Data Adjustment at INL

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Outline

- Sensitivity, UQ, and Adjustment Methodologies
- Global adjustment example
- Interface effect adjustment example
- Conclusions

Sensitivity and UQ Methodology

- **Classical perturbation theory, GPT (Generalized Perturbation Theory), and EGPT (Equivalent Generalized Perturbation Theory) are used for calculating importance functions associated to different type of integral parameters: K_{eff}, reaction rate ratios, reactivity coefficients.**
- **Importance functions are then integrated with forward solutions to obtain sensitivity coefficients.**
- **Sensitivity coefficients are folded with covariance data in order to evaluate uncertainties on the integral parameters**
- **The ERANOS code system is used for solving the related equations (Boltzmann) and perform the perturbation integrals in the neutron field.**
- **The NUTS code is used for calculating sensitivities in the nuclide (Bateman equation) field.**

Sensitivity for Reaction Rate Ratios

For a critical system, only reaction rate ratio can be calculated, otherwise there is no solution to the generalized importance equation. The source has to be orthogonal to the direct flux and give no contribution to the total balance:

$$\left(A^{*}-\frac{F^{*}}{K}\right)\tilde{\Psi}^{*}=\frac{\sigma_f(r,E)}{\left\langle\sigma_f\Phi_1\right\rangle}-\frac{\sigma_f(r,E)}{\left\langle\sigma_f\Phi_2\right\rangle}$$

If we, for instance, consider the power peak, this parameter can be expressed as the ratio:

$$R=\frac{\left\langle\Sigma_p\underline{\Phi}\right\rangle_{MAX}}{\left\langle\Sigma_p\underline{\Phi}\right\rangle_{\mathrm{Re}\,actor}}=\frac{I_1}{I_2}$$

with Σ_p the power cross-section, essentially represented by $E_f \bullet \Sigma_f$, where E_f is the average energy released per fission.

Sensitivity for Reaction Rate Ratios

The direct effect sensitivity coefficient for Σ_p are (numerator and denominator) defined as:

$$\mathrm{S_j} = \frac{\partial \mathrm{I_1}}{\partial \Sigma_\mathrm{p}} \cdot \frac{\Sigma_\mathrm{p}}{\mathrm{I_1}} - \frac{\partial \mathrm{I_2}}{\partial \Sigma_\mathrm{p}} \cdot \frac{\Sigma_\mathrm{p}}{\mathrm{I_2}}$$

The indirect sensitivity coefficients are defined as:

$$S_j = \left\langle \underline{\Psi}^*, \sigma_j \underline{\Phi} \right\rangle$$

and Ψ^* is the importance function solution of:

$$\left(A^* - \frac{F^*}{K} \right) \tilde{\Psi}^* = \frac{\Sigma_p(r,E)_{Max}}{I_1} - \frac{\Sigma_p(r,E)_{\mathrm{Re}\,actor}}{I_2}$$

The Case of Reactivity Coefficients (EGPT)

For the Equivalent Generalized Perturbation Theory the integral parameter is defined as:

$$I_s = \frac{1}{k'} - \frac{1}{k} = \frac{\left\langle \Phi^*, (\partial A - \partial F)\Phi' \right\rangle}{\left\langle \Phi^*, \frac{1}{k'} F'\Phi' \right\rangle}$$

Where $(\partial A - \partial F)$ characterizes the reactivity coefficient and the sensitivity coefficients are calculated using the fact that changing the order of the derivatives does not change the results:

$$\frac{\sigma}{I_s}\frac{dI_s}{d\sigma} = \frac{\left\langle \Phi'^*, (\partial A' - \partial F')\Phi' \right\rangle}{\left\langle \Phi'^*, \frac{1}{k'} F'\Phi' \right\rangle} - \frac{\left\langle \Phi^*, (\partial A - \partial F)\Phi \right\rangle}{\left\langle \Phi^*, \frac{1}{k} F\Phi \right\rangle}$$

The Case of Reactivity Coefficients (EGPT)

A reactivity coefficient (like the Doppler effect) can be expressed:

$$\Delta\rho = \left(1-\frac{1}{K_p}\right)-\left(1-\frac{1}{K}\right)=\frac{1}{K}-\frac{1}{K_p}$$

where K_p corresponds to a variation of the Boltzmann operator such that :

$$M \rightarrow M_p\left(= M + \delta M_p\right) \qquad \underline{\Phi} \rightarrow \underline{\Phi}_p\left(=\underline{\Phi}+\delta\underline{\Phi}_p\right)$$

$$\underline{\Phi}^* \rightarrow \underline{\Phi}^*_p\left(=\underline{\Phi}^*+\delta\underline{\Phi}^*_p\right) \qquad K \rightarrow K_p\left(= K+\delta K_p\right)$$

The sensitivity coefficients (at first order) for $\Delta\rho$ to variations of the σ_j are given as :

$$S_j^{RO}=\frac{\partial(\Delta\rho)}{\partial\sigma_j}\cdot\frac{\sigma_j}{\Delta\rho}=\left\{\frac{1}{I_f^p}\left\langle\underline{\Phi}^*_p,\sigma_j\underline{\Phi}_p\right\rangle-\frac{1}{I_f}\left\langle\underline{\Phi}^*,\sigma_j\underline{\Phi}\right\rangle\right\}$$

where $I_f=\left\langle\underline{\Phi}^*,F\underline{\Phi}\right\rangle$ **and** $I_f^p=\left\langle\underline{\Phi}^*_p,F\underline{\Phi}_p\right\rangle$

The Case of Nuclide Transmutation

The generic nuclide K transmutation during irradiation can be represented as the nuclide density variation between time t_0 and t_F. If we denote n_F^K the “final” density, the appropriate sensitivity coefficients are given by :

$$S_j^K = \frac{\partial n_F^K}{\partial \sigma_j} \cdot \frac{\sigma_j}{n_F^K} = \frac{1}{n_F^K} \int_{t_0}^{t_F} \underline{n}^* \sigma_j \underline{n} \quad dt$$

where the time dependent equations to obtain n* and n are the classical Bateman equation and its adjoint equation, with appropriate boundary conditions:

$$\frac{dn_k(t)}{dt} = \sum_{j=1}^{K-1} C_{kj} n_j(t) - C_{kk} n_k(t)$$

Target Accuracy Assessments

- Target accuracy assessments are the inverse problem of the uncertainty evaluation.
- In order to establish priorities and target accuracies on data uncertainty reduction, a formal approach can be adopted by defining target accuracy on design parameter and finding out required accuracy on data.
- The unknown uncertainty data requirements can be obtained by solving a minimization problem where the sensitivity coefficients in conjunction with the existing constraints provide the needed quantities to find the solutions:

$$\sum_i \lambda_i / d_i^2 = \min \qquad i = 1 \ldots I$$

$$\sum_i S_{ni}^2 d_i^2 < Q_n^T \qquad n = 1 \ldots N$$

where d_i are the uncertainties to be found, S_{ni} are the sensitivity coefficients for the integral parameter Q_n, Q^T are the target accuracies on the N integral parameters, and λ_i are cost parameters.

Representativity

- A further use of sensitivity coefficients is, in conjunction with a covariance matrix, a representativity analysis of proposed or existing experiments.
- The calculation of correlations among the design and experiments allow to determine how representative is the latter of the former, and consequently, to optimize the experiments and to reduce their numbers.

$$\mathbf{r}_{\mathbf{RE}} = \frac{\left(\mathbf{S}_{\mathbf{R}}^{+}\mathbf{D}\mathbf{S}_{\mathbf{E}}\right)}{\left[\left(\mathbf{S}_{\mathbf{R}}^{+}\mathbf{D}\mathbf{S}_{\mathbf{R}}\right)\left(\mathbf{S}_{\mathbf{E}}^{+}\mathbf{D}\mathbf{S}_{\mathbf{E}}\right)\right]^{1/2}}$$

- Formally one can reduce the estimated uncertainty on a design parameter by a quantity that represents the knowledge gained by performing the experiment:

$$\Delta\mathbf{R}_1^2 = \Delta\mathbf{R}_0^2\left(1-\mathbf{r}_{\mathbf{RE}}^2\right)$$

Representativity

If more than one experiment is available, the Eq. (50) can be generalized. In the case of two experiments, characterized by sensitivity matrices S_{E1} and S_{E2} the following expression:

$$\Delta R_0'^{\,2} = \Delta R_0^2 \left[1 - \frac{1}{1 - r_{12}^2} \left(r_{R1} - r_{R2} \right)^2 - \frac{2}{1 + r_{12}} r_{R1} r_{R2} \right]$$

$$r_{12} = \frac{\left(S_{E1}^{+} D S_{E2} \right)}{\left[\left(S_{E1}^{+} D S_{E1} \right) \left(S_{E2}^{+} D S_{E2} \right) \right]^{1/2}}$$

$$r_{R1} = \frac{\left(S_{R}^{+} D S_{E1} \right)}{\left[\left(S_{R}^{+} D S_{R} \right) \left(S_{E1}^{+} D S_{E1} \right) \right]^{1/2}}$$

$$r_{R2} = \frac{\left(S_{R}^{+} D S_{E2} \right)}{\left[\left(S_{R}^{+} D S_{R} \right) \left(S_{E2}^{+} D S_{E2} \right) \right]^{1/2}}$$

Statistical Adjustment Method

The method makes use of:

- **"a priori" nuclear data covariance information,**
- **integral experiments analysis to define C/E values**
- **integral experiment uncertainties**
- **sensitivity coefficients**

If we define: $\mathbf{y_j = (\sigma_j^{adj} - \sigma_j)/\sigma_j}$ **and** $\mathbf{y_{Qi}^{exp} = (Q_i^{exp} - Q_i)/Q_i}$ **,**
the $\mathbf{y_i}$ **are given by:**

$$y_i = \left(S^T D_Q^{-1} S + D^{-1}\right)^{-1} S^T D_Q^{-1} \, y_{Qi}^{exp}$$

where $\mathbf{D_Q}$ **is the covariance matrix of the experiments,** $\mathbf{D}$ **the covariance matrix of the cross sections and** $\mathbf{S}$ **is the sensitivity vector. It will also result an adjusted covariance matrix for the nuclear data.**

Statistical Adjustment Method

If we define B_p the “a priori” nuclear data covariance matrix, S_B the sensitivity matrix of the performance parameters B (B=1…..B_{TOT}) to the J nuclear data, the “a priori” covariance matrix of the performance parameters is given by:

$$B_B = S_B^T B_p S_B$$

It can be shown that, using a set of I integral experiments A, characterized by a sensitivity matrix S_A, besides a set of statistically adjusted cross-section data, a new (“a posteriori”) covariance matrix can be obtained:

$$\boxed{\tilde{B}_p} = B_p - B_p S_A \left(S_A^T B_p S_A + B_A \right)^{-1} S_A^T B_p$$

where B_A is the integral experiment uncertainty matrix.

Statistical Adjustment Method

This matrix can then be used to define a new ("a posteriori") covariance matrix for the performance parameters B:

$$
\begin{aligned}
\tilde{B}_B &= S_B^T \tilde{B}_p S_B = \{ B_B - \\
&- S_B^T B_p S_A \left(S_A^T B_p S_A + B_A \right)^{-1} S_A^T B_p S_B \} = \\
&= B_B \{ 1 - (S_B^T B_p S_B)^{-1} (S_A^T B_p S_A + B_A)^{-1} \times \\
&\times (S_A^T B_p S_B)^2 \}
\end{aligned}
$$

From this expression, it results that in order to reduce the performance parameter "a priori" uncertainties, the most effective integral experiments are those:

- **with "representative" sensitivity profiles ($S_A \sim S_B$) and**
- **small experimental uncertainties ($B_A \sim 0$).**

Statistical Adjustment Method

If we consider only one performance parameter B and only one experiment "i", and if we put $B_A = 0$, we obtain the expression of the "representativity" of one integral experiment:

$$r_{iB} = \frac{\left(S_i^T B_p S_B\right)}{\left[\left(S_i^T B_p S_i\right)\left(S_B^T B_p S_B\right)\right]^{1/2}}$$

Then, we can consider the previous equation as a generalized expression for the reference parameter uncertainty reduction. This generalized expression accounts for more than one experiment and allows estimating the impact of any new experiment in the reduction of the "a priori" uncertainty of the design performance parameters.

GLOBAL ADJUSTMENT

Adjustment Criteria

- **Reference system** is the Advanced Burner Reactor (metal and oxide fuel) as considered within GNEP

- The selected integral experiments meet a series of **requirements**: a) low and well documented experimental uncertainties; b) enabling to separate effects (e.g., capture and fission); and c) allowing validating global energy and space dependent effects.
  - irradiation experiment for b)
  - “representative experiments” for c)
  - specific spatial effects are singled out with appropriate experiments (e.g. experiments with or without blankets)

- **Global** statistical adjustment: $\tilde{B}_p = B_p - B_p S_A \left(S_A^T B_p S_A + B_A\right)^{-1} S_A^T B_p$

- **Four bands of energy**: 20 MeV, 0.5 MeV, 67 KeV, 2 KeV

List of integral experiments used in the adjustment

Experiment	Parameter to be analyzed			Fuel Type	Pu/(U+Pu)
	Critical mass	Reaction Rates	Irradiation Experiment		
GODIVA	Yes	Yes	-	U Metal	0.0
JEZEBEL[239]	Yes	Yes	-	Pu Metal	1.0
JEZEBEL[240]	Yes	-	-	Pu Metal	1.0
ZPR-3/53	Yes	Yes	-	PuC-UC	0.42
ZPR-3/54	Yes	Yes	-	PuC-UC	0.42
ZPPR-15	Yes	Yes		Pu-U Metal	0.13
COSMO[a]	-	Yes	-	PuO_2-UO_2	0.27
CIRANO[a]	Yes	-	-	PuO_2-UO_2	0.27
PROFIL[b]	-	-	Yes	PuO_2-UO_2	0.27
TRAPU[b]	-	-	Yes	PuO_2-UO_2	0.27

a) experiments performed in the MASURCA facility
b) irradiation experiments performed in the PHENIX reactor

C/E and Associated Uncertainties (σ) Before and After Adjustment

Type of Experiment	old C/E ± σ	new C/E ± σ	Type of Experiment	old C/E ± σ	new C/E ± σ
U235 Capture PROFIL1 (a)	0.977 ± 0.020	1.009 ± 0.009	**Cm244 TRAPU2 (b)**	**0.872± 0.023**	**0.978 ± 0.021**
U238 Capture PROFIL1 (a)	1.004 ± 0.023	1.005 ± 0.010	U238 Fission Rate COSMO(c)	0.988 ± 0.015	1.006 ± 0.010
Pu238 Capture PROFIL2 (a)	**1.744 ± 0.040**	**1.015 ± 0.036**	Np237 Fission Rate COSMO (c)	0.960 ± 0.015	0.979 ± 0.011
Pu239 (N,2N) PROFIL1 (a)	**0.752 ± 0.150**	**0.949± 0.133**	**Pu238 Fission Rate COSMO (c)**	**1.083 ± 0.025**	**1.005 ± 0.023**
Pu239 Capture PROFIL1 (a)	0.963 ± 0.030	1.021 ± 0.015	Pu239 Fission Rate COSMO (c)	0.983 ± 0.013	0.984 ± 0.003
Pu240 Capture PROFIL1 (a)	1.001 ± 0.022	0.995 ± 0.013	Pu240 Fission Rate COSMO (c)	1.034 ± 0.023	1.016 ± 0.016
Pu241 Capture PROFIL1 (a)	**0.847 ± 0.041**	**0.871± 0.013**	Pu241 Fission Rate COSMO (c)	0.998 ± 0.020	1.013 ± 0.017
Pu242 Capture PROFIL1 (a)	**1.092 ± 0.035**	**1.128 ± 0.019**	Pu242 Fission Rate COSMO (c)	1.000 ± 0.023	1.002 ± 0.022
Am241 Capture PROFIL1 (a)	1.000 ± 0.020	1.003± 0.015	**Am241 Fission Rate COSMO (c)**	**1.074 ± 0.023**	**1.003 ± 0.022**
Np237 Capture PROFIL2 (a)	0.988 ± 0.036	1.009± 0.022	Am243 Fission Rate COSMO (c)	1.059 ± 0.023	1.008 ± 0.021

C/E and Associated Uncertainties (σ) Before and After Adjustment (cont.)

Type of Experiment	old C/E ± σ	new C/E ± σ	Type of Experiment	old C/E ± σ	new C/E ± σ
U236 TRAPU2 (b)	0.965 ± 0.010	0.995 ± 0.009	k_{eff} GODIVA (d)	1.000 ± 0.001	0.999 ± 0.001
Np237 TRAPU2 (b)	**0.880 ± 0.033**	**0.954 ± 0.026**	U238 Fission Rate GODIVA (d)	0.955 ± 0.012	0.965 ± 0.004
Pu238 TRAPU2 (b)	0.942 ± 0.010	1.000 ± 0.006	Np237 Fission Rate GODIVA (d)	0.991 ± 0.016	1.003 ± 0.010
Pu239 TRAPU2 (b)	1.006 ± 0.005	1.001 ± 0.004	Pu239 Fission Rate GODIVA (d)	0.986 ± 0.017	0.987 ± 0.003
Pu240 TRAPU2 (b)	0.982 ± 0.006	1.000 ± 0.006	k_{eff} JEZEBEL9 (e)	1.000 ± 0.002	1.001 ± 0.001
Pu241 TRAPU1 (b)	1.005 ± 0.006	1.001 ± 0.003	U238 Fission Rate JEZEBEL9 (e)	0.974 ± 0.009	0.984 ± 0.004
Pu242 TRAPU1 (b)	0.998 ± 0.008	1.012 ± 0.004	Np237 Fission Rate JEZEBEL9 (d)	1.009 ± 0.017	1.021 ± 0.010
Am241 TRAPU2 (b)	0.985 ± 0.039	0.986± 0.005	k_{eff} JEZEBEL0 (e)	1.000 ± 0.002	0.999 ± 0.002
Am242 TRAPU2 (b)	1.029 ± 0.043	1.032 ± 0.013	**k_{eff} CIRANO (f)**	**1.007 ± 0.002**	**1.002 ± 0.001**
Am243 TRAPU1 (b)	0.939 ± 0.026	0.974 ± 0.020	k_{eff} ZPPR-15	0.999± 0.002	0.999± 0.001
Cm242 TRAPU1 (b)	1.003 ± 0.039	0.971 ± 0.013	**k_{eff} ZPR-3/53**	**1.009 ± 0.002**	**1.001 ± 0.001**
Cm243 TRAPU2 (b)	**0.462 ± 0.031**	**0.999 ± 0.031**	**k_{eff} ZPR-3/54**	**1.008 ± 0.002**	**1.000 ± 0.001**

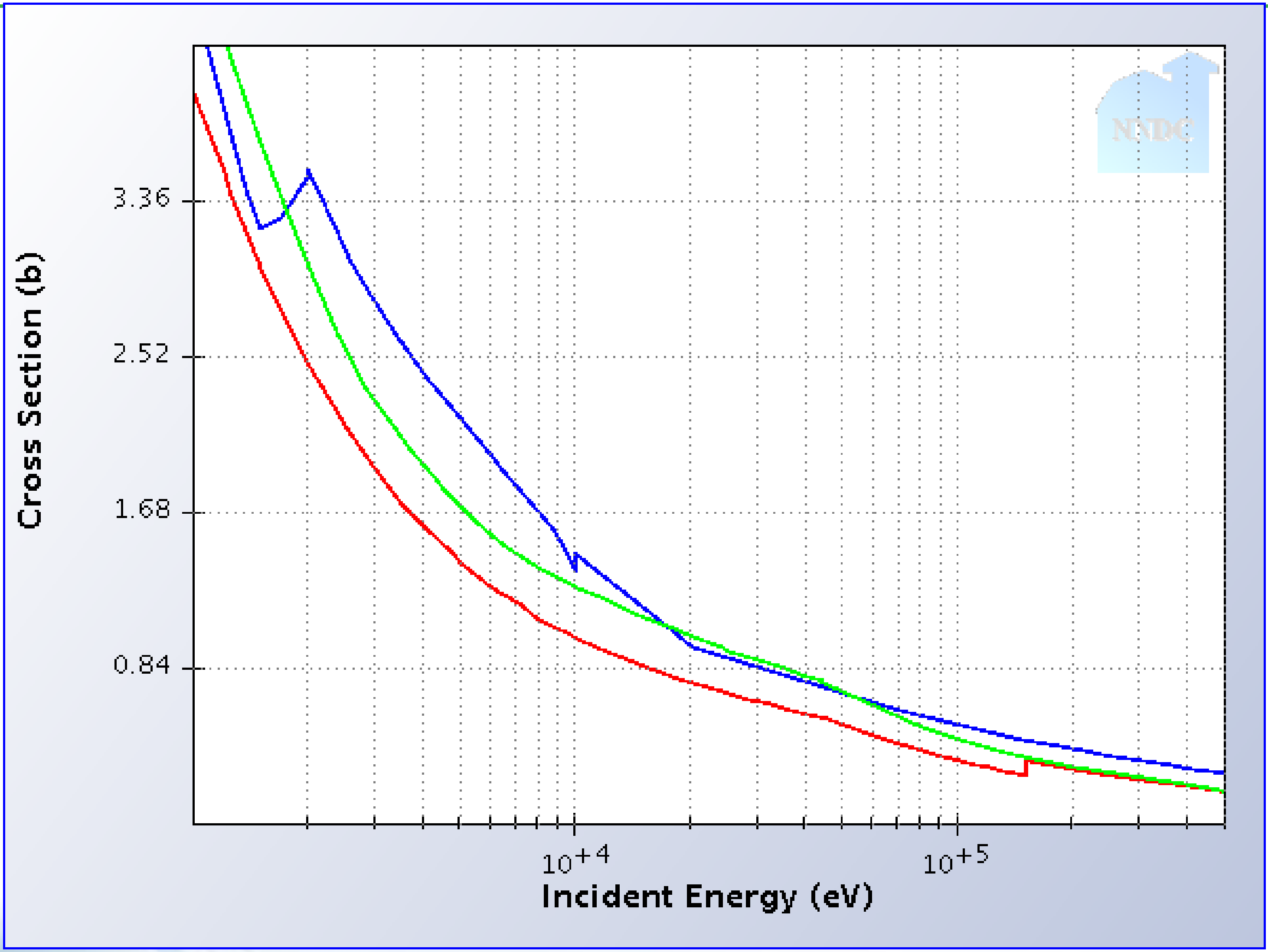
Calculated Adjusted Data Change and Original and Adjusted Standard Deviation (%)

Param.	Adjus. %	Stand. Deviat. %		Param.	Adjus. %	Stand. Deviat. %	
		Orig.	Adj.			Orig.	Adj.
Pu238 σ^{cap} gr. 2	-61.9	50.0	22.7	Pu240 σ^{cap} gr. 2	-0.7	14.0	3.4
Pu238 σ^{cap} gr. 3	-67.4	50.0	12.0	Pu240 σ^{cap} gr. 3	-0.4	9.0	2.0
Pu238 σ^{cap} gr. 4	-60.7	50.0	24.3	Pu241 σ^{cap} gr. 2	8.9	14.8	9.3
Pu238 σ^{fis} gr. 1	-11.6	18.3	7.7	Pu241 σ^{fis} gr. 1	2.9	15.0	6.0
Pu239 σ^{cap} gr. 3	5.0	8.9	5.8	Pu241 σ^{fis} gr. 2	2.7	16.9	5.4
Pu239 σ^{cap} gr. 4	11.3	12.6	7.6	Pu242 σ^{cap} gr. 3	7.1	38.1	10.2
				Pu242 σ^{fis} gr. 1	-0.6	16.6	2.6

Calculated Adjusted Data Change and Original and Adjusted Standard Deviation (%)(cont.)

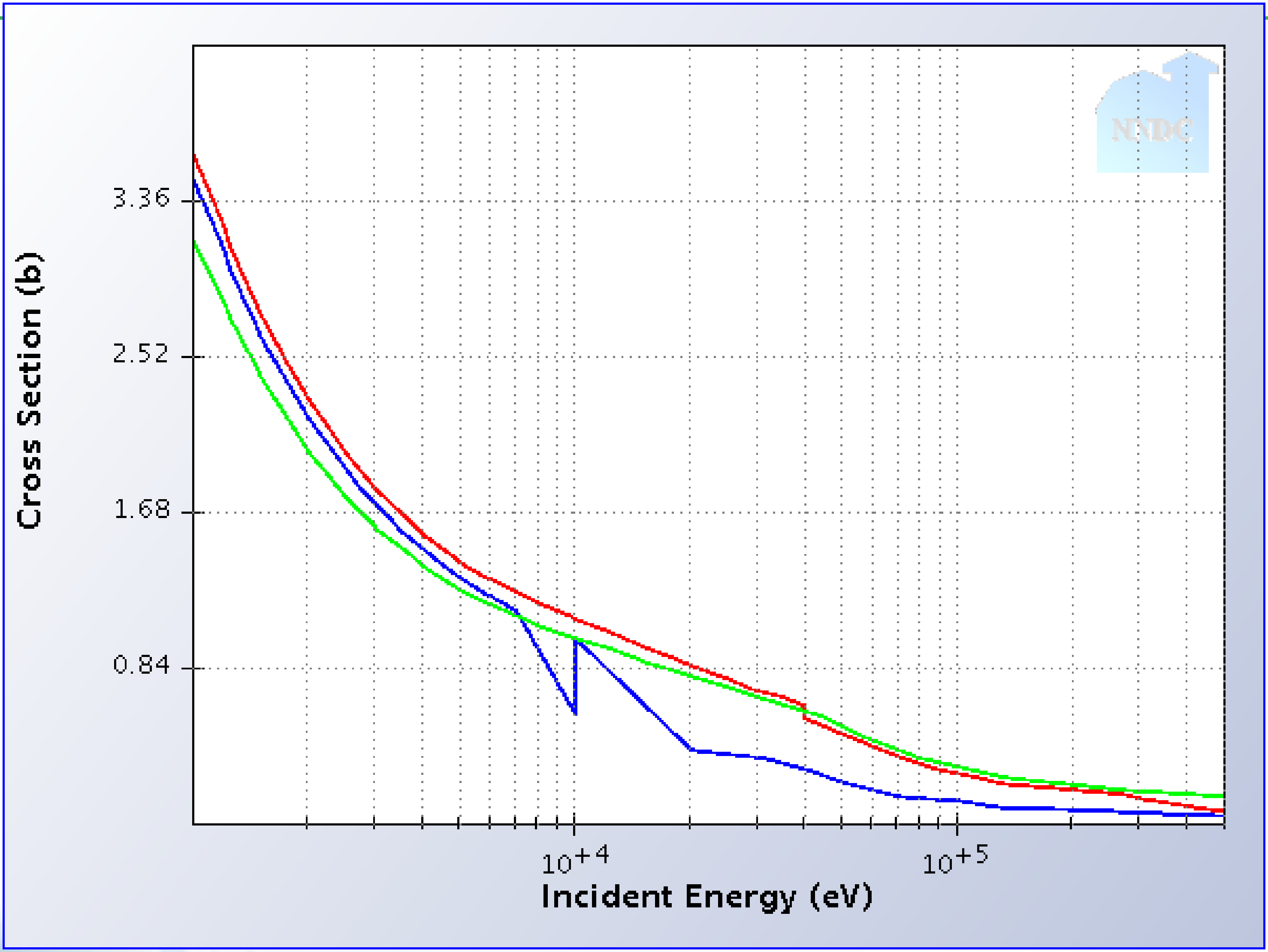
Param.	Adjus. %	Stand. Deviat. %		Param.	Adjus. %	Stand. Deviat. %	
		Orig.	Adj.			Orig.	Adj.
Cm242 σ^{cap} gr. 2	**101.5**	100.0	70.7	**U238 σ^{n2n} gr. 1**	**9.6**	5.0	3.1
Cm242 σ^{cap} gr. 3	**139.5**	100.0	24.5	**Pu239 σ^{n2n} gr. 1**	**25.8**	**30.0**	**14.1**
Cm242 σ^{cap} gr. 4	**96.8**	100.0	74.3				
Am241 σ^{fis} gr. 1	**-7.7**	**8.3**	**2.4**				
Am243 σ^{cap} gr. 2	**5.2**	6.0	5.6	**U238 σ^{inel} gr. 1**	3.5	17.1	8.5
Am243 σ^{cap} gr. 3	**9.7**	5.5	3.5	**Fe56 σ^{inel} gr. 1**	**-7.9**	10.5	8.4
Am243 σ^{cap} gr. 4	**9.1**	5.6	3.9	**Na23 σ^{inel} gr. 1**	-3.4	16.7	14.3
Am243 σ^{fis} gr. 1	**-5.7**	6.1	2.3				

Pu-238 (n,γ)



Blue ENDF/B-VII.0; Red JEFF-3.1; Green JENDL-3.3

Cm-242 (n,γ)



Blue ENDF/B-VII.0; Red JEFF-3.1; Green JENDL-3.3

ZPPR-15 k_{eff} correlation with other experiments after adjustment

Type of Experiment	A-posteriori Correlation
U-238 Capture, PROFIL1	-0.22
Pu-240 Capture, PROFIL1	0.11
Pu-239, TRAPU2	-0.21
U-238 Fission Rate, COSMO	0.18
Np-237 Fission Rate, COSMO	0.11
Pu-241 Fission Rate, COSMO	0.20
Np-237 Fission Rate, GODIVA	-0.07
Np-237 Fission Rate, JEZEBEL9	-0.07
k_{eff}, CIRANO	0.30
k_{eff}, ZPR-3/53	0.08
k_{eff}, ZPR-3/54	-0.05

K_{eff} Uncertainties [pcm] calculated with the BOLNA (BNL; ORNL; LANL; NRG; ANL) covariance matrix and adjusted covariance

Reactor	BOLNA 4 groups	Adjusted Covariance
ABR Oxide	1439	639
ABR Metal	1460	639

Summary on Global Adjustment

- A global adjustment has been applied to the uncertainty reduction on the criticality of the Advanced Burner Reactor, (both metal and oxide core versions) of the GNEP initiative.

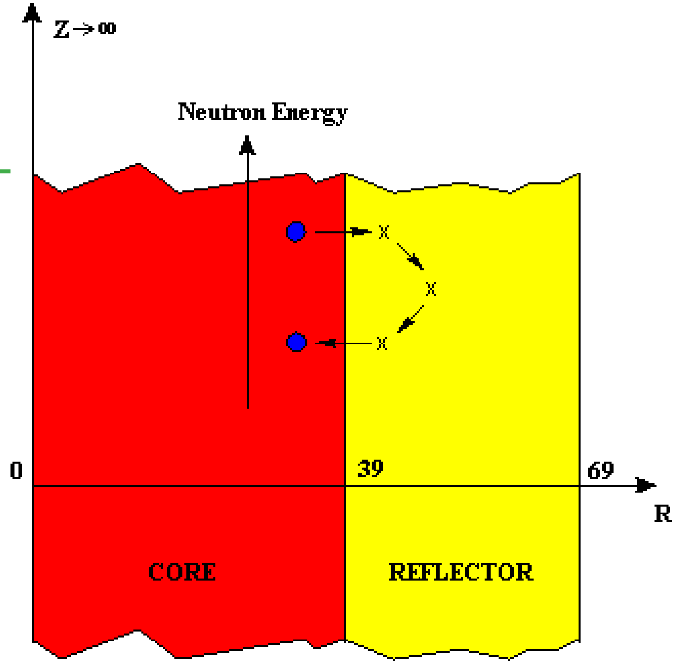
- It is remarkable that already at this stage it has been possible to indicate a few significant improvements of the present ENDF/B-VII data file, that have as consequence:

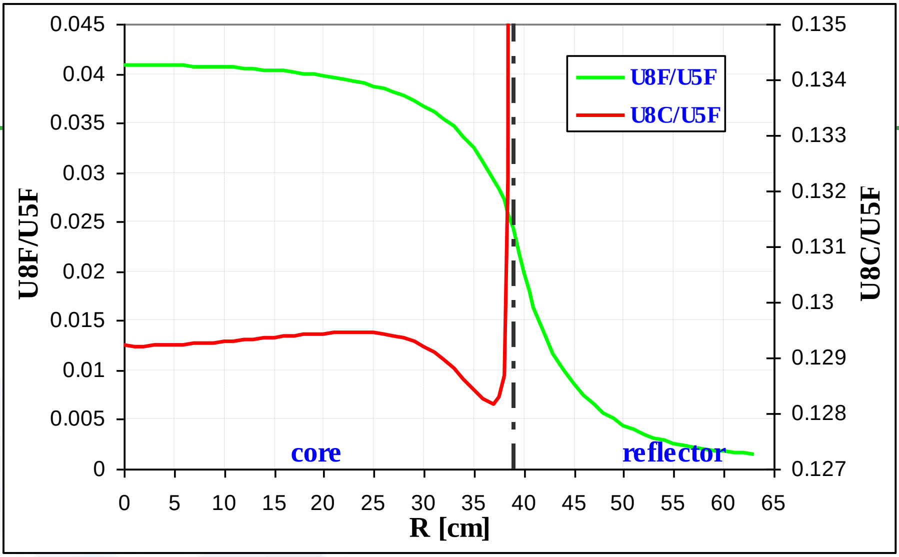
  - to reduce by more than a factor of two the present uncertainty, e.g., of the ABR cores keff and
  - to improve significantly the prediction of TRU nuclide densities during the cycle.

Interface Effects Adjustment

The Problem

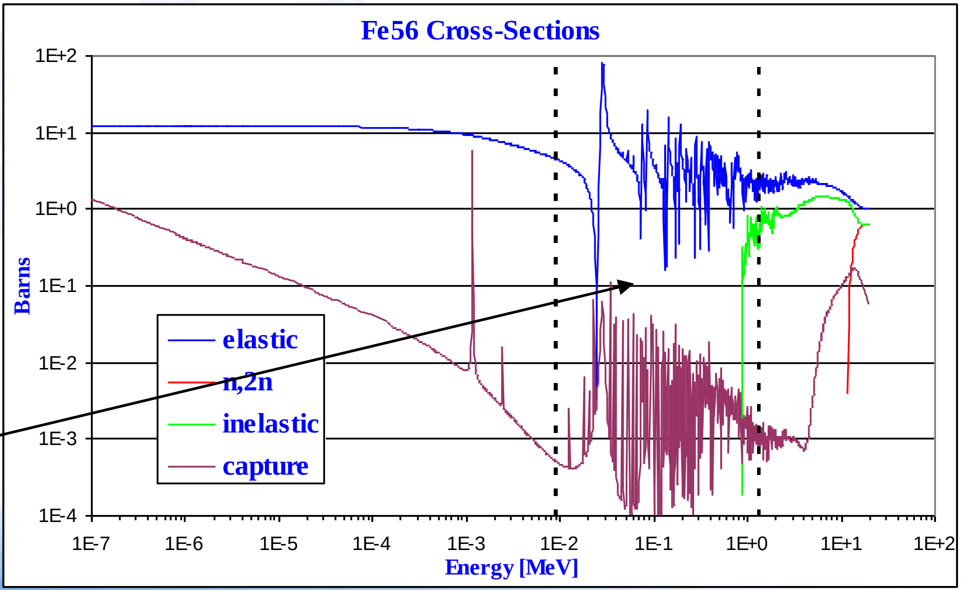
- **Interface effects (e.g. core/reflector interfaces) are expected to play an important role in burner type of future fast reactors, in particular for power distribution assessment due to the existence of severe space and energy neutron flux distribution transients at interfaces.**
- **A detailed multigroup energy treatment to account for spectrum transient at interfaces dramatically improves the agreement with a reference continuous energy Monte Carlo calculation.**
- **However, when analyzing experimental configurations that were purposely conceived for studying these types of effects (replacing blankets with reflectors) still large discrepancies can be observed for reaction rates gradients in regions close to boundaries between core and reflector.**
- **An adjustment has been performed using the ENDF/B-VII data and the AFCI (GNEP) 1.0 covariance data in order to better understand the origin of the discrepancy and provide feedbacks to nuclear data evaluators.**



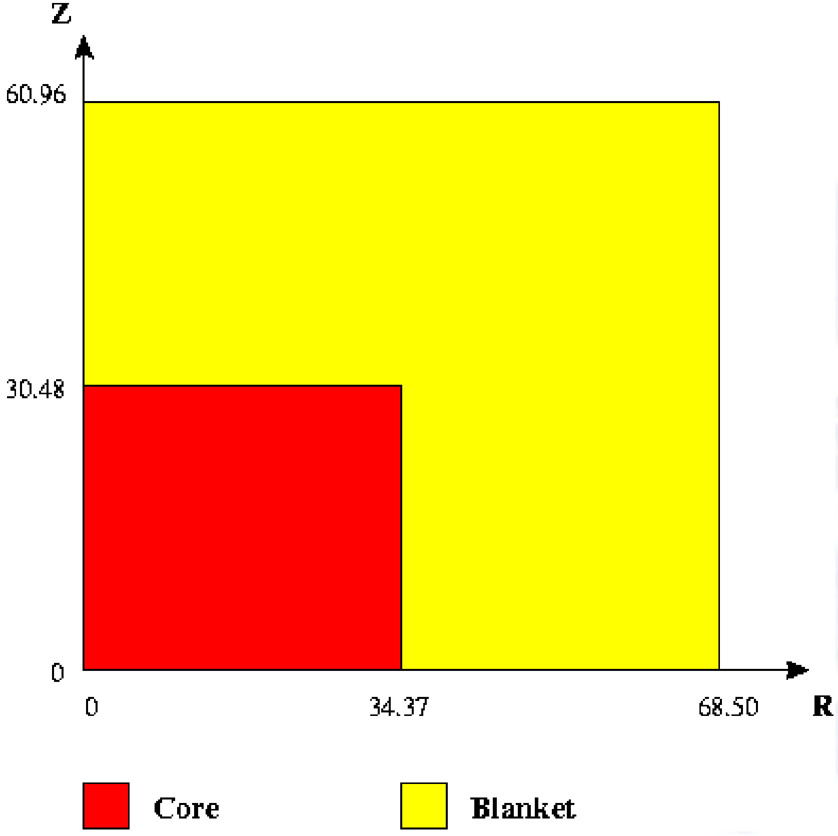


Spectral Indices vary strongly at interface

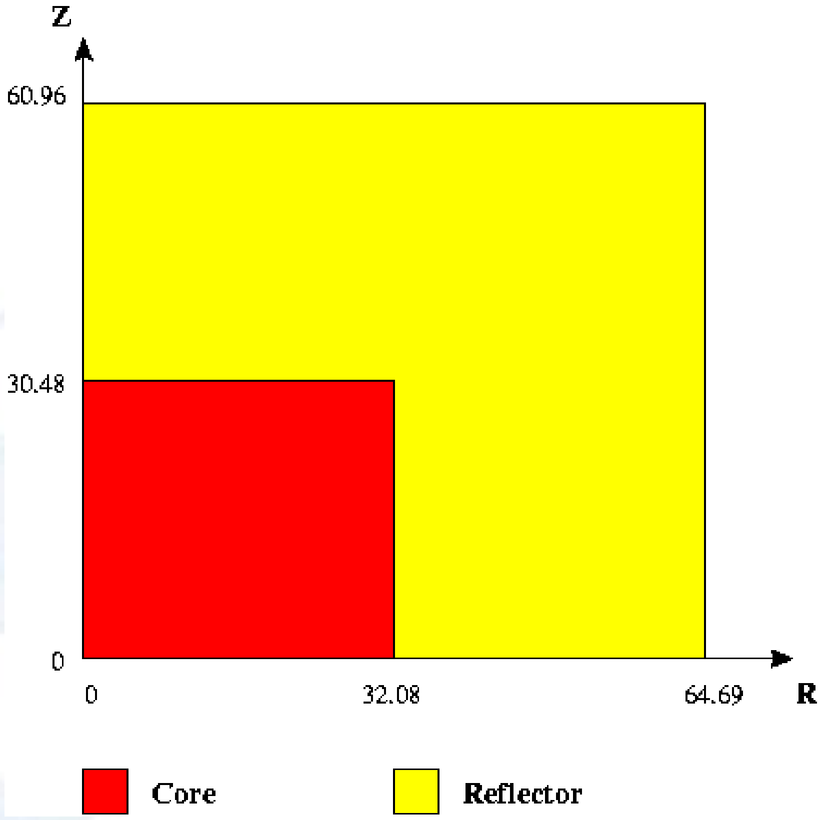
- *There is a severe spectrum transient at the interface that extends from 10 cm inside the core to 10 cm in the reflector, mostly due to the fine structure of iron cross section in the keV energy region.*



ZPR-3 Configurations

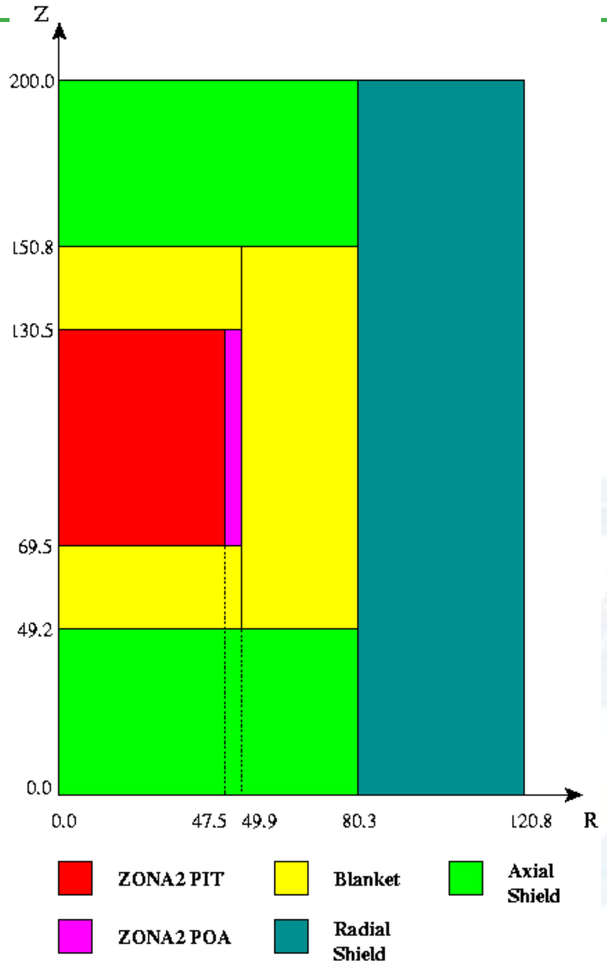


ZPR-3 Assembly 53

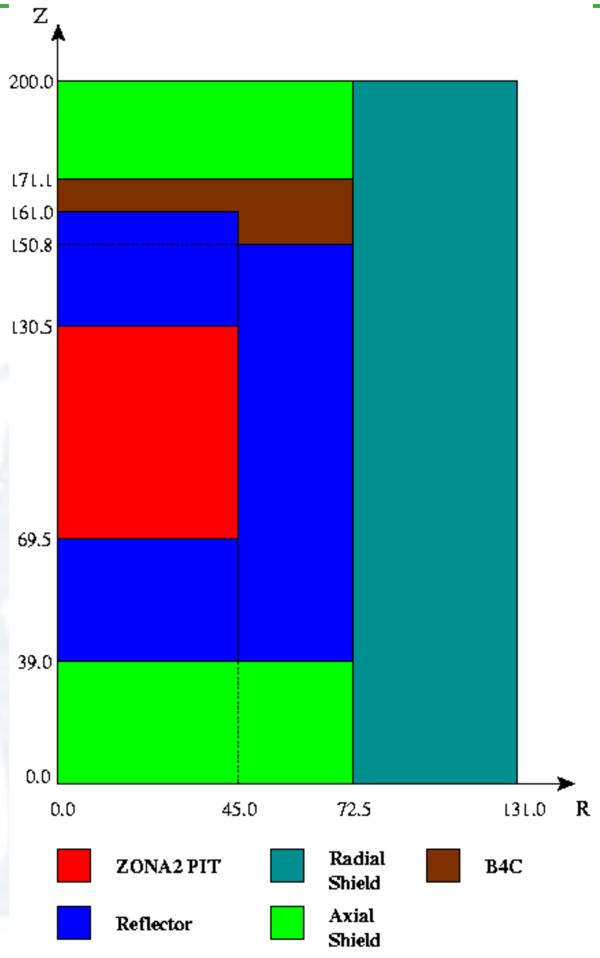


ZPR-3 Assembly 54

CIRANO Configurations

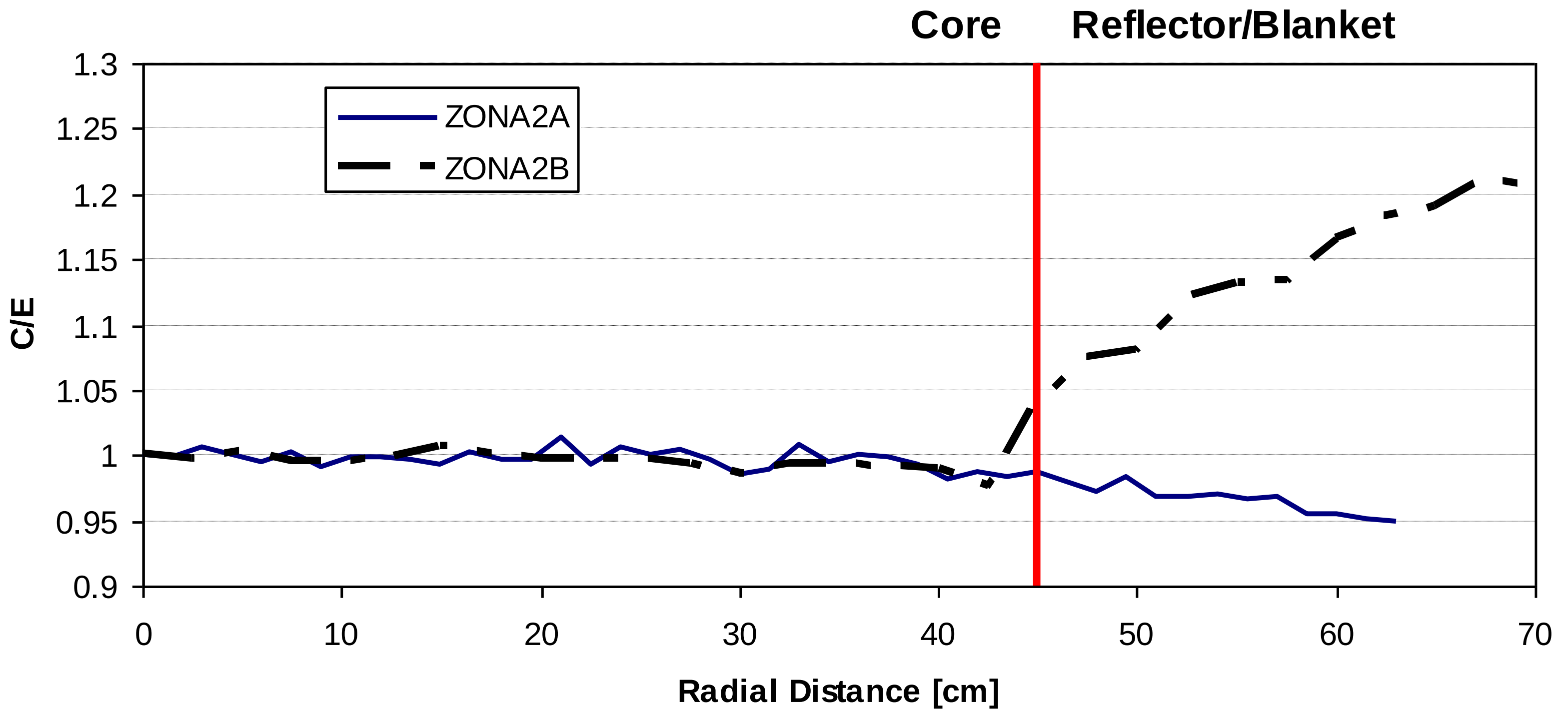


CIRANO 2A



CIRANO 2B

Adjustment for Reflector Effect

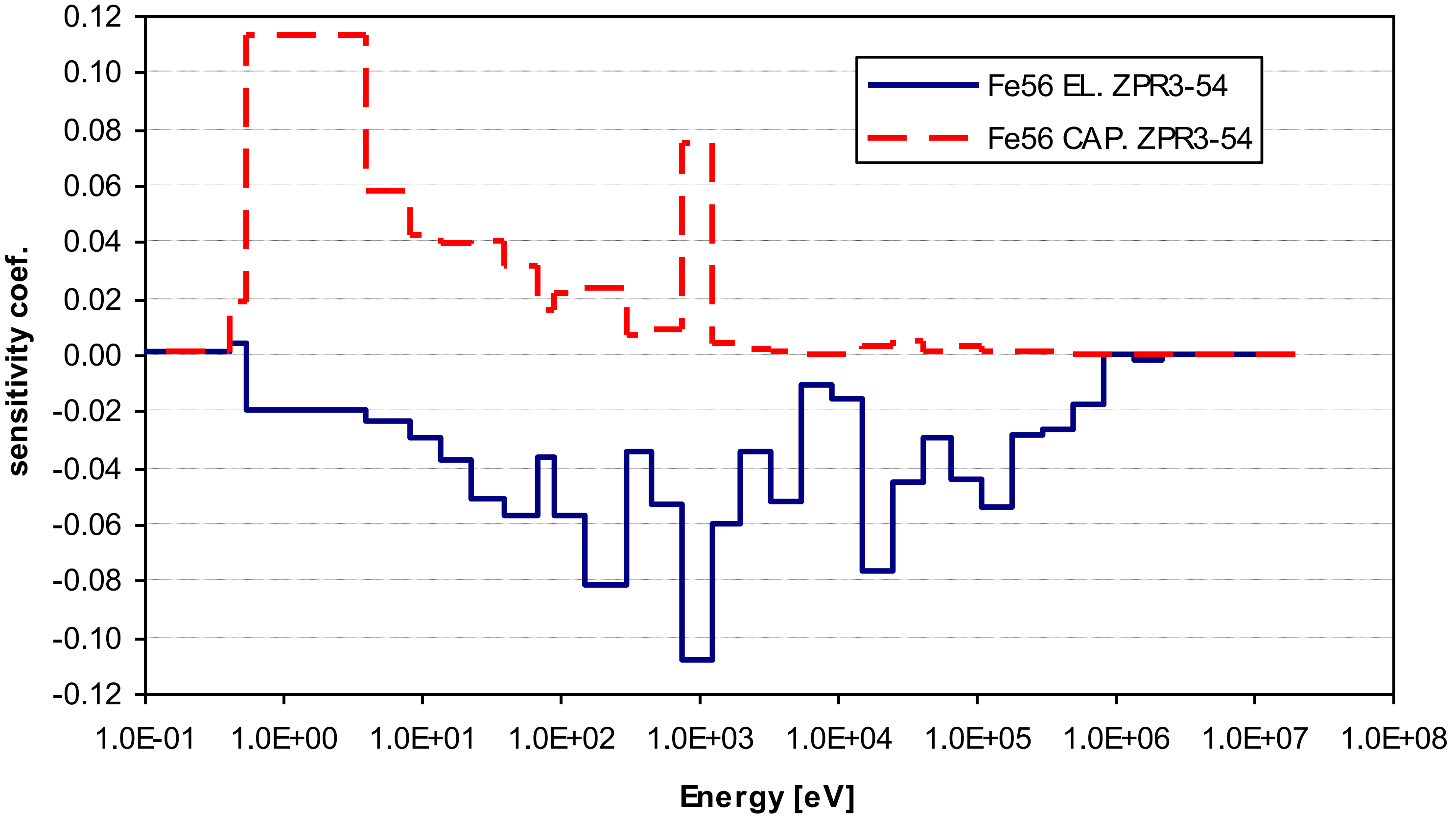


C/E in U235 fission rate distribution in CIRANO 2A (Blanket) and CIRANO 2B (Reflector)

Integrated sensitivity coefficients

		F9 gradient		F8 gradient	
		ZPR3-53 (U blkt)	ZPR-54 (Fe refl)	ZPR3-53 (U blkt)	ZPR-54 (Fe refl)
Fe-56	capture	0.0	0.32	0.0	0.02
	inelastic	0.1	-0.02	0.0	0.61
	elastic	0.1	-0.77	0.04	0.05
U238	capture	0.38	0.0	0.02	0.0
	inelastic	0.19	0.0	1.18	0.02
	fission	-0.09	0.0	-0.11	0.0

Sensitivity profile of Fe56 elastic and capture to B10 n,α slope in ZPR3-54



Initial and new C/E from adjustment using original covariance data.

Experiment	old C/E ± σ	new C/E ± σ	Experiment	old C/E ± σ	new C/E ± σ
B10(n,α) Slope ZPR3-54	0.913 ± 0.030	0.991 ± 0.019	U235 Fission Slope CIRANO 2B	0.893 ± 0.030	0.963 ± 0.015
U235 Fission Slope ZPR3-54	0.989 ± 0.030	1.045 ± 0.011	Np237 Fission Slope CIRANO 2B	1.076 ± 0.030	1.019 ± 0.009
Pu239 Fission Slope ZPR3-54	0.937 ± 0.030	0.990 ± 0.011	B10(n,α) Slope ZPR3-53	1.107 ± 0.030	1.084 ± 0.002
U238 fission Slope ZPR3-54	1.202 ± 0.030	1.019± 0.020	Pu239 Fission Slope ZPR3-53	1.098 ± 0.030	1.049 ± 0.004
U238 Fission Slope CIRANO 2B	1.221 ± 0.030	1.080 ± 0.015	U238 fission Slope ZPR3-53	1.386 ± 0.030	0.988 ± 0.029
Pu239 Fission Slope CIRANO 2B	0.870 ± 0.030	0.940 ± 0.014	U235 Fission Slope CIRANO 2A	1.013 ± 0.030	1.005 ± 0.001

Adjusted multigroup cross section using original covariance data.

Param.	Adjus. %	Stand. Deviat. %		Param.	Adjus. %	Stand. Deviat. %		Param.	Adjus. %	Stand. Deviat. %	
		Initial	Adj.			Initial	Adj.			Initial	Adj.
C12 σ^{el} gr. 3	-0.2	2.5	2.5	C12 σ^{inel} gr. 2	-1.6	17.8	17.8	Cr52 σ^{cap} gr. 19	7.1	20.0	19.9
Cr52 σ^{el} gr. 7	-5.8	19.9	19.8	Cr52 σ^{el} gr. 10	-6.8	22.7	22.6	Fe54 σ^{el} gr. 14	-2.4	13.5	13.2
Fe54 σ^{el} gr. 15	-2.8	15.9	15.7	Fe56 σ^{cap} gr. 20	16.6	10.0	5.6	Fe56 σ^{cap} gr. 23	16.1	10.0	6.0
Fe56 σ^{cap} gr. 24	16.1	10.0	6.0	Fe56 σ^{cap} gr. 26	16.2	10.0	6.0	Fe56 σ^{cap} gr. 27	16.2	10.0	6.0
Fe56 σ^{cap} gr. 28	16.2	10.0	6.0	Fe56 σ^{cap} gr. 29	16.2	10.0	5.9	Fe56 σ^{cap} gr. 30	14.1	8.6	5.1
Fe56 σ^{cap} gr. 31	6.9	5.0	3.6	Fe56 σ^{el} gr. 4	8.7	3.8	3.1	Fe56 σ^{el} gr. 5	13.2	5.0	3.7
Fe56 σ^{el} gr. 14	-1.3	3.0	2.9	Fe56 σ^{el} gr. 20	-1.4	3.2	3.1	Fe56 σ^{el} gr. 23	-1.3	3.0	2.9
Fe56 σ^{inel} gr. 3	3.8	3.3	3.2	Fe56 σ^{inel} gr.4	-16.7	5.5	3.4	Fe56 σ^{inel} gr.5	-43.5	12.7	6.4
Fe56 σ^{inel} gr. 6	-49.7	15.0	8.2	Ni58 σ^{el} gr. 13	-52.3	24.0	19.2	Ni58 σ^{el} gr. 14	-60.3	27.6	22.1
Ni60 σ^{el} gr. 14	-8.4	30.2	30.1	U238 σ^{el} gr. 5	21.7	18.8	7.0	U238 σ^{inel} gr. 2	-22.5	30.3	26.9
U238 σ^{inel} gr. 3	-26.1	20.1	7.2	U238 σ^{inel} gr. 4	-25.6	19.4	4.0	U238 σ^{inel} gr. 5	-24.2	20.6	7.1
U238 σ^{inel} gr. 6	-20.0	16.9	7.1								

Modified Covariance Data

- Because of a ~30% uncertainty on Ni58 elastic in the resonance region, there is a very large adjustment (close to 70%) that results in a significant contribution to the discrepancy reduction for low energy reaction rates gradients in the case of CIRANO 2B. The quite large uncertainty associated to the Ni58 is probably fairly artificial and due to a lack of modeling of the large resonances for structural materials.
- Moreover, the covariance data for Fe56 were derived directly from JENDL 3.3 data, and that are probably slightly optimistic for the elastic (~3% standard deviation) and inelastic (~ 5% standard deviation) cross sections.
- In order to avoid this rather artificial type of effects, we have tentatively modified a few uncertainty data (namely the standard deviations in all groups of: Ni58 elastic (set to 8%), Fe56 elastic (set to 8%), and Fe56 inelastic (set to 15%)). With these modified covariance data, a new adjustment was attempted .

Initial and new C/E from adjustment using modified covariance data.

Experiment	old C/E ± σ	new C/E ± σ	Experiment	old C/E ± σ	new C/E ± σ
B10(n,α) Slope ZPR3-54	0.913 ± 0.030	1.018 ± 0.022	U235 Fission Slope CIRANO 2B	0.893 ± 0.030	0.939 ± 0.010
U235 Fission Slope ZPR3-54	0.989 ± 0.030	1.054 ± 0.012	Np237 Fission Slope CIRANO 2B	1.076 ± 0.030	1.021 ± 0.009
Pu239 Fission Slope ZPR3-54	0.937 ± 0.030	1.002 ± 0.012	B10(n,α) Slope ZPR3-53	1.107 ± 0.030	1.084 ± 0.002
U238 fission Slope α ZPR3-54	1.202 ± 0.030	0.998± 0.022	Pu239 Fission Slope ZPR3-53	1.098 ± 0.030	1.050 ± 0.004
U238 Fission Slope CIRANO 2B	1.221 ± 0.030	1.059 ± 0.016	U238 fission Slope ZPR3-53	1.386 ± 0.030	0.988 ± 0.029
Pu239 Fission Slope CIRANO 2B	0.870 ± 0.030	0.920 ± 0.010	U235 Fission Slope CIRANO 2A	1.013 ± 0.030	1.005 ± 0.001

Adjusted multigroup cross section using modified covariance data.

Param.	Adjus. %	Stand. Deviat. %	
		Initial	Adj.
C12 σ^{el} gr. 3	-0.2	2.5	2.5
Cr52 σ^{el} gr. 7	-8.0	19.9	19.9
Fe54 σ^{el} gr.14	0.1	15.9	15.8
Fe56 σ^{cap} gr. 24	8.9	10.0	10.0
Fe56 σ^{cap} gr. 28	9.1	10.0	9.9
Fe56 σ^{cap} gr. 31	3.8	5.0	4.9
Fe56 σ^{el} gr.7	-2.2	8.0	7.9
Fe56 σ^{el} gr.10	-3.1	8.0	7.9
Fe56 σ^{el} gr.13	-7.9	8.0	7.9
Fe56 σ^{el} gr.18	-7.9	8.0	8.0
Fe56 σ^{el} gr.21	-7.9	8.0	7.9
Fe56 σ^{el} gr.24	-7.9	8.0	7.9
Fe56 σ^{el} gr.27	-7.9	8.0	7.9
Fe56 σ^{el} gr.31	-7.8	8.0	8.0
Fe56 σ^{inel} gr. 4	-38.5	15.0	13.1
Ni58 σ^{el} gr.14	-5.7	8.0	7.9
U238 σ^{inel} gr. 2	-21.3	30.3	30.2
U238 σ^{inel} gr. 5	-24.5	20.6	14.2
C12 σ^{inel} gr. 2	-1.4	17.8	17.8
Cr52 σ^{el} gr.10	-9.4	22.7	22.6
Fe56 σ^{cap} gr. 20	10.4	10.0	9.5
Fe56 σ^{cap} gr. 26	8.9	10.0	10.0
Fe56 σ^{cap} gr. 29	9.1	10.0	9.9
Fe56 σ^{el} gr.4	14.4	8.0	8.0
Fe56 σ^{el} gr.8	-2.9	8.0	8.0
Fe56 σ^{el} gr.11	-3.5	8.0	7.9
Fe56 σ^{el} gr.14	-7.9	8.0	7.8
Fe56 σ^{el} gr.19	-7.9	8.0	7.9
Fe56 σ^{el} gr.22	-7.9	8.0	8.0
Fe56 σ^{el} gr.25	-7.9	8.0	8.0
Fe56 σ^{el} gr.28	-7.9	8.0	8.0
Fe56 σ^{inel} gr. 2	-6.4	15.0	15.0
Fe56 σ^{inel} gr. 5	-37.7	15.0	10.3
Ni60 σ^{el} gr.14	-12.6	30.2	30.1
U238 σ^{inel} gr. 3	-25.7	20.1	19.2
U238 σ^{inel} gr. 6	-20.1	16.9	16.8
Cr52 σ^{cap} gr. 19	10.2	20.0	19.8
Fe54 σ^{el} gr.14	0.1	13.5	13.4
Fe56 σ^{cap} gr. 23	8.8	10.0	10.0
Fe56 σ^{cap} gr. 27	9.0	10.0	9.9
Fe56 σ^{cap} gr. 30	8.0	8.6	8.6
Fe56 σ^{el} gr.5	15.0	8.0	8.0
Fe56 σ^{el} gr.9	-2.9	8.0	8.0
Fe56 σ^{el} gr.12	-6.5	8.0	8.0
Fe56 σ^{el} gr.17	-7.9	8.0	7.9
Fe56 σ^{el} gr.20	-7.9	8.0	7.6
Fe56 σ^{el} gr.23	-7.9	8.0	7.9
Fe56 σ^{el} gr.26	-7.9	8.0	7.9
Fe56 σ^{el} gr.29	-7.9	8.0	7.9
Fe56 σ^{inel} gr. 3	4.7	15.0	14.6
Fe56 σ^{inel} gr. 6	-35.8	15.0	14.0
U238 σ^{el} gr. 5	22.1	18.8	18.7
U238 σ^{inel} gr. 4	-25.4	19.4	15.9

Major contributors to new C/E after adjustment using modified covariance data

Experiment	Total Relative Change	Major Contributors					
		Parameter	Contribution	Parameter	Contribution	Parameter	Contribution
B10(n,α) Slope ZPR3-54	11.5	Fe56 σ^{inel} gr. 6	0.9	Fe56 σ^{el} gr. 20	0.9	Fe56 σ^{cap} gr. 20	0.8
U235 Fission Slope ZPR3-54	6.5	Fe56 σ^{inel} gr. 6	0.9	Fe56 σ^{el} gr. 20	0.7	Fe56 σ^{cap} gr. 20	0.6
Pu239 Fission Slope ZPR3-54	6.9	Fe56 σ^{inel} gr. 6	0.8	Fe56 σ^{el} gr. 20	0.6	Fe56 σ^{cap} gr. 20	0.6
U238 fission Slope ZPR3-54	-17.0	Fe56 σ^{inel} gr. 5	-10.8	Fe56 σ^{inel} gr. 4	-7.0	Fe56 σ^{el} gr. 5	0.8
U238 Fission Slope CIRANO 2B	-13.2	Fe56 σ^{inel} gr. 5	-7.9	Fe56 σ^{inel} gr. 4	-5.9	Fe56 σ^{el} gr. 5	0.9
Pu239 Fission Slope CIRANO 2B	5.7	Fe56 σ^{cap} gr. 20	0.6	Fe56 σ^{el} gr. 20	0.6	Fe56 σ^{inel} gr. 6	0.5
U235 Fission Slope CIRANO 2B	5.1	Fe56 σ^{cap} gr. 20	0.6	Fe56 σ^{el} gr. 20	0.6	Fe56 σ^{inel} gr. 6	0.4
Np237 Fission Slope CIRANO 2B	-5.1	Fe56 σ^{inel} gr. 6	-2.6	Fe56 σ^{inel} gr. 5	-1.7	Fe56 σ^{inel} gr. 4	-1.2
B10(n,α) Slope ZPR3-53	-2.0	U238 σ^{inel} gr. 5	-0.9	U238 σ^{inel} gr. 4	-0.8	U238 σ^{inel} gr. 3	-0.4
Pu239 Fission Slope ZPR3-53	-4.4	U238 σ^{inel} gr. 5	-1.6	U238 σ^{inel} gr. 4	-1.4	U238 σ^{inel} gr. 3	-0.8
U238 fission Slope ZPR3-53	-28.7	U238 σ^{inel} gr. 5	-11.4	U238 σ^{inel} gr. 4	-10.0	U238 σ^{inel} gr. 3	-5.2
U235 Fission Slope CIRANO 2A	-0.8	U238 σ^{inel} gr. 4	-0.3	U238 σ^{inel} gr. 5	-0.3	Fe56 σ^{inel} gr. 4	-0.1

Summary on Interface Effects Adjustment

- A statistical adjustment has shown that using experimental reaction rate distributions, measured in different cores with different reflectors (ZPR3 53 and 54, and CIRANO assemblies), one can put in evidence nuclear data that should be improved in order to obtain better calculation-to-experiment agreement.
- The results obtained in the study offer some clear indication towards the improvement needed in the inelastic cross sections both of Fe-56 and of U-238. Another indication is related to the need of improvement of the Fe-56 capture cross section in the 1 keV energy range.
- Finally, the study has also underlined that in order to consolidate the present results and trend indications for data improvement, it is needed to further strengthen the covariance data that are used in the uncertainty analysis and subsequent statistical adjustment. In particular a new reevalaution of covariance matrices for Fe-56, Ni-58, and Cr-52 will be needed.

Conclusions

- INL has several capabilities for computing sensitivity coefficients, perform uncertainty evaluation, select experiments based on representativity, carry out target accuracy assessment, and make nuclear data adjustments.

- Several exercises have already been carried out and feedbacks have been performed to nuclear data evaluators.

- At present INL is very active in an AFCI project for uncertainty reduction related to nuclear data via data adjustment

- Work has also started in collaboration with BNL for performing a consistent data adjustment on basic nuclear parameters (optical model, and resonance parameters) using integral experiments.