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Impact of Benchmarks on Potential MOX Throughput

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INTRODUCTION

The Oak Ridge National Laboratory (ORNL) has been developing specialized sensitivity and uncertainty computational analysis capabilities as part of the U.S. Department of Energy (DOE) Nuclear Criticality Safety Program (NCSP) Task entitled, Applicable Ranges of Bounding Curves and Data (AROBCAD). Within the AROBCAD task is a requirement to implement the developing capabilities to address DOE production/safety issues. The DOE has a vested interest in assuring cost effective, but safe, process operations with poorly-moderated plutonium and uranium mixed oxides (MOX) that will be encountered at the proposed U.S. MOX Fuel Fabrication Facility undergoing U.S. Nuclear Regulatory Commission licensing. In accordance with the ORNL AROBCAD commitment to DOE to apply these new capabilities, ORNL provided computational sensitivity and uncertainty evaluations in support of a recent Organization of Economic and Cooperative Development (OECD) Nuclear Energy Agency (NEA) *Workshop on the need for integral critical experiments with low-moderated MOX fuels* [1]. This workshop was held to address the need for integral experiments involving low-moderated MOX powder systems. Comparative sensitivity and uncertainty computations were performed for weapons-grade plutonium and uranium oxide (WGMOX) and reactor-grade plutonium and uranium oxide (RGMOX) systems as related to available and proposed critical experiments. This paper presents the results of computational studies to examine the sensitivities, uncertainties, and suggested computational limit penalties relative to MOX powder application characteristics provided in Table 1.

ANALYSIS

The sensitivities of various applications' selected nuclide-reaction pairs were calculated using the TSUNAMI-1D [2] sequence of the SCALE [3] code system. TSUNAMI-1D utilizes the XSDRNPM [4] module to calculate the adjoint and forward fluxes that are then used to calculate the sensitivity coefficients. The most important nuclide-reaction pairs were determined to be ^{239}Pu-fission, ^{240}Pu-capture, ^{235}U-fission, and ^{238}U-capture.

Table 1. MOX powder application characteristics

Parameter	RGMOX	WGMOX
PuO_2 content, wt %	12.5 – 30	6.5 – 22
Powder density, g/cm^3	4.6 – 5.5	5.5
Water content, wt %	3 – 5	1 – 5
Uranium enrichment, wt %	$^{235}U \leq 1.2$	$^{235}U \leq 1.2$
Plutonium composition, wt %	$^{240}Pu \geq 17$	$^{240}Pu \sim 4$

Comparisons between selected applications and critical experiments were evaluated by using the integral indices g [5,6], c_k and E_{sum} [7]. The proposed experiment contains 30 wt% PuO_2 in the RGMOX (25.2 wt% ^{240}Pu) fuel rods that are placed in a 1.07-cm square-pitched 31 by 31 array inside a parallelepiped tank partially filled with water (characteristics of the proposed experiment have been defined in a white paper entitled "Project of Critical Experiments for Nuclear Criticality Codes Validation for Low-moderated 'MOX' Fissile Media" by Institut de Radioprotection et de Surete Nucleaire, Department of Prevention and Studies of Accidents). The comparisons included proposed as well as 95 selected benchmarks from the International Handbook of Evaluated Criticality Safety Benchmark Experiments [8].

SAFE LIMITS

The effect of computational bias and uncertainty as well as the computational penalty on MOX throughput is provided by determining the variance in subcritical volumes as impacted by an accepted subcritical margin in k_{eff} for safety. The penalty assessment methodology used in this work is based on the assumption that a benchmark with a greater sensitivity for the nuclide, reaction and energy group triplet of interest sufficiently covers the triplet in the application. The approach that is used in this method is to determine the differences between the application and benchmark sensitivities for all triplets that are not covered, and to quantify the importance of this noncoverage in terms of its final effect on the k_{eff} value of the application as a computational penalty after utilizing the cross section uncertainties. The percent decrease in volume of MOX powder as a function of percent safety limit (in units of calculated k_{eff}) is shown in Figure 1 for selected RGMOX and WGMOX applications. Assuming the standard deviation of the data that are not in the covariance data file that has been used is 0.15 and standard deviation of χ for ^{238}U, ^{241}Pu and ^{242}Pu is 0.05, computational penalty is 0.3% and 1.0%, respectively (compared against existing benchmarks and the proposed experiment). Corresponding reduction in MOX batch volumes for selected RGMOX and WGMOX applications are 3.9% and 11.5%, respectively. When the standard deviation value if increased from 0.15 to 0.25, the reduction in MOX batch volumes for RGMOX and WGMOX are 7% and 30%, respectively. From these results, it is clear that the bias and uncertainty in the cross sections, or calculated values, or computational penalty affect the volume of safe MOX powder batch considerably. The effects are greater for WGMOX as they are more sensitive to changes in cross sections due to higher ^{239}Pu content.

SUMMARY AND CONCLUSIONS

Based on the range of system parameter values that are characteristic for RGMOX and WGMOX, a total of 36 application configurations (corresponding to the ranges in Table 1) have been investigated for determining the applicability of the proposed experiment to the validation of the low-moderated MOX fuel blending operations.

In addition, the status of existing benchmarks for validation of MOX fuel blending processes has been assessed by determining the computational penalty for the nuclide-reaction sensitivities of the MOX powder systems. Even the highest computational penalty is <1% of the calculated k_{eff} value, because most of the cross sections for the nuclides in these systems are known with small uncertainty.

Larger safely subcritical k_{eff} limits affect allowable safe MOX powder volumes considerably. Experiments that can provide good bases for similarity can reduce the computational penalty as well as provide additional sources for reducing bias and uncertainty associated with the calculation of the k_{eff} of MOX powder applications.

Finally, the tools that have been used to assess the utility of the proposed benchmark can also be used to improvise any proposed experiments or evaluate other experiment designs in order to better fit the applications for validation purposes.

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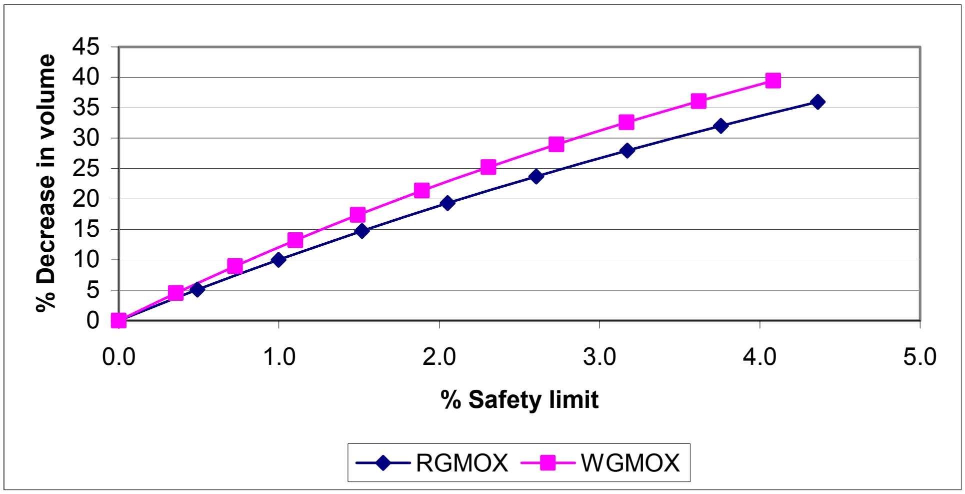

Figure 1. Percent decrease in volume as a function of percent safety limit