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Summary

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## **Value Rankings of Selected Critical Experiments for Burnup Credit Validations**

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# Value Rankings of Selected Critical Experiments for Burnup Credit Validations

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## Introduction

Key elements in proposed burnup-credit (BUC) criticality safety applications are the validation of spent fuel isotopic predictions and actinide/fission product cross sections. Isotopic assay data is available and a number of assessments have been generated with respect to validation of isotopic concentrations in spent fuel. However, the generation of critical experiments with spent fuel has been largely stymied in the U.S., while most of the foreign experiments remain proprietary. In this work, a series of analyses were performed in order to evaluate the relevance of various existing and proposed experimental programs with respect to BUC criticality safety validation. These experimental programs include the French critical experiments with HTC pins,<sup>1</sup> which simulate the actinide concentrations of burned spent fuel (37 GWd/MTU) without the presence of fission products and the Valduc<sup>2</sup> fission product solution experiments in which fission products are individually placed into solutions at the center of an experimental core. Other experiments analyzed include the use of doped fission product worths from the CERES/MINERVE<sup>3</sup> program, the ANL(NRAD) program,<sup>4</sup> the REBUS program<sup>5</sup> in Belgium, the PROTEUS program<sup>6</sup> in Switzerland, and the NERI-sponsored program<sup>7</sup> at SNL in the U.S.

The analysis of the French HTC set of experiments is incomplete, however, the results are felt to be representative of the overall set. Five of the HTC experiments were analyzed using

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approximate models, since the details are not available due to their proprietary nature.

Approximately 150 HTC experiments have been performed including arrays in pure water, arrays in poisoned water, pool storage configurations, consolidated pool storage configurations, shipping cask configurations, and mixed arrays of HTC and UO<sub>2</sub> pins. Only the “array in pure water” configurations were included in this study.

The Valduc fission product solution experiments are designed to measure the integral worth of individual fission product isotopes by placing cans of fission-product-bearing solutions at the center of an experimental core. The publicly available results included in this work are from a single experiment<sup>2</sup> with <sup>149</sup>Sm. Approximately ten <sup>149</sup>Sm experiments will ultimately be available, however, this study treats the single experiment as representative of the entire set. The proposed experiments in the NERI-sponsored program at SNL are similar in nature to the Valduc fission product solution experiments, except that the former program uses thin fission product foils that are integral to the fuel pins.

### **Methods of Comparison**

A newly-developed approach to validation<sup>8</sup> utilizes two different parameters as measures of applicability; one is a global measure for system-to-system applicability ( $c_k$  value), the other is a nuclide-specific measure of applicability ( $T$  value). These parameters are based on sensitivity and uncertainty analysis (S/U) techniques currently under development at ORNL as part of the DOE Nuclear Criticality Safety Program (NCSP). Where specific models of these experiments were not available, or not available in sufficient detail, comparison was performed by examination of the estimated worths of the various fission products with respect to their worth in a cask-type environment.

### **Results**

The  $c_k$  values for the HTC experiments indicate a high degree of applicability to a series of infinite pin-cell calculations for burnups ranging from 10–60 GWd/MTU. The  $T$  values also

indicate a high degree of applicability for the primary plutonium isotopes for burnups less than 60 GWd/MTU. Thus, these experiments are beneficial to BUC validation efforts.

The Valduc fission product experiments are evaluated using only the nuclide-specific  $T$  parameters. This is because the system-to-system parameters are not currently appropriate for fission-products due to the lack of uncertainty data on the fission product cross sections. Also an examination of the  $T$  values is performed only for  $^{149}\text{Sm}$ , since this is the only experiment in the open literature.

The  $T$  values obtained for the single Valduc experiment indicated that it is highly applicable to  $^{149}\text{Sm}$  capture in the series of pin-cell applications for 10–60 GWd/MTU. This indicates that the fission product solution experiments should be good experiments for validation of the fission products in a cask environment. These fission product solution experiments are valuable in that they allow for the effect of individual fission product cross section uncertainties on the system  $k_{\text{eff}}$  to be evaluated separately. This information is useful in combination with the additional data derived from the CERES-type measurements with doped-fission products, where the contribution of fission product cross section uncertainties to the worth of the fission product itself is obtained. The CERES-type measurements are very sensitive to the fission product cross section uncertainties, however, the Valduc-type experiments have fission product cross section sensitivities that are nearly the same as those in an actual cask environment. The NERI experiments were not explicitly modeled, however, based on their similarity to the Valduc experiments, the conclusions are expected to be similar as well.

The details on the configurations for the REBUS, PROTEUS, and ANL(NRAD) are not currently available. Thus, the relative importance of these experiments for BUC validation will be based on the predicted reactivity changes relative to those in a spent fuel cask. In order to put the relative rankings of these experiments in perspective, the units of the predicted reactivity will be in percent mil (PCM) which corresponds to a  $\Delta k$  of  $10^{-5}$ .

Using infinite-pin arrays to simulate a cask environment, the fission products cumulatively represent a negative worth of about 15000 PCM (15% in k-eff). The major fission products (FP) are typically worth about 1000 PCM each. It is desirable that the experimental worths be the same order of magnitude, particularly in this case because of the desire to analyze the experiments with Monte Carlo. The three experimental programs mentioned above are currently planning on measuring only the lumped FP worths, not individual FP worths. Therefore, the target worths should be in the 15000 PCM range. The predicted values for REBUS, PROTEUS, and ANL(NRAD) are 1000–2000, 10–100, and 10–20 PCM, respectively. Thus, even the most sensitive experiment, REBUS, is still about an order of magnitude below the target reactivities. Further work is needed to understand how these experiments may be best utilized.

In summary, a prudent approach to BUC validation should involve assay data validation, followed by cross section validation for the actinides and fission products. The existing MOX fuel criticals combined with French HTC experiments are believed to be sufficient for actinide-only cross section validation purposes. Applications that take credit for fission products additionally need to validate individual fission-product cross sections. Validation is best accomplished by a combined approach of large-sample, individual fission product worth measurements, like the Valduc or NERI experiments and the small-sample, individual doped-fission product worth measurements like CERES/MINERVE. The remaining REBUS, PROTEUS, and ANL spent-fuel-sample worth experiments may be useful as an overall check on the reactivity effects of spent fuel.

While not explicitly included in this study, the use of commercial reactor critical (CRC) experimental data in BUC validation was briefly explored. A single CRC case indicated that the use of this type of experiment showed promise and should be investigated further.

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