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| Title: | Minimum Critical Mass of Heterogeneous Moderated Plutonium Metal Systems |
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| Intended for: | 2015 American Nuclear Society Annual Meeting, 2015-06-07/2015-06-11 (San Antonio, Texas, United States) |
| Issued: | 2015-03-04 |

# Minimum Critical Mass of Heterogeneous Moderated Plutonium Metal Systems

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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 is underway to determine the effect of fissile material piece size/shape on minimum critical mass of a system.

Different piece shapes of fissile material are related using surface area to volume (SA-VOL) ratio. 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.

## DESCRIPTION OF CALCULATIONAL STUDY

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

The analysis performed consists of a parametric study utilizing the neutron transport code MCNP6 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 plutonium 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 shapes were then compared at points with the same plutonium volume density to demonstrate that the key relationship between varying piece shape is SA-VOL ratio. The SA-VOL ratios are captured in Table I.

Table I. SA-VOL Ratios

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

Utilizing the information from Table I a SA-VOL ratio versus critical mass curve is generated. The curve establishes the minimum critical mass for a collection of pieces with a given SA-VOL ratio. Additionally, it determines the minimum SA-VOL ratio for which reactivity increases from moderation cannot overcome reactivity decreases from reduced core density (i.e. separation of material pieces).

## RESULTS

Figure 1 below displays the water reflected data from Figure 31 of LA-10860 with calculation results of water reflected and moderated arrays of spheres, cubes, and rods. The total array volume in each configuration was varied to find the critical mass.

Although the shapes of the pieces differ, those pieces with equal SA-VOL ratios behave the same neutronically in heterogeneous arrays. This is illustrated by the four colored groupings with equal SA-VOL ratios. Note that the dimensions reported are the diameter of spheres and rods and side length of cubes.

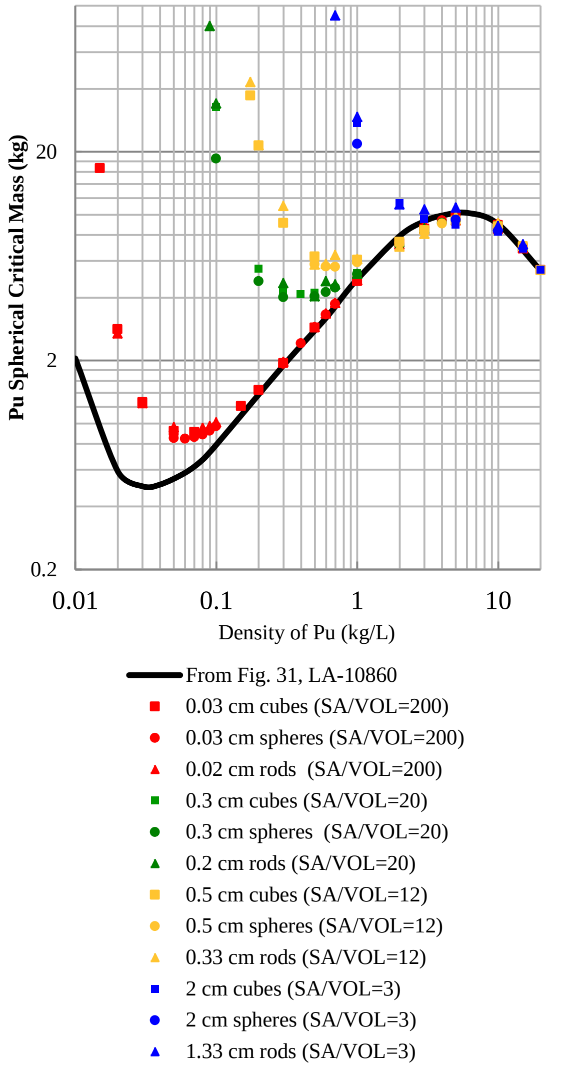

Fig. 1. Results Compared with Data from Figure 31 of LA-10860

As illustrated in Figure 1, as pieces get larger (i.e. more heterogeneous with smaller SA-VOL ratio) the minimum critical mass starts to increase. This effect results from the moderation of neutrons becoming less and less effective due to increased self-shielding of larger individual pieces. Once piece sizes reach a SA-VOL ratio of a certain magnitude the reactivity increase from additional neutron moderation can no longer overcome the reactivity decrease from the reduced core density. At this point the minimum critical mass is achieved when the material is in a solid metal configuration.

A complete set of data is shown in Figure 2 for arrays of cubes with varying SA-VOL ratios. Moving from left to right in Figure 2, the cube size increases and the SA-VOL ratio decreases.

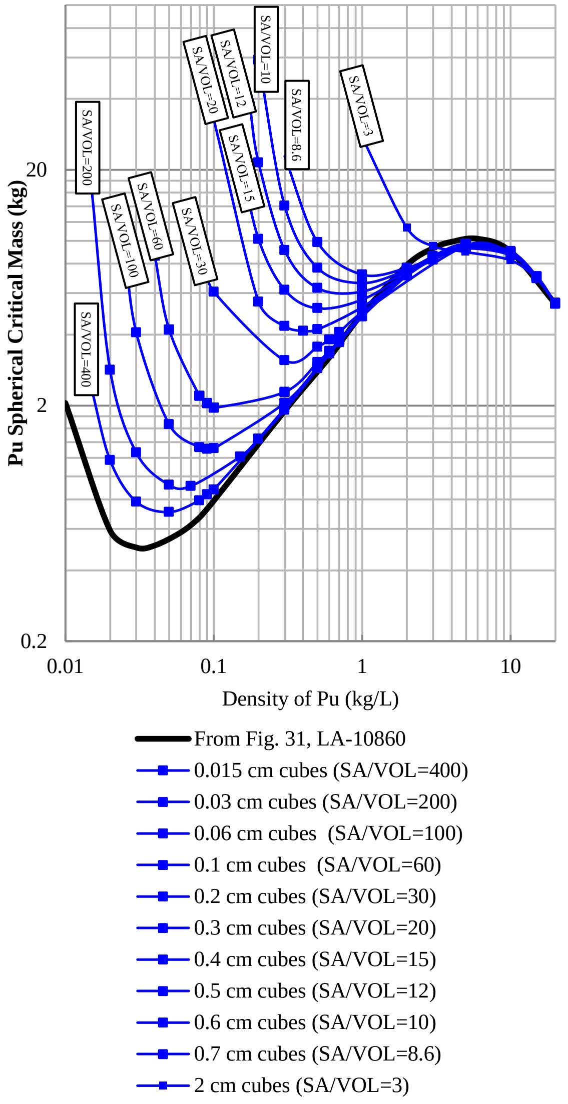

Fig. 2. Results of Arrays of Cubes with varying SA-VOL ratios compared with Data from Figure 31 of LA-10860

Plotting the SA-VOL ratio versus the minimum critical masses in Figure 2, the curve shown in Figure 3 is generated.

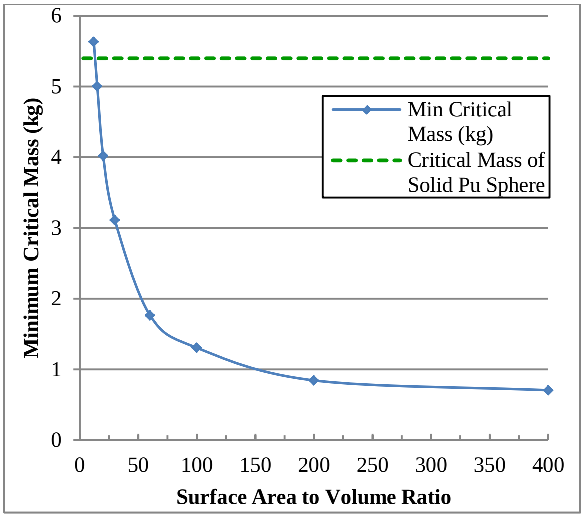

Fig. 3. SA-VOL Ratio vs. Minimum Critical Mass for Reflected Moderated Arrays

Interpolating from the data in Figure 3, an array of material pieces with SA -VOL ratios of 13 represents the point at which reactivity increase from increased moderation and reactivity decrease from reduced core density would be completely balanced. Arrays of pieces that have a SA-VOL ratio < 13 cannot be made more reactive with increased moderation and thus for these pieces, the most reactive configuration is in a solid metal chunk. Arrays of pieces that have a SA-VOL ratio > 13 can achieve more reactivity with increased moderation and thus will be more reactive when optimally spaced in a moderated array.

The data in Figure 3 yields useful insight into the minimum critical mass achievable for an array of material pieces with known SA-VOL ratio and can provide a valuable baseline in future criticality safety analyses.

## REFERENCES

1. "Critical Dimensions of Systems Containing $^{235}$U, $^{239}$Pu, and $^{233}$U," LA-10860, Los Alamos National Laboratory, Los Alamos, NM (1986).