

Preparation of sensitivity coefficients for shielding (ASPIS Fe88), k_{eff} and β_{eff} benchmarks

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PURPOSE

- Mainly criticality benchmarks are used for ND validation and adjustment studies. However, k_{eff} is a very global parameter;
- Validation against other type of measurements provides a complementary view and wider scope validation;
- The following experimental measurements were considered for ND validation & adjustment:
 - **Critical benchmarks**
 - **Kinetics measurements**
 - **Shielding benchmarks**

SINBAD: FISSION NEUTRONICS

Benchmark / quality	Additional information needed on
ASPIS Iron ~ ♦♦	n source description, positioning / dimension uncertainty, some specifications inconsistent or not complete
ASPIS Iron-88 ~ ♦♦♦	New MCNP model. Additional information needed: <ul style="list-style-type: none"> - detectors arrangement (e.g. stacking) - gaps between the slabs - absolute calibration of neutron source & dilution factor - effect of the cave walls
ASPIS Graphite ♦♦♦	New MCNP model. Additional information needed: <ul style="list-style-type: none"> - detectors arrangement in the slots (dimensions are inconsistent)
ASPIS Water ♦♦♦	New MCNP model. Supplementary information needed on: <ul style="list-style-type: none"> - NE-213 spectrometer - water tank (container, bowing effects) - experimental room
ASPIS n/γ water/steel arrays ~ ♦♦♦	Supplementary information needed on: <ul style="list-style-type: none"> - detectors arrangement - bowing of the water tanks - background subtraction - cave walls

SINBAD: FISSION NEUTRONICS

Benchmark / quality	Additional information needed on
ASPIS PCA REPLICA ◆◆◆	Supplementary information needed on: - set-up of the activation foils - rear wall of the ASPIS cave
NESDIP-2 ◆ / ◆◆	New MCNP model. Supplementary information needed on: - activation foils positioning & housing - background subtraction method, calibration
NESDIP-3 ◆◆◆	- ” -
JANIS-1 ◆◆◆	- ” -
JANIS-8 ◆◆◆	- ” -
EURACOS Iron ~ ◆◆	New MCNP model, source model, uncertainty. Supplementary information needed on: source (spectrum, spatial distribution), energy structure of the proton recoil spectra, neutron spectrometers response functions, additional details on the geometry (room return), on geometry and material composition uncertainties. Limited applicability – fast neutron attenuation in iron only.
EURACOS Na ~ ◆◆	- ” -
HARMONIE ◆	too simplified geometry, materials and neutron source description

ASPIS IRON-88

- First SINBAD evaluation in ~1997 (A. Every, myself)

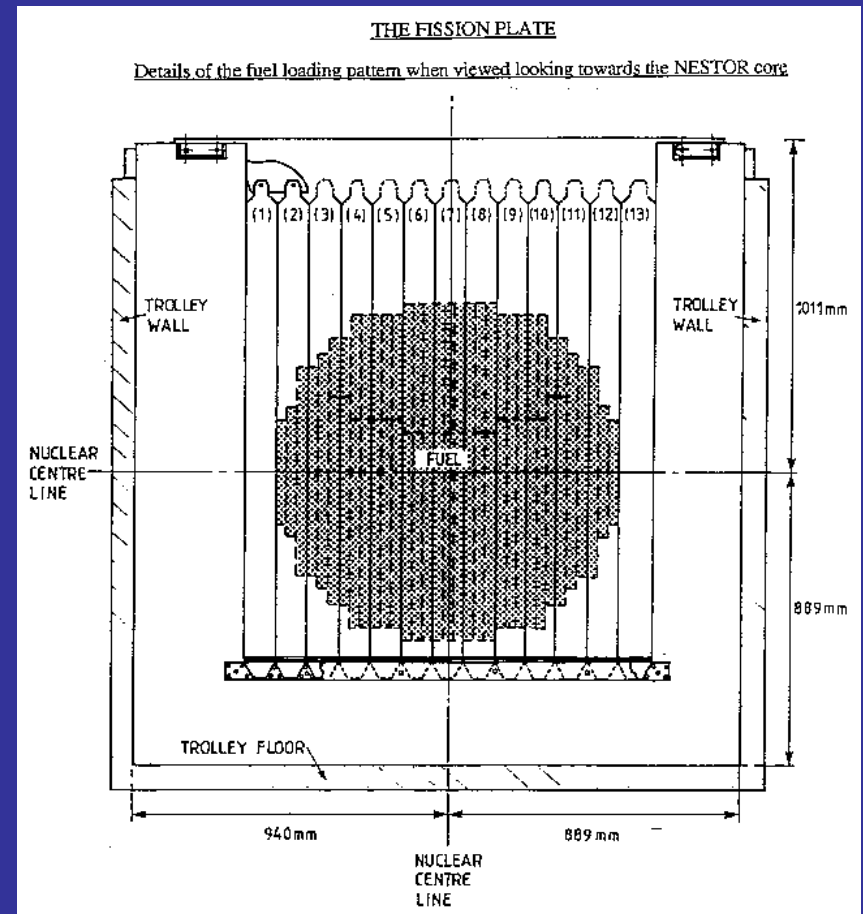
- Quality re-evaluation & analysis by A. Milocco, I. Kodeli in 2014 -2016

Neutron transport for penetrations up to 67 cm in steel.

Fission plate (93% enriched UAl alloy) driven by thermal neutrons from the NESTOR reactor. Absolute source strength and spatial distribution is determined by fission product counting and $^{55}\text{Mn}(n,\gamma)$ RR measurements over XY front surface.

Au, Rh, In, S and Al activation foils irradiated in 7.4-mm air gaps between 13 mild steel plates of the size of 1.8 m x 1.9 m x 5.1 cm. Measured reaction rate axial distributions:

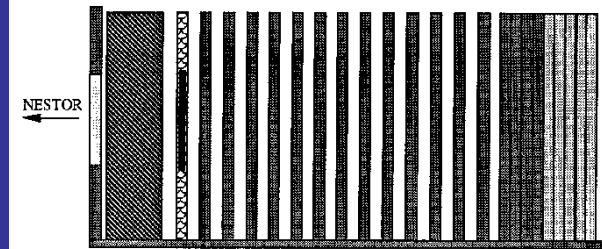
- $^{197}\text{Au}(n,\gamma)$ under Cd
- $^{32}\text{S}(n,p)$
- $^{103}\text{Rh}(n,n')$
- $^{115}\text{In}(n,n')$
- $^{27}\text{Al}(n,\alpha)$



ASPIS IRON-88

Au, Rh, In, S and Al activation foils installed in 7.4-mm air gaps.

Figure 1 Schematic side elevation of the shield in the iron 88 single material benchmark experiment



KEY

- Fuel
- ▨ Mild Steel
- ▩ Stainless Steel
- ▤ Fission Plate
- ▥ Graphite
- ▦ Aluminium

All components are 182.9cm wide by 191.0cm high
Not To Scale

Detector	Diameter (mm)	Thickness (mm)	Typical Mass (g)	Cadmium Cover (inches)	Counting System	Systematic Absolute Calibration (2σ uncertainty)
Au197 (n, gamma)	12.7	0.05	0.12 - 0.13	50/1000	NaI	0.9%
Rh103 (n, n')	12.7	0.015	0.20	-	NaI	3.0%
In115 (n, n')	38	1.63	12.79	-	GeLi detector	1.9%
S32 (n, p) Pressed Pellet	38.1	2.41	5	-	Plastic Scintillator	5.0%
S32 (n, p) Cast Pellet	51	5.6	22	-	Plastic Scintillator	5.0%
Al27 (n, alpha)	50	3.1	16.72	-	Ge detector	2.2%

ASPIS IRON88 - uncertainties

Au, Rh, In, S and Al activation foils installed in 7.4-mm air gaps.
Experimental uncertainties (2σ):

- Source power normalisation: 8 %
- Calibration: 1 – 5%
- Counting statistics: ~1 – 1.5% (except few S locations)

Additional uncertainties:

- Source (spectrum & spatial distribution)
- Room return (~2% threshold RR, Au measured with/without fuel)
- Foil positioning & arrangement
- Geometry descriptions & modelling, material compositions, dimensions

Total uncertainties on calculated results

Source of uncertainty	Sulphur		Indium		Rhodium		Gold		Aluminium	
	A2	A15	A2	A11	A2	A15	A2	A15	A2	A7
Source strength	8.0%	8.0%	8.0%	8.0%	8.0%	8.0%	8.0%	8.0%	8.0%	8.0%
Iron nuclear data	1.3%	60.6%	1.9%	26.6%	1.6%	10.6%	2.4%	10.6%	1.0%	39.8%
Carbon nuclear data	0.2%	0.4%	0.1%	0.2%	0.1%	0.2%	0.6%	0.2%	0.4%	0.8%
Detector cross-sections	10.2%	14.8%	8.0%*	15.0%*	6.0%	15.2%	5.2%	5.0%	12.0%*	14.0%*
Slab effective mass	0%	1.1%	0%	0.5%	0%	0.3%	0%	0.2%	0%	0.5%
Model approximations	-	-	-	-	-	-	-	-	-	-
Source spectrum	4.8%	4.8%	2.0%*	2.0%*	1.5%	1.5%	0.4%	0.4%	15.4%	15.4%
Monte Carlo statistics	2.6%	6.6%	2.8%	4.6%	2.0%	4.2%	8.0%	6.4%	6.4%	9.2%
TOTAL	14.1%	63.4%	12.0%	32.0%	10.4%	20.7%	12.7%	15.6%	22.1%	46.5%

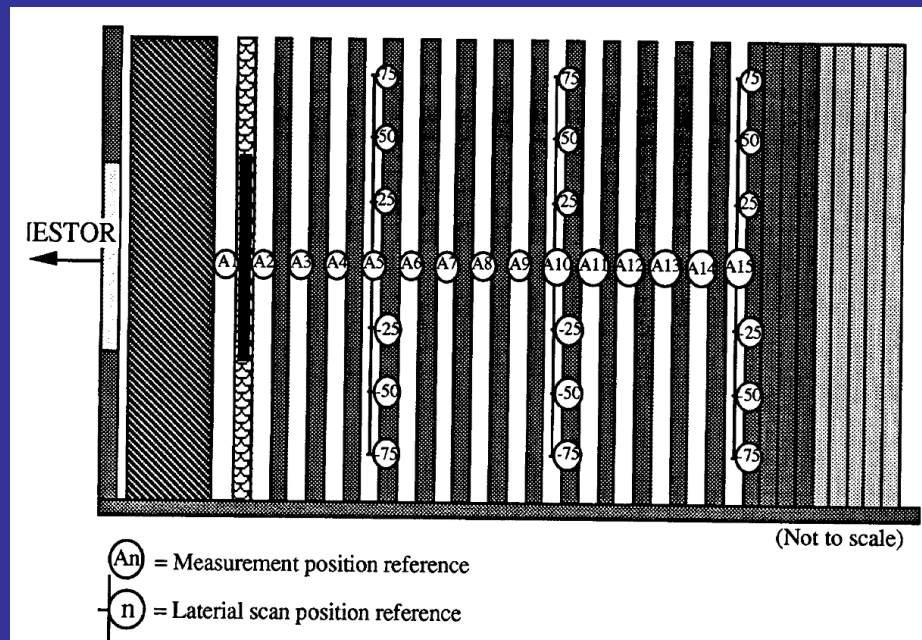
* Estimated value

Note : all uncertainties are quoted at the 2 s.d. level

ASPIS IRON88 - Quality evaluation & analysis (2014-16)

New MCNP & DORT/SUSD3D models

- Sensitivity study (ongoing):
 - Source fission spectrum
 - Activation foil positioning
 - Source (radial) distribution
 - Impurities in Fe
- Cross-section sensitivity – uncertainty analysis (SUSD3D)



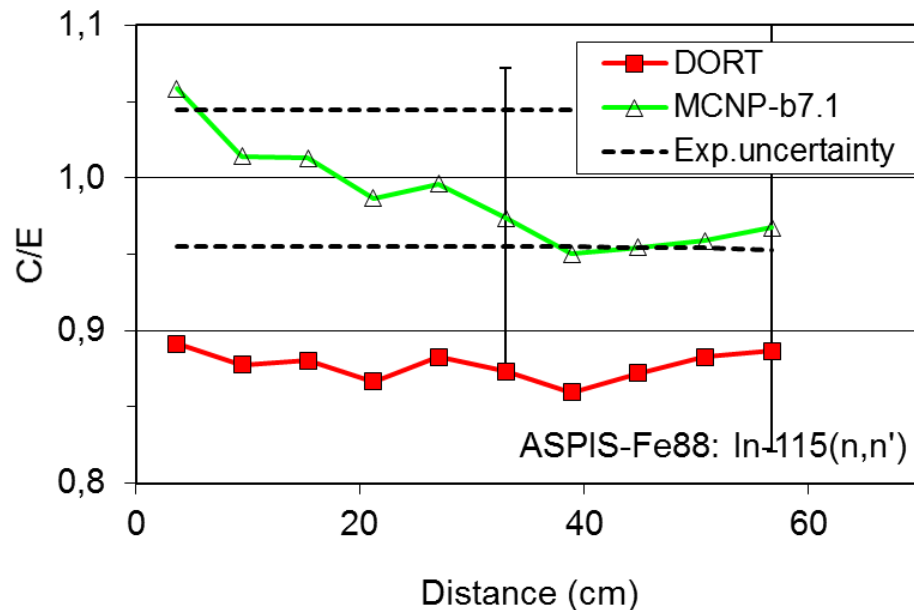
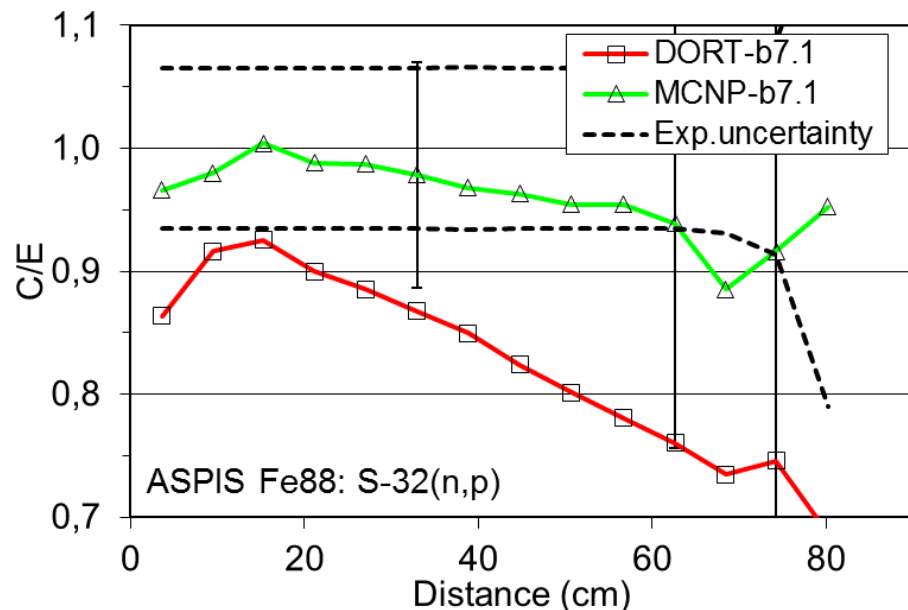
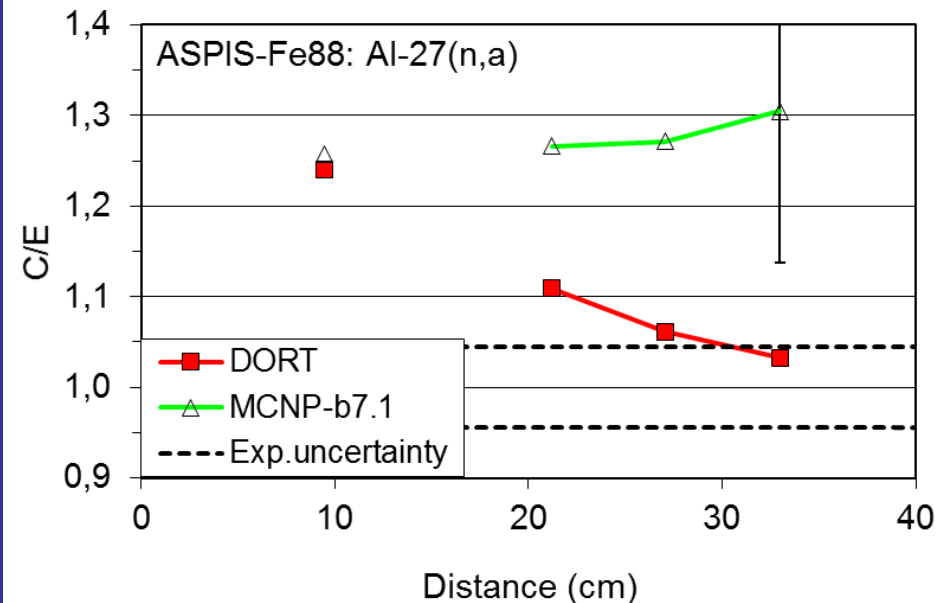
QA: Ranked as experiment of benchmark quality. Nevertheless, more information would be advisable on:

- detector arrangement (e.g. foil stacking)
- gaps between the slabs
- **neutron source**: uncertainty in XY distribution, NESTOR Φ_{th} contribution
- **background correction**: effect of the cave walls & low E flux from NESTOR.

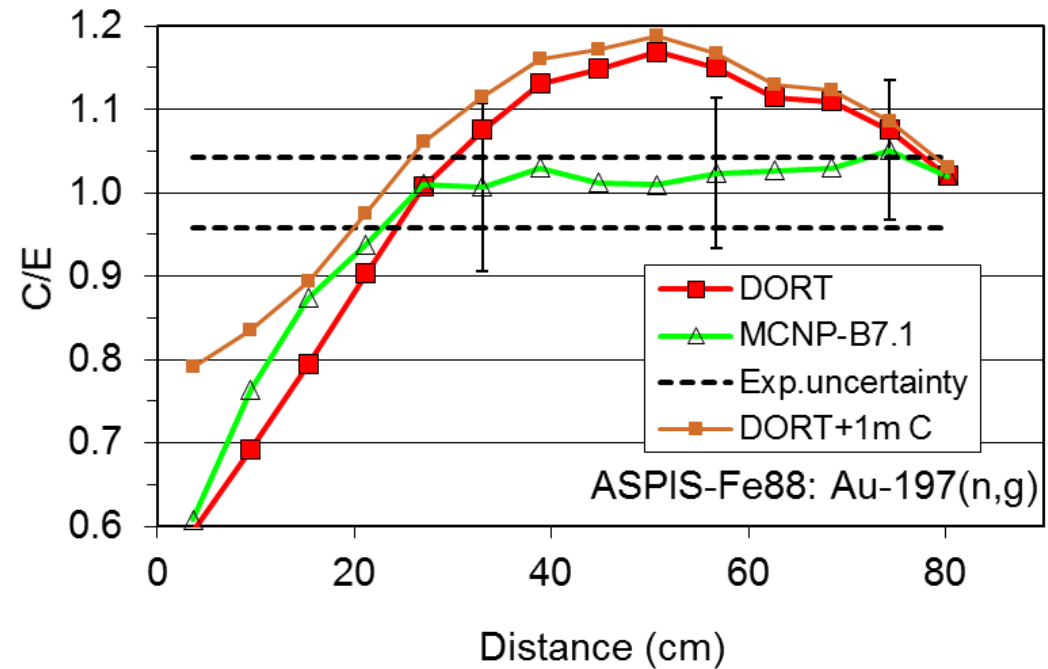
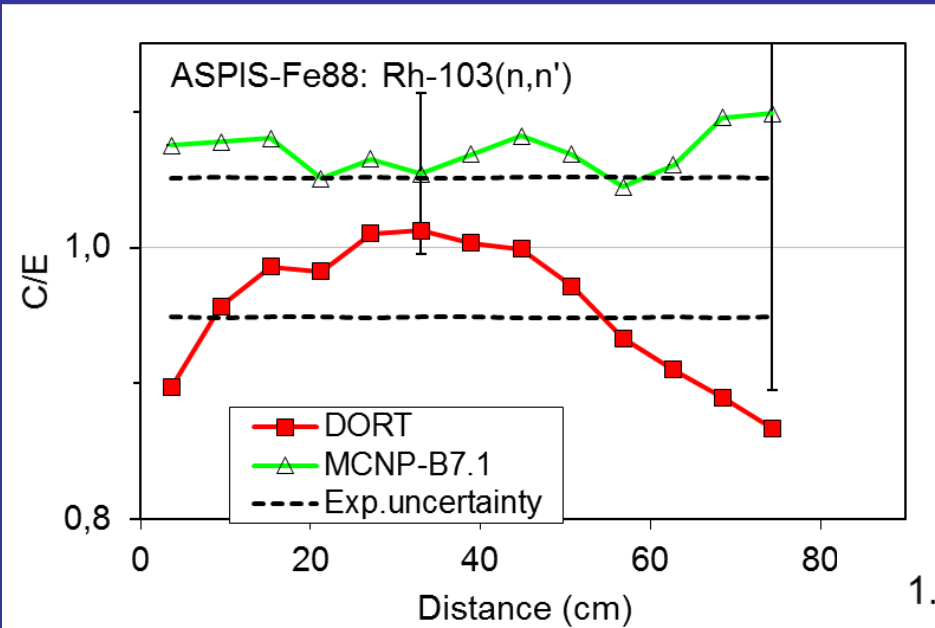
Transport & S/U analysis

C/E comparison

- **MCNP** using ENDF/B-VII.1 & CIELLO xs
- **DORT/SUSD3D** simplified 2D model using ECCO 33-group ENDF/B-VII.1 xs. Used for xs sensitivity/uncertainty analysis.
- **$\Delta C \gg \Delta E$!!!!!**

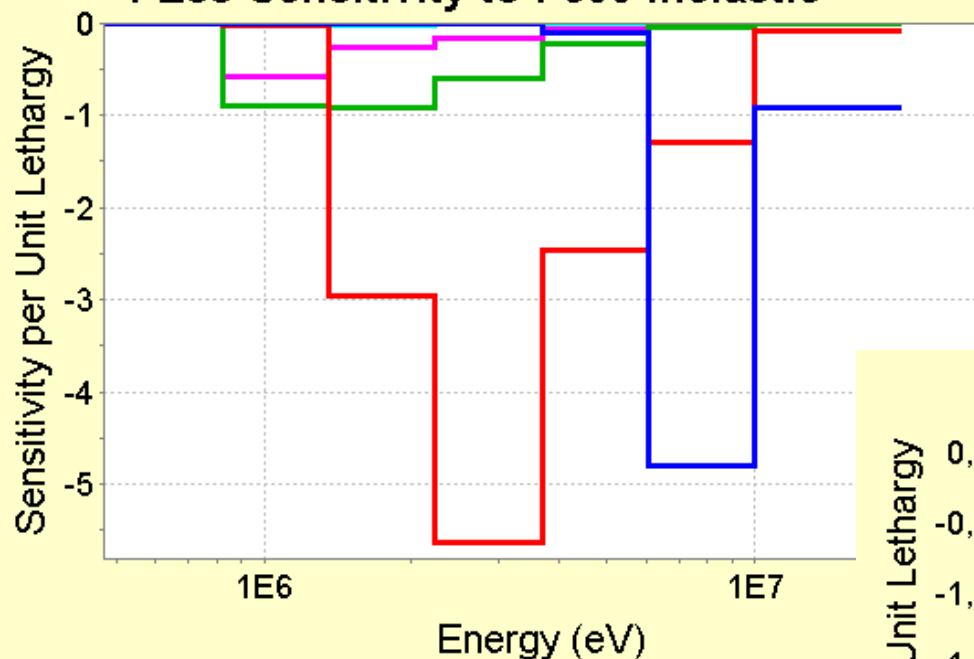


Transport & S/U analysis



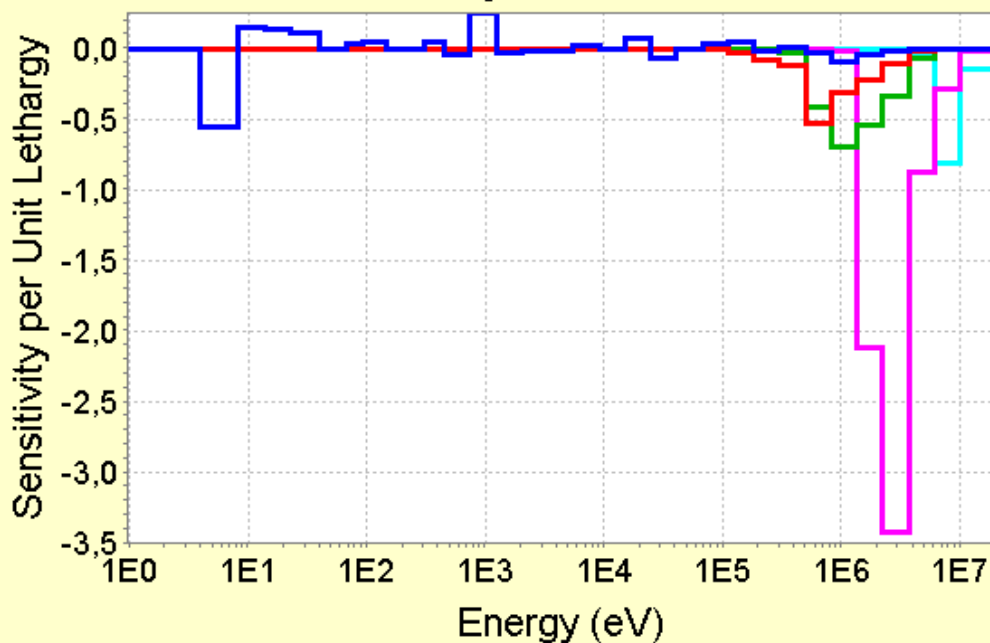
Sensitivity (SUSD3D/DORT)

FE88-Sensitivity to Fe56 inelastic



- fe88.al.bt IRON88-Al27na-A7 56FE Inel. MF3/MT4
- fe88.s.bt IRON88-S32np-A14 56FE Inel. MF3/MT4
- fe88.in.bt IRON88-In115nn-A7 56FE Inel. MF3/MT4
- fe88.rh.bt IRON88-Rh93nn-A7 56FE Inel. MF3/MT4
- fe88.au.bt IRON88-Au197ng-A14 56FE Inel. MF3/MT4

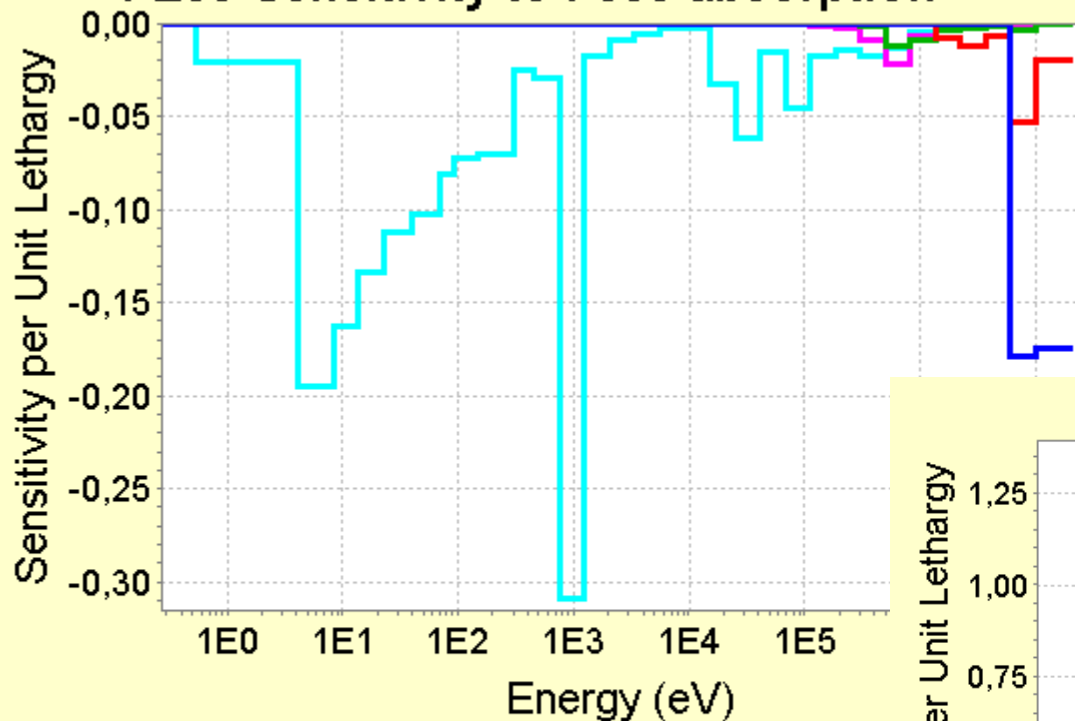
FE88-Sensitivity to Fe56 elastic



- fe88.au.bt IRON88-Au197ng-A14 56FE Elas. MF3/MT2
- fe88.rh.bt IRON88-Rh93nn-A7 56FE Elas. MF3/MT2
- fe88.in.bt IRON88-In115nn-A7 56FE Elas. MF3/MT2
- fe88.s.bt IRON88-S32np-A14 56FE Elas. MF3/MT2
- fe88.al.bt IRON88-Al27na-A7 56FE Elas. MF3/MT2

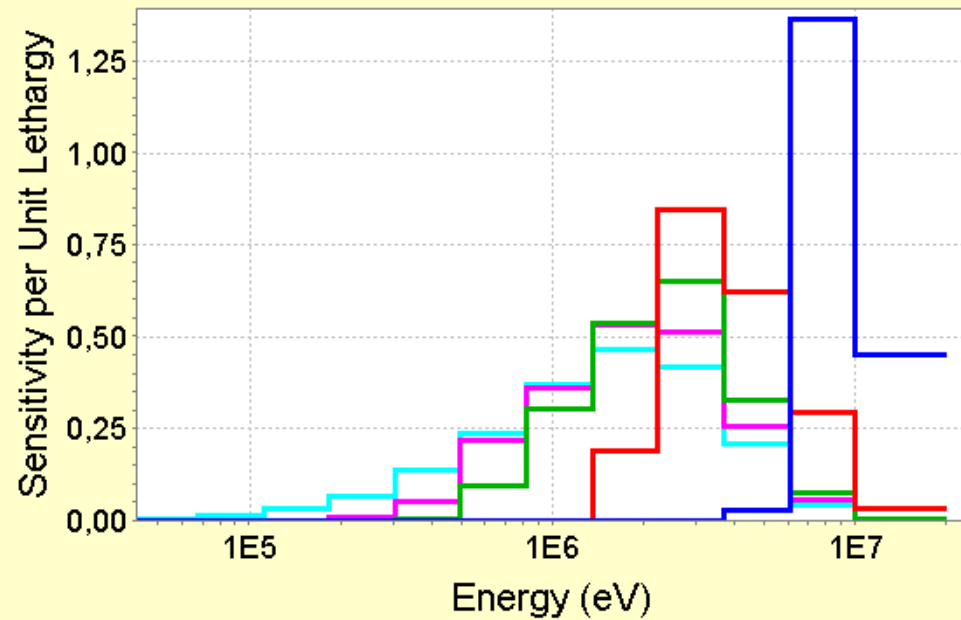
Sensitivity (SUSD3D/DORT)

FE88-Sensitivity to Fe56 absorption



- fe88.al.bt IRON88-Al27na-A7 56FE (n.abs) MF3/MT102
- fe88.s.bt IRON88-S32np-A14 56FE (n.abs) MF3/MT101
- fe88.in.bt IRON88-In115nn-A7 56FE (n.abs) MF3/MT102
- fe88.rh.bt IRON88-Rh93nn-A7 56FE (n.abs) MF3/MT102
- fe88.au.bt IRON88-Au197ng-A14 56FE (n.abs) MF3/MT102

FE88-Sensitivity to U235 PFNS



- fe88.al.bt IRON88-Al27na-A7 235U Chi-p MF5/MT18
- fe88.s.bt IRON88-S32np-A14 235U Chi-p MF5/MT18
- fe88.in.bt IRON88-In115nn-A7 235U Chi-p MF5/MT18
- fe88.rh.bt IRON88-Rh93nn-A7 235U Chi-p MF5/MT18
- fe88.au.bt IRON88-Au197ng-A14 235U Chi-p MF5/MT18

ASPIS IRON-88 – computational vs. experimental uncertainties

Reaction		ΔC (%)				ΔE (%)
		Σ_{tr} (ENDF/B7.1)	$\sigma_{SAD}(P_N)$ (EFF-2.4)	Σ_d (IRDF)	Total	
$^{32}\text{S}(n,p)$	A7	9.3	1.3	~3	9.9	6.5
	A12	19.4	2.2	3.5	19.8	6.5
	A14	24.0	2.5	3.5	24.3	8.6
$^{115}\text{In}(n,n')$	A7	10.1	0.6	~2	10.3	4.5
	A11	15.1	0.9	~2	15.5	4.7
$^{103}\text{Rh}(n,n')$	A7	5.7		~1	5.8	5.1
	A11	18.5		~1	18.5	5.1
$^{27}\text{Al}(n,a)$	A7	12.4	3.4	~0.5	(12.9)	4.7
$^{197}\text{Au}(n,\gamma)$	A7	10.0	0.1	0.2	10.0	4.2
	A11	8.8	0.1	0.2	8.8	4.2
	A14	8.0	0.1	0.2	8.0	4.2

FILES PREPARED

- Benchmarks/responses considered:
 - FLATTOP-Pu, SNEAK-7A & -7B: k_{eff} and β_{eff} ,
 - ASPIS-FE88: reaction rates $^{197}\text{Au}(n,\gamma)$, $^{32}\text{S}(n,p)$, $^{103}\text{Rh}(n,n')$, $^{115}\text{In}(n,n')$, $^{27}\text{Al}(n,\alpha)$
- Cross-section sensitivity profiles to:
 - Isotopes: U-234, -235, -238, Pu-239, -240, -241; O-16, Fe-56,
 - Reactions: σ_t , σ_{el} , σ_{inel} , σ_c , ν_p , ν_d , χ , $P_1(\text{elastic})$, (n,α) for O-16; detector responses to be included,
 - 33 ECCO energy group structure,
- C/E values and uncertainties: ΔE (systematic & statistical) and ΔC (M/C statistics),
- Infinite diluted cross-sections from ENDF/B-VII.1 in 33 groups.

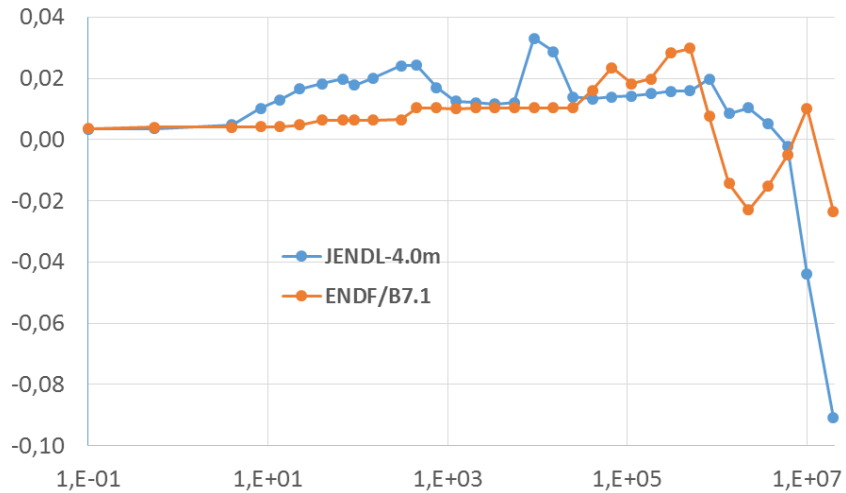
Fe88 ΔE covariance matrix

assuming totally correlated power normalisation uncertainty

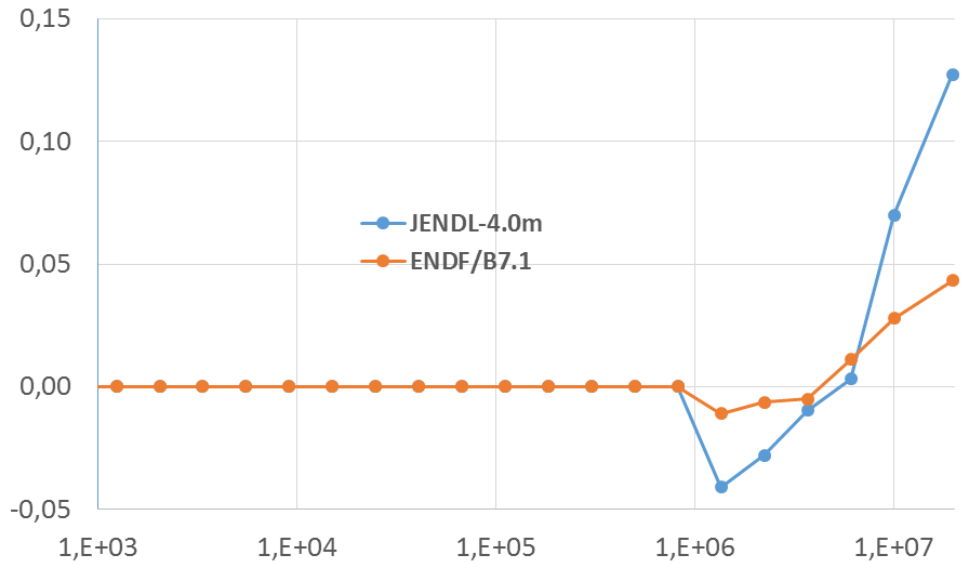
		Au			Rh		In		S			Al	
		A7	A11	A14	A7	A14	A7	A11	A7	A12	A14	A7	
		1 σ (%)	4,2	4,2	4,2	5,1	5,1	4,5	4,7	6,5	6,5	8,6	4,7
Au	A7	4,2	1,000	0,953	0,953	0,747	0,747	0,847	0,811	0,586	0,586	0,443	0,811
	A11	4,2	0,953	1,000	0,953	0,747	0,747	0,847	0,811	0,586	0,586	0,443	0,811
	A14	4,2	0,953	0,953	1,000	0,747	0,747	0,847	0,811	0,586	0,586	0,443	0,811
Rh	A7	5,1	0,747	0,747	0,747	1,000	0,961	0,697	0,668	0,483	0,483	0,365	0,668
	A14	5,1	0,747	0,747	0,747	0,961	1,000	0,697	0,668	0,483	0,483	0,365	0,668
In	A7	4,5	0,847	0,847	0,847	0,697	0,697	1,000	0,927	0,547	0,547	0,413	0,757
	A11	4,7	0,811	0,811	0,811	0,668	0,668	0,927	1,000	0,524	0,524	0,396	0,724
S	A7	6,5	0,586	0,586	0,586	0,483	0,483	0,547	0,524	1,000	0,970	0,733	0,524
	A12	6,5	0,586	0,586	0,586	0,483	0,483	0,547	0,524	0,970	1,000	0,733	0,524
	A14	8,6	0,443	0,443	0,443	0,365	0,365	0,413	0,396	0,733	0,733	1,000	0,396
Al	A7	4,7	0,811	0,811	0,811	0,668	0,668	0,757	0,724	0,524	0,524	0,396	1,000

Examples of the results of adjustment exercise: JENDL-4.0 vs. ENDF/BVII.1

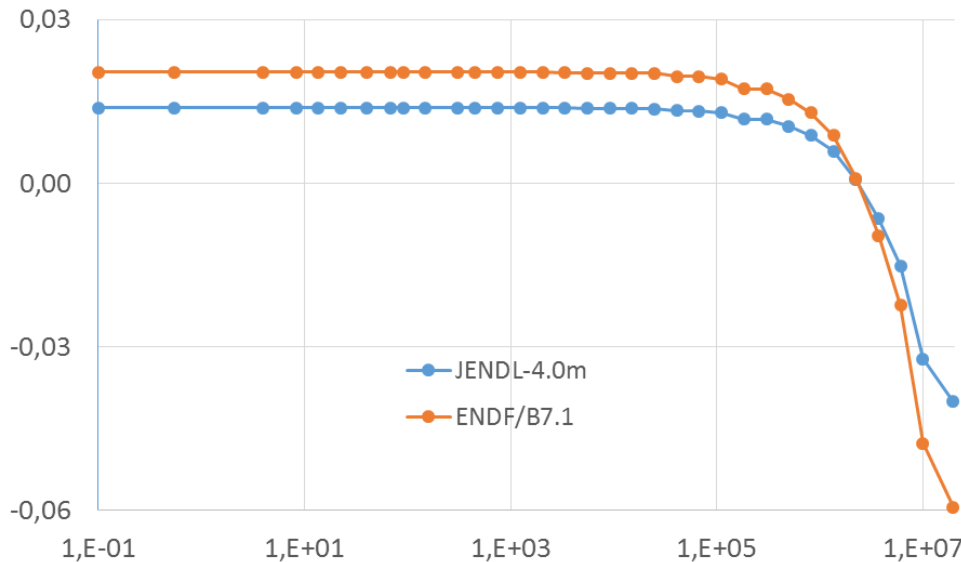
Fe-56 elastic



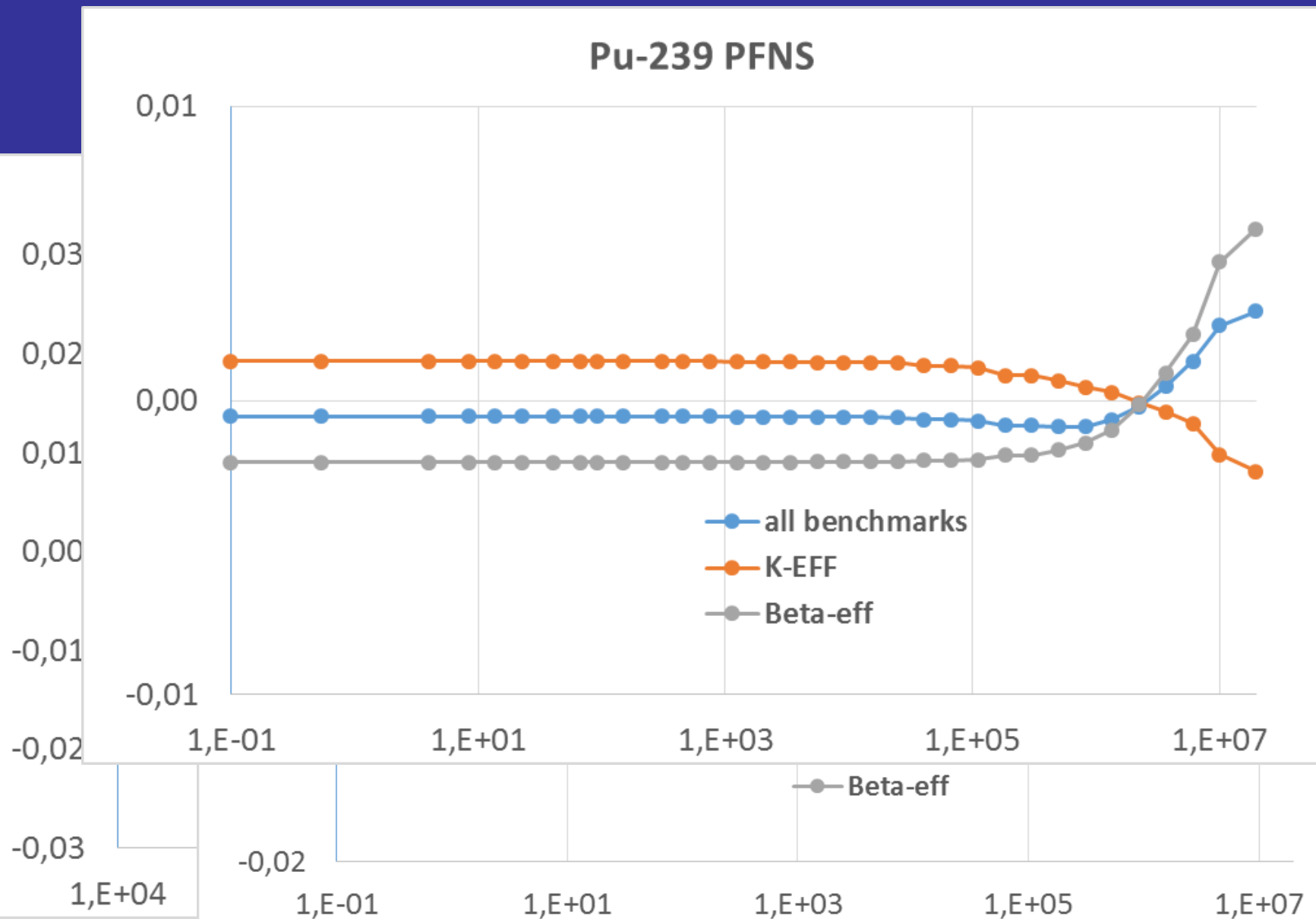
Fe-56 inelastic



U-235 PFNS



Adjustment exercise examples



Conclusions

- Use of **kinetics measurements and shielding benchmarks in addition to critical benchmarks is suggested** for ND validation & adjustment since providing a complementary view and wider scope validation;
- The SINBAD database currently contains compilations and evaluations of experiments for **48 reactor shielding** problems, **31 for fusion** neutronics shielding and **23 for accelerator** shielding cases. **17 experiment re-evaluations to be updated.**
- ASPIS Iron88 benchmark, included in SINBAD in the mid-1990ies was recently re-evaluated and re-analysed using M/C & S_N transport and S/U codes (MCNP, DORT/SUSD3D) and **ranked as experiment of benchmark quality.**
- Sensitivity profiles, C/E values and the corresponding uncertainties available from NEA in 33-groups for FLATTOP-Pu, SNEAK-7A & 7B and ASPIS-Fe88 benchmarks.
- **For validation and demonstration purposes the adjustment exercise was performed showing reasonable results.**