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1	1	Design Agent	A.L. Ramble	2/19/97	T5-54	1	1	Peer Rev.	E.M. Miller	2/19/97	40-35
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CSER 97-001: Criticality Safety Limits for PFP 26-Inch Vacuum Line Removal

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Fluor Daniel Northwest Inc., Richland, WA 99352

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Abstract: This CSER addresses the criticality limits and process controls related to removal of several hundred feet of abandoned 3 and 4 inch nominal diameter vacuum header, and associated smaller diameter piping runs, located in the duct level of the 234-5Z Building in rooms 262, 263, and 264. The material in the duct was presumed to be wet so that optimum moderation was assumed for the analysis. It was determined that, with proper precautions, sections of duct containing up to 4 kg of fissile material could be cut, transported to an NDA station, and thence to disposal or to Glovebox 235-B-2 for additional sectioning and cleaning as required.

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Sheri Martens FEB 28 1997
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CSER 97-001:

**CRITICALITY SAFETY LIMITS FOR PFP
26-INCH VACUUM LINE REMOVAL**

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1.0 INTRODUCTION AND SUMMARY

As part of the plutonium stabilization operations in the 234-5Z Building, several runs of 26-inch (26 inches of Hg) process vacuum header, along with associated smaller piping is to be cut into sections and disposed of. This criticality safety evaluation report (CSER) requested by Nirider (1996) addresses the removal of several hundred feet of abandoned 3 and 4 inch nominal diameter vacuum header and associated smaller diameter piping runs located in the duct level of the 234-5Z Building in rooms 262, 263, and 264 as shown in the two attached drawings.

Portions of the vacuum header to be removed contain significant amounts of plutonium, mainly in the form of oxides. Due to the nature of the system operations the material within the pipe is thought to be wet, and possibly to have slumped to the bottom of the pipe cross-section rather than to be uniformly distributed around the pipe circumference. Additional conservatism is therefore required and all analyses in this CSER assume the material to be optimally moderated. The small size of the piping (nominal 4 inch or less)

provides a favorable geometry so that reasonably long pieces with a relatively high fissile loading can be safely cut and handled as long as specified limits and controls are observed.

This evaluation determines that Plutonium Finishing Plant (PFP) operations may cut and remove sections of 4 inch nominal diameter and smaller vacuum lines, transport the cut sections within the 234-5Z Building, and perform disposition operations on the sections in the 235-B-2 glovebox using the following criticality safety limits and controls in the Criticality Prevention Specification (CPS) for this work.

1. Before beginning activities to cut or dismantle any duct section from its currently installed position, there must be verification that there is no more than 0.5 liters of free liquid in the section to be removed or in the same or connected piping at a higher elevation than the section to be removed. Accumulations of up to 2 liters may be removed using equipment meeting the requirements of Item 7 below. If more than 2 liters of liquid are discovered in the piping, work shall be stopped until a revised plan is developed and approved for removal of the liquid.
2. Only one segment of piping is to be removed at a time. A cut-off pipe section is to be removed from the work area and any fissile material spills are to be cleaned up before making the cut to separate another pipe section.
3. The project is to be planned so that the total amount of fissile material contained in a piping section to be removed is less than 4 kg as determined by the high value of the most recent nondestructive assay (NDA) measurement. If unexpected fissile material accumulations in excess of 4 kg are discovered in the removed pipe section, work shall be stopped until a revised plan is developed and approved.
4. Unless the cut at the upper end is closed by a nonflammable, heat resistant plug or blank, no more than 8 kg of fissile material may be present between a cut at the upper end of a header and a blanked-off or plugged lower end (whether or not a drain is present). This is to preclude the possibility of a critically unsafe condition due to water entering the cut at the higher end washing material down and filling the lower end.
5. At least three physical barriers and/or administrative controls in procedures are to be included to prevent water access into the fissile material deposits inside the still-connected piping or into any detached pipe sections or pieces. Examples include the following:
 - A CPS limit for the project that prohibits the addition of water (or other liquid hydrogenous materials) with the exceptions of that contained in the hardening foam, in lubricants used in the sawing operation, and in wrung-out damp rags used for cleanup.

- A greenhouse/glovebag that houses the duct sectioning operations to exclude fire-sprinkler water access. It is recommended that a nonhydrogenous fire extinguisher be available near the glovebag to handle potential fires in the plastics caused by sparks from the sawing operation.
 - Capping the ends of removed duct sections and open ends of piping still in place with nonflammable, heat resistant blanks or plugs.
 - The double wrapping and sealing of the cut-off pipe sections for contamination control before transfer out of the greenhouse/glovebag.
6. Minimum edge-to-edge spacing between detached pipe sections, any loaded container, and piping or ducting containing an accumulation of plutonium will be 25 cm (10 inches) inside the greenhouse/glovebag, and 91 cm (3 feet) outside the greenhouse/glovebag. Minimum edge-to-edge spacing between containers larger than 0.5 liter holding plutonium in water will be 91 cm (3 feet). Inside glovebox 235-B-2, minimum edge-to-edge spacing between fissile bearing containers (including cut pieces of vacuum system piping) will be 25 cm (10 inches). Because of the relatively high fissile loadings allowed for this operation, the strict observance of spacing limits is considered to be extremely important.
- EXCEPTION: When a pipe section is cut from the vacuum header in the greenhouse/glovebag, or is cut into two pieces in the glovebox, the cut ends shall be moved apart and the minimum 25 cm spacing established as soon as practicable.
- EXCEPTION: During cutting and cleaning operations in the glovebox, a single 0.5 liter polyjar or slip-top container may be brought up to a pipe section for the purpose of transferring material. When the transfer is complete, the minimum 25 cm spacing shall be reestablished.
7. Liquid will be removed from vacuum system piping when required using only geometrically safe tubing and containers as approved by the CSR.
8. Use of plastic will conform to Section G of CPS-Z-185-80010, Rev./Mod. C-2, *General Limits*. The glovebag and greenhouse (if used) will be constructed in such a way as to prevent a sudden ingress of water from forming a cone or hemisphere too large to be geometrically favorable for criticality prevention. It is very important that the plastic sleeving on detached ducting be taped with a maximum spacing of 6 inches along the entire length of the duct section to preclude the formation of a critical geometry should material leak out of the duct into the sleeving.

9. Handling of non-standard containers shall conform to CPS-Z-165-80330, Rev./Mod. C-0, *200 Gram Storage/Transportation Limit for Non-Standard Containers*, except that cutoff pipe sections and pieces may contain up to 4 kg of plutonium provided that three barriers to water entry are provided as specified in Item 5 above. At least two of the three barriers shall be physical barriers on the pipe section itself (e.g. leak-tight end plugs and plastic wrap) so as to prevent any leakage of fissile material into the surrounding container, as well as to prevent entry of water into the pipe section.
10. If a cut off pipe section is put in a 55 gallon drum for NDA and/or transport between the work area and the glovebox, the spacing and fissile material limits of CPS-Z-165-80100, *Out of Hood Fissile Material Storage*, will not be used. Instead, the requirements of items 6 and 9 above will apply. Only one pipe section may be placed in a drum. It is especially important that the pipe section be sealed by two physical barriers, as required by item 9 above, (e.g. leak-tight end plugs and plastic wrap) to prevent any leakage of fissile material into the drum. When used for this purpose, the 55 gallon drum is to be used only as a transport container and not for long term storage. A drum containing a duct section is to be attended at all times when the cover is removed. Minimum edge-to-edge spacing between loaded drums, and between loaded drums and other loaded containers and piping or ducting containing an accumulation of plutonium will be 91 cm (3 feet).
11. For this operation the only fissile bearing containers allowed in the glovebox are 0.5 liter containers and nominal 4-inch diameter or smaller pipe sections. Inside glovebox 235-B-2, minimum edge-to-edge spacing between fissile unit volume masses (including cut pieces of vacuum system piping) will be 25 cm (10 inches). Two unit volumes of three 0.5-liter containers are allowed in the glovebox at one time. Each unit volume is to be separated from cut pieces of vacuum system piping and other unit volume masses by a minimum of 25 cm (10 inches). Because of the relatively high fissile loadings allowed for this operation, the strict observance of spacing limits is considered to be extremely important. Only one pipe section which would make the total glovebox fissile loading greater than or equal to 400 g (wet) or 2.5 kg (dry) is to be brought into the glovebox at a time. More than one pipe section can be loaded into the glovebox under provisions of the existing glovebox CPS (CPS-Z-165-80290) if the total glovebox loading does not exceed 400 g (wet) or 2.5 kg (dry).

EXCEPTION: When a pipe section is cut into two pieces in the glovebox, the cut ends shall be moved apart and the minimum 25 cm spacing established as soon as practicable.

EXCEPTION: During cutting and cleaning operations in the glovebox, a single 0.5 liter polyjar or slip-top container may be brought up to a pipe section for the purpose of transferring material. When the transfer is complete, the minimum 25 cm spacing shall be reestablished.

12. Allowed containers are as follows:
 - Segments of detached piping
 - 0.5 liter cans/jars for cleanup
 - Geometrically safe spill-collection funnel and geometrically safe collection container (e.g. 10-liter polybottle [4.37 inch ID])
 - Other geometrically safe containers approved by the CSR.
13. Fire Fighting Category will be C.
14. Criticality Alarm System (CAS) coverage is required.

Pieces of vacuum system piping or other material disposed of as waste from the glovebox or the NDA station pass beyond the scope of this CSER and should be packaged and handled in accordance with applicable PFP and Central Waste Complex (CWC) limits and procedures.

2.0 DESCRIPTION OF PROJECT

This project involves the removal of several hundred feet of abandoned 3 and 4 inch nominal diameter vacuum header and associated smaller piping runs located in the duct level of the 234-5Z Building in rooms 262, 263, and 264 as shown in the two attached drawings (including the run of abandoned 3 inch reference piping shown in the second drawing).

The cutting operations will take place inside a glovebag in order to reduce the potential for release of contamination. Some of the piping will be plugged at the locations to be cut using a hardening foam. Other pipe sections will be cut within a hardened plastic box or sleeve. After a pipe section is released from the header, it will be wrapped and placed in a container for transport to the NDA station. Based on the results of this more accurate NDA, the pipe section can be directly consigned to disposal or transferred to glovebox 235-B-2 where it can be cut into smaller pieces as necessary, and removable material cleaned from the inside of the piping and placed inside 0.5 liter containers. The pipe pieces and other material will then be prepared for disposal from the glovebox.

3.0 PREVIOUS ANALYSES

The CPS-Z-165-80141 Rev./Mod. B-2, *26-inch Vacuum System*, provides limits for preventing a possible criticality from Pu accumulations in demisters. Total plutonium in a demister body is limited to 400 g with total Pu in the demister leg being limited to 1000 g. Mass, volume, and spacing limits are also provided for movable containers associated with demister draining and flushing operations. Explicit limits are not given for fissile or liquid accumulations in the vacuum lines other than the demister legs. The reference drawing for the 26-inch vacuum system is H-2-96418. Drawings for system components and associated systems are listed in CPS-Z-165-80141. The analyses for these limits were documented in CSER 78-013, *26-Inch Hg Vacuum System* (Thomas 1978, Altschuler 1991) and CSER 94-011, *Use of Glovebags for Demister Draining Operations* (Hess 1994).

The CPS-Z-165-80290 Rev./Mod. A-0 provides limits to prevent a criticality during plutonium operations in Glovebox 235-B-2 in Room 235C of the 234-5-Z Building. This glovebox has no regular function. Five sets of limits are provided to allow performance of one-time or non-routine activities such as inspecting, weighing, sampling, repackaging, sorting contents of waste drums, and disassembly of HEPA filters. The analyses for these limits were documented in CSAR 79-041, *Miscellaneous Processes* (Chiao 1979) and CSAR 83-001, *235-B-2 Sorting Glovebox* (Altschuler 1983).

4.0 EVALUATION OF CRITICALITY SAFETY CONTROLS

Evaluation of the removal of 26-inch (26 inch Hg) vacuum process lines primarily uses a fissile mass limit and the geometrically favorable size of the pipe (4 in. nominal diameter or less) to establish that the removed sections of the piping will remain subcritical. Since the material within the line is presumed to be wet and possibly to have slumped to the lower portions of the duct circumference, optimum moderation has been assumed in establishing the mass limit. It is expected, however, that the material will actually be undermoderated so that it is considered prudent to preclude the addition of water to the interior of the cut sections or remaining system components so as to maximize the safety margin with respect to moderation. Similarly, full reflection is assumed in order to remove any concern with respect to the amount of plastic wrap or ALARA shielding which can be used for the protection and safety of operating personnel.

4.1 PLUTONIUM CONTROL

The first limit to prevent criticality is the mass of fissile material in a section of removed piping. In this case the maximum nominal size of the pipe to be removed is 4 inches. For conservatism, the actual maximum inside diameter of the duct is assumed to be that for schedule 5 steel pipe as shown in Table 1 along with the associated maximum volume per foot.

Table 1: Maximum inside diameter and volume per ft of duct (from p. II.A.2-6 of Carter et al. 1969)

Nominal Size (in.)	Actual Inside Diameter (in.)	Volume/ft (L/ft)
4	4.33	2.90
3	3.33	1.71
2	2.25	0.782
1	1.19	0.219

Assuming the material to be evenly distributed along the length of the section, the minimum critical ^{239}Pu linear density for a cylinder is given in Figure III.A.7(100)-3 of ARH-600 (Carter 1969). The results for optimally

moderated and fully reflected material in an infinite cylinder are shown in Table 2.

Table 2: Minimum ^{239}Pu critical densities for an infinite cylinder (optimum moderation and full reflection)

Diameter (in.)	Diameter (cm)	Minimum Critical ^{239}Pu Density	
		Linear (kg/ft)	Volumetric (g/cm ³)
4.33	11.0	9.80	3.38
3.33	8.46	11.9	6.96
2.25	5.72	11.0	14.1
1.19	3.02	*	*

* Required ^{239}Pu density exceeds 19.6 g/cm³ (pure metal) for cylinder diameters less than 1.75 in. (4.45 cm)

The theoretical maximum density for PuO_2 is 11.46 g/cm³ which corresponds to a plutonium density of 10.1 g Pu/cm³. The required critical density for nominal 2 inch pipe therefore exceeds the maximum density attainable with PuO_2 .

A cylinder length equal to at least 4 diameters is required for a finite cylindrical geometry to approach an effectively infinite length for criticality purposes. The resulting ^{239}Pu critical masses corresponding to section lengths equal to 4 diameters are shown in Table 3.

Table 3: Minimum ^{239}Pu critical masses for cylinders assuming optimum moderation and full reflection

Diameter (in.)	Diameter (cm)	4 Dia. Segment Length (ft)	Minimum Critical Mass (kg)
4.33	11.0	1.44	14.1
3.33	8.46	1.11	13.2
2.25	5.72	0.75	8.25
1.19	3.02	0.40	*

Nominal 2 inch and smaller diameters are geometrically safe for PuO_2 (or other compounds which could be present in this case) since Pu densities required for criticality exceed that of fully dense oxide (see Table 2).

For a highly localized concentration of material within the duct, an optimally moderated, fully reflected spherical geometry with a diameter equal to the inside diameter of the duct is assumed. Minimum critical ^{239}Pu masses for a sphere are given in Figure III.A.9(100)-4 of ARH-600 (Carter 1969). Resulting minimum critical masses and required fissile densities are shown in Table 4.

Table 4: Minimum ^{239}Pu critical masses for spheres assuming optimum moderation and full reflection

Diameter (in.)	Diameter (cm)	Volume of Sphere (L)	Minimum Critical Mass (kg)	Minimum Pu Density (g/cm^3)
4.33	11.0	0.697	8.3	11.9
3.33	8.46	0.317	5.8	18.3
2.25	5.72	0.0978	*	*
1.19	3.02	0.0145	*	*

* Required ^{239}Pu density exceeds 19.6 g/cm^3 (pure metal)

Spherical Pu concentrations which can fit inside Nominal 4 inch and smaller diameters are geometrically safe for PuO_2 (or other compounds which could be present in this case) since Pu densities required for criticality exceed that of fully dense oxide in every case.

Once the duct section has been cut, It may be set in a vertical position in the transport container where material could leak past the end plug into the plastic overwrap. As a worst case, it is assumed that all the fissile material in the section runs to the lower end and enough leaks into the plastic overwrap to form a layer of material 0.75 inches thick outside the duct (limited only by the required tape wrap of the plastic sleeving). The fissile material and associated water is then assumed to form a homogeneous sphere with a diameter 1.5 inches larger than the inside diameter of the duct. (No credit is taken for the presence of the duct wall.) As before, optimum moderation and full reflection are assumed.

Minimum critical ^{239}Pu masses for a sphere are given in Figure III.A.9(100)-4 of ARH-600 (Carter 1969). Resulting minimum critical masses for these larger diameter spheres and required fissile densities are shown in Table 5.

Table 5: Minimum ^{239}Pu critical masses for spheres assuming optimum moderation and full reflection

Duct (in.)	Diameter Sphere (in.)	Volume of Sphere (L)	Minimum Critical Mass (kg)	Minimum Pu Density (g/cm^3)
4.33	5.83	1.70	10.3	6.06
3.33	4.83	0.967	9.2	9.51
2.25	3.75	0.453	6.8	15.0
1.19	2.69	0.167	*	*

* Required ^{239}Pu density exceeds 19.6 g/cm^3 (pure metal)

As before, nominal 2 inch and smaller diameter pipes lead to geometrically safe configurations for PuO_2 (or other compounds which could be present in this case) since Pu densities required for criticality exceed that of fully dense oxide. The minimum critical masses for nominal 3 and 4 inch ducts, however, are more restrictive than those for horizontal sections where the material is assumed to remain within the pipe (see Table 3). The most restrictive case is the 9.2 kg minimum critical mass for the nominal 3 inch duct set on end. WHC-CM-4-29, *Nuclear Criticality Safety Manual*, specifies that when mass control is used and is maintained only by administrative controls, the fraction of critical mass set as the operational limit shall be ≤ 0.45 unless double batching is not credible. The maximum operational mass limit is then $0.45 \times 9.2 \text{ kg} = 4.14 \text{ kg}$. To allow additional margin for error, the maximum fissile content of any cut section will be limited to 4 kg.

Most of the vacuum header (3 or 4 inch nominal diameter) to be cut slopes down and is drained at the low end through a 1 in. connecting line into a demister. The preliminary plan is to begin cutting segments from the high end of such a header so that the remaining portions will have an open drain for excess water. At some point, however, a cut may be made at the low end of the line and segments removed working up the slope of the header. If the lower end of the header is cut and capped, the line upstream will no longer have an open drain (if one was initially present). If water is then introduced to the upstream portion, fissile material could be carried down the line and accumulate against the lower end cap and plastic overwrap leading to a situation similar to the previous case where a section is stood on end and material leaks past the end plug into the taped overwrap. This situation is not as severe, however, in that the duct is nearly horizontal so that there would be much less tendency for the dense Pu compounds to be carried along the duct with the water. It is therefore assumed that half of the fissile content of the upstream section of duct could be carried down to the capped end, leak past the end cap and form a homogeneous spherical mass at the lower end of the duct. Based upon this consideration, and the analysis of the vertical duct section, it is therefore specified that no more than 8 kg of fissile material be present between two cuts in the duct header. The concern here is that water could enter the cut at the higher end and leak past the plug at the lower end filling the plastic overwrap, possibly leading to a critically unsafe configuration.

If a header which is blanked off, or has been cut off and plugged at the lower end, is opened at the upper end, the header becomes a container and it is possible, based on the information in Tables 2 and 3, to produce an unsafe condition if water enters the header and washes material down and fills the lower end. For this reason, the 8 kg limit above shall also apply to the total amount of fissile material between an open cut end in a header and a blanked-off or plugged lower end. Note that, due to the small size of the drain line to the demister, and the possibility that it could be plugged by a large amount of material being washed down from the higher end, a header terminating in a demister shall be considered as being blanked off for this purpose.

4.2 MODERATION CONTROL

The material inside the 26-inch vacuum system duct sections to be removed is presumed to be wet. The bulk density of PuO_2 powder can be less than 1 g/cm^3 . If 1 g/cm^3 powder is saturated with water (without increasing its volume), the corresponding H/Pu ratio can be as high as 23.9. Even if excess water is poured off, therefore, this material could still have a H/Pu ratio > 20 and must be treated as fully moderated according to CPS-Z-165-80010, *General Limits* and CPS-Z-165-80100, *Out-of-Hood Fissile Material Storage*. The mass limits developed above are therefore designed to prevent criticality even for optimum moderation. In reality, however, the material is expected to be undermoderated, so it is considered prudent to preclude water from entering either the remaining duct, or removed sections, in order to maximize the safety margin with respect to moderation. If free liquid is present in or above a section of piping to be cut, it should be drained to the extent practicable to minimize movement of material inside the duct and to reduce spread of contamination during the cutting operations, as well as to minimize potential moderation. If free liquid is drained from the duct header, smaller connecting lines, or a cut segment, geometrically safe funnels, tubing, and containers must be used because the amount and concentration of plutonium in the liquid will not be known.

Procedures for this project are not to allow introduction of any hydrogenous liquids, except for the small quantities associated with the hardening foam, lubricants used in sawing the duct, or damp rags used for cleanup or catching hot saw filings. Water or other hydrogenous liquids from any other source shall be excluded under the limits section of a CPS to be established for this project. The duct dismantling will be carried out inside glovebags to reduce the potential for the spread of contamination and to prevent ingress of water to the fissile material due to possible activation of the fire-control sprinkler (the most plausible water source of significance). Addition of water to exposed fissile material will be further precluded by capping off flanges and cut ends. These caps are to be nonflammable and sufficiently heat resistant so as to prevent entry of fire fighting or sprinkler water in case of an actual fire. The plastic overwrap required for contamination control is to be no larger in diameter than necessary to perform its function, and is to be securely taped with a maximum spacing between tapings of 6 inches in accordance with CPS-Z-165-80010, *General Limits*.

The demister leg valve (if present) should be kept open after cutting has started on the upstream header to maintain a drainage path until a cut at the lower end of the header isolates the valve from the main body of the remaining header.

4.3 SPACING CONTROLS

All of the wrapped and sealed duct segments obtained from the operations are to be considered fissile-bearing containers. Since the material in the ducts is presumed to be wet, spacing of these containers is necessary to preclude a criticality should a large amount of reflection also be introduced. Once a section has been cut and moved away from the vacuum header inside the

glovebag/greenhouse, a minimum edge to edge spacing of 10 inches (25 cm) shall be maintained between the cut segment and vacuum system components or other ducting containing a fissile accumulation in accordance with CPS-Z-165-80141, *26-inch Vacuum System*. Outside the glovebag/greenhouse, the general spacing limit of 3 feet (91 cm) for containers of undetermined content (CPS-Z-165-80010, *General Limits*) shall apply to all fissile bearing containers including 55 gallon drums used to contain a duct segment and containers used for holding liquid drained from the ducting.

The cut-off piping sections are to be subjected to an NDA for a more accurate measurement of the plutonium content before disposition. Fissile content and section size permitting, the material may be disposed of directly from the NDA station. If the section has more than the allowed plutonium content of 4 kg, the work is to stop and a revised work plan developed and approved before the section is moved from the NDA station.

4.4 SPILLAGE CONTINGENCY

Spilled material could accumulate inside the glovebag used to contain the operations, but should not be able to form a shape geometrically conducive to a criticality because of CPS restrictions on the use of plastics. However, assuming 5 kg of plutonium (25% more than the maximum allowable in a cut duct section) spilled into the glovebag and formed an optimally moderated sphere with nominal moderation (1 inch of water equivalent), a volume of more than 10 liters of water would be required to produce a criticality under optimum conditions (Pu homogeneously mixed with the moderating water). This volume corresponds to about 7 feet of nominal 4 inch duct (4.33 inch ID) filled half full of water. It is not considered credible that such an accumulation of water could exist undetected in a section of duct to be cut. In addition, the geometry of the ducting and engineered use of plastics precludes a sufficient volume to allow a critical configuration to form even if significant free water were in the ducting. No additional limits are required for this contingency.

4.5 GLOVEBOX OPERATIONS

After NDA, each duct section not consigned directly to disposal is to be moved to glovebox 235-B-2 for further cutting into smaller pieces as required and for removal of material from the interior of the duct pieces. It has been shown previously in this analysis that criticality is not a concern for a nominal 4 inch (or smaller) pipe section containing a maximum of 4 kg of Pu, even with optimum moderation and full reflection, as long as the material stays within the duct and surrounding plastic wrap and as long as the section remains in one piece. Once the section is cut, however, the potential may exist for creating a critical array by arranging cut pieces side by side since the analysis based on cylindrical geometry is no longer valid.

The worst such case would be the dividing of a pipe section into two pieces, each containing 2 kg of Pu, with the cut pieces then being placed side by side so as to form a square of fissile material geometrically similar to an infinite slab. It is not considered credible that the material in the pieces

would be uniformly mixed with a density low enough to fill more than half the cross section of the duct after it is cut. It is therefore assumed that each duct piece is half full of a uniform Pu-water mix. The parameters of the resulting square arrays for the relevant duct sizes are shown in Table 6. In order to make a square array, each duct piece is assumed to have a length equal to twice the actual ID of the duct. No credit is taken for the effect of the two wall thicknesses between the two duct pieces. The volume shown is half the total interior volume of the two duct pieces.

Table 6: Array parameters for two cut duct pieces
laid side by side

Duct Inside Diameter (in)	Array Size (in)	Area (in ²)	Area (ft ²)	Volume (in ³)	Volume (L)
4.33	8.66 x 8.66	75.0	0.521	128	2.09
3.33	6.66 x 6.66	44.4	0.308	58.0	0.951
2.25	4.50 x 4.50	20.3	0.141	17.9	0.293
1.19	2.38 x 2.38	5.66	0.0393	2.65	0.0434

Note that the array size corresponds to four times the maximum thickness of the material inside the duct pieces (i.e., half the duct ID). The array can therefore be conservatively approximated as an infinite slab (which minimizes the surface to volume ratio for this geometry). The resulting criticality parameters for an assumed full thickness infinite slab are shown in Tables 7 and 8 for full reflection and nominal reflection (1 inch of water equivalent), respectively. Minimum critical Pu areal concentrations were obtained from Figure III.A.8(100)-3 of ARH-600 (Carter 1969) with optimum moderation assumed in both cases. The assumed slab thickness is equal to half the pipe ID, and assumes part of the material leaves the pipe, mixes with the water outside, and forms a slab geometry. All the fissile material is assumed to remain within a square with dimensions given in Table 6. The last column in Tables 7 and 8 give the required initial Pu density inside the pipe.

Table 7: Infinite slab criticality parameters
for arrays shown in Table 6 - full reflection

Inside Diameter (in)	Slab Thickness (in)	Minimum Crit. Pu Conc. (kg/ft ²)	Min. Crit. Mass (kg)	Pu Density in Pipe (g/cm ³)
4.33	2.17	2.2	1.15	0.55
3.33	1.67	7.5	2.31	2.43
2.25	1.13	12.7	1.79	6.11
1.19	0.595	16.2	0.637	14.7

Table 8: Infinite slab criticality parameters
for arrays shown in Table 6 - nominal reflection

Inside Diameter (in)	Slab Thickness (in)	Minimum Crit. Pu Conc. (kg/ft ²)	Min. Crit. Mass (kg)	Pu Density in Pipe (g/cm ³)
4.33	2.17	25.	13.0	6.22
3.33	1.67	31.	9.55	10.0
2.25	1.13	36.	5.08	17.3
1.19	0.595	*	*	*

* Required ²³⁹Pu density exceeds 19.6 g/cm³ (pure metal)

Criticality is possible for the fully reflected case as shown in Table 7, but only if spacing control limits are severely violated and the glovebox is flooded. The double contingency principle is therefore satisfied in that failure of two independent process controls (interaction controls and reflection controls) are necessary to produce the possibility of a criticality.

As shown in Table 8, a criticality is not possible even for the highly unfavorable geometry assumed, given only nominal reflection (1 inch of water equivalent). Note that the maximum allowed Pu mass remains less than 45% of that required for criticality except for the nominal 2 inch duct, and in that case the required Pu density is far greater than the maximum attainable for PuO₂.

Once the duct segment is cut into shorter pieces, the material inside will be removed either by pouring or scraping with long-handled spatulas into 0.5 liter polyjars or slip-lid cans. For a criticality to be possible in a single polyjar or slip-lid can, it must contain slightly more than 5 kg of Pu as shown in Figure III.A.9(100)-4 of ARH-600 (Carter 1969). This requires a density greater than 10 g/cm³ even for optimum moderation and full reflection, which is close to the theoretical maximum density of PuO₂, and far exceeds the maximum credible density of wet PuO₂ powder. Criticality is therefore not a concern for 0.5 liter polyjars or slip-lid cans for this operation.

For this operation the only fissile bearing containers allowed in the glovebox are 0.5 liter containers and nominal 4-inch diameter or smaller pipe sections. A total of six 0.5 L containers are allowed in the glovebox at any one time. Except as modified below, a minimum spacing of 25 cm (10 inches) shall be maintained between cut duct segments and containers or unit volumes. Three of the 0.5-liter containers may be clustered into a single unit volume for purposes of spacing control. Two unit volumes of three 0.5-liter containers are allowed in the glovebox at one time. Each such unit volume must be separated from another unit volume and from other individual containers (including cut piping sections) by a minimum of 25 cm (10 inches). 4 kg of optimally moderated Pu requires at least 6 L of volume in a fully

reflected sphere to form a critical system. Six 0.5-L containers represents only half the minimum critical volume. When a pipe section is cut into two pieces, the pieces shall be moved apart and a minimum 25 cm spacing established as soon as practicable. A single 0.5 liter polyjar or slip-top container may be brought up to a pipe section for the purpose of transferring material. When the transfer is complete, the minimum 25 cm spacing shall be reestablished.

For this one-time operation, pipe sections with up to 4 kg of Pu may be brought into Glovebox 235-B-2 for sectioning and/or cleaning. However, only one duct segment which would make the total glovebox fissile loading greater than or equal to 400 g (wet) or 2500 g (dry) is to be brought into the glovebox at a time. The existing CPS for Glovebox 235-B-2, CPS-Z-165-80290, Section B, allows a 400 g total limit in the glovebox for material with unlimited moderation. Section A allows a 2500 g limit if the material is dry (i.e., $H/Pu \leq 2.0$). More than one pipe section can be loaded into the glovebox under provisions of the existing CPS if these fissile mass limits are not exceeded. All material (resulting duct pieces, containers, plastic bags, packaging, and trash) from operations on the previous duct segment(s) must be removed from the glovebox, and all spills of fissile material cleaned up, before the next pipe section(s) can be loaded in.

5.0 RECOMMENDED PROCEDURES AND CONTROLS

It is recommended that the following items be included in the CPS and procedures:

- a) Activities shall cease pending review by Nuclear Safety and Criticality and Shielding if new NDA or other measurements reveal plutonium deposits more than 50% greater than amounts expected on the basis of the previous surveys.
- b) Controls and limits for the 235-B-2 glovebox for this one-time operation should be similar to those for disassembly of Pu contaminated HEPA filters for the same glovebox in CPS-Z-165-80290 Rev./Mod. A-0 except for the maximum plutonium limit of 4 kg per vacuum duct segment to be cut and cleaned and the spacing limit of 25 cm (10 inches) between containers and duct pieces.

6.0 REVIEWERS COMMENTS

H.J. Goldberg of the Criticality and Shielding group carried out an independent, technical review of CSER 97-001, for which the following comments were provided.

The Criticality Safety Evaluation Report CSER 97-001 has been reviewed and the results were found to be technically justified, with a bias on the conservative side. The criticality handbook was checked independently for all of the bounding cases and the values found agreed with the CSER being reviewed. In addition all hand calculations were repeated.

E. M. Miller of the Criticality and Shielding group carried out an independent, technical review of CSER 97-001, for which the following comments were provided.

The technical arguments for qualifying the criticality safety of the duct run to be removed and handling cut off duct sections were found to be sound and the quoted criticality parameters in the tables were confirmed by review of the referenced data. The report incorporates suggested changes and expansions to make it consistent with *Addendum 1 to CSAR 95-013: Revised PFP E-4 Duct Removal Critical Limits for Downcomers, ALARA Shielding, NDAed Segments, and 6-inch and Smaller Piping*, WHC-SD-SQA-CSA-20407, Rev. 0, that specifies requirements for removal of E-4 ducting.

It should be clearly recognized that allowing 4 kg of wet Pu in a duct segment is only safe because of the limitation that the duct must be 4-inch pipe or smaller which allows sufficient neutron leakage to keep the system subcritical. The surrounding plastic and metal containers used to prevent contamination must be used only as protective barriers and not as a container. Any leakage from the duct must be dealt with immediately following prescribed procedures. The use of shielding to meet ALARA is allowed by this analysis that included fully reflected duct segments, but it should be recognized that the increase in reflector/shielding decreases the safety margin and should not be left on piping or duct segments beyond the time it reduces dose to workers. When drums or boxes are used to protect the plastic wrapped duct segments, flooding of the boxes must be prevented by maintaining surveillance when the drum or box is open. If flooded, a leak from the duct could produce a critical geometry in the large space if it were filled with water. The 4 kg of Pu in the duct segment is safe because the duct is a small diameter container. To maintain this safe geometry, the Pu be kept in that restricting diameter and water not be allowed to move it out of the duct. When removing Pu from the duct in Glovebox 235-B-2, the control of geometry must be maintained by keeping the Pu in the duct or in a half liter container, and not allowing the Pu to spill out into a pile of uncontrolled dimensions especially if the Pu is wet.

7.0 REFERENCES

- Altschuler 1991, S.J. Altschuler, *Addendum 2 to CSER 78-013: Demister Legs in the Plutonium Finishing Plant*, WHC-SD-SQA-CSA-20337 Rev 0, July 1991.
- Altschuler 1983, S.J. Altschuler, *CSAR 83-001: 235-B-2 Sorting Glovebox*, WHC-SD-SQA-CSA-20267 Rev 0, May 1983.
- Carter 1969, R.D. Carter, G.R. Kiel and K.R. Ridgway, *Criticality Handbook*, ARH-600. Atlantic Richfield Company, Richland, Washington, original issue June 28, 1968, latest update June 15, 1980.
- Chiao 1979, T. Chiao, *Miscellaneous Processes*, Criticality Safety Analysis Report for RHO-MA-165, Criticality prevention Specification for CPS 80.24, November 1979.
- Hess 1994, A.L. Hess, *Cser 94-011: Use of Glovebags for Demister Draining Operations*, WHC-SD-SQA-CSA-20376 Rev 0, December 1994.
- Nirider 1996, Correspondence No. 15C00-96-GAJ-070 from L.T. Nirider, BWHC to D.P. Hughes, FDNW, "26-inch Process Vacuum Line Removal, 234-5Z Building, 200 West Area, Letter of Instruction, Work order #E55941," dated December 9, 1996.
- Thomas 1978, L.E. Thomas, *CSAR 78-013: 26-Inch Hg Vacuum System*, Criticality Safety Analysis Report for RHO-MA-165, Criticality Prevention Specification 80.14-1, December 1978.
- WHC-CM-4-29, *Nuclear Criticality Safety Manual*, Westinghouse Hanford Company, Richland Washington.

SEGMENT 4 LABEL KEY

AA1-448 - PART OF SEGMENT 4 TO BE REPLACED

LEGEND

- = REFERENCE PIPING
- - - = PIPING TO BE REMOVED
- . - = PIPING TO BE REMOVED (LATER)
- = PIPING REMOVED TO DATE
- BLACK
- PURPLE
- CYAN
- GREEN

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SCALE: NONE
 HISC. DATE: 11/11/97
 HISC. NO. 1 DATE: 11/11/97

FPF 94-1 DUCT REMEDIATION
 E4 EXHAUST & PROCESS
 VACUUM SYSTEM

ES-94-1 SH 2 OF 3

HNF-SD-SQA-CSA-526, Rev. 0

CHECKLIST FOR INDEPENDENT TECHNICAL REVIEW

DOCUMENT REVIEWED

NUMBER: CSER 97-001

TITLE: Criticality Safety Limit for PFP 26-inch Vacuum Line Removal

AUTHOR(s): D. A. Himes

I. Method(s) of Review

- (X) Input data checked for accuracy
- (NA) Independent calculation performed
 - () Hand calculation
 - () Alternate computer code: _____
- (X) Comparison to experiment or previous results
- () Alternate method (define) _____

II. Checklist (either check or enter NA if not applied)

- (X) Task completely defined
- (X) Activity consistent with task specification
- (X) Necessary assumptions explicitly stated and supported
- (X) Resources properly identified and referenced
- (X) Resource documentation appropriate for this application
- (X) Input data explicitly stated
- (X) Input data verified to be consistent with original source
- (X) Geometric model adequate representation of actual geometry
- (X) Material properties appropriate and reasonable
- (NA) Mathematical derivations checked including dimensional consistency
- (NA) Hand calculations checked for errors
- (X) Assumptions explicitly stated and justified
- (NA) Computer software appropriate for task and used within range of validity
- (NA) Use of resource outside range of established validity is justified
- (NA) Software runstreams correct and consistent with results
- (NA) Software output consistent with input
- (X) Results consistent with applicable previous experimental or analytical findings
- (X) Results and conclusions address all points and are consistent with task requirements and/or established limits or criteria
- (X) Conclusions consistent with analytical results and established limits
- (NA) Uncertainty assesment appropriate and reasonable
- () Other (define) _____

III. Comments: _____

IV. REVIEWER: _____

DATE: 14 February 1997

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		Date 1/28/97
Project Title/Work Order		EDT No. 619424
CSER 97-001, Criticality Safety Limits for PFP 26-Inch Vacuum Line Removal		ECN No. N/A

Name	MSIN	Text With All Attach.	Text Only	Attach./ Appendix Only	EDT/ECN Only
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S.R. Gedeon	H0-35	X
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