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The Effect of Iron and Actinide Data on Physics Parameters of Advanced Fast Systems without Radial Blankets

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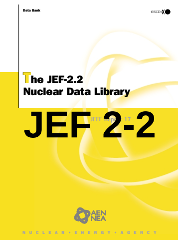

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1 Introduction

In the framework of the CEA/PSI cooperation on the physics of plutonium recycling in fast systems and in the context of the JEF Project, data comparison studies were completed for the second core, ZONA2-A3, in the CIRANO experimental programme at the MASURCA reactor [1].

The CIRANO programme was proposed in support of the CAPRA (Accrued Consumption of Plutonium in Fast Reactors) project [2] and is dedicated to the study of the characteristics of plutonium and minor actinide burning cores: replacement of the fertile blankets, variation of the plutonium isotopic vector, and increased plutonium enrichment.

The first CIRANO core built in MASURCA, ZONA2-A, consisted of mixed uranium/plutonium fuel with an high content of plutonium (about 25 %), constituting the starting point for the changes outlined above. These changes have begun with the replacement of the radial and axial fertile blankets surrounding the core by sodium/steel assemblies. The second core developed, ZONA2-A3, forms an intermediate step in this process as the radial, but not the axial blanket has been replaced.

In this study, for the main structural (reflector) material ^{56}Fe and actinides ^{239}Pu, ^{240}Pu, ^{238}U, the performance of the JEF-2.2 data library has been compared with that of the JENDL-3.2, ENDF/B-VI (Rev. 3), and BROND-2.1 libraries, using the PSI deterministic code system.

In addition to critical mass balance components, the sodium void worth resulting from voiding of the full height (60 cm) of the four central fuel assemblies of ZONA2-A3 has been determined. The reactivity effect of three partially voided conditions has also been simulated: voiding of two thirds (40 cm) of the central section of the four assemblies, voiding of one third (20 cm) of the central section, and voiding of the top and bottom 10 cm sections (corresponding to twice one sixth of the full height).

It is found that the systematic use of JEF-2.2 data (for all ZONA2-A3 nuclides) leads globally to more satisfactory agreement between calculation and experiment [3]. However, some unexplained residual discrepancies and possibly compensating effects have been noticed.

2 Computational Method

Pointwise and fine group cross-sections were processed using NJOY (Version 89.62). MICROR was used to convert this data into working libraries for the two-region cell code MICROX-2.

Fundamental mode spectrum MICROX-2 calculations were performed for six different regions: inner fuel zone with and without sodium, axial blanket, stainless steel radial reflector, radial and axial shields [3]. These calculations resulted in sets of 33-group region-dependent cross sections.

The isotropic component of these cross sections were collapsed in space using the P_0 moment of the regional flux. The anisotropic cross sections were homogenized using the transport-corrected collision rate (equal to the P_0 moment of the regional flux times the macroscopic transport cross-section, this computed from the regional diffusion coefficient).

In the fuel region with and without sodium, the required P_0 flux moment for this spatial homogenization resulted from two-dimensional, axially homogeneous, cylindrical, critical assembly calculations in which the cell was described heterogeneously in the radial direction (the critical core heights had to be searched for).

In the (axial) blanket region, this P_0 flux moment was determined from one-dimensional calculations of the cell with an arbitrary small buckling, so as to avoid vanishing anisotropic cell fluxes.

In the radial reflector region, it was obtained from one-dimensional source calculations in which the resulting fission spectrum in the fuel region was assumed to be a spatially independent, isotropic neutron source.

Full reactor forward and adjoint calculations (with and without sodium) were performed in cylindrical geometry using the two-dimensional transport-theory code TWODANT with transport-corrected P_2S_8 approximations.

" Bucklings " for important actinide fission rates and for $D\phi^*$ [4], estimated from computed fission rate and adjoint flux distributions in the radial and axial directions starting from the reactor center, were deduced from J_0 and cosine fits over appropriate radial and axial regions, respectively.

3 Results

3.1 k_{eff}

3.1.1 ^{56}Fe

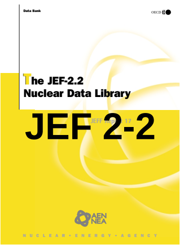
^{56}Fe Data from	Radial Reflector	Axial Blanket	Core	All Regions
JEF-2.2	1.00883	1.00883	1.00883	1.00883
JENDL-3.2	**1.02045** **+1.13**	1.01029 +0.14	1.01179 +0.29	**1.02611** **+1.67**
ENDF/B-VI (Rev. 3)	1.00676 -0.20	1.00876 -0.01	1.00901 +0.02	1.00645 -0.23
BROND-2.1	1.00465 -0.41	1.00950 +0.07	1.00812 -0.07	1.00286 -0.59

Table 1: Computed k_{eff} as a Function of ^{56}**Fe Data** in Different Zones (First Lines). Relative Changes in % of $\delta k/(k^*k')$, k=1.00883 (Second Lines)

3.1.2 Actinides

Actinide Data from	^{239}Pu	^{240}Pu	^{238}U
JEF-2.2	1.00883	1.00883	1.00883
JENDL-3.2	1.01042 +0.16	1.00837 -0.05	1.00867 -0.02
ENDF/B-VI (Rev. 3)	1.00890 +0.01	1.01041 +0.16	1.01228 +0.34
BROND-2.1	**0.99165** **-1.72**	1.01132 +0.24	could not be processed

Table 2: Computed k_{eff} as a Function of **Actinide Data** (in the Core, First Lines). Relative Changes in % of $\delta k/(k^*k')$, k=1.00883 (Second Lines)



3.2 Sodium Void

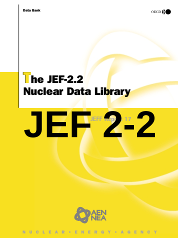
3.2.1 ^{56}Fe

Relative Height of the Voided Region to the Full Core Height	JEF-2.2	JENDL-3.2	ENDF/B-VI (Rev. 3)	BROND-2.1
1.0	-24	-16	-25	-26
2/3	+60	+63	+60	+59
1/3	+56	+57	+56	+56
1/6+1/6 (ext.)	-77	-73	-78	-78

Table 3: Calculated Sodium Void Coefficients (pcm) for Different Heights of the Voided Region, as a Function of ^{56}Fe Data in the Radial Reflector

^{56}Fe Data From	Radial Reflector	Axial Blanket	Core	All Regions
JEF-2.2	-24	-24	-24	-24
JENDL-3.2	-16	-28	-14	+1
ENDF/B-VI (Rev. 3)	-25	-24	-24	-27
BROND-2.1	-26	-25	-26	-31

Table 4: Calculated Sodium Void Coefficient (pcm) in the Case of the Voidage of the Full Height as a Function of ^{56}Fe Data in Different Regions



3.2.2 Actinides

Relative Height of the Voided Region to the Full Core Height	JEF-2.2	JENDL-3.2	ENDF/B-VI (Rev. 3)	BROND-2.1
1.0	-24	-23	-21	**-10**
2/3	+60	+61	+63	+74
1/3	+56	+57	+58	+65
1/6+1/6 (ext.)	-77	-77	-77	-77

Table 5: Calculated Sodium Void Coefficients (pcm) for Different Heights of the Voided Region, as a Function of ^{239}**Pu Data**

Relative Height of the Voided Region to the Full Core Height	JEF-2.2	JENDL-3.2	ENDF/B-VI (Rev. 3)	BROND-2.1
1.0	-24	-23	-29	-27
2/3	+60	+60	+56	+57
1/3	+57	+57	+54	+54
1/6+1/6 (ext.)	-77	-77	-78	-77

Table 6: Calculated Sodium Void Coefficients (pcm) for Different Heights of the Voided Region, as a Function of ^{240}**Pu Data**

Relative Height of the Voided Region to the Full Core Height	JEF-2.2	JENDL-3.2	ENDF/B-VI (Rev. 3)
1.0	-24	-26	**-12**
2/3	+60	+58	+68
1/3	+56	+55	+61
1/6+1/6 (ext.)	-77	-77	-74

Table 7: Calculated Sodium Void Coefficients (pcm) for Different Heights of the Voided Region, as a Function of ^{238}**U Data** in the Core

3.3 Bucklings

3.3.1 Dϕ*

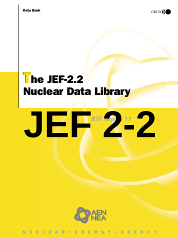
^{56}Fe Data from	Radial Buckling	Axial Buckling	Total Buckling
JEF-2.2	11.51	9.87	21.38
JENDL-3.2	**10.92**	9.85	**20.77**
ENDF/B-VI (Rev. 3)	11.61	9.87	21.47
BROND-2.1	11.72	9.88	21.60

Table 8: Computed Bucklings, Expressed in Units of 10^{-4}cm^{-2}, as a Function of **^{56}Fe Data in the Radial Reflector**

3.3.2 Fission Rates for Important Actinides

Actinide	Radial Buckling	Axial Buckling	Total Buckling
^{235}U	10.64 -6.5	8.07 -0.2	18.71 -3.8
^{239}Pu	10.99 -6.0	8.83 -0.2	19.82 -3.4
^{237}Np	11.81 -4.8	10.60 -0.1	22.41 -2.6
^{238}U	11.90 -4.6	10.56 -0.1	22.46 -2.5
^{240}Pu	11.69 -5.0	10.34 -0.1	22.03 -2.7

Table 9: Computed Bucklings, Expressed in Units of 10^{-4}cm^{-2} (First Lines), and Their Relative Changes (%) Originating When Using **JENDL-3.2 Data for ^{56}Fe in the Radial Reflector** (Second Lines)



3.4 Main Points

- k_{eff}:
  - ^{56}Fe: We observe the main regional spread, if different data for iron is used in the radial reflector (about 1.5 %, see Table 1), due to discrepant elastic scattering cross sections (see Figure 1). The larger are these cross sections, the larger is the computed k_{eff}, since a smaller amount of neutrons leak out from the core into the reflector region [5].

    When using different iron data in the whole reactor, the resulting spread, amounting to about 2.3 %, is much larger than in ZONA2-A (less than 1 %), since the radial fertile blanket has been replaced by sodium/steel assemblies.
  - Actinides: The use of ENDF/B-VI (Rev. 3) data for ^{238}U in the core and especially of BROND-2.1 data for ^{239}Pu leads to a noticeable variation of k_{eff} (see Table 2). The magnitude of this variation is significant, if compared to the delayed neutron fraction.

- **Radial Power Distribution and Bucklings:**

  As a consequence of above discussion, the curvature of the radial power density profile decreases significantly, leading to smaller radial bucklings, if ^{56}Fe data from JENDL-3.2 is used (see Figure 2 and Tables 8-9).

- **Sodium Void Coefficient:**

  A significantly larger sensitivity of the computed sodium void coefficient to iron data is observed in the case of voiding the full height (60 cm) of the four central fuel assemblies than in the remaining three cases investigated (see Tables 3-7), due to stronger competition between leakage and absorption component.

  - ^{56}Fe: As expected, the sodium void coefficient becomes less negative, if JENDL-3.2 data is used in the radial reflector region (see Tables 3-4). In the case of voiding the full height, the sodium void coefficient reaches even a positive value, if JENDL-3.2 data is used everywhere in the reactor (see Table 4).
  - Actinides: A large variation of the sodium void coefficient is observed when using ^{238}U data from ENDF/B-VI (Rev. 3) in the core and ^{239}Pu from BROND-2.1 (see Table 5 and Table 7). These changes are not due to leakage effects.

3.5 Conclusions and Recommendations

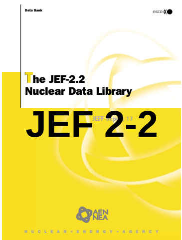
Sensitivities of reflector gains and sodium void to nuclear data have been calculated with the PSI deterministic code system for CIRANO ZONA2-A3, a mixed uranium/plutonium fueled core built in MASURCA, in which the radial fertile blanket has been replaced by sodium/steel assemblies.

Although sodium data differ between European, American and Russian evaluations, no significant sensitivity on either evaluation was observed, either for k_{eff} or for the sodium void coefficient.

A significantly larger sensitivity of the computed sodium void coefficient to iron data is observed in the case of voiding the full height of the four central fuel assemblies.

By comparing with available experimental data [3], we can conclude that the systematic use of the **JEF-2.2 data library** (for all ZONA2-A3 nuclides) **leads globally to more satisfactory agreement between calculation and experiment:** The BROND-2.1 file for ^{239}Pu does not seem to be suitable for these kinds of investigations (too low fission cross section). The cause for the surprisingly large impact of ^{238}U data from ENDF/B-VI (Rev. 3) in the core, leading to less accurate predictions of experimental values, must be still clarified.
However, even when systematically using JEF-2.2 data, some unexplained residual discrepancies (e.g. in k_{eff}) remain and various compensating effects between (homogenization) methods and iron data, particularly at the core/reflector interface (see Figure 2), are likely to take place.

In this context, the additional use of the most accurate available data for ^{56}Fe (**EFF-3.0**) is recommended, and similar analyses of new cores, in which both radial and axial blankets are replaced by sodium/steel assemblies, would be beneficial in further understanding and reducing these discrepancies.
As far as actinide data for ^{238}U, ^{239}Pu and ^{240}Pu are concerned, the JEF-2.2 evaluation seems to be suitable for these kinds of applications.



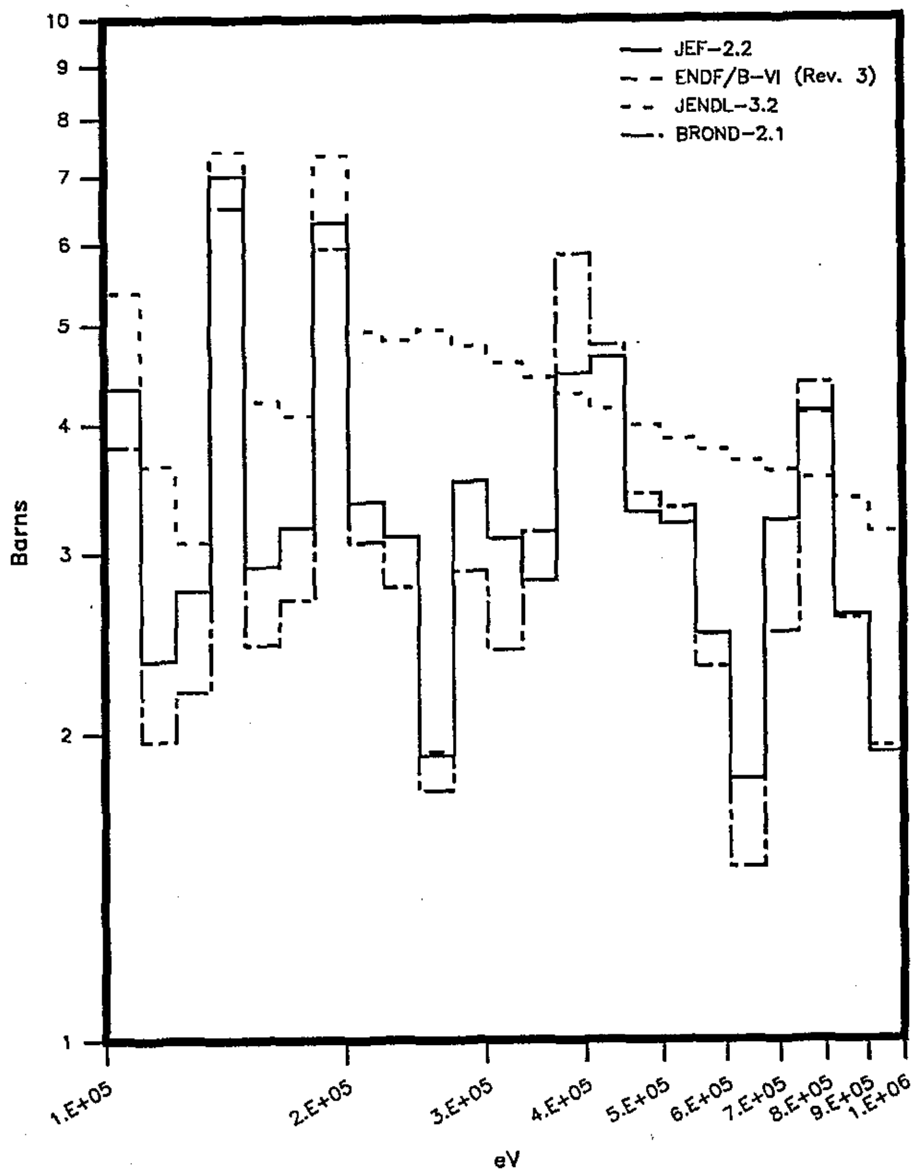
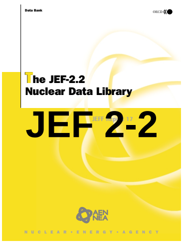


Figure 1: Elastic Scattering Cross Sections for ^{56}Fe



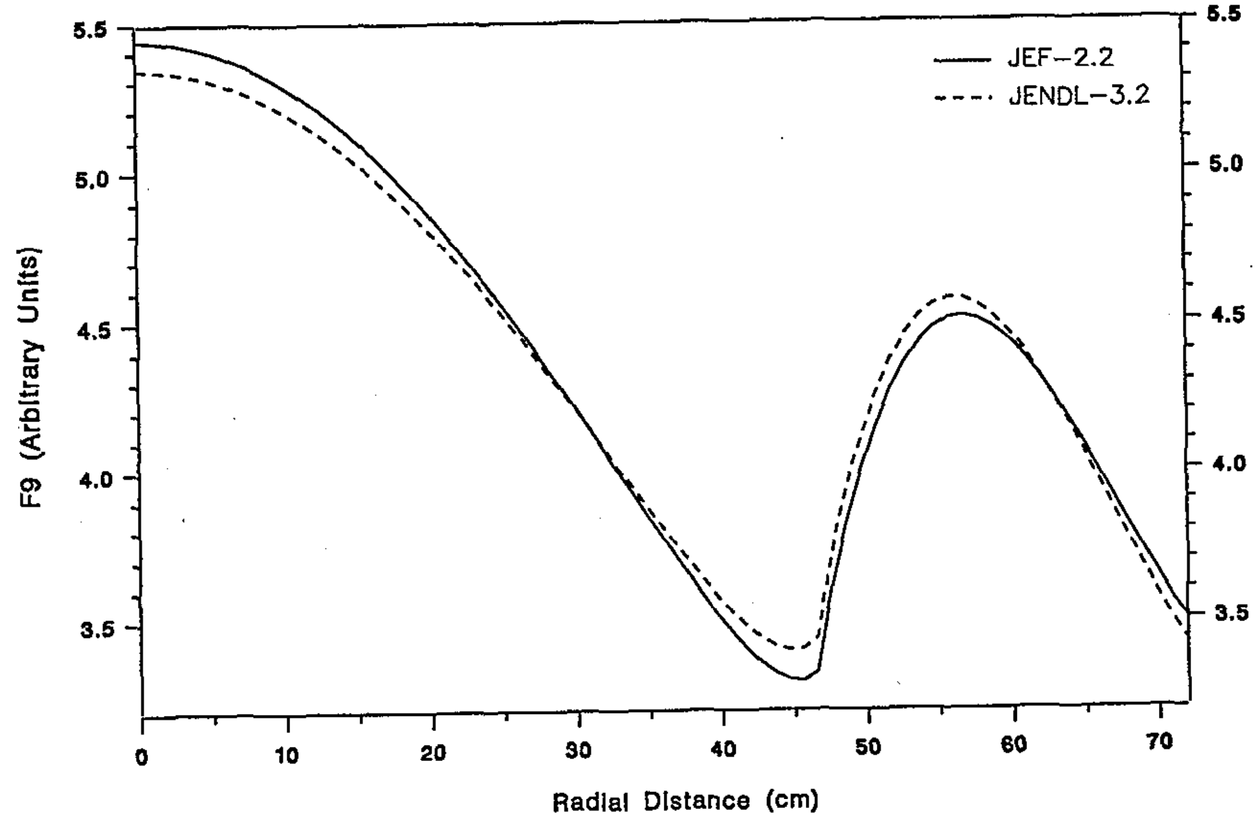


Figure 2: ^{239}Pu Fission Rate (F9) Radial Profiles, Axially Centered, Normalized to Equal Power, Obtained Using ^{56}Fe Data from JEF-2.2 and JENDL-3.2 in the Radial Reflector

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4 Acknowledgment

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References

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