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PARAMETRIC ANALYSIS OF HOLDUP IN HEPA FILTERS

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1.0 SUMMARY

This technical document (TECH) contains an analysis of several conditions deemed credible for plutonium oxide buildup in high-efficiency air particulate (HEPA) filters to determine the effect of holdup inside the filter on reactivity. This document is performed in accordance with NCS-AP-005, R3 [Ref. (1)].

2.0 DESCRIPTION

Operations within some production areas such as gloveboxes (GBs) or dropboxes may generate fissionable holdup, typically in the form of dry oxides which may accumulate in thin layers on surfaces, or within local HEPA filters. The calculations within this TECH seek to validate that under normal conditions the extra reactivity provided by credible amounts of holdup entrained within a HEPA filter is insignificant regardless of whether it is actively in use, removed during maintenance, or otherwise placed within an inventoried glovebox.

Historical holdup within HEPA filters has been documented in NCS-TECH-22-006, R1 [Ref. (2)]. A maximum of 368.8g of holdup has been found in a glovebox filter, which represents an extreme outlier. Most locations have holdup amounts below 120g even when accounting for normal outliers. For the sake of conservatism, 500g of plutonium in the form of oxide was chosen to determine the effects on normal condition reactivity.

3.0 METHODOLOGY

MCNP6 calculations were performed using ENDF B/VII cross section sets on the high-performance computing cluster Blowfish, with code and validation information as stated in NCS-TECH-21-001, R3 [Ref. (3)]. The calculations herein are used solely to compare the reactivity, $k_{eff} = k_{calc} + 2\sigma$, of varying densities and configurations of holdup in the enclosures without determining subcriticality. Therefore, no USL is defined or compared against. Nevertheless, comparison of calculations performed to the Area of Applicability (AOA) is shown below.

Table 1: Area of Applicability

Parameter	Validation AOA	Calculation AOA
Fissile Material	^{239}Pu	^{239}Pu
Fissile Material Form	Pu Metal, PuO_2, and $Pu(NO_3)_4$	Pu Metal, PuO_2
$H/^{239}Pu$	$0 \leq H/^{239}Pu \leq 2807$	0
Average Neutron Energy Causing Fission (MeV)	0≤ANECF≤1.935	1.6631≤ANECF≤1.7495
^{240}Pu	0 to 42.9 wt% ^{240}Pu	0 wt% ^{240}Pu
Moderating Materials	None, water, graphite, polystyrene	SiO_2[1]
Reflecting Materials	None, water, steel, oil, Plexiglass, polyethylene, graphite, W, Cu, U, Th, Al, Ni, Fe, Pb, Cd, Mo, Be, BeO	Water, steel, SiO_2
Other Materials	Concrete, PVC, Ga, B, Gd, Ta	None
Geometry	Cylinder array, cylinder, slab, sphere, hemisphere, stacked discs, cuboid, annular	Cylinder

3.1 k Source

For the ingot alone, 20000 neutrons were run using 450 cycles total, discarding 50 cycles.

As multi-item, dispersed configurations required a higher number of neutrons and cycles for Shannon entropy convergence, all other configurations ran 25000 neutrons using 450 cycles total, discarding 100 cycles.

3.2 Materials

The following materials are used:

- ^{239}Pu metal/oxide
- 304 stainless steel
- Water
- Fiberglass/glass wool (modeled as SiO_2)

These materials are modeled using compositions and mass densities given in NCS-TECH-18-024, R3 [Ref. (4)]. The fiberglass was modeled using several densities working back from

[1] Silicon Dioxide is not considered a significantly moderating material as explained in Section 3.2.4

measurements taken in LA-UR-21-24848 [Ref. (5)] and the theoretical bulk density taken from that of quartz (2.648g/cc) rather than amorphous glass (2.196g/cc) for the sake of conservatism, as higher densities of fiberglass were determined to be more reactive, see Section 4.2. The plutonium in the ingot is modeled at theoretical density for the sake of conservatism. In Appendix A, another configuration with all void space modeled as pure quartz is modeled to determine a reasonable upper bound on reactivity increase from density. All holdup is modeled as PuO_2 filling void space within the filter using a bulk density deemed to be a credible conservative maximum.

3.3 SiO_2 Justification

3.3.1 Validation

The purpose of this tech is to determine the difference in reactivity between several configurations of a HEPA filter likely to be present within a glovebox and not to enforce upper subcritial limits. As AoA validation is primarily used to determine upper subcritical limits, the use of SiO_2 in the calculations without the inclusion as a moderator in the validation of the Blowfish computer cluster (as detailed in NCS-TECH-21-001 for plutonium systems) is deemed to be adequate for the purposes of this document.

3.3.2 Density

While there are not records of the density of the type of filter medium available either in existing records or at request to the manufacturer, LA-UR-21-24848 [Ref. (5)] determined the mass of a smaller HEPA filter, model#0-007-D-43-R0-NU-00-00-Z93555H. The drawing referenced in the models used in this TECH is the similar model#0-007-D-43-R0-NU-00-00Z93555G [Ref. (6)]. The drawing of the smaller filter assembly for 8” diameter filters, 26Y-202057 [Ref. (7)] does not specify revision, only Z93555 filters must be used. As such for the purposes of this TECH it will be assumed that the filters are similar enough that the calculations performed will be accurate. This is aided by the fact that the dimensions of the filters are identical, both having an 8” diameter and 5-7/8ths” depth. Using the recorded mass of being between 5 to 7 lbs, minimum and maximum fiberglass densities were determined. The minimum fiberglass density was determined by assuming a filter weight of 5lbs, subtracting the mass of the stainless steel frame, then dividing by the volume of the whole HEPA filter for a density of 0.2131g/cc. The maximum fiberglass density was determined similarly but instead using 7 lbs and dividing by the volume of only the pack medium for a density of 0.5884 g/cc.

Both the minimum and maximum cases were tested for each HEPA filter height configuration to ensure that the most reactive configuration would be analyzed. Depending on whether the HEPA serves primarily as a neutron reflector or as a moderator, a bounding density could be either low or high.

3.3.3 Moderation

The most highly moderated configuration of Pu(0) in SiO_2 is not significantly lower energy than the least moderated configuration, with a maximum ΔANECF value of 0.00880 MeV, which is considerably lower than the moderation provided from incidental water reflection with a maximum ΔANECF value of 0.04550 MeV. As such, SiO_2 is considered to be a very weak moderator for the purposes of this document.

3.3.4 Modeling

The calculations performed herein model a generic enclosure with internal dimensions of 36 by 36 by 36 inches and exterior walls constructed of 7/16-inch type 304 stainless steel and is not further externally reflected. This enclosure setup is identical to that used in NCS-TECH-21-021, R0 [Ref. (8)].

A 4.5kg Pu(0) metal cylinder is modeled on the floor of the enclosure placed directly in the center below the HEPA filter to determine the maximal effect on reactivity caused by the filter. The ingot is modeled as an ingot with a H/D ratio of unity and represents a bounding generic fissionable material item in most fissionable material operations. For the configurations where the filter is at the top of the glovebox it is assumed that the ingot has full 1-inch 4π water reflection. For the configurations where the filter has fallen or is otherwise detached and placed on top of the ingot, the top layer of reflection is removed leaving 1 inch of water reflection surrounding everything except the top which is in active contact with the HEPA filter.

For the sake of conservatism, 500g of plutonium oxide was placed within the HEPA filter media with varying density. The maximum density was achieved when all void space within the filter was taken by plutonium oxide forming a small cylinder with a H/D of 1.The minimum density was assumed to be when the filter had a H/D ratio of 1 cylinder of oxide filling as much space as possible within the filter without deviating from a H/D ratio of 1 (See Figure 6). As the maximum quantity of holdup ever recorded in a HEPA filter was 368.6g [Ref. (3)], 500g of holdup is deemed to bound all credible conditions. The configuration of holdup in the geometry of a cylinder is considered sufficiently bounding of real material holdup configurations. Holdup would tend to disperse in a conical, thinly cylindrical, or hemispherical fashion around the bottom face of a filter, resulting in a wider spread. By collecting material in a concentrated cylinder, interaction between holdup and the resident 4.5kg ingot is maximized. This convention is further supported by results below that demonstrate that the most reactive configurations are not those that maximize interaction between holdup and resident material but rather those that maximize the density of the holdup (i.e., those that model the holdup as compact).

3.4 Filter

There are three primary filters within the facility surveyed for this TECH, the most common of which is the 8" diameter Z93555 filters referenced in Section 3.3.2 and shown in Figure 1, larger 12" diameter cylindrical filters as detailed in 26Y-202130 Combined [Ref. (9)] and shown in Figure 2, and "box" filters present within hoods as shown in Figure 3. While a design drawing was not available for these "box" filters at the time of writing, approximate measurements were taken with LIDAR showing dimensions of roughly 24" x 24" x 10".

It's assumed that two HEPA filters are placed on top of each other such that to remove one, a new one simply needs to be pushed in, minimizing potential exposure to radioactive particulate matter as is described in TA55-DOP-068 [Ref. (10)]. Due to this, the height of the HEPA filter was doubled even in the event of the filter being placed within the glovebox for the sake of conservatism. Spacers are not modeled as they would only increase spacing to the holdup present within the filter and only provide a small amount of reflection.

The filter analyzed does not match the exact dimensions of any of the filters present within the facility but rather a conservative mixture of dimensions chosen to bound the three filters present. A cylinder with a 24” diameter and 40” total height after doubling was chosen as both cylindrical filters are bounded by the added reflection. While the box filter is not necessarily bounded due to the reduced planar reflection, given that the box filters are considerably shorter, are an exception to the double stacking detailed in TA55-DOP-068 [Ref. (10)], and that hoods are far less likely to have significant holdup than active processing gloveboxes as shown in NCS-TECH-22-006, R1[Ref. (2)] it was deemed that the modeled filter is sufficiently conservative.

Figure 1. Example of 8” Diameter HEPA Filter Above GB

Figure 2. Example of 12” Diameter HEPA Filter Above GB

Figure 3. Example of Box Filter Above Hood

4.0 ANALYSIS

An initial test configuration was performed using a generic 4.5kg Pu(0) ingot with 1” of incidental water reflection inside of a generic 3’ by 3’ by 3’ internal glovebox with 7/16” thick 304 Stainless Steel walls.

Herein, Δk is defined as $k_1 - k_0$ such that k_0 is the reference case and k_1 is the experimental case. As such, positive Δk values reflect an increase in reactivity. %Δk is defined as the relative change of the experimental case in comparison to the base case using the formula $\frac{k_1 - k_0}{k_0}$.

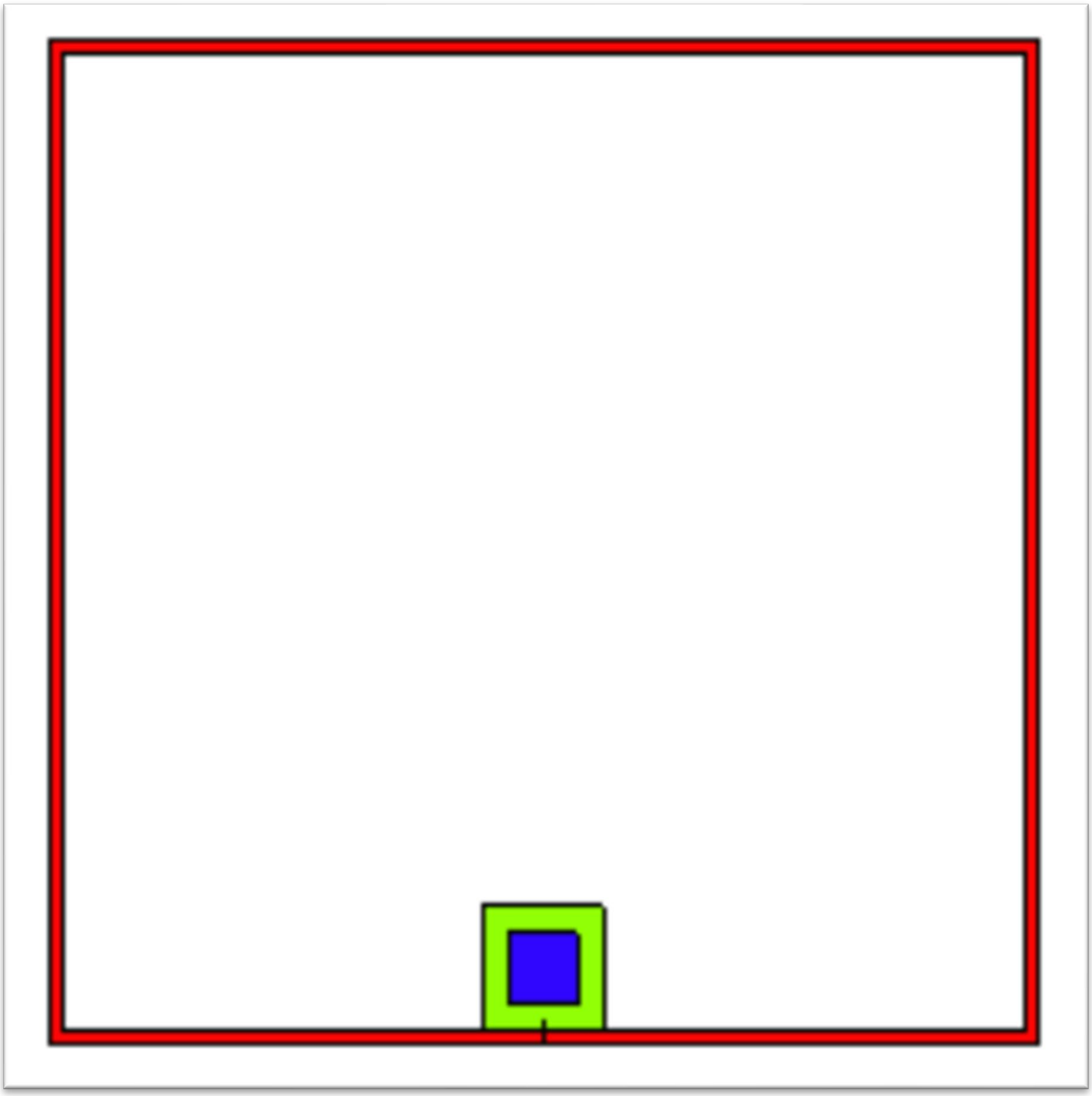

Figure 4. XZ Axis Image of Generic Plutonium Ingot in Glovebox

■Pu metal; ■ Glovebox (304SS); ■ Water

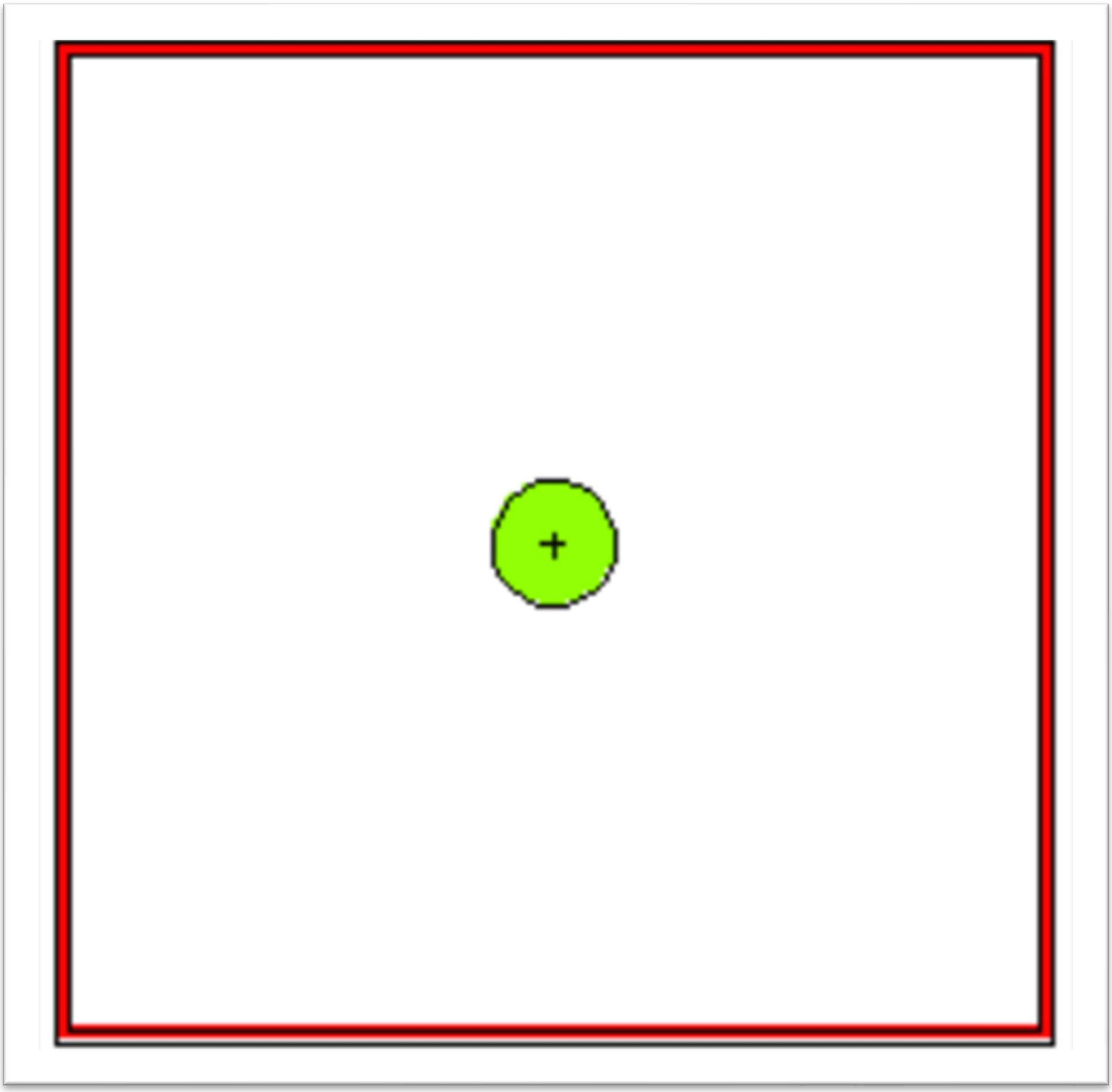

Figure 5. XY Axis Image of Generic Plutonium Ingot in Glovebox

Pu metal; Glovebox (304SS); Water

This configuration was used as a baseline configuration to compare reactivity against. The k_{calc} value was determined to be 0.87093 with a σ of 0.00024 for a k_{eff} of 0.87141.

4.1 Ceiling Results

The first considered configuration was a condition with two HEPA filters stacked on top of each other at the roof of the glovebox, centered directly above the test ingot. This condition maintained a conservative 4π 1” water reflection.

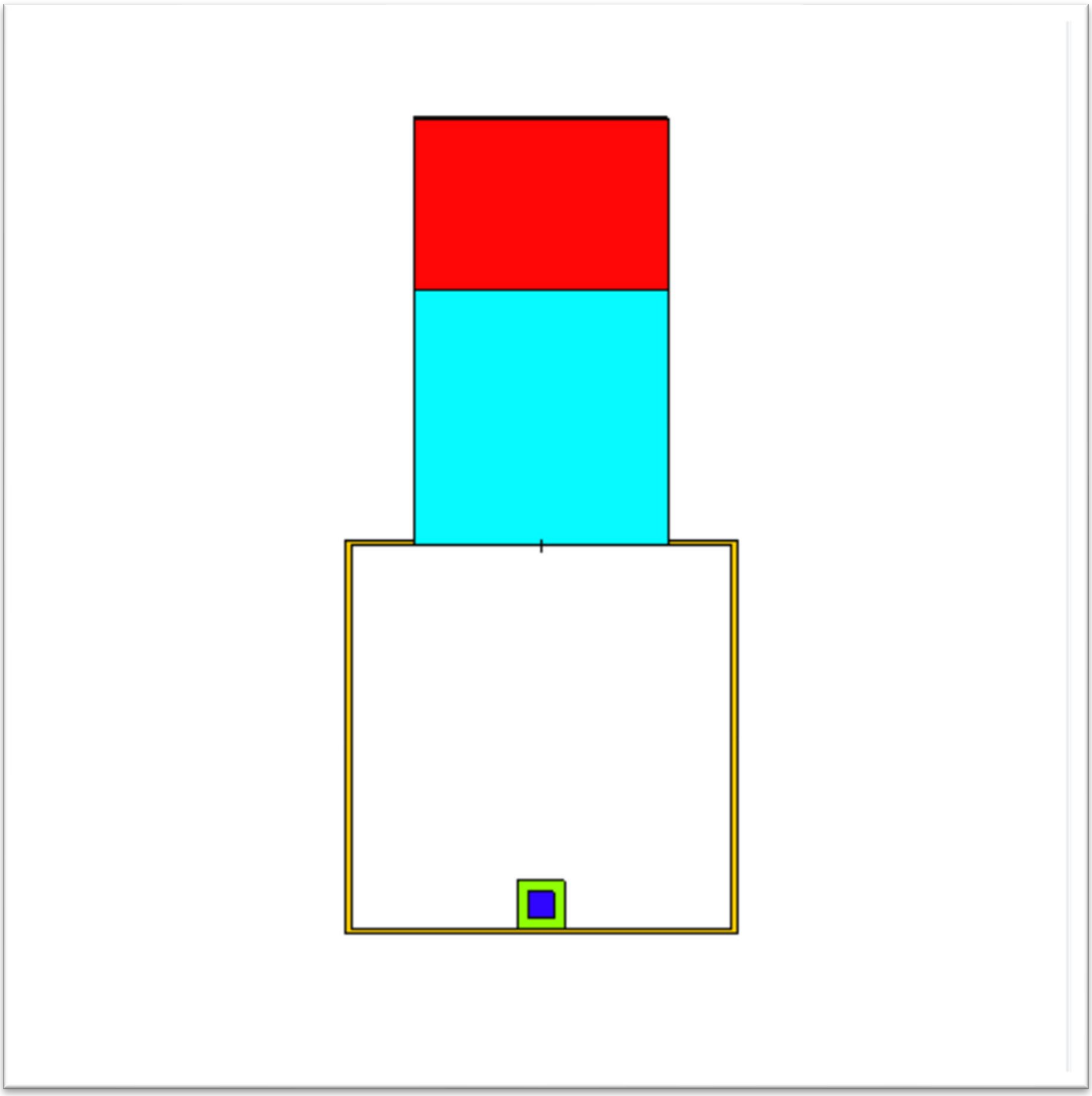

Figure 6. XZ Axis Image of Minimum Pu Density HEPA Filter on Ceiling

Pu metal; Filter without Pu; Pu oxide in filter; Water; Glovebox (304SS)

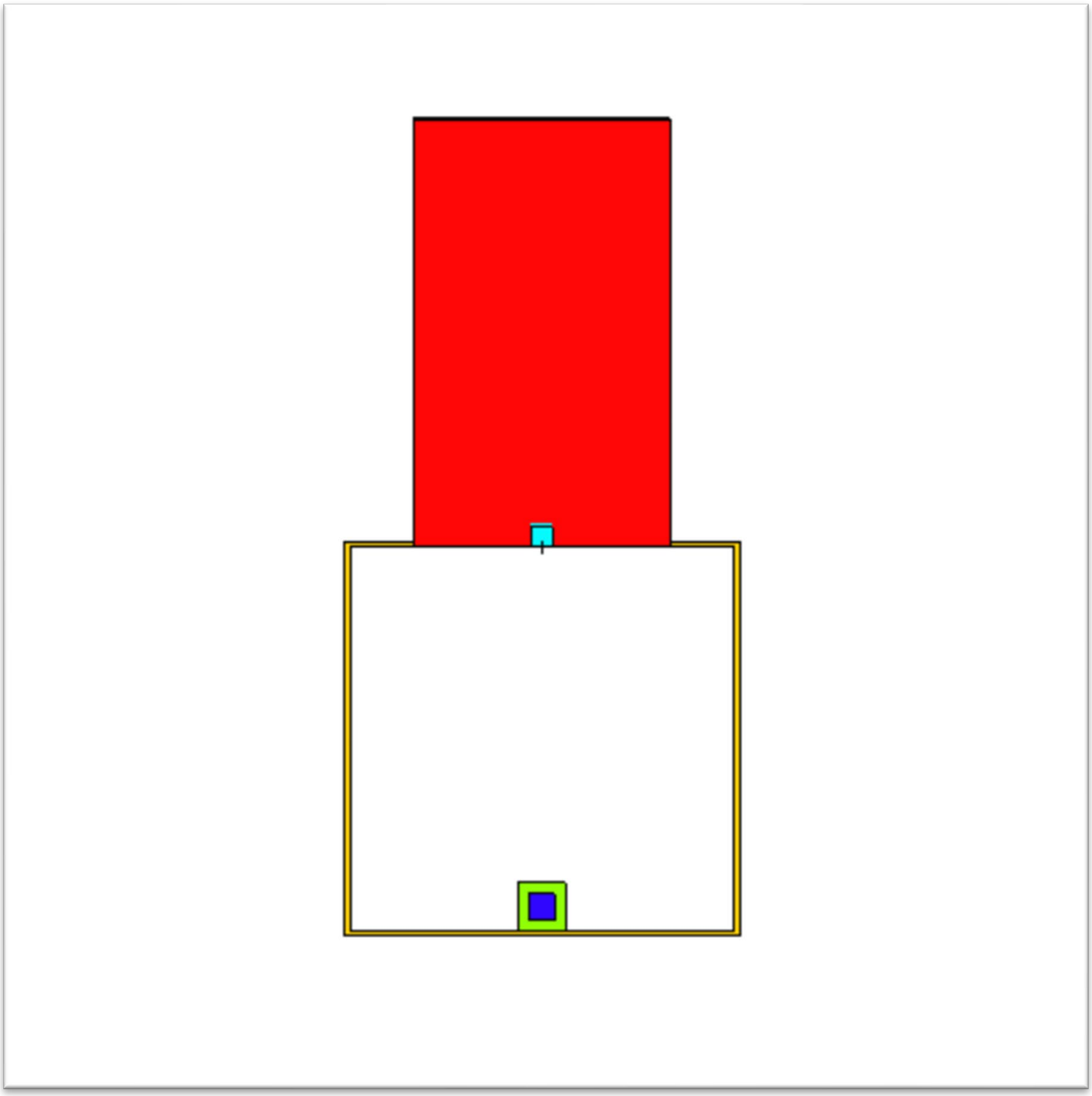

Figure 7. XZ Axis Image of Maximum Pu Density HEPA Filter on Ceiling

■Pu metal; ■Filter without Pu; ■ Pu oxide in filter; ■ Water; ■ Glovebox (304SS)

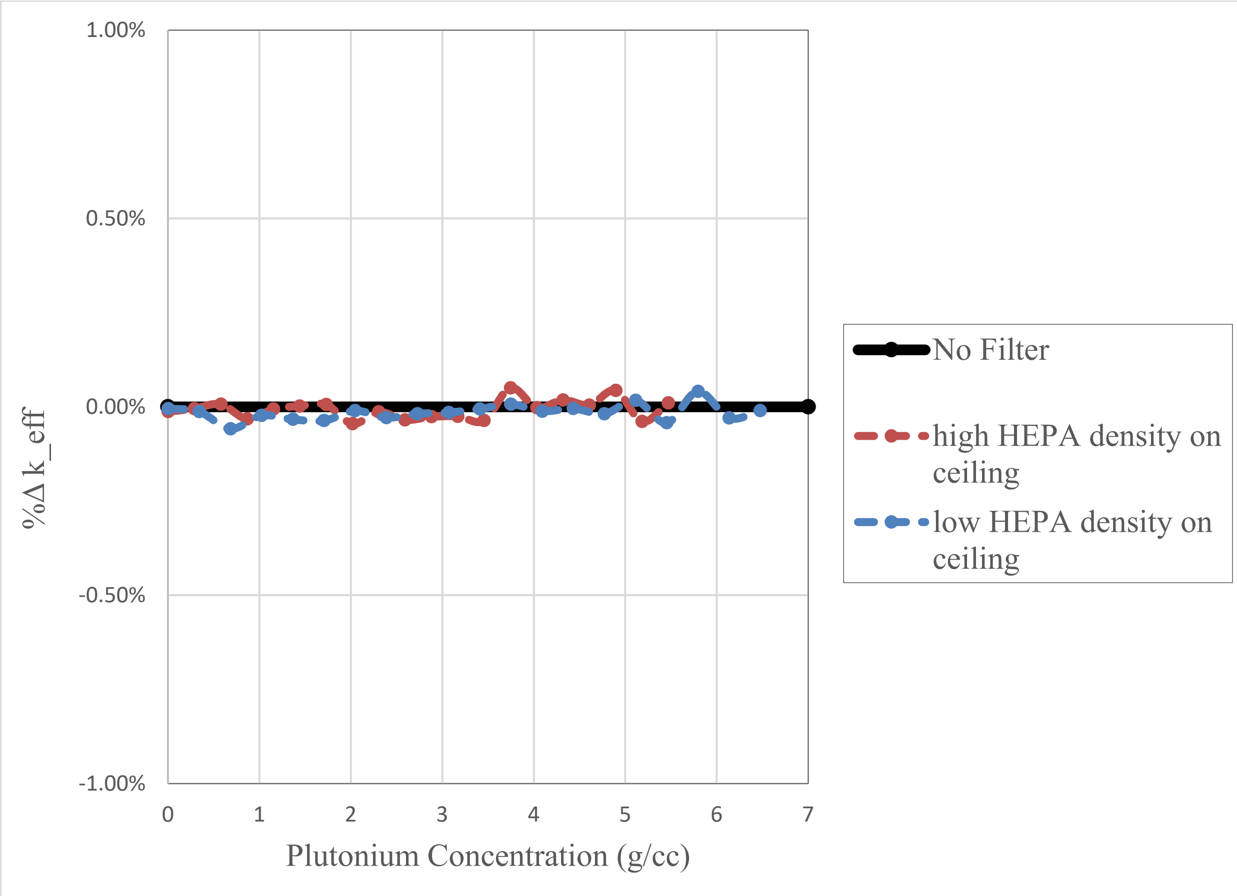

Figure 8. Chart of k_{eff} vs Plutonium Concentration in Glovebox Ceiling

As is clear from this graph, and as should be expected from a high separation between items, when the HEPA filter is placed within the ceiling of the glovebox the reactivity does not meaningfully increase due to the lack of neutronic interaction with the holdup material. It may be possible that the modeled filter is marginally more reflective than the bare glovebox, but any effect caused by this is minimal and not detectable above statistical variance. As such, further graphs will focus primarily on the filter placed directly atop the test ingot.

The particular density ranges for each configuration were chosen as they range from a minimum density where the plutonium is spread out as much as possible within the filter while still maintaining a H/D of 1, up to a maximum density where the plutonium oxide fully fills the void space of the filter, minimizing the size of the collected holdup assuming the bulk density of plutonium oxide.

4.2 Direct Placement Results

Of primary concern is the placement of the HEPA filter and contained plutonium directly on top of the test ingot. As this both increases neutronic interaction and reflection provided by the filter, it is assumed that it will be a more reactive configuration.

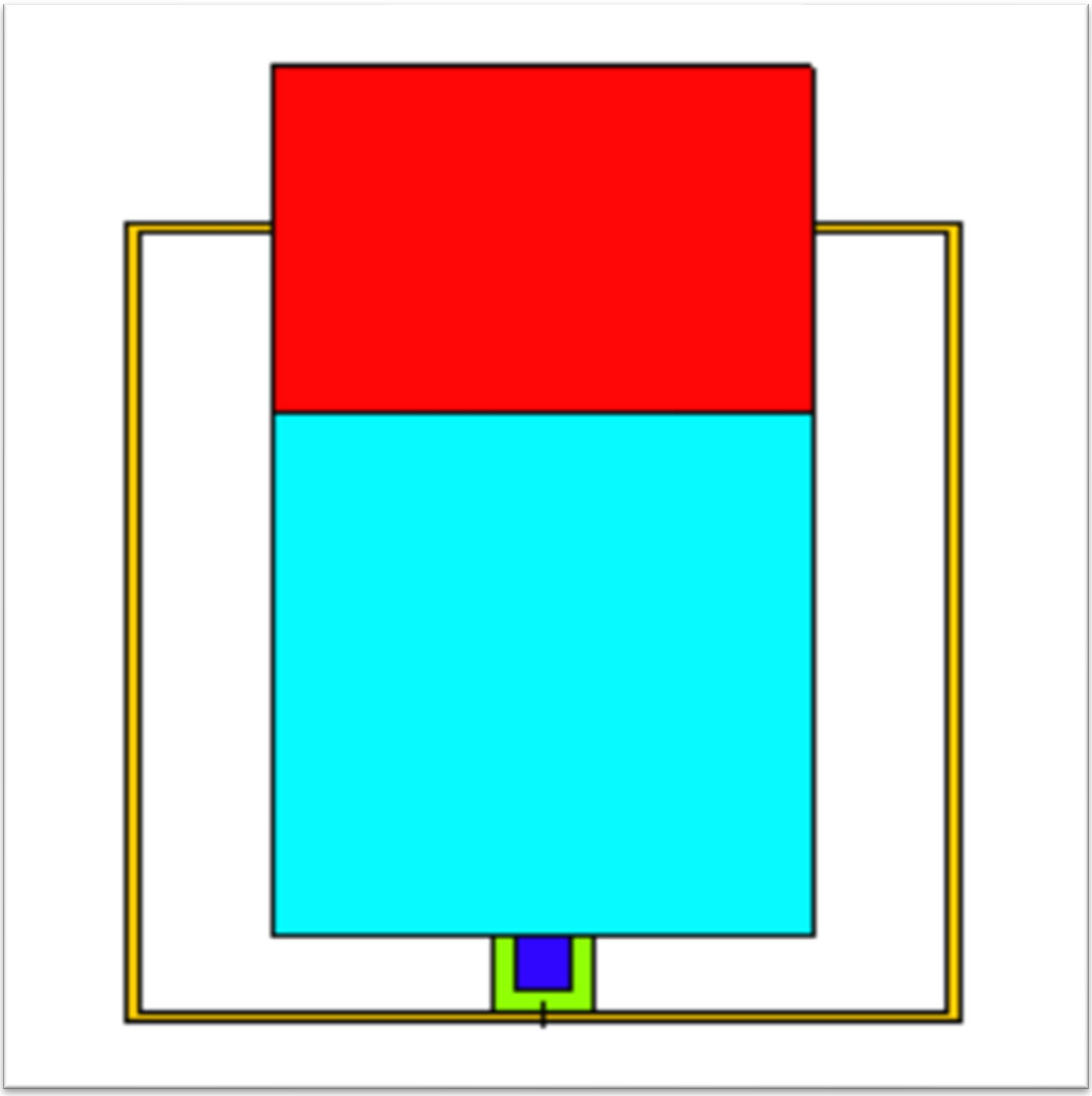

Figure 9. XY Axis Image of Minimum Pu Density HEPA Filter on Top of Ingot

■Pu metal; ■Filter without Pu; ■ Pu oxide in filter; ■ Water; ■ Glovebox (304SS)

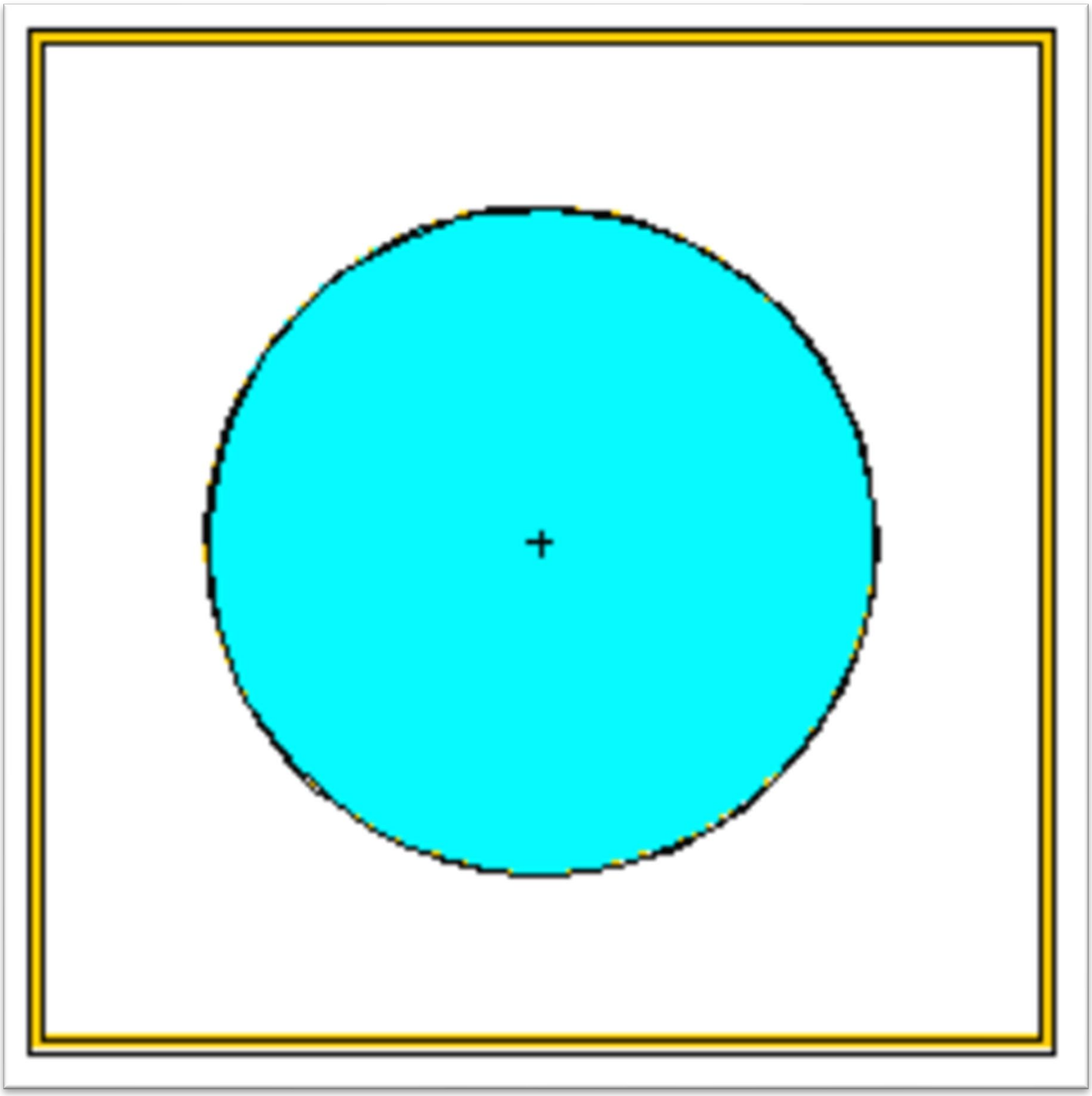

Figure 10. Internal XY View of Pu Within HEPA Filter

Pu oxide in filter; Glovebox (304SS)

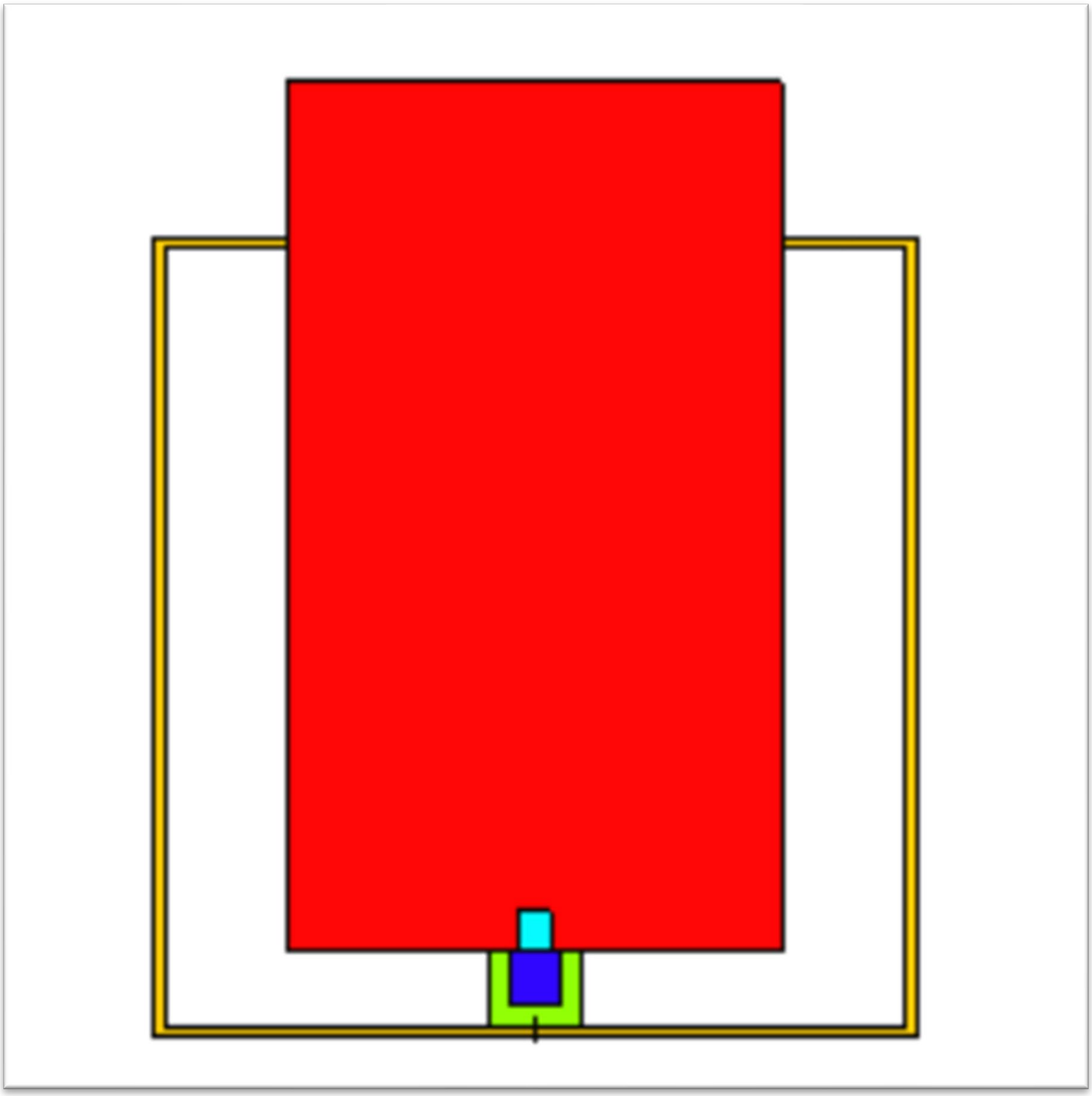

Figure 11. XZ Axis Image of Maximum Pu Density HEPA Filter On Top of Ingot

Pu metal; Filter without Pu; Pu oxide in filter; Water; Glovebox (304SS)

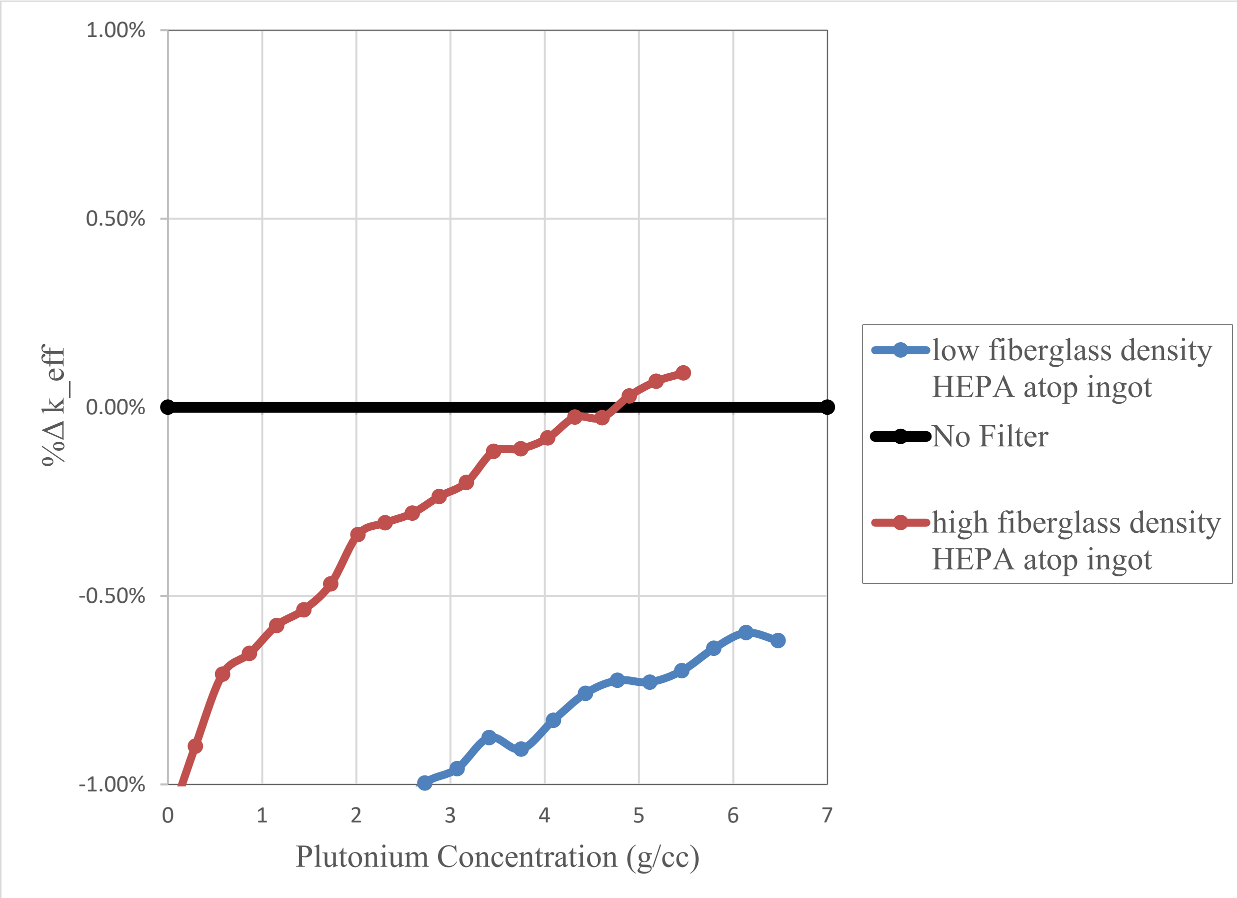

Figure 12. Δk_{eff} vs Pu Concentration for HEPA Placed on Top of Ingot, Varying HEPA Density

For an ingot with only incidental water reflection in a generic glovebox the k_{calc} value was found to be 0.87093 with a σ of 0.00024, returning a k_{eff} value of 0.87141. Comparatively, for cases where the filter is placed directly on top of the ingot, the results depend more significantly on the density of the pack media. Using the lower calculated density, Δk values were strictly negative from the loss of top facing water reflection as the HEPA filter provides less reflection than assumed 1-inch incidental water reflection. The higher possible density, however, returned a small but positive Δk with a maximum of 0.00041, or roughly 0.059%, showing a small but ultimately insignificant increase in reactivity from the interaction with plutonium oxide in the holdup combined with the less effective reflection of the HEPA filter.

Among all configurations, the highest observed k_{eff} value was 0.8722 in the configuration with maximized fiberglass density directly on top of the ingot with the highest plutonium density.

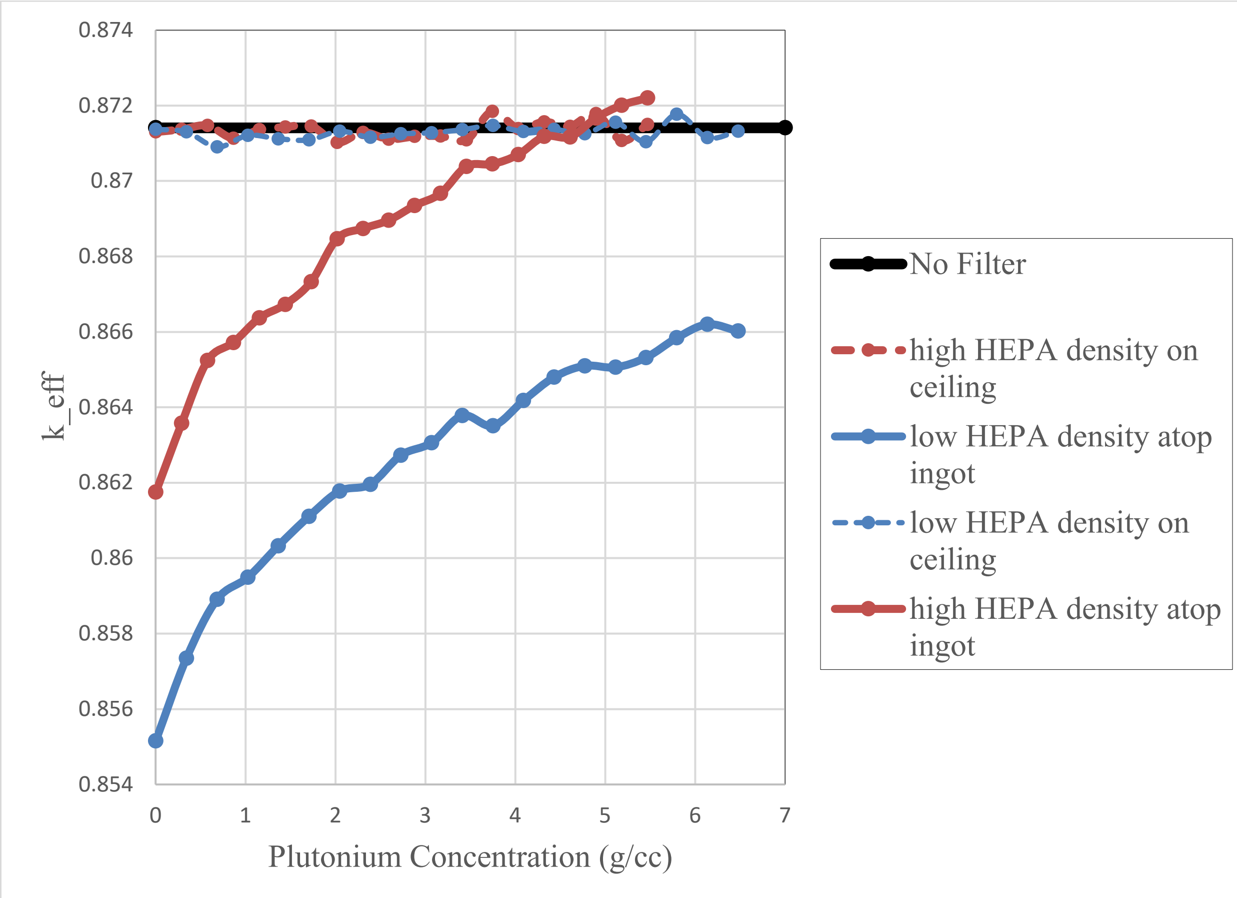

Figure 13. Chart of k_{eff} vs Plutonium Concentration in Varying Configurations

5.0 CONCLUSION

The analysis documented herein demonstrates that plutonium holdup within a HEPA filter can increase the reactivity in an enclosure if sufficient fissionable holdup mass is present. However, even with 500g of material present in the filter under ideal circumstances the reactivity increase is negligible with a Δk of only 0.00079, or 0.091%. Further, this is significantly more holdup than has been observed within recorded outlying cases. Any increase in reactivity noted here is judged to be subsumed by the ideal, conservative modeling conventions typically used in other evaluations to model normal and credible abnormal conditions, as well as the ideal, conservative modeling conditions used herein to model holdup. As the effects in reactivity resulting from the most reactive possible conditions modeled were barely resolvable, it is deemed that any credible quantity of holdup present in a HEPA filter during normal conditions (e.g., placed on top of GBs, being changed out, etc.) will not have meaningful impact on criticality.

5.1 Caveats

This does not necessarily hold for other filters that use other filter material, especially those with the potential to act as moderators such as polypropylene.

Additionally, this may not hold for environments capable of causing physical or chemical change to the filter or holdup material. High temperatures are liable to melt the pack material, increasing the density significantly. See Appendix A for more on the effect of increased density on reactivity. Chemical changes could include solvation and change reactivity in unpredictable ways that will need to be accounted for on a case-by-case basis.

This TECH does not seek to make any statements about the effect of hold-up on conditions subsequent to credible abnormal conditions, aside from a filter potentially falling into a GB unexpectedly.

6.0 REFERENCES

1. **NCS-AP-005, R3.** *Technical Documents.*

2. **NCS-TECH-22-006, R1.** *Statistical Distribution of Holdup in HEPA Filters and Gloveboxes.*

3. **NCS-TECH-21-001, R3.** *Criticality Safety General Technical Bases and Guidance.*

4. **NCS-TECH-18-024, R3.** *Material Definitions Library for Criticality Safety Calculations.*

5. **LA-UR-21-24848.** *Assembly Operations Welding Filter(s) in Drum Calculation.*

6. **Z93555G.** *Technical Drawing of Model#0-007-D-43-R0-NU-00-00-Z93555G.*

7. **26Y-202057.** *Technical Drawing of 8" Diameter Exhaust Filter Assembly.*

8. **NCS-TECH-21-021, R0.** *Parametric Analysis of Holdup in Enclosures.*

9. **26Y-202130.** *Technical Drawing of 12" Diameter Exhaust Filter Assembly.*

10. **TA55-DOP-068.** *Replacing the Glovebox Exhaust HEPA Filter to the Zone 1 Vent.*

11. **Z23075.** *Technical Drawing of Model#D-007-W-42-N2-NU-00-23-Z23075.*

Appendix A. Idealized Density Configuration

As a clear line can be drawn between the reactivity of the system and the density of the filter medium, another configuration was suggested to test the logical extreme of this case. For this, it was assumed that pure crystalline quartz (2.648g/cc), which while less realistic is more dense than amorphous glass, would fill all void space left by plutonium. That is to say, homogenous mixtures of Pu in oxide and quartz, without crediting any void space, are modeled. In the highest plutonium density configuration, there was effectively a single puck of pure plutonium oxide with a crystalline quartz shell as shown below:

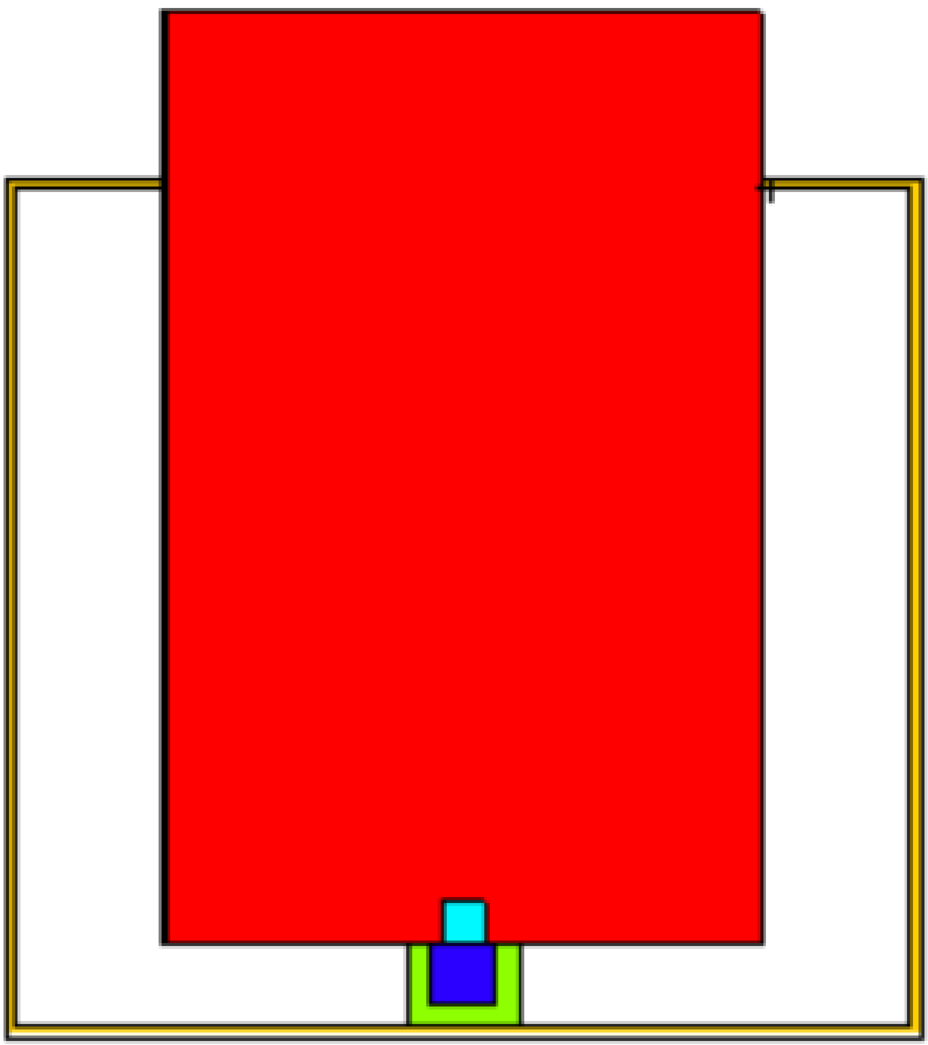

Figure 14. XZ Axis Image of Maximum Pu Density Quartz Shell on Top of Ingot

Pu metal; Quartz Crystal; Pu oxide; Water; Glovebox (304SS)

For lower density configurations, it approximated other low plutonium density configurations similar to Figure 9 although with significantly higher density of SiO_2 due to the modeling of quartz instead of fiberglass.

For each of the density configurations, five tests were run using increments of 100g of plutonium from 100g to 500g to determine the effect of just density on reactivity and of the plutonium oxide holdup and a chart of percent change in reactivity was made.

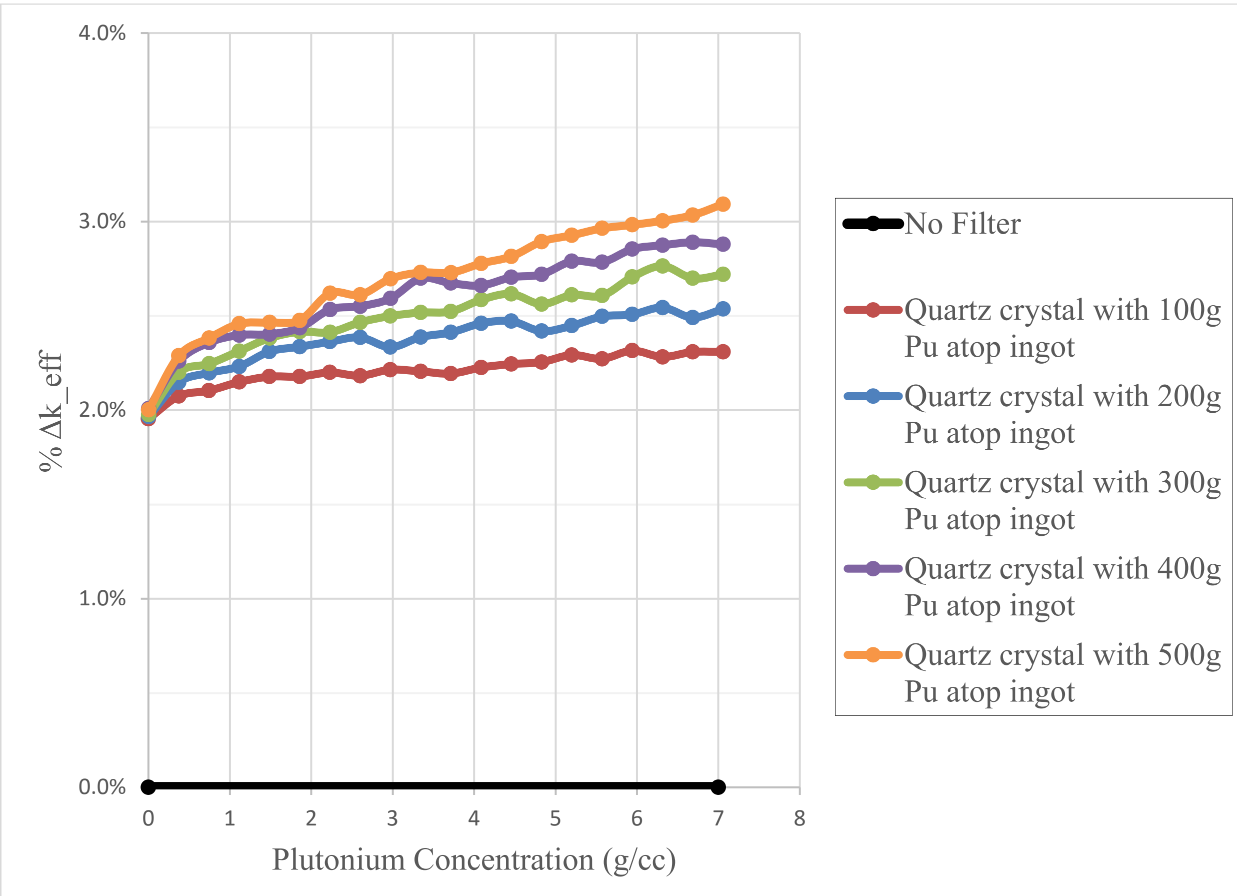

Figure 15. %Δk_{eff} vs Pu Concentration for Quartz Crystal Placed on Top of Ingot, Varying Total Holdup

From this it is clear that a nontrivial amount of reactivity can be added to the system. However, this system was modeled extremely conservatively, introducing over 1000lbs of pure quartz into the glovebox. Given the incredible mass required for a maximum reactivity increase of 3.0%, it's likely very reasonable to consider any reflection that can be added by a HEPA filter composed primarily of SiO_2 to be negligible under any normal and most abnormal conditions.

This configuration lends further credibility to the assumption that SiO_2 does not act as a moderator within the system as the minimum recorded ANECF was 1.6631 MeV despite adding such a large quantity of non-fissile material.

Appendix B. In-Field LIDAR Measurements

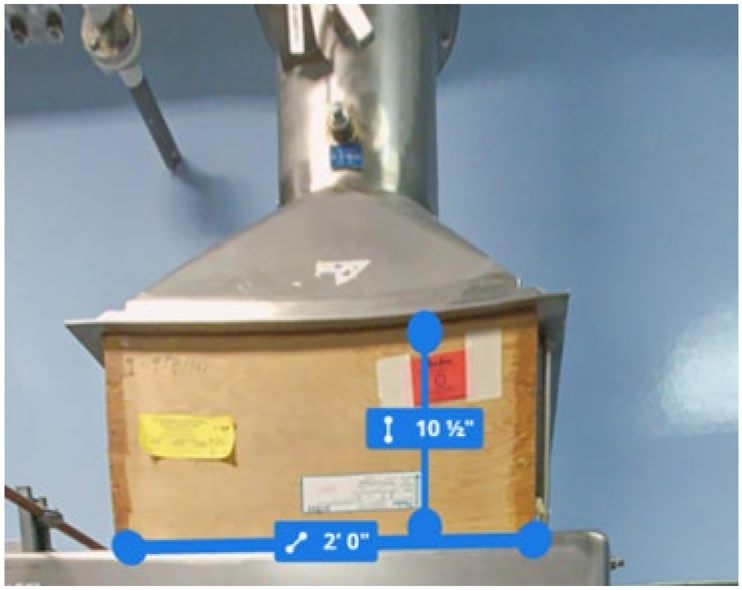

Figure 16. XZ Axis LIDAR Measurements of Hood Filter

Figure 17. Y Axis Measurement of Hood Filter