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Title: Minimum Critical Masses of Heterogeneous Moderated Plutonium and Uranium Metal Systems and Their Practical Application to Operation Limits

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Minimum Critical Masses of Heterogeneous Moderated Plutonium and Uranium Metal Systems and Their Practical Application to Operation Limits

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Introduction

In criticality safety analysis it is important to recognize the significant differences in reactivity achieved when material transitions from the solid to solution regime. However, the intermediate area of mixed heterogeneous systems (i.e. collections of small pieces) has not been well characterized. To that end, a study was completed to determine the effect of fissile material piece size/shape on the minimum critical mass of a system.

This study explores the relationship of three characteristic shapes of fissile material: spheres, cubes, and rods. Ultimately a SA-VOL ratio versus critical mass curve was developed for reference by criticality safety practitioners.

Calculational Study

The study presented represents a calculation-based investigation of moderated arrays of fissionable material to expand on the plutonium and uranium solution curves (cf. Figure 31 and Figure 10 of LA-10860) to add the heterogeneous regime between a pure solid and solution of fissionable material.

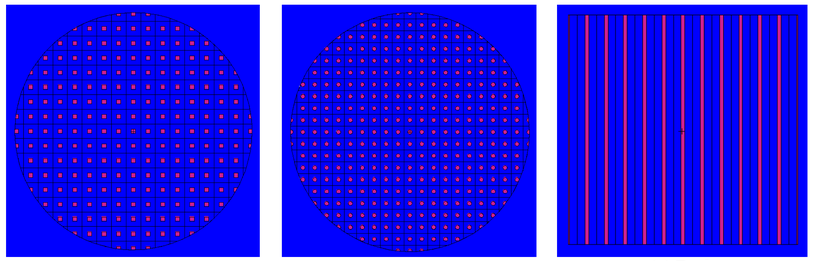
The analysis performed consists of a parametric study utilizing the neutron transport code MCNP6 with the ENDF VII.1 cross section library to calculate the critical mass of systems composed of moderated arrays of varying sizes of spheres, cubes, or elongated rods (height >> diameter). The boundary of the array was increased to find the critical mass for that particular piece geometry and fissionable material volume density. In this study no bias was used and the critical mass was taken to be the mass in the array at k_{calc}=1.00.

The different models, illustrated in Figure 1, were then compared at points with the same fissionable material volume density to demonstrate that the key relationship between varying piece shape is SA-VOL ratio. The formulas for SA-VOL ratios are captured in Table I.

Table 1. SA-VOL Ratios.

Shape	SA-VOL Ratio
Sphere	6/D
Cube	6/S
Rod (h>>D)	4/D

Figure 1. MCNP Models



(a) Cubes **(b) Spheres** **(c) Rods**

Conclusions

The results shown in Figures 6 and 7 shed additional light on the behavior of plutonium and uranium systems as they transition from homogenous solution systems to metal systems. Plutonium pieces with a SA-VOL ratio < 13 cannot be made more reactive by increasing moderation and thus these pieces are most reactive as a solid metal chunk. Plutonium pieces with a SA-VOL ratio > 13 can be made more reactive by adding moderation to the system. Uranium responds much more quickly to moderation and thus pieces of nearly any size will become more reactive with the addition of moderation.

Acknowledgements

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Results – Plutonium

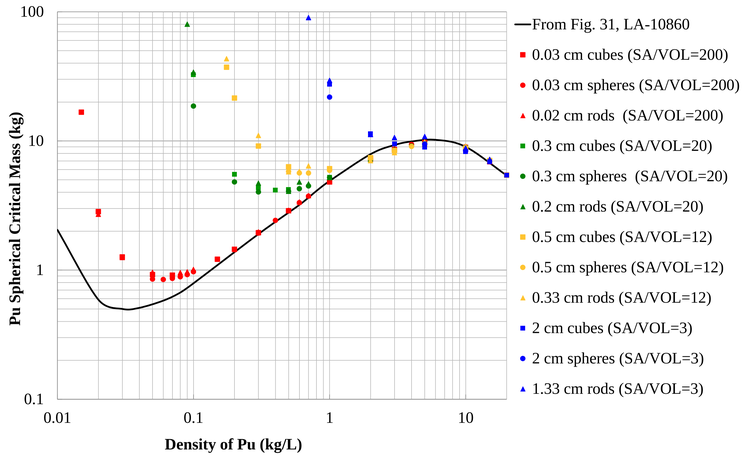

Figure 2 Plutonium Results Compared with Data from Figure 31 of LA-10860.

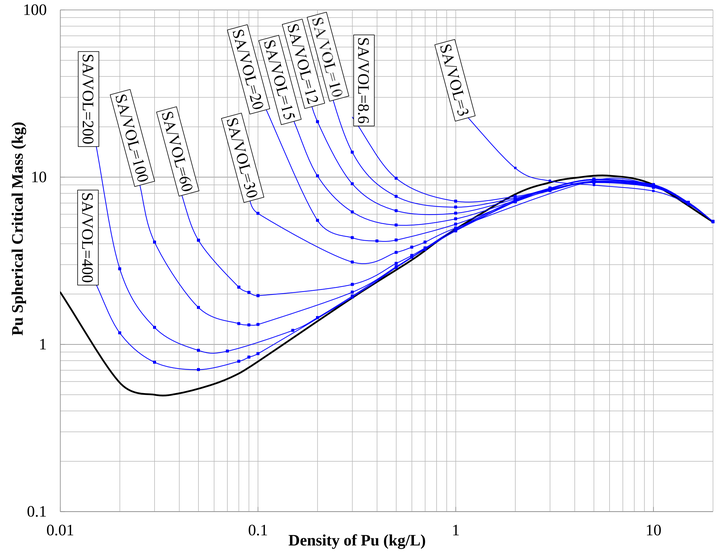

Figure 4 Plutonium Results of Arrays of Spheres with varying SA-VOL ratios compared with Data from Figure 31 of LA-10860.

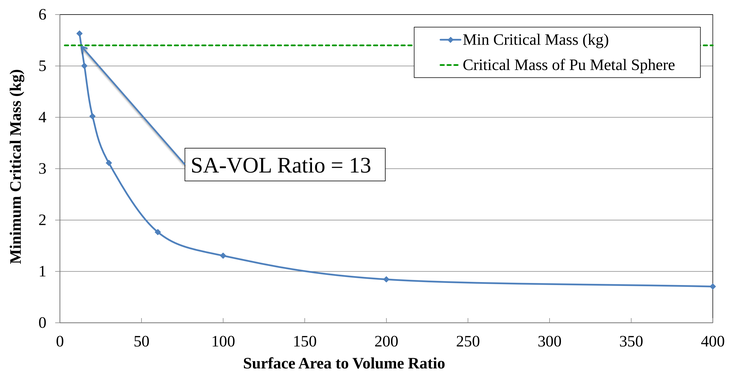

Figure 6 Plutonium SA-VOL Ratio vs. Minimum Critical Mass for Reflected Moderated Arrays.

Results – Uranium

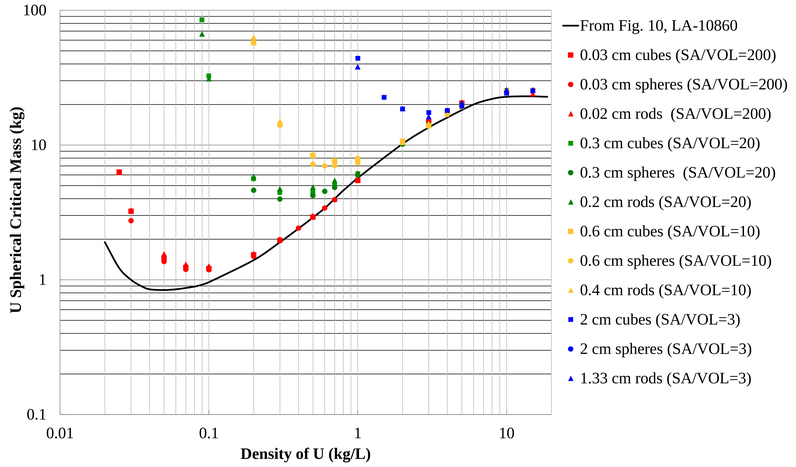

Figure 3 Uranium Results Compared with Data from Figure 10 of LA-10860.

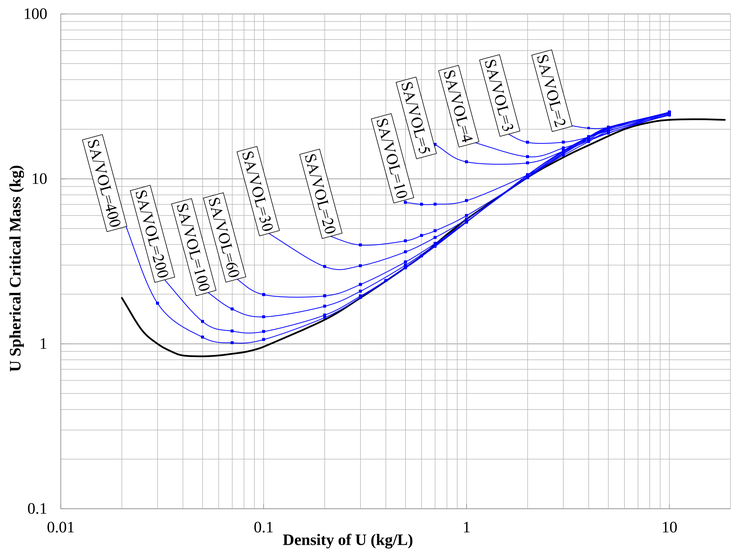

Figure 5 Uranium Results of Arrays of Cubes with varying SA-VOL ratios compared with Data from Figure 10 of LA-10860.

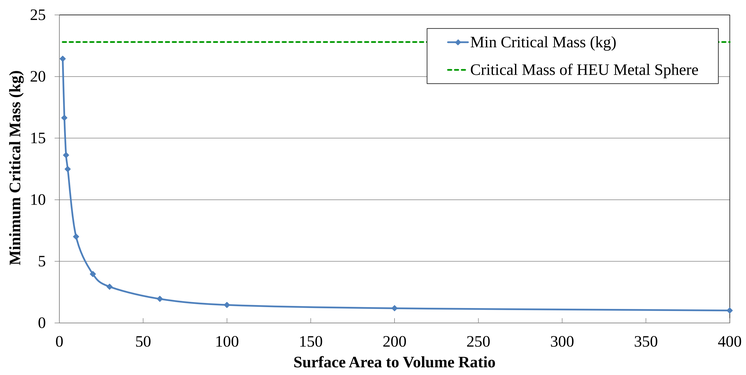

Figure 7 Uranium SA-VOL Ratio vs. Minimum Critical Mass for Reflected Moderated Arrays