On the effect of the resonant dependent scattering law

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NJOY Workshop

Topics

- The limitation of the existing models
- The new scattering kernel formula
- Some safety and operational aspects of the resonant dependent kernel

The existing methods and the importance of the new kernel

- The MCNP code as well as the NJOY use approximated solution for the secondary scattering kernel.
- Practically the used models in both codes ignore to some extent the influence of the resonances on the scattering kernels.
- MCNP uses above ~10 eV (300K) the asymptotic kernel
- The new kernel is mathematically consistent and in accordance with the BROADR module (Doppler broadening) of NJOY

Ideal Gas Kernel

IDEAL GAS KERNEL: CONSTANT σ_b

$$\sigma_s^T(E \rightarrow E', \vec{\Omega} \rightarrow \vec{\Omega}') =$$

$$\frac{\sigma_b}{4\pi k_B T}\sqrt{\frac{E'}{E}} \exp\left(-\beta/2\right) S^T(\alpha, \beta) \,,$$

$$S^T(\alpha, \beta) = \frac{\exp\left[-(\alpha^2 + \beta^2)/(4\alpha)\right]}{2\sqrt{\pi\alpha}}$$

$$\alpha = \frac{E + E' - 2\sqrt{EE'}\mu_0^{lab}}{A k_B T}, \qquad \beta = \frac{E' - E}{k_B T}$$

IDEAL GAS KERNEL: ENERGY DEPENDENT $\sigma_s(E_r)$

$$\sigma_s^T(E \rightarrow E', \vec{\Omega} \rightarrow \vec{\Omega}') =$$

$$\frac{1}{4\pi E}\sqrt{\frac{A+1}{A\pi}} \int_{\epsilon_{max}}^{\infty} d\xi \int_{\tau_0(\xi)}^{\tau_1(\xi)} d\tau$$

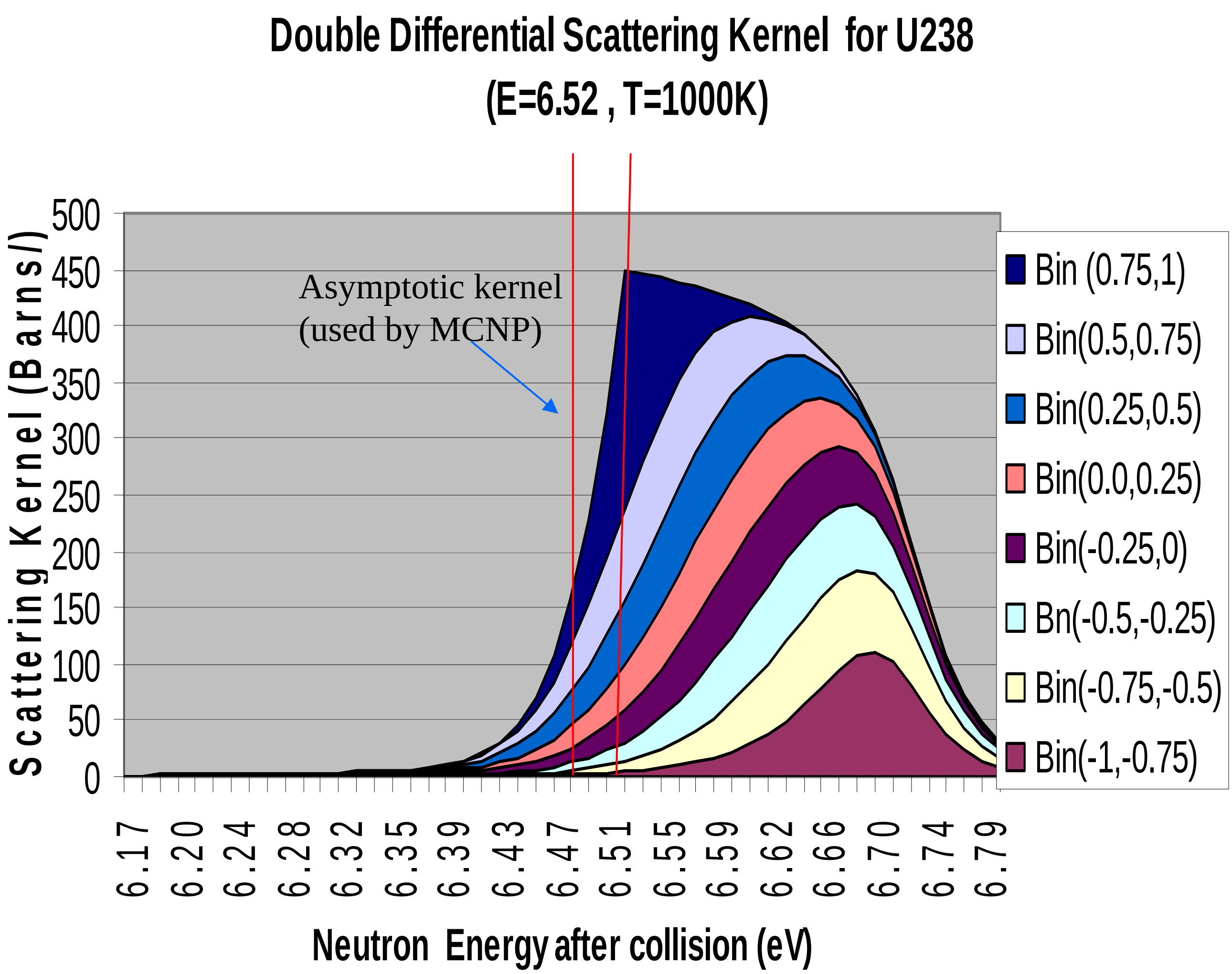
$$\left[\frac{(\xi + \tau)}{2}\right] \left(\frac{A+1}{A}\right)^2 \sigma_s \left[\left(\frac{A+1}{A^2}\right) \frac{[\xi + \tau]^2}{4} k_B T\right]$$

$$\exp\left\{v^2 - \left[\frac{(\xi + \tau)^2}{4A} + \frac{(\xi - \tau)^2}{4}\right]\right\} \left[\frac{\epsilon_{max}\epsilon_{min}(\xi - \tau)^2}{B_0 sin\hat{\varphi}}\right]$$

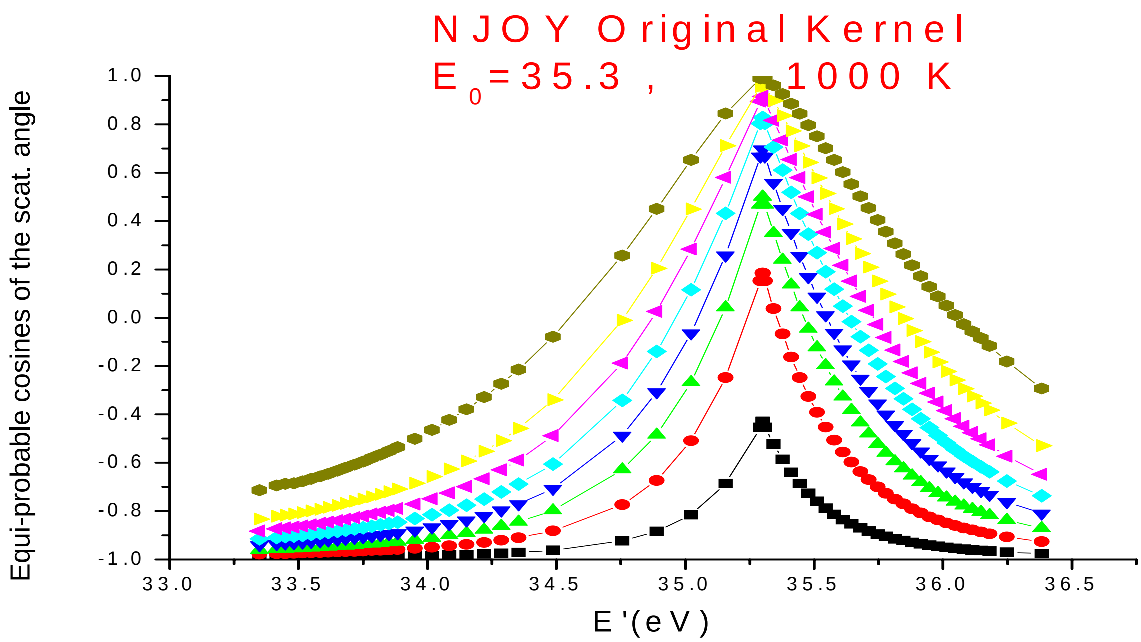
Inclusion of the new scattering formula in NJOY and MCNP

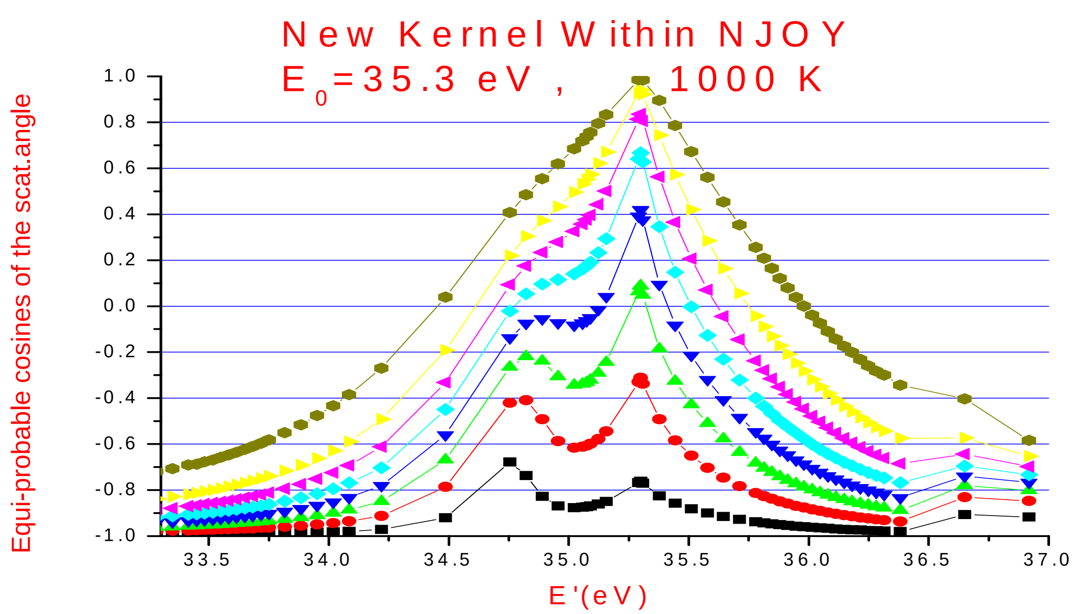
- The scattering kernel for nuclides with energy dependent cross – sections was coded in its new mathematical form (see ANE vol.31 ,2004 pp.9-23) into the THERMR module replacing the statement: “call error('thermr','iinc=2 not programmed.',' ') “
- The relevant MCNP subroutines were modified to deal with S(a,b) tables in the resonance energy range

The double differential scattering kernel



Original kernel and the new one using NJOY





Geometrical design and material composition

Geometrical dimensions of the pin cell

Pin cell Benchmark	Tellier	PWR UOX
Fuel radius	0.40950 cm	0.4 cm
Cladding outer radius	0.47436 cm	0.45 cm
Equivalent cell radius	0.71354 cm	0.67703 cm

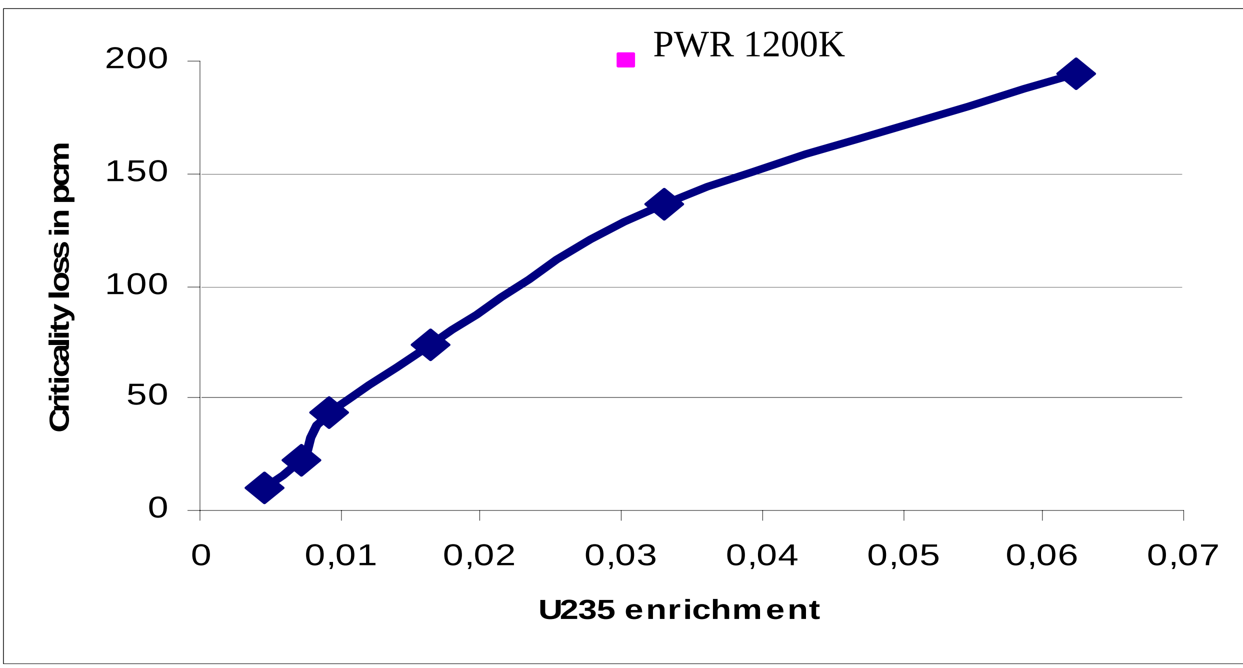
Nuclide Densities

Isotope	**Zone**	**Density 10^{24} a/cm^3 Tellier**	**pwr uox**
^{235}U	Fuel		0.00070803
^{238}U	Fuel	0.021758	0.022604
^{16}O	Fuel	0.044925	0.046624
^{27}Al	Clad	0.039220	
Zr	Clad		0.043241
^{16}O	Moderator	0.066988	0.066988
^{1}H	Moderator	0.033414	0.033414

Relative change in Doppler effect due to usage of 940 *S*(a,b) tables for U238

Energy range in eV	Doppler change $300k - 1200k$	Doppler change $1200K - 1800K$
10- 2.76	-9.96242E-03	-3.5329E-02
27.7 -10	0.4753E+00	0.1914E+00
48.05 - 27.7	2.7984E+00	1.4193E+00
75.5 - 48.05	0.1736E+00	0.2422E+00
120 - 75.5	0.0224E+00	0.1542E+00
186 - 120	-2.77763E-02	-1.38375E-02
210 - 186	0.0217E+00	0.1540E+00
total 210-2.76	0.2464E+00	0.23440E+00
total 3354.6 - 2.76	0.0910E+00	0.1751E+00

Reactivity loss in pcm, using resonance dependent **S(a,b)** tables for the “Tellier based” fuel pin at 1200 K**.**

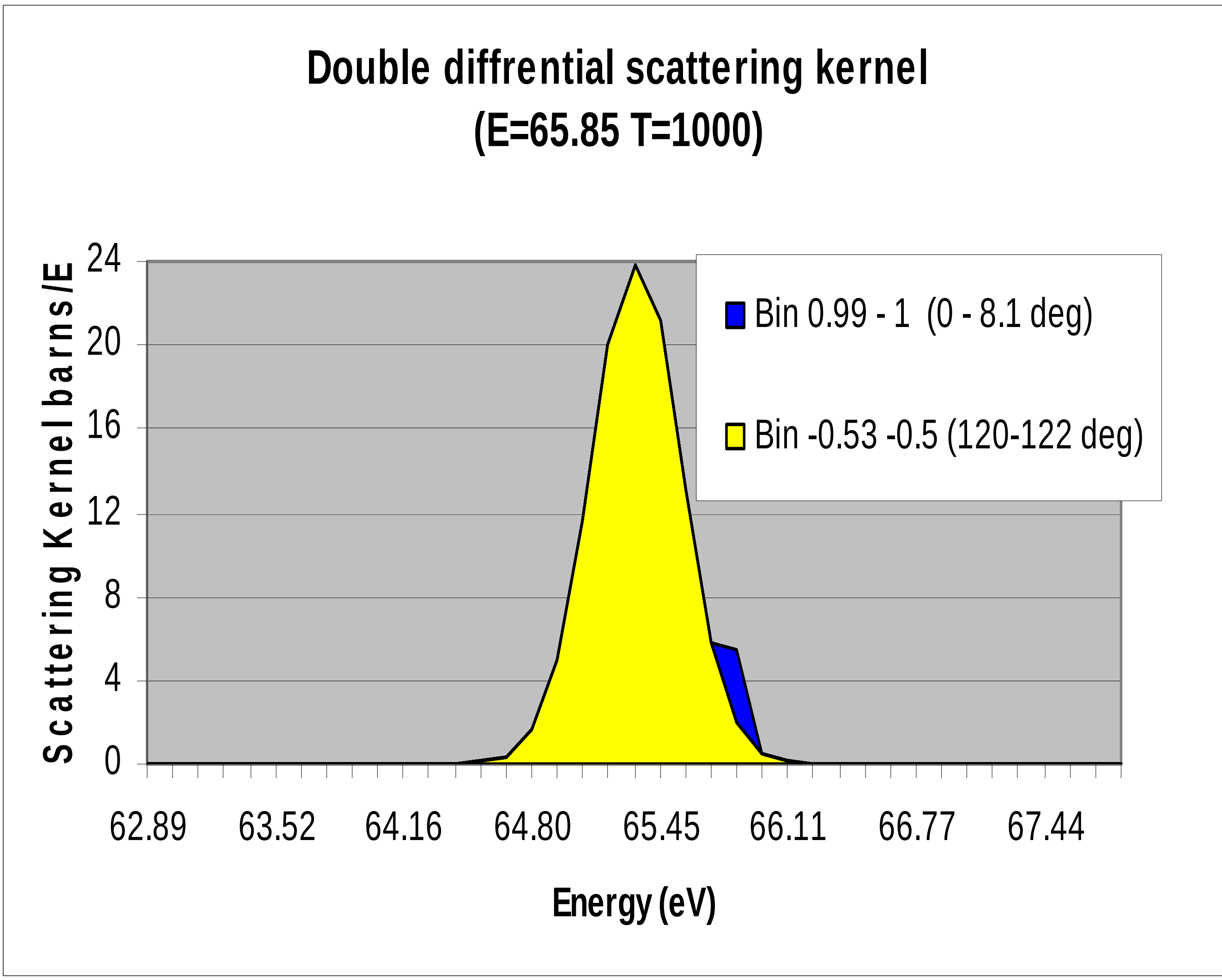


PWR pin cell 1200 K: 200 (+/-10) pcm loss
1800 K: 550 (+/-10) pcm loss

Capture experiment for the 1*eV* resonance of 240PuO2

- Liou and Chrien measured an effective temp. of 277 K for an experiment at 294 K.
- 149 S(a,b) tables were generated for the 4.2 and 0.2 eV energy range
- Between 4.2-1.7 eV 3% reduction in the absorption was calculated compared to the original MCNP method. Below 1.7 eV no effect was observed.
- The new kernel fit the trend of the experiment (which can not be explained by the Lamb's theory)

Impact on transmission measurements



SUMMARY

- The new kernel corrects the inconsistencies of previous scattering kernel formulations.
- The changes in Absorption rate Doppler and Criticality are not negligible
- Mixtures of U238 with other isotopes may lead to different results.
- Above 210 eV relevant resonances for the new treatment should be selectively chosen.
- The new kernel affects capture measurements and can improve transmission measurements.