

LA-UR-16-28195

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Title:	A Practical Assessment of the Effect of Water Interspersed with Plutonium Metal Hemishells - 2016 ANS Winter Meeting
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Intended for:	American Nuclear Society, 2016-11-08 (Las Vegas, Nevada, United States)
Issued:	2016-10-31 (rev.1)

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A Practical Assessment of the Effect of Water Interspersed with Plutonium Metal Hemishells

2016 ANS Winter Meeting Las Vegas, NV

Ning Zhang

2016-11-08





- EST.1943 —

What is plutonium?



Pluto on Pluto

What is plutonium?



Not Plutonium



Purified Plutonium Ring

What is plutonium?



Plutonium is an element in the periodic table with a atomic number of 94.

Plutonium has many isotopes.

Many plutonium isotopes have a critical mass.

The ANS-8.1 single-parameter subcritical limit for ²³⁹Pu metal is 5.0 kg.

What is a hemishell?



Nautilus Hemishell

What is a hemishell?



Not the right shape



A carbon steel hemishell from some Chinese manufacture sitting on the ground

What is a hemishell?



- A hemishell is a geometric shape.
- Think of a hollowed sphere, with a thickness, cut in half.
- If the inner radius of the hemishell approaches zero, it becomes a half sphere.

What is a plutonium hemishell?





What is a plutonium hemishell?

Insert Plutonium Hemishell Picture Here...



Rocky Flats Uranium Hemishells



Depiction of Stacked Hemishells

What does water have to do with plutonium hemishells?

- Water is one of the most abundant material on Earth.
- Water can seep through complex geometries.
- Water can be tight fitting around existing objects.
- Many chemicals contain some water, or behave similar to water.
- Water is a great common neutron reflector.
- Water is an awesome neutron moderator.

- Water is a headache for Criticality Safety Analysts!
- The ANS-8.1 single-parameter subcritical limit for ²³⁹Pu metal is 5.0 kg.
- The ANS-8.1 single-parameter subcritical limit for ²³⁹Pu aqueous mixtures is 450 g.
- ~ factor of 10 difference.

But I have ²³⁹Pu hemishells, and they are metal, I don't have ²³⁹Pu in aqueous mixtures!

• Neutrons don't care about what you think

According to Section 5.3 Metallic units of ANSI/ANS-8.1:

The enrichment subcritical limit for uranium and the mass subcritical limits given in Table 3 apply to a single piece having no concave surfaces. They may be extended to an assembly of pieces, provided that there is no neutron moderating material interspersed with the pieces.

• ANS-8.1 SPSL for metal may be extended to an assembly of pieces (i.e., multiple hemishells) provided that there is no neutron moderating materials interspersed with the pieces.

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But I have ²³⁹Pu hemishells, and they are metal, I don't have ²³⁹Pu in aqueous mixtures!

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- ANS-8.1 SPSL for metal may be extended to an assembly of pieces (i.e., multiple hemishells) provided that there is no neutron moderating materials interspersed with the pieces.
- Then comes the water...
- Water can seep through the stacked hemishells.
- Water is a neutron moderating material, interspersed with the pieces.

But I have ²³⁹Pu hemishells, and they are metal, I don't have ²³⁹Pu in aqueous mixtures!



- Then comes the water...
- Water can seep through the stacked hemishells.
- Water is a neutron moderating material, interspersed with the pieces.

So water + ²³⁹Pu hemishells = bad? Do I run away?

- It depends...
- First, is there an issue/concern?
- At what mass/geometry/configuration does it become an issue/concern?
- A parametric study was conducted using MCNP6.1 with input decks generated from WORM (Write One, Run Many)
- WORM is a general-purpose input deck specification language, written by Tom Jones.

So water + ²³⁹Pu hemishells = bad Do I run away? (continued)

- Three different ²³⁹Pu metal (ρ=19.84 g/cm³) hemishells masses were modeled, 4.5 kg, 5.0 kg and 6.0 kg.
- The number of ²³⁹Pu hemishells were varied, ranging from 1 6.
- Three stacked hemishells each contain 2.0 kg ²³⁹Pu adds up to a total mass of 6.0 kg.
- For each mass, and each arrangement of numbers of hemishells, the inner diameter and shell-to-shell spacing were varied.
- The parametric study assumes equal masses per hemishell.
- All hemishell inner diameters will all vary the same way for each shell.
- The shell-to-shell spacing between each hemishell will all vary the same way for the spacing between each shell.
- Furthermore, in order to determine what is subcritical for each configuration, Whisper, was used.

Whisper

- Whisper is a sensitivity/uncertainty-based tool developed by LANL's Monte Carlo Methods, Codes & Applications Group.
- Whisper may be used to determine the baseline upper subcritical limit (USL), for a particular problem.
- Whisper selects the most relevant benchmarks from a large collection of existing benchmarks, by using sensitivity-uncertainty methods, determines bias and bias uncertainty using extreme value theory, estimates the extra Margin-of-Subcriticality (MoS) due to nuclear data uncertainties, and includes extra MoS to bound potential unknown code errors.
- <u>https://mcnp.lanl.gov/</u> Reference Collection contains much more information about Whisper.

Single Hemishell Results



Two Hemishells Results









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We stopped at 6 hemishells

Where Interspersed Water Mixed with Plutonium Metal Hemishells Presents a Nuclear Criticality Accident Potential

# of Hemishells	Total Mass: 4,500 g	Total Mass: 5,000 g	Total Mass: 6,000 g
1	N/A	N/A	I.D. < 5 cm
2	N/A	N/A	I.D. < 5 cm
3	N/A	N/A	I.D. < 3 cm
4	24 cm < I.D. < 64 cm or 2 cm < Spacing < 6 cm	24 cm < I.D. < 85 cm or 2 cm < Spacing < 7 cm	20 cm < I.D. < 85 cm or 1 cm < Spacing < 7 cm
5	20 cm < I.D. < 85 cm or 1 cm < Spacing < 7 cm	20 cm < I.D. < 85 cm or 1 cm < Spacing < 8 cm	18 cm < I.D. < 110 cm or 1 cm < Spacing < 8 cm
6	19 cm < I.D. < 85 cm or 0.1 cm < Spacing < 8 cm	18 cm < I.D. < 110 cm or 0.1 cm < Spacing < 8 cm	17 cm < I.D. < 110 cm or 0.1 cm < Spacing < 8 cm

Conclusion

- Neutrons don't care about what you think.
- Stacked hemishells have a criticality accident potential, under flooding conditions.
- Reducing mass may not solve the problem.

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