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Title: Criticality Safety Evaluation of Standard Criticality Safety Requirements #1-520 g Operations in PF-4

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Criticality Safety Evaluation Document

Title: Criticality Safety Evaluation of Standard Criticality Safety Requirements #1—520 g Operations in PF-4

Criticality Safety Evaluation Team Review/Approval

Operations Approval

This evaluation was generated with personnel familiar with the operations described herein to assure:

- **the accuracy and applicability of the process description,**
- **the completeness and accurate characterization of the upset conditions addressed, and**
- **the applicability, usability, clarity, and validity of the controls.**

Operations Responsible Supervisor Approval:

Printed ORS Name	ORS Org.	Date	ORS Signature
J. A. Trujillo	C-AAC	2/28/17	[signature]

CSO Review/Acknowledgement:

Printed CSO Name	CSO Org.	Date	CSO Signature
P. T. Martinez	C-AAC	2/28/17	[signature]

Nuclear Criticality Safety Approval

This evaluation has been generated in accordance with the ANSI/ANS-8 standards per SD130.

CSED Preparer (CSA-Q):

Printed CSA Name	CSA Org.	Date	CSA Signature
E. P. Elliott	NCS	2/28/17	[signature]

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A. R. Wysong	NCS	2/28/17	[signature]

NCS Management Reviewer:

Printed NCS Manager Name	NCS Mgr. Org.	Date	NCS Mgr. Signature
A. R. Wysong	NCS	2/28/17	[signature]

Operations Responsible Manager (ORM)Review/Approval

I approve this evaluation as the criticality safety basis for the operation and establish and approve the requirements for the process described herein.

Operations Responsible Manager Reviewer:

Printed ORM Name	ORM Org.	Date	ORM Signature
A. K. Slemmons	C-AAC	2/28/2017	[signature]

Derivative Classification Review

☒ UNCLASSIFIED ☐ Export Controlled Information ☐ Official Use Only ☐ Unclassified Controlled Nuclear Information Guidance Used:	☐ CONFIDENTIAL ☐ SECRET ☐ Restricted Data ☐ Formerly Restricted Data ☐ National Security Information Guidance Used:

DC/RO Name/Z Number:	Organization:	Signature:	Date:
ERNIE ELLIOTT 135267	NCSD	[signature]	2/28/17

1. Summary

Guidance has been requested from the Nuclear Criticality Safety Division (NCSD) regarding processes that involve 520 grams of fissionable material or less. This Level-3 evaluation was conducted and documented in accordance with NCS-AP-004 (Ref. 1), formerly NCS-GUIDE-01.

This evaluation is being written as a generic evaluation for all operations that will be able to operate using a 520-gram mass limit. Implementation for specific operations will be performed using a Level 1 CSED, which will confirm and document that this CSED can be used for the specific operation as discussed in NCS-MEMO-17-007 (Ref. 2). This Level 3 CSED updates and supersedes the analysis performed in NCS-TECH-14-014 (Ref. 3).

This new CSED replaces NCS-CSED-16-067 and addresses NNSA findings and observations on that CSED as listed in Appendix C.

2. Recommended Controls

CRITICALITY SAFETY REQUIREMENTS	
Administrative Controls	
<u>Material Limits</u>	
Pu in Metal/Compounds/Dry-Residue/Solution	≤ 520 grams
Other fissionable isotopes (not including ^{233}U) may be treated as Pu on a gram-for-gram basis per PA-RD-01009.	
OR	
Pu and ^{233}U in Metal/Compounds/Dry-Residue/Solution	≤ 150 grams
<u>Additional Restrictions</u>	
• Fissionable solutions are collected in ≤ 2.2 liter containers • The PA-RD-01009, *TA55 Criticality Safety Requirements* limit on cleaning solution of up to 2 liters total does not apply to this FMO	
Engineered Controls	
• N/A	

2.1 Control Description

2.1.1 Pu in metal/compounds/dry-residue/solution ≤ 520 g

This control: 1) reduces the consequence of a mass upset, and 2) restricts the problem so as to make the analysis tractable. This control limits the amount of fissionable material to less than or equal to 520 grams. Personnel can ensure they are in compliance with this control by ensuring there is no more than 520 grams plutonium in metal/compounds/dry-residues/solutions.

2.1.2 Other fissionable isotopes (not including ^{233}U) may be treated as Pu on a gram-for-gram basis per PA-RD-01009

This control allows other fissionable material to be treated as Pu on a gram-for-gram basis provided that they are in agreement with the following restrictions:

- Am may use the one-for-one gram equivalence provided that the wt. % of ^{242}Am is ≤10% of the total Am.
- Cm may use the one-for-one gram equivalence provided that the combined wt. % of ^{243}Cm and ^{245}Cm is ≤5% of the total Cm.
- ^{241}Pu may use the one-for-one gram equivalence if the isotopic concentration is less than the isotopic concentration of ^{240}Pu.

Personnel can ensure they are in compliance by ensuring there is no more than 520 g of fissionable material and that the substituted material follows the above restrictions.

2.1.3 Pu and ^{233}U in metal/compounds/dry-residue/solution ≤ 150 g

This control reduces the consequences of a mass upset. This control limits the amount of material allowed in the fissionable material operation to less than or equal to 150 grams when ^{233}U is present in the location. Personnel can ensure they are in compliance with this control by ensuring there is no more than 150 grams of material present in the location when they have ^{233}U.

2.1.4 Fissionable solutions are collected in ≤ 2.2 liter containers

This control reduces the consequences of a mass upset condition. This control limits the volume of individual containers allowed in the fissionable material operation to less than or equal to 2.2 liters each. Personnel can ensure they are in compliance with this control by ensuring that only containers with volumes no larger than 2.2 liters are used.

2.1.5 The PA-RD-01009, TA55 Criticality Safety Requirements limit on cleaning solution of up to 2 liters total does not apply to this FMO.

PA-RD-01009 (Ref. 4) presents general criticality safety requirements that apply across all PF-4 operations. Section 5.1.1 of PA-RD-01009 (Ref. 4) allows housekeeping and maintenance supplies, and up to 2 liters of cleaning solutions to be used in operations. This statement allows operations under the scope of this analysis to be exempted from the cleaning solution limit of 2 liters stated in Section 5.1.1 of PA-RD-01009 (Ref. 4) as it is shown not to be necessary via explicit analysis in this evaluation.

2.2 Safety Basis and Elevation of Criticality Safety Controls

The controls in this evaluation were evaluated against the criterion in Section 6.5.5 of SD-130 (Ref. 5). It was determined that no controls meet the requirements for referral to safety basis personnel for consideration of elevation into the safety basis documentation.

3. Process Descriptions

This process description provides a general overview for actual or potential 520 g operations within PF-4; it is up to the individual criticality safety analyst to provide a more detailed process description for the specific L1 CSED for all operations that may implement this L3 CSED. The application of this standard criticality safety requirements evaluation is detailed in NCS-MEMO-17-007 (Ref. 2).

3.1 General Location Description

For the purpose of this evaluation, this applies to 520 g operations located inside of PF-4. The individual analyst shall provide a location description for the specific operation in the L1 CSED.

3.2 Material Handling

Fissionable material in the form of plutonium metal, compounds, oxides, dry-residues, and/or solutions is introduced/removed to/from the various locations within various containers (e.g., slip-tops, food packs, Hagans, SAVYs, hat cans, etc.). Fissionable solutions will be in containers with a volume no larger than 2.2 liters. Fissionable material will also be handled and processed during the operation at the specific location. In glovebox operations, the material enters through the spool piece. The spool piece shall only be used for the attended transfer of fissionable material and not for staging.

3.3 Operations

The following activities are general descriptions of the kinds of processes that may occur within PF-4 for a 520 g operation. This list is not all-inclusive and is presented here to provide a general overview of the wide scope of operations that are performed, even under such small mass limits.

Staging of Process Materials: This typically involves simple storing of the items in the confines of the glovebox and/or instrument. No activities are necessarily associated with “staging” other than the movement of the material item(s) into the staging glovebox and/or instrument and any eventual handling for removal.

Chemical Analyses and Materials Characterization: Various analytical activities may be carried out on Pu-bearing materials (generally samples of material generated elsewhere) in 520 g limited operations such as (not all-inclusive):

- Chromatography
- Spectroscopy
- Isotopic analysis
- Radioanalysis
- Density analysis
- X-ray diffraction
- Mechanical and physical properties testing
- Physical alteration – crushing, shearing, puncturing, etc.
- Gas sampling/analysis
- General wet analytical chemistry methods, electrochemistry, and physical chemistry

Equipment associated with these types of operations varies greatly and should be considered on a case-by-case basis for criticality concerns including internal (non-visible) spill potential, material buildup/accumulation over time, thick shielding, and mishaps such as potential for internal coolant leaks (flooding a large internal cavity), etc. Various reagents, compressed gases, and cryogens (e.g.

liquid nitrogen or helium) may be employed in operations, either directly contacting the Pu material or as part of the function of the analytical equipment (e.g. cooling of detectors). Cryogens can potentially alter the minimum mass needed to achieve criticality and must therefore be considered on a case-by-case basis for operations where the Pu is cooled in this manner. Cryogens typically operate with small amounts of fissionable material and may not require additional analyses other than the analysis provided in this L3 CSED. However, it is up to the individual analyst to determine if the L3 CSED provides a sufficient analysis for the operation.

Small Batch Chemistry: "Small batch chemistry" as applied here recognizes that miscellaneous facility missions may require research-type, unique, or small campaign chemistry support that does not warrant larger-scale modification of gloveboxes, etc. Activities associated with small batch chemistry may include processes such as, or similar to: chemical dissolution; purification chemistry; precipitation; filtration; distillation; and calcination. It is expected that such operations will be performed in small laboratory-scale vessels and equipment (beakers, hot plates, etc.) and will be considered as a type of "small batch chemistry" for purposes of this CSED. Various reagents, compressed gases, and cryogens may be employed in chemical operations, either directly contacting the Pu material or as part of the function of the analytical equipment (e.g. cooling of detectors). Cryogens can potentially alter the minimum mass needed to achieve criticality and must therefore be considered on a case-by-case basis for operations where the Pu is cooled in this manner. Cryogens typically operate with small amounts of fissionable material and may not require additional analyses other than the analysis provided in this L3 CSED. However, it is up to the individual analyst to determine if the L3 CSED provides a sufficient analysis for the operation.

Sampling: Activities related to sampling typically involve opening a container of process material and transfer of relatively small quantities of the parent container material to another container to accommodate some form of the analysis/characterization of the sample.

Weighing: Material may be weighed on a balance as a part of normal process activities. Sometimes material is transferred from one container to another during the weighing process in order to allow operators to visually confirm the contents.

Waste Sorting: Waste materials may require sorting and segregation for removal from the glovebox lines and proper disposal. Waste materials typically consist of contaminated glovebox wastes and may include used process containers, bottles, crucibles, and other small equipment with potential to contain/hold Pu in some form.

Splitting/Combining: Accumulations of material may be combined or split among multiple approved containers in order to efficiently perform various operations on that material.

3.4 Maintenance, Housekeeping, Holdup

The glovebox and equipment require regular maintenance, housekeeping, and cleaning. Such activities require small amounts of fluid introduced to the FMO. Hand tools and diagnostic equipment may also be used as needed. The operation may also produce hold-up in the glovebox or on the instrument.

4. Normal and Credible Abnormal Process Conditions

The discussions presented in the sub-sections here are intended as generalizations of typical conditions existing for miscellaneous operations with a 520 g limit.

Note: *In no case do these discussions represent or imply rigorous or complete consideration of every configuration and/or process situation in 520 g operations in PF-4.* ***The analyst must carefully consider the applicability and appropriateness of these discussions and conclusions to each unique process situation.***

Section 5 of this document demonstrates that each credible configuration discussed in the subsequent sections will remain subcritical.

The evaluation team, including the operations responsible supervisor, operations personnel, and criticality safety analysts used a What-If technique to identify changes in process conditions that may have an impact on the criticality safety and categorized them as normal conditions or credible abnormal conditions.

This evaluation satisfies the Process Analysis Requirement of ANSI/ANS-8.1 (Ref. 6) as required by SD130 (Ref. 5) and the application of the Double Contingency Principle of ANSI/ANS-8.1 as recommended by SD130.

4.1 Incidental Reflection

Common sources of incidental reflection are the hands of the operators, hand tools, non-fissionable reagents/solutions, or other equipment in close proximity to the fissionable material, etc. 1-in of tight fitting water typically bounds the incidental neutron reflection from these sources. Furthermore, it is understood that the 520 g mass limit may be applied to many analytical chemistry, metallography, or other operations where numerous containers/vials of reagents/solutions are present. The total volume of non-fissionable solution in these locations can be large (tens of liters), however these solutions are contained in many disparate containers/vials, which cannot form close fitting reflection of fissionable material. The 1-in of water reflection, when applied to an optimized homogenous spherical mixture of 520 g Pu and water (~17.3 liter volume), results in an additional close fitting reflection of ~9.5 liters of water. This representation of incidental reflection is bounding of any reactivity worth contribution from the actual incidental reflection sources discussed above. Additionally, the 1-in of incidental reflection is bounding in upset conditions where its presence around an additional item and the homogenous mixture of Pu and water results in an even greater amount of solution present as close fitting reflection.

Note that some operations may have substantial amounts of equipment, tools, non-fissionable solution, and/or other materials that may provide significant thick close fitting reflection and exceed the effects of 1-in of tight fitting water (e.g. use of water baths for cooling, immersion density measurements, etc.). If this is determined to be present in the location of an individual fissionable material operation, the analysis in this evaluation may not be sufficient to ensure subcriticality and an independent criticality safety evaluation would be required.

4.2 Normal Conditions

Normal conditions are limited to those within a single glovebox or staged in an instrument outside of a glovebox such that there is adequate spacing (~6 inches, Ref. 7) for the operation to be neutronically isolated from other fissionable material operations. The process may involve, separately or concurrently, one or more of the operations mentioned in Section 3.3. A single operation may also involve multiple gloveboxes, each with a 520 g Pu limit.

4.2.1 Operations

The 520 g mass limit applies to Pu in metal, solution, oxide, powder, compound, and dry residue. Under normal conditions, the operation may contain up to 520 g Pu (limited to a single container volume of 2.2 liters when in solution) within the scope of this evaluation presented here. If ^{233}U is present within the operation, the operation may only contain up to 150 g of fissionable material.

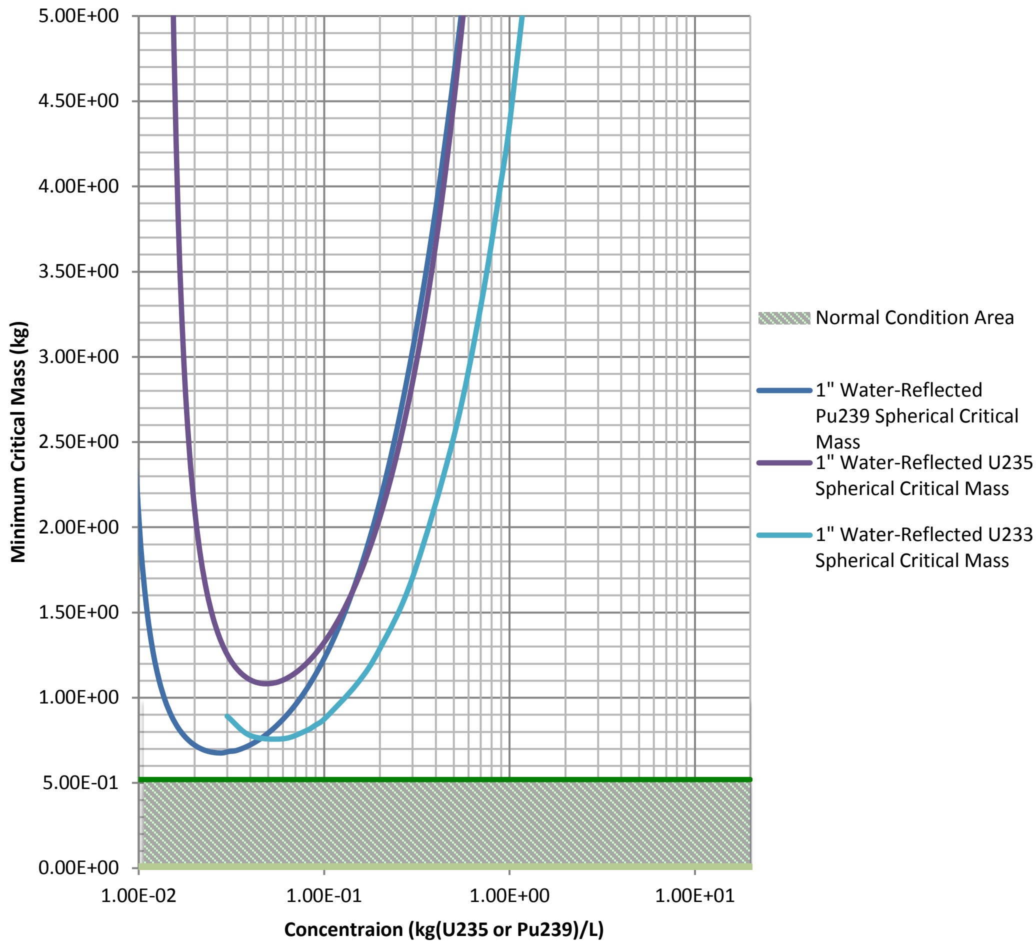


Figure 1. Comparison of the Normal Condition Area of Applicability to Minimum Critical Masses of ^{239}Pu, ^{235}U, and ^{233}U

In a dry (unmoderated) state such as metals, dry oxides, non-moderated process residue compounds, etc., the minimum critical mass for Pu is at least an order of magnitude greater than 520 g for ideal configurations (Ref. 8). For Pu metal, the minimum critical mass is ~5.4 kg, with full water reflection around a Pu sphere. More realistic operational configurations, such as unreflected, non-spherical geometries, etc., have a critical mass over 10 kilograms. Pu solutions, on the other hand, have a minimum critical mass of 520 g (Ref. 8).

Additionally, the operation may substitute Pu for other fissionable isotopes (excluding ^{233}U) on a gram-for-gram basis or have up to 150 grams of fissionable material when ^{233}U is present. The bounding fissionable isotope for the normal conditions of 520 g operations with the controls derived in this evaluation is Pu. This is shown in Figure 1. Figure 1 shows the applicable region for normal conditions as well as 1-in water reflected critical mass curves for ^{239}Pu, ^{235}U, and ^{233}U. The ^{239}Pu and ^{235}U data is from Reference 9 while the ^{233}U critical mass data was developed with the perl script Worm Solver and the methodology detailed in Reference 10 for a sphere of ^{233}U and water at various concentrations surrounded by 1 inch of tight fitting water reflection. The graph shows that the Pu minimum critical mass curve provides the closest point to the normal condition region. Therefore, ^{239}Pu is bounding of ^{235}U and ^{233}U under normal conditions.

The bounding normal configuration considered for this evaluation is a solution containing 520 g of Pu surrounded by 1-in of water reflection. This configuration is determined to remain subcritical in Section 5.2.1.

4.2.2 Moderators

Operations may have moderators (e.g., water, graphite, beryllium, etc.) present in the operation. Beryllium is a moderator that is able to produce a critical system with less than 520 g of fissionable material (Ref. 11). However, according to Reference 11, it is judged not credible to get the amount of beryllium (>300 kg) needed to produce such a system within typical operation environments. This configuration would also require full water reflection and an idealized geometry that is not credible to occur in typical operating environments.

4.2.3 Reflectors

Some operations within PF-4 that operate under a 520 g mass limit may have reflector materials that are more effective than water (e.g., beryllium, beryllium oxide, graphite, etc.) The presence of these reflectors in the operation may result in configurations that are not bounded by the analysis performed in this general L3 CSED. The analyst should carefully examine the location of the operation while creating the individual L1 CSED in order to determine whether there is a significant amount of these materials. As a general rule, analysts may consider that 1-in of tight fitting water will bound at least ~0.8-cm of tight fitting reflector material for all materials analyzed in NCS-TECH-16-008 (Ref. 10). This approximation was determined by comparing the data for water and beryllium oxide, which is the bounding reflector material in the document. The analyst should analyze NCS-TECH-16-008 to determine if 1-in of water bounds materials when dealing with reflector thicknesses >0.8-cm.

Additionally, some gloveboxes may be lined with a non-corrosive material (e.g. kynar) that may be a better reflector than water to protect the glovebox structure. This lining is usually present in aqueous operations and operations with chemical processes. The lining of these gloveboxes is typically thin enough that 1-in of water is bounding of the incidental reflection from it. However, the analyst must ensure that this assumption is valid in the specific L1 evaluation. Providing the thickness of the lining and using NCS-TECH-16-008 to justify that 1-in of water is bounding is one method the analyst may use.

4.2.4 Temperature

Operations using the 520 g mass limit may also involve significant temperature changes (e.g., furnaces, cryogens, etc.) In furnaces, it is possible for the fissionable material to have a geometrical change due to melting. The analysis performed in this CSED assumes an idealized, most reactive credible geometry and therefore, a change in geometry from a furnace will be bound by the analysis performed here.

As discussed earlier, cryogens can potentially lower the minimum critical mass for the fissionable material. However, cryogens typically do not have the moderating capabilities of liquid water. Additionally, cryogens will only have an effect on the minimum critical mass of a system if there is a non-absorbing moderator present. Cryogens will need to be separately analyzed in the operation specific L1 CSED if such a moderator is present and the operation still falls into the scope of this evaluation. A new L3 CSED may be needed to analyze the operation.

Therefore, operations that fall under the scope of this evaluation and require the use of furnaces and cryogenic materials with neutron absorption properties will remain subcritical.

4.2.5 Maintenance, Housekeeping, Holdup

It is possible for small amounts of loose fissionable material to be dispersed throughout the glovebox. Some of this loose material could be taken up by the airflow of the ventilation system and captured on the local high-efficiency particulate absorption (HEPA) filter in gloveboxes. Additionally, material hold-up does occur on the glovebox and equipment surfaces. Due to housekeeping and maintenance practices, the small amount of fissionable material potentially involved in hold-up is minimized and separated from other potential accumulations of fissionable material. The amount of hold up expected from 520 g operations is expected to be no more than 50 g. The 50 g of hold up is expected to be in a dry, unmoderated state. The holdup material will be scattered across the operation location such that interaction with the fissionable material being processed is negligible. Therefore, it is not necessary to include the presence of holdup in the analysis of normal and credible abnormal conditions. Therefore, the normal conditions with the presence of holdup will remain subcritical.

4.3 Credible Abnormal Conditions

4.3.1 Loss of Mass Control

The credible loss of mass upset conditions discussed below have no identifiable cause in common with other credible upset conditions discussed in this analysis. All credible loss of mass control upset conditions are shown to remain subcritical in Section 5.2.2.

4.3.1.1 Single item overmass

It is credible, though unlikely due to operator training and the material control and accountability system in PF-4, that personnel allow a single item greater than 520 g of fissionable material to be introduced to this location. This may come about by a measurement error (e.g., measurement instrument provides inaccurate value) or labeling/accounting error (e.g., information provided by the NMCA system is incorrect, or movement of an incorrect item.) It is judged not credible that a single approved item would have a measurement error exceeding 10%. A solution containing 572 g of Pu is the bounding credible upset for this loss of mass control. The operation is determined to remain subcritical during this mass upset condition in Section 5.2.2.1.

Additionally, if there were a single item overmass while the operation was operating under the 150 g ^{233}U limit, this upset would result in ~165 grams (from the 10% mass error). This system is still bound by the overmass configuration of a solution containing 572 g of Pu and is shown to be subcritical in Section 5.2.2.1.

4.3.1.2 Introduction of an additional item of fissionable material

It is credible, though unlikely, that an additional item of fissionable material is introduced to the operation while the process is at capacity. It is unlikely due to operator training, the presence of written procedures while performing the operation, and the material control and accountability system of PF-4. This may come about by an inadvertent action of trained personnel, faulty equipment (measurement error), or an error in the material accountability software.

The worst-case scenario is the collocation of two items of fissionable material. The following configurations are judged bounding of the inadvertent introduction of an additional item of fissionable material for the facility:

- 4.5 kg Pu in metal
- 520 g Pu in solution from double batching or material transfer
- 4.5 kg Pu in oxide
- 6.0 kg Pu hemishell from material transfer
- 150 g ^{233}U in solution from double batching or material transfer

A discussion of these items is provided below.

The overmass configuration for each of these items is evaluated in Section 5.2.2.2 of this evaluation and is shown to remain subcritical. Therefore, operations will remain subcritical during the additional item of fissionable material mass upset condition.

4.3.1.2.1 Additional item overmass of 4.5 kg Pu metal ingot

In the facility, 4.5 kg is considered the bounding mass for a single Pu metal ingot. Other operations in the facility use 4.5 kg as a mass limit and the material transfer carts also use this limit for Pu metal (Ref. 12). Therefore, a mass upset of 4.5 kg of Pu metal must be considered for a general CSED. The Pu metal ingot would have to be introduced into the operation through a material transfer.

The bounding configuration is 520 g of Pu in solution collocated with a 4.5 kg Pu metal ingot. This configuration is shown to be subcritical in Section 5.2.2.2.1.

4.3.1.2.2 Additional item overmass of 520 g Pu in solution

An additional item overmass of 520 g Pu in solution is what would result in a double batching scenario. Additionally, 520 g Pu in solution is also considered bounding for the facility. 520 g is the minimum critical mass necessary to make a Pu system reach critical. This extra solution would be introduced in a 2.2-liter bottle because the material transfer carts are limited to this volume for Pu bearing solution vessels (Ref. 12).

The bounding configuration is 520 g of Pu in solution collocated with an additional 2.2 liters of 520 g Pu in solution. While this configuration is not credible due to the solubility of plutonium, it is determined that this configuration is bounding of any credible abnormal condition resulting from the introduction of excess mass in solution. This configuration is shown to be subcritical in Section 5.2.2.2.2.

Additionally, this mass upset is special in that it adds more solution (affecting both mass and volume). In Figure 1, ^{239}Pu bounds ^{235}U and ^{233}U for the normal conditions. As shown in Figure 1, there are concentration ranges where the ^{239}Pu curve does not bound the uranium curves. This upset models a total mass of 1040 g and a total solution volume of ~19.5 liters (~17.3 liters [optimized solution concentration] from normal conditions and an additional 2.2 liter container). This additional mass and volume require further analysis to determine whether ^{239}Pu is still bounding of the uranium curves. The graph from Figure 1 is reproduced in Figure 2, now showing the area of applicability for this loss of mass control. As shown in Figure 2, the ^{239}Pu minimum critical mass curve is still bounding of the ^{235}U curve at the credible masses in this evaluation; however, the ^{233}U curve is not bound by the ^{239}Pu curve.

However, because ^{233}U will be limited to no more than 150 grams, it is not credible that there would be 1040 grams of fissionable material present in the operation location as a result of a single upset event. While the operation is using the 150-gram mass limit, an operator may bring in an additional 520 grams of fissionable material. The most reactive, credible configuration while the operation is operating under the 150-gram mass limit would be 150 grams of ^{233}U (or a combination of Pu and ^{233}U) in solution and an additional 2.2 liters of 520 grams of Pu in solution. As shown in the analysis of normal conditions in Section 4.2, 520 grams of Pu in an optimally moderated solution is bounding of 520 g of ^{233}U in an optimally moderated solution. Therefore, the double batch of Pu solutions discussed previously in this section is bounding of this configuration and is shown to be subcritical in Section 5.2.2.2.2.

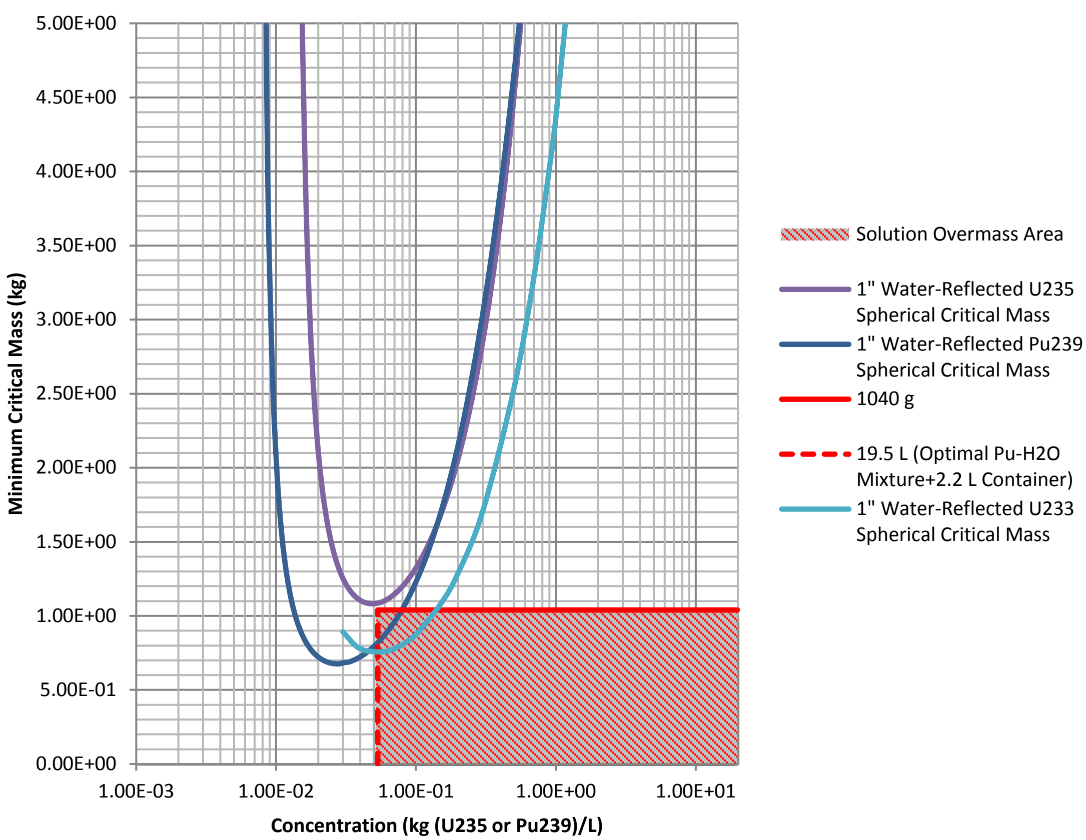


Figure 2. Comparison of the Solution Overmass Condition Area of Applicability to Minimum Critical Masses of ^{239}Pu, ^{235}U, and ^{233}U

4.3.1.2.3 Additional item overmass of 4.5 kg Pu in Oxide

In the facility, the highest amount of Pu oxide found in a single container in the facility is equal to 7000 g of Pu in PuO_2 from oxide processing operations (Ref. 13). There are three ways that PuO_2 can be introduced into an operation: a hand carried item, material transfer carts, and the glovebox trolley line. Hand carrying an item is limited to 50 g of material (Ref. 14). Therefore, it is not credible that a unit of 7000 g Pu in PuO_2 would be introduced by this method. Material transfer carts (PF4-CARTS-02) are limited to 4500 g Pu in PuO_2 per location (Ref. 12). There are one and two location carts used in the facility. In order to get an introduction of oxide with a Pu mass greater than 4500 g, the operator would have to introduce two separate containers at the same time. Due to posted limits, operator training, and the two person rule in PF-4, it is not credible for an operator to introduce two 4500 g Pu in PuO_2 containers into 520 g operations simultaneously. Therefore, it is also not credible that a unit of 7000 g Pu in PuO_2 would be introduced through a cart. The last method would be for an introduction through the trolley lines. The trolley line has a restriction that containers may have no more than 4500 g Pu in PuO_2 (Ref. 13, 15). Containers entering and exiting oxide processing operations follow this trolley line restriction. Additionally, only one container of 4500 g Pu in PuO_2 can fit in the trolley bucket at a time (Ref. 15). Therefore, it is not credible that a single container of 7000 g of Pu in PuO_2 would be introduced into 520 g operations (Ref. 15).

The bounding configuration is 520 g of Pu in solution collocated with 4500 g Pu in PuO_2. This configuration is shown to be subcritical in Section 5.2.2.2.3.

4.3.1.2.4 Additional item overmass of 6.0 kg Pu hemishell

Some operations throughout the facility have a 6.0 kg Pu hemishell mass limit. Therefore, it is necessary to analyze this mass upset scenario to allow this CSED to be implemented in any location throughout the facility. The CSEDs for these hemishell operations limit the inner diameter of the hemishell to a minimum of 4-in.

The bounding configuration is 520 g of Pu in solution collocated with a 6.0 kg hemishell that has an inner diameter of 4-in. There would not be solution inside the hemishell because that could only result from processing or dropping a container of solution into the hemishell. Operators would not begin processing a hemishell within the operation because of the presence of written operating procedures and the two-man rule required in the rooms of the facility. Therefore, there will be no solution in the hemishell. The configuration would be a hemishell next to a separate container or containers of Pu in solution. This configuration is shown to be subcritical in Section 5.2.2.2.4.

4.3.1.2.5 Additional item overmass of 150 grams of ^{233}U in solution

An additional item overmass of 150 grams of ^{233}U in solution would result from a double batch. This overmass could occur when the operation already contains 520 grams of Pu in an optimally moderated solution or 150 grams of ^{233}U (or 150 g of both ^{233}U and Pu) in an optimally moderated solution. The additional solution item would be limited to 2.2 liters because this is the size of solution bearing containers used in the facility.

The configuration with 520 grams of Pu in an optimally moderated solution collocated next to an additional 150 grams of ^{233}U is shown to be subcritical in Section 5.2.2.2.5.

The configuration of 150 grams of ^{233}U in an optimized solution with an additional 150 grams of ^{233}U in 2.2 liters of solution is bound by the first configuration discussed in this section. As shown in the normal conditions in Section 4.2, Pu is bounding for the normal case conditions, which is 520 grams of Pu in an optimally moderated solution. The first configuration discussed in this section discusses 520 g of Pu in an optimally moderated solution collocated next to 150 grams of ^{233}U. Therefore, the second configuration is shown to be subcritical in Section 5.2.2.2.5.

4.3.2 Loss of Moderation Control

Moderation is not controlled in this operation because an idealized geometry is needed to achieve criticality with such a small amount of material. From Figure 31 of LA-10860-MS (Ref. 8), the system would require ~17.3 liters, optimal water moderation, and full water reflection. Although the operation will allow for an optimal water moderated solution, fissionable solutions will be stored in 2.2 liter containers, which will cause the critical mass of the system to increase. Additionally, while there may be vials and containers of reagents/solutions surrounding fissionable material, these containers would not exceed the effects of 1-in of tight fitting water reflection, as discussed in Section 4.1. Therefore, moderation is not controlled.

Additionally, 150 grams of ^{233}U in solution is bound by 520 g of Pu in solution. Therefore, moderation does not need to be controlled for 520 g operations.

Moderators more effective than water have been previously discussed in Section 4.2.3.

4.3.3 Loss of Reflection Control

Reflection is not controlled in this operation. 520-gram operations require full water reflection, an ideal geometry, and optimal moderation in order to reach critical. Fissionable solutions will be in containers no larger than 2.2 liters, which will increase the minimum critical mass of the system. This would mean the system would remain subcritical under full water reflection. Additionally, as discussed in Section 4.1, the credible reflection conditions of the operations under the scope of this evaluation are bound by 1-inch of water, which is used in the analysis in Section 5.

4.3.4 Loss of Interaction Control

The following loss of interaction control scenario has no identifiable cause in common with other credible abnormal conditions discussed in this evaluation. This loss of interaction control upset is independent of other control losses because this scenario occurs due to fissionable material located outside of the operation coming within 6 inches of the 520 g operation location.

4.3.4.1 Interaction with Fissionable Material Unit Outside of the Operation

It is credible, though unlikely, for fissionable material being transferred outside of the operation (e.g., cart, hand carried, staging of material in spool piece, etc.) to come within 6 inches of fissionable material operation. This is unlikely because of formality of operations and that fissionable material is typically kept away from fixed fissionable material operations to avoid potential damage to glovebox systems, gloves, etc.

However, a cart could inadvertently be staged within the 6-inch boundary. Material transfer carts (CARTS-02) in the facility are always under the following material limits per location (Ref. 12):

- 4500 g Pu in Metal/Compounds/Dry Residue (MCDR) OR
- 100 g Annular Polyethylene Shielded Container with Pu in MCDR OR
- 6000 g Pu in Hemishells and Waist Bands OR
- 520 g Pu in Solution OR

- 1 pit

The evaluation for carts (Ref. 12) in the facility takes into account the loss of interaction control and the introduction of additional fissionable material while the cart is at capacity. The analysis performed in the cart evaluation analyzes an additional unit with a greater mass than the 520 g of Pu in this operation and has shown it to be subcritical.

It is also credible that an operator may drop a fissionable material item while unloading a cart or transferring the material. The fissionable material may then come within the 6-inch boundary. This upset condition is bound by the overmass upset of an additional item of fissionable material and is shown to be subcritical in Section 5.2.2.2.

Finally, it is also credible that an operator inadvertently stages fissionable material in a spool piece while the operation is at capacity. The fissionable material will be within the 6-inch boundary in this scenario. This upset condition is bounded by the overmass upset of an additional item of fissionable material and is shown to be subcritical in Section 5.2.2.2.

4.3.4.2 Significant Neutronic Interaction with Nearby Fixed Fissionable Material Operations

Any location using this L3 CSED must have 6 inches of spacing between it and the boundary of other fixed fissionable material operations. If any changes to the fissionable material operation take place, Nuclear Criticality Safety must be contacted for guidance prior to the change. It is not considered credible that a location be changed without guidance from criticality safety. Additionally, if the fixed location for the operation were to be inadvertently changed such that another fissionable material operation would be within the 6-in boundary, this configuration is bounded by the additional item overmass upset event and is shown to be subcritical in Section 5.2.2.2.

4.3.5 Loss of Volume Control

The following loss of volume control scenario has no identifiable cause in common with other credible abnormal conditions discussed in this evaluation. This loss of volume control upset is independent of other control losses because this scenario occurs due to the introduction of a fissionable unit with larger than allowed volume.

4.3.5.1 Individual solution container larger than the allowed 2.2 L

It is credible, though unlikely, that a single container of solution could be greater than 2.2 L. This upset is unlikely due to the formality of operations, and posted limits at the operation location.

This upset is evaluated and determined to be subcritical in Section 5.2.6.2.

4.3.6 Loss of Density Control

There is no credit taken for material densities of solutions, metal, oxides, or dry compounds. Each of these material forms is analyzed using the most reactive density. Solutions are analyzed at varying concentrations such that the optimal concentration is analyzed for normal conditions and upset conditions. Therefore, there are no controls on density/concentration.

4.3.7 Loss of Enrichment Control

The analysis performed in Section 5 of this evaluation uses Pu(0) in the 520 g plutonium solution. This is bounding of the isotopic compositions found in the PF-4 inventory. Therefore, enrichment is not controlled.

4.3.8 Loss of Absorber Control

No credit is taken for neutron absorbers present in the material being processed or the containers that are used. Furthermore, the presence of absorbers would increase the safety margin of the operation. Therefore, there are no controls on absorbers.

4.3.9 Loss of Geometry Control

There are no credited controls on geometry. The 520 g limit is based on optimal geometry, so no specific geometry is credited for subcriticality. The models run here assumed the most-reactive, credible geometries.

4.3.9.1 Stacking

Stacking of additional mass upset fissionable material items upon the normal condition fissionable material items in the FMO was considered. The normal condition fissionable solution items are required to be in 2.2-liter or smaller containers.

For stacking of an item from a mass upset scenario introduced to the FMO to occur, the containers would have to be placed (purposely) close together to provide support for the item and may actually have to be restrained to keep from turning over (which can not happen inadvertently). Stacking without turning the bottles over would require the item to be placed carefully on top of the bottle array; even then, the bottles would likely turn over under the weight of the item on top.

For this scenario to occur inadvertently is not credible. Therefore, it is not necessary to analyze the stacking of mass upset items on top of the solution unit in this evaluation.

4.3.10 Concurrent Loss of Control of Multiple Parameters

4.3.10.1 Seismic event with subsequent introduction of water

It is credible, though unlikely, that a release of water from the overhead fire suppression system occurs following a seismic event. It is unlikely due to the infrequency of a seismic event. The seismic event could also compromise the structural integrity of the glovebox/instrument/enclosure at the operation location. Should this occur, water may ingress into the glovebox/instrument/enclosure in a non-disruptive manner (e.g., flow along interior surfaces, drip from ceiling of a glovebox) and accumulates with fissionable material within accumulation point(s) (e.g., tilted glovebox/instrument/enclosure).

While it is difficult to characterize credible configurations for this highly unlikely abnormal condition, it is not credible that the ideal configuration needed to have a 520 g operation reach a critical state would result (Ref. 8). The solutions are kept in 2.2-liter containers. 520 g operations require at least 17.3 liters of solution in an idealized geometry (sphere) with full water reflection to reach critical. Therefore, the operation will remain subcritical under this upset scenario.

Additionally, 150 g of ^{233}U is much less than the minimum critical mass for a fully water reflected system required for a solution to reach a critical state (Ref. 8). Therefore, the operation will still remain subcritical if the operation experienced this upset operating under the 150 g mass limit.

4.3.10.2 Fire event with subsequent introduction of water

It is credible, though unlikely, that a fire initiates and causes water to be released from the overhead fire suppression system and introduced into the fissionable material operation location while it is at capacity. It is unlikely due to the infrequency of fires large enough to cause damage to a glovebox/instrument/enclosure such that water is able to enter the operation. There are two distinct fire scenarios, but they each result in the same bounding configuration.

The first fire scenario is a room fire (e.g., from a large trashbag) that causes water to be released from the fire suppression system. In the event of a room fire, the integrity of a glovebox/instrument/enclosure cannot be assumed (e.g., breaches in the gloves), and it therefore could be that water would enter the glovebox in a non-disruptive manner (e.g., enter through exposed glovebox ports).

The second scenario is a fire within the fissionable material operation boundaries (e.g., equipment malfunction, process material, waste) that propagates such that material form could change as well as the loss of containment of fissionable material (e.g., container integrity becomes compromised and material is spilled). It is judged credible that a fire of sufficient magnitude to compromise the glovebox integrity and actuate the overhead fire suppression system occurs. Water would enter the glovebox in a non-disruptive manner (e.g., enter through exposed glovebox ports). The water may then envelop the fissionable material. Additionally, it is credible that the fire may breach the 2.2-liter containers such that the solution could potentially collect in area.

While it is difficult to characterize the credible configurations for this highly unlikely abnormal condition, it is judged not credible for the operation to inadvertently create the ideal geometry needed for a 520 g Pu system to reach critical. Therefore, the operation will remain subcritical under this upset scenario.

Additionally, 150 g of ^{233}U is much less than the minimum critical mass for a fully water reflected system required for a solution to reach a critical state (Ref. 8). Therefore, the operation will still remain subcritical if the operation experienced this upset operating under the 150 g mass limit.

4.3.10.3 Use of fire-extinguishing agents due to metal fire

It is credible, though unlikely, that a metal fire initiates and nearby personnel use an available fire-fighting agent to smother the fire. It is unlikely because fires themselves are unlikely events. With regards to a first responder's use of extinguishing agents—they would be acting in an emergency condition and may use an approved fire-extinguishing agent (Ref. 16).

A bounding configuration is the fire-fighting agent atop the collocation of all allowed fissionable material. This configuration is determined to remain subcritical in Section 5.2.11.3.

Fire extinguishing methods, of which first-responders are trained, preclude the use of water for metal fires unless needed to prevent the spread of fire beyond the room of origin. As such, any additional water being provided by first responders would enter the operation in a non-disruptive manner.

5. Analysis

5.1 Evaluation Methods

5.1.1 Handbook Data

Information from accepted handbooks of critical and/or subcritical limits (e.g., LA-10860-MS (Ref. 8) and TID-7016 (Ref. 17)) is utilized.

5.1.2 Computational Methods

Some analyses in this evaluation were performed using computational methods, including updated computations originally published in NCS-TECH-14-014 (Ref. 2). The calculations were performed on the high performance computing cluster (HPC) “Moonlight” using MCNP6 Version 1.0 with ENDF/B-VII.1 continuous cross-section sets, as validated in accordance to the requirements defined in ANSI/ANS-8.24 (Ref. 18), and documented in References 19 and 20. The validation is approved for use by NCS-MEMO-16-030 (Ref. 21).

Reference 20 states that the Upper Subcritical Limit (USL) is defined as:

$$\text{USL}=1.0+\text{Bias-Bias Uncertainty-MOS-AoA}$$

Where,
MOS is the Margin of Subcriticality, and
AOA is the Area of Applicability.

Based on the computational method’s validation, the Bias-Bias Uncertainty between the benchmarks and experiments was determined to be 0.01. The materials, physical configurations, and neutron spectra are such that the calculations performed lie in the areas of applicability. Therefore, the AoA is 0. A margin of subcriticality of 0.02 is judged sufficient for the computations performed in this analysis. Therefore, the USL is determined to be 0.97. Hence, computational results performed during the course of this evaluation may be considered subcritical for

$$k_{eff}+2\sigma\leq 0.97$$

Where,
k_{eff} is the value of calculated k from the computational model, and
σ is the Monte Carlo uncertainty associated with the calculation.

Material definitions are given in Appendix A. These materials are evaluated within the validation report (Ref. 20). Simple geometries (e.g., sphere, slab, or cylinder) are used in the calculations. For cylinder geometries, the height-to-diameter (H/D) of the fissionable material is varied such that the criticality safety margin is demonstrated for typical process containers.

At least 10,000 neutrons per cycle, and at least 200 active cycles were used for each reported result. The convergence of the fission source was verified via Shannon entropy test and relevant statistical checks.

Note that calculations involving U-233 were completed for comparison (Figures 1 and 2) and thus do not require validation as subcriticality for systems with U-233 is concluded from fraction of critical mass calculations using handbook data (Ref. 17).

5.2 Analysis of Normal and Credible Abnormal Process Conditions

5.2.1 Normal Conditions

Under normal conditions, all operations that fall within the scope of this Level 3 CSED may contain up to 520 grams of Pu(0). The minimum critical mass for a 100% ^{239}Pu system is 520 g (Ref. 8). Below is the critical mass curve for this system from Figure 31 of Reference 8.

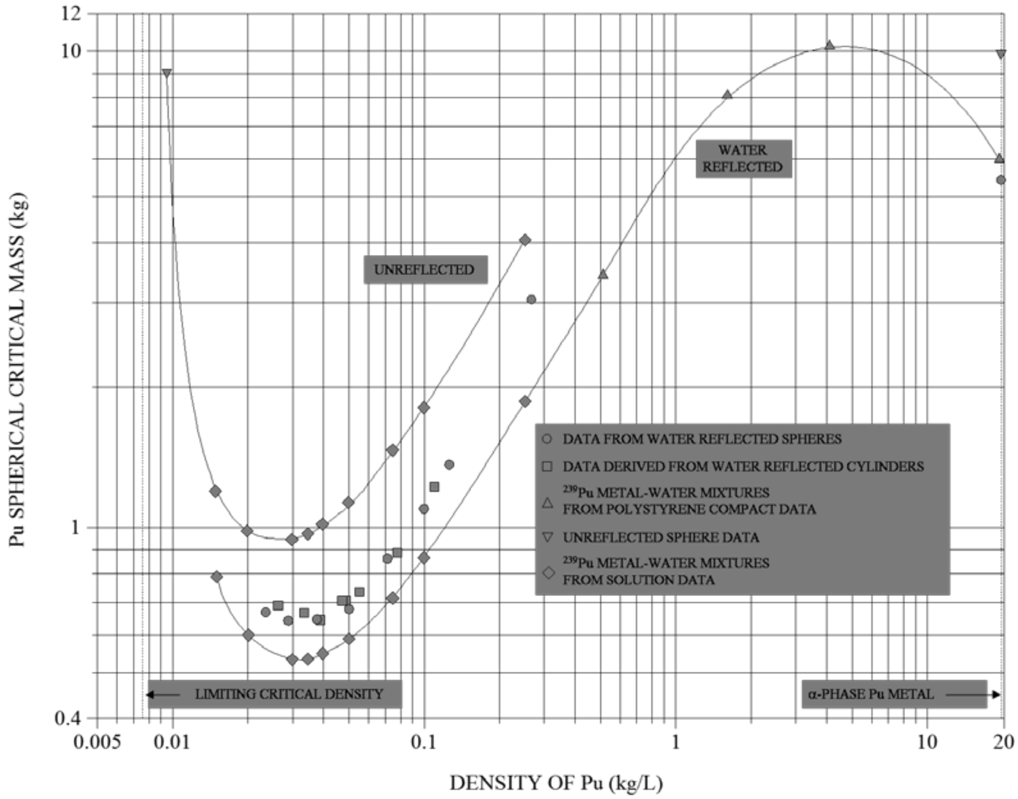


Figure 3. Minimum Critical ^{239}Pu Mass versus ^{239}Pu Density from LA-10860-MS (Ref. 8)

From Figure 3, the minimum critical mass of ~520 grams occurs at a Pu(0) density of ~30 g/L. A system of 520 grams of Pu(0) requires a sphere of a Pu(0) metal-water mixture (Pu(0) is assumed to be fine metal particles suspended uniformly in water) that is surrounded by tight fitting thick (12 inches or more) water reflection. The system would also require ~17.3 liters of solution. Under normal conditions, the operation will have no more than 520 g Pu(0). The idealized geometry needed to reach a critical state is not credible to occur under normal conditions. Additionally, the critical mass of the system will increase well above the allowed 520 g Pu mass limit due to the following physical realities of the operational configurations:

- Non-ideal (non-spherical) geometries of process containers;
- Limited volumes (2.2 liters) of individual fissionable solution containers;
- Various non-fissionable process material diluents (metals; nitrate, chloride, or hydroxide solution complexes; and other contaminants)

Therefore, the normal conditions of this operation will remain subcritical and due to the factors cited above, the safety margin is sufficient.

5.2.2 Loss of Mass Control

5.2.2.1 Single item overmass

5.2.2.1.1 520 g solution unit overmass

To assess the abnormal condition of a single item overmass, right circular cylinder of 572 g Pu(0) in solution was modeled. The solution is modeled as a cylinder because containers in the facility are cylindrical. The computational model fixed the mass of the Pu(0) in the solution unit while the concentration was varied from 25 to 35 g/L and subsequently; the volume was varied as well. The height-to-diameter ratio (H/D) of the solution container was varied from 0.6 to 1.4. The unit was centered along the z-axis. The cylinder was surrounded with 1-in of tight fitting water to account for sources of incidental reflection. The solution used was a plutonium metal water mixture. See Figure 4 for a drawing of the modeled scenario.

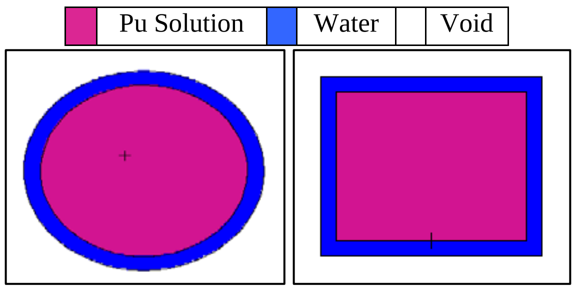


Figure 4. YX (left) and YZ (right) views of a container of 572 g Pu(0) in solution surrounded by 1-in of tight fitting water

The results of the computation can be found in Figure 5.

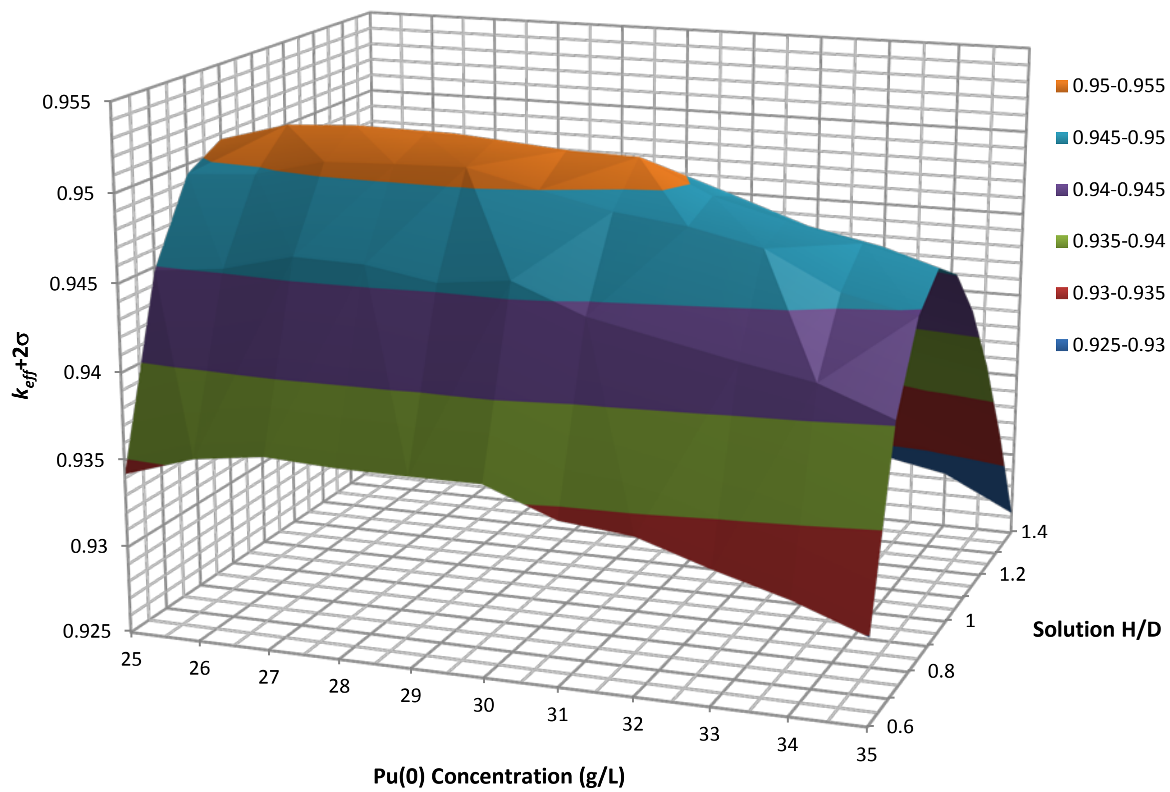


Figure 5. Mass upset, single item overmass: k_{eff} vs. Pu(0) concentration vs. Solution H/D

The highest k_{eff} of this configuration is equal to **0.953** with a Pu(0) concentration of 27 g/L (~21.2 L volume) and a solution H/D of 0.9. This value is below the USL of 0.97. Therefore, the operation will remain subcritical under the mass upset condition of a single item overmass.

5.2.2.2 Introduction of an additional item of fissionable material

To assess the abnormal condition of the introduction of an additional item of fissionable material, a defense in depth analysis of bounding overmass scenarios for PF-4 was performed for this generic CSED.

5.2.2.2.1 4.5 kg Pu in metal/oxide/compound/dry residue

To assess this configuration, the additional mass upset item would have to be in the bounding material form, metal. The configuration was a 4.5 kg Pu(0) metal ingot (right circular cylinder) collocated with a right circular cylinder of ~17.3 liters of 520 g Pu(0) in solution. The solution unit was fixed at the origin (base at XYZ coordinate of (0, 0, 0)) while the Pu(0) metal ingot was modeled in a side-by-side configuration, where the metal ingot was placed next to the solution unit. The H/D of the solution unit was varied from 0.2 to 1.6 while the ingot H/D was from 0.8 to 2.8. The solution was modeled with a concentration of 30 g/L (Ref. 8) initially and then varied at the optimum H/D. The units were surrounded with 1-in of tight fitting water to bound sources of incidental reflection. See Figure 6.

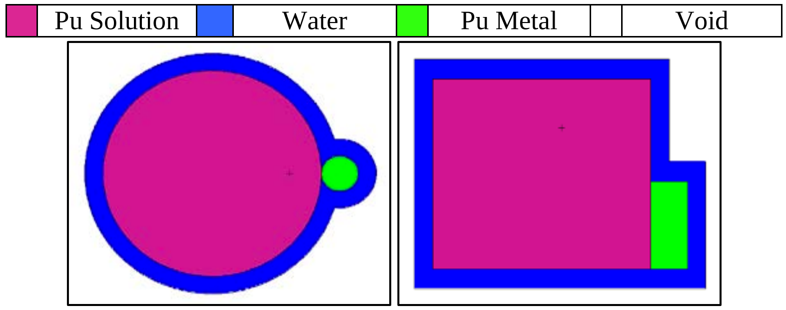


Figure 6. YX (left) and YZ (right) view of 4.5 kg Pu(0) metal ingot to the side of 520 g Pu(0) in solution

The results for the computation are shown in Figure 7.

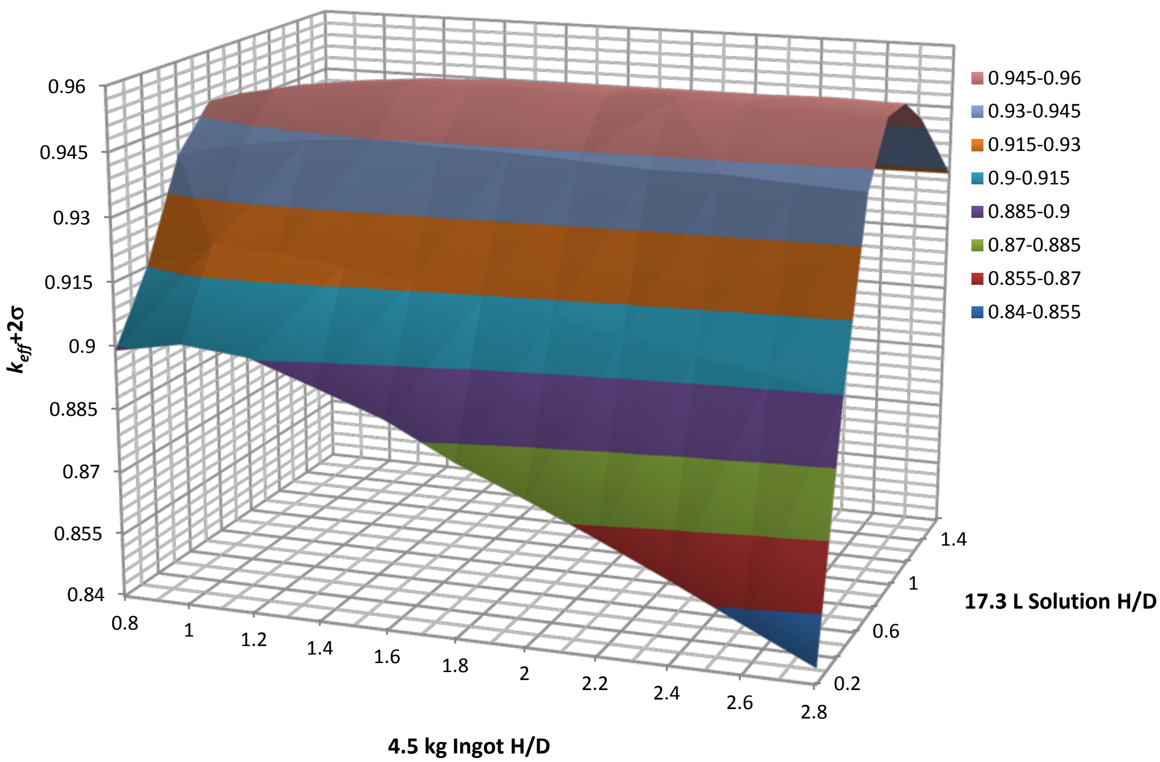


Figure 7. Mass Upset, 4.5 kg ingot side-by-side: *k_{eff}* vs. 4.5 kg ingot H/D vs. 17.3 L solution H/D

The highest k_{eff} of this configuration is equal to **0.956** at an ingot H/D of 2.2 and a solution H/D of 0.8.

The model was then held at the optimum H/D values while the solution concentration was varied from 25 g/L to 35 g/L. The results are shown in Figure 8.

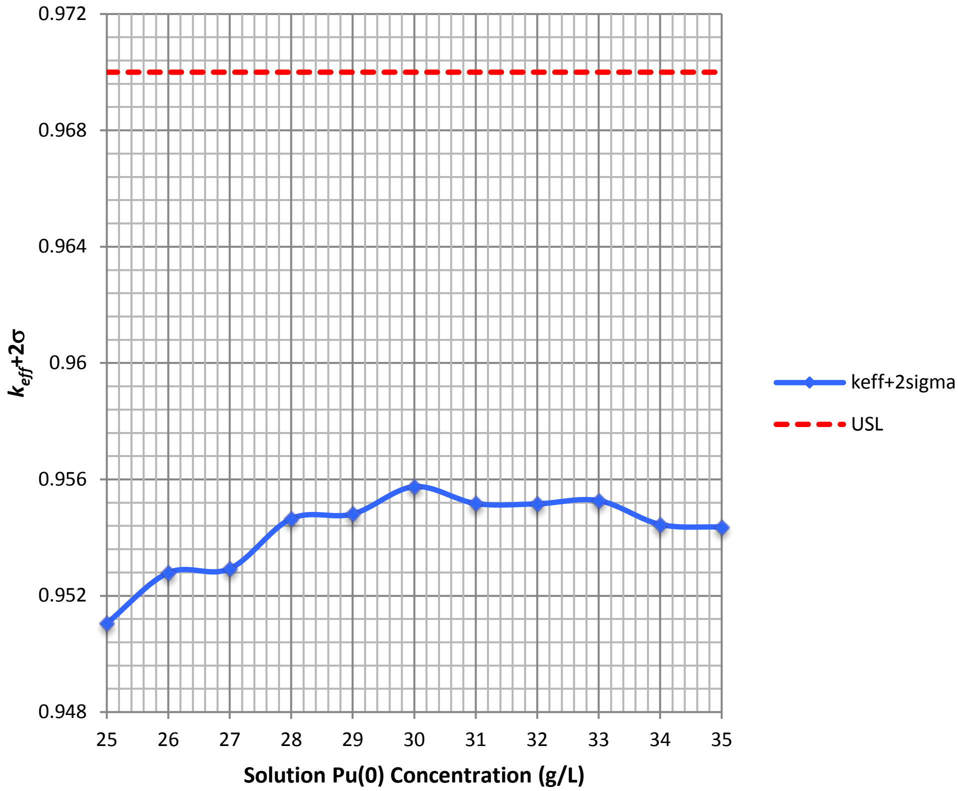


Figure 8. Mass Upset, 4.5 kg ingot side-by-side: k_{eff} vs. Pu(0) Solution Concentration

The highest k_{eff} of this configuration is equal to **0.956** at a solution concentration of 30 g/L. This k_{eff} is below the USL of 0.97. Therefore, the operation will remain subcritical under the 4.5 kg metal ingot side-by-side mass upset condition.

5.2.2.2.2 520 g Pu(0) in solution from double batching or material transfer

The next configuration was a 2.2-liter unit of 520 g Pu(0) in solution collocated with a ~17.3-liter unit of 520 g Pu(0) in solution (30 g/L concentration). 2.2 liters was chosen as the volume of the interaction unit because the fissionable solution bearing containers used in the facility are 2.2 liters. The 2.2-liter solution unit was modeled as a right circular cylinder. The two solutions were modeled as a plutonium metal water mixture. The 17.3-liter solution unit was fixed at the origin (cylinder base at XYZ coordinate of (0, 0, 0)) while the 2.2-liter solution unit was modeled in a side-by-side configuration. The configuration modeled the two fissionable material units as close together as possible and therefore, is considered bounding configurations. The 2.2-liter solution unit was placed directly to the side of the 17.3-liter solution unit. The H/D ratio of the 17.3-liter solution unit was varied from 0.2 to 1.6 while the 2.2-liter solution unit was from 0.6 to 2.6. The 17.3-liter unit had a concentration of 30 g/L initially and then was varied at the optimum H/D. The units were surrounded with 1-in of tight fitting water to bound sources of incidental reflection. See Figure 9.

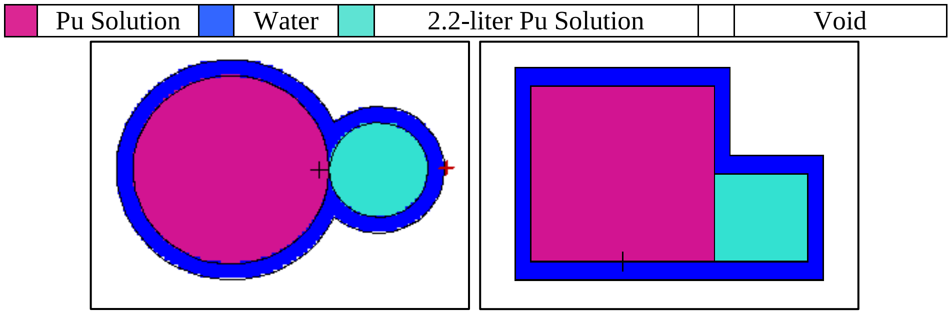


Figure 9. YX (left) and YZ (right) views of 2.2-liters of 520 g Pu(0) in solution to the side of 17.3-liters of 520 g Pu(0) in solution

The results for the computation are shown in Figure 10.

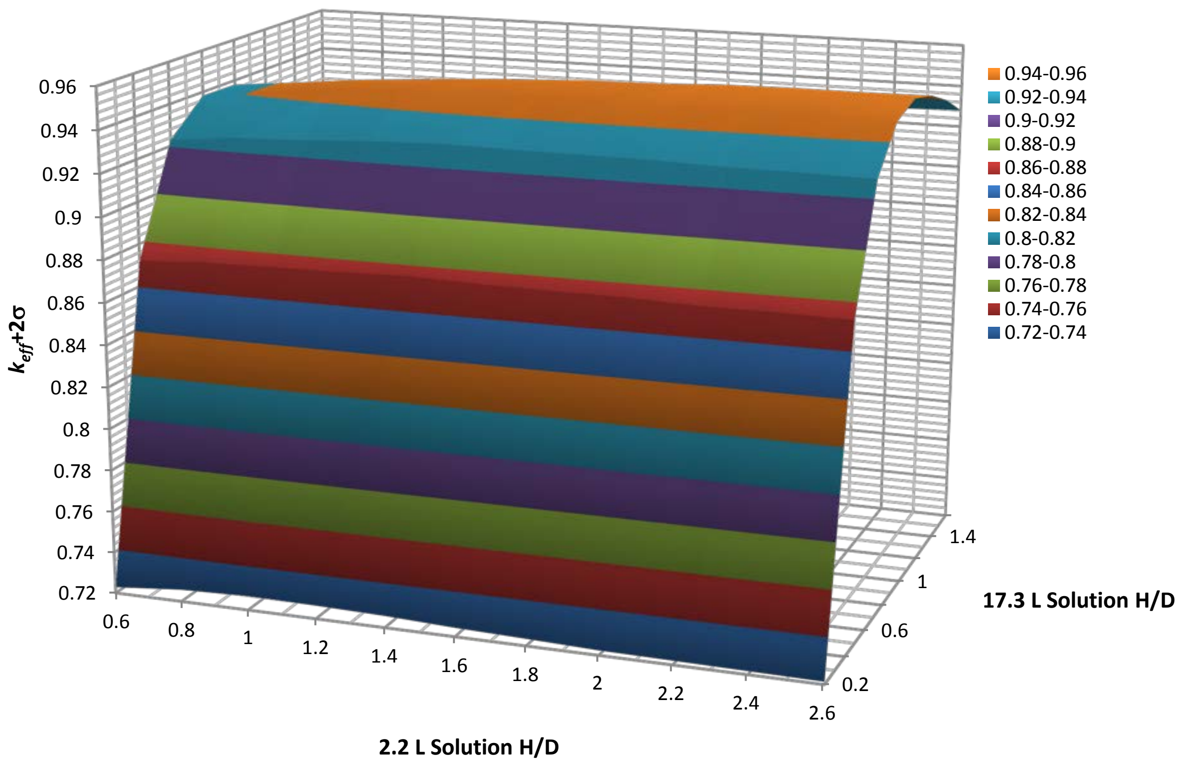


Figure 10. Mass Upset, 2.2 L of 520 g Pu(0) in solution side-by-side: k_{eff} vs. 2.2 L solution H/D vs. 17.3 L solution H/D

The highest k_{eff} of this configuration is equal to **0.952** at a 2.2-liter solution H/D of 2.2 and a 17.3-liter solution H/D of 1.0.

The model was then held at the optimum H/D values while the concentration of the original solution was varied from 25 g/L to 35 g/L. The 2.2 L solution concentration was held constant to adhere to the 2.2-liter solution container control. The results are shown in Figure 11.

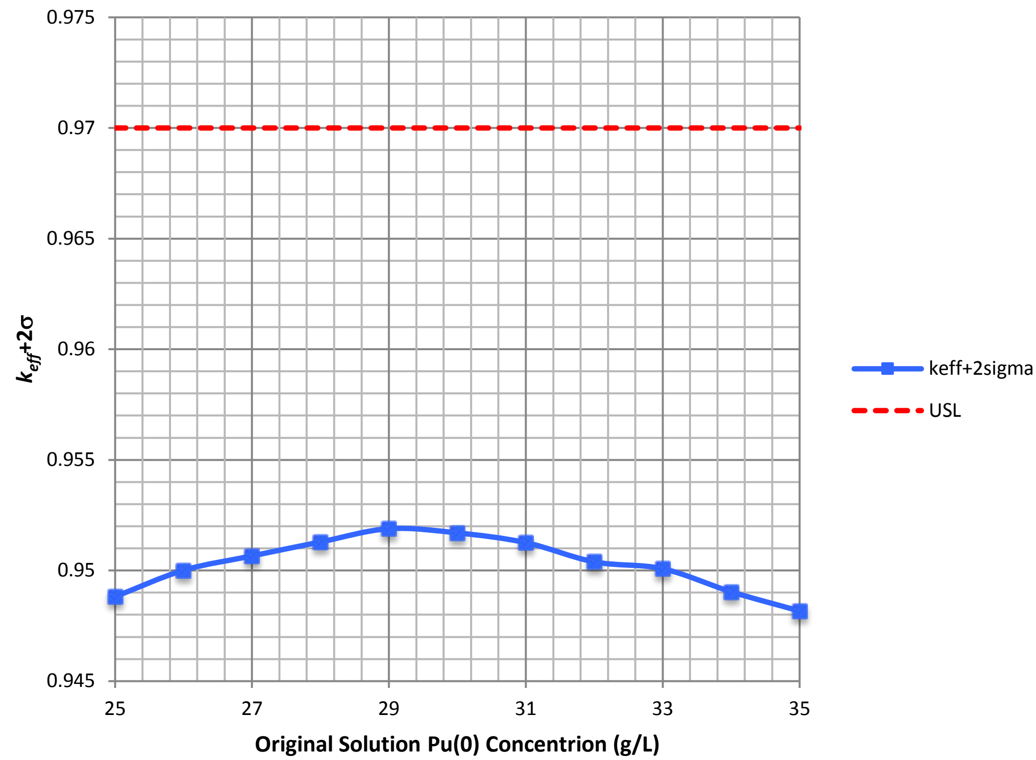


Figure 11. Mass Upset, 2.2 L of 520 g Pu(0) solution side-by-side: k_{eff} vs. Pu(0) Solution Concentration

The highest k_{eff} of this configuration is equal to **0.952** at a solution concentration of 29 g/L. This k_{eff} is below the USL of 0.97.

As explained in Section 4.3.1.2.2, the configuration with 150 g of ^{233}U with an additional 2.2-liter container with 520 g Pu is bounded by the configuration analyzed previously in this Section.

Therefore, the operation will remain subcritical under the 520 g Pu(0) in solution side-by-side mass upset condition.

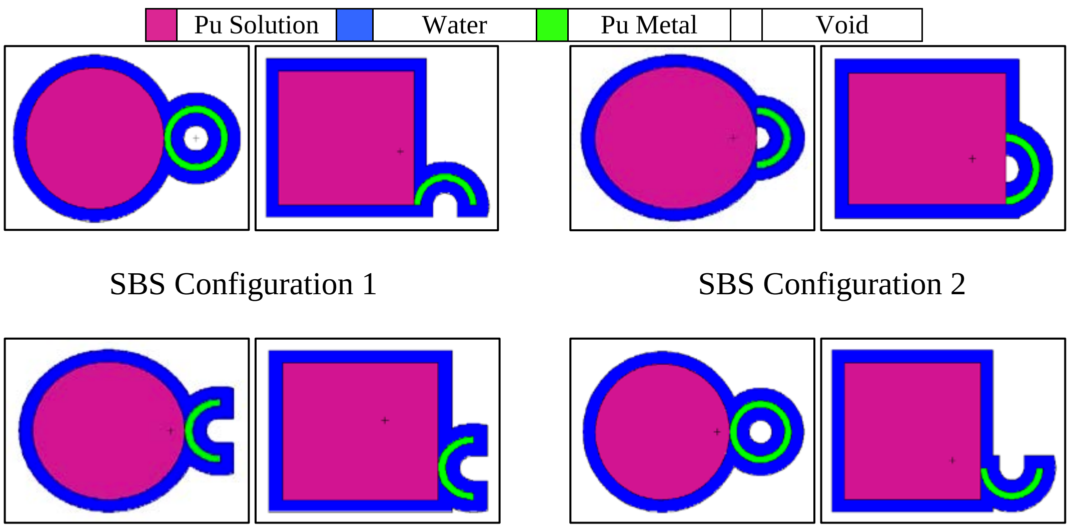
5.2.2.2.3 4.5 kg Pu in oxide from material transfer

The 4.5 kg Pu in oxide from material transfer upset scenario is bound by the introduction of an additional item of 4.5 kg Pu in metal upset. While a single unit of metal will be more reactive than a single unit of oxide of equivalent Pu mass, the normal conditions in this analysis uses a large container of solution. Since oxide has a lower density than metal, it is possible that an oxide overmass upset may provide a system with a higher reactivity than the metal overmass upset due to the increase in interaction between the solution unit and the oxide unit. However, when considering both the metal density (19.84 g/cc) and the oxide density (theoretical of 11.46 g/cc, bulk of 4-5.5 g/cc, and tap of 4.9-6.7 g/cc [Ref. 13]), the difference in radii (for a sphere of these densities at equivalent masses) is small and the effect on the solid angle would be negligible. Additionally, the lower density of the oxide would lower reactivity. Therefore, the 4.5 kg Pu in oxide from material transfer mass upset is bound by the 4.5 kg Pu in metal mass upset and is shown to be subcritical in Section 5.2.2.2.1.

5.2.2.2.4 6.0 kg Pu hemishell from material transfer

The final configuration was a 6.0 kg Pu(0) hemishell collocated with a 17.3-liter container of 520 g Pu(0) in solution (30 g/L concentration). The hemishell was modeled with a 4-in inner diameter. The 17.3-liter solution unit was fixed at the origin (cylinder base at XYZ coordinate of (0, 0, 0)) while the hemishell was modeled in both a side-by-side configuration.

In the side-by-side configuration, the hemishell was placed directly to the side of the 17.3-liter solution unit in four different configurations, as shown in Figure 12. The H/D of the 17.3-liter solution unit was varied from 0.2 to 1.6. The solution concentration was varied from 25 g/L to 35 g/L. The hemishell and the solution unit were surrounded by 1-in of tight fitting water to bound sources of incidental reflection.



SBS Configuration 1 SBS Configuration 2

SBS Configuration 3 SBS Configuration 4

Figure 12. YX (left) and YZ (right) views of 6.0 kg Pu(0) hemishell placed next to 17.3-liters of 520 g Pu(0) in solution in various configurations

The results for the four side-by-side configurations are shown in Figures 13-16.

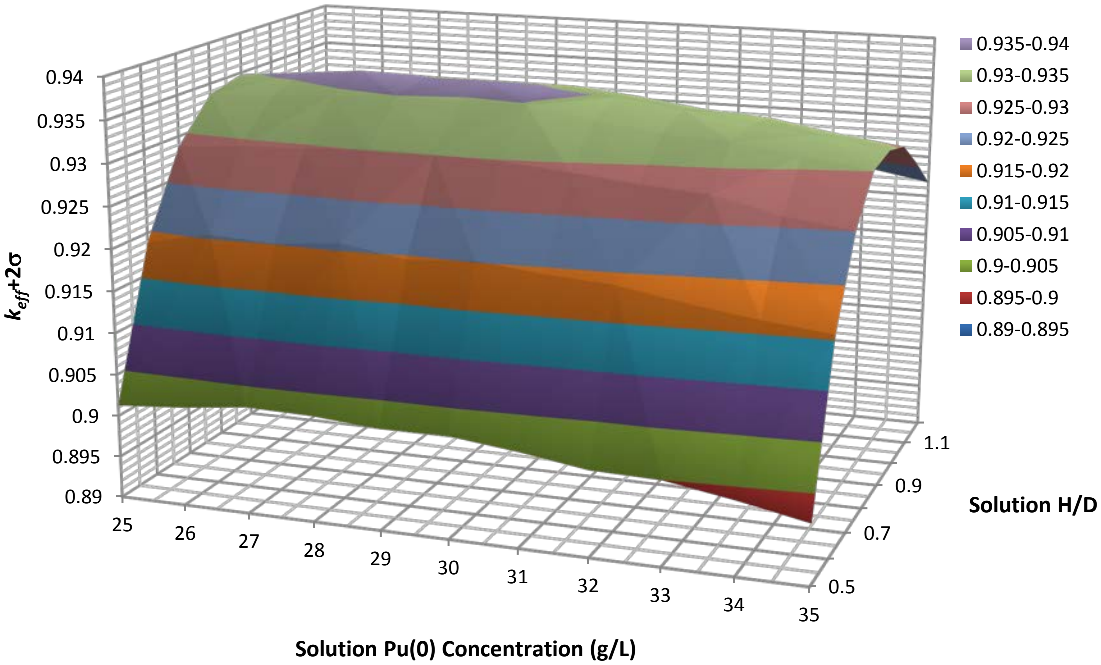


Figure 13. Mass Upset, 6.0 kg Hemishell SBS Configuration 1: k_{eff} vs. Solution Concentration vs. Solution H/D

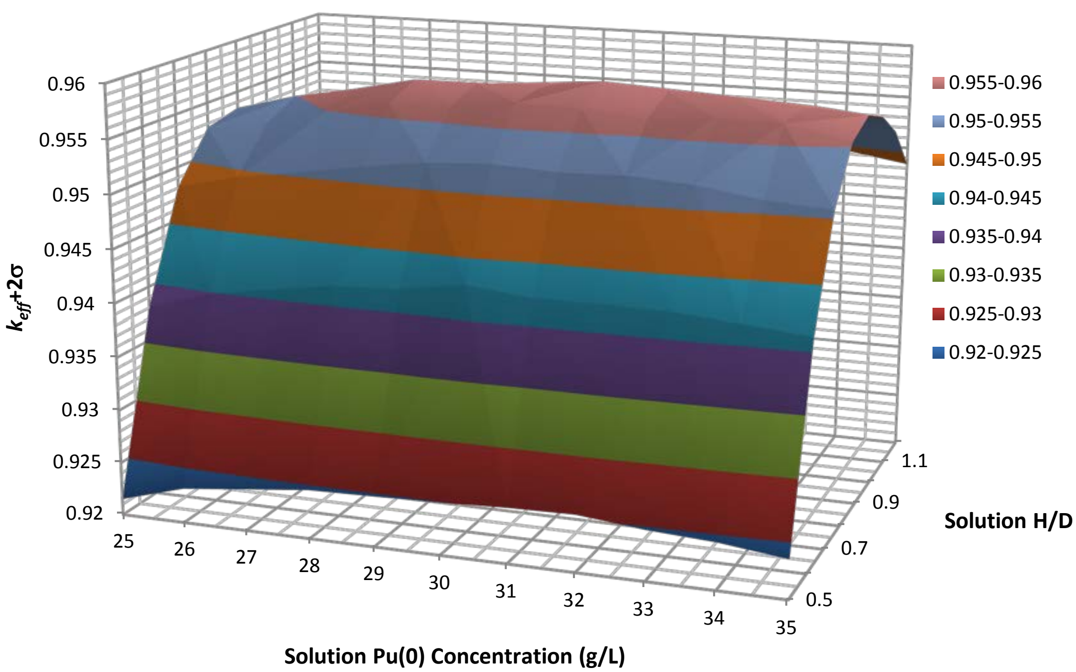


Figure 14. Mass Upset, 6.0 kg Hemishell SBS Configuration 2: k_{eff} vs. Solution Concentration vs. Solution H/D

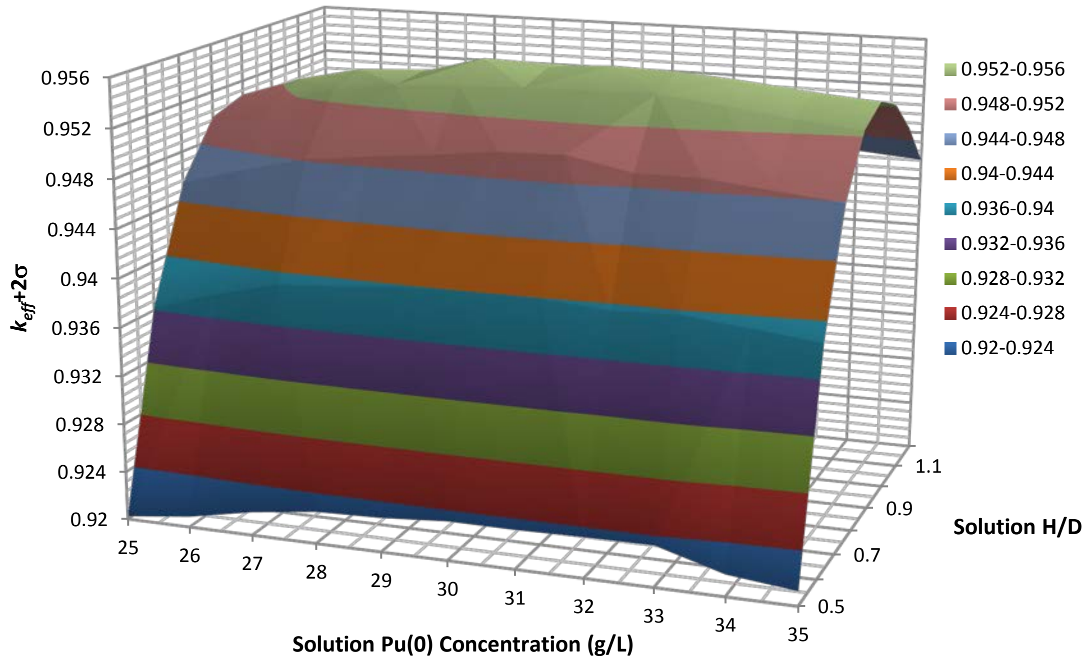


Figure 15. Mass Upset, 6.0 kg Hemishell SBS Configuration 3: k_{eff} vs. Solution Concentration vs. Solution H/D

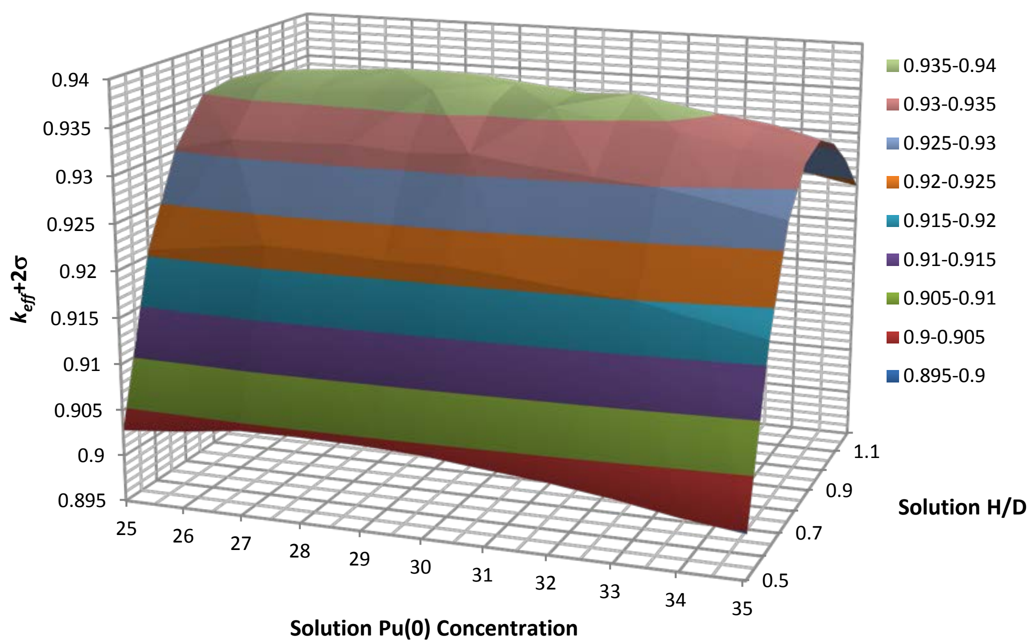


Figure 16. Mass Upset, 6.0 kg Hemishell SBS Configuration 4: k_{eff} vs. Solution Concentration vs. Solution H/D

The highest k_{eff} values for all hemishell side-by-side configurations are shown in Table 1 below. All results in table 1 are below the USL of 0.97. Therefore, the operation will remain subcritical under the 6.0 kg hemishell loss of mass control upset scenario.

Table 1. Results of the 6.0 kg hemishell mass upset scenario

SBS Configuration Number	Solution Pu(0) Concentration (g/L)	Solution H/D	k_{eff}
1	27	0.9	**0.937**
2	31	0.9	**0.959**
3	31	0.9	**0.956**
4	28	0.9	**0.938**

5.2.2.2.5 150 g ^{233}U in solution from a double batch or solution transfer

The additional item of 150 g of ^{233}U in 2.2 liters of solution upset is shown to be subcritical by analyzing a configuration of 520 g Pu in an optimally moderated solution collocated with 150 g of ^{233}U in 2.2 liters of solution. To analyze this configuration, the fraction of the critical mass for Pu was determined by dividing 520 grams by the minimum 1-in water-reflected critical mass for Pu. The minimum critical mass for a 1-in water reflected sphere of optimally water moderated Pu solution is ~676 g (Ref. 8). 520 grams would be ~77% of the minimum critical mass. Then the fraction of the critical mass for ^{233}U was determined by using the ^{233}U 1-in water-reflected curve shown in Figure 2.5 of TID-7016 (Ref. 17). Table 2 contains the values for the minimum critical masses and the masses a 2.2-liter container would have at various concentrations. Table 2 also contains the fraction of the critical mass for the 2.2-liter bottle at the various concentrations and the sum of that fraction of the critical mass and the fraction of the critical mass for Pu.

Table 2. Results for ^{233}U fraction of critical mass

Concentration (kg/L)	1" Water-Reflected ^{233}U Subcritical Mass Limit from TID-7016 (Ref. 17) (kg)	2.2-Liter Container Mass (kg)	^{233}U Fraction of Critical Mass	Sum of Pu and ^{233}U Fractions of Critical Mass
0.03	0.680	0.066	0.098	0.866
0.04	0.620	0.088	0.142	0.911
0.06	0.640	0.132	0.207	0.976
0.07	0.670	0.154	0.230	0.999

As shown in Table 2, even when the 2.2-liter container has 154 grams, the sum of the fractions is less than 1, meaning that it is still subcritical. Additionally, Figure 2.5 in Reference 17 uses values of subcritical mass limits, meaning that the system would be even more subcritical than what is presented in this analysis. Therefore, this configuration will remain subcritical.

Additionally, the second configuration, as discussed in Section 4.3.1.2.5, of 150 grams of ^{233}U in an optimally moderated solution collocated with a 2.2-liter container of 150 grams of ^{233}U in solution is bound by the analysis of the first configuration in this section because the initial 150 grams of ^{233}U is bound by 520 grams of Pu in an optimally moderated solution.

Therefore, the operation will remain subcritical under the 150 g ^{233}U in solution mass upset event.

5.2.3 Loss of Moderation Control

As discussed in Section 4.3.2 moderation is not controlled.

5.2.4 Loss of Reflection Control

As discussed in Section 4.3.3, reflection is not controlled.

5.2.5 Loss of Interaction Control

5.2.5.1 Interaction with Fissionable Material Outside of the Operation

This loss of interaction control is bounded by the loss of mass control of an additional item, which is shown to be subcritical in Section 5.2.2.2. Therefore, the interaction with fissionable material outside of the operation interaction upset condition will remain subcritical.

5.2.5.2 Interaction with Nearby Fixed Fissionable Material Operations

This loss of interaction control is bounded by the loss of mass control of an additional item, which is shown to be subcritical in Section 5.2.2.2. Therefore, the interaction with nearby fixed fissionable material operations upset condition will remain subcritical.

5.2.6 Loss of Volume Control

5.2.6.1 Individual solution and liquid container larger than the allowed 2.2 L

The analysis performed for this evaluation assumed a single container of optimally moderated solution with a volume much greater than 2.2 liters to analyze the most reactive configuration for 520 g Pu operations. Therefore, if a container of solution with a volume greater than 2.2 liters were used in the operation, it would remain subcritical.

5.2.7 Loss of Concentration/Density Control

The analysis performed in this evaluation use theoretical density values and the most reactive concentration for solutions. Therefore, concentration/density is not controlled.

5.2.8 Loss of Enrichment Control

The analysis performed in this evaluation uses Pu(0). Pu(0) is bounding of any isotopic composition found in the PF-4 inventory. Therefore, enrichment is not controlled.

5.2.9 Loss of Absorber Control

As discussed in Section 4.3.8, no credit is taken for the presence of an absorber. Therefore, no absorber control is needed.

5.2.10 Loss of Geometry Control

As discussed in Section 4.3.9, the analyses performed in this evaluation assume the most reactive credible configuration. Therefore, geometry is not controlled.

5.2.11 Concurrent Loss of Multiple Parameters

5.2.11.1 Seismic event with subsequent introduction of water

As mentioned in Section 4.3.10.1, it is not credible that a seismic event would result in the ideal configuration needed to make a 520 g operation reach critical.

5.2.11.2 Fire event with subsequent introduction of water

As mentioned in Section 4.3.10.2, it is not credible that a fire event with subsequent introduction of water would result in the ideal configuration needed to make a 520 g operation reach critical.

5.2.11.3 Use of fire-extinguishing agents due to metal fire

According to PA-RD-01009 (Ref. 4), dry fire extinguishing agents that are authorized for use in PF-4 gloveboxes include graphite powder, magnesium oxide, and MET-L-X. These fire-extinguishing agents and a few others have been studied in NCS-TECH-14-027 (Ref. 22) and NCS-TECH-15-009 (Ref. 23). The TECH documents conclude that reflector worth of the agents tested are bounded by water. Therefore, the operation will remain subcritical in the event that these fire-extinguishing agents are used.

It is also expected that some locations will have Stat-X fire-extinguishing systems installed. The Stat-X system is an aerosol generator that contains a potassium-based aerosol that provides rapid suppression of fires (Ref. 24). The Stat-X particulates are described as buoyant and are easily vented from enclosures/protected areas. Deposition onto horizontal surfaces is expected to be extremely thin and the particulates will not form a continuous layer. It is not expected that the use of this fire-extinguishing agent will provide enough reflection to exceed a fully water reflected system. Therefore, the operation will remain subcritical even if fire-extinguishing agents are used.

6. Conclusion

520 g operations under the scope of this evaluation and the criticality safety requirements in Section 2.0 of this document will remain subcritical under normal and credible abnormal conditions. Criticality safety requirements were determined utilizing the Double Contingency Principle recommendation. Please contact NCS at your earliest convenience if you have any questions or concerns regarding this evaluation.

7. References

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2) **NCS-MEMO-17-007**, *Application of Standard Criticality Safety Requirement Evaluations*, 2017-02-13.
3) **NCS-TECH-14-014**, *General Defense of the Sub-criticality of the 520 g Pu Any Form Limit,* 2014-04-03.
4) **PA-RD-01009, R6,** *TA55 Criticality Safety Requirements*, 2015-06-22.
5) **SD-130, R3**, *Nuclear Criticality Safety Program,* 2015-09-24.
6) **ANSI-ANS-8.1-2014**, *Nuclear Criticality Safety in Operations with Fissionable Materials Outside Reactors*.
7) **NCS-TECH-15-001**, *Parametric Studies of Interaction in Generic "Process Conditions",* 2015-08-03.
8) **LA-10860-**MS, *Critical Dimensions of Systems Containing ^{235}U, ^{239}Pu, and ^{233}U—1986 Revision,* July 1987.
9) **NCS-TECH-08-014**, *Pu and U Critical Mass and Volume Curves for Various Moderators and Reflectors*, 2008-06-18.
10) **NCS-TECH-16-008**, *Critical Mass Curves of Plutonium Spheres with Various Reflectors,* 2016-08-25.
11) **NCS-TECH-16-011**, *Practical Moderator Concerns with Typical Glovebox Operations,* 2016-08-29.
12) **NCS-CSED-15-136**, *Criticality Safety Evaluation for Operational Use of Fissionable Material Transport Carts in PF-4*, 2016-02-04.
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14) **NCS-CSED-13-015**, *Criticality Safety Evaluation for Handling Small Quantities of Fissionable Material in PF-4*, 2013-01-30.
15) **C-AAC-16-036**, *P520 Plutonium Oxide Credible Upset*, 2016-08-23.
16) **TA55-AP-108, R2**, *TA-55 Emergency Response Guides*, 2015-04-01.
17) **TID-7016**, *Nuclear Safety Guide Revision 2*, June 1978.
18) **ANSI/ANS-8.24-2007**, *Validation of Neutron Transport Methods for Nuclear Criticality Safety.*
19) **NCS-MEMO-15-011**, *Approval for Use of MCNP6 Version 1.0 on the Moonlight HPC,* 2015-04-17.
20) **NCS-TECH-15-005**, *Validation of MCNP6 Version 1.0 with the ENDF/B-VII.1 Cross Section Library for Plutonium Metals, Oxides, and Solutions on the High Performance Computing Platform Moonlight,* 2015-04-16.
21) **NCS-MEMO-16-030**, *Approval for Use of Existing Criticality Safety Validations,* 2016-08-02.

22) **NCS-TECH-14-027**, *Reflector Worth of Dry Chemical and Powder Extinguishing Agents*, 2014-11-25.

23) **NCS-TECH-15-009**, *Incidental Reflector Comparison of Containerized Dry Fire Extinguishing Agents*, 2015-04-28.

24) **http://www.statx.com/Fixed_System_Thermal.asp**, accessed 2016-08-17.

Appendix A- Material Information

Material	Density (g/cm^3)	ZAIDs	Fraction (+ atom/ - weight)
Water	1.0	1001.80c	2.0
		8016.80c	1.0
		lwtr.20t	
520 g Pu Solution at 30 g/L	1.02848790322581	94239.80c	7.5575181593426e-05
		1001.80c	0.0667547842334083
		8016.80c	0.0333773921167041
		lwtr.20t	
572 g Pu Solution at 27 g/L	1.02563911290323	94239.80c	6.80176634340834e-05
		1001.80c	0.0667648934889711
		8016.80c	0.0333824467444856
		lwtr.20t	
Plutonium Metal	19.84	94239.80c	1.0
2.2 L of 520 g Pu Solution	1.22445014662757	94239.80c	0.000595440824675478
		1001.80c	0.0660593899871147
		8016.80c	0.0330296949935573
		lwtr.20t	
750 U-233 Solution at 60 g/L	18.424	92233.80c	0.000206733474744042
		8016.80c	0.0332827888574167
		1001.80c	0.0665655777148335
		lwtr.20t	

Note: Other plutonium and uranium-233 solutions with different fractions/densities were used when varying concentration. These were excluded from this list. However, the fractions and densities were calculated/generated with the same method.

Appendix B
Cross-walk of Comment Resolution Associated with

ISS-OPS-1.12-2017-714434

Finding 1 – The limit table, and AP-522, allow other isotopes to be handled under the plutonium limits. This evaluation allows solution processing and relied on volume control to ensure subcriticality under the over-mass condition. The volume controls are not demonstrated to be bounding for uranium solutions which may have a lower critical volume than plutonium solutions. (ANSI/ANS 8.19, Section 8.1)

Resolution: Figures have been added to the analysis that shows that ^{239}Pu is bounding of ^{235}U and it supports the gram-for-gram substitution. Additionally, there has been a control added on the amount of ^{233}U allowed to be substituted to reduce the consequences of a mass upset and ensure that the operation is still bound by the ^{239}Pu analysis performed in this evaluation. Section 5.2.2.2.5 also provides an analysis to show that the operation will remain subcritical with the new ^{233}U limit.

Observation 1 – The volume controls specify that solutions are collected in bottles. This is a potential infraction trap where solutions contained in other containers may meet the intent of the volume control, but not meet the specific container type requirement.

Resolution: Changed wording throughout the CSED and the limit set to remove the bottle specification and replace it with the general term “container”.

Observation 2 – Section 2.1.3 appears to expand the volume control requirement to non-fissile liquids. It is not clear that non fissile liquids require control based on the technical analysis presented. There is no language in the limit table specifying if control of non-fissile liquids is required.

Resolution: The limit table has been modified with language specifying a control on non-fissile liquids. This control is necessary to ensure that the over-mass conditions remain subcritical. Additionally, Section 4 has been updated to clearly state that reflection is not controlled.

Observation 3 – Several sections analyze “upsets” of parameters that are not under control, and where the analysis demonstrated that control is unnecessary. Examples include: 5.2.3- Moderation Reflection, 5.2.4- Interaction, 5.2.10.3- firefighting (effectively reflection).

Resolution: Language has been updated to better reflect controlled parameters.