Refinement of the Santamarina–Hfaiedh energy mesh between 22.5 eV and 11.4 keV

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Motivation of this study

- Attempt to improve the accuracy of the lattice calculation
- Creation of multigroup energy mesh with an improved selection of energy group limits in the resolved energy domain
  - the lower part of the resolved energy domain ($E \leq 22.5\,\mathrm{eV}$) is treated without self-shielding model using the existing SHEM–281g mesh
  - the upper part of the resolved energy domain ($22.5\,\mathrm{eV} < E \leq 11.1\,\mathrm{keV}$) is treated with a simplified self-shielding model together with a finer mesh referred as SHEM–361g
- A simplified self-shielding model, the subgroup projection method (SPM), is used

Probability tables of cross sections

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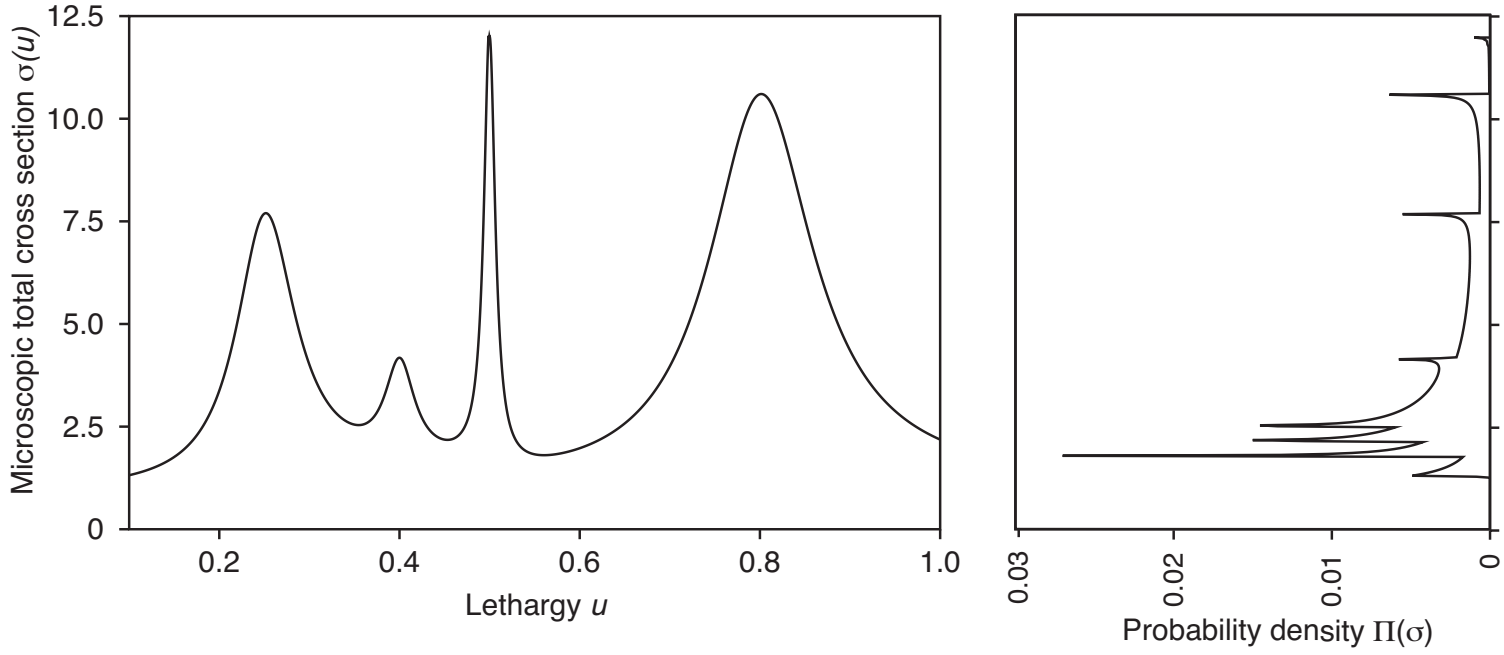
Many legacy and advanced self-shielding model are based on probability tables of cross sections



$$\Pi(\sigma) \simeq \sum_{k=1}^{K} \delta(\sigma - \sigma_k)\,\omega_k \quad \text{with} \quad \sum_{k=1}^{K} \omega_k = 1 \quad .$$

Probability tables of cross sections 2

Any Riemann integral in lethargy, with a σ–dependent integrand, can be replaced by an equivalent Lebesgue integral:

$$\frac{1}{\Delta u_g} \int_{u_{g-1}}^{u_g} du\ f\left[\sigma(u)\right] = \int_0^{\max(\sigma)} d\sigma\, \Pi(\sigma)\, f(\sigma)$$

We obtain the following discretization:

$$\frac{1}{\Delta u_g} \int_{u_{g-1}}^{u_g} du\ f\left[\sigma(u)\right] \simeq \sum_{k=1}^{K} \omega_k\, f(\sigma_k) \quad .$$

Probability tables are used in many self-shielding approaches

- the Sanchez-Coste method of Apollo2
- the CALENDF-based subgroup approaches (ECCO, SPM, Ribon extended)
- the subgroup method of Helios and Wims–7

Probability tables of cross sections 3

In real situations, the integrand is containing more than a simple σ–dependent function:

- a term in $\mathrm{e}^{u-u'}$ is due to the elastic slowing-down kernel. This term creates a slowing-down correlation in probability tables. This correlation vanishes at high energy (above 10 keV) or if the energy mesh is fine.
- in case of overlapping resonances from many isotopes, the mutual shielding effect creates correlations between different resonant isotopes.
- the cross sections of a unique isotope present in the lattice at different temperatures are highly correlated. This is the temperature correlation effect.

The subgroup projection model

We used a simplified self-shielding method known as the subgroup projection model (SPM), with the following characteristics:

- based on CALENDF probability tables obtained from Autolib data present in the cross section libraries
- the slowing-down correlation is not represented. $\Rightarrow$ A finer energy mesh is required.
- validated in the energy domain $4.96\,\mathrm{eV} < E \leq 11.1\,\mathrm{keV}$ (accepted Nucl. Sci. Eng. paper).
- the mutual shielding effect is represented (using CALENDF correlated weight matrices).
- the temperature correlation effect is represented (using CALENDF correlated weight matrices).

NOTE: XMAS–172g and SHEM–281g cannot be used with SPM because the groups are too large.

Available energy meshes

XMAS–172 UK–French standard mesh currently used in a large fraction of available cross-section libraries

- Defined in up107 official update of NJOY99
- Group widths in the resolved energy domain are too large to neglect slowing-down correlation effects

SHEM–281 French standard mesh currently used is latest computational schemes. Used at CEA, Areva and EDF.

- Group widths in the resolved energy domain are too large to neglect slowing-down correlation effects

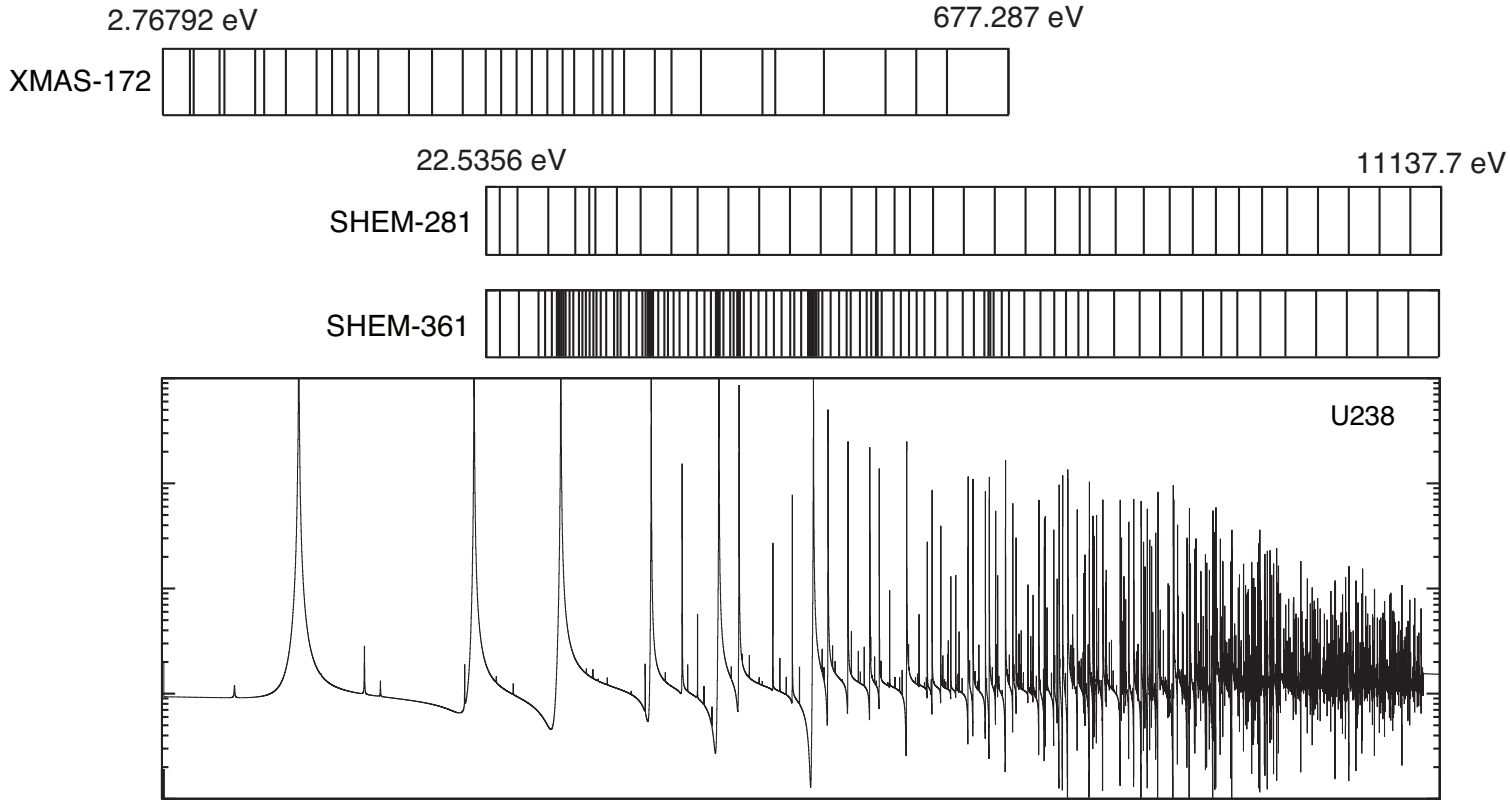
SHEM–361 Proposed in this study

- Group widths in the resolved energy domain are small
- It is possible to neglect slowing-down correlation effects.

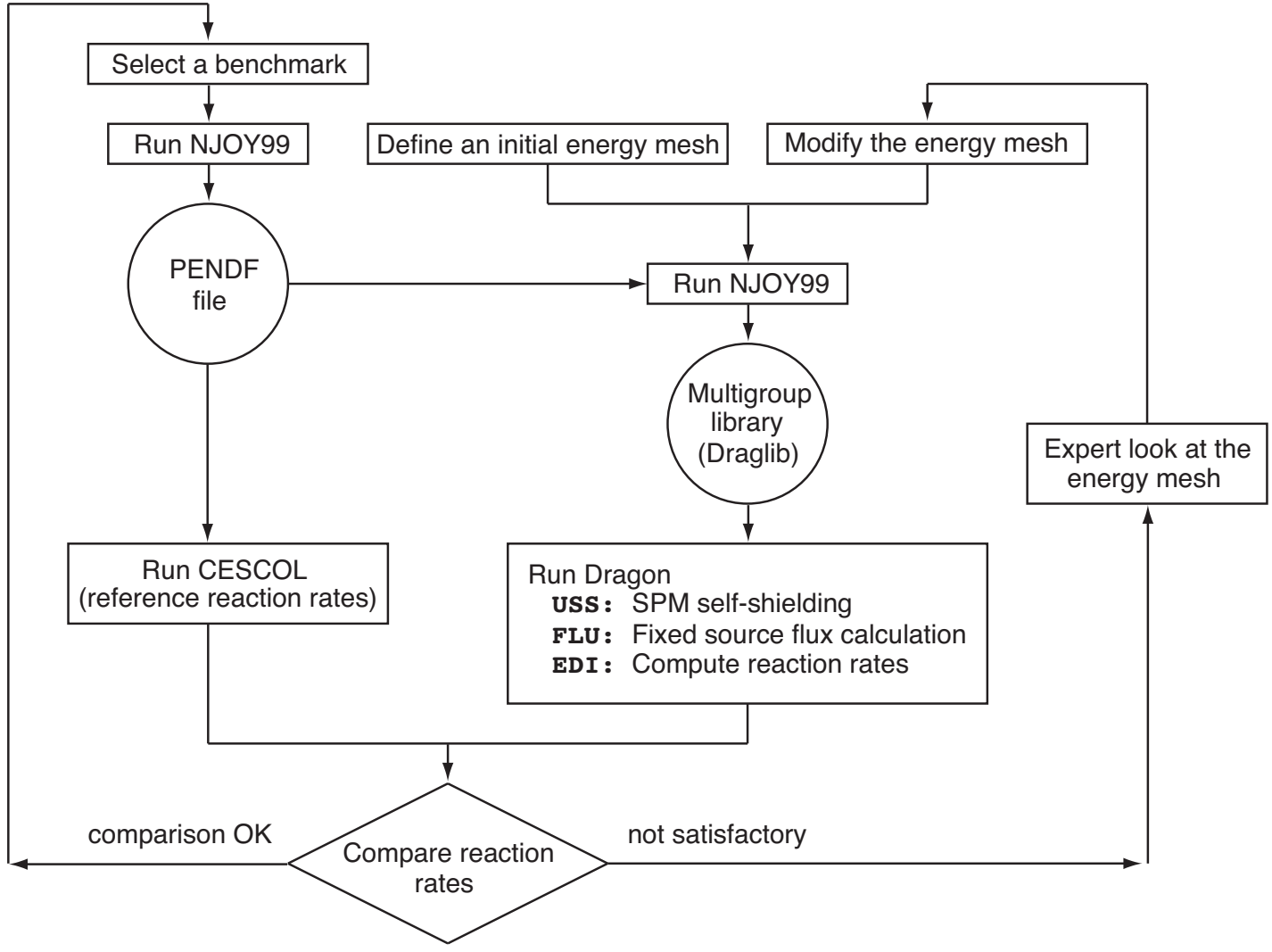
Available energy meshes

The figure represents the energy groups

- located in the resolved energy domain
- where a self-shielding model is applied, taking into account the position of resonances.

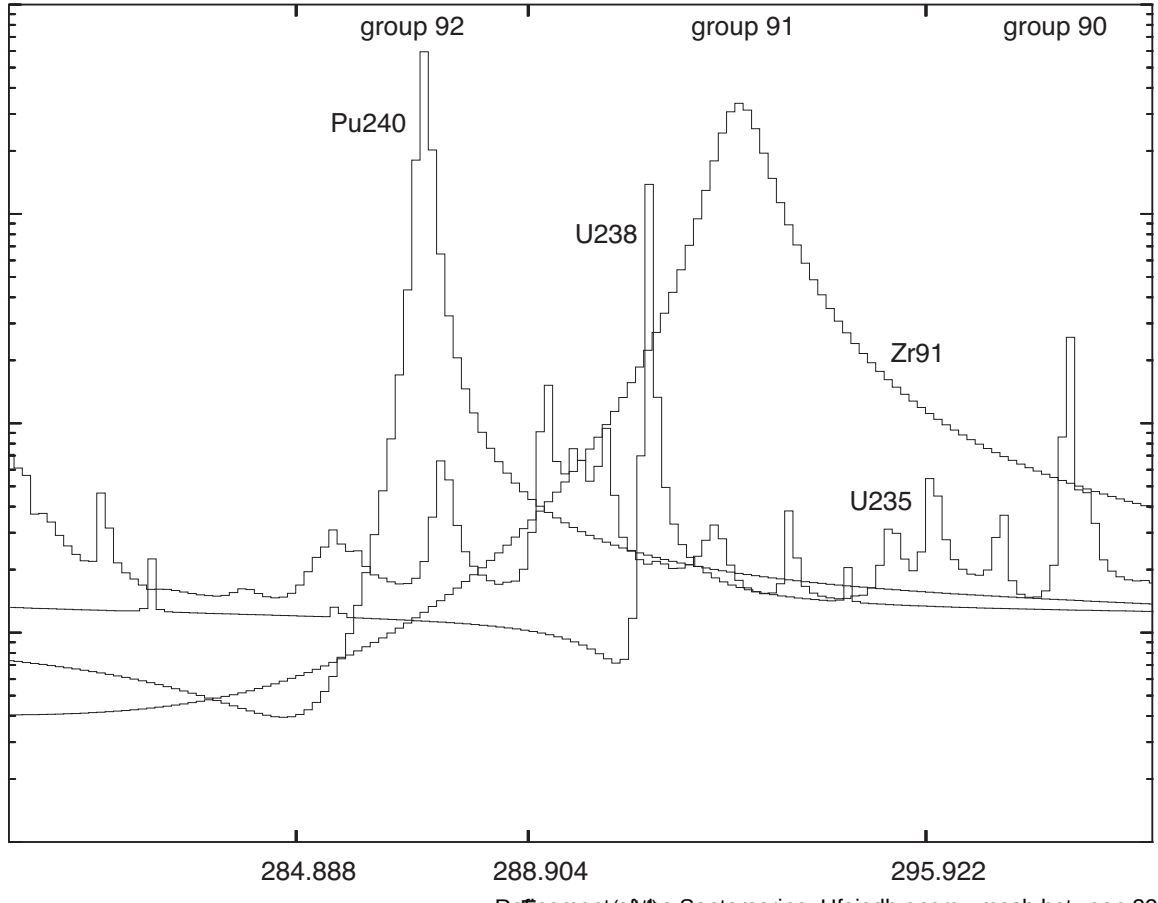


Modification strategy



Modification strategy

- reduce discrepancies between `CESCOL:` and `USS:+FLU:`
- avoid splitting a resonance in two parts
- use more groups in resonant sub-domains.



Validation

A tool based on SHEM–361g and SPM was validated using

- One-neutron source testcases similar in geometry to the UOX and MOX Rowland's benchmarks
  - cross sections were defined in the resolved energy domain and distributed over SHEM–361 energy groups 56 to 173, located between 22.5 eV and 11.14 keV.
  - a 1.0 n/cm^3/s source was placed in group number 56, located between 9.1188 keV and 11.138 keV.
  - the absorption rates are computed in the remaining energy groups.
- Reference CESCOL calculations are ultra-fine energy mesh slowing-down calculations
- A fifth benchmark was added, including a strong temperature gradient in fuel.

UOX one-neutron source benchmarks 1

	Case 1 Isoth. 293K	Case 2 Reduced H_2O density	Case 3 Fuel at 900K	Case 4 Isoth. 574K	Case 5 Temp. ∇ in fuel
ϵ^{int} (%)	-0.059	-0.145	0.057	-0.014	0.070
$\bar{\epsilon}$ (%)	0.546	0.555	0.519	0.542	0.529
ϵ^{max} (%)	3.337	2.781	2.513	2.602	2.419
in group	142	142	106	106	79
^{235}U ϵ^{int} (%)	0.353	0.361	0.360	0.351	0.362
^{238}U ϵ^{int} (%)	-0.242	-0.377	-0.066	-0.170	-0.048
^{238}U ϵ^{int} (%)					
shell 1	0.051	-0.117	0.357	0.201	0.520
shell 2	0.023	-0.144	0.353	0.218	0.419
shell 3	-0.299	-0.425	0.090	-0.085	-0.090
shell 4	-0.508	-0.611	-0.378	-0.515	-0.645
shell 5	-0.806	-0.884	-1.129	-1.095	-1.347
shell 6	-1.158	-1.262	-1.669	-1.540	-1.919

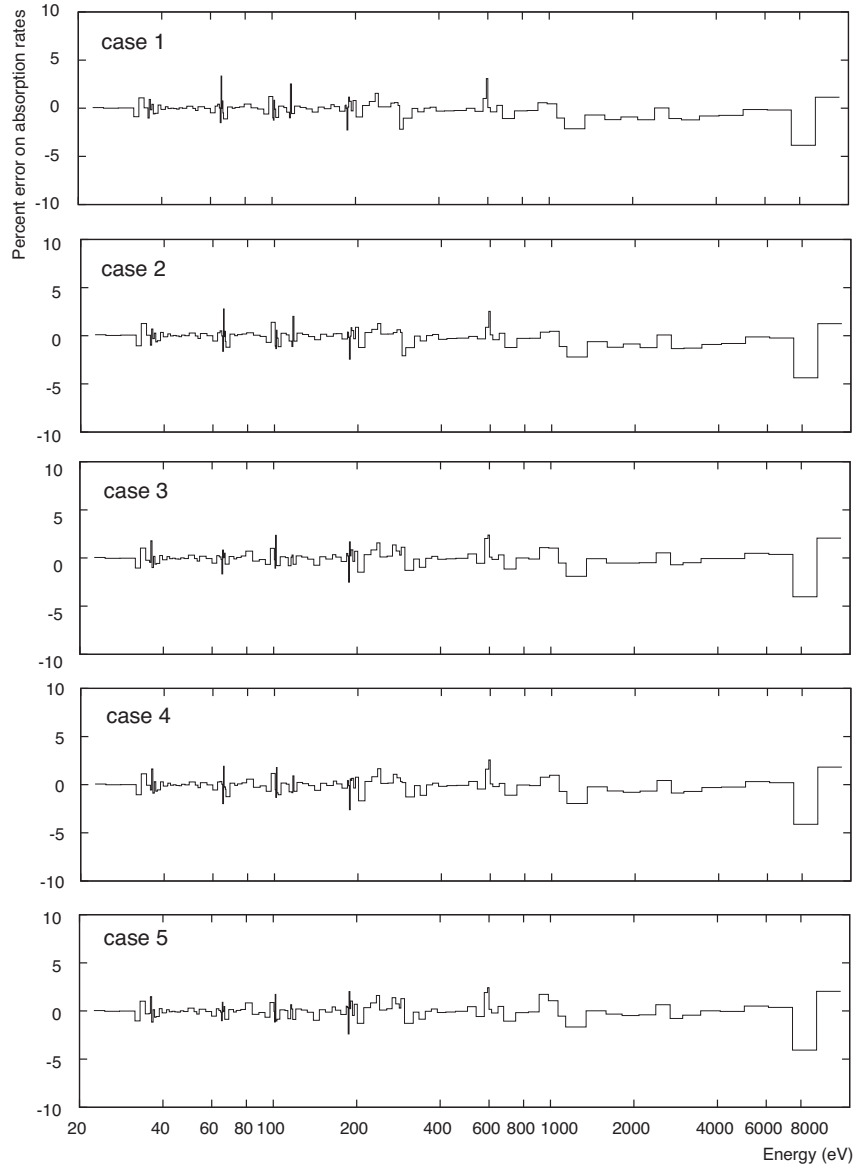
MOX one-neutron source benchmarks 1

	MOX fuel 1 Isoth. 300K	MOX fuel 1 Fuel at 560K	MOX fuel 2 Isoth. 300K	MOX fuel 2 Fuel at 560K	MOX fuel 1 Temp. ∇ in fuel
ϵ^{int} (%)	0.098	0.157	0.140	0.211	0.211
$\bar{\epsilon}$ (%)	0.751	0.777	0.816	0.841	0.770
ϵ^{max} (%)	3.079	3.458	3.495	3.508	3.318
in group	124	124	67	124	124
^{235}U ϵ^{int} (%)	0.420	0.402	0.403	0.382	0.389
^{238}U ϵ^{int} (%)	-0.209	-0.024	-0.204	-0.013	0.121
^{238}Pu ϵ^{int} (%)	0.237	0.303	0.355	0.421	0.343
^{239}Pu ϵ^{int} (%)	0.241	0.220	0.380	0.372	0.198
^{240}Pu ϵ^{int} (%)	0.597	0.536	0.504	0.465	0.569
^{241}Pu ϵ^{int} (%)	0.372	0.363	0.345	0.336	0.351
^{242}Pu ϵ^{int} (%)	0.657	0.400	0.464	0.278	0.206
^{241}Am ϵ^{int} (%)	0.342	0.335	0.324	0.313	0.317

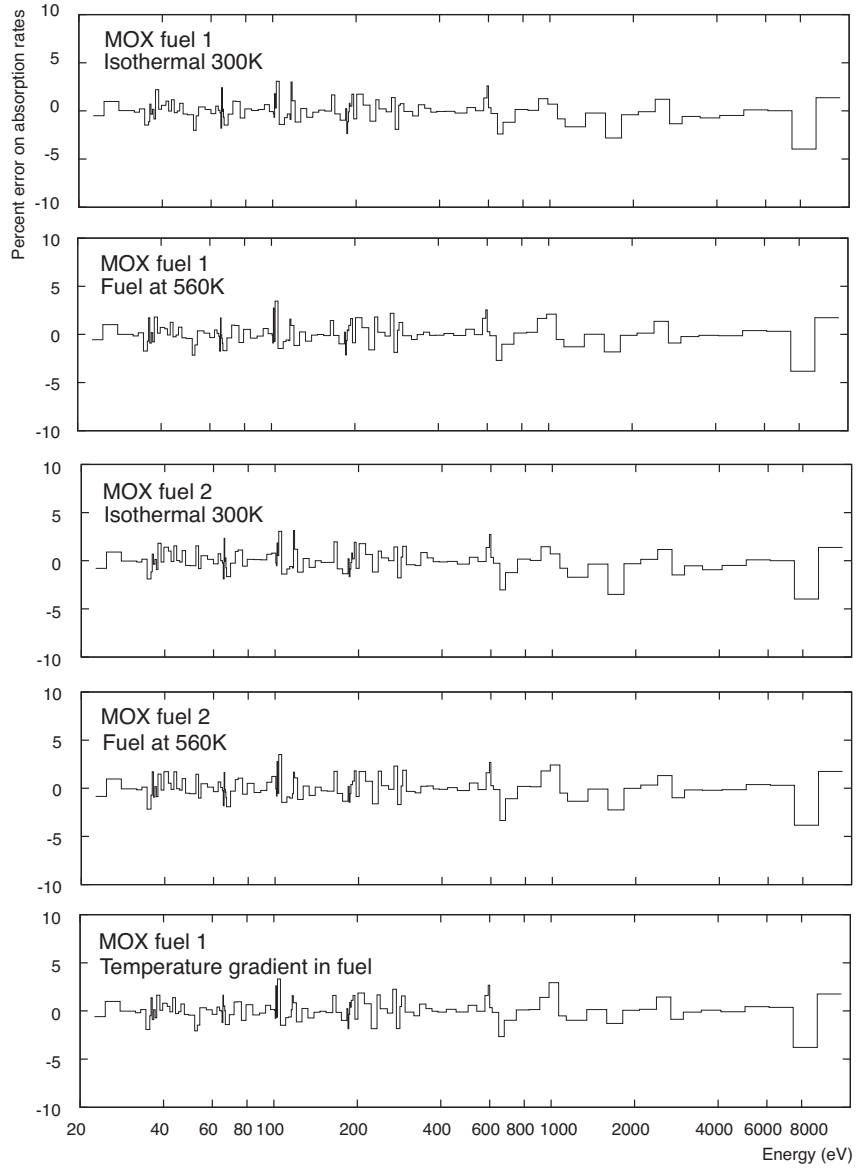
MOX one-neutron source benchmarks 2

	MOX fuel 1 Isoth. 300K	MOX fuel 1 Fuel at 560K	MOX fuel 2 Isoth. 300K	MOX fuel 2 Fuel at 560K	MOX fuel 1 Temp. ∇ in fuel
ϵ^{int} (%)	0.098	0.157	0.140	0.211	0.211
$\bar{\epsilon}$ (%)	0.751	0.777	0.816	0.841	0.770
$\epsilon^{\max}$ (%)	3.079	3.458	3.495	3.508	3.318
in group	124	124	67	124	124
^{238}U ϵ^{int} (%)					
shell 1	0.242	0.557	0.248	0.564	0.860
shell 2	0.079	0.401	0.089	0.410	0.530
shell 3	-0.309	-0.051	-0.301	-0.036	-0.350
shell 4	-0.570	-0.548	-0.571	-0.531	-0.743
shell 5	-0.946	-1.160	-0.946	-1.147	-0.770
shell 6	-1.513	-1.696	-1.513	-1.685	-1.853

% error on UO2 absorption rates. 1



% error on MOX absorption rates.



Conclusions

- The SHEM–361g mesh is permitting a better representation of self-shielding phenomena between 22.5 eV and 11.14 keV.
- The SPM is a good candidate for performing resonance self-shielding calculations in association with SHEM–361g.
- This optimized SHEM–361g could be used in FBR calculations in order to reduce drastically the computing time linked to the current 1968 group structure.
- The SPM is compatible with any type of solution of the transport equation.
- The SPM permits the representation of distributed self-shielding effects, mutual shielding effects and temperature gradient effects.
- The SPM, coupled with SHEM–361g solves the longstanding problems of resonance escape factor and Doppler coefficient calculations in MOX and HCLWR lattices.

Ressources

Available at `http://www.polymtl.ca/merlin/` on October 1st. The distribution available in Version 4.0.2 is including

- Updates to NJOY99 (definitions of SHEM–281 and SHEM–361)
- Availability if the SPM within the `USS:` module of Dragon Version4
- Open sources Draglibs in XMAS–172, SHEM–281 and SHEM–361 formats for
  - Jef 2.2
  - ENDF/B–VI rel. 8
  - Jeff 3.1
  - ENDF/B–VII rel. 0
- PyNjoy system to automate NJOY99 processing.