On the SMORES Capability for Minimum Critical Mass Determination

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INTRODUCTION

A new SCALE control module SMORES (SCALE Material Optimization and REplacement Sequence) was recently developed to automate the search for minimum critical mass or for maximum k_{eff}.[1-3] The purpose of the present work is to illustrate the capability of the new SCALE sequence for minimum critical mass (MCM) determination.

DESCRIPTION OF THE ACTUAL WORK

The illustration is done by applying the SMORES sequence to determine the MCM of two types of systems: (A) A system consisting of a single fissile material moderated and reflected by heavy-water; and (B) A system consisting of a single fissile material in combination with two moderating materials – polyethylene (Poly) and beryllium (Be).

Type A systems were found by previous researchers to offer the lowest MCM of a given fissile material when in combination with a single moderating/reflecting material.[4-6] Type B systems were considered in a previous study[7] but considered only ^{239}Pu fissile isotope and used infinite dilution cross-sections.

The MCM search methodology is described in references 1 and 2. In the following we'll focus on the obtained results.

RESULTS

MCM in D_2O

The systems considered are 240 cm in radius spheres of D_2O with several hundred grams of a fissile material. The fissile material is initially uniformly distributed over a central sphere that is 60 cm in radius. The sphere is divided into 120 half-a-centimeter thick zones. The composition across a zone is constant. The optimization variable is the concentration of the fissile material in each of the zones.

Figure 1 illustrates the optimal concentration of ^{235}U in practically infinite D_2O medium. The MCM is found to be 344.84 g ^{235}U. The uranium occupies the innermost 32 cm spherical region, and its concentration monotonously increases towards the center.

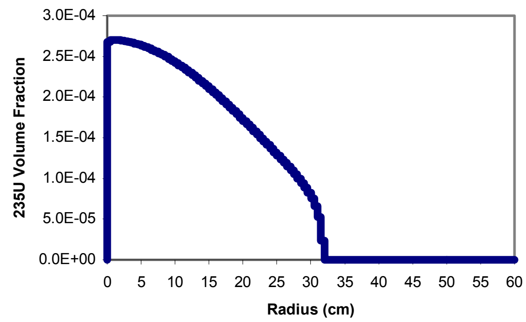

Fig. 1. Optimal ^{235}U distribution in D_2O yielding minimum critical mass of 344.84 g.

A similar analysis done for other fissile materials resulted in 295.60 g for ^{233}U, 204.24 g for ^{239}Pu and 135.96 g for ^{241}Pu. The general shape of the fissile material distribution is similar to that of Figure 1 but the core radius and the peak concentration are fissile material dependent.

The results for the ^{239}Pu – D_2O system can be compared with results reported in reference 5. The minimum critical mass at room temperature was found[5] to be 390 g; it corresponds to a thin shell of ^{239}Pu that is 50 cm in outer diameter and is immersed in a 240 cm cube of D_2O. Heavy-water fills the ^{239}Pu sphere interior as well.

From the close to a factor of two difference in the critical mass it appears that the optimal spatial distribution of ^{239}Pu identified by SMORES is significantly more reactive than that of the spherical shell of reference 5. In order to verify this hypothesis the SCALE sequence used for the SMORES analysis was applied for calculating k_{eff} of thin spherical shells made of

204.24 g of ^{239}Pu in a 240 cm in radius D_2O sphere. The maximum k_{eff} was found to be 0.883 – lower than for the SMORES defined core (k_{eff}=1.0). It corresponds to a shell that is 50 cm in outer diameter.

MCM In Polyethylene and Beryllium

Figure 2 shows the optimal composition of a Type B spherical system composed of ^{235}U, Poly and Be. The system outer radius is 140 cm. The initial composition was a uniform mixture of the three constituents over a central sphere that is 20 cm in radius. This "core" was divided into 0.5cm thick zones. The optimization process segregated the Poly and the Be; the Poly occupying the innermost 8.5 cm and the Be the rest of the system. The critical mass is 201.22 g; significantly lower than with D_2O. The ^{235}U concentration spikes at the interface between the Poly and the Be. A similar phenomenon was observed when using infinite-dilution cross sections.[7]

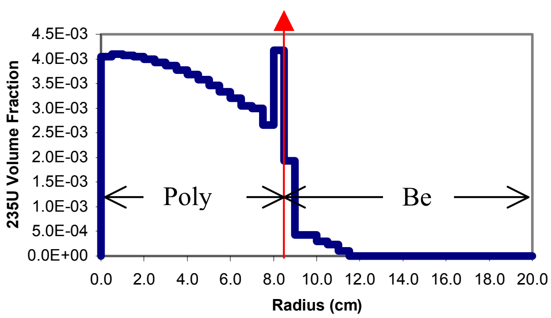

Fig. 2 Optimal ^{235}U distribution with polyethylene and beryllium moderators/reflectors yielding minimum critical mass of 201.22 g.

Similar optimization calculations with SMORES resulted in 151.66 g for ^{233}U and 118.98 g for ^{239}Pu. The latter value is only slightly larger than the 112 g obtained using the infinitly diluted cross sections of the DABL69 library[7].

Concluding Remarks

The new SMORES sequence of SCALE is useful for identifying minimum critical mass. As such it could help the criticality safety community for bounding the MCM or of k_{eff}. A continuous distribution of fissile material in a central sphere in D_2O moderator/reflector gives a higher k_{eff} than a spherical shell made of the same mass. A combination of Poly and Be offer a smaller MCM than attainable with D_2O.

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