disconnected from the main drain headers

leading to Tank TK-D8, or to restrict access to a sink by lock and key. A locked door may restrict access to these sinks with the key controlled by the managing organization. A locked door will control the access to the sinks in Room 143. Sinks in other rooms may also be controlled this way.

5.13.2 Dishwasher in Room 221E

Operations has classified the dishwasher in Room 221E as inactive. Although the dishwasher has a drain to 241-Z Tank TK-D8, it is not contaminated because it was not used and is not allowed to be used since it is classified as inactive. To reclassify the dishwasher for active use in washing items containing fissile material would require review and criticality posting by the criticality safety program. This programmatic control is considered adequate to assure double contingency for the dishwasher as a source of fissile material to Tank TK-D8.

5.13.3 Steam System

Steam system condensate drain in Room 153 and Room 152 are part of a steel enclosed system that is not contaminated with fissile material and does not carry or process fissile material. The condensate draining to Tank TK-D8 is not a credible source of fissile material.

5.13.4 PPSL and Process Gloveboxes

Gloveboxes 4, 6, and 9 in Room 179 can be posted up to 400 grams of plutonium in each glovebox and these gloveboxes have an active drain to Tank TK-D8. Since they do not have criticality drains, flooding these gloveboxes would send waste to Tank TK-D8. The evaluations supporting these limits do not require operable criticality drains (CSER 78-001, 79-002 and addenda, 79-003, 79-014, and 79-015 and addendum 1, CPS-L-114-00020). Thus, the drains in these gloveboxes that lead to Tank TK-D8 are required to be in plugged Section 3.2.

Gloveboxes 10 and 12 in Room 179 are posted for 3 unit masses of up to 400 grams of plutonium per unit mass. Glovebox 188-1, having the Lab Prototype Calciner, including the off-gas scrubber and phase disengaging tanks, in Room 188 is posted for 14,000 grams of plutonium with a 7,000 gram limit for dispersible plutonium (CSER 99-001, CPS-L-114-00050). These gloveboxes do have operable criticality drains, so there will be no impact on criticality by plugging the process drains leading to Tank TK-D8. Section 3.2.11 of this CSER requires that the criticality drains for Gloveboxes 10 and 12 in Room 179 and Glovebox 188-1 in Room 188 to be operable if the process drains leading to Tank TK-D8 are plugged. To prevent accidental dumping fissile waste into these drains, Process Control 9 in Section 3.2 requires the drains be blocked or access be controlled by lock and key. When the drains are blocked, the criticality drains must be operable.

Gloveboxes HC-60 and HC-230C-2 are currently inactive. Glovebox HC-60 has 232 grams of plutonium holdup, while Glovebox HC-230C-2 is not connected to the drain headers and has not gone hot yet. If these gloveboxes become active, then the drain headers

must be plugged or the evaluations for these gloveboxes must provide double contingency for the sources to Tank TK-D8.

Glovebox HA-9A has a sizable amount of holdup, but the glovebox is inactive, has no solution lines inside the box, and is covered by a lead shroud. This lead shroud will protect the glovebox from falling objects during a seismic or fire event, and prevent the introduction of water into the glovebox. Since this analysis counts on the shroud as part of the barriers to entry of fissile waste to the drain in the glovebox, this CSER requires the shroud remain in place or another control be used to prevent entry of fissile waste into this drain.

5.13.5 Floor Drains

The floor drain in Room 180 is blocked and requires no further analysis. The floor drains in Room 191 must be blocked. This CSER requires that these floor drains remain blocked.

5.13.6 Decontamination Drains

Safety and decontamination have a total of four drains from safety showers in corridor 4B, from an eyewash station outside Room 156, and from a floor drain in each of two decontamination Rooms 125 and 196. These sources would receive only contamination from a few people at most. The amount of fissile material would be insignificant. The limited nature of these sources make it incredible that they would challenge the criticality mass limits for Tank TK-D8.

5.13.7 Off-Gas Scrubber, Room 232

The off-gas scrubber is located in Room 232 and is connected to the drain headers leading to Tank TK-D8. This source must be blocked.

5.14 FISSILE MATERIAL OUTSIDE TANKS

The paragraphs below describe fissile containers allowed in the 241-Z vaults and their effects on the reactivity of the 241-Z tanks.

5.14.1 Vault Floor and Sump

A maximum of 400 grams of plutonium or equivalent fissile material is allowed on the vault floor and sump in each 241-Z tank vault. The overflow tank TK-D7 mass limit is 400-grams in addition to the limit for the TK-D7 tank vault floor and sump. The overflow tank limit of 400 grams is less than the minimum critical mass for a container and could not form a critical configuration. The fissile mass in a sump may not be known and needs to be spaced from other fissile material. A vault sump with liquid or solid accumulations greater than 0.5 inches is treated as containing more than 100 g. By defining the sump as containing more than 100 g, the General Limits, CPS-Z-165-80010, specifies the spacing from other fissile

material. The overflow tank in the vault with Tank TK-D7 is spaced at least 3 feet from TK-D7, and along with the 3 feet spacing required between containers and between tanks and containers makes this tank effectively neutronically isolated. The amount of fissile material and its distribution inside the overflow tank provides no reactivity effect on the TK-D7 tank, the fissile material in the sump, or the containers allowed in each vault. If the total contents of 900 grams of fissile material were to leak from the tank, it would form a slab on the vault floor and sump that is thinner than in the tank and thus less reactive. Section 5.4, Fissile Slab on Tank Floor, shows that this would be a more unfavorable geometry and require at least 40 kg of plutonium for a minimum critical mass.

A leak of the 241-Z tank contents from the tank to the tank vault floor and the sump of greater than 400 grams of plutonium is considered unlikely, and therefore a contingency. The 400 gram plutonium mass is the historical mass limit for the floor and sump in each 241-Z vault. It was originally based upon showing that leakage of the old tank limit of 400 grams into the vault was not a criticality safety concern because the fissile material would enter a geometry that was less reactive than the tank. Also, if 400 fissile grams of plutonium from another container allowed in the vault should end up in the sump, it is not a criticality safety issue. For the 900-gram limit set, a significant leak (exceeding the 400-g limit) is a contingency. If the total contents of 900 grams of fissile material were to leak from the tank, it would form a slab on the vault floor and sump that is thinner than in the tank and thus less reactive. Section 5.4, Fissile Slab on Tank Floor, shows that this would be a more unfavorable geometry and require at least 40 kg of plutonium for a minimum critical mass. The same geometry arguments used for 400 grams in a more favorable geometry would show that the tank leakage would be safe. The 55-gallon drum and lard can mass and spacing limits are based on infinite arrays of those containers. The fissile areal density of 900 grams of plutonium in the large 241-Z tank is much lower than the areal densities for the maximum 100 grams in a lard can or 400 grams in a 55-gallon drum. The density would be even lower if the tank material leaked from the tank into the larger volume of the tank vault. Neither the 241-Z tanks nor the concrete around the sump area would create a more reactive arrangement than infinite arrays of 55-gallon drums or lard cans.

Accumulation of up to 400 grams of plutonium in a tank vault sump, followed by transfer of this material to a 241-Z tank that was already at its 900-gram mass limit was identified as a contingency. Double batching a tank by transferring the entire 900 gram content of Tank TK-D8 to Tank TK-D5, for a total of 1800 grams of plutonium was addressed in Section 5.9, and found to be double contingent. Since the 400 grams from the sump is less than the 900 grams from a tank, the inadvertent transfer of the sump contents to the wrong tank is also double contingent.

5.14.2 55-Gallon Drum

A maximum of one 55-gallon drum, loaded and spaced per CPS-Z-165-80100, is allowed per 241-Z vault. The 55-gallon drum in a tank vault may contain up to 400 grams of fissile material under one of the several categories of drum mass limits and moderation limits. CPS-Z-165-80100 requires a minimum of 3 feet spacing between the 55-gallon drum and any lard cans, between the 55-gallon drum and sump deposits, and between the 55-gallon drum and any tank. Arrays of fissile material containers are required to be spaced a minimum of three feet apart, and any array is also required to be spaced a minimum of three feet apart from any fissile

material greater than 100 grams. This spacing effectively isolates the arrays neutronically from each other and from other fissile material.

An overbatch of the 55-gallon drum in the tank vault area was identified as a contingency. These 55-gallon drums were shown to be double contingent for a mass overbatch in an infinite planar array by the analyses supporting CPS-Z-165-80100. The fissile areal density of 900 grams of plutonium in the large 241-Z tank is much lower than the areal densities for the maximum 400 grams in a 55-gallon drum. The density would be even lower if the tank material leaked from the tank into the larger floor area of the tank vault. Neither the 241-Z tanks nor the concrete around the sump area would create a more reactive arrangement than an infinite array of 55-gallon drums. Therefore an over-mass of the 55-gallon drum is double contingent.

A loss of spacing between the 55-gallon drum and other containers, or between the 55-gallon drum and the tank, was also identified as a contingency. These 55-gallon drums were shown to be double contingent for a spacing violation in an infinite planar array by the analyses supporting CPS-Z-165-80100. The fissile areal density of 900 grams of plutonium in the large 241-Z tank is much lower than the areal densities for the maximum 400 grams in a 55-gallon drum. The density would be even lower if the tank material leaked from the tank into the larger floor area of the tank vault. Neither the 241-Z tanks nor the concrete around the sump area would create a more reactive arrangement than an infinite array of 55-gallon drums. Therefore, a violation of the spacing limits for the 55-gallon drum is double contingent.

5.14.3 Lard Can

A maximum of 3 lard cans, loaded and spaced per CPS-Z-165-80100, are allowed per 241-Z vault. Each lard can may contain up to 100 grams of fissile material. Spacing is not required between lard cans, but a minimum of 3 foot is required between any lard can and the 55-gallon drum, between any lard can and the sump, and between any lard can and each tank. These lard cans were shown to be double contingent in an infinite planar array by CSAR 79-037 (Altschuler 1979). Arrays of fissile material containers are required to be spaced a minimum of three feet apart, and any array is also required to be spaced a minimum of three feet apart from any fissile material greater than 100 grams. This spacing effectively neutronically isolates the arrays from each other and from other fissile material.

An overbatch of the lard cans in the tank vault area was identified as a contingency. These lard cans were shown to be double contingent for a mass overbatch in an infinite planar array by CSAR 79-037 (Altschuler 1979). The fissile areal density of 900 grams of plutonium in the large 241-Z tank is much lower than the areal densities for the maximum 100 grams in a lard can. The density would be even lower if the tank material leaked from the tank into the larger floor area of the tank vault. Neither the 241-Z tanks nor the concrete around the sump area would create a more reactive arrangement than an infinite array of lard cans. Therefore an over-mass of the lard cans is double contingent.

A loss of spacing between lard cans and other containers, or between the lard cans and a tank was also identified as a contingency. These lard cans were shown to be double contingent for a spacing violation in an infinite planar array by CSAR 79-037 (Altschuler 1979). The fissile areal density of 900 grams of plutonium in the large 241-Z tank is much lower than the areal

densities for the maximum 100 grams in a lard can. The density would be even lower if the tank material leaked from the tank into the larger floor area of the tank vault. Neither the 241-Z tanks nor the concrete around the sump area would create a more reactive arrangement than an infinite array of lard cans. Therefore a violation of the spacing limits for the lard cans is double contingent.

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APPENDIX A

INDEPENDENT REVIEW COMMENTS AND CHECKLIST

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Desk Instruction 2.0, Rev. 1

CHECKLIST FOR TECHNICAL PEER REVIEW

Document Reviewed - HNF-8782 Rev. 0

Title: CSER 01-009: PFP 241-Z Waste Tanks 900 Gram Mass Limit

Author: E. M. Miller

Date: October 2001

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

D. G. Erickson [signature] 10/10/01

Technical Peer Reviewer (printed name and signature) Date

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

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

Peer Review Comments

D. G. Erickson, a qualified Criticality Safety Specialist, of the Criticality and Shielding group in FFS Safety Analysis and Nuclear Engineering carried out an independent, technical review of Revision 0 of HNF-8782, *CSER 01-09: PFP 241-Z Waste Tanks 900 Gram Mass Limit*. This review of the analysis consisted of the documentation as well as the calculational input and output files.

The technical arguments given in the report were found to be sound for qualifying the criticality safety of the 241-Z waste tanks with a 900 gram mass limit in place of the previous 400 gram limit. The acceptability of the new mass limit is based on maintaining strict controls on the disposal of waste materials. These controls consist of controls on mass of waste to be disposed, bookkeeping, use of drain lines, and allowable waste materials.

This analysis utilized a non-credible, very conservative geometry to come up with the new mass limit. Assuming that any material either as solution with a concentration of 35 g Pu/l or as particulate with a density = 0.035 g Pu/cm^3 can form any specific compact shape in these large tanks is not reasonable. The most credible shape for any of these waste materials would be a slab. For the very low plutonium concentrations expected, this would require at least 10's of kg's of plutonium, if not a 100 or more kg's to create a critical system, even with settled solids.

The modeled geometry, consisting of a conical pile of the plutonium-water mixture on a concrete reflecting floor with a full water reflection above is a very conservative representation of any actual system. Some of the more obvious conservatisms are assuming a plutonium-water mixture versus a more likely plutonium nitrate based solution, not accounting for the neutron absorption of the stainless steel tank and the optimized geometry with the worst concentration material. Small changes to any one of the above conservatisms could significantly increase the calculated minimum critical mass.

The review of the conceivable critical geometries demonstrates that the author considered many other possible scenarios as well as the limiting scenario described in the previous paragraph. The review of the unlikely off-normal condition analysis (contingencies) also demonstrated that the system would remain safely subcritical under all credible, identified, upset conditions.

During the review process many various issues (i.e. technical, editorial, and organizational) were raised. These issues have all been adequately resolved in the final document.

The report was reviewed for technical accuracy, consistency, coverage of all credible contingencies, and adequacy of limits. Significant changes to the report were suggested, and have been incorporated. Discrepancies, inconsistencies, editorial presentation issues and technical issues, etc., were raised and have been adequately resolved.

It should be noted that implementation of the controls on the inputs to the tanks will not be a simple task, and PFP operations will need to be vigilant in assuring that the proper operating procedures and work plans are being followed.

This reviewer affirms that based on the analysis contained in CSER 01-009, HNF-8782, Rev. 0, the increase of the mass limit for the 271-Z waste tanks to 900 grams, with the appropriate controls, is safe from a nuclear criticality standpoint.

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APPENDIX B

MCNP COMPUTER CODE VALIDATION

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B.1 VALIDATION PROCEDURE

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

This method is illustrated in Figure B.1. Critical is defined as a k_{eff} of unity, adjusted by the bias established from the comparison of calculations with benchmarks. This bias includes the mean difference between the calculated and measured benchmark k_{eff}s and a 1.645 multiplier on the standard deviation of the calculated k_{eff} to have 95% confidence that 95% of the population is below this value. The bias is combined with the safety margin of 0.05 (a safety limit that k_{eff}* must be less than or equal to 0.95) to compare with the calculated value and statistical uncertainty of the computer calculated k_{eff}s of this CSER analysis. The calculated target k_{eff} is established by adding the bias, 0.05, and 1.645 times the one-sigma uncertainty of the calculated k_{eff} for the particular CSER analysis and subtracting that value from 1.0. For the analyses in this CSER, all the computer statistical uncertainties were less than ± 0.002, so this value was used to set the target k_{eff}s as described in Section B.2.

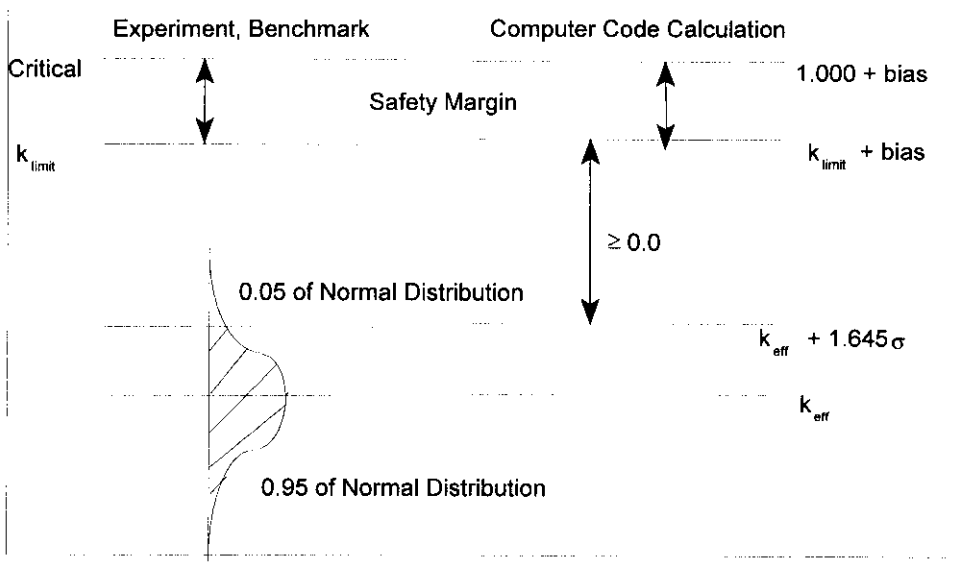

Figure B.1. Logic of Validation Procedure

B.2 GENERIC VALIDATION FOR PLUTONIUM SYSTEMS

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

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

The 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 below that limit. This is expressed by the following formula:

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

Where:

b_L = lower tolerance limit for 95% confidence that 95% of population is below this limit,

k_{avg} = the average of the k_{eff}'s calculated by MCNP4B,

k_b = a multiplier found from statistical tables for non-central t-distribution, and depends on number of degrees of freedom, and

σ_{avg} = standard deviation of the MCNP k_{eff}'s.

Bias is calculated by the following formula:

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

where:

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

The bias for the plutonium metal group was significantly different than for all other groups. For this reason, it was concluded that separate bias values for metal and non-metal groupings would be appropriate. The lower tolerance limit for the metal group (17 benchmark critical experiments) was calculated at 0.9884. The lower tolerance limit for the non-metal group (126 benchmark critical experiments) was 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 k_{eff}* (bias-adjusted k_{eff}) does not exceed 0.95 at the 95% confidence level. This is expressed by the following:

$$k_{eff}^* = k_{eff} - \text{bias} + 1.645 * \sigma$$

and

$$k_{eff}^* \leq k_{limit}$$

Therefore,

$$k_{eff} - \text{bias} + 1.645 * \sigma \leq k_{limit}$$

or

$$k_{eff} \leq k_{limit} + \text{bias} - 1.645 * \sigma$$

where:

k_{eff}	=	k_{eff} value given by MCNP4B 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
σ	=	standard deviation given by MCNP4B calculation for system in question, and
k_{limit}	=	0.95 for plutonium systems, generally.

For a standard deviation (σ) of 0.002 or less, the k_{eff} for plutonium metal systems must be:

$$k_{eff} - (-0.015) + 1.645 * 0.002 \leq 0.95$$

$$k_{eff} \leq 0.932$$

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

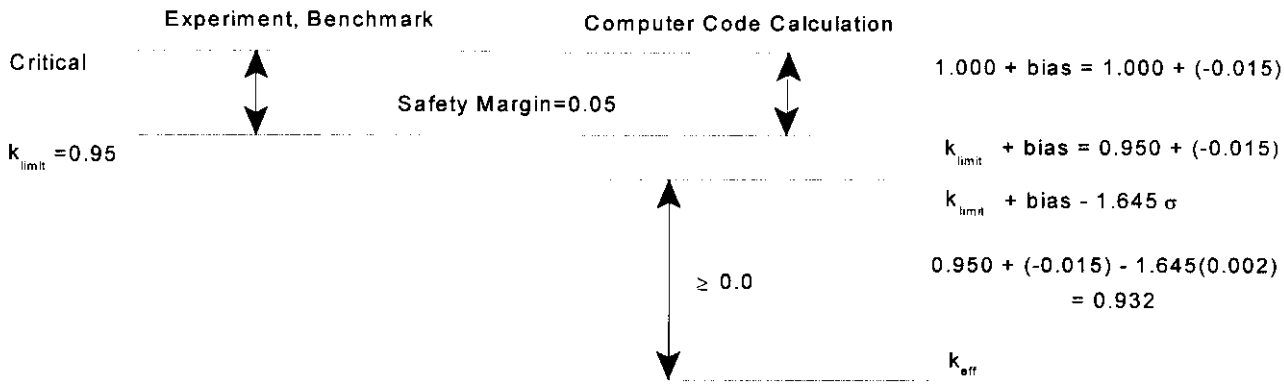

Figure B.2. Implementation of Validation Procedure for Plutonium Metal Systems

For a standard deviation (σ) of 0.002 or less, the k_{eff}* value for non-metal systems is:

$$k_{eff} - (-0.005) + 1.645 * 0.002 \leq 0.95$$

$$k_{eff} \leq 0.942$$

On this basis, it is determined that the true k_{eff} (k_{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_{eff}, and $\sigma \leq 0.002$) is limited to a maximum value of **0.942**.

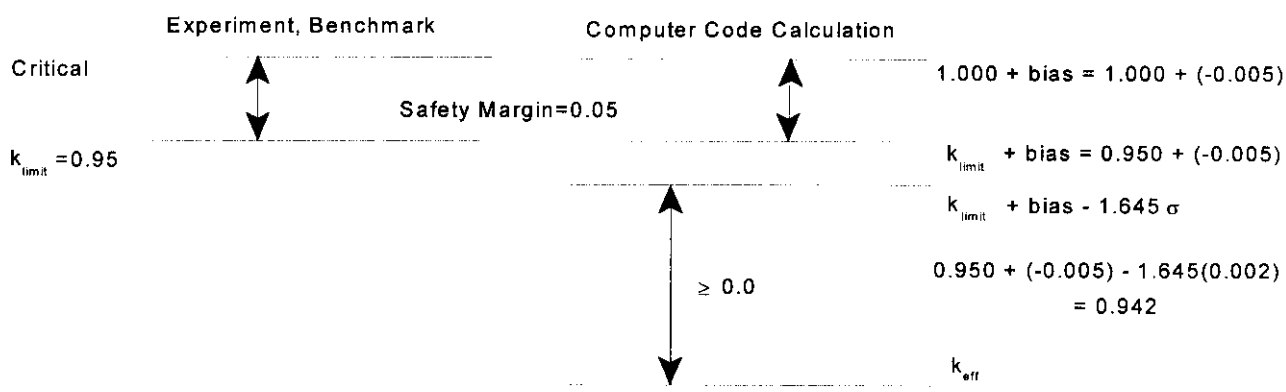

Figure B.3 Implementation of Validation Procedure for Non-Metal Plutonium Systems

B.3 VALIDATION OF MCNP4B

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).

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APPENDIX C

MCNP MODEL, CALCULATIONS, AND INPUT FILES

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1.0 GEOMETRY

A simple but conservative model was created for the critical mass calculations. The model (Figure 1) includes an obtuse cone enclosed by a sphere (r=100 cm). The cone and the sphere of this model simulates the most reactive configuration of fissile material settled in a tank. The bottom of the cone sits on a concrete floor, which takes up lower half of the sphere. The full water reflection of the fissile material is simulated by water surrounding the lateral area of the cone and occupying the rest of the upper half of the sphere. The model also conservatively excludes the structural steel of the tanks, which may absorb neutrons when they scatter outward.

The KZ option of the MCNP4B (Briesmeister 1997) surface definitions is used to describe a cone. The axis of symmetry of the cone coincides with the Z-axis of the geometry, which is described by the following equation

$$(X^2 + Y^2)^{1/2} - \underline{t}\,(Z - \underline{z}) = 0. \qquad (1)$$

Where $\underline{z}$ is the vertex height and $\underline{t}$ is the tangent of the opening angle. The vertex height can be determined by the following expression

$$\underline{z} = \{3000 \times \mathcal{M} / [\rho \times \pi\,(\tan\langle\alpha/2\rangle)^2\,]\}^{1/3}. \qquad (2)$$

Where $\mathcal{M}$ is the fissile mass in grams, α is the vertex angle, and ρ is the fissile-water mixture density in gram per liter (g/L). This specifies a cone whose vertex is $(x, y, z) = (0, 0, \underline{z})$ and whose axis is parallel to the z-axis. The tangent $\underline{t}$ of the opening angle of the cone is $\tan\langle\alpha/2\rangle$.

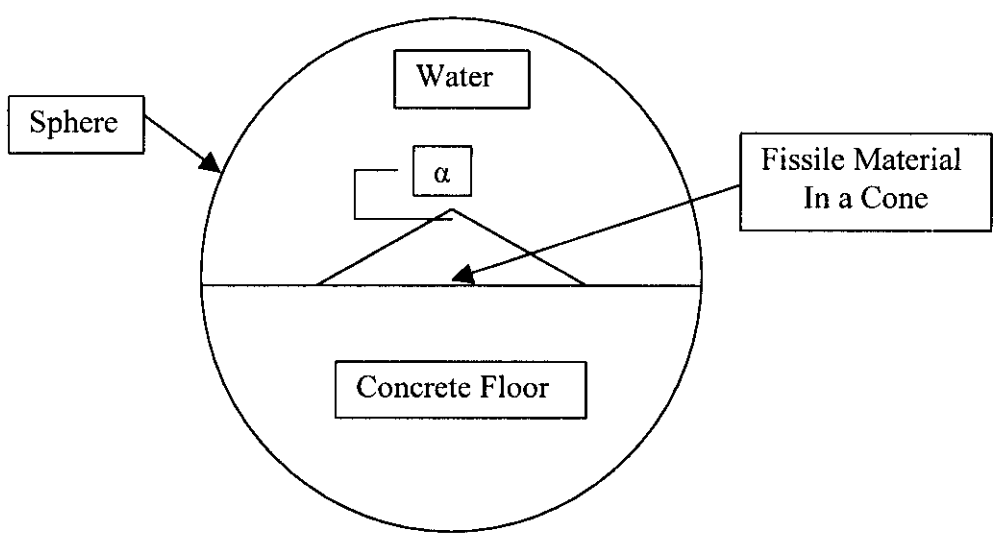


Figure 1. Obtuse Cone on Thick Dry Concrete Floor with Full Water Reflection

2.0 MATERIALS

Three parametric studies were performed to find the most reactive configuration. They are the hydrogen content of concrete, the fissile concentration of the solution or particulate, and the ^{240}Pu content of the fissile material.

2.1 MOISTURE OF CONCRETE

The value of 0.5 weight percent hydrogen is assumed to be the standard minimum, which is referred to as "dry" concrete. The value of 1.23 weight percent hydrogen is assumed to be the maximum, which is referred to as "wet" concrete, although it is physically dry. Table 1 lists the two concrete compositions.

Table 1. Concrete Compositions

Element	MCNP ID	Dry Wt. %	Wet Wt. %
H	1001.50c	0.50	1.23
O	8016.50c	52.10	51.37
Si	14000.50c	25.60	25.60
Ca	20000.50c	7.40	7.40
Al	13027.50c	6.60	6.60
Fe	26000.55c	5.30	5.30
Mg	12000.50c	1.30	1.30
K	19000.50c	1.20	1.20

The density of 2.35 g/cm^3 is used for both the dry and the wet concrete in the calculations.

2.2 FISSILE MATERIALS

Three fissile concentrations were investigated. They are 25 g Pu/L, 35 g Pu/L, and 75 g Pu/L, based on the plutonium metal density of 19.8 g/cm^3. The plutonium metals at those concentrations are mixed with water to be optimally moderated. Section 3.0 of this appendix shows the reason of this selection. These concentrations are the ρ values in Section 1.0 (geometry), Equation (2). Given the apex angle (α) of the cone and the mass, the vertex height ($\underline{z}$) can be determined from Equation (2). Table 2 shows calculations for vertex determination when apex angle $\alpha = 140^\circ$ with various masses.

Table 2. Plutonium Mass, Fissile Concentration and Vertex Height

M (gram)	**Concentration (g Pu/L)**	**Vertex Height (cm)**
700	25	15.24358
700	35	13.62629
700	75	10.56931
900	25	16.57557

M (gram)	Concentration (g Pu/L)	Vertex Height (cm)
900	35	14.81696
900	75	11.49286
1100	25	17.72224
1100	35	15.84197
1100	75	12.28791
1300	25	18.73709
1300	35	16.74915
1300	75	12.99157
1500	25	19.65251
1500	35	17.56745
1500	75	13.62629
1700	25	20.48978
1700	35	18.31589
1700	75	14.20682
1900	25	21.26370
1900	35	19.00770
1900	75	14.74343
2100	25	21.98505
2100	35	19.65251
2100	75	15.24358

2.3 ISOTOPIC CONTENT

The fissile systems referred to in this document are plutonium systems. The nuclide weight fractions, the mixture densities, and the H/X ratios are determined from fissile concentrations. Three types of isotope contents are investigated. The first is the system with 100 wt.% ^{239}Pu with no ^{240}Pu in it. The second has 3 wt.% ^{240}Pu. The third has 5 wt.% ^{240}Pu.

Table 3. Isotopic Contents

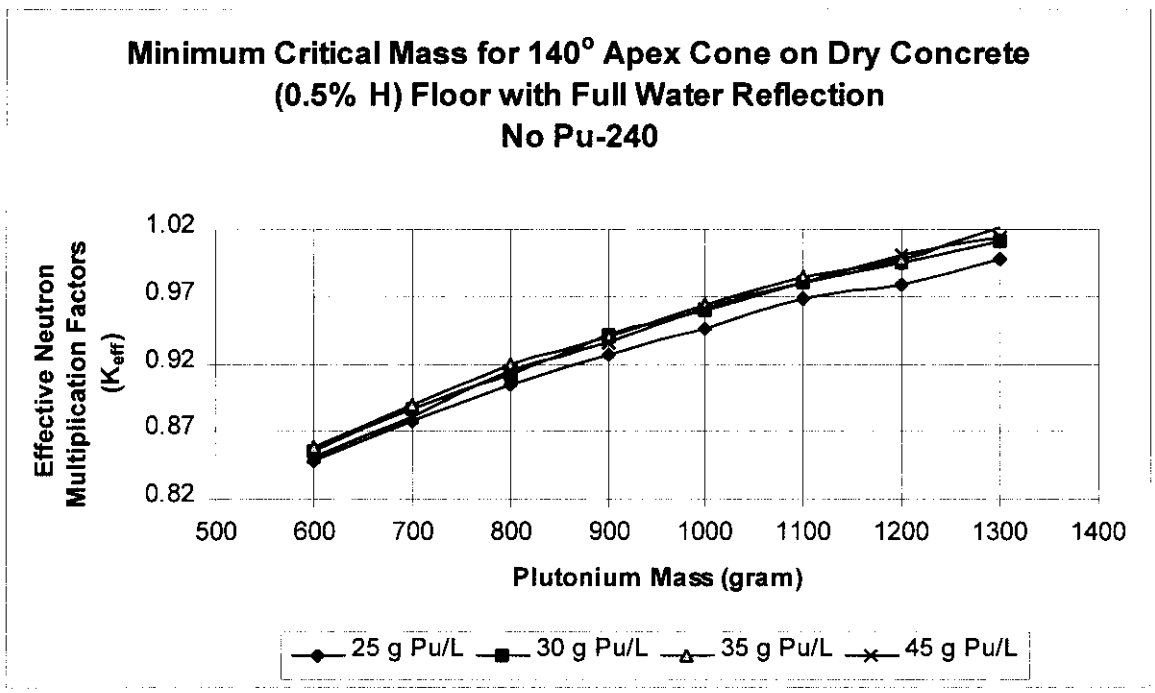
Pu-240 Content	Concentr. (g Pu/L)	Pu-239 (wt.%)	Pu-240 (wt.%)	H (wt.%)	O (wt.%)	H/X (wt.%)	Mix dens. (g/cm^3)
0 %	25	0.024420	0	0.109162	0.866418	1060.21	1.023738
0 %	35	0.033874	0	0.108104	0.858022	756.92	1.033232
0 %	75	0.070014	0	0.104060	0.825926	352.51	1.071212
3 %	25	0.023687	0.000733	0.109162	0.866418	1060.21	1.023738
3 %	35	0.032858	0.001016	0.108104	0.858022	756.92	1.033232
3 %	75	0.067914	0.002100	0.104060	0.825926	352.51	1.071212
5 %	25	0.023199	0.001221	0.109162	0.866418	1060.21	1.023738
5 %	35	0.032181	0.001694	0.108104	0.858022	756.92	1.033232
5 %	75	0.066513	0.003501	0.104060	0.825926	352.51	1.071212

3.0 RESULTS

The Monte Carlo code MCNP4B (Lan 1999) is used to model and calculate the results. The code was certified (Schwinkendorf 1998) and validated (Erickson 1998 and Lan 1999) for plutonium such as the fissile material in this tank. The neutron source of 3000 particles are generated and sampled each cycle with the k_{eff}s of the first 10 cycles discarded before combined averages are taken. The results are concluded at 100 active cycles of calculations. The statistical uncertainties of those calculated results are in the vicinity of 0.001.

A preliminary analysis was made to see the effect of fissile concentrations in the range of 25 g Pu/L to 45 g Pu/L where the plutonium mass vs. critical sphere volumes are shown to be smooth (Figure III.A.9(100)-4, Carter 1968). Figure 2 is the graphical representation of the calculated results of a 140° cone. The figure shows that the k_{eff}s are flat from 30 g Pu/L to 45 g Pu/L for this particular configuration. Therefore, the concentrations of 25 g Pu/L, 35 g Pu/L, and 75 g Pu/L are selected for the rest of the calculations.

Figure 2. Effect of Fissile Concentrations in the Range of 25 ~ 45 g Pu/L



3.1 WET VS. DRY CONCRETE

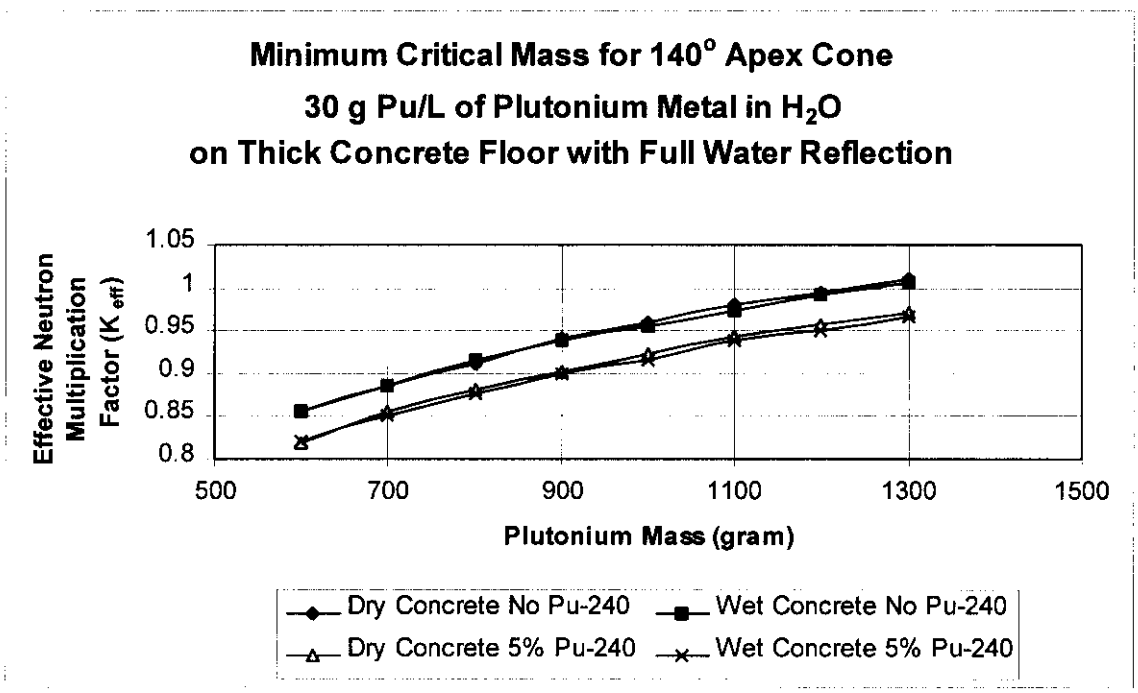
Table 4 shows the k_{eff} results of dry vs. wet concrete floor reflection of a cone having 30 g Pu/L concentration of fissile material and various plutonium mass accumulations inside the cone. The results show very little difference in reactivity when the hydrogen content of the contacting concrete floor changes from 0.5 to 1.23 wt. %. Figure 3 is the graphical representation of the

results listed in Table 1. Therefore, the dry concrete composition is used for the rest of the calculations.

Table 4. K_{eff} Result for Dry vs. Wet Concrete Floor Reflection at 30 g Pu/L Concentration

M (grams)	0 % Pu-240		5 % Pu-240	
	Dry concrete	Wet concrete	Dry concrete	Wet concrete
600	0.856	0.856	0.818	0.820
700	0.887	0.886	0.855	0.851
800	0.911	0.915	0.881	0.877
900	0.941	0.938	0.902	0.899
1000	0.960	0.956	0.922	0.915
1100	0.980	0.974	0.943	0.938
1200	0.995	0.991	0.958	0.951
1300	1.012	1.006	0.971	0.967

Figure 3. K_{eff} Results for Dry vs. Wet Concrete Floor Reflection at 30 g Pu/L Concentration



3.2 ^{240}PU CONTENT

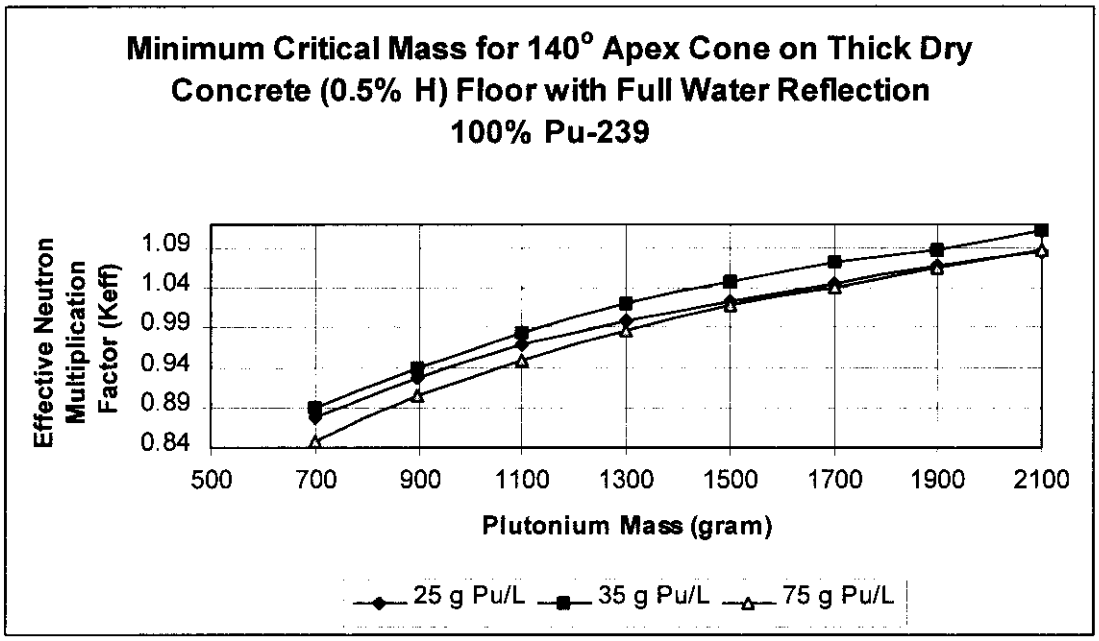
Section 2.3 shows the isotopic contents of the 3 fissile systems being investigated. They are the 100% ^{240}Pu fissile material with no ^{240}Pu in it, the 3 wt.% ^{240}Pu fissile material, and the 5 wt % ^{240}Pu fissile material. The calculated results for those fissile systems are tabulated and graphed in the following 3 subsections.

3.2.1 Zero Percent ^{240}Pu

Table 5. K_{eff} Results of 100 wt.% ^{240}Pu Fissile Material

Case Number	concentration (g Pu/L)	M (grams)	vertex (cm)	k_{eff}	sigma
1	25	700	15.244	0.877	0.0014
2	25	900	16.576	0.927	0.0012
3	25	1100	17.722	0.968	0.0013
4	25	1300	18.737	0.998	0.0014
5	25	1500	19.653	1.024	0.0014
6	25	1700	20.490	1.045	0.0013
7	25	1900	21.264	1.068	0.0016
8	25	2100	21.985	1.085	0.0014
21	35	700	13.626	0.890	0.0016
22	35	900	14.817	0.940	0.0016
23	35	1100	15.842	0.985	0.0017
24	35	1300	16.749	1.021	0.0015
25	35	1500	17.567	1.048	0.0018
26	35	1700	18.316	1.072	0.0016
27	35	1900	19.008	1.088	0.0017
28	35	2100	19.653	1.114	0.0016
51	75	700	10.569	0.848	0.0017
52	75	900	11.493	0.904	0.0020
53	75	1100	12.288	0.950	0.0017
54	75	1300	12.992	0.985	0.0018
55	75	1500	13.626	1.018	0.0021
56	75	1700	14.207	1.041	0.0018
57	75	1900	14.743	1.066	0.0016
58	75	2100	15.244	1.087	0.0019

Figure 4. K_{eff} Results of 100 wt.% ^{239}Pu Fissile Material



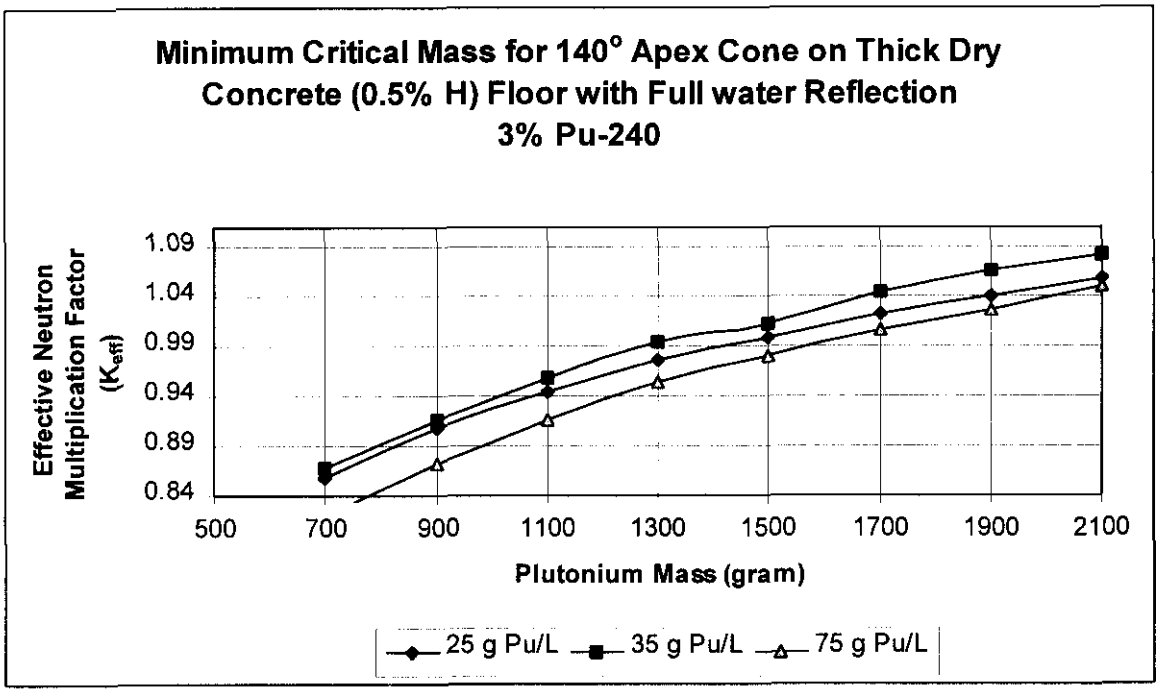
3.2.2 Three Percent ^{240}Pu

Table 6. K_{eff} Results of 3 wt.% ^{240}Pu Fissile Material

Case Number	concentration (g Pu/L)	M (grams)	vertex (cm)	k_{eff}	sigma
1	25	700	15.244	0.858	0.0016
2	25	900	16.576	0.907	0.0016
3	25	1100	17.722	0.945	0.0016
4	25	1300	18.737	0.975	0.0015
5	25	1500	19.653	0.999	0.0015
6	25	1700	20.490	1.022	0.0014
7	25	1900	21.264	1.040	0.0013
8	25	2100	21.985	1.057	0.0016
21	35	700	13.626	0.869	0.0015
22	35	900	14.817	0.917	0.0016
23	35	1100	15.842	0.957	0.0018
24	35	1300	16.749	0.993	0.0016
25	35	1500	17.567	1.013	0.0017
26	35	1700	18.316	1.043	0.0016
27	35	1900	19.008	1.066	0.0017
28	35	2100	19.653	1.082	0.0017
51	75	700	10.569	0.820	0.0017
52	75	900	11.493	0.873	0.0018

Case Number	concentration (g Pu/L)	M (grams)	vertex (cm)	k_{eff}	sigma
53	75	1100	12.288	0.916	0.0018
54	75	1300	12.992	0.953	0.0018
55	75	1500	13.626	0.979	0.0021
56	75	1700	14.207	1.005	0.0020
57	75	1900	14.743	1.026	0.0018
58	75	2100	15.244	1.050	0.0018

Figure 5. K_{eff} Results of 3 wt.% ^{240}Pu Fissile Material



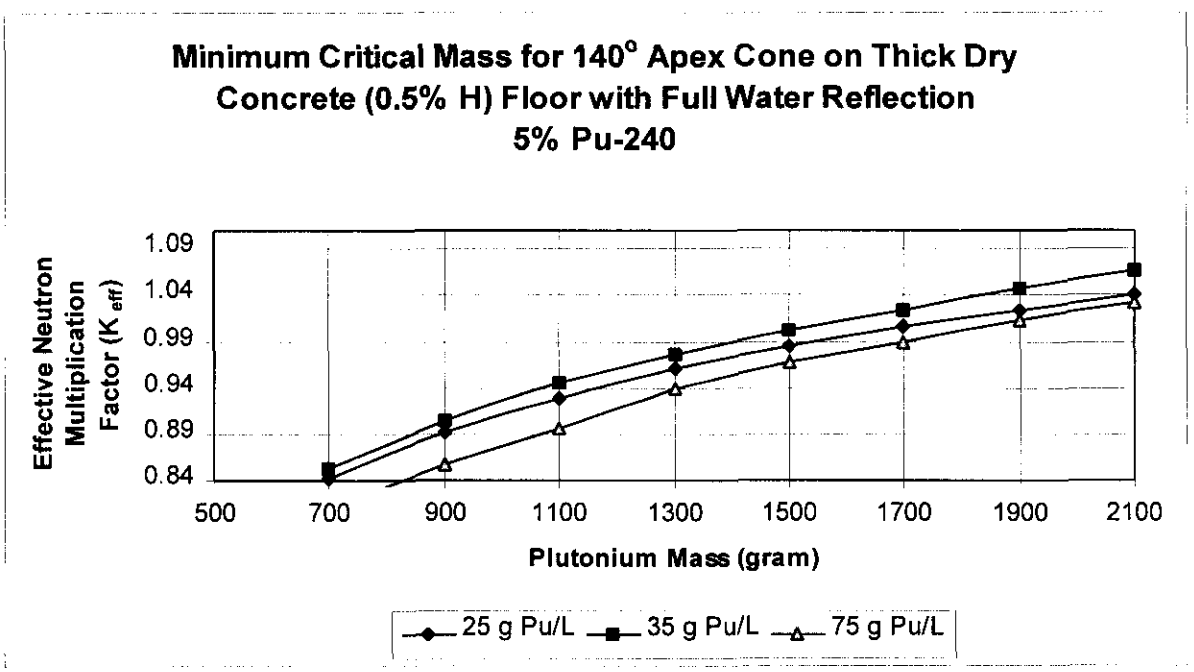
3.2.3 Five Percent ^{240}Pu

Table 7. K_{eff} Results of 5 wt.% ^{240}Pu Fissile Material

Case Number	concentration (g Pu/L)	M (grams)	vertex (cm)	k_{eff}	sigma
1	25	700	15.244	0.842	0.0017
2	25	900	16.576	0.891	0.0015
3	25	1100	17.722	0.928	0.0016
4	25	1300	18.737	0.961	0.0013
5	25	1500	19.653	0.985	0.0015
6	25	1700	20.490	1.005	0.0014

Case Number	concentration (g Pu/L)	M (grams)	vertex (cm)	k_{eff}	sigma
7	25	1900	21.264	1.023	0.0013
8	25	2100	21.985	1.042	0.0014
21	35	700	13.626	0.852	0.0017
22	35	900	14.817	0.905	0.0017
23	35	1100	15.842	0.946	0.0015
24	35	1300	16.749	0.976	0.0014
25	35	1500	17.567	1.001	0.0016
26	35	1700	18.316	1.024	0.0015
27	35	1900	19.008	1.047	0.0012
28	35	2100	19.653	1.066	0.0017
51	75	700	10.569	0.808	0.0020
52	75	900	11.493	0.858	0.0015
53	75	1100	12.288	0.896	0.0019
54	75	1300	12.992	0.939	0.0021
55	75	1500	13.626	0.968	0.0018
56	75	1700	14.207	0.990	0.0019
57	75	1900	14.743	1.013	0.0020
58	75	2100	15.244	1.033	0.0017

Figure 6. K_{eff} Results of 5 wt.% ^{240}Pu Fissile Material



4.0 COMPARISON OF SHAPES

To determine the critically safe plutonium mass limit in a large and geometrically unfavorable tank, potential fissile-liquid mixing configurations to be considered are sphere, hemisphere, cone, or slab. While the sphere, hemisphere, and slab are easy to define and critical masses are well known, the cone shape is more difficult. Table 8 provides a comparison of the geometric characteristics and k_{eff} for these configurations of 100 wt.% $^{239}Pu - H_2O$ mixture optimally moderated.

Table 8. Shape Characteristics of optimum $^{239}Pu - H_2O$ mixture

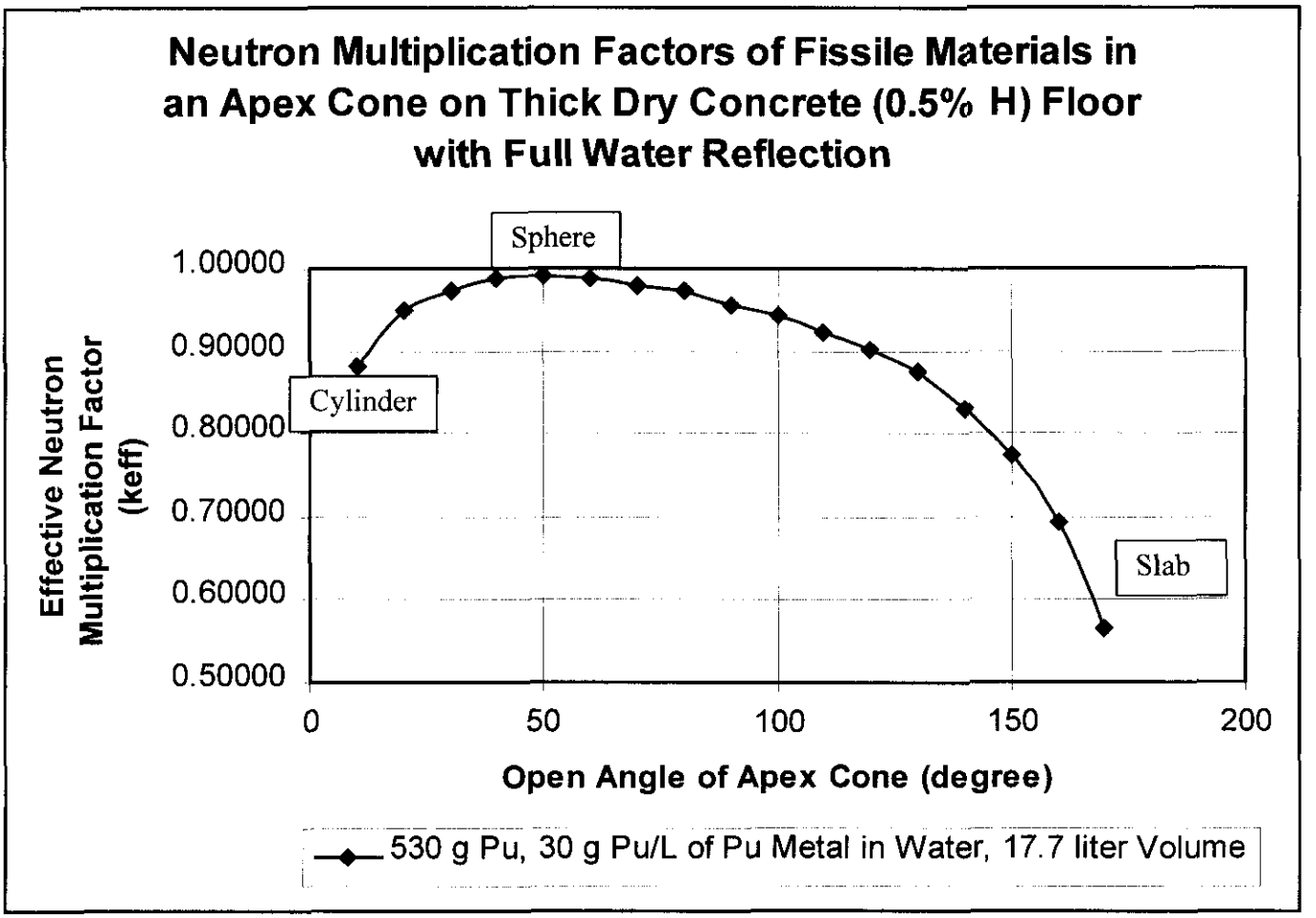
	Mass (grams)	**Mixture (g Pu/L)**	**Volume (liter)**	**Radius (cm)**	**Height (cm)**	**α (degree)**	**k_{eff}**
sphere	530	30	17.6	16.16	-	-	1.019
hemisphere	530	30	17.6	20.23	-	-	0.986
slab	530	30	17.6	152.4	0.242	-	0.081
slab	23,000	30	784	152.4	10.74	-	1.091
cone	530	30	17.6	35.92	13.07	140°	0.829
cone	530	30	17.6	35.92	42.65	50°	0.990

The models of the three additional geometric shapes (sphere, hemisphere, and slab) explored in previous analyses are compared to a cone. The sphere is surrounded by water and rests on a concrete floor. The circular part of a hemisphere is surrounded by water and the bottom rests on a concrete floor. The slab has diameter of 10 ft. (tank size) with the top adjacent to water and the bottom rests on a concrete floor. Figure 7 shows the results for these shapes and for a cone of vertex angles from 10° to 170°.

5.0 CONSERVATISMS

For information and to demonstrate just how conservative the model is a case was run utilizing the 1300 g Pu-water cone with 3 wt.% 240Pu @ 35 g Pu/L. A 1/8" steel layer was added between the cone and the concrete reflection to conservatively model the ~3/8" thick bottom of the tank. Case 24 from Table 6 had a k_{eff} of 0.993. This new case had a k_{eff} = 0.977. A similar change on the k_{eff} can also be seen if Pu(NO3)4 is used in place of the Pu-water solution.

Figure 7. Sphere, Cylinder, and Slab Equivalencies of a Cone



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7.0 MCNP INPUT FILES

Dry Concrete, 3% Pu-240

```
140 deg. apex cone 1.i, 25 g Pu/L metal (19.8 g/cc), mcm 700 g
    1     1 -1.023738    -1     2                imp:n=1    $ fissile material
    2     2 -1.00         1     2          -3    imp:n=1    $ full water reflection
    3     3 -2.35                    -2    -3    imp:n=1    $ concrete floor
    4     0                              3    imp:n=0    $ outside world

c    ------- cone ----------------------------------------
    1        kz     15.24358  7.54863   -1                 $ 140 degree apex cone
    2        pz      0.000                                 $ floor
    3        so    100.0                                   $ outside world

mode  n
c     ----------------------------------------------------
m1    94239.55c -0.023687  1001.50c -0.109162  8016.50c -0.866418 $ 25 gPu/L concentration
      94240.50c -0.000733                                         $ 3% Pu-240
mt1    lwtr.01t                                                   $ rho=1.023738,h/x=1060.4
c    ----------------------------------------------------
c m1  94239.55c  1.00      8016.50c 38.3725    1001.50c  72.745   $ rho=1.364406,  boat
c mt1  lwtr.01t
c     ----------------------------------------------------
m2                         8016.50c -0.888889  1001.50c -0.111111 $ rho=1.000000, water
mt2    lwtr.01t
c    ----------------------------------------------------
c m2   1001.50c  0.66667   8016.50c  0.3333                      $ rho=1.00      , h20
c mt2  lwtr.01t
c    ----------------------------------------------------
m3     1001.50c -0.0050    8016.50c -0.5210   14000.50c -0.2560   $ rho=2.35   concrete
      20000.50c -0.0740   26000.55c -0.0530   13027.50c -0.0660
      12000.50c -0.0130   19000.50c -0.0120                      $ concrete
mt3    lwtr.01t
c    ----------------------------------------------------
c m3   1001.50c  0.0642    8016.50c  0.5916   14000.50c  0.2405   $ rho=2.37   concrete
c     20000.50c  0.0738   26000.55c  0.0299                      $ concrete
c mt3  lwtr.01t
c    ----------------------------------------------------
c m4    7014.50c  0.790000  8016.50c  0.210000                     $ rho=0.00129 ar, air
kcode  3000 1.0  10  100
ksrc   0.1    0.1    1.0
prdmp   j  -300  1  3
totnu
print
ctme   10

140 deg. apex cone 2.i, 25 g Pu/L metal (19.8 g/cc), mcm 900 g
    1     1 -1.023738    -1     2                imp:n=1    $ fissile material
    2     2 -1.00         1     2          -3    imp:n=1    $ full water reflection
    3     3 -2.35                    -2    -3    imp:n=1    $ concrete floor
    4     0                              3    imp:n=0    $ outside world

c    ------- cone ----------------------------------------
    1        kz     16.57557  7.54863   -1                 $ 140 degree apex cone
    2        pz      0.000                                 $ floor
    3        so    100.0                                   $ outside world

mode  n
c     ----------------------------------------------------
m1    94239.55c -0.023687  1001.50c -0.109162  8016.50c -0.866418 $ 25 gPu/L concentration
      94240.50c -0.000733                                         $ 3% Pu-240
mt1    lwtr.01t                                                   $ rho=1.023738,h/x=1060.4
c    ----------------------------------------------------
c m1  94239.55c  1.00      8016.50c 38.3725    1001.50c  72.745   $ rho=1.364406,  boat
c mt1  lwtr.01t
c     ----------------------------------------------------
m2                         8016.50c -0.888889  1001.50c -0.111111 $ rho=1.000000, water
mt2    lwtr.01t
c    ----------------------------------------------------
c m2   1001.50c  0.66667   8016.50c  0.3333                      $ rho=1.00      , h20
c mt2  lwtr.01t
c    ----------------------------------------------------
m3     1001.50c -0.0050    8016.50c -0.5210   14000.50c -0.2560   $ rho=2.35   concrete
      20000.50c -0.0740   26000.55c -0.0530   13027.50c -0.0660
      12000.50c -0.0130   19000.50c -0.0120                      $ concrete
mt3    lwtr.01t
c    ----------------------------------------------------
c m3   1001.50c  0.0642    8016.50c  0.5916   14000.50c  0.2405   $ rho=2.37   concrete
c     20000.50c  0.0738   26000.55c  0.0299                      $ concrete
c mt3  lwtr.01t
c    ----------------------------------------------------
c m4    7014.50c  0.790000  8016.50c  0.210000                     $ rho=0.00129 ar, air
kcode  3000 1.0  10  100
ksrc   0.1    0.1    1.0
prdmp   j  -300  1  3
totnu
print
ctme   10

140 deg. apex cone 3.i, 25 g Pu/L metal (19.8 g/cc), mcm 1100 g
    1     1 -1.023738    -1     2                imp:n=1    $ fissile material
```

```
    2     2 -1.00          1     2          -3     imp:n=1    $ full water reflection
    3     3 -2.35                     -2    -3     imp:n=1    $ concrete floor
    4     0                                 3     imp:n=0    $ outside world

c    ------- cone ----------------------------------------------------------------
    1        kz     17.72224  7.54863   -1                    $ 140 degree apex cone
    2        pz      0.000                                    $ floor
    3        so    100.0                                      $ outside world

mode  n
c     ---------------------------------------------------------------------------
m1    94239.55c -0.023687  1001.50c -0.109162  8016.50c -0.866418 $ 25 gPu/L concentration
      94240.50c -0.000733                                        $ 3% Pu-240
mt1    lwtr.01t                                                  $ rho=1.023738,h/x=1060.4
c    ----------------------------------------------------------------------------
c m1  94239.55c  1.00      8016.50c 38.3725    1001.50c  72.745   $ rho=1.364406,  boat
c mt1  lwtr.01t
c     ---------------------------------------------------------------------------
m2                         8016.50c -0.888889  1001.50c -0.111111 $ rho=1.000000, water
mt2    lwtr.01t
c    ----------------------------------------------------------------------------
c m2   1001.50c  0.66667   8016.50c  0.3333                      $ rho=1.00      , h20
c mt2  lwtr.01t
c    ----------------------------------------------------------------------------
m3     1001.50c -0.0050    8016.50c -0.5210   14000.50c -0.2560   $ rho=2.35   concrete
      20000.50c -0.0740   26000.55c -0.0530   13027.50c -0.0660
      12000.50c -0.0130   19000.50c -0.0120                       $ concrete
mt3    lwtr.01t
c    ----------------------------------------------------------------------------
c m3   1001.50c  0.0642    8016.50c  0.5916   14000.50c  0.2405   $ rho=2.37   concrete
c     20000.50c  0.0738   26000.55c  0.0299                      $ concrete
c mt3  lwtr.01t
c    ----------------------------------------------------------------------------
c m4    7014.50c  0.790000  8016.50c  0.210000                     $ rho=0.00129 ar, air
kcode  3000 1.0  10  100
ksrc   0.1    0.1    1.0
prdmp   j  -300  1  3
totnu
print
ctme   10
```

140 deg. apex cone 4.i, 25 g Pu/L metal (19.8 g/cc), mcm 1300 g

```
    1     1 -1.023738    -1     2                imp:n=1    $ fissile material
    2     2 -1.00          1     2          -3     imp:n=1    $ full water reflection
    3     3 -2.35                     -2    -3     imp:n=1    $ concrete floor
    4     0                                 3     imp:n=0    $ outside world

c    ------- cone ----------------------------------------------------------------
    1        kz     18.73709  7.54863   -1                    $ 140 degree apex cone
    2        pz      0.000                                    $ floor
    3        so    100.0                                      $ outside world

mode  n
c     ---------------------------------------------------------------------------
m1    94239.55c -0.023687  1001.50c -0.109162  8016.50c -0.866418 $ 25 gPu/L concentration
      94240.50c -0.000733                                        $ 3% Pu-240
mt1    lwtr.01t                                                  $ rho=1.023738,h/x=1060.4
c    ----------------------------------------------------------------------------
c m1  94239.55c  1.00      8016.50c 38.3725    1001.50c  72.745   $ rho=1.364406,  boat
c mt1  lwtr.01t
c     ---------------------------------------------------------------------------
m2                         8016.50c -0.888889  1001.50c -0.111111 $ rho=1.000000, water
mt2    lwtr.01t
c    ----------------------------------------------------------------------------
c m2   1001.50c  0.66667   8016.50c  0.3333                      $ rho=1.00      , h20
c mt2  lwtr.01t
c    ----------------------------------------------------------------------------
m3     1001.50c -0.0050    8016.50c -0.5210   14000.50c -0.2560   $ rho=2.35   concrete
      20000.50c -0.0740   26000.55c -0.0530   13027.50c -0.0660
      12000.50c -0.0130   19000.50c -0.0120                       $ concrete
mt3    lwtr.01t
c    ----------------------------------------------------------------------------
c m3   1001.50c  0.0642    8016.50c  0.5916   14000.50c  0.2405   $ rho=2.37   concrete
c     20000.50c  0.0738   26000.55c  0.0299                      $ concrete
c mt3  lwtr.01t
c    ----------------------------------------------------------------------------
c m4    7014.50c  0.790000  8016.50c  0.210000                     $ rho=0.00129 ar, air
kcode  3000 1.0  10  100
ksrc   0.1    0.1    1.0
prdmp   j  -300  1  3
totnu
print
ctme   10
```

140 deg. apex cone 5.i, 25 g Pu/L metal (19.8 g/cc), mcm 1500 g

```
    1     1 -1.023738    -1     2                imp:n=1    $ fissile material
    2     2 -1.00          1     2          -3     imp:n=1    $ full water reflection
    3     3 -2.35                     -2    -3     imp:n=1    $ concrete floor
    4     0                                 3     imp:n=0    $ outside world

c    ------- cone ----------------------------------------------------------------
    1        kz     19.65251  7.54863   -1                    $ 140 degree apex cone
    2        pz      0.000                                    $ floor
    3        so    100.0                                      $ outside world
```

```
mode  n
c     ---------------------------------------------------------------------------------
m1    94239.55c -0.023687  1001.50c -0.109162  8016.50c -0.866418 $ 25 gPu/L concentration
      94240.50c -0.000733                                         $ 3% Pu-240
mt1    lwtr.01t                                                  $ rho=1.023738,h/x=1060.4
c    ---------------------------------------------------------------------------------
c m1  94239.55c  1.00      8016.50c 38.3725    1001.50c  72.745   $ rho=1.364406,  boat
c mt1  lwtr.01t
c     ---------------------------------------------------------------------------------
m2                         8016.50c -0.888889  1001.50c -0.111111 $ rho=1.000000, water
mt2    lwtr.01t
c    ---------------------------------------------------------------------------------
c m2   1001.50c  0.66667   8016.50c  0.3333                       $ rho=1.00      , h20
c mt2  lwtr.01t
c    ---------------------------------------------------------------------------------
m3     1001.50c -0.0050    8016.50c -0.5210   14000.50c -0.2560   $ rho=2.35   concrete
      20000.50c -0.0740   26000.55c -0.0530   13027.50c -0.0660
      12000.50c -0.0130   19000.50c -0.0120                       $ concrete
mt3    lwtr.01t
c    ---------------------------------------------------------------------------------
c m3   1001.50c  0.0642    8016.50c  0.5916   14000.50c  0.2405   $ rho=2.37   concrete
c     20000.50c  0.0738   26000.55c  0.0299                       $ concrete
c mt3  lwtr.01t
c    ---------------------------------------------------------------------------------
c m4    7014.50c  0.790000  8016.50c  0.210000                     $ rho=0.00129 ar, air
kcode  3000 1.0  10  100
ksrc   0.1    0.1    1.0
prdmp   j  -300  1  3
totnu
print
ctme   10

140 deg. apex cone 6.i, 25 g Pu/L metal (19.8 g/cc), mcm 1700 g
    1     1 -1.023738    -1     2                imp:n=1    $ fissile material
    2     2 -1.00         1     2          -3    imp:n=1    $ full water reflection
    3     3 -2.35                    -2    -3    imp:n=1    $ concrete floor
    4     0                              3    imp:n=0    $ outside world

c    ------- cone ---------------------------------------------------------------------
    1        kz     20.48978  7.54863   -1                    $ 140 degree apex cone
    2        pz      0.000                                     $ floor
    3        so    100.0                                       $ outside world

mode  n
c     ---------------------------------------------------------------------------------
m1    94239.55c -0.023687  1001.50c -0.109162  8016.50c -0.866418 $ 25 gPu/L concentration
      94240.50c -0.000733                                         $ 3% Pu-240
mt1    lwtr.01t                                                  $ rho=1.023738,h/x=1060.4
c    ---------------------------------------------------------------------------------
c m1  94239.55c  1.00      8016.50c 38.3725    1001.50c  72.745   $ rho=1.364406,  boat
c mt1  lwtr.01t
c     ---------------------------------------------------------------------------------
m2                         8016.50c -0.888889  1001.50c -0.111111 $ rho=1.000000, water
mt2    lwtr.01t
c    ---------------------------------------------------------------------------------
c m2   1001.50c  0.66667   8016.50c  0.3333                       $ rho=1.00      , h20
c mt2  lwtr.01t
c    ---------------------------------------------------------------------------------
m3     1001.50c -0.0050    8016.50c -0.5210   14000.50c -0.2560   $ rho=2.35   concrete
      20000.50c -0.0740   26000.55c -0.0530   13027.50c -0.0660
      12000.50c -0.0130   19000.50c -0.0120                       $ concrete
mt3    lwtr.01t
c    ---------------------------------------------------------------------------------
c m3   1001.50c  0.0642    8016.50c  0.5916   14000.50c  0.2405   $ rho=2.37   concrete
c     20000.50c  0.0738   26000.55c  0.0299                       $ concrete
c mt3  lwtr.01t
c    ---------------------------------------------------------------------------------
c m4    7014.50c  0.790000  8016.50c  0.210000                     $ rho=0.00129 ar, air
kcode  3000 1.0  10  100
ksrc   0.1    0.1    1.0
prdmp   j  -300  1  3
totnu
print
ctme   10

140 deg. apex cone 7.i, 25 g Pu/L metal (19.8 g/cc), mcm 1900 g
    1     1 -1.023738    -1     2                imp:n=1    $ fissile material
    2     2 -1.00         1     2          -3    imp:n=1    $ full water reflection
    3     3 -2.35                    -2    -3    imp:n=1    $ concrete floor
    4     0                              3    imp:n=0    $ outside world

c    ------- cone ---------------------------------------------------------------------
    1        kz     21.26370  7.54863   -1                    $ 140 degree apex cone
    2        pz      0.000                                     $ floor
    3        so    100.0                                       $ outside world

mode  n
c     ---------------------------------------------------------------------------------
m1    94239.55c -0.023687  1001.50c -0.109162  8016.50c -0.866418 $ 25 gPu/L concentration
      94240.50c -0.000733                                         $ 3% Pu-240
mt1    lwtr.01t                                                  $ rho=1.023738,h/x=1060.4
c    ---------------------------------------------------------------------------------
c m1  94239.55c  1.00      8016.50c 38.3725    1001.50c  72.745   $ rho=1.364406,  boat
c mt1  lwtr.01t
c     ---------------------------------------------------------------------------------
```

```
m2                          8016.50c -0.888889  1001.50c -0.111111 $ rho=1.000000, water
mt2    lwtr.01t
c     ---------------------------------------------------------------------------
c m2   1001.50c  0.66667   8016.50c  0.3333                       $ rho=1.00      , h20
c mt2  lwtr.01t
c     ---------------------------------------------------------------------------
m3     1001.50c -0.0050    8016.50c -0.5210   14000.50c -0.2560   $ rho=2.35   concrete
      20000.50c -0.0740   26000.55c -0.0530   13027.50c -0.0660
      12000.50c -0.0130   19000.50c -0.0120                       $ concrete
mt3    lwtr.01t
c     ---------------------------------------------------------------------------
c m3   1001.50c  0.0642    8016.50c  0.5916   14000.50c  0.2405   $ rho=2.37   concrete
c     20000.50c  0.0738   26000.55c  0.0299                       $ concrete
c mt3  lwtr.01t
c     ---------------------------------------------------------------------------
c m4    7014.50c  0.790000  8016.50c  0.210000                     $ rho=0.00129 ar, air
kcode  3000 1.0  10  100
ksrc   0.1    0.1    1.0
prdmp   j  -300  1  3
totnu
print
ctme   10

140 deg. apex cone 8.i, 25 g Pu/L metal (19.8 g/cc), mcm 2100 g
    1     1 -1.023738    -1     2                  imp:n=1    $ fissile material
    2     2 -1.00         1     2            -3    imp:n=1    $ full water reflection
    3     3 -2.35                     -2     -3    imp:n=1    $ concrete floor
    4     0                                 3     imp:n=0    $ outside world

c     ------- cone ---------------------------------------------------------------
    1        kz     21.98505  7.54863   -1                     $ 140 degree apex cone
    2        pz      0.000                                      $ floor
    3        so    100.0                                        $ outside world

mode  n
c     ---------------------------------------------------------------------------
m1     94239.55c -0.023687  1001.50c -0.109162  8016.50c -0.866418 $ 25 gPu/L concentration
       94240.50c -0.000733                                        $ 3% Pu-240
mt1    lwtr.01t                                                   $ rho=1.023738,h/x=1060.4
c     ---------------------------------------------------------------------------
c m1   94239.55c  1.00      8016.50c 38.3725    1001.50c  72.745   $ rho=1.364406,  boat
c mt1  lwtr.01t
c     ---------------------------------------------------------------------------
m2                          8016.50c -0.888889  1001.50c -0.111111 $ rho=1.000000, water
mt2    lwtr.01t
c     ---------------------------------------------------------------------------
c m2   1001.50c  0.66667   8016.50c  0.3333                       $ rho=1.00      , h20
c mt2  lwtr.01t
c     ---------------------------------------------------------------------------
m3     1001.50c -0.0050    8016.50c -0.5210   14000.50c -0.2560   $ rho=2.35   concrete
      20000.50c -0.0740   26000.55c -0.0530   13027.50c -0.0660
      12000.50c -0.0130   19000.50c -0.0120                       $ concrete
mt3    lwtr.01t
c     ---------------------------------------------------------------------------
c m3   1001.50c  0.0642    8016.50c  0.5916   14000.50c  0.2405   $ rho=2.37   concrete
c     20000.50c  0.0738   26000.55c  0.0299                       $ concrete
c mt3  lwtr.01t
c     ---------------------------------------------------------------------------
c m4    7014.50c  0.790000  8016.50c  0.210000                     $ rho=0.00129 ar, air
kcode  3000 1.0  10  100
ksrc   0.1    0.1    1.0
prdmp   j  -300  1  3
totnu
print
ctme   10

140 deg. apex cone 21.i, 35 g Pu/L metal (19.8 g/cc), mcm 700 g
    1     1 -1.033232    -1     2                  imp:n=1    $ fissile material
    2     2 -1.00         1     2            -3    imp:n=1    $ full water reflection
    3     3 -2.35                     -2     -3    imp:n=1    $ concrete floor
    4     0                                 3     imp:n=0    $ outside world

c     ------- cone ---------------------------------------------------------------
    1        kz     13.62629  7.54863   -1                     $ 140 degree apex cone
    2        pz      0.000                                      $ floor
    3        so    100.0                                        $ outside world

mode  n
c     ---------------------------------------------------------------------------
m1     94239.55c -0.032858  1001.50c -0.109162  8016.50c -0.866418 $ 25 gPu/L concentration
       94240.50c -0.001016                                        $ 3% Pu-240
mt1    lwtr.01t                                                   $ rho=1.033232,h/x=1060.4
c     ---------------------------------------------------------------------------
c m1   94239.55c  1.00      8016.50c 38.3725    1001.50c  72.745   $ rho=1.364406,  boat
c mt1  lwtr.01t
c     ---------------------------------------------------------------------------
m2                          8016.50c -0.888889  1001.50c -0.111111 $ rho=1.000000, water
mt2    lwtr.01t
c     ---------------------------------------------------------------------------
c m2   1001.50c  0.66667   8016.50c  0.3333                       $ rho=1.00      , h20
c mt2  lwtr.01t
c     ---------------------------------------------------------------------------
m3     1001.50c -0.0050    8016.50c -0.5210   14000.50c -0.2560   $ rho=2.35   concrete
      20000.50c -0.0740   26000.55c -0.0530   13027.50c -0.0660
      12000.50c -0.0130   19000.50c -0.0120                       $ concrete
```

```
mt3    lwtr.01t
c     ---------------------------------------------------------------------------
c m3   1001.50c  0.0642    8016.50c  0.5916   14000.50c  0.2405   $ rho=2.37   concrete
c     20000.50c  0.0738   26000.55c  0.0299                       $ concrete
c mt3  lwtr.01t
c     ---------------------------------------------------------------------------
c m4    7014.50c  0.790000  8016.50c  0.210000                     $ rho=0.00129 ar, air
kcode  3000 1.0  10  100
ksrc   0.1    0.1    1.0
prdmp   j  -300  1  3
totnu
print
ctme   10

140 deg. apex cone 22.i, 35 g Pu/L metal (19.8 g/cc), mcm 900 g
    1      1 -1.033232    -1     2                  imp:n=1    $ fissile material
    2      2 -1.00         1     2          -3      imp:n=1    $ full water reflection
    3      3 -2.35                     -2    -3      imp:n=1    $ concrete floor
    4      0                              3      imp:n=0    $ outside world

c     ------- cone ---------------------------------------------------------------
    1        kz     14.81696  7.54863   -1                     $ 140 degree apex cone
    2        pz      0.000                                      $ floor
    3        so    100.0                                        $ outside world

mode  n
c     ---------------------------------------------------------------------------
m1     94239.55c -0.032858  1001.50c -0.109162  8016.50c -0.866418 $ 25 gPu/L concentration
       94240.50c -0.001016                                        $ 3% Pu-240
mt1    lwtr.01t                                                   $ rho=1.033232,h/x=1060.4
c     ---------------------------------------------------------------------------
c m1   94239.55c  1.00      8016.50c 38.3725    1001.50c  72.745   $ rho=1.364406,  boat
c mt1  lwtr.01t
c     ---------------------------------------------------------------------------
m2                          8016.50c -0.888889  1001.50c -0.111111 $ rho=1.000000, water
mt2    lwtr.01t
c     ---------------------------------------------------------------------------
c m2   1001.50c  0.66667   8016.50c  0.3333                       $ rho=1.00      , h20
c mt2  lwtr.01t
c     ---------------------------------------------------------------------------
m3     1001.50c -0.0050    8016.50c -0.5210   14000.50c -0.2560   $ rho=2.35   concrete
      20000.50c -0.0740   26000.55c -0.0530   13027.50c -0.0660
      12000.50c -0.0130   19000.50c -0.0120                       $ concrete
mt3    lwtr.01t
c     ---------------------------------------------------------------------------
c m3   1001.50c  0.0642    8016.50c  0.5916   14000.50c  0.2405   $ rho=2.37   concrete
c     20000.50c  0.0738   26000.55c  0.0299                       $ concrete
c mt3  lwtr.01t
c     ---------------------------------------------------------------------------
c m4    7014.50c  0.790000  8016.50c  0.210000                     $ rho=0.00129 ar, air
kcode  3000 1.0  10  100
ksrc   0.1    0.1    1.0
prdmp   j  -300  1  3
totnu
print
ctme   10

140 deg. apex cone 23.i, 35 g Pu/L metal (19.8 g/cc), mcm 1100 g
    1      1 -1.033232    -1     2                  imp:n=1    $ fissile material
    2      2 -1.00         1     2          -3      imp:n=1    $ full water reflection
    3      3 -2.35                     -2    -3      imp:n=1    $ concrete floor
    4      0                              3      imp:n=0    $ outside world

c     ------- cone ---------------------------------------------------------------
    1        kz     15.84197  7.54863   -1                     $ 140 degree apex cone
    2        pz      0.000                                      $ floor
    3        so    100.0                                        $ outside world

mode  n
c     ---------------------------------------------------------------------------
m1     94239.55c -0.032858  1001.50c -0.109162  8016.50c -0.866418 $ 25 gPu/L concentration
       94240.50c -0.001016                                        $ 3% Pu-240
mt1    lwtr.01t                                                   $ rho=1.033232,h/x=1060.4
c     ---------------------------------------------------------------------------
c m1   94239.55c  1.00      8016.50c 38.3725    1001.50c  72.745   $ rho=1.364406,  boat
c mt1  lwtr.01t
c     ---------------------------------------------------------------------------
m2                          8016.50c -0.888889  1001.50c -0.111111 $ rho=1.000000, water
mt2    lwtr.01t
c     ---------------------------------------------------------------------------
c m2   1001.50c  0.66667   8016.50c  0.3333                       $ rho=1.00      , h20
c mt2  lwtr.01t
c     ---------------------------------------------------------------------------
m3     1001.50c -0.0050    8016.50c -0.5210   14000.50c -0.2560   $ rho=2.35   concrete
      20000.50c -0.0740   26000.55c -0.0530   13027.50c -0.0660
      12000.50c -0.0130   19000.50c -0.0120                       $ concrete
mt3    lwtr.01t
c     ---------------------------------------------------------------------------
c m3   1001.50c  0.0642    8016.50c  0.5916   14000.50c  0.2405   $ rho=2.37   concrete
c     20000.50c  0.0738   26000.55c  0.0299                       $ concrete
c mt3  lwtr.01t
c     ---------------------------------------------------------------------------
c m4    7014.50c  0.790000  8016.50c  0.210000                     $ rho=0.00129 ar, air
kcode  3000 1.0  10  100
ksrc   0.1    0.1    1.0
```

```
prdmp   j  -300  1  3
totnu
print
ctme   10

140 deg. apex cone 24.i, 35 g Pu/L metal (19.8 g/cc), mcm 1300 g
    1     1 -1.033232    -1     2                  imp:n=1    $ fissile material
    2     2 -1.00         1     2            -3    imp:n=1    $ full water reflection
    3     3 -2.35                     -2     -3    imp:n=1    $ concrete floor
    4     0                              3    imp:n=0    $ outside world

c    ------- cone ---------------------------------------------------------------
    1        kz     16.74915  7.54863   -1                    $ 140 degree apex cone
    2        pz      0.000                                    $ floor
    3        so    100.0                                      $ outside world

mode  n
c     ---------------------------------------------------------------------------------
m1    94239.55c -0.032858  1001.50c -0.109162  8016.50c -0.866418 $ 25 gPu/L concentration
      94240.50c -0.001016                                        $ 3% Pu-240
mt1    lwtr.01t                                                  $ rho=1.033232,h/x=1060.4
c    ---------------------------------------------------------------------------------
c m1  94239.55c  1.00      8016.50c 38.3725    1001.50c  72.745   $ rho=1.364406,  boat
c mt1  lwtr.01t
c     ---------------------------------------------------------------------------------
m2                         8016.50c -0.888889  1001.50c -0.111111 $ rho=1.000000, water
mt2    lwtr.01t
c    ---------------------------------------------------------------------------------
c m2   1001.50c  0.66667   8016.50c  0.3333                      $ rho=1.00      , h20
c mt2  lwtr.01t
c    ---------------------------------------------------------------------------------
m3     1001.50c -0.0050    8016.50c -0.5210   14000.50c -0.2560   $ rho=2.35   concrete
      20000.50c -0.0740   26000.55c -0.0530   13027.50c -0.0660
      12000.50c -0.0130   19000.50c -0.0120                       $ concrete
mt3    lwtr.01t
c    ---------------------------------------------------------------------------------
c m3   1001.50c  0.0642    8016.50c  0.5916   14000.50c  0.2405   $ rho=2.37   concrete
c     20000.50c  0.0738   26000.55c  0.0299                      $ concrete
c mt3  lwtr.01t
c    ---------------------------------------------------------------------------------
c m4    7014.50c  0.790000  8016.50c  0.210000                     $ rho=0.00129 ar, air
kcode  3000 1.0  10  100
ksrc   0.1    0.1    1.0
prdmp   j  -300  1  3
totnu
print
ctme   10

140 deg. apex cone 25.i, 35 g Pu/L metal (19.8 g/cc), mcm 1500 g
    1     1 -1.033232    -1     2                  imp:n=1    $ fissile material
    2     2 -1.00         1     2            -3    imp:n=1    $ full water reflection
    3     3 -2.35                     -2     -3    imp:n=1    $ concrete floor
    4     0                              3    imp:n=0    $ outside world

c    ------- cone ---------------------------------------------------------------
    1        kz     17.56745  7.54863   -1                    $ 140 degree apex cone
    2        pz      0.000                                    $ floor
    3        so    100.0                                      $ outside world

mode  n
c     ---------------------------------------------------------------------------------
m1    94239.55c -0.032858  1001.50c -0.109162  8016.50c -0.866418 $ 25 gPu/L concentration
      94240.50c -0.001016                                        $ 3% Pu-240
mt1    lwtr.01t                                                  $ rho=1.033232,h/x=1060.4
c    ---------------------------------------------------------------------------------
c m1  94239.55c  1.00      8016.50c 38.3725    1001.50c  72.745   $ rho=1.364406,  boat
c mt1  lwtr.01t
c     ---------------------------------------------------------------------------------
m2                         8016.50c -0.888889  1001.50c -0.111111 $ rho=1.000000, water
mt2    lwtr.01t
c    ---------------------------------------------------------------------------------
c m2   1001.50c  0.66667   8016.50c  0.3333                      $ rho=1.00      , h20
c mt2  lwtr.01t
c    ---------------------------------------------------------------------------------
m3     1001.50c -0.0050    8016.50c -0.5210   14000.50c -0.2560   $ rho=2.35   concrete
      20000.50c -0.0740   26000.55c -0.0530   13027.50c -0.0660
      12000.50c -0.0130   19000.50c -0.0120                       $ concrete
mt3    lwtr.01t
c    ---------------------------------------------------------------------------------
c m3   1001.50c  0.0642    8016.50c  0.5916   14000.50c  0.2405   $ rho=2.37   concrete
c     20000.50c  0.0738   26000.55c  0.0299                      $ concrete
c mt3  lwtr.01t
c    ---------------------------------------------------------------------------------
c m4    7014.50c  0.790000  8016.50c  0.210000                     $ rho=0.00129 ar, air
kcode  3000 1.0  10  100
ksrc   0.1    0.1    1.0
prdmp   j  -300  1  3
totnu
print
ctme   10

140 deg. apex cone 26.i, 35 g Pu/L metal (19.8 g/cc), mcm 1700 g
    1     1 -1.033232    -1     2                  imp:n=1    $ fissile material
    2     2 -1.00         1     2            -3    imp:n=1    $ full water reflection
    3     3 -2.35                     -2     -3    imp:n=1    $ concrete floor
```

```
    4     0                                  3     imp:n=0    $ outside world

c    ------- cone ---------------------------------------------------------------
    1        kz     18.31589  7.54863   -1                    $ 140 degree apex cone
    2        pz      0.000                                    $ floor
    3        so    100.0                                      $ outside world

mode  n
c     ---------------------------------------------------------------------------------
m1    94239.55c -0.032858  1001.50c -0.109162  8016.50c -0.866418 $ 25 gPu/L concentration
      94240.50c -0.001016                                        $ 3% Pu-240
mt1    lwtr.01t                                                  $ rho=1.033232,h/x=1060.4
c    ---------------------------------------------------------------------------------
c m1  94239.55c  1.00      8016.50c 38.3725    1001.50c  72.745   $ rho=1.364406,  boat
c mt1  lwtr.01t
c     ---------------------------------------------------------------------------------
m2                         8016.50c -0.888889  1001.50c -0.111111 $ rho=1.000000, water
mt2    lwtr.01t
c    ---------------------------------------------------------------------------------
c m2   1001.50c  0.66667   8016.50c  0.3333                      $ rho=1.00      , h20
c mt2  lwtr.01t
c    ---------------------------------------------------------------------------------
m3     1001.50c -0.0050    8016.50c -0.5210   14000.50c -0.2560   $ rho=2.35   concrete
      20000.50c -0.0740   26000.55c -0.0530   13027.50c -0.0660
      12000.50c -0.0130   19000.50c -0.0120                       $ concrete
mt3    lwtr.01t
c    ---------------------------------------------------------------------------------
c m3   1001.50c  0.0642    8016.50c  0.5916   14000.50c  0.2405   $ rho=2.37   concrete
c     20000.50c  0.0738   26000.55c  0.0299                      $ concrete
c mt3  lwtr.01t
c    ---------------------------------------------------------------------------------
c m4    7014.50c  0.790000  8016.50c  0.210000                     $ rho=0.00129 ar, air
kcode  3000 1.0  10  100
ksrc   0.1    0.1    1.0
prdmp   j  -300  1  3
totnu
print
ctme   10

140 deg. apex cone 27.i, 35 g Pu/L metal (19.8 g/cc), mcm 1900 g
    1     1 -1.033232    -1     2                  imp:n=1    $ fissile material
    2     2 -1.00         1     2          -3      imp:n=1    $ full water reflection
    3     3 -2.35                     -2    -3      imp:n=1    $ concrete floor
    4     0                                 3      imp:n=0    $ outside world

c    ------- cone ---------------------------------------------------------------
    1        kz     19.00770  7.54863   -1                    $ 140 degree apex cone
    2        pz      0.000                                    $ floor
    3        so    100.0                                      $ outside world

mode  n
c     ---------------------------------------------------------------------------------
m1    94239.55c -0.032858  1001.50c -0.109162  8016.50c -0.866418 $ 25 gPu/L concentration
      94240.50c -0.001016                                        $ 3% Pu-240
mt1    lwtr.01t                                                  $ rho=1.033232,h/x=1060.4
c    ---------------------------------------------------------------------------------
c m1  94239.55c  1.00      8016.50c 38.3725    1001.50c  72.745   $ rho=1.364406,  boat
c mt1  lwtr.01t
c     ---------------------------------------------------------------------------------
m2                         8016.50c -0.888889  1001.50c -0.111111 $ rho=1.000000, water
mt2    lwtr.01t
c    ---------------------------------------------------------------------------------
c m2   1001.50c  0.66667   8016.50c  0.3333                      $ rho=1.00      , h20
c mt2  lwtr.01t
c    ---------------------------------------------------------------------------------
m3     1001.50c -0.0050    8016.50c -0.5210   14000.50c -0.2560   $ rho=2.35   concrete
      20000.50c -0.0740   26000.55c -0.0530   13027.50c -0.0660
      12000.50c -0.0130   19000.50c -0.0120                       $ concrete
mt3    lwtr.01t
c    ---------------------------------------------------------------------------------
c m3   1001.50c  0.0642    8016.50c  0.5916   14000.50c  0.2405   $ rho=2.37   concrete
c     20000.50c  0.0738   26000.55c  0.0299                      $ concrete
c mt3  lwtr.01t
c    ---------------------------------------------------------------------------------
c m4    7014.50c  0.790000  8016.50c  0.210000                     $ rho=0.00129 ar, air
kcode  3000 1.0  10  100
ksrc   0.1    0.1    1.0
prdmp   j  -300  1  3
totnu
print
ctme   10

140 deg. apex cone 28.i, 35 g Pu/L metal (19.8 g/cc), mcm 2100 g
    1     1 -1.033232    -1     2                  imp:n=1    $ fissile material
    2     2 -1.00         1     2          -3      imp:n=1    $ full water reflection
    3     3 -2.35                     -2    -3      imp:n=1    $ concrete floor
    4     0                                 3      imp:n=0    $ outside world

c    ------- cone ---------------------------------------------------------------
    1        kz     19.65251  7.54863   -1                    $ 140 degree apex cone
    2        pz      0.000                                    $ floor
    3        so    100.0                                      $ outside world

mode  n
c     ---------------------------------------------------------------------------------
```

```
m1     94239.55c -0.032858  1001.50c -0.109162  8016.50c -0.866418 $ 25 gPu/L concentration
       94240.50c -0.001016                                         $ 3% Pu-240
mt1     lwtr.01t                                                   $ rho=1.033232,h/x=1060.4
c     ---------------------------------------------------------------------------------
c m1   94239.55c  1.00       8016.50c 38.3725    1001.50c  72.745   $ rho=1.364406,  boat
c mt1   lwtr.01t
c     ---------------------------------------------------------------------------------
m2                           8016.50c -0.888889  1001.50c -0.111111 $ rho=1.000000, water
mt2     lwtr.01t
c     ---------------------------------------------------------------------------------
c m2    1001.50c  0.66667    8016.50c  0.3333                       $ rho=1.00      , h20
c mt2   lwtr.01t
c     ---------------------------------------------------------------------------------
m3      1001.50c -0.0050     8016.50c -0.5210   14000.50c -0.2560   $ rho=2.35   concrete
       20000.50c -0.0740    26000.55c -0.0530   13027.50c -0.0660
       12000.50c -0.0130    19000.50c -0.0120                       $ concrete
mt3     lwtr.01t
c     ---------------------------------------------------------------------------------
c m3    1001.50c  0.0642     8016.50c  0.5916   14000.50c  0.2405   $ rho=2.37   concrete
c      20000.50c  0.0738    26000.55c  0.0299                       $ concrete
c mt3   lwtr.01t
c     ---------------------------------------------------------------------------------
c m4     7014.50c  0.790000  8016.50c  0.210000                      $ rho=0.00129 ar, air
kcode   3000 1.0  10  100
ksrc    0.1    0.1    1.0
prdmp    j  -300  1  3
totnu
print
ctme    10

140 deg. apex cone 51.i, 35 g Pu/L metal (19.8 g/cc), mcm 700 g
    1      1 -1.071212    -1     2                imp:n=1    $ fissile material
    2      2 -1.00         1     2          -3    imp:n=1    $ full water reflection
    3      3 -2.35                    -2     -3    imp:n=1    $ concrete floor
    4      0                                 3    imp:n=0    $ outside world

c     ------- cone ---------------------------------------------------------------
    1         kz      10.56931  7.54863   -1                   $ 140 degree apex cone
    2         pz       0.000                                    $ floor
    3         so     100.0                                      $ outside world

mode   n
c     ---------------------------------------------------------------------------------
m1     94239.55c -0.067914  1001.50c -0.104060  8016.50c -0.825926 $ 75 gPu/L concentration
       94240.50c -0.002100                                         $ 3% Pu-240
mt1     lwtr.01t                                                   $ rho=1.071212,h/x=352.512
c     ---------------------------------------------------------------------------------
c m1   94239.55c  1.00       8016.50c 38.3725    1001.50c  72.745   $ rho=1.364406,  boat
c mt1   lwtr.01t
c     ---------------------------------------------------------------------------------
m2                           8016.50c -0.888889  1001.50c -0.111111 $ rho=1.000000, water
mt2     lwtr.01t
c     ---------------------------------------------------------------------------------
c m2    1001.50c  0.66667    8016.50c  0.3333                       $ rho=1.00      , h20
c mt2   lwtr.01t
c     ---------------------------------------------------------------------------------
m3      1001.50c -0.0050     8016.50c -0.5210   14000.50c -0.2560   $ rho=2.35   concrete
       20000.50c -0.0740    26000.55c -0.0530   13027.50c -0.0660
       12000.50c -0.0130    19000.50c -0.0120                       $ concrete
mt3     lwtr.01t
c     ---------------------------------------------------------------------------------
c m3    1001.50c  0.0642     8016.50c  0.5916   14000.50c  0.2405   $ rho=2.37   concrete
c      20000.50c  0.0738    26000.55c  0.0299                       $ concrete
c mt3   lwtr.01t
c     ---------------------------------------------------------------------------------
c m4     7014.50c  0.790000  8016.50c  0.210000                      $ rho=0.00129 ar, air
kcode   3000 1.0  10  100
ksrc    0.1    0.1    1.0
prdmp    j  -300  1  3
totnu
print
ctme    10

140 deg. apex cone 52.i, 35 g Pu/L metal (19.8 g/cc), mcm 900 g
    1      1 -1.071212    -1     2                imp:n=1    $ fissile material
    2      2 -1.00         1     2          -3    imp:n=1    $ full water reflection
    3      3 -2.35                    -2     -3    imp:n=1    $ concrete floor
    4      0                                 3    imp:n=0    $ outside world

c     ------- cone ---------------------------------------------------------------
    1         kz      11.49286  7.54863   -1                   $ 140 degree apex cone
    2         pz       0.000                                    $ floor
    3         so     100.0                                      $ outside world

mode   n
c     ---------------------------------------------------------------------------------
m1     94239.55c -0.067914  1001.50c -0.104060  8016.50c -0.825926 $ 75 gPu/L concentration
       94240.50c -0.002100                                         $ 3% Pu-240
mt1     lwtr.01t                                                   $ rho=1.071212,h/x=352.512
c     ---------------------------------------------------------------------------------
c m1   94239.55c  1.00       8016.50c 38.3725    1001.50c  72.745   $ rho=1.364406,  boat
c mt1   lwtr.01t
c     ---------------------------------------------------------------------------------
m2                           8016.50c -0.888889  1001.50c -0.111111 $ rho=1.000000, water
mt2     lwtr.01t
```

```
c     ---------------------------------------------------------------------------
c m2   1001.50c  0.66667   8016.50c  0.3333                        $ rho=1.00      , h20
c mt2  lwtr.01t
c     ---------------------------------------------------------------------------
m3     1001.50c -0.0050    8016.50c -0.5210   14000.50c -0.2560   $ rho=2.35   concrete
      20000.50c -0.0740   26000.55c -0.0530   13027.50c -0.0660
      12000.50c -0.0130   19000.50c -0.0120                       $ concrete
mt3    lwtr.01t
c     ---------------------------------------------------------------------------
c m3   1001.50c  0.0642    8016.50c  0.5916   14000.50c  0.2405   $ rho=2.37   concrete
c     20000.50c  0.0738   26000.55c  0.0299                       $ concrete
c mt3  lwtr.01t
c     ---------------------------------------------------------------------------
c m4    7014.50c  0.790000  8016.50c  0.210000                     $ rho=0.00129 ar, air
kcode  3000 1.0  10  100
ksrc   0.1    0.1    1.0
prdmp   j  -300  1  3
totnu
print
ctme   10

140 deg. apex cone 53.i, 35 g Pu/L metal (19.8 g/cc), mcm 1100 g
    1     1 -1.071212    -1     2                  imp:n=1    $ fissile material
    2     2 -1.00         1     2          -3      imp:n=1    $ full water reflection
    3     3 -2.35                     -2    -3      imp:n=1    $ concrete floor
    4     0                                 3      imp:n=0    $ outside world

c    ------- cone ---------------------------------------------------------------
    1        kz     12.28791  7.54863   -1                     $ 140 degree apex cone
    2        pz      0.000                                      $ floor
    3        so    100.0                                        $ outside world

mode  n
c     ---------------------------------------------------------------------------
m1    94239.55c -0.067914  1001.50c -0.104060  8016.50c -0.825926 $ 75 gPu/L concentration
      94240.50c -0.002100                                         $ 3% Pu-240
mt1    lwtr.01t                                                  $ rho=1.071212,h/x=352.512
c     ---------------------------------------------------------------------------
c m1  94239.55c  1.00      8016.50c 38.3725    1001.50c  72.745   $ rho=1.364406,  boat
c mt1  lwtr.01t
c     ---------------------------------------------------------------------------
m2                         8016.50c -0.888889  1001.50c -0.111111 $ rho=1.000000, water
mt2    lwtr.01t
c     ---------------------------------------------------------------------------
c m2   1001.50c  0.66667   8016.50c  0.3333                        $ rho=1.00      , h20
c mt2  lwtr.01t
c     ---------------------------------------------------------------------------
m3     1001.50c -0.0050    8016.50c -0.5210   14000.50c -0.2560   $ rho=2.35   concrete
      20000.50c -0.0740   26000.55c -0.0530   13027.50c -0.0660
      12000.50c -0.0130   19000.50c -0.0120                       $ concrete
mt3    lwtr.01t
c     ---------------------------------------------------------------------------
c m3   1001.50c  0.0642    8016.50c  0.5916   14000.50c  0.2405   $ rho=2.37   concrete
c     20000.50c  0.0738   26000.55c  0.0299                       $ concrete
c mt3  lwtr.01t
c     ---------------------------------------------------------------------------
c m4    7014.50c  0.790000  8016.50c  0.210000                     $ rho=0.00129 ar, air
kcode  3000 1.0  10  100
ksrc   0.1    0.1    1.0
prdmp   j  -300  1  3
totnu
print
ctme   10

140 deg. apex cone 54.i, 35 g Pu/L metal (19.8 g/cc), mcm 1300 g
    1     1 -1.071212    -1     2                  imp:n=1    $ fissile material
    2     2 -1.00         1     2          -3      imp:n=1    $ full water reflection
    3     3 -2.35                     -2    -3      imp:n=1    $ concrete floor
    4     0                                 3      imp:n=0    $ outside world

c    ------- cone ---------------------------------------------------------------
    1        kz     12.99157  7.54863   -1                     $ 140 degree apex cone
    2        pz      0.000                                      $ floor
    3        so    100.0                                        $ outside world

mode  n
c     ---------------------------------------------------------------------------
m1    94239.55c -0.067914  1001.50c -0.104060  8016.50c -0.825926 $ 75 gPu/L concentration
      94240.50c -0.002100                                         $ 3% Pu-240
mt1    lwtr.01t                                                  $ rho=1.071212,h/x=352.512
c     ---------------------------------------------------------------------------
c m1  94239.55c  1.00      8016.50c 38.3725    1001.50c  72.745   $ rho=1.364406,  boat
c mt1  lwtr.01t
c     ---------------------------------------------------------------------------
m2                         8016.50c -0.888889  1001.50c -0.111111 $ rho=1.000000, water
mt2    lwtr.01t
c     ---------------------------------------------------------------------------
c m2   1001.50c  0.66667   8016.50c  0.3333                        $ rho=1.00      , h20
c mt2  lwtr.01t
c     ---------------------------------------------------------------------------
m3     1001.50c -0.0050    8016.50c -0.5210   14000.50c -0.2560   $ rho=2.35   concrete
      20000.50c -0.0740   26000.55c -0.0530   13027.50c -0.0660
      12000.50c -0.0130   19000.50c -0.0120                       $ concrete
mt3    lwtr.01t
c     ---------------------------------------------------------------------------
```

```
c m3   1001.50c  0.0642    8016.50c  0.5916   14000.50c  0.2405   $ rho=2.37   concrete
c     20000.50c  0.0738   26000.55c  0.0299                       $ concrete
c mt3  lwtr.01t
c    ---------------------------------------------------------------------------
c m4    7014.50c  0.790000  8016.50c  0.210000                     $ rho=0.00129 ar, air
kcode  3000 1.0  10  100
ksrc   0.1    0.1    1.0
prdmp   j  -300  1  3
totnu
print
ctme   10

140 deg. apex cone 55.i, 35 g Pu/L metal (19.8 g/cc), mcm 1500 g
    1     1 -1.071212    -1     2                 imp:n=1    $ fissile material
    2     2 -1.00         1     2          -3     imp:n=1    $ full water reflection
    3     3 -2.35                    -2    -3     imp:n=1    $ concrete floor
    4     0                              3     imp:n=0    $ outside world

c    ------- cone ---------------------------------------------------------------
    1        kz     13.62629  7.54863   -1                    $ 140 degree apex cone
    2        pz      0.000                                     $ floor
    3        so    100.0                                       $ outside world

mode  n
c     ---------------------------------------------------------------------------
m1    94239.55c -0.067914  1001.50c -0.104060  8016.50c -0.825926 $ 75 gPu/L concentration
      94240.50c -0.002100                                        $ 3% Pu-240
mt1    lwtr.01t                                                  $ rho=1.071212,h/x=352.512
c    ---------------------------------------------------------------------------
c m1  94239.55c  1.00      8016.50c 38.3725    1001.50c  72.745   $ rho=1.364406,  boat
c mt1  lwtr.01t
c     ---------------------------------------------------------------------------
m2                         8016.50c -0.888889  1001.50c -0.111111 $ rho=1.000000, water
mt2    lwtr.01t
c    ---------------------------------------------------------------------------
c m2   1001.50c  0.66667   8016.50c  0.3333                       $ rho=1.00      , h20
c mt2  lwtr.01t
c    ---------------------------------------------------------------------------
m3     1001.50c -0.0050    8016.50c -0.5210   14000.50c -0.2560   $ rho=2.35   concrete
      20000.50c -0.0740   26000.55c -0.0530   13027.50c -0.0660
      12000.50c -0.0130   19000.50c -0.0120                       $ concrete
mt3    lwtr.01t
c    ---------------------------------------------------------------------------
c m3   1001.50c  0.0642    8016.50c  0.5916   14000.50c  0.2405   $ rho=2.37   concrete
c     20000.50c  0.0738   26000.55c  0.0299                       $ concrete
c mt3  lwtr.01t
c    ---------------------------------------------------------------------------
c m4    7014.50c  0.790000  8016.50c  0.210000                     $ rho=0.00129 ar, air
kcode  3000 1.0  10  100
ksrc   0.1    0.1    1.0
prdmp   j  -300  1  3
totnu
print
ctme   10

140 deg. apex cone 56.i, 35 g Pu/L metal (19.8 g/cc), mcm 1700 g
    1     1 -1.071212    -1     2                 imp:n=1    $ fissile material
    2     2 -1.00         1     2          -3     imp:n=1    $ full water reflection
    3     3 -2.35                    -2    -3     imp:n=1    $ concrete floor
    4     0                              3     imp:n=0    $ outside world

c    ------- cone ---------------------------------------------------------------
    1        kz     14.20682  7.54863   -1                    $ 140 degree apex cone
    2        pz      0.000                                     $ floor
    3        so    100.0                                       $ outside world

mode  n
c     ---------------------------------------------------------------------------
m1    94239.55c -0.067914  1001.50c -0.104060  8016.50c -0.825926 $ 75 gPu/L concentration
      94240.50c -0.002100                                        $ 3% Pu-240
mt1    lwtr.01t                                                  $ rho=1.071212,h/x=352.512
c    ---------------------------------------------------------------------------
c m1  94239.55c  1.00      8016.50c 38.3725    1001.50c  72.745   $ rho=1.364406,  boat
c mt1  lwtr.01t
c     ---------------------------------------------------------------------------
m2                         8016.50c -0.888889  1001.50c -0.111111 $ rho=1.000000, water
mt2    lwtr.01t
c    ---------------------------------------------------------------------------
c m2   1001.50c  0.66667   8016.50c  0.3333                       $ rho=1.00      , h20
c mt2  lwtr.01t
c    ---------------------------------------------------------------------------
m3     1001.50c -0.0050    8016.50c -0.5210   14000.50c -0.2560   $ rho=2.35   concrete
      20000.50c -0.0740   26000.55c -0.0530   13027.50c -0.0660
      12000.50c -0.0130   19000.50c -0.0120                       $ concrete
mt3    lwtr.01t
c    ---------------------------------------------------------------------------
c m3   1001.50c  0.0642    8016.50c  0.5916   14000.50c  0.2405   $ rho=2.37   concrete
c     20000.50c  0.0738   26000.55c  0.0299                       $ concrete
c mt3  lwtr.01t
c    ---------------------------------------------------------------------------
c m4    7014.50c  0.790000  8016.50c  0.210000                     $ rho=0.00129 ar, air
kcode  3000 1.0  10  100
ksrc   0.1    0.1    1.0
prdmp   j  -300  1  3
totnu
```

```
print
ctme   10

140 deg. apex cone 57.i, 35 g Pu/L metal (19.8 g/cc), mcm 1900 g
    1     1 -1.071212    -1     2                  imp:n=1    $ fissile material
    2     2 -1.00         1     2          -3      imp:n=1    $ full water reflection
    3     3 -2.35                     -2    -3      imp:n=1    $ concrete floor
    4     0                                 3      imp:n=0    $ outside world

c    ------- cone ---------------------------------------------------------------------
    1        kz     14.74343  7.54863   -1                    $ 140 degree apex cone
    2        pz      0.000                                    $ floor
    3        so    100.0                                      $ outside world

mode  n
c     ---------------------------------------------------------------------------------
m1    94239.55c -0.067914  1001.50c -0.104060  8016.50c -0.825926 $ 75 gPu/L concentration
      94240.50c -0.002100                                        $ 3% Pu-240
mt1    lwtr.01t                                                  $ rho=1.071212,h/x=352.512
c    ---------------------------------------------------------------------------------
c m1  94239.55c  1.00      8016.50c 38.3725    1001.50c  72.745   $ rho=1.364406,  boat
c mt1  lwtr.01t
c     ---------------------------------------------------------------------------------
m2                         8016.50c -0.888889  1001.50c -0.111111 $ rho=1.000000, water
mt2    lwtr.01t
c    ---------------------------------------------------------------------------------
c m2   1001.50c  0.66667   8016.50c  0.3333                      $ rho=1.00      , h20
c mt2  lwtr.01t
c    ---------------------------------------------------------------------------------
m3     1001.50c -0.0050    8016.50c -0.5210   14000.50c -0.2560   $ rho=2.35   concrete
      20000.50c -0.0740   26000.55c -0.0530   13027.50c -0.0660
      12000.50c -0.0130   19000.50c -0.0120                       $ concrete
mt3    lwtr.01t
c    ---------------------------------------------------------------------------------
c m3   1001.50c  0.0642    8016.50c  0.5916   14000.50c  0.2405   $ rho=2.37   concrete
c     20000.50c  0.0738   26000.55c  0.0299                      $ concrete
c mt3  lwtr.01t
c    ---------------------------------------------------------------------------------
c m4    7014.50c  0.790000  8016.50c  0.210000                     $ rho=0.00129 ar, air
kcode  3000 1.0  10  100
ksrc   0.1    0.1    1.0
prdmp   j  -300  1  3
totnu
print
ctme   10

140 deg. apex cone 58.i, 35 g Pu/L metal (19.8 g/cc), mcm 2100 g
    1     1 -1.071212    -1     2                  imp:n=1    $ fissile material
    2     2 -1.00         1     2          -3      imp:n=1    $ full water reflection
    3     3 -2.35                     -2    -3      imp:n=1    $ concrete floor
    4     0                                 3      imp:n=0    $ outside world

c    ------- cone ---------------------------------------------------------------------
    1        kz     15.24358  7.54863   -1                    $ 140 degree apex cone
    2        pz      0.000                                    $ floor
    3        so    100.0                                      $ outside world

mode  n
c     ---------------------------------------------------------------------------------
m1    94239.55c -0.067914  1001.50c -0.104060  8016.50c -0.825926 $ 75 gPu/L concentration
      94240.50c -0.002100                                        $ 3% Pu-240
mt1    lwtr.01t                                                  $ rho=1.071212,h/x=352.512
c    ---------------------------------------------------------------------------------
c m1  94239.55c  1.00      8016.50c 38.3725    1001.50c  72.745   $ rho=1.364406,  boat
c mt1  lwtr.01t
c     ---------------------------------------------------------------------------------
m2                         8016.50c -0.888889  1001.50c -0.111111 $ rho=1.000000, water
mt2    lwtr.01t
c    ---------------------------------------------------------------------------------
c m2   1001.50c  0.66667   8016.50c  0.3333                      $ rho=1.00      , h20
c mt2  lwtr.01t
c    ---------------------------------------------------------------------------------
m3     1001.50c -0.0050    8016.50c -0.5210   14000.50c -0.2560   $ rho=2.35   concrete
      20000.50c -0.0740   26000.55c -0.0530   13027.50c -0.0660
      12000.50c -0.0130   19000.50c -0.0120                       $ concrete
mt3    lwtr.01t
c    ---------------------------------------------------------------------------------
c m3   1001.50c  0.0642    8016.50c  0.5916   14000.50c  0.2405   $ rho=2.37   concrete
c     20000.50c  0.0738   26000.55c  0.0299                      $ concrete
c mt3  lwtr.01t
c    ---------------------------------------------------------------------------------
c m4    7014.50c  0.790000  8016.50c  0.210000                     $ rho=0.00129 ar, air
kcode  3000 1.0  10  100
ksrc   0.1    0.1    1.0
prdmp   j  -300  1  3
totnu
print
ctme   10
```

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