HETEROGENEOUS REACTIVITY EFFECTS IN MEDIUM- AND HIGH-ENRICHED URANIUM METAL-WATER SYSTEMS

Jerry J. Lichtenwalter
Computational Physics and Engineering Division
Oak Ridge National Laboratory
Oak Ridge, TN 37831

Submitted to
American Nuclear Society
Nuclear Criticality Safety Division Topical Meeting on
Criticality Safety Challenges in the Next Decade
Chelan, Washington
September 7-12, 1997

The submitted manuscript has been authored by a contractor of the U.S. Government under contract No. DE-AC05-96OR22464. Accordingly, the U.S. Government retains a nonexclusive, royalty-free license to publish or reproduce the published form of this contribution, or allow others to do so, for U.S. Government purposes.

*Managed by Lockheed Martin Energy Research Corp. for the U.S. Department of Energy under contract number DE-AC05-96OR22464.

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.
DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.
HETEROGENEOUS REACTIVITY EFFECTS IN MEDIUM- AND HIGH-ENRICHED URANIUM METAL-WATER SYSTEMS

Jerry J. Lichtenwalter
Computational Physics and Engineering Division
Oak Ridge National Laboratory
P. O. Box 2008
Oak Ridge, TN 37831-6370
(423) 574-4538

I. INTRODUCTION

The effect of heterogeneity on reactivity of low-, medium-, and high-enriched, water-moderated uranium metal systems has been examined for various hydrogen-to-fissile (H/X) ratios using the CSAS1X sequence in SCALE1 and MCNP.2 For the calculations, an infinite array of close-packed unit cells was modeled which consisted of centered uranium metal spheres surrounded by water (see Figure 1).

The enrichments used correspond to the average enrichments of fragmented fuel plates in three proposed waste shipments from Oak Ridge National Laboratory. The analysis performed to obtain peak reactivity for each enrichment as a function of particle size and H/X ratio led to the development of the topic discussed in this paper.

II. ANALYTICAL METHOD

The CSAS1X control module of the SCALE code system invokes the functional modules BONAMI and NITAWL to perform resonance self-shielding calculations and XSDRNPM to solve the one-dimensional (1-D) Boltzmann transport equation. BONAMI and NITAWL include a corrective factor, the Dancoff factor, that is applied to the escape probability from a fuel lump to approximate the effect of the presence of other fuel lumps in the system.

Currently, SCALE treats interaction of the first, second, and third nearest neighbors for a spherical lattice. Interaction to neighbors beyond the third nearest is treated by an approximation based on the untreated solid angle method.3

III. CALCULATIONS

Infinite neutron multiplication factor, $k_\infty$, calculations using the SCALE 238-group ENDF/B-V cross-section library and involving an infinite array of cells were performed where the pitch (and thus H/X) was varied for a particular uranium metal sphere diameter at 8.29, 15.18, 44.93, and 92.98% enrichments. SCALE calculations of infinite homogeneous uranium metal-water mixtures were performed at several H/X ratios for comparison purposes.

By examining the SCALE Dancoff factor at small particle sizes and explicitly modeling the cell in the Monte Carlo continuous energy code MCNP, insight can be gained into the amount of error in a heterogeneous calculation that is attributable to the Dancoff factor. The MCNP models consisted of a uranium metal sphere in a water-moderated cell of various pitch values and a mirror reflection boundary condition (infinite system).
IV. RESULTS

Figures 2 through 5 present $k_e$ values versus $H/X$ (or pitch) for 8.28, 15.18, 44.93, and 92.98% enriched uranium metal spheres in unit cells moderated by water. The figures also provide results of calculations involving infinite homogeneous mediums of uranium metal and water. All $k_e$ values are from the 1-D discrete-ordinates code XSDRNPM unless explicitly specified as Monte Carlo code MCNP calculations.

Two immediate observations from the figures are (1) that the 8.29 and 15.18% enriched uranium exhibits a thermal peak reactivity while the 44.93 and 92.98% enriched uranium exhibits a fast and thermal peak reactivity, and (2) that the thermal peak reactivity approaches the fast peak reactivity as the particle size increases.

Some difficulty in distinguishing the effect of heterogeneity occurs in the SCALE calculations due to a breakdown that is observed in SCALE for the spherical lattice systems when the particle diameter is small (i.e., ~0.02 cm). Small particle systems have a predicted behavior in that they physically approach an infinite homogeneous system. For these systems very near an $H/X$ of zero, the Dancoff factor of SCALE should and does approach 1.0, and the small particle size system reactivity approaches that of the infinite homogeneous system. However, as the $H/X$ ratio begins to increase from its minimum for small particle sizes, a breakdown in the calculation of $k_e$ occurs. The breakdown is a result of a deficiency in the algorithm that calculates Dancoff factors for systems where the fourth and further neighbors become important. Eventually, as the $H/X$ ratio increases, the Dancoff factor begins to approach zero, and the fourth and further neighbors become unimportant as heterogeneous effects become unimportant (the single fuel lump becomes isolated in the moderator). At this point, the reactivity of small particle sizes calculated by SCALE again physically approaches the infinite homogeneous systems calculated by SCALE and the small particle size systems calculated by MCNP.

The MCNP curves follow the homogeneous curves for a 0.02-cm-diam particle more closely than SCALE because MCNP does not rely on a Dancoff correction. The difference in $k_e$ for the small particle MCNP and SCALE homogeneous system calculations may result from code approximations, uncertainty in Monte Carlo calculations, cross sections, etc. The MCNP results are in good agreement with SCALE, and homogeneous system results indicate that the difference between the SCALE 0.02-cm-diam particle system calculations and homogeneous system calculations are principally a result of error in the Dancoff approximation. MCNP predicts about a 1% heterogeneous effect at a particle size of 0.02 cm and SCALE predicts about a 2% effect. The difference is probably attributable to SCALE. This is reaffirmed by the additional MCNP calculations at larger particle diameters. These MCNP calculations agree very well with SCALE since the Dancoff correction for the distant neighbors becomes less important as particle size increases. It is known that the Dancoff factor correction in SCALE has the property of being slightly high for a spherical system so that the bias in $k_{ef}$ will be positive, as seen here.

As the particle size increases, the error in the Dancoff correction decreases. Again, this can be observed from the MCNP calculations with 0.90-cm-diam, 2.0-cm-diam, 1.25-cm-diam, and 1.25-cm-diam particles for 8.29, 15.18, 44.93, and 92.98% enrichments, respectively. The calculated $k_e$ difference between MCNP and SCALE at these diameter particles is significantly less than that for 0.02-cm-diam particles.

For low $H/X$ ratios there is a potential for underestimating reactivity of enriched uranium systems if heterogeneous effects are neglected. It is generally accepted that homogeneous systems are more reactive in the medium- and high-enrichment range for minimum volume (generally occurring around the peak $k_e$) and minimum mass (at an $H/X$ ~ 500 for uranium systems). From the figures, heterogeneous reactivity effects are seen to be negligible above $H/X$ ~ 500; however, heterogeneous reactivity effects would influence the minimum volume system’s reactivity possibly by as much as 10-12% for 8.29% enriched uranium, 5-8% for 15.18% enriched uranium, and 5-7% for 44.93% enriched uranium. If relying on limited moderation (i.e., $H/X < 20$), neglecting heterogeneous effects could underestimate $k_e$ by as much 7% for 15.18, 44.93, and 92.98% enriched uranium.

ACKNOWLEDGMENTS

This research was sponsored in part by the U.S. Department of Energy Laboratory Cooperative Postgraduate Research Training Program at Oak Ridge National Laboratory by the Oak Ridge Institute of Science and Education.

REFERENCES


Figure 2. 8.29% enriched uranium metal spheres in water.

Figure 3. 15.18% enriched uranium metal spheres in water.
Figure 4. 44.93% enriched uranium metal spheres in water.

Figure 5. 92.98% enriched uranium metal spheres in water.