Impact of Zirconium Data on the Physics of U-Free Cells

by

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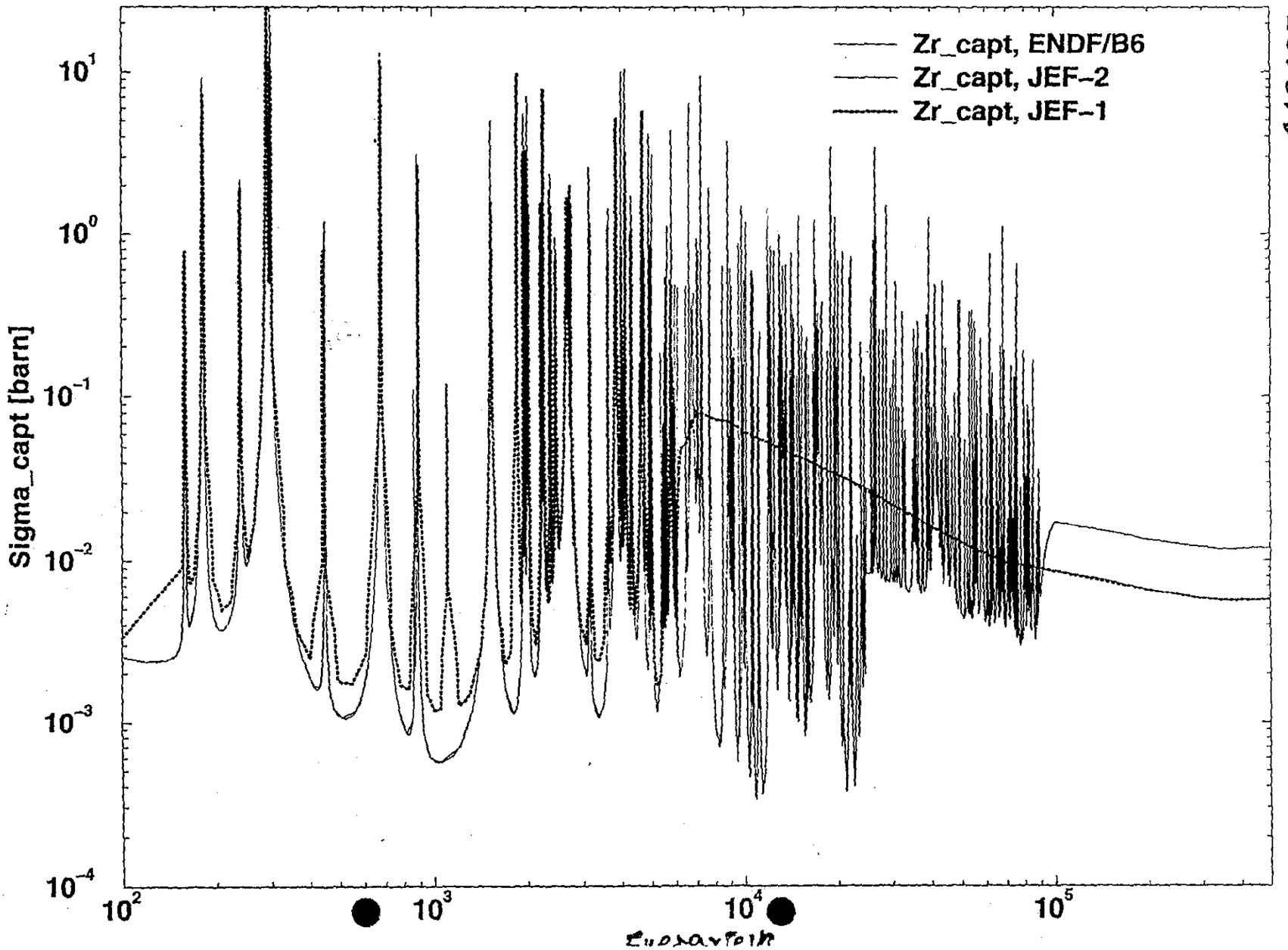
Comparison of Zr Absorption Cross Sections from Different Libraries



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Available Results

- for RG1, RG3, WG1,
- at BOL and EOL,
- using data from the JEF-1.1, JEF-2.2, and ENDF/B-VI (Rev. 4) evaluations[1,2],
- Zr data from Zr-nat,
- Zr data from the Zr-isotopes.

[1] Additionally, Zr data from the ENDF/B-IV evaluation, because BOXER is using this data.

[2] Data from the JENDL-3.2 library is in preparation (water and erbium are not available on the data basis).

Computed:

- k_∞
- **Fluxes,**
- **reaction rates**
  - fission, "absorption = (n,2n)", and production,
  - in 6 energy groups (with boundaries at 14.9 MeV, 821 keV, 9.1 keV, 4 eV, 1.3 eV, 407 meV, 0.0),
  - normalised to a total absorption of unity,
  - for the single nuclides,
  - for fuel, clad, coolant, and the cell.
- **Void coefficients for 10%, 50%, 95%, and 99.9% void.**
- **Temperature coefficient of the fuel** from 600 to 900 degree C.

Methods and Data

- Methods
  - Homogeneous reference calculations with **MICROX-2/ONEDANT**,
    - using cell averaged cross sections,
    - in which **different data libraries** are used with variable upper energy boundaries for the thermal range.
  - Heterogeneous calculations with **MICROX-2/ONEDANT**,
    - using region averaged cross sections,
    - in which **different data libraries** are used with a different number of energy groups.

Methods and Data (Continued)

- Methods

- – Heterogeneous calculations with **MICROX-2/ONEDANT**, in which **the BOXER methodology is simulated:**
  - * Zr cross sections in the clad are the same as in the fuel,
  - * the resonance calculation is performed starting from 900 eV.

- Data

Specific data libraries for the cell code MICROX-2 were generated using **NJOY94.10/MICROR**.

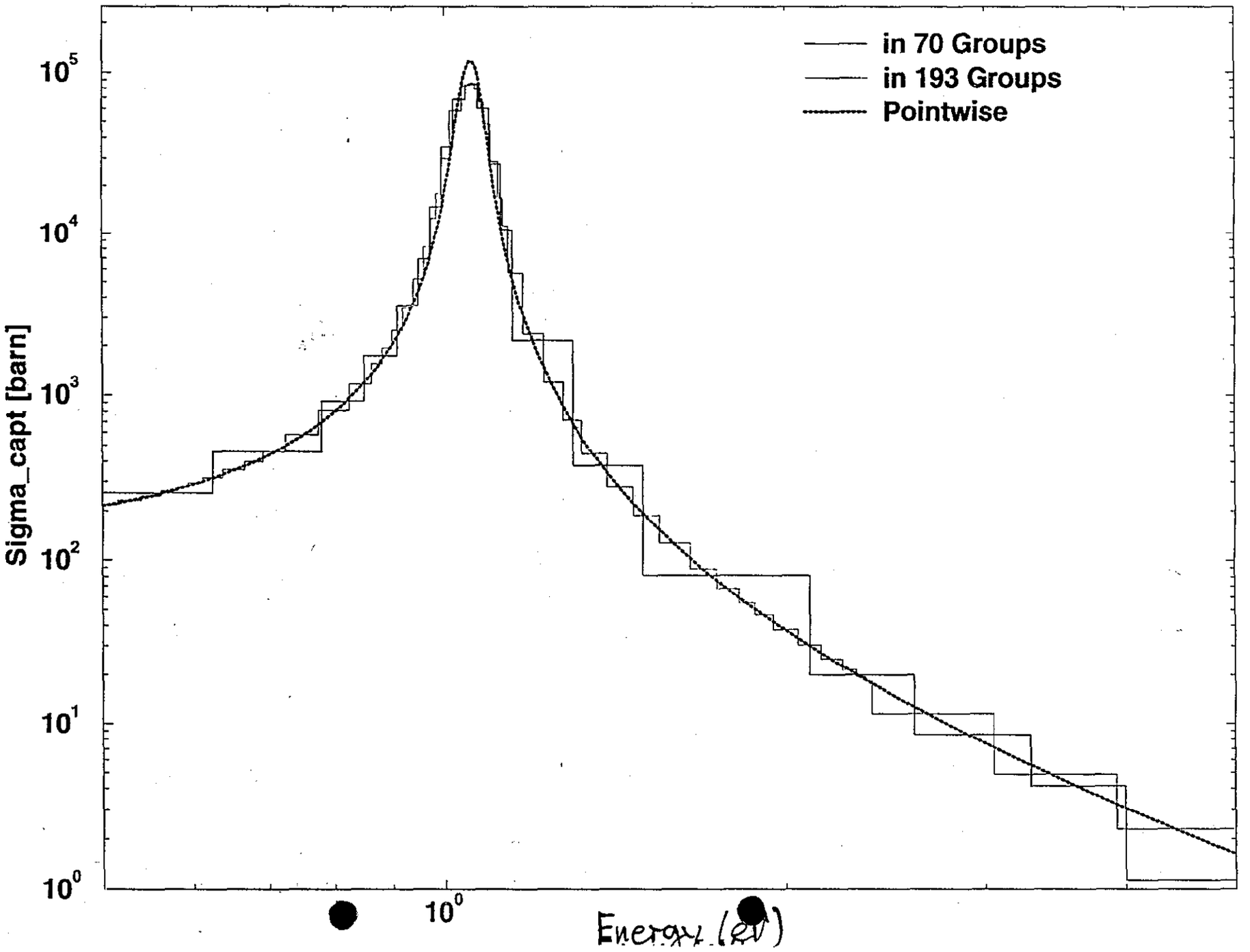
MICROX-2 (Reference) Calculations

- Fission spectrum: Linear combination of data for the single actinides.
- **Dancoff factors:** pre-calculated **analytically** (Segev's method) for the square lattice.
- **Above 7.1 keV: Bondarenko formalism:**
  - semi-log,
  - $\sigma_0 = 10^{10}$, 1000, 100, 50, 20, 10, 5, 1 barns, for all nuclides except ^{16}O,
  - in 60 fine groups ($\Delta U = 0.1$),
  - weighting function: **EPRI cell LWR** (IWT=5), irrespectively of the voided situation.
- **Resonance calculation in 2 zones**, performed
  - in the energy range **7.1 keV - 2.4 eV**,
  - using $\sim$ 10000 energy points equally spaced in lethargy,
  - **clad and moderator are smeared,**
  - UR range is not shielded.
- **Below 2.4 eV**: Thermal treatment **in 101 fine energy "points".**

The JEF-2.2 Nuclear Data Library

JEF 2-2

Comparison of Pu–240 Capture Cross Sections



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Results (10% Void)

Δk_∞ against results with pure JEF-1.1 data		
pcm	JEF-2.2	ENDF/B-VI (Rev. 4)
RG3 (0 % void)	-497	+132
WG1 (0 % void)	-789	-792

Δk_∞ against results with pure JEF-1.1 data		
pcm	JEF-2.2	ENDF/B-VI (Rev. 4)
RG3 (10 % void)	-469	+357
WG1 (10 % void)	-759	-673

Variation of the void coefficient		
pcm/% void	JEF-2.2	ENDF/B-VI (Rev. 4)
RG3	+2	+20
WG1	+2	+7

Results (95% Void)

Δk_∞ against results with pure JEF-1.1 Data				
pcm	JEF-1.1 (Zr-Isos)	JEF-2.2	JEF-2.2 (Zr-Isos)	ENDF/B-VI (Rev. 4)
RG3 (0 % void)	-288	-497	-669	+132
WG1 (0 % void)	-294	-789	-916	-792

Δk_∞ against results with pure JEF-1.1 Data				
pcm	JEF-1.1 (Zr-Isos)	JEF-2.2	JEF-2.2 (Zr-Isos)	ENDF/B-VI (Rev. 4)
RG3 (95 % void)	-312	+1611	+793	+4676
WG1 (95 % void)	-638	+1335	+542	+1753

Variation of the void coefficient				
pcm/% void	JEF-1.1 (Zr-Isos)	JEF-2.2	JEF-2.2 (Zr-Isos)	ENDF/B-VI (Rev. 4)
RG3	**-0**	**+21**	**+14**	**+43**
WG1	**-2**	**+14**	**+9**	**+16**

$$\alpha_i = \frac{\frac{1}{P_2} \cdot \left(\frac{\Delta P_i}{k_1} - \Delta A_i \right)}{\Delta x}$$

and

$$C_x = \frac{\Delta \varrho}{\Delta x} = \sum_i \alpha_i$$

with:

C_x : Differential Reactivity Change

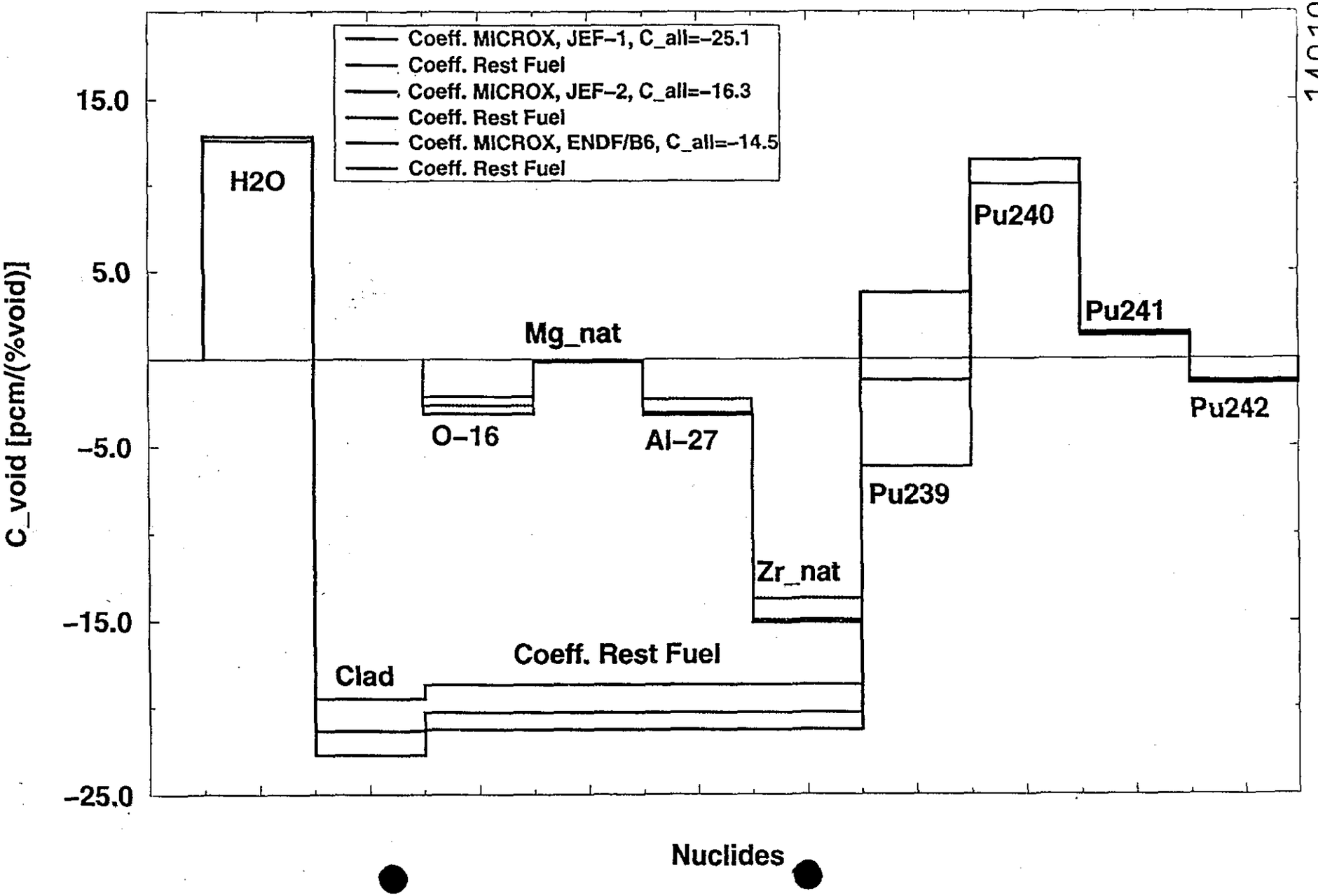
α_i : Contribution of Nuclide i

P : Production Rates

A : Absorption Rates

k_1 : initial Eigenvalue

Void Coefficient for 0 to 95% void for Fuel-1 with WG-Pu separated into the contributions of the nuclides



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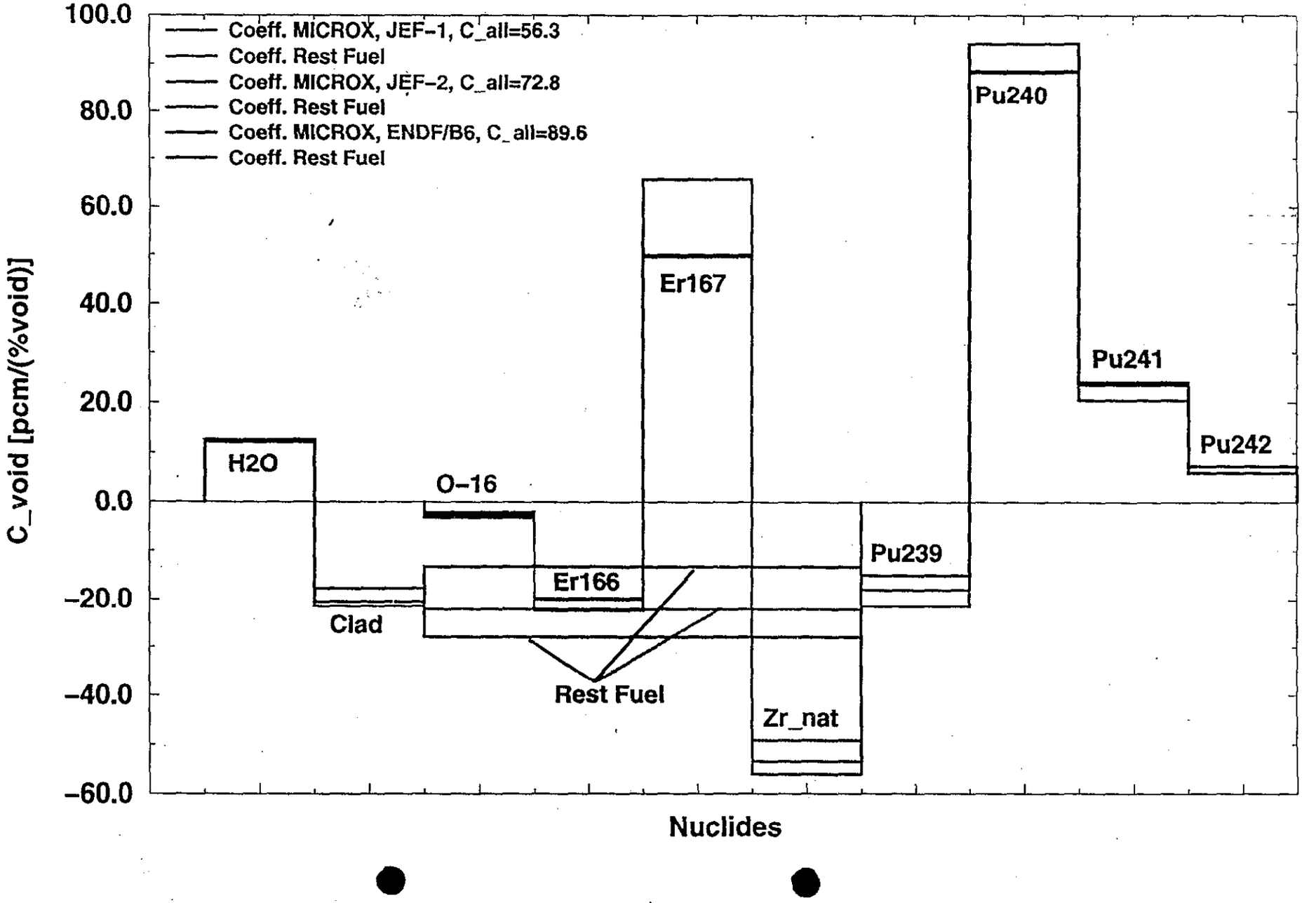
Void Coefficient for 0 to 95% void for Fuel–3 separated into the contributions of the nuclides



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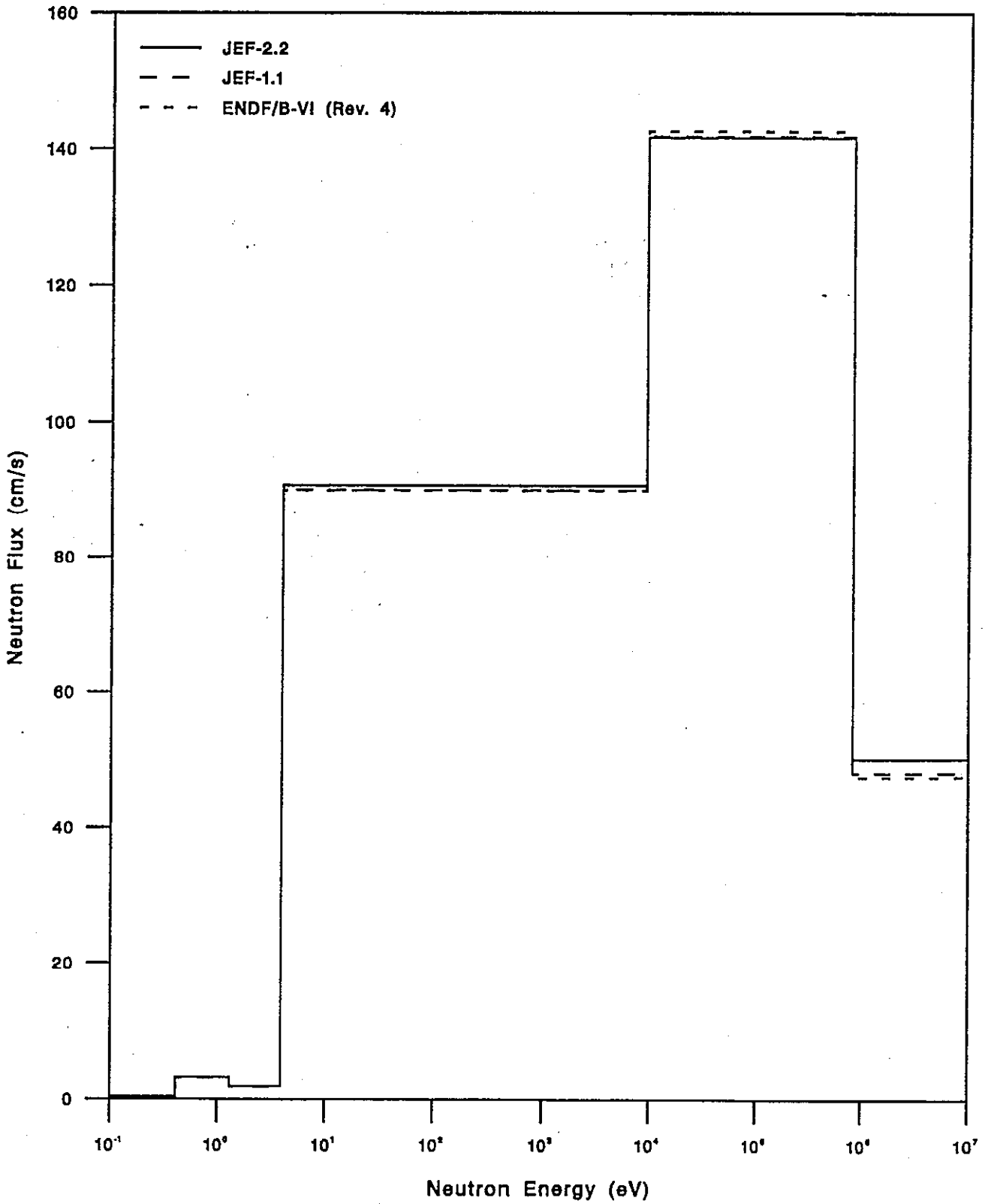
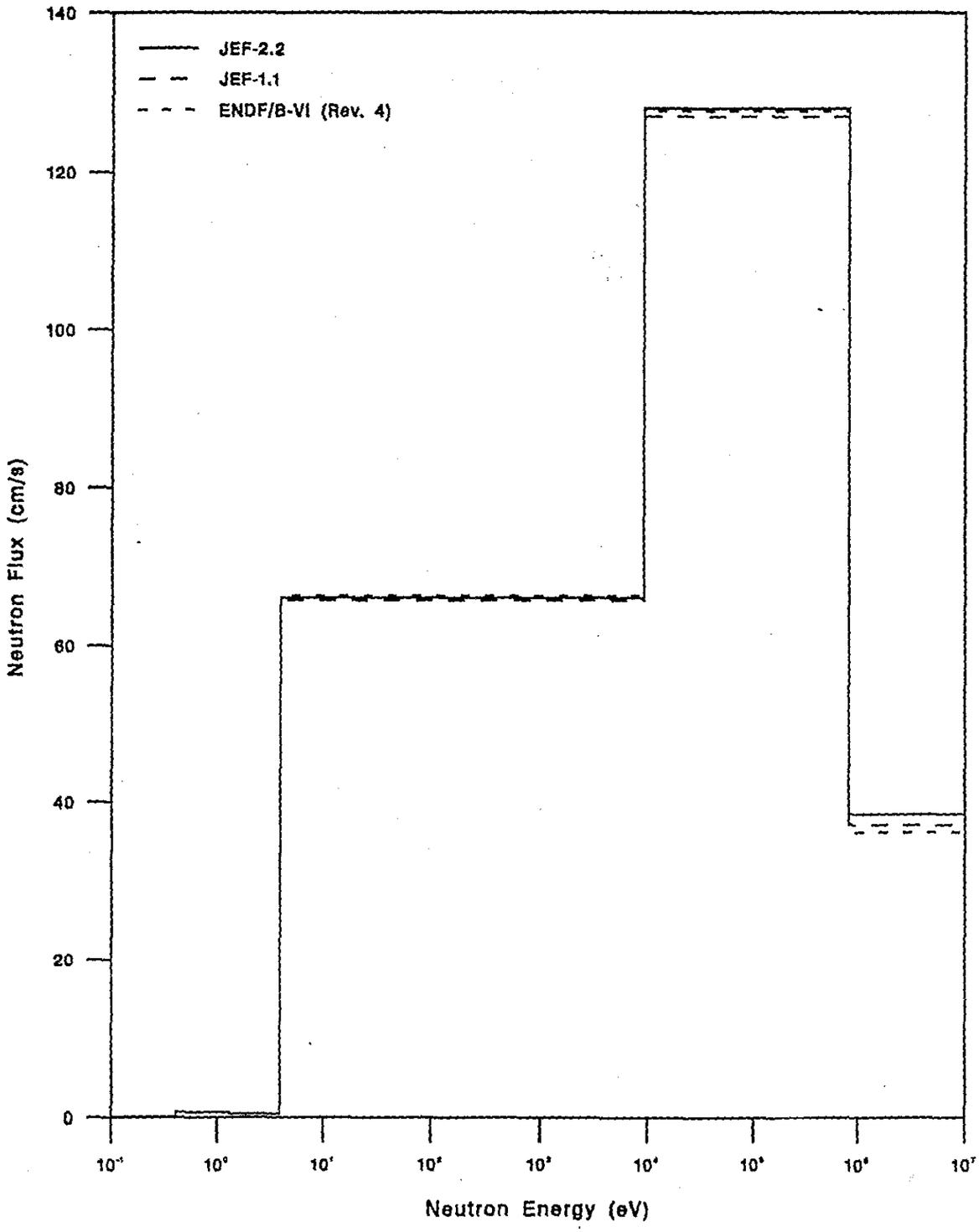
Total Flux in 6 Groups (WG1, 95% Void)



Total Flux in 6 Groups (RG3, 95% Void)



We observe:

- **Zr-nat ====> Zr-Isotopes:**
  The computed void coefficient slightly decreases.

- **JEF-1.1 ====> JEF-2.2 ====> ENDF/B-VI (Rev. 4):**
  The computed void coefficient **increases**.

- This **increase** becomes **bigger when increasing the voided fraction** (resonance range becomes more important), and

- is **significantly larger** for cells with **erbium**.

We find:

- **JEF-1.1 ====> JEF-2.2**:
  The **increase** of the void coefficient is mostly **due to ^{239}Pu**, and **zirconium** (in both the fuel and the clad).

- **JEF-2.2 ====> ENDF/B-VI (Rev. 4)**:
  The **increase** is **due to** (^{167}Er,) **^{240}Pu, and ^{239}Pu.**
  However, the **contribution of zirconium decreases** and is similar to that obtained using JEF-1.1 data.

Results
(Fuel Temperature Coefficient)

for RG3 from 600 to 900 degree C			
Data	JEF-1.1	JEF-2.2	JEF-2.2 (Zr-Isos)
pcm/degree C	-1.608	-1.618	-1.621

Results (at EOL)

Effects against results with pure JEF-1.1 data			
Δk_∞ WG1 0 % Void (pcm)	Δk_∞ RG3 0 % Void (pcm)	Δk_∞ RG3 95 % Void (pcm)	Δ(Void Coeff.) RG3 (pcm/ % Void)
JEF-2.2 data			
-442	-418	+775	+12

Results at EOL

- **No additional deviations** induced by **fission product and minor actinide** cross sections.

- These deviations are **smaller** than at **BOL**, due to the burn-up of ^{239}Pu.

Summarising Results

PSI-BOXER ("JEF-1.1")	-66
CEA-APOLLO (JEF-2.2)	-33

- New calculations with MICROX-2

BOXER-Simulation	-54
JEF-1.1 (Zr-nat from ENDF/B-IV)	-48
JEF-1.1 (Zr-Isotopes)	-42
JEF-1.1	-39
JEF-2.2 (Zr-Isotopes)	-30
JEF-2.2	-26
ENDF/B-VI (Rev. 4)	-23

Example: Void Coefficient from 0 to 95 % Void (pcm/% Void) for WG1

Concluding Remarks

- The computed k_∞-values for the normal situation (0 %-void) agree better than the k_∞-values for the voided case.

- **Correct calculation of the void coefficient** (for "high" voided fraction $\geq\sim$90%) ===> **Uncertainties** in the data for **zirconium, erbium, ^{239}Pu, and ^{240}Pu** must be **reduced**.