The Effect of Different Nuclear Data on the Calculated Sodium-Void Coefficient in Advanced Fast Reactors

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1 Abstract

In the framework of the PSI/CEN cooperation on physics of plutonium recycling in fast systems, criticality and sodium-void coefficient calculations were performed for a reference experiment in the MASURCA facility, using different data libraries. The sodium-void coefficient has been determined for the voidage of the full height (60 cm) of the 4 central fuel assemblies. In addition, partial voidage has been considered, where two thirds (40 cm) and one third (20 cm) of the full core height have been voided from the inside to the outside, as well as the top and bottom 10 cm.

2 Methods and Data Used

The PSI code system has been used.

1. The required basic nuclear data was systematically generated with NJOY (Version 89.62, including a modification in RECONR to the p-wave capture in structural materials suggested by Rowlands and Eaton) and the JEF-2.2-evaluation. For ^{23}Na, ^{56}Fe, ^{238}U, ^{239}Pu, ^{240}Pu, and ^{241}Pu, additional data from the American, Japanese, and Russian evaluations, i. e. from ENDF/B-VI (Rev. 2), JENDL-3.2, and BROND-2.1 were considered.

2. The coupling and reformatting code MICROR was used to produce suitable pointwise and fine group data for the cell calculations (24362 points in the resonance range between 8 keV and 2eV, equally spaced in velocity, and 92 fast and epithermal groups).

3. These data were used with the spectrum cell code MICROX-2 and led first to the generation of regionwise coarse group data. Hereby, 6 different cell types (representing inner and outer fuel zones, axial, radial blankets and reflectors) have been considered. The surrounding stainless steel frame of the fuel assemblies has been smeared into the moderator (sodium) region. The cell calculations were performed in the fundamental mode spectrum. As in the past, we have considered the standard coarse energy structure for fast breeder reactor calculations (33 broad groups), including 30 fast and epithermal groups below 15 MeV, mostly equally spaced in lethargy (lethargy width is 0.5).

4. In the voided and non voided fuel regions, the regionwise cross sections (vectors and matrices) were then homogenized in the radial direction using the code MIX in connection with fluxes, currents, and second moment Legendre expansions of the flux. These resulted from a two-dimensional, axially homogeneous, cylindrical, critical assembly calculation with exactly the cell composition in the radial direction. Hereby, for each of the cases analyzed, a critical height search had to be performed first.

   The direct calculation of the required spatially dependent flux moments (in the current PSI-version of the code MICROX-2) was found to be inadequate for treating such cells in which fuel and moderator macroscopic cross sections are very different.

5. In the blanket regions, the radial homogenization was performed using fluxes, currents, and second moment Legendre expansions of the fluxes, resulting from an additional one-dimensional calculation of the cell with an arbitrary "small" buckling, so as to avoid vanishing total anisotropic cell fluxes: No significant sensitivity of the results was found to this buckling, particularly even if the (large) negative critical buckling was used instead.

6. In the reflector regions, the cross sections came directly from a homogeneous MICROX-2 calculation.

7. Core calculations were finally carried out with the diffusion- /transport-theory (burnup) code 2DTB (TWODANT for transport calculations, 2DB for diffusion calculations), using 65 fine meshes in the x- and 61 fine meshes in the y- directions. P_2S_8 was used.

8. Additionally, a complete series of sensitivity coefficient calculations were performed with the exact perturbation method for carefully assessing the important sensitivity of the sodium-void coefficient to the ^{238}U inelastic cross section in the fuel region (see Figure 1). Using a suitably updated version of the MICROR code, the required cross sections to be perturbed, calculated as the sum of all available inelastic level matrix cross sections for a given incident group, were doubled before performing the cell calculations. Correspondingly, the total cross section was modified to match the sum of (n,2n), (n,3n), capture, fission, elastic and inelastic scattering cross sections (calculated from the matrices).

   As a result of this methodology, the important spectral changes in the unit fuel cell were accounted for in the modification of the coarse group cross sections.

3 Discussion

3.1 k_{eff}

1. Except for the Russian evaluation in general, for ^{238}U from ENDF/B-VI (Rev. 2), and for ^{56}Fe from JENDL-3.2, the predicted eigenvalues k_{eff} are weakly sensitive to the nuclear data used.

2. The impact of the different ^{56}Fe (elastic scattering) cross sections on k_{eff} (see Table 1) is less pronounced than in similar systems in which the blankets were removed, because a smaller amount of neutrons are scattered back into the core.

3.2 Sodium-Void Coefficient

1. No significant impact of the iron cross sections has been observed (see Table 1).

2. Except for the Russian file, the sodium-void coefficient is weakly sensitive to the use of different sodium data (see Tables 2-5), although the American, Russian, and European/Japanese evaluations seem to base on different experimental data.

3. The Russian evaluation in general, and ^{239}Pu in particular, do not seem to be too adequate and are not recommended for these kinds of calculations (see Tables 6-9).

4. The simultaneous use of Japanese data for heavy nuclides instead of JEF-2.2 data would possibly reverse the sign of the computed full height sodium-void coefficient and lead to improved predictions for partial voidage as well (see Tables 6-9). It has been found that the absorption component of the sodium-void coefficient becomes systematically smaller, if Japanese data is used for heavy nuclides.

4 Results

^{56}Fe Data From	k_{eff}	Na-Void Coefficient (C/E)
JEF-2.2	1.0118	-1.327
ENDF/B-VI (Rev. 2)	1.0119	-1.327
JENDL-3.2	**1.0134**	**-1.391**
BROND-2.1	1.0111	-1.291

Table 1: Multiplication Factor k_{eff} and Ratio of Calculated to Measured Sodium-Void Coefficients (Voided Height is 60 cm) Obtained Using JEF-2.2 Data. ^{56}Fe Data from Different Evaluations in the Radial Blanket Region

Voided Height (cm)	Na-Void Coefficient (C/E)
20	1.016
40	1.171
60	-1.327
10-10 (ext.)	+0.739

Table 2: Ratio of Calculated to Measured Sodium-Void Coefficients Obtained Using JEF-2.2 Data and the Reference Method (k_{eff}=1.0118)

Voided Height (cm)	Na-Void Coefficient (C/E)
20	0.978
40	1.125
60	-1.264
10-10 (ext.)	0.714

Table 3: Ratio of Calculated to Measured Sodium-Void Coefficients Obtained Using JEF-2.2 Data and the Reference Method. **Sodium from ENDF/B-VI (Rev. 2)** (k_{eff}**=1.0115**)

Voided Height (cm)	Na-Void Coefficient (C/E)
20	1.029
40	1.187
60	-1.336
10-10 (ext.)	0.750

Table 4: Ratio of Calculated to Measured Sodium-Void Coefficients Obtained Using JEF-2.2 Data and the Reference Method. **Sodium from JENDL-3.2** (k_{eff}**=1.0120**)

Voided Height (cm)	Na-Void Coefficient (C/E)
20	1.067
40	1.259
60	**-1.964**
10-10 (ext.)	0.716

Table 5: Ratio of Calculated to Measured Sodium-Void Coefficients Obtained Using JEF-2.2 Data and the Reference Method. **Sodium from BROND-2.1** (k_{eff}=**1.0112**)

^{238}U Data From	k_{eff}	Na-Void Coefficient (C/E)
JEF-2.2	**1.0118**	**-1.327**
ENDF/B-VI (Rev. 2)	**1.0148**	**-1.009**
JENDL-3.2	**1.0123**	**-0.545**

Table 6: Multiplication Factor k_{eff} and Ratio of Calculated to Measured Sodium-Void Coefficients (Voided Height is 60 cm) Obtained Using JEF-2.2 Data. ^{238}U from Different Evaluations

^{239}Pu Data From	k_{eff}	Na-Void Coefficient (C/E)
JEF-2.2	**1.0118**	**-1.327**
ENDF/B-VI (Rev. 2)	1.0113	-1.191
JENDL-3.2	**1.0129**	**-0.336**
BROND-2.1	**0.9949**	**-2.500**

Table 7: Multiplication Factor k_{eff} and Ratio of Calculated to Measured Sodium-Void Coefficients (Voided Height is 60 cm) Obtained Using JEF-2.2 Data. ^{239}Pu from Different Evaluations

^{240}Pu Data From	k_{eff}	Na-Void Coefficient (C/E)
JEF-2.2	**1.0118**	**-1.327**
ENDF/B-VI (Rev. 2)	1.0133	-1.073
JENDL-3.2	**1.0114**	**-1.300**
BROND-2.1	1.0142	-0.973

Table 8: Multiplication Factor k_{eff} and Ratio of Calculated to Measured Sodium-Void Coefficients (Voided Height is 60 cm) Obtained Using JEF-2.2 Data. ^{240}Pu from Different Evaluations

^{241}Pu Data From	k_{eff}	Na-Void Coefficient (C/E)
JEF-2.2	**1.0118**	**-1.327**
ENDF/B-VI (Rev. 2)	1.0120	-0.764
JENDL-3.2	**1.0121**	**-0.872**
BROND-2.1	1.0119	-0.545

Table 9: Multiplication Factor k_{eff} and Ratio of Calculated to Measured Sodium-Void Coefficients (Voided Height is 60 cm) Obtained Using JEF-2.2 Data. ^{241}Pu from Different Evaluations

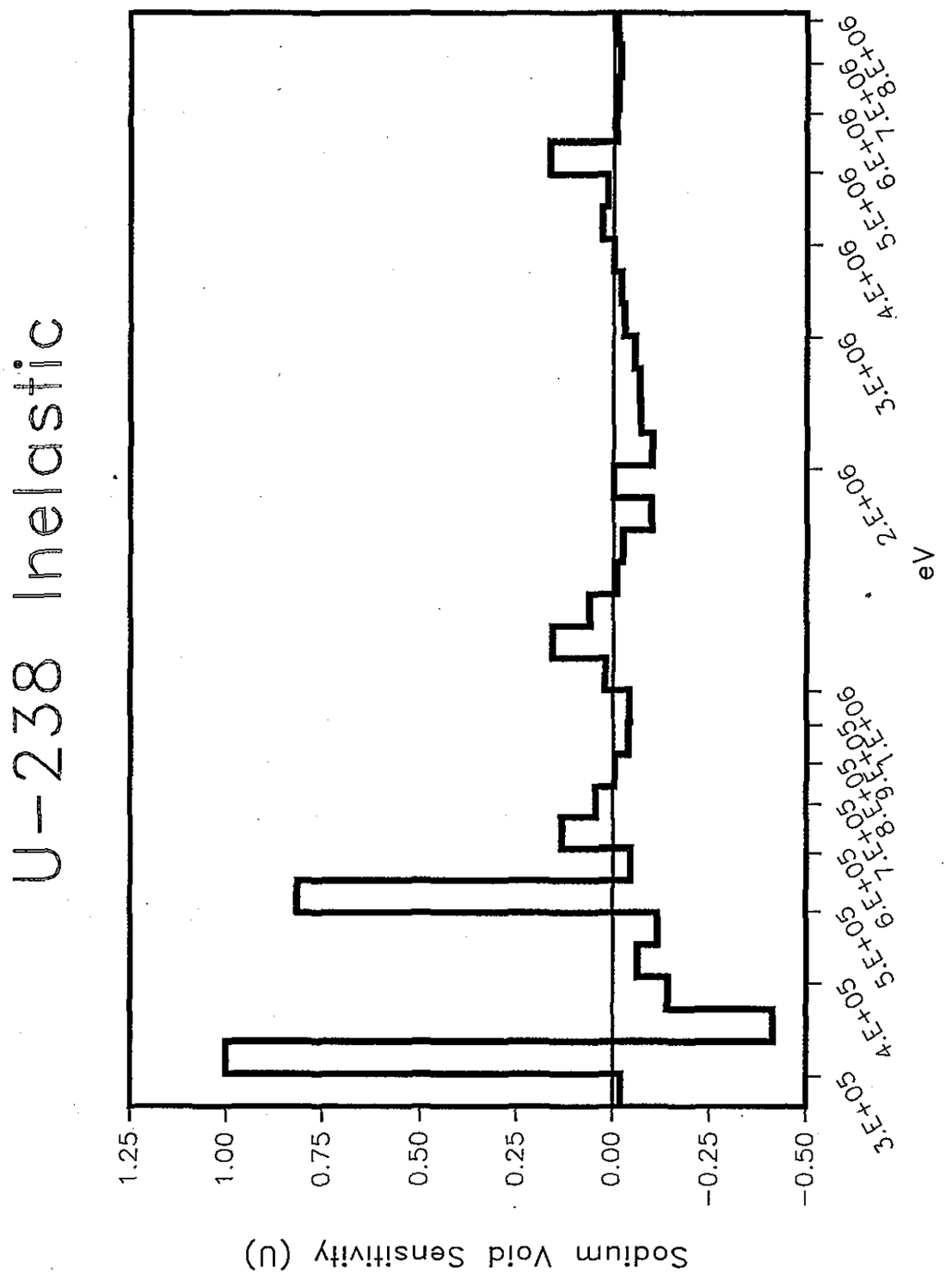

Figure 1: Energy Dependent Sensitivity Coefficient of the Sodium-Void Coefficient Due to the ^{238}U Inelastic Scattering Cross Section in the Fuel Region