MACROSCOPIC CROSS SECTIONS FOR THE MANAGEMENT
OF WEAPONS-GRADE Pu FUELS IN BWRs

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One possible method to reduce the enrichment of the surplus of weapons-grade plutonium is to
irradiate mixed oxide fuels (MOX) in commercial nuclear reactors like the boiling water reactors built by
General Electric. Contributions to evaluate this possibility are currently made by the Oak Ridge
National Laboratory (ORNL) and its contractors. Because important decisions are to be made based on
calculations, our calculational procedures, in particular the two-dimensional Scandpower proprietary
code HELIOS, were benchmarked against available experience with near weapons-grade Pu fuel and
against other codes.

In this work we report our calculations of diffusion theory macroscopic cross section as function of
burnup, for different combinations of operational parameters. These results are to be input later to the
code FORMOSA-B, developed at North Carolina State University (NCSU), to study fuel management
strategies in the long range operation of BWR's with MOX fuels. Seventeen cases for various conditions
of the fuel assemblies were specified by NCSU. These correspond to different combinations of void
fractions, fuel temperatures, control rods and history. The middle section of the 9x9 rods MOX fuel
assembly for GE-11 BWR design is shown in Fig. 1.
In the whole assembly, seven rod positions are occupied by two water rods, so for the middle section of the assembly there are in fact 74 rods (26 MOX rods, 32 UO$_2$ rods and 16 UO$_2$-Gd rods). The figure was produced by the ORION module of the HELIOS code and shows that the details of the calculations follows the real geometry of the assembly including the complexities of the control rods. The curvilinear and straight segments in Fig. 1 shows not only the different regions of the assembly, but also the nodalization for the collision probability algorithm used by HELIOS to solve the transport equations, particularly remarkable is the radial nodes included in the Gd pins. The assembly has 3 axial regions, beside the Middle, already described: Upper (18 MOX rods, 8 vanishing rods, 32 UO$_2$ rods and 16 Gd rods), and Lower (like the Middle, but with higher concentration of Gd) so the 17 cases defined by NSCU must be computed for each of the three axial regions. In summary a label which is a combination of all the parameters described above has to be attached to each cross section set.
Calculations corresponding to the $k_{inf}$ of the uncontrolled middle assembly were compared with GE calculations published in Ref. 1. The results are shown in Fig. 2 as function of burnup, the main difference is around the peak in $k_{inf}$ produced by the burning of the Gd rods, a region particularly sensitive to the effects of the leakage on the neutron spectra, and in general the agreement is good.

![Figure 2](image)

**Fig. 2.** Differences in the calculation of $k_{inf}$ as function of burnup for the uncontrolled middle assembly at 40% void fraction. The crosses are for the set without upscattering at 3 eV.

Two energy group cross sections were collapsed from the 34-energy groups, ENDF/B-VI based, HELIOS calculations to be used later with FORMOSA-B. To avoid upscattering between groups, a 3 eV upper limit for the thermal group was chosen. The burnup grid contains 37 points: 9 between 0 and 200 MWd/t in steps of 25 a region sensitive to Sm transients, 20 between 1,000 and 20,000 MWd/t in steps of 1,000, a region sensitive to Gd burnup transients, and 8 between 25,000 and 60,000 MWd/t in steps of 5,000 beyond the Gd region. Routine checks were done with the collapsed set by recalculating $k_{inf}$, critical bucklings and migration lengths and comparing them with the original 34 groups calculations. As reference for the future macroscopic calculations a comprehensive set of data were collected for each
case and include, beyond a mere cross section library, data such as: burnup maximum and location in the bundle, burnup map, power maximum and location in the bundle, power map, delayed neutron data, Xe and Sm edits, average bundle isotopics, pin-per-pin isotopics, and isotopics per pin type. In conclusion, a very detailed library of cross sections was generated for the fuel management of weapons-grade MOX fuels in BWR's. The sophistication of the calculation procedure coded in HELIOS made possible to run very realistic 2-D models. Good agreement with General Electric proprietary physics methods has been shown.

REFERENCES


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