An Alternative to the SAS2H/ORIGEN-S Sequence to Account for Water-Density Effects in BWR Systems

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An Alternative to the SAS2H/ORIGEN-S Sequence to Account for Water-Density Effects in BWR Systems

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A scheme to generate one-group problem-dependent cross-section libraries for point-depletion calculations with the ORIGEN-S code was developed as an alternative to the SAS2H sequence of the SCALE code system. The methodology, named Automatic Rapid Processing (ARP), generates libraries by interpolating in SAS2H precomputed cross section libraries. The method has been used to generate ORIGEN-S cross section libraries on a personal computer resulting in a great reduction of computer time without a sacrifice of accuracy over that required by corresponding SAS2H calculations. The ARP scheme generates ORIGEN-S libraries by interpolating in burnup and enrichment for PWR assemblies. The intent of this work is to describe a procedure which extends the application of the ARP methodology to BWR assemblies by including the axial water-density effects in the generation of the ORIGEN-S cross-section libraries. The axial liquid-to-steam change of state in BWR systems leads to a variation in the water density and significant cross-section changes as a function of the water density. To account for the axial water-density changes in a SAS2H calculation, the water density is entered explicitly in the generation of the one-group ORIGEN-S cross-section libraries generated from the SCALE 27-group library. In its original version, ARP does not account for the effects of water-density variation in ORIGEN-S cross-section library generation, and, therefore, its application is restricted to systems for which the impact of this parameter is negligible.

To update the ARP methodology to account for the water-density effect, a detailed study of the cross-section change with this parameter was performed with an 8×8 (General Electric) BWR assembly. The SAS2H sequence was used to compute ORIGEN-S cross-section libraries at various water densities. ORIGEN-S cross-section libraries were created for axial water densities varying from 0.2 g/cm³ to 0.9 g/cm³ in steps of 0.1 g/cm³. The strategy adopted consisted of defining a function \( f(p) \) as the ratio of the cross sections calculated at water density \( p \) to the cross section \( \sigma_{ref} \) calculated at a density of 0.2 g/cm³:
A one-cycle SAS2H calculation was performed for a total burnup of 60.0 GWd/MTU with 21 libraries per cycle, including fresh fuel cross sections and for 5 enrichments; namely 1.5, 2.0, 3.0, 4.0, and 5.0 wt % of $^{235}$U. The variation of the $f(p)$ versus $p$ for hydrogen absorption cross sections at 5 burnups and a specific enrichment of 3.0% is indicated in Fig. 1. In ORIGEN-S, the effective one-group cross section is constructed such that its product with the thermal flux is equal to the reaction rate over the entire energy range. With increasing moderation, the thermal flux increases faster than the reaction rate, and for most reaction types (e.g., $1/v$ absorption), the effective cross section decreases.

In addition to $p$, the function $f$ is also a function of burnup ($b$) and enrichment ($e$); that is, $f(b,e,p)$. A multinomial fit of this function was performed in the following manner: for a constant enrichment and burnup, the change of $f$ with $p$ was fitted to a fourth-order polynomial; subsequently, each of the 5 coefficients was fitted to a fourth-order polynomial in burnup; finally, each of the five burnup coefficients was fitted to a second-order polynomial in enrichment.

In the approach presented here, ARP generates ORIGEN-S cross-section libraries for a specified axial water density $p$, as follows:

1. first, interpolate in burnup and enrichment within the basic cross section libraries generated at the reference axial water density, to obtain the reference cross section for each isotope, $\sigma_{ref}$;

2. subsequently, for each isotope, compute the function $f(b,e,p)$ from the multinomial fitting parameters;

3. finally, compute the cross section at water density $p$ as

$$f(p) = \frac{\sigma(p)}{\sigma_{ref}}.$$
\[
\sigma(b,e,\rho) = f(b,e,\rho) \sigma(b,e,\rho_{ref})
\]

As can be seen, the function \( f \) acts as a correction factor to the cross section calculated at the reference density to give the cross section at the desired water density.

To verify the adequacy of the method, a series of SAS2H calculations for the 8 x 8 BWR assembly were performed at four water densities, an enrichment of 3 wt % \(^{235}\text{U}\), irradiated for 880 days with a specific power density of 37.5 MW/MTU, and five libraries generated per the cycle. The ARP methodology was then used to generate ORIGEN-S libraries for assemblies with the same burnups, enrichment, and irradiation history. Table 1 shows comparisons of the nuclide concentrations calculated with the ORIGEN-S code at the end of the cycle using libraries generated by SAS2H and ARP. The results indicate that the enhanced ARP methodology reproduces the SAS2H calculations very well.

REFERENCES


Table 1. Comparisons of calculations by SAS2H and ARP method of spent fuel isotopics for four water densities

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<thead>
<tr>
<th>Water density (g/cm³)</th>
<th>Nuclide concentrations (gram-atom)*</th>
<th>0.3</th>
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<td>ARP</td>
<td>SAS2H</td>
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<tr>
<td>235U</td>
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</table>

*The fuel was irradiated for 880 days with a burnup of 33,000 MWd/MTU.

**Read as 3.44 × 10^1.**
Fig. 1. Function $f(\rho)$ for hydrogen for five burnups.