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CSM 1576: Criticality Safety Evaluation of a New 3013 Calorimeter for Use Under OSP 332.032

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NUCLEAR OPERATIONS DIRECTORATE
Nuclear Criticality Safety Division

March 25, 2010
CSM 1576

TO: Kevin Mahoney

FROM: Catherine Percher

SUBJECT: Criticality Safety Evaluation of a New 3013 Calorimeter for Use Under OSP 332.032

1.0 Introduction

Materials Management (MM) has purchased a new calorimeter to be used in B332, Room 1314A under Operational Safety Plan (OSP) 332.032, *Nuclear Material Measurements*. Calorimeters quantitatively measure the decay heat produced by fissionable material to verify the fissionable mass of items for Material Control and Accountability (MC&A). The new commercially-available calorimeter, the Setaram Large Volume air bath Calorimeter (LVC) 3013, was specially designed for measuring 3013 cans. Operations have requested Standard Criticality Control Conditions (SCCCs) consistent with the other calorimeters and MC&A workstations covered by OSP 332.032. This report documents the criticality safety evaluation of the new LVC 3013 with SCCCs A, V1, V2, and V6. An addendum to this evaluation, CSM 1576, Addendum 1, *Criticality Safety Evaluation of Approved Items for LVC 3013 under OSP 332.032* (U), provides the technical basis for SCCC V3 and the accompanying approved item list from OSP 332.032.

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2.0 Description of Operations

Workstations covered by OSP 332.032 measure the physical properties of nuclear material. The measurements verify the contents of packages containing fissionable materials that are to be shipped off-site, received from off site, or moved between Material Balance Areas (MBA). Measurements are also made in support of Safeguards and Security requirements, programmatic needs, and waste certification. Based on the calorimetry and the isotopic composition of each batch, the amount of accountable fissionable material can be calculated for material balance and safeguards controls. Calorimeters quantitatively measure heat from the radioactive decay of fissionable material in an item by determining the transfer of energy from an "active cell" (one that contains the item) to a "reference cell" (an empty cell). Four of the five of the calorimeters currently in use by MM are water-bath calorimeters; the two air-filled cells are surrounded by water to thermally isolate the system. The fifth calorimeter is an air-bath calorimeter that used insulation material to thermally isolate the system.

2.1 Description of the Setaram LVC 3013

The new Setaram LVC 3013 calorimeter is an air-bath calorimeter. Instead of water providing insulation inside the calorimeter, a combination of an air gap and alternating layers of aluminum 2017 and polyetherimide (a low-density foam) provides thermal isolation to the system. The calorimeter measures heat by means of Peltier elements around the measurement cell. The Peltier elements determine the temperature difference between the sample and the aluminum thermal block, taking into account a comparison with the reference (empty) cell. The thermal block is maintained at a reference temperature by the use of heaters, which is why the unit is classified as an Active Differential Isothermal Calorimeter. Appendix B gives more information about the calorimeter as provided by the vendor.

A cross-sectional schematic of the calorimeter, provided by Seteram, is shown in Figure 2.1. The "active cell" is shown in red on the left. The "reference cell" is the cell on the right. There is an air gap between the two cells to create an insulating barrier to minimize thermal effects from the active cell on the reference cell.

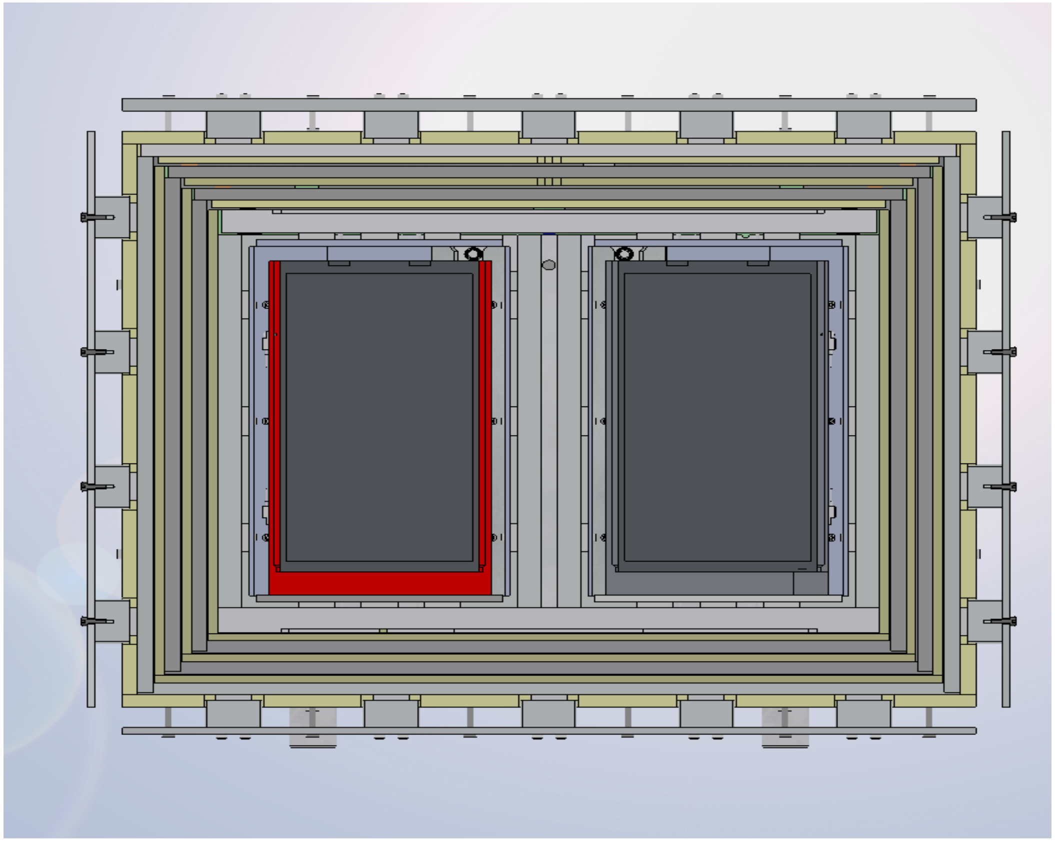
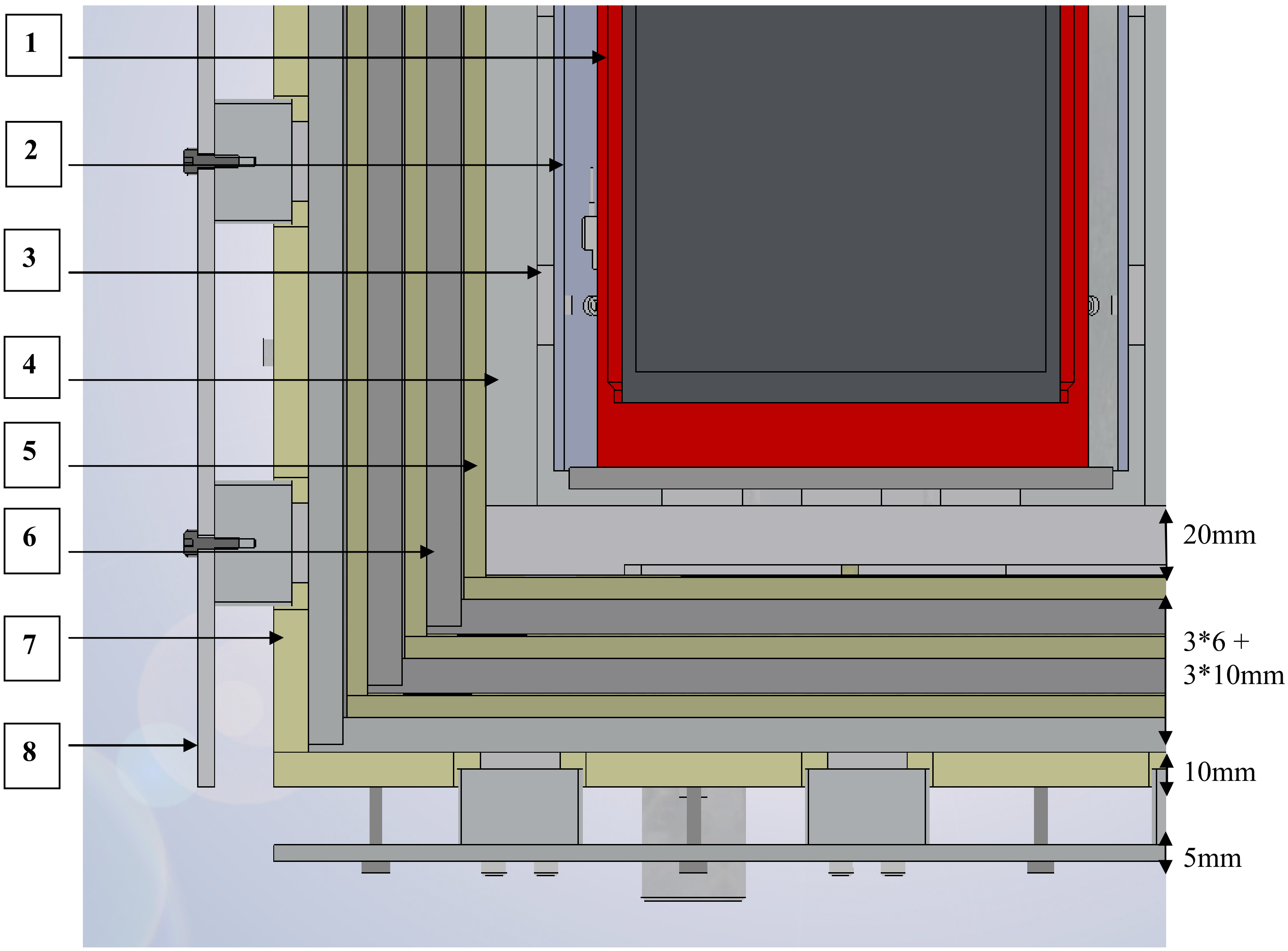


Figure 2.1: Cross-Sectional View of the Seteram LVC 3013 Calorimeter

The external dimensions (including wheels and associated electronics) of the calorimeter are 65.5 cm wide, 57.7 cm deep, and 84.2 cm high. Because this calorimeter is specially designed to measure 3013 cans, the internal measurement volume is smaller than the other existing calorimeters. The measurement cell has internal dimensions of 13.7 cm diameter and a height of 26.7 cm. Based on these measurements, the cell volume is a very limited 3.935 liters.

Figure 2.2 shows additional detail about the layers that make up the LVC 3013. Table 2-1 gives details concerning the materials used in the construction of the calorimeter, including densities and total volume and mass present in the calorimeter.

Figure 2.2: LVC 3013 Schematic Showing Cross-Sectional Layers and Materials



Position	Description	Material	Thickness
1	Built in Joule Effect Supply	Aluminum 2017	4 mm
2	Aluminum Housing	Aluminum 2017	3 mm
3	Peltier Element and Air Gap	Bismuth Telluride / Air Bi_2Te_3	3.8 mm
4	Thermal Block	Aluminum 2017	20 mm
5	Insulation Layer (3 layers)	Polyethermide ($C_{37}H_{24}O_6N_2$)	6 mm
6	Insulation Layer (3 layers)	Aluminum 2017	10 mm
7	Final Insulation Layer	Polyethermide	10 mm
8	Convection Plate	Aluminum 2017	5 mm

Table 2-1: LVC-3013 Material Specifications

Material	Density (g/cm^3)	Total volume in the calorimeter (m3)	Total mass in the calorimeter (kg)
Aluminum 2017	2.79	0.0542	151.25
Steel S235 (E24)	7.85	0.0059	46.13
Stainless steel 304L	8.00	0.0020	15.89
Bismuth telluride	7.73	0.0002	1.59
Polyetherimide	0.11	0.0241	2.65

3.0 Requirements Documentation

This evaluation is written in accordance with the LLNL Criticality Safety Program as described in Document 20.6, Criticality Safety, LLNL Environment, Safety, and Health Manual. This document also satisfies the content and format requirements of DOE-STD-3007-2007, and the Nuclear Criticality Safety Division Procedure, CS-P-004, Rev. 5, *Criticality Safety Evaluations*.

4.0 Methodology

Calculations were performed using MCNP5, Version 1.30, using the ENDF/B-VI, Release 6 cross section data set (.60c). All calculations documented in this report were performed on the SURYA Sun workstation. The SURYA workstation is running on a Sun Solaris 5.8 operating system, and MCNP5 was compiled with Sun Workshop 6 Update 2 C and Sun Workshop 6 Update 2 F90 Compilers.

Verification of the installation of MCNP5 has been previously documented.[1] A subset of benchmarks[2] has been selected from the ICSBEP handbook to estimate bias and establish a subcritical limit for the application of MCNP in the present analysis. The validation calculations are reported in Appendix B. The selected benchmarks closely resemble the fissile materials, such as plutonium metal spheres, and reflectors and moderators, such as aluminum, water, and polyethylene, which are considered in the calculations in this analysis. As described in Appendix B, with a 2% safety margin, the calculated subcritical limit is 0.962.

5.0 Normal Operations and Credible Abnormal Conditions

5.1 Normal Operating Conditions

During normal operations, all fissionable materials will be in tightly sealed primary containers. The LVC 3013 is designed to measure 3013 cans, which are welded, doubly encapsulated stainless steel cans. 3013 are not required to be measured in a calorimeter can. For all other items, the primary containers will first be loaded into a calorimeter (cal) can, which will also be tightly sealed. The cal can will then be placed into the calorimeter active well and the reference

[1] Shang-Chih Philip Chou, *Verification of the Installation of SCALE5, MCNP5 Versions 1.20 and 1.30, and MCNP4C2,* CSAM06-031, CSS, LLNL, Livermore, CA, February 14, 2006.
[2] NEA/NSC/DOC (95) 07, *International Handbook of Evaluated Criticality Safety Benchmark Experiments*, OECED, September 2007 Edition.

cell will be left empty.   The cal can may be filled with aluminium foil or aluminium shot (small aluminium pellets) to increase heat transfer between the item and the calorimeter walls. Liquids are not allowed in the workstation unless the workstation is being operated under SCCC A. As shown in Section 6.0 of this report, the reflection provided by the LVC 3013 is less effective than 1" of close-fitting water reflection.

The various SCCCs provide the limits and controls for each workstation, as detailed below. Only one primary container or secondary container is permitted within the LVC 3013 workstation. This restriction does not apply to multiple calibration standards that may be placed within the workstation.

SCCC A

Material and Form:

A. *Fissionable material mass limits are as follows:*

Pu mass is limited to 65 grams

or

^{235}U mass is limited to 110 grams

B. *The fissionable material form is uncontrolled*

Moderators: *Uncontrolled*

Reflectors: *Uncontrolled*

Shape: *Uncontrolled*

SCCC V1

Material and Form:

A. *The fissionable material shall be metal or dry non-hydrogenous compounds and may exist with any dry non-hydrogenous materials (including Be) provided the following mass limits are satisfied:*

Pu mass is limited to 2500g within a total net weight of 3500g

or

^{235}U mass is limited to 3500g within a total net weight of 3500g

or

^{233}U mass is limited to 2000g within a total net weight of 3500g.

B. *The fissionable material mass and net weight limits must each be satisfied. Any combination of fissionable and non-fissionable material masses is allowed provided the fissionable and net weight limits are each satisfied, e.g. a Pu mass of 1000g may exist with 2500g of other material (net weight ≤3500g), but 1000g of Pu may not exist with 3500g of other material (net weight >3500g).*

C. *The mass limit for combinations of Pu, ^{235}U, and ^{233}U shall be that of the most restrictive material present unless that material is present at a mass of 10g or less (then it may be neglected when determining the applicable mass limit). The masses of all fissionable materials in the combination shall be counted against the mass limit.*

Moderators and Reflectors:

A. *Liquids are not allowed.*

B. *Hydrogenous materials are not allowed with the exception of those packaging materials specifically authorized in the Building 332 FSP, Appendix C.*

SCCC V2

Material and Form:

A. The fissionable material shall be bare metal or oxide.

B. Fissionable material shall be limited to no more than 4500g of Pu or 10,000g of ^{235}U.

C. Primary containers containing fissionable metal shall be limited to no more than 2500g of Pu or ^{235}U.

Reflectors:

A. Liquids are not allowed.

B. Beryllium is not allowed.

C. No other solids are allowed with the exception of packaging materials specifically authorized in the Building 332 FSP, Appendix C.

Moderators:

Moderators, including hydrogenous mixtures (e.g. water, oils, or plastics), beryllium, graphite, deuterium, or compounds of these materials are not allowed.

SCCC V3

Material and Form:

A. One approved Item from the Approved Item List (Appendix E) for Condition V3 is allowed.

Moderators and Reflectors:

A. Liquids are not allowed.

B. No other solids are allowed with the exception of those packaging materials specifically authorized in the Building 332 FSP, Appendix C or in the Approved Item List (Appendix E of this OSP).

Condition V6

Material and Form:

A. The fissionable material shall be dry metal, salts, ceramics, or non-hydrogenous compounds, which may be in the form of pieces, chips, fines, or powders. Beryllium is not allowed.

B. The fissionable material mass is 120 g of Pu. The Pu mass limit shall apply to combinations of Pu and ^{235}U.

Moderators and Reflectors:

A. Liquid moderators are not allowed.

B. Cladding on fissionable material is not controlled.

Shape:

A. Only one container with a maximum volume of 5 liters.

B. Shape of the fissionable material inside the container is not controlled.

5.2 Credible Abnormal Operating Conditions

Table 5.1 lists the postulated credible abnormal contingencies, and the barriers and controls in place to preclude their occurrence, for the LVC 3013 workstation.

Table 5.1: Contingency Table for LVC 3013 Workstation

Contingency	Description	Barriers	Controls
Loss of Mass Control	Additional mass is brought into the calorimeter workstation over the allowed limit	- SCCC limit - COMATS check on transfer - Independent check by two operators prior to transfer	- SCCC A, V1, V2, V3, and V6 mass limits - OP-B332-001, *Operating Procedure for B332 Material Movements*
Loss of Moderator Control	Additional moderator is introduced into a workstation when fissionable material is present	- SCCC limit on moderators - All items in sealed primary containers - Inspection of calorimeter wells for water - Sealed primary containers - Use of cal can	- SCCC V1, V2, V3, and V6 prohibition on liquids - OSP Control 4.3.2.1-Primary Fissionable Material Container - OSP Control 4.3.2.12-No Liquid Moderators - OSP control 4.3.2.14-Inspection of Counting and Pre-Heater Chambers

Contingency	Description	Barriers	Controls
Loss of Reflector Control	Additional unanticipated reflection is present in the workstation when fissionable material is present	- SCCC limit on reflectors - All items in sealed primary containers - Inspection of calorimeter wells for water - Approved equipment	- SCCC V1, V2, V3, and V6 prohibition on liquids - OSP Control 4.3.2.12- No Liquid Moderators - OSP control 4.3.2.14- Inspection of Counting and Pre-Heater Chambers - OSP Section 4.2- Approved Equipment - B332 Configuration management program
Fire	Fire results in introduction of sprinkler water into workstation and mixing with fissionable material particulates	- Sealed primary containers - Use of calorimeter can - Calorimeter is metal clad and provides standoff and thermal isolation of fissionable material from a fire - Calorimeter well is < 4L - Limited combustibles and ignition sources	- OSP Control 4.3.2.1- Primary Fissionable Material Container - OSP Control 4.1.3- Limit on Flammable Solvents - ACP-B332-019, *B332 Housekeeping and Flammable/ Combustible Materials Control Procedure* - Criticality Hazard Type 2

6.0 Evaluation and Results

6.1 Calorimeter Model

Using the calorimeter data provided by Setaram, the LVC 3013 was simplified and modeled in MCNP5. Details on the material compositions and densities used in the MCNP5 model is given in Appendix C, and sample MCNP5 input models are provided in Appendix D. Figure 6.1 shows cross-sectional side and top views of the MCNP5 calorimeter model. Detailed engineering drawings were not provided, so the model had to be simplified based on the information known (as Documented in Section 2 and Appendix B. The calorimeter was modeled on a concrete floor (not shown in Figure 6.1)

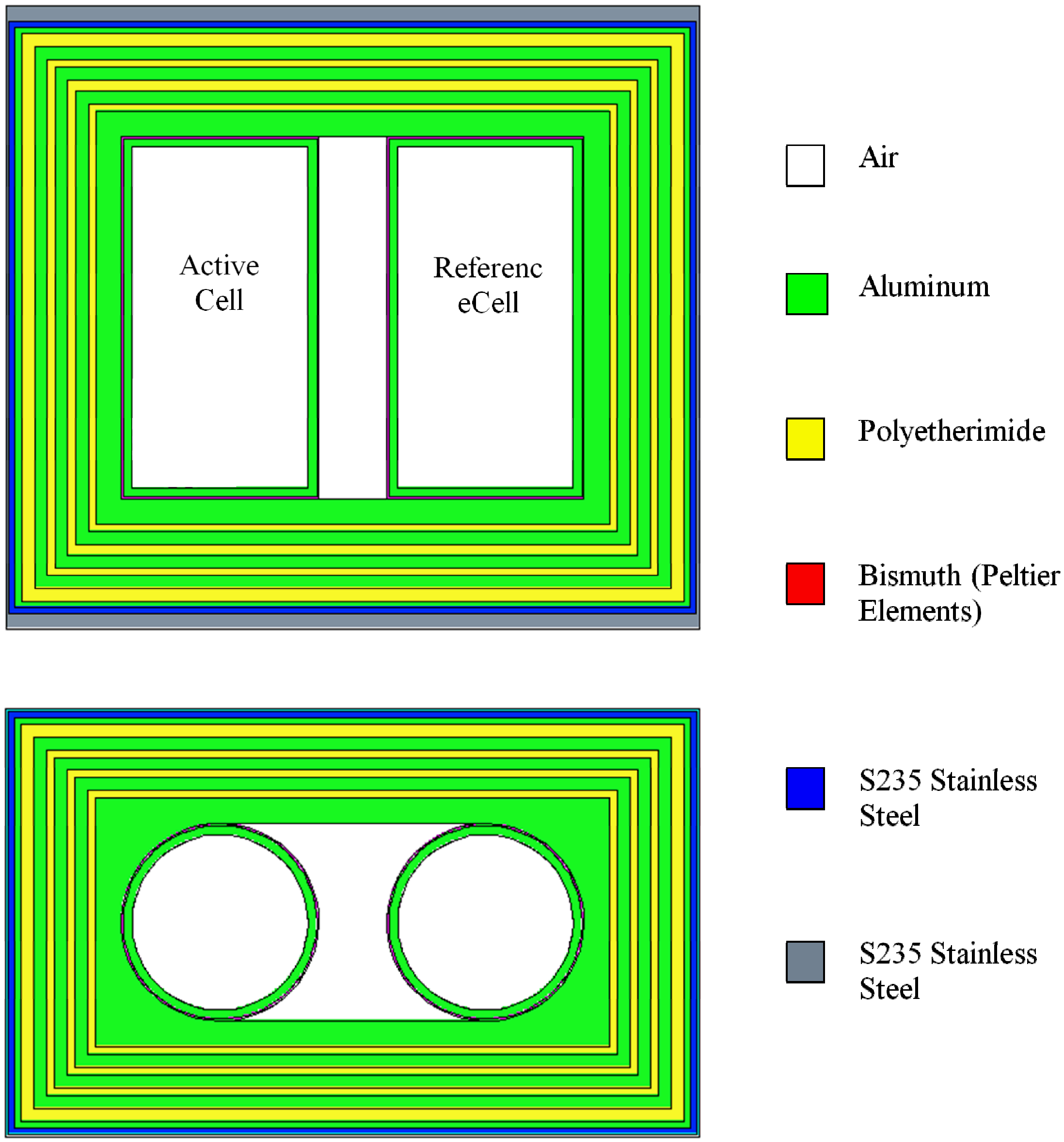


**Figure 6.1: Schematic of MCNP5 LVC 3013 Model,
Side and Top-Down Cross Sectional Views**

6.2 Normal Conditions

Under normal conditions, only one item will be loaded into the active well of the calorimeter. Aluminum foil is sometimes used to cushion fissionable material within primary containers (per B332 FSP Appendix C) and it is also used for heat transfer in calorimeter cans. As documented in CSM 978[3], this aluminum foil has a measured nominal density of 0.09 g/cc. Additionally, aluminum shot is sometimes used for heat

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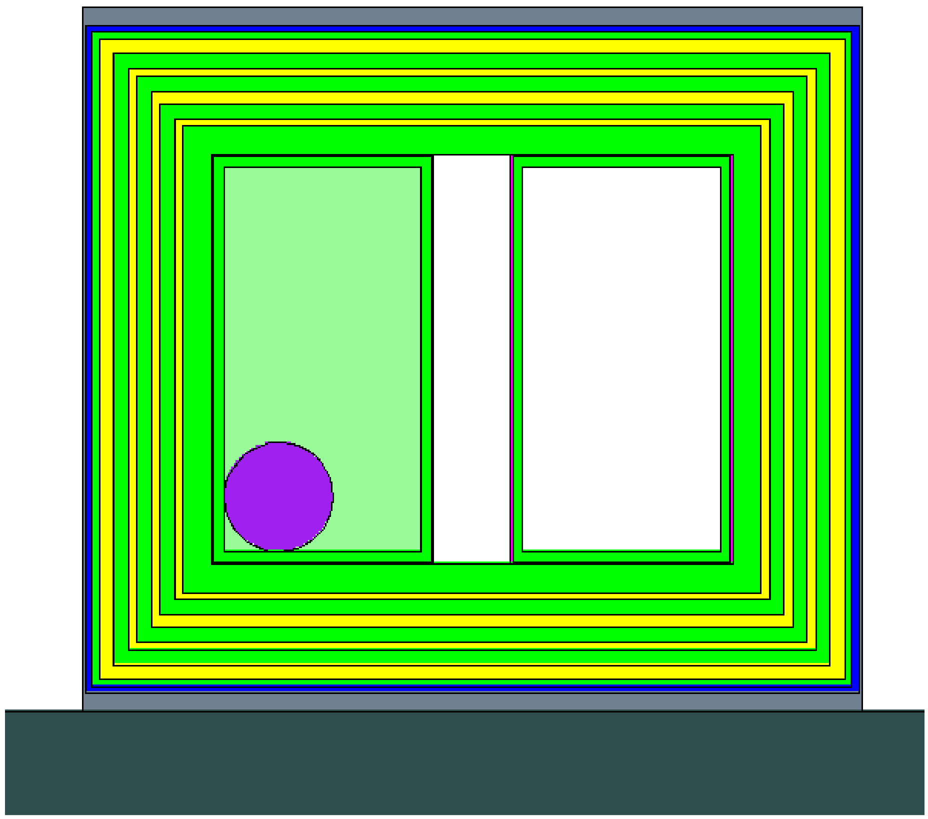
[3] Gathers, R. *Foil Packaging*. Lawrence Livermore National Laboratory. CSM 978. April 30, 1998.

transfer in the calorimeter cans. The density of the aluminum shot was measured, as documented in CSM 960, Rev 3[4], by filling a quart can of known volume with aluminum shot and weighing the full and empty can. Using the known volume and the weight of the Al shot, the nominal density was determined to be 1.6687 g/cc.

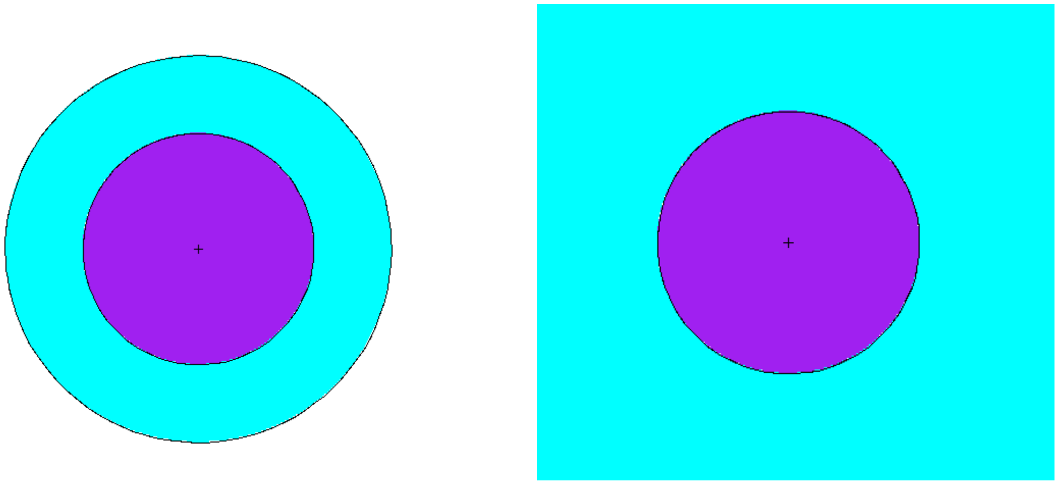
To bound a single item, a 4.5 kg alpha plutonium ball was modeled in the LVC 3013, as shown in Figure 6.2. A 4.5 kg Pu ball will bound single items allowed under SCCCs A, V1, V2, and V6. Aluminum shot (modeled as solid Al at a density of 1.6687) filled the active cell of the LVC 3013 (shown in light green in Figure 6.2). For comparison, the same Pu ball was modeled under 1 inch of water reflection and infinite water reflection conditions (Figure 6.3). The results of these calculations are given under the pictures and summarized in Table 6-1.



Case ID: calpal
$k_{eff} = 0.8486 \pm 0.0005$

Figure 6.2: 4.5 kg Pu Ball in LVC 3013.

[4] Kessler, S. Criticality Safety Evaluation for OSP 332.032, Nuclear Material Measurements Rooms 1314, 1314A, and 1337B. Lawrence Livermore National Laboratory. CSM 960, Revision 5. May 20, 2004.



Case ID: puh
k_{eff} = 0.8571 ± 0.0006

Case ID: puw
k_{eff} = 0.9339 ± 0.0008

Figure 6.3: 4.5 kg Pu wall with 1" Water Reflection (left) and Infinite Water Reflection (right).

Table 6-1: Normal Conditions Calculations

Case ID	Description	k_{eff} (std)
calpal	4.5 kg alpha Pu ball in corner of active volume	0.84857(52)
puw	4.5 kg alpha Pu ball with infinite water	0.93393(75)
puh	4.5 kg alpha Pu ball with 1" water (hands)	0.85706(61)

As shown by the preceding calculations, the reflection provided by the calorimeter, even with close-fitting aluminum shot modeled inside the active volume, is inferior to 1" of water reflection and very inferior to full water reflection.

6.3 Abnormal Operating Conditions

The following section discussed credible abnormal operating conditions for the LVC 3013 operations under various SCCCs. The technical basis for SCCC A is based on CSM 936A[5], which analyzed optimally moderated fissile isotopes with polyethylene and superior reflectors, including beryllium. The minimum critical mass for ^{239}Pu was shown to be 165 grams with a beryllium reflector. ^{235}U under the same conditions resulted in a minimum critical mass of 250 g. Since SCCC A only allows up to 65 grams of ^{239}Pu or 110 g of ^{235}U, CSM 936A shows this condition to be safely sub-critical under all credible conditions of optimum moderation and reflection including over-batching a workstation. Consequently, operations under SCCC A are not included in this evaluation.

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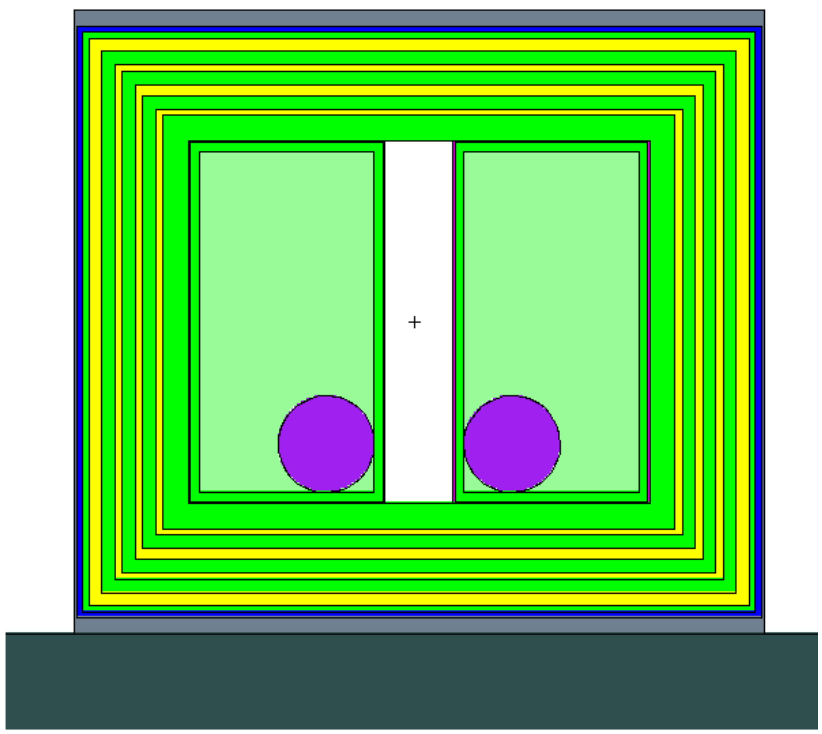
[5] Heinrichs, D. *^{233}U, ^{235}U, and ^{239}Pu Minimum Critical Masses (High Density Polyethylene Moderation with Various Reflector Materials.* Lawrence Livermore National Laboratory. CSM 936A. February 9, 1998.

6.3.1 Loss of Mass Control

The most likely abnormal condition is a violation of the mass limits through inadvertent overbatching by an operator. A number of calculations were completed to examine potential overmass conditions.

6.3.1.1 Loading Both Cells

The calorimeter has two cells, the active cell and the reference cell. The reference cell is designed to remain empty during fissionable material measurements as the calorimeter operates by comparing the heat generated by the active cell to the empty reference cell. Nevertheless, a calculation was done to examine the effect of overmassing the calorimeter by loading both cells with the 4.5 kg of alpha plutonium. The geometry for the model is shown in Figure 6.4. A k_{eff} increase of about 2.5% over the singly-loaded calorimeter, as detailed in Section 6.2. In the off-normal condition that both cells are loaded, the system will remain subcritical (k_{eff} = 0.8729(5)).

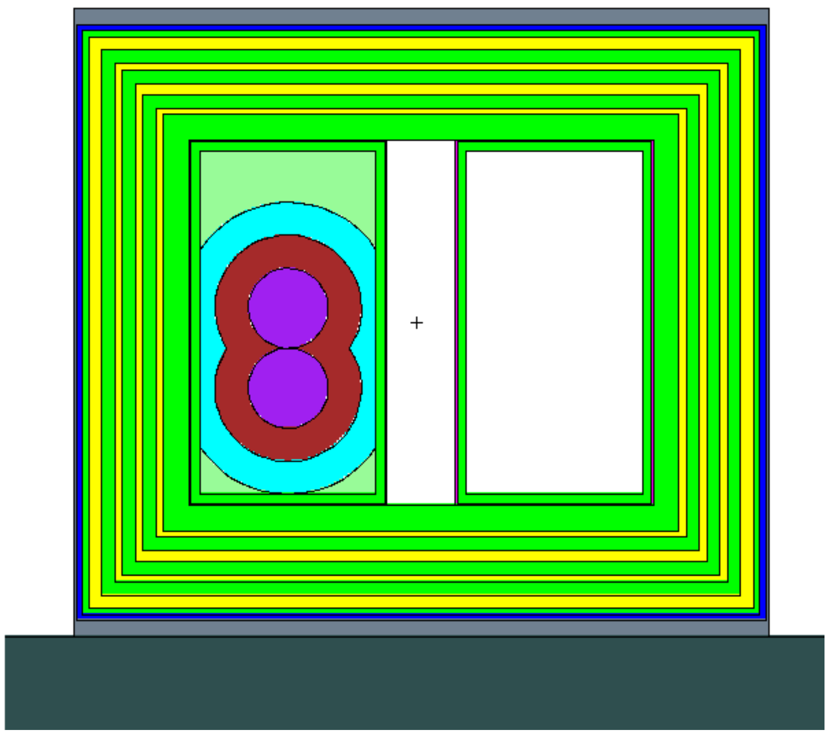


Case ID: cal2pu
$k_{eff} = 0.8729 \pm 0.0005$

Figure 6.4: Two Cell Overmass Model. Two 4.5 kg alpha Pu balls were modeled in active and the reference cells of the LVC 3013.

SCCC V1 Analysis

The maximum credible overmass scenario under SCCC V1 consists of a total of 5000 grams of Pu (two 2500 g items) with 1000 g of beryllium cladding (the most reactive reflector available in B332). Intermixing Pu and beryllium would result in a less reactive configuration, as while beryllium is a very good reflector of neutrons, it is not as effective a moderator. An MCNP5 model was developed that placed two 2500 g alpha Pu spheres in contact in the LVC 3013 and reflected by 2000 g of close-fitting Be reflection, backed by 1" of water reflector to bound operator hands. The balance of the active well was modeled as full of aluminum shot (aluminum with a density of 1.6687 g/cc). The geometry is illustrated in Figure 6.5. K_{eff} for this highly conservative model was a safely subcritical 0.9184(7).

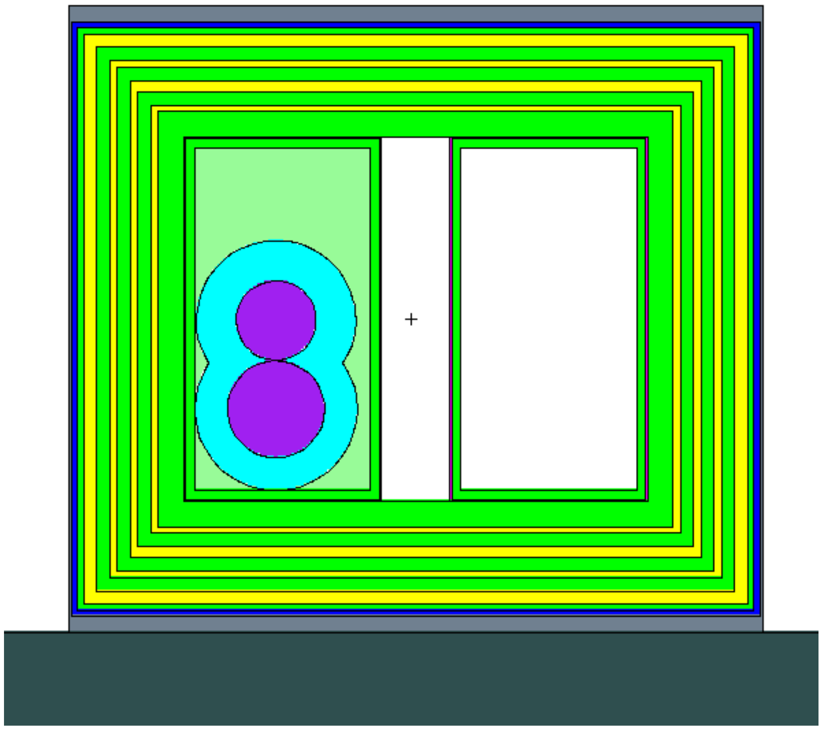


Case ID: v1om
$k_{eff} = 0.9184 \pm 0.0007$

Figure 6.5: V1 Overmass Model. Two 2.5 kg alpha Pu balls with 2 kg of Be reflector (shown in brown) with 1" of water reflection were modeled in the LVC 3013.

6.3.1.2 SCCC V2 Analysis

SCCC V2 allows up to 4.5 kg of plutonium metal in the LVC 3013. However, V2 also limits the maximum ^{239}Pu mass per container is 2.5 kg. Therefore, the maximum credible overmass condition for SCCC V2 is 4.5 kg of plutonium overmassed with one additional container (2.5 kg) of material, for a total of 7 kg. An MCNP5 model was developed that placed one 4500 g alpha Pu sphere and one 2500 g alpha Pu sphere in contact in the LVC 3013 and reflected by 1" of water reflector to bound operator hands. The balance of the active well was modeled as full of aluminum shot (aluminum with a density of 1.6687 g/cc). The geometry is illustrated in Figure 6.6. This is a highly conservative model because the items are modeled as spheres and in reality the 7 kg would be split up into three different containers. K_{eff} for this case was a safely subcritical 0.9526(7).



Case ID: v2om
$k_{eff} = 0.9526 \pm 0.0007$

Figure 6.6: V2 Overmass Model. One 4.5 kg alpha Pu ball and one 2.5 kg alpha Pu ball with 1" of water reflection were modeled in the LVC 3013.

6.3.1.3 SCCC V6 Analysis

The fissionable material under SCCC V6 is limited to 120 g of Pu or ^{235}U as dry metal, salts, ceramics, or non-hydrogenous compounds, which may be in the form of pieces, chips, fines, or powders. Beryllium is specifically excluded. SCCC V6 was created to allow the storage of materials contaminated with small amounts of fissile materials. The basis for V6 is documented in CSM 1165[6], which looked at bounding cases up to 300 g of Pu moderated by polyethylene and reflected by close-fitting full water reflection. This analysis bounds the overbatch condition of 240 g under V6 in the LVC 3013, which provides significantly less than full water reflection.

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[6] Parra, S. Technical Basis for Standard Criticality Control Condition V6 for OSP 332.084. Lawrence Livermore National Laboratory. CSM 1165. May 10, 2002.

6.3.2 Loss of Liquid Moderator Control

No liquid moderators are allowed under SCCC V1, V2, or V6. All fissionable material items are required to be in sealed primary containers, per Control 4.3.2.1 of OSP 332.032. Opening primary containers is not allowed under the OSP. The primary containers provide a containment barrier to protect workers and therefore would also be water-tight to immersion. Additionally, the calorimeters require the use of a water-tight calorimeter can. Therefore, at minimum, there are two water-tight layers between the fissionable material and any water in-leakage: 1) the sealed primary container and 2) the sealed calorimeter can or, in the case of 3013 cans, two sealed, welded stainless steel cans. The calorimeter lid is required to be closed whenever possible to minimize the possibility of liquids entering the counting cells, per OSP control 4.3.2.12. Due to this control, the time the containers may be potentially exposed to water is very limited and would only be during packing and unpacking of the calorimeter. Additionally, a control exists to check the calorimeter well for water in-leakage before SNM may be placed into the counting cells (OSP control 4.3.2.14). Because of these controls and the number of layers between any potential water intrusion and the contained fissionable material, the possibility of a criticality accident would require at least two independent, unlikely, and concurrent failures.

6.3.3 Loss of Reflector Control

Reflection available in the workstation is fixed by the design of the calorimeter and was shown to be inferior to 1" of water reflection and full water reflection. If additional reflection was introduced by sprinkler activation, the items allowed under SCCCs A, V1, V2, and V6 would remain subcritical as shown by the subcritical result of 4.5 kg of Pu fully water reflected by water (Section 6.2).

6.3.4 Fire

The LVC 3013 provides little in the form of combustible material to sustain a fire. The 2.65 kg of polyetherimide (plastic) present in the calorimeter is encased in stainless steel and aluminum and is thus unlikely to catch fire. Ignition sources are also very limited and consist of the detector electronics associated with the calorimeter. If a fire were to occur in Room 1314A, the LVC 3013 would provide stand-off and thermal insulation of any item in its active volume. Additionally, the calorimeter well is designed for 3013 cans and thus has an inner diameter of 13.7 cm and a height of 26.7 cm, leading to a limited volume of less than 4 L arranged as a non-compact cylinder with a H/D ratio of 2.

The B332 Documented Safety Analysis (DSA)[7] concluded that the maximum credible fire in would be at the Pan Shuffler in Room 1337. The Pan Shuffler, which used large amounts of stainless-steel clad polyethylene for radiation shielding, contains the highest combustible loading in the facility at 27.82 lb/ft^2. Based on this combustible loading, the

[7] Lawrence Livermore National Laboratory. *Plutonium Facility Building 332 Documented Safety Analysis*. UCRL-AR-119434-06-Vol 1. April 2008.

maximum compartment-average temperature during a fire was determined to be 815ºC. In contrast, the LVC 3013 only contains 1.4116 lb/ft^2 (2.65 kg of polyetherimide in a 3837 cm^2 footprint). At a maximum temperature of 815ºC, breeching steel cans is not considered credible. Even if the item is alpha plutonium, which will go through phase changes, the steel containers are not expected to be damaged based on experimental data from ISO-756[8]. During these experiments, in which Pu was burned inside both sealed and open tuna and pineapple cans, the cans were not damaged other than discoloration. It was concluded that "a sealed metal can containing Pu could withstand an exterior fire for an extended period of time."

For a criticality accident to be possible due to a fire in the calorimeter workstation, fissionable material in particulate form would have to mix with fire-fighting water in a volume conducive to a criticality. This would necessitate a breach of at least two sealed containers, the primary container and the calorimeter can. If those two containers were breached, the available collection volume is only 4 L and not in an appropriate configuration to sustain a criticality. Due to limited ignition sources and limited combustibles reducing the severity and temperature of a fire, breaching both containers under fire conditions and subsequent mixing of the fissionable material in a shape able to sustain a criticality is considered beyond extremely unlikely.

7.0 Limits and Controls

Five calorimeters are already in use and covered by OSP 332.032. No additional controls are required as a result of the LVC 3013 analysis. Therefore, all controls applicable to the other five calorimeters shall be required for operation of the LVC 3013. Criticality controls from OSP 332.032 are reproduced in italics below (Section 4.3 of the OSP), with required changes indicated in red. Since the LVC 3013 workstation number is not finalized, a placeholder of "14##" is used in the control changes.

4.3 Criticality Hazard

A criticality accident could result in lethal doses of radiation and potential loss of containment. Such an accident could be caused by an excess mass of fissionable, moderating, and/or reflecting materials in the workstation.

4.3.1 Control—Applicability of Conditions at a Workstation

SCCCs are applicable to the workstations as indicated in the table below. Only one SCCC and its associated criticality safety controls can exist at a workstation at any one time.

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[8] Felt, R.E. *Burning and Extinguishing Characteristics of Plutonium Metal Fires*. AEC R&D Report. Isochem, Inc. Richland, WA. August 1967.

Workstation #	***Applicable Criticality Control Conditions***
WS 1415, 1416, 1419, 1422, 1423, 1425, 1428, 1429, 1430, 1431, 1433, 1435, 1436, 1437, 14XX, 3718, 3719, 3720, 3721, and 3722, and Transfer/Work Table	*A, V1, V2, V3, or V6*
WS 1426	*A or V1*

4.3.2 Specific Criticality Safety Controls for Workstations

4.3.2.1 Control—Primary Fissionable Material Container

Primary fissionable material containers shall be sealed.

4.3.2.2 Control—Secondary/Over-pack Fissionable Material Container

Secondary/over-pack containers shall be closed.

4.3.2.3 Control—Opening of Primary Fissionable Material Container

Opening of primary fissionable material containers is strictly prohibited in any workstation covered by this OSP, including the Transfer/Work Table.

4.3.2.4 Control—Containers Calorimeters and Preheaters

Only one outer container shall be placed into any calorimeter or pre-heater chamber at one time. These may consist of a sealed primary fissionable material container, a closed secondary/overpack container, a Cal can, or a pre-heater can. A closed secondary/over-pack container may contain multiple primary fissionable material containers. A Cal can may contain multiple calibration standards

4.3.2.5 Control—Containers in Isotopic Counters

Only one outer container shall be placed into any isotopic counter at one time. These may consist of a primary fissionable material container or a closed secondary/overpack container. A closed secondary/overpack container may contain multiple primary fissionable material counter.

4.3.2.6 Control—Containers on Transfer/Work Table

Only one sealed primary fissionable material container or one closed secondary/over-pack container shall be placed on the entire Transfer/Work table at one time. The closed secondary/over-pack container may contain multiple primary fissionable material containers.

Multiple calibration standards may be placed on the Transfer/Work Table at one time. When one or more calibration standards are present on the Transfer/Work Table no other fissionable material containers shall be permitted on the Transfer/Work Table.

4.3.2.7 Control—Loading of the Cal Can or Pre-heater Can

Only one single container (either primary or secondary/over-pack) shall be loaded into a Cal can or pre-heater can at one time. However, multiple calibration standards may be loaded into a single Cal can on the Transfer/Work Table. When one or more calibration standards are present in a Cal can or pre-heater, no other fissionable material containers shall be permitted.

4.3.2.8 Control—Workstations 3718, 3719, 3720, 3721, and 3722

Before installing the calorimeter can lid into the calorimeter can, inspect the O-ring for damage and engagement in O-ring groove. Inspect the (8) locking pins for tightness. If the O-ring or the O-ring groove is damaged or the pins are loose, do not use, and label as defective. Once the lid is closed, the vent valve on the lid shall be closed and the anti-rotation lock shall be engaged. See Reference ESN-93-902 for additional information regarding maintenance and procedures for the calorimeter cans.

4.3.2.9 Control—Workstation 1426

The shielded storage on WS 1426 is designed to accommodate more than one standard at one time. The sum of all standards placed in the shielded storage workstation (WS 1426) shall not exceed the fissionable mass limit for the posted condition.

4.3.2.10 Control—Workstation 1425

Only one container is permitted in WS 1425 (shielded storage), unless the containers all have green ES&H labels. If the container has a green ES&H label, the number of containers placed in this workstation shall be kept to the minimum necessary for these operations. The sum of all fissionable material in green ES&H labeled containers placed in WS 1425 *shall not exceed the fissionable mass limit for the posted condition.*

4.3.2.11 Control—Addition of Water to Workstation

When filling calorimeter water baths, there shall be no fissionable material in the counting chambers and the counting chambers shall be closed to ensure that no water enters the counting chamber.

4.3.2.12 Control—No Liquid Moderators under SCCC V1, V2, and V3

All workstation counting chambers shall be kept closed whenever possible to minimize the possibility of liquids entering the counting chambers.

4.3.2.13 Control—Reference Cell for Workstations 14XX, 1416, 1435, 1436, 1437, and 3718

The reference cell for WS 14XX, 1416, 1435, 1436, 1437, and 3718 shall remain empty at all times. This reference cell shall have a tamper indicating device (TID) installed. The operator shall verify the tamper indicating device on the reference cell for WS 14XX, 1416, 1435, 1436, 1437, and 3718 is intact before placing any material into the counting chamber of the workstation. If the TID is not intact, follow the guidelines in Section 4.1.3, Response to and Recovery from a Control Violation, of the B332 FSP.

4.3.2.14 Control—Inspection of Counting and Preheater Chambers

All counting and preheater chambers of a workstation shall be inspected before fissionable material is placed in them to ensure that there is no water in the workstation chamber. If water is detected in a workstation chamber with fissionable material, follow the guidelines in Section 4.1.3 of B332 FSP.

If water is detected in a workstation with no fissionable material, the operation shall be stopped, the lid shall be secured to prohibit use and the Materials Management Supervisor contacted to initiate repairs.

4.3.2.15 Control—Workstations in Condition V3

Workstations 1429, 1430 and 1431 shall be considered a single workstation when using SCCC V3 the "Approved Item Condition." Workstations 3719, 3720, 3721 and 3722 shall be considered a single workstation when using SCCC V3 the "Approved Item Condition." With the approved item in one of these workstations, the other workstations shall be empty. Concurrent normal operations with fissile material in other workstations in Room 1314 and 1337B are not further restricted by this control.

4.3.2.16 Control—Isotopic Counters

All workstation isotopic counters shall be kept closed whenever possible to minimize the possibility of liquids entering the counting chamber.

4.3.2.17 Control- 14XX 3013 Calorimeter

When 3013 cans are being measured in 14XX, a calorimeter can is not required. However, a cal can is required when any other non-3013 items are being measured in 14xx.

8.0 Criticality Hazard Type

The criticality hazard type for OSP 332.032 is Type 2. Water is allowed for firefighting only if fissionable materials are not involved in the fire or they can be safely removed (or isolated) from the fire.

9.0 Conclusion

Given the criticality safety controls listed in Section 7.0 the operations described in OSP 332.032 with the LVC 3013 meet the double contingency principle and may be conducted safely from a criticality safety standpoint.

Appendix A
MCNP5 Validation

A total of 9 experiments were selected from the latest ICSBEP Handbook. The benchmark inputs from the Handbook were rerun on SURYA with ENDF/B-VI cross-sections and the results are provided in Table A-1.

The errors in the benchmarks from both statistical and experimental uncertainties reported in the Handbook are 0.35% or less in k_{eff}.

A subcritical limit can be established using the following equation:

$$SL = 1 - \beta - 3\sigma - SM$$

where β is the estimated bias, σ is the error in the bias and calculational statistical uncertainty in the benchmark calculations and calculations in this analysis, and SM is an additional safety margin to assure subcriticality.

To establish a conservative subcritical limit, the bias will be taken as the largest difference between the critical value and the benchmark value calculated in Table E-1 (k_{eff} = 1.0069). Hence, β = 0.0069. This method was chosen to estimate bias rather than using the average values since the benchmark set is small. The error is taken as $\sigma = \sqrt{(0.0033^2 + 0.0014^2)} = .0036$ where the statistical uncertainty in all calculations used in this analysis was kept to ± .0014 or less.

A conservative subcritical limit can then be established as:

$$SL = 1 - 0.0069 - 3(0.0036) - 0.02 = 0.962$$

where a safety margin of 2% was chosen for this application. This is a relatively small safety margin, but is considered adequate to assure subcriticality because of the very close similarity in the benchmark experiments and the calculational models considered in this analysis.

Table A-1   Selected Benchmarks

Benchmark ID	**Description**	**Benchmark Model** $k_{eff} \pm 1\sigma$	**MCNP** $k_{eff} \pm 1\sigma$
PU-MET-FAST-001	Bare Pu (δ, 95) metal sphere	1.0000 ± 0.002	1.0004 ± 0.0008
PU-MET-FAST-011	Water reflected Pu (alpha) metal sphere	1.0000 ± 0.0010	0.9989 ± 0.0009
PU-MET-FAST-013	Copper reflected Pu fuel rods	1.0034 ± 0.0023	1.0010 ± 0.0007
PU-MET-FAST-014	Nickel reflected Pu (alpha) metal sphere	1.0037 ± 0.0031	1.0062 ± 0.0007
PU-MET-FAST-016	Flooded Arrays of 3 kg alpha Pu Cylinders	1.0000 ± 0.0033	1.0069 ± 0.0008
PU-MET-FAST-020	Depleted uranium reflected Pu Sphere	0.9993 ± 0.0017	1.0003 ± 0.0007
PU-MET-FAST-024	Polyethylene reflected Pu(δ, 98%) metal sphere	1.0000 ± 0.0020	1.0029 ± 0.0006
PU-MET-FAST-026	Steel reflected Pu (δ, 98%) metal sphere	1.0000 ± 0.0024	0.9984 ± 0.0006
PU-MET-FAST-031	Pu(alpha, 88%) metal sphere reflected by polyethylene	1.0000 ± 0.0021	1.0048 ± 0.0007
PU-MET-FAST-032	Pu(alpha, 88%) metal sphere reflected by steel	1.0000 ± 0.0020	0.9996 ± 0.0006
PU-SOL-THERM-008	Concrete-reflected spheres of Pu nitrate solutions	1.0000 ± 0.003	0.9967 ± 0.0009

Appendix B

LVC 3013 Description Document

Appendix C

Materials and Compositions

Table C-1. Summary of Materials and Compositions

Description	Element	Isotope Fraction (weight percent) (‡ atom fraction)
Alpha Pu Density: 19.84 g/cm^3	Pu-239	0.95
	Pu-240	0.05
High Density Polyethylene (HDPE) Density: 0.967 g/cm^3	^{1}H	2(‡)
	C	1(‡)
Water Density: 1.0 g/cm^3	^{1}H	2(‡)
	^{16}O	1‡)
Aluminum Shot Density: 1.6687 g/cm^3	Al	1
Polyethermide Density: 0.11 g/cm^3	^{1}H	24(‡)
	C	37(‡)
	^{16}O	6(‡)
	^{14}N	2(‡)
Aluminum 2017 Density: 2.79 g/cm^3	Mg	0.008
	Al	0.947
	Cu	0.045
304 Stainless Steel Density: 7.96 g/cm^3	^{58}Ni	4.3417-3(‡)
	^{60}Ni	1.7170-3(‡)
	^{61}Ni	7.5579-5(‡)
	^{62}Ni	2.4404-4(‡)
	^{64}Ni	6.3858-5(‡)

	^{50}Cr	6.8367-4(‡)
	^{52}Cr	1.3695-2(‡)
	^{53}Cr	1.5826-3(‡)
	^{54}Cr	4.0057-4(‡)
	^{54}Fe	3.3660-3(‡)
	^{56}Fe	5.5199-2(‡)
	^{57}Fe	1.3477-3(‡)
	^{58}Fe	1.7453-4(‡)
Magnussen’s Concrete Density: 2.147 g/cm^3	^{16}O	0.499
	Ca	0.26
	C	0.105
	K	0.00945
	Mg	0.0942
	Si	0.421
	Al	0.00786
	Fe	0.0056
	H	0.00332
	S	0.0025
	Ti	0.0015
	Na	0.0014
	Cl	0.00052
	^{55}Mn	0.00051
Steel S235 Density: 7.85 g/cm^3	C	0.002
	^{55}Mn	0.014

	Cu	0.006
	Al	0.978

Sample MCNP5 Models

```
V3om
Plutonium sphere in 3013 Calorimeter
c Plutonium sphere
c
1  1  -19.84  -1           imp:n=1 $ Plutonium Sphere
2  1  -19.84  -2           imp:n=1 $ 2nd pu overmass
3  7  -1.0    (-3:-4) 1 2    imp:n=1 $ water hands
10 11 -1.6687 3 4 -10       imp:n=1 $ Active Vol of Cal
11 4  -2.79   10 -11        imp:n=1 $ Joule Effect supply/Al housing
12 6  -7.73   11 -12        imp:n=1 $ Peltier Element
20 0        -20 2          imp:n=1 $ Reference Cell
21 4  -2.79   20 -21        imp:n=1 $ Joule Effect supply/Al housing
22 6  -7.73   21 -22        imp:n=1 $ Peltier Element
25 0        -25 12 22      imp:n=1 $ air gap between cells
30 4  -2.79  -30 (25 12 22)  imp:n=1 $ Al Thermal Block
31 3  -0.11  -31 30         imp:n=1 $ Polyethermide Layer 1
32 4  -2.79  -32 31         imp:n=1 $ Al Layer 1
33 3  -0.11  -33 32         imp:n=1 $ Polyethermide Layer 2
34 4  -2.79  -34 33         imp:n=1 $ Al Layer 2
35 3  -0.11  -35 34         imp:n=1 $ Polyethermide Layer 3
36 4  -2.79  -36 35         imp:n=1 $ Al Layer 3
37 3  -0.11  -37 36         imp:n=1 $ Final Insulation Layer
38 4  -2.79  -38 37         imp:n=1 $ Convection Plate
39 2  -8.00  -39 38         imp:n=1 $ 304 Stainless Steel case
40 5  -7.85  -40 39         imp:n=1 $ S235 Steel case
97 9  -2.147 -41 -99        imp:n=1 $ Concrete Floor
98 0         40 41 -99     imp:n=1 $ Outer refl
99 0         99           imp:n=0 $ Outside world

c  Surface Cards
1  s   -0.526 0 -7.016  3.7832
2  s   -0.526 0 -0.1  3.1107
3  s   -0.526 0 -7.016  6.3232
4  s   -0.526 0 -0.1  6.2214
10 rcc  0 0 -13.34 0 0 26.68 6.85
11 rcc  0 0 -14.04 0 0 28.08 7.55
12 rcc  0 0 -14.19 0 0 28.38 7.7
20 1 rcc  0 0 -13.34 0 0 26.68 6.85
```

```
21 1 rcc  0 0 -14.04 0 0 28.08 7.55
22 1 rcc  0 0 -14.19 0 0 28.38 7.7
25 rpp   0    20.7   -7.7   7.7  -14.19  14.19
30 rpp  -9.7  30.4   -9.7   9.7  -16.19  16.19
31 rpp -10.3  31    -10.3  10.3  -16.69  16.69
32 rpp -11.3  32    -11.3  11.3  -17.69  17.69
33 rpp -11.9  32.6  -11.9  11.9  -18.59  18.59
34 rpp -12.9  33.6  -12.9  12.9  -19.59  19.59
35 rpp -13.5  34.2  -13.5  13.5  -20.19  20.19
36 rpp -14.5  35.2  -14.5  14.5  -21.19  21.19
37 rpp -15.5  36.2  -15.5  15.5  -22.19  22.19
38 rpp -16    36.7  -16    16    -22.69  22.69
39 rpp -16.5  37.2  -16.5  16.5  -23.19  23.19
40 rpp -16.7  37.4  -16.7  16.7  -24.39  24.39
41 pz  -24.39
99 so  100

TR1   20.7 0 0
kcode 5000 1. 50 250
ksrc -0.5 0 -7
c
c    Alpha Plutonium metal- 19.84 g/cc
c
m1   94239.60c 0.95
     94240.60c 0.05
c
c    304 Stainless Steel- 7.96 g/cc
c
m2   28058.60c 4.3417-3 28060.60c 1.7170-3
     28061.60c 7.5579-5 28062.60c 2.4404-4
     28064.60c 6.3858-5 24050.60c 6.8367-4
     24052.60c 1.3695-2 24053.60c 1.5826-3
     24054.60c 4.0057-4 26054.60c 3.3660-3
     26056.60c 5.5199-2 26057.60c 1.3477-3
     26058.60c 1.7453-4
c
c    Polethermide- 0.11 g/cc
c
m3   01001.60c 24
     06000.60c 37
```

```
    08016.60c 6
    07014.60c 2
mt3  poly.01t
c
c    Aluminum 2017- 2.79 g/cc
c
m4   12000.60c  -0.008
    13027.60c  -0.947
    29000.     -0.045
c
c    Steel s235- 7.85
c
m5   06000.60c  -0.002
    25055.60c  -0.014
    29000.     -0.006
    26000.     -0.978
c
c    Bismuth telluride- 7.73 g/cc
c
m6   83209.60c  1
c
c    water- 1.0 g/cc
c
m7   01001.60c 2 08016.60c 1
mt7  lwtr.01t
c
c    Polyethylene- 0.967 g/cc
c
m8   01001.60c 2 06012.60c 1
mt8  poly.01t
c
c
c -------- Magnussen's Concrete --------
m9    08016 -0.499
     20000 -0.226
     06012 -0.105
     19000 -0.00945
     12000 -0.0942
     14000 -0.0421
     13027 -0.00786
```

```
      26000 -0.0056
      01001 -0.00332
      16000 -0.0025
      22000 -0.0015
      11023 -0.0014
      17000 -0.00052
      25055 -0.00051
mt9   lwtr.60t
c
c  Aluminum shot
c
m11   13027.60c 1
c
```