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END EFFECTS IN THE CRITICALITY ANALYSIS OF BURNUP CREDIT CASKS*

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M. C. Brady and C. V. Parks
Computing and Telecommunications Division
Oak Ridge National Laboratory
Oak Ridge, Tennessee

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INTRODUCTION

A study to evaluate the effect of axially dependent burnup on k_{eff} has been performed as part of an effort to qualify procedures to be used in establishing burnup credit in shipping cask design and certification.

AXIALLY DEPENDENT ANALYSES

This study was performed using a generic 31-element modular cast-iron cask (wall thickness 33.1 cm) with a 1-cm-thick borated stainless-steel basket for reactivity control. (Detailed specifications of the cask model are given in ref. 1.) Fuel isotopics used here are those of the 17 × 17 Westinghouse assemblies from the North Anna Unit 1 reactor. Virginia Power (VP) provided detailed spatial isotopics for the fuel assemblies in-core at beginning-of-cycle 5 (BOC-5) as generated from their PDQ analyses.[2] Twenty-two axial planes were defined in the original VP data. The isotopics used in this study were for a 3.41 initial wt % ^{235}U and an average burnup of 31.5 GWd/MTU.

Case Descriptions

KENO V.a was used to calculate k_{eff} in the water-filled cask for the five cases:

1. Number densities were averaged over the entire height of the fuel representing the average burnup case (31.5 GWd/MTU).
2. Three nearly equal axial regions were defined: 114.3, 137.16, and 114.3 cm. The appropriate number densities were volume weighted over each of these regions to represent the average burnup for each region (i.e., 30.7, 34.6, and 28.5 GWd/MTU).
3. The three axial regions defined in this case isolated the ends of the fuel as separate regions: 34.29, 297.18, and 34.29 cm. Again, the number densities were volume weighted over each interval to represent an average burnup for each region yielding values of 23.0, 33.8, and 20.1 GWd/MTU.
4. Seven axial regions were defined with lengths of 11.43, 34.29, 68.58, 137.16, 68.58, 34.29, and 11.43 cm. The average burnups calculated for each of these regions were 16.9, 27.8, 34.4, 34.6, 32.7, 24.9, and 14.4 GWd/MTU, respectively.
5. Fifteen axial regions of length(cm)/burnup(GWd/MTU) were defined as follows: 5.74/15.7, 5.74/18.2, 11.43/23.4, 11.43/28.6, 11.43/31.5, 22.86/33.5, 22.86/34.8, 182.90/34.5, 22.86/33.1, 22.86/31.2, 11.43/28.6, 11.43/25.5, 11.43/20.5, 5.74/15.7, and 5.74/13.2.

The geometry model for the cask included pin-by-pin descriptions of each fuel assembly in the 31-element cask. Each of the KENO V.a cases was performed with ~300,000 particle histories in order to achieve the proper convergence. These results are given in Table 1.

Results

The largest value of k_{eff} was calculated for the 3-plane case (case 2) in which the fuel was divided into nearly equal parts. In the large midsection, the value of average burnup closely represents the true burnup since only small changes in burnup occur in this region. However, the burnup for the large end regions is underestimated because of the influence of the rod tips. In case 3, where the tips are more isolated, the effect is decreased yielding a lower value of k_{eff}. Recall that the lower burned fuel is more reactive. Increasing the number of axial zones at the ends where the burnup is varying sharply should result in more accurate representations of the burnup and, therefore, k_{eff} values.

Note that k_{eff} is a global parameter, and that although some differences are seen in Table 1 for the different axial analyses, they are small. The results for the 7- and 15-plane cases are statistically the same. The change in k_{eff} for the 1-plane case to the 15-plane case is just over 1%. The largest difference is that between the 1-plane case and the 3-equal-axial-plane case (<1.5%).

HYPOTHETICAL CASK REFLOOD EVENT

Concern has been expressed that the relatively unburned ends may pose a criticality hazard when the cask is flooded. It has been shown that in a cask design with no fixed poison, modeling the tips as a 1-ft region of fresh fuel (>1.55 wt % ^{235}U), a criticality event can occur when the cask is hypothetically flooded.[3] The generic 31-element cask design used in this study was subjected to these conditions. Isotopics for the one foot of fresh fuel at the assembly tips were those taken from the VP-PDQ results for 3.6 wt % ^{235}U. Fuel isotopics used for the remainder of the fuel assembly were for 3.41 wt % ^{235}U and 31.5 GWd/MTU. The resulting k_{eff} for this cask model under these conditions was 0.9787 ± 0.0011. It is impossible that fuel assemblies satisfying the burnup requirements expected for burnup credit casks could have a foot of unburned fuel at the tips.

A calculation representing a more realistic flooding transient was performed. In this analysis, the 15-plane cask model described as case 5 was used. The cask reflood scenario was modeled by evaluating the static k_{eff} as a function of water height as each axial region was successively filled with water from the bottom up. The results for this analysis are given in Fig. 1. Note that k_{eff} reaches 93% of the fully flooded value at a water height of 34.46 cm. The overall analysis shows k_{eff} asymptotically approaching the fully flooded value as a monotonic function of water height. No reactivity peaks were noted.

CONCLUSIONS

It appears that the effort and expense required to model multiple axial planes might be safely circumvented by performing analyses for a single axial plane (average conditions) and simply adding 2 or 3% to the calculated k_{eff} as a bias for axial effects. Additional axial studies reported in refs. 1 and 4 also substantiate these conclusions.

REFERENCES

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4. S. E. Turner, "An Uncertainty Analysis – Axial Burnup Distribution Effects," Proceedings of a Workshop on the Use of Burnup Credit in Spent Fuel Transport Casks, ed. T. L. Sanders, Washington, DC, February 21–22, 1988, SAND89-0018, TTC-0884, UC-820, October 1989.

Table 1. KENO V.a results for axial study of 31.5 GWd/MTU fuel

Case	Number of axial planes	k_{eff}
1	1	0.8583 ± 0.0013
2	3	0.8717 ± 0.0012
3	3	0.8613 ± 0.0012
4	7	0.8676 ± 0.0012
5	15	0.8664 ± 0.0011

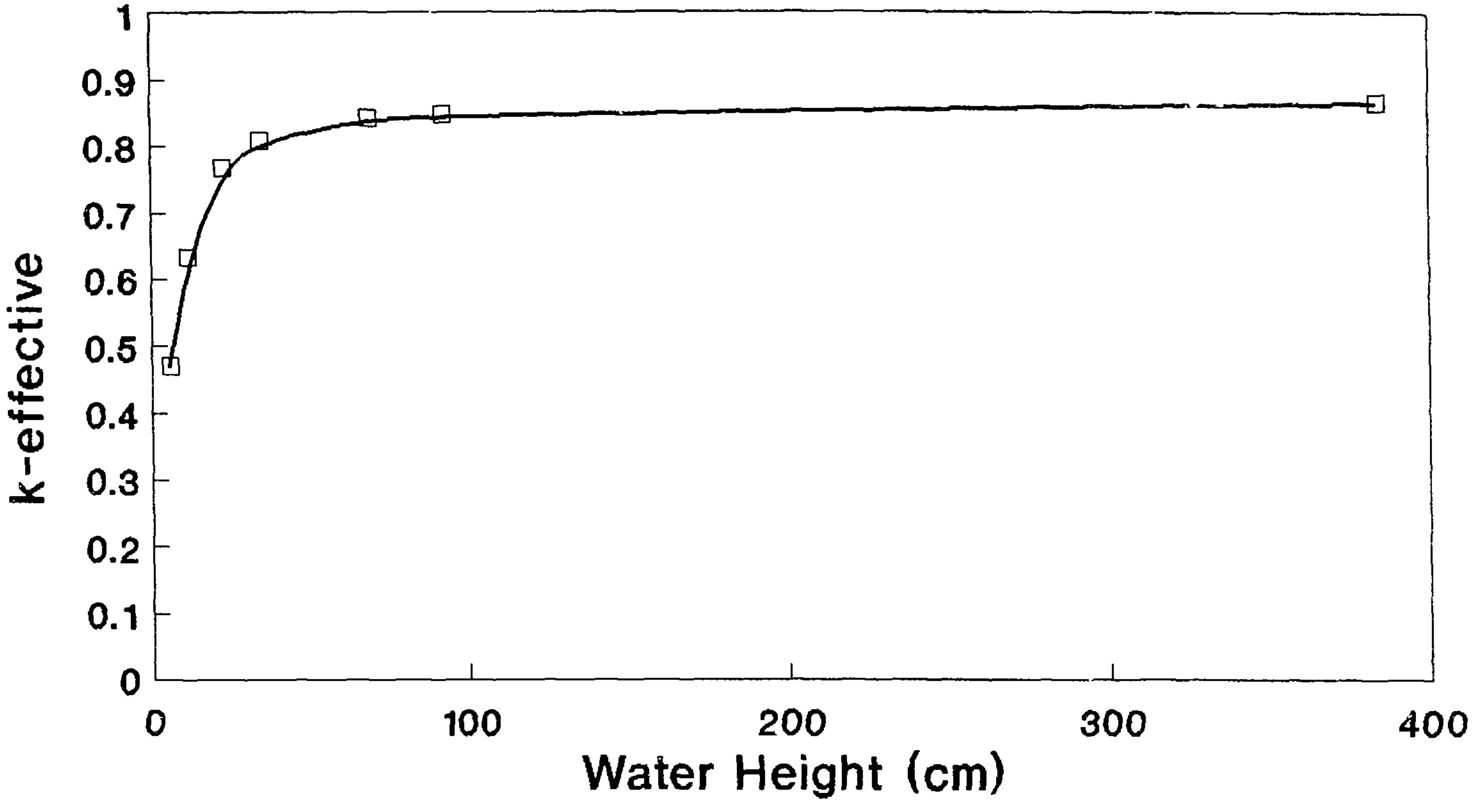

Fig. 1. k_{eff} results from cask reflooding event.