SINBAD Benchmark analysis of new Iron Cross-sections

I. Kodeli (JSI, Ljubljana, Slovenia)

WPEC-CIELO Meeting, NEA- Issy-les-Moulineaux, May 10, 2016

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

I. Kodeli, Sensitivity and Uncertainty in the Effective Delayed Neutron Fraction (β_{eff}), *Nucl. Instr. & Methods in Phy. Res. A* **715** (2013) 70-78

Advantages & inconveniences of different benchmarks

Benchmark	+	-
Critical	N>> CPU time <<	$\Delta C \sim \Delta E$ global
Kinetics	$S_\beta \neq S_k$ CPU time <<	$\Delta C \sim \Delta E$ global
Shielding	$\Delta C >> \Delta E$	CPU time >> older exp.

SINBAD - Radiation Shielding Experiments Scope and Objectives

- Compilation of high quality experiments for validation and benchmarking of computer codes and nuclear data used for radiation transport and shielding problems encompassing:
    - reactor shielding, PV dosimetry **(48)**
    - fusion blanket neutronics **(31)**
    - accelerator shielding **(23)**
- Low and inter-mediate
  energy particles applications.
- **Contains 102 experiments**

sinbadis.htm

SINBAD: Re-evaluated Fe Shielding Benchmarks

SINBAD Benchmark / quality	Additional information needed on; (new data)
OKTAVIAN Fe ~ ♦♦♦ or ♦♦	very large uncertainties of the measurements
FNS Iron dogleg-duct ♦♦	neutron source spectrum, detector response function
TUD Iron slab ~ ♦♦♦	neutron source, pulse height spectrum
FNG Stainless Steel ~ ♦♦♦	A comprehensive geometry description would be helpful
FNG ITER Dose Rate ♦♦♦	/
FNG/TUD ITER Bulk ~ ♦♦♦	n &g flux uncertainties, original pulse-height distributions
FNG ITER Bulk ♦♦♦	/
IPPE-Fe , 14 MeV n source	(new 2D & 3D MCNP5 models prepared)
JANUS phase I ♦♦♦ & VIII ♦♦♦	
ASPIS NESDIP 2 ♦/♦♦ & 3 ♦♦♦	neutron source spectrum approximations
Ispra Iron ♦♦ & Iron88 ♦♦♦	Geometry model details and approximations, background ?
ISIS 800 MeV protons (120cm Concrete & 60cm Iron) ~ ♦♦♦	(new MCNPX model prepared)
HIMAC 400 MeV/nucleon C ions on Fe shield ~ ♦♦♦	large measurement uncertainties, unfolding uncertainty and parameter uncertainties needed (new PHITS model prepared)
TIARA 43 & 68 MeV Protons ♦♦♦	

Recently re-evaluated SINBAD benchmarks used for iron benchmarking

SINBAD Benchmark / quality	Additional information needed on; (new data)
ASPIS IRON-88 ♦♦♦	new MCNP5 models
JANUS phase I ♦♦♦	new MCNP5 models
ASPIS NESDIP 3 ♦♦♦	neutron source spectrum approximations
EURACOS Fe ~♦ or ♦♦	Source, geometry model details and approximations, background, spectrometer response functions (new MCNP5 models)

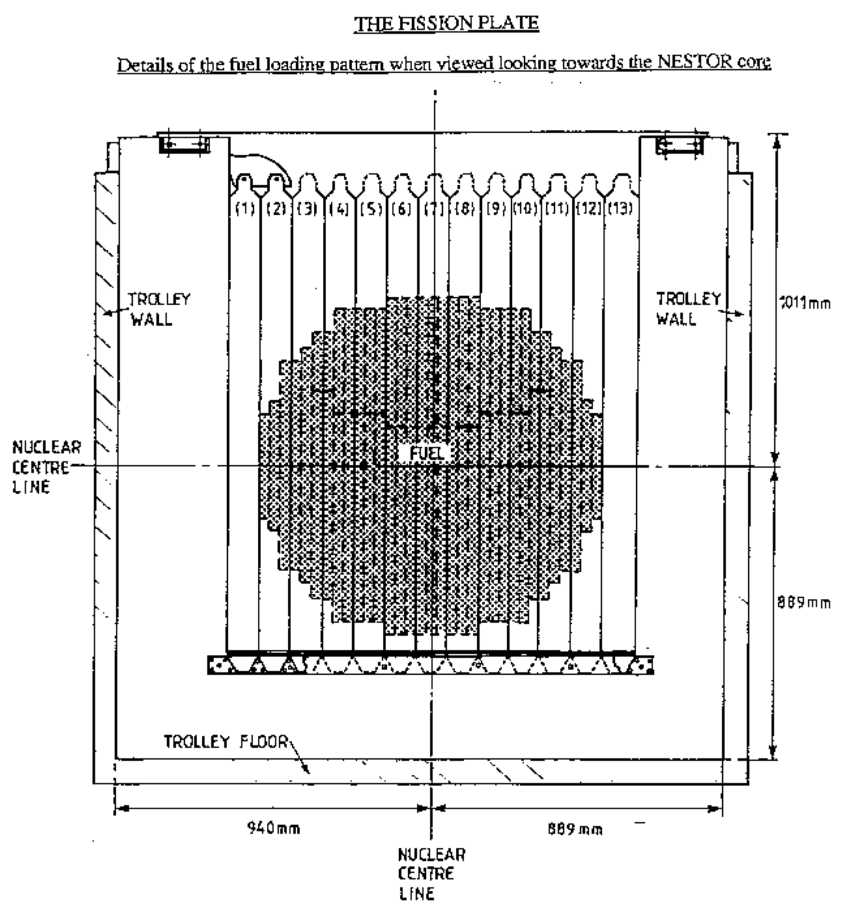
ASPIS IRON-88

- 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}Mn(n,γ) RR measurements over XY front surface.

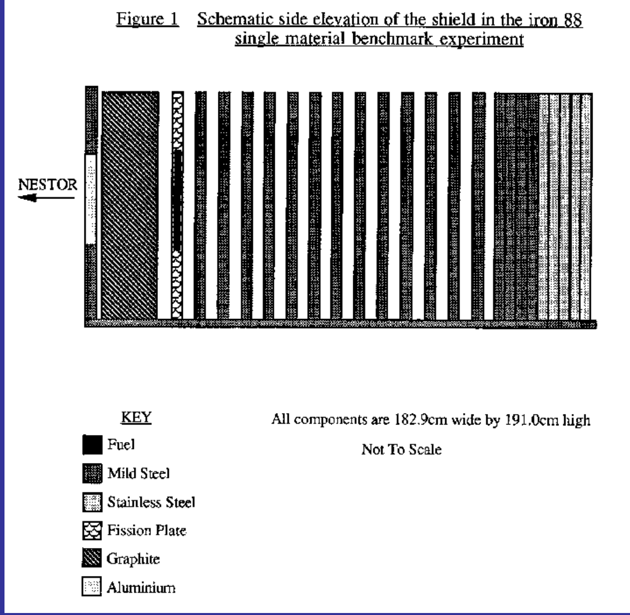


Au, Rh, In, S and Al activation foils irradiated in 7.4-mm air gaps between 13 mild steel plates of the size of 1.8 m x 1.9 m x 5.1 cm. Measured reaction rate axial distributions:

- ^{197}Au(n,γ) under Cd
- ^{32}S(n,p)
- ^{103}Rh(n,n')
- ^{115}In(n,n')
- ^{27}Al(n,α)

ASPIS IRON-88

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

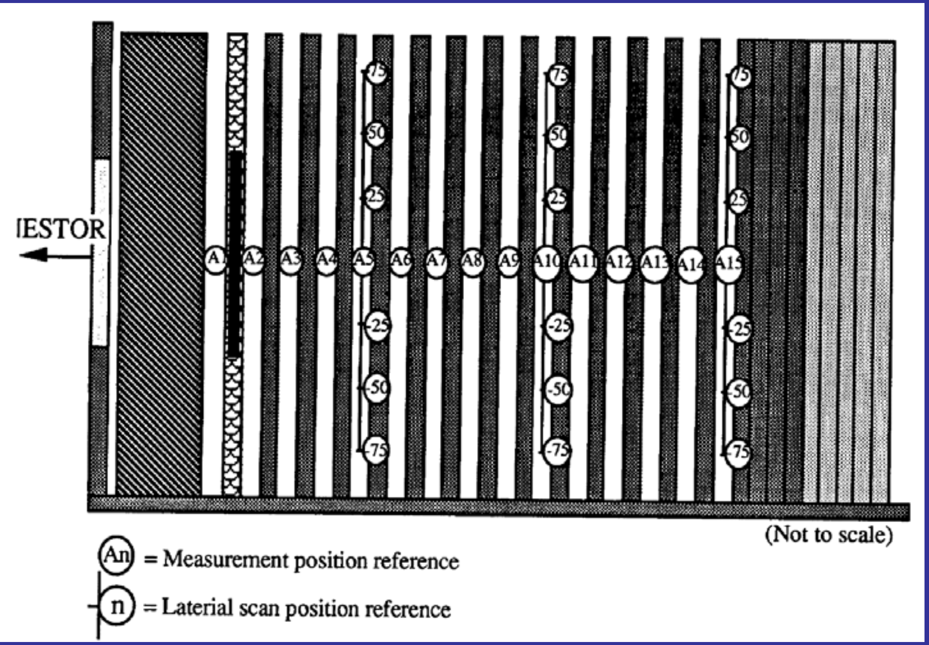


Detector	Diameter (mm)	Thickness (mm)	Typical Mass (g)	Cadmium Cover (inches)	Counting System	Systematic Absolute Calibration (2σ uncertainty)
Au197(n,gamma)	12.7	0.05	0.12 -0.13	50/1000	NaI	0.9%
Rh103(n,n')	12.7	0.015	0.20	-	NaI	3.0%
In115(n,n')	38	1.63	12.79	-	GeLi detector	1.9%
S32(n,p) Pressed Pellet	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 - 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)
- Massimo Pescarini (TORT model)



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

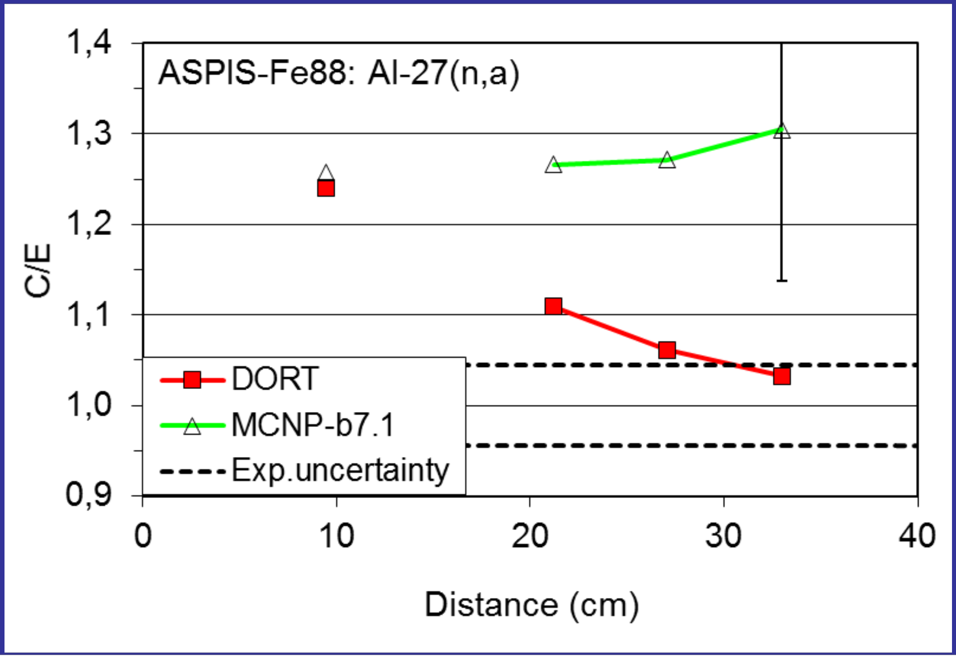
- detector arrangement (e.g. foil stacking)
- gaps between the slabs
- neutron source: uncertainty in XY distribution, NESTOR Φ_{th} contribution
- background correction: effect of the cave walls & low E flux from NESTOR.

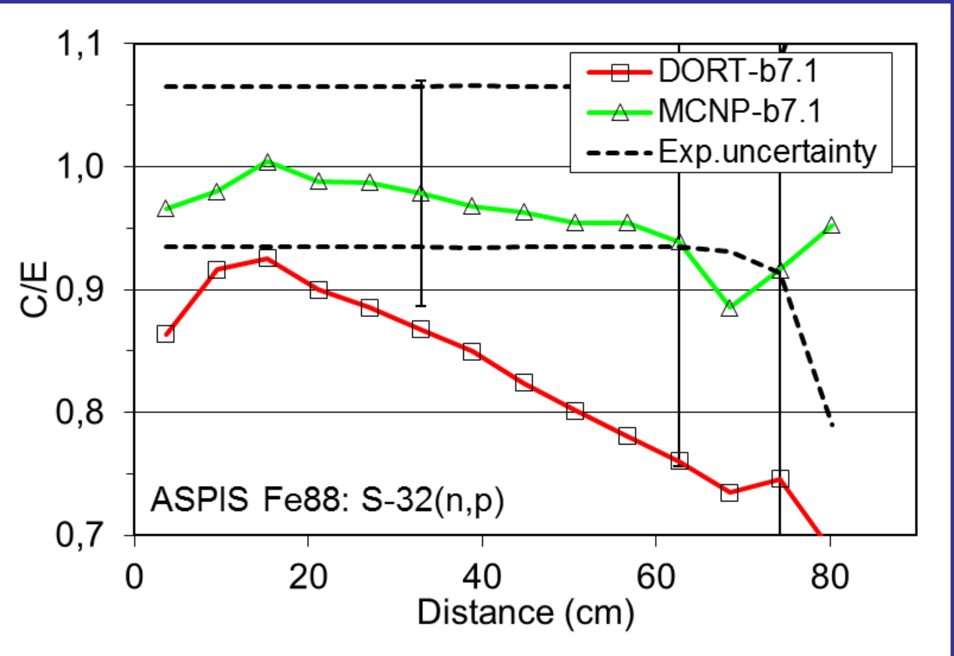
A. Milocco, I. Kodeli, Quality assessment of SINBAD evaluated experiments (ASPIS), 2015

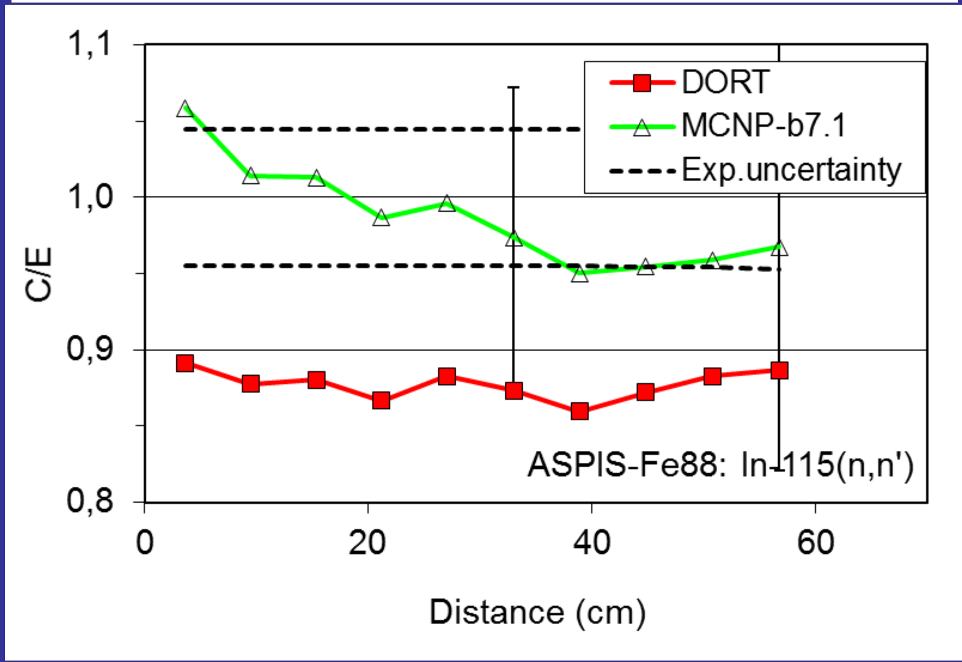
Transport & S/U analysis

C/E comparison

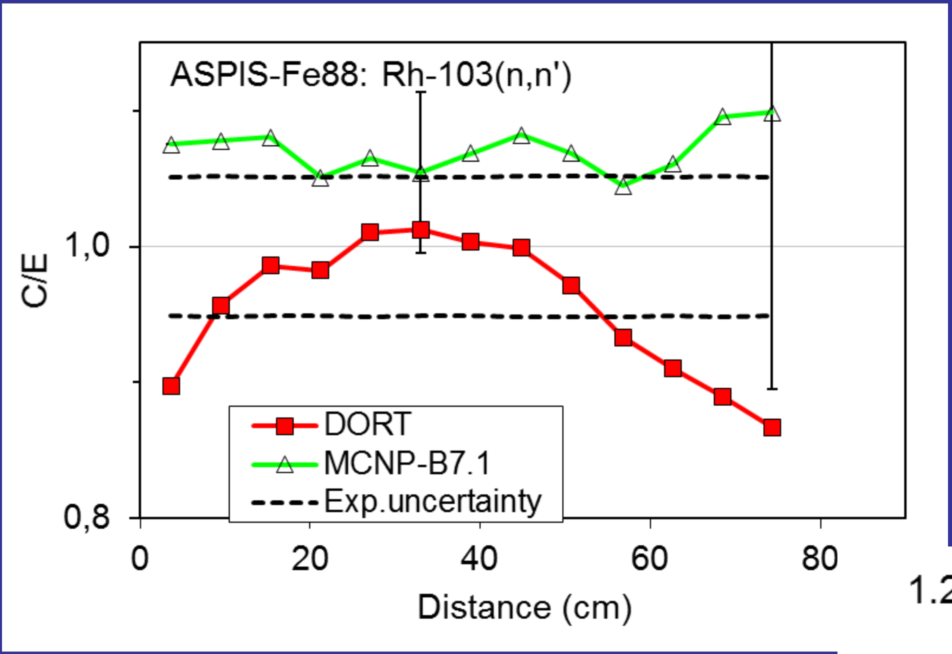
- **MCNP** using ENDF/B-VII.1 & CIELLO xs
- **DORT/SUSD3D** simplified 2D model using ECCO 33-group ENDF/B-VII.1 xs. Used for xs sensitivity/uncertainty analysis.
- **ΔC >> ΔE !!!!!**

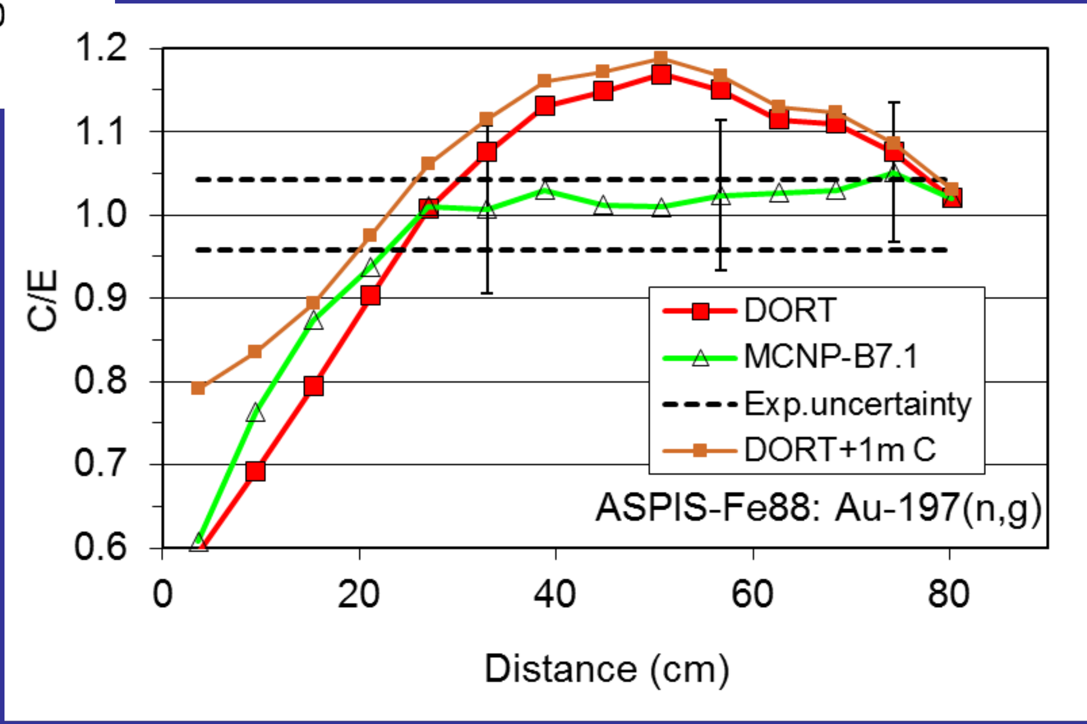




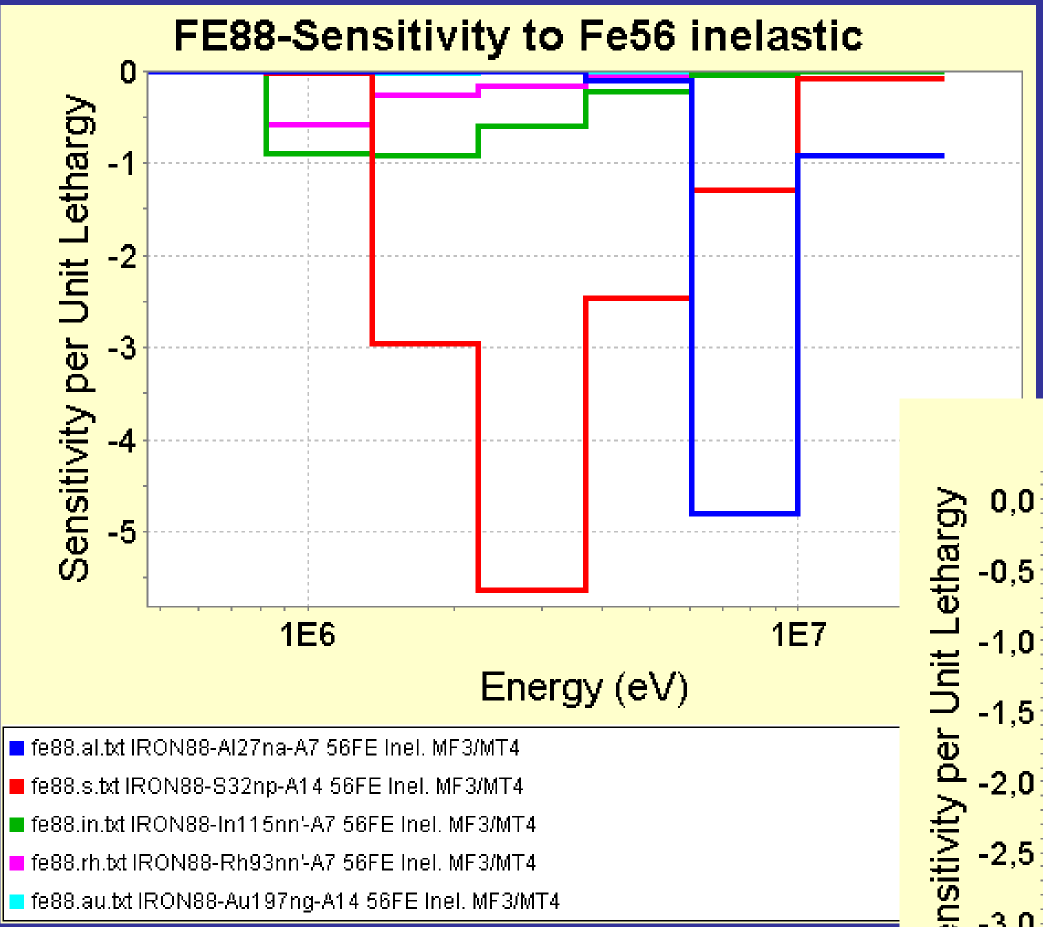


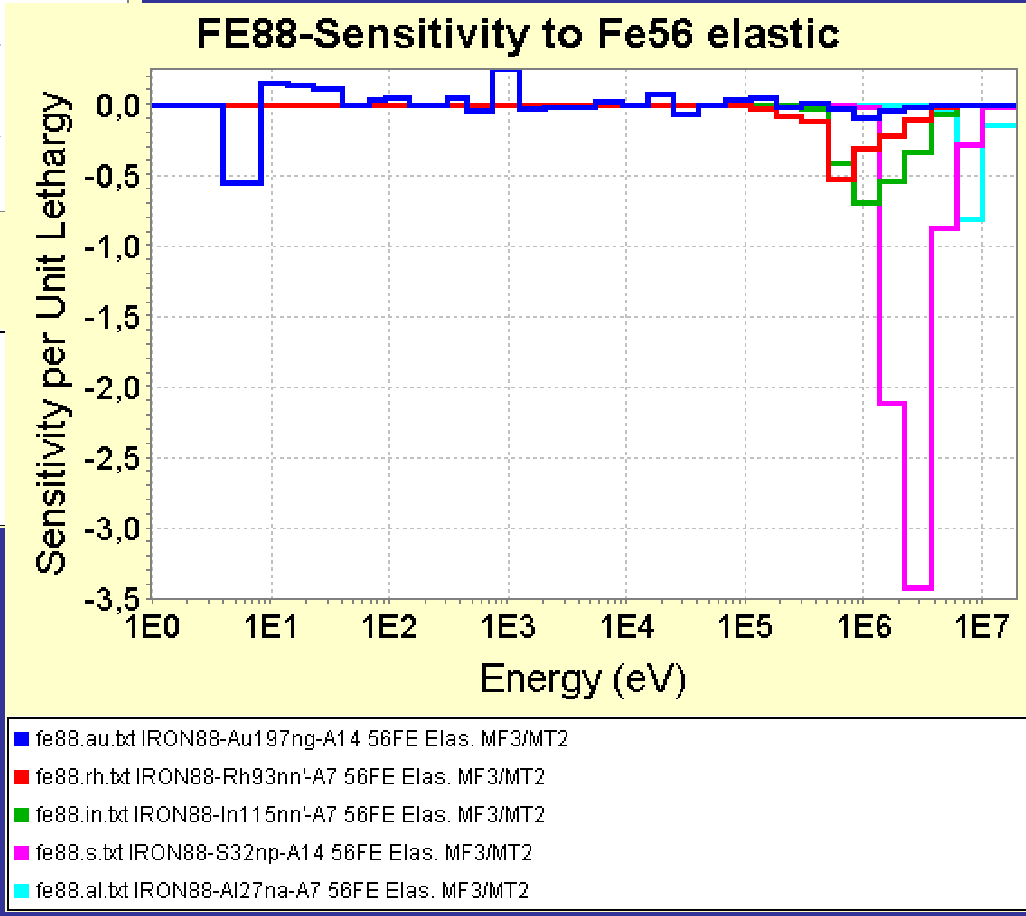
Transport & S/U analysis



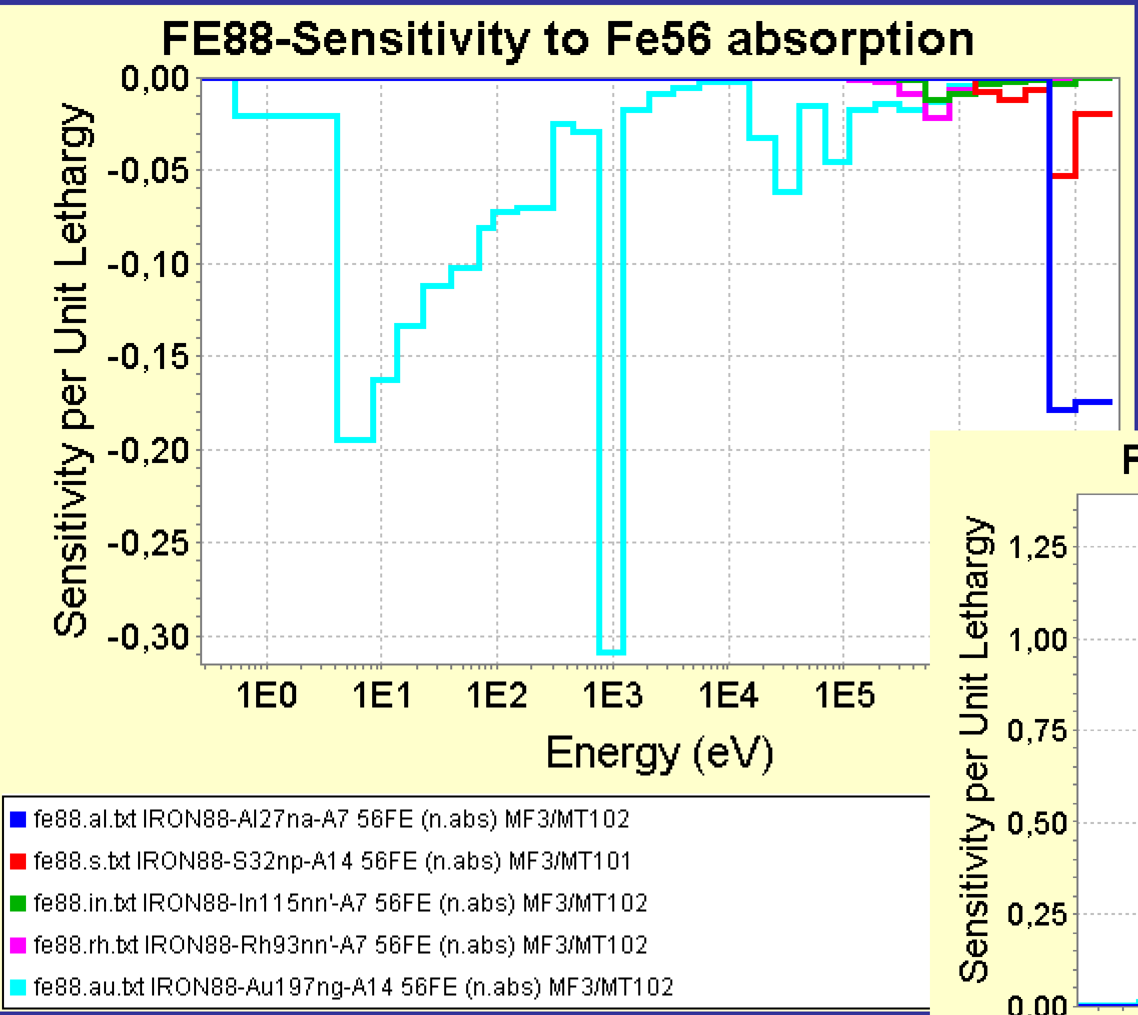


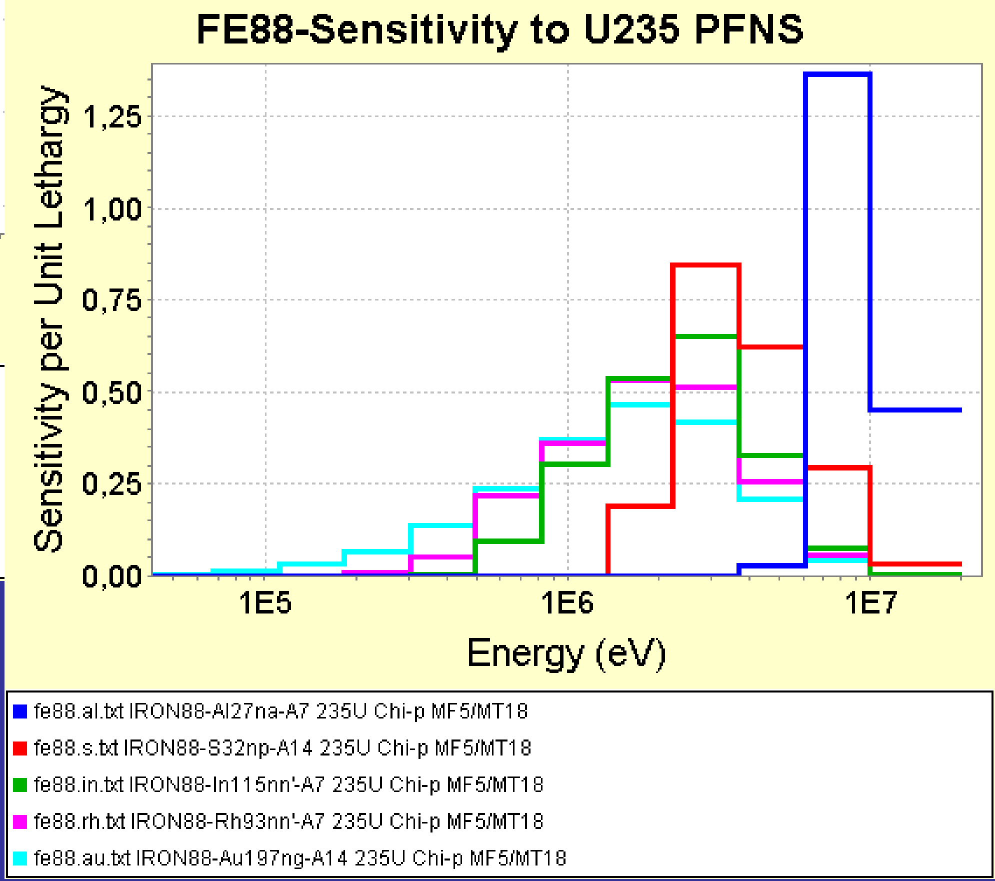
Sensitivity (SUSD3D/DORT)





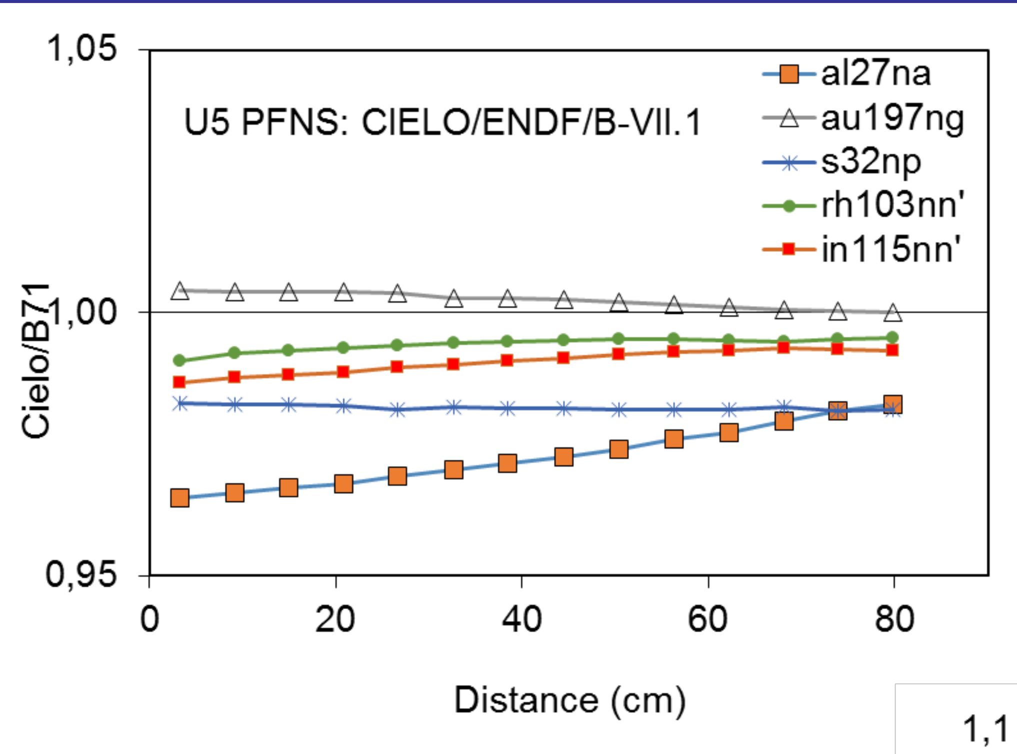
Sensitivity (SUSD3D/DORT)





ASPIS IRON-88 – computational vs. experimental uncertainties

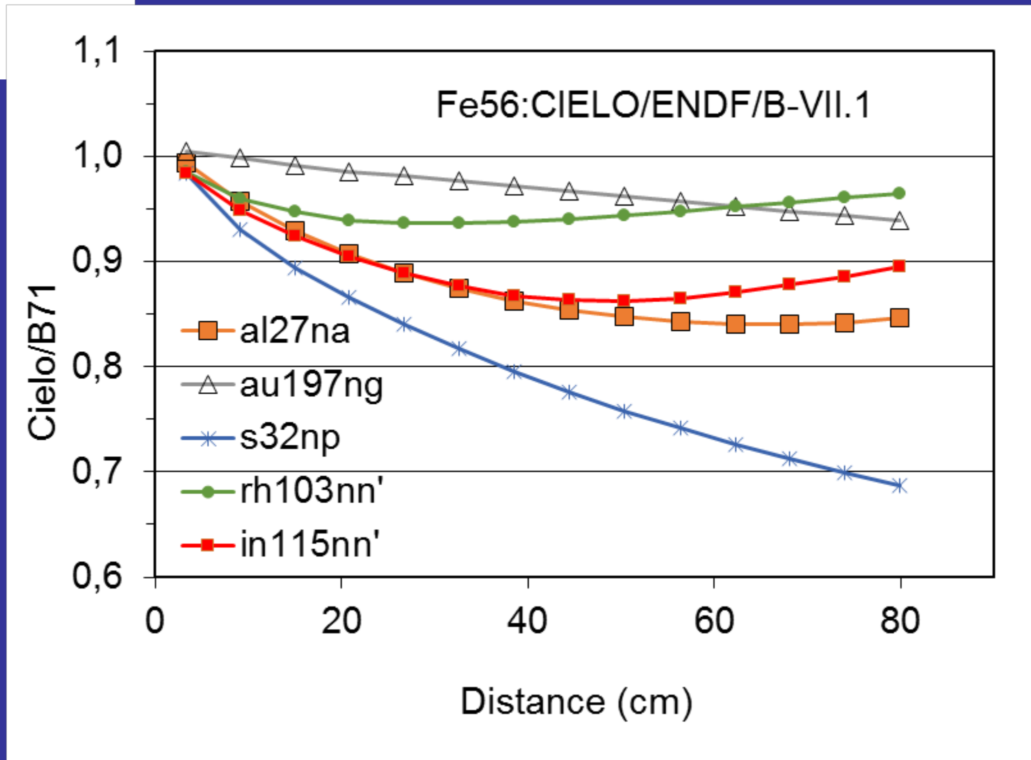
Reaction		ΔC (%)				ΔE (%)
		Σ_{tr} (ENDF/B7.1)	σ_{SAD} (P_N) (EFF-2.4)	Σ_d (IRDFF)	Total	
$^{32}S(n,p)$	A7	9.3	1.3	~3	**9.9**	**6.5**
	A12	19.4	2.2	3.5	**19.8**	**6.5**
	A14	24.0	2.5	3.5	**24.3**	**8.6**
$^{115}In(n,n')$	A7	10.1	0.6	~2	**10.3**	**4.5**
	A11	15.1	0.9	~2	**15.5**	**4.7**
$^{103}Rh(n,n')$	A7	5.7		~1	**5.8**	**5.1**
	A11	18.5		~1	**18.5**	**5.1**
$^{27}Al(n,a)$	A7	12.4	3.4	~0.5	**(12.9)** **~15**	**4.7**
$^{197}Au(n,\gamma)$	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**



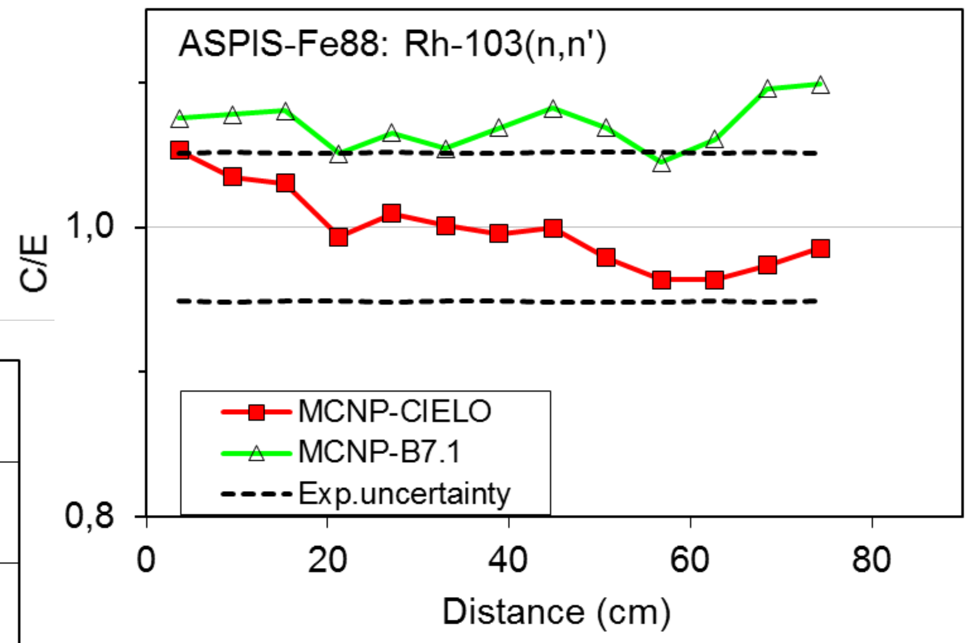
CIELO/ENDF/B-VII.1

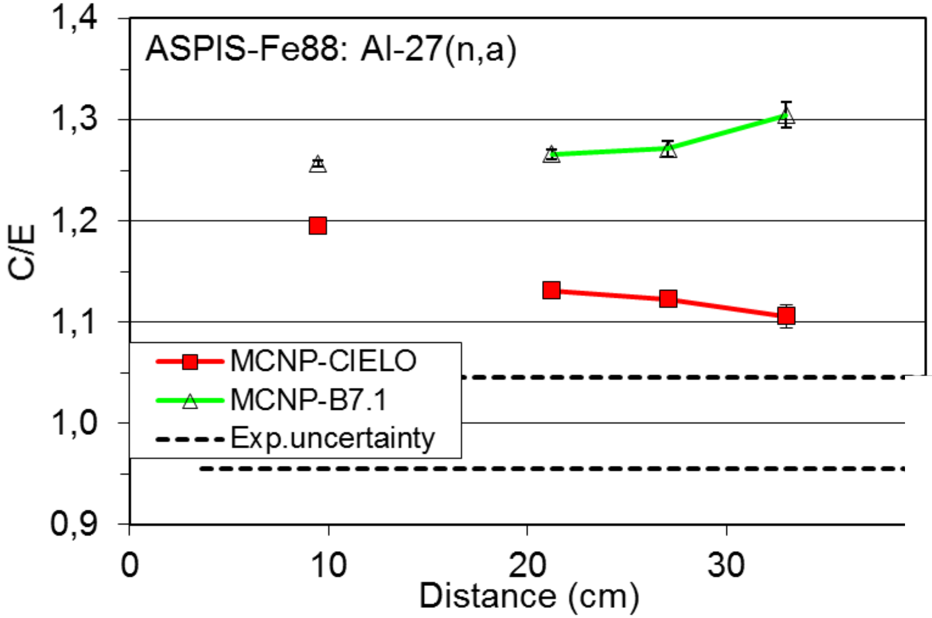
DORT calculations using:

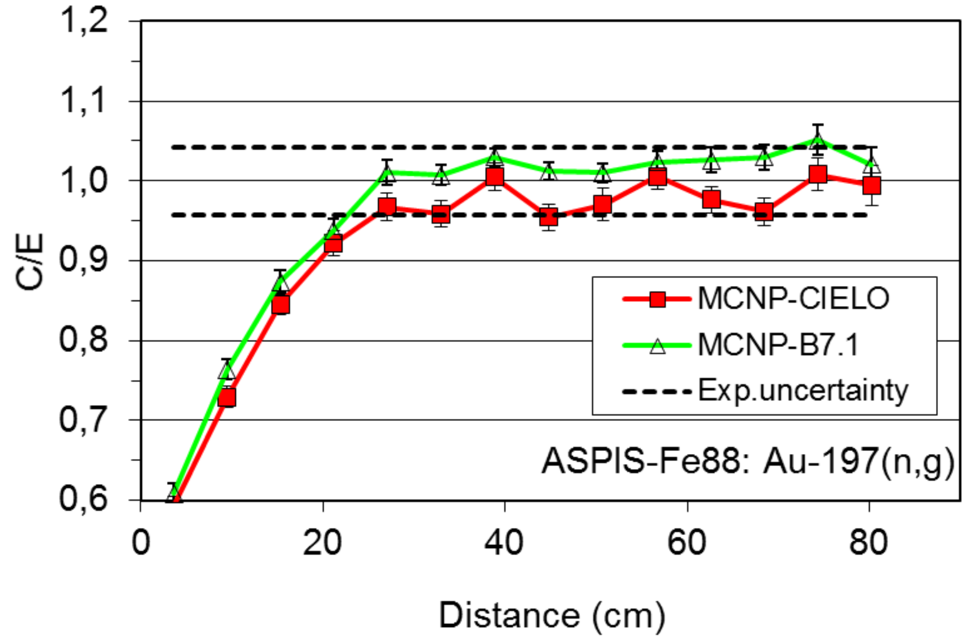
- new PFNS of U235
- new Fe-56 data



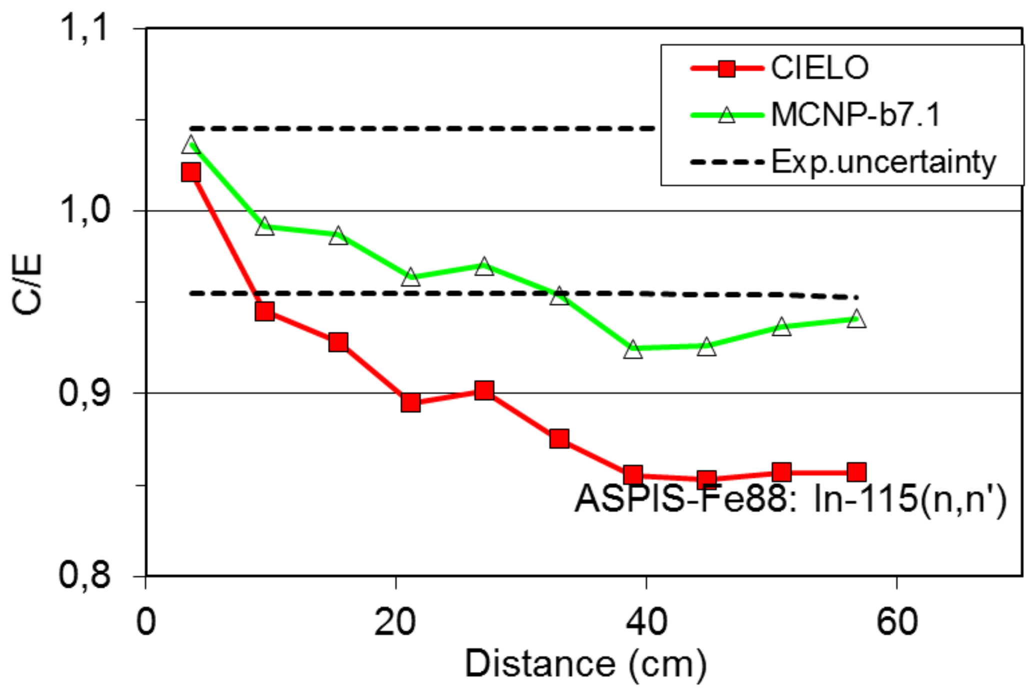
ENDF/BVII.1 – Fe56ib15k

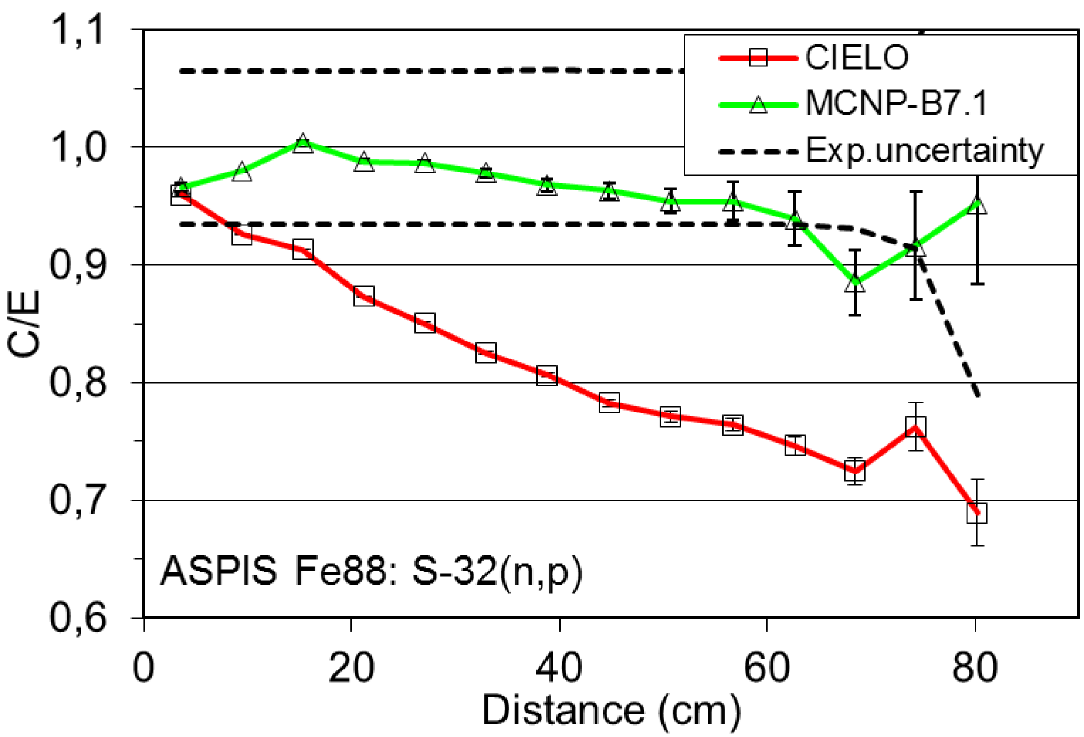






ENDF/BVII.1 – Fe56ib15k

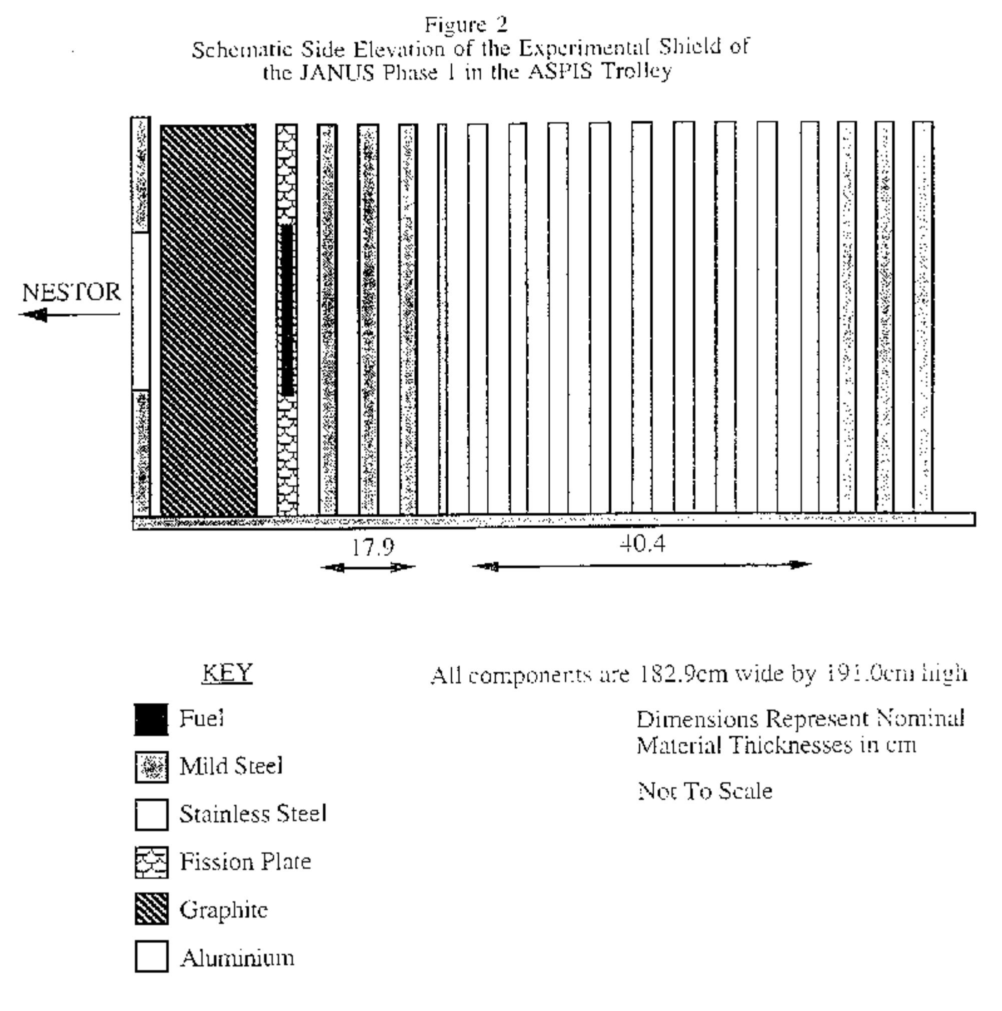


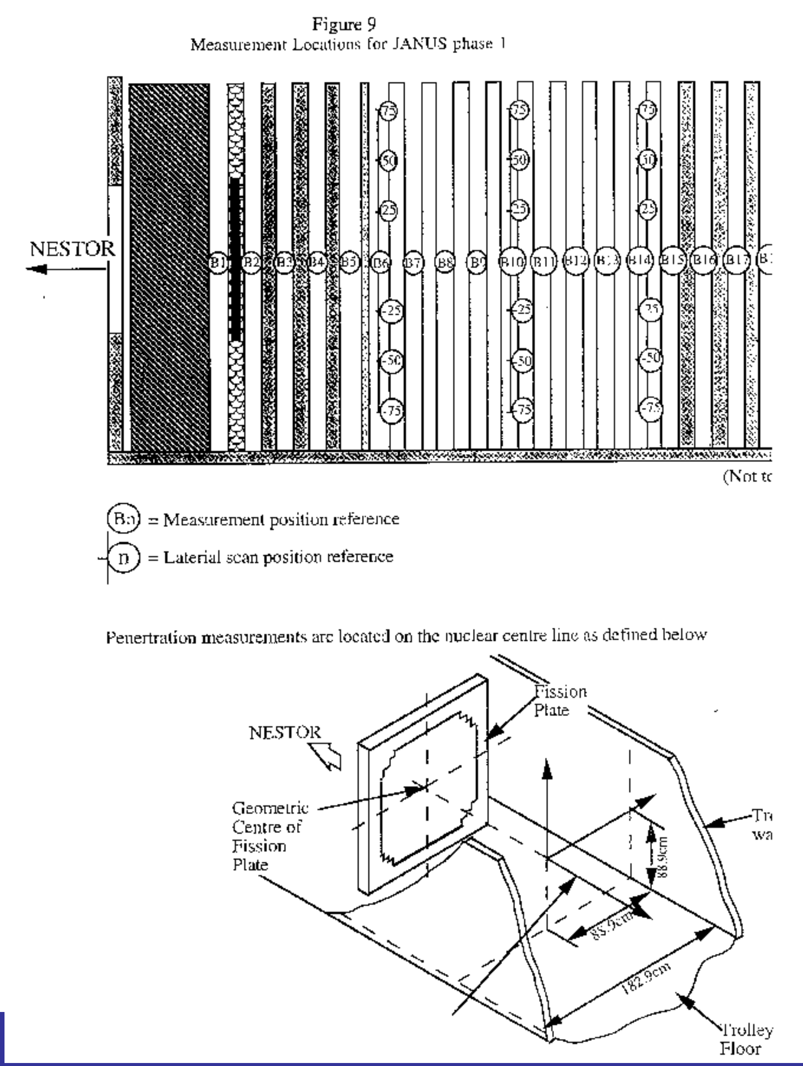


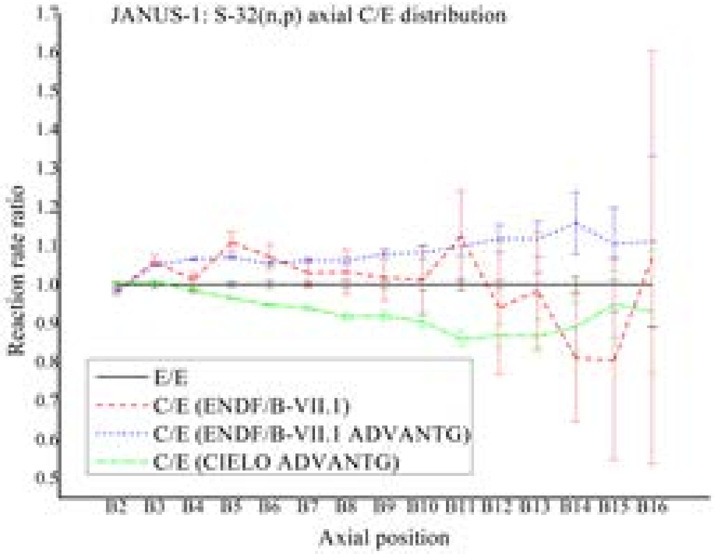
ASPIS JANUS-1 (1986)

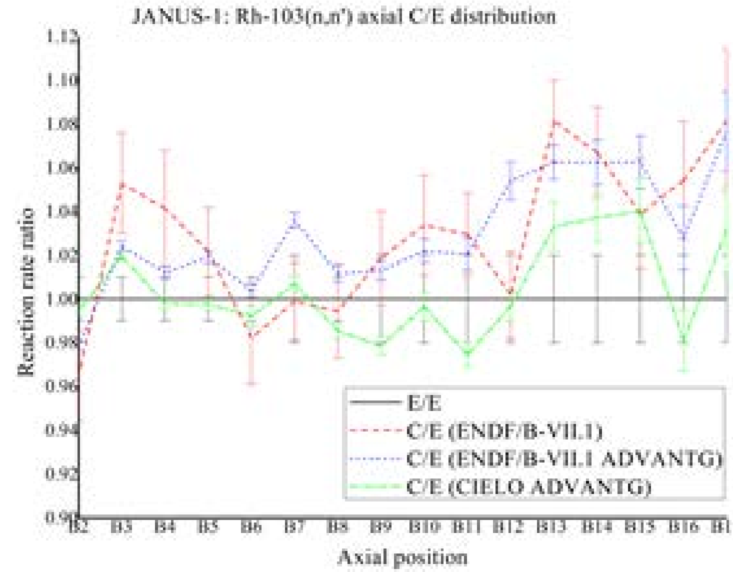
- NESTOR graphite reflector n. source, converted by fission plate
- Attenuation in stainless and mild steel
- Reaction rate axial and lateral distributions:
  - $^{32}S(n,p)$
  - $^{55}Mn(n,\gamma)$ under Cd
  - $^{197}Au(n,\gamma)$ under Cd
  - $^{103}Rh(n,n')$
- For lateral distributions, no exp. unc. given!

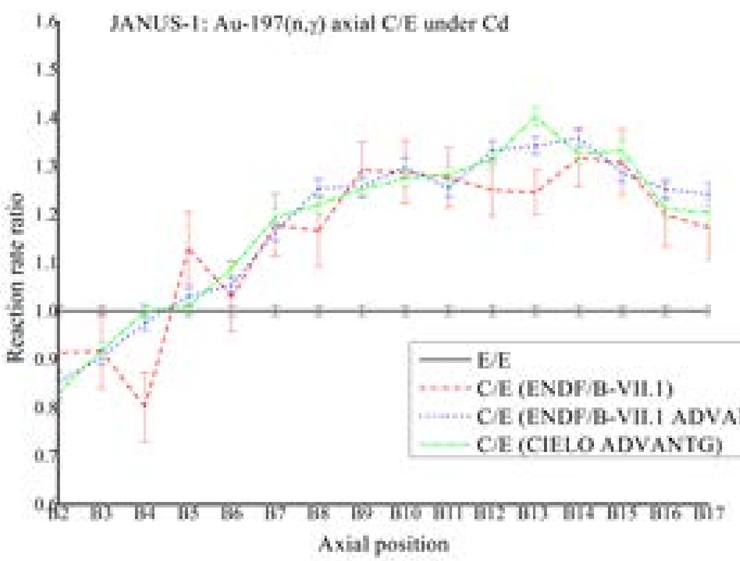
Measurement positions

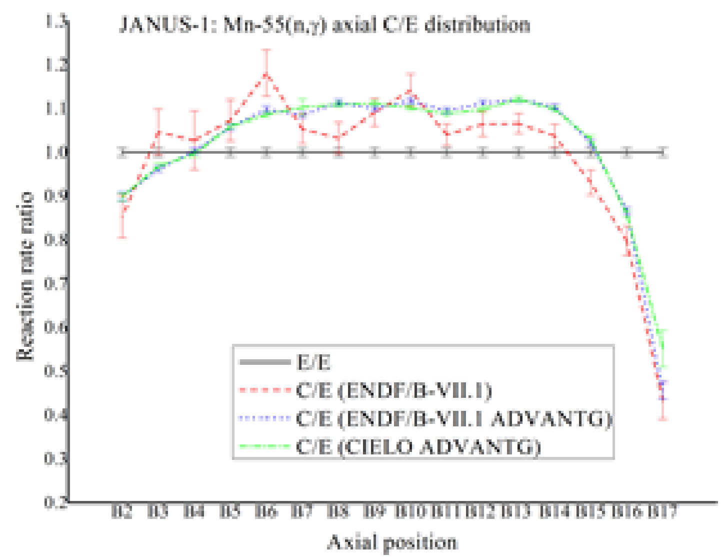





JANUS-1: S-32(n,p) axial C/E distribution
Reaction rate ratio
Axial position
E/E
C/E (ENDF/B-VII.1)
C/E (ENDF/B-VII.1 ADVANTG)
C/E (CIELO ADVANTG)


JANUS-1: Rh-103(n,n') axial C/E distribution
Reaction rate ratio
Axial position
E/E
C/E (ENDF/B-VII.1)
C/E (ENDF/B-VII.1 ADVANTG)
C/E (CIELO ADVANTG)

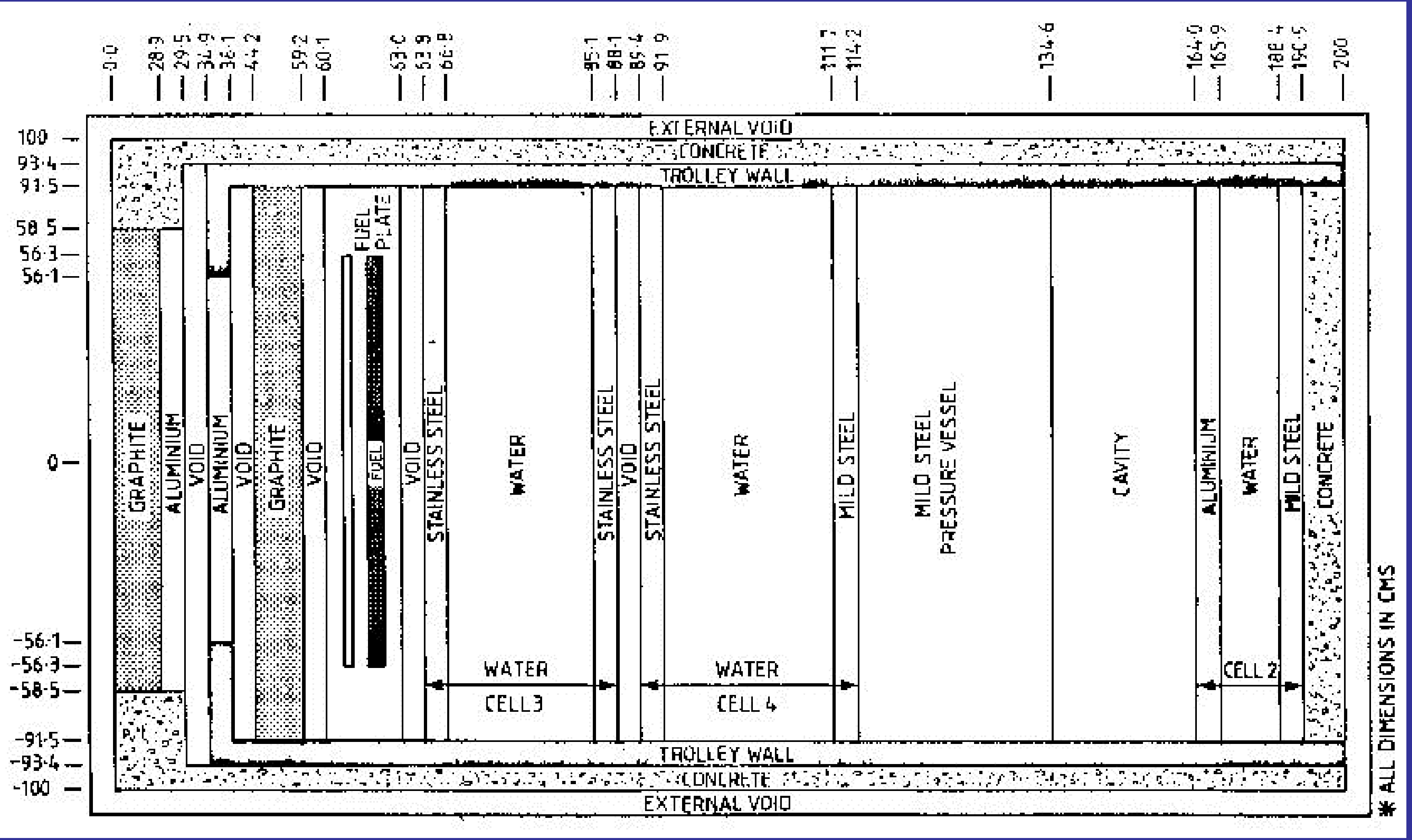

JANUS-1: Au-197(n,γ) axial C/E under Cd
Reaction rate ratio
Axial position
E/E
C/E (ENDF/B-VII.1)
C/E (ENDF/B-VII.1 ADVANTG)
C/E (CIELO ADVANTG)


JANUS-1: Mn-55(n,γ) axial C/E distribution
Reaction rate ratio
Axial position
E/E
C/E (ENDF/B-VII.1)
C/E (ENDF/B-VII.1 ADVANTG)
C/E (CIELO ADVANTG)

ASPIS NESDIP-3 (1985)

- NESTOR graphite reflector n. source, converted by fission plate
- Attenuation in mild steel, SS, and water (simulating PWR shielding)
- Reaction rate axial distributions:
  - $^{32}S(n,p)$
  - $^{103}Rh(n,n')$

NESDIP-3



EXTERNAL VOID
CONCRETE
TROLLEY WALL
GRAPHITE
ALUMINIUM
VOID
ALUMINIUM
VOID
GRAPHITE
VOID
FUEL PLATE
FUEL
VOID
STAINLESS STEEL
WATER
STAINLESS STEEL
VOID
STAINLESS STEEL
WATER
MILD STEEL
MILD STEEL PRESSURE VESSEL
CAVITY
ALUMINIUM
WATER
MILD STEEL
CONCRETE
WATER
CELL 3
WATER
CELL 4
CELL 2
TROLLEY WALL
CONCRETE
EXTERNAL VOID
100
93·4
91·5
58·5
56·3
56·1
0
-56·1
-56·3
-58·5
-91·5
-93·4
-100
0·0
134·6
200
* ALL DIMENSIONS IN CMS

Measurement positions

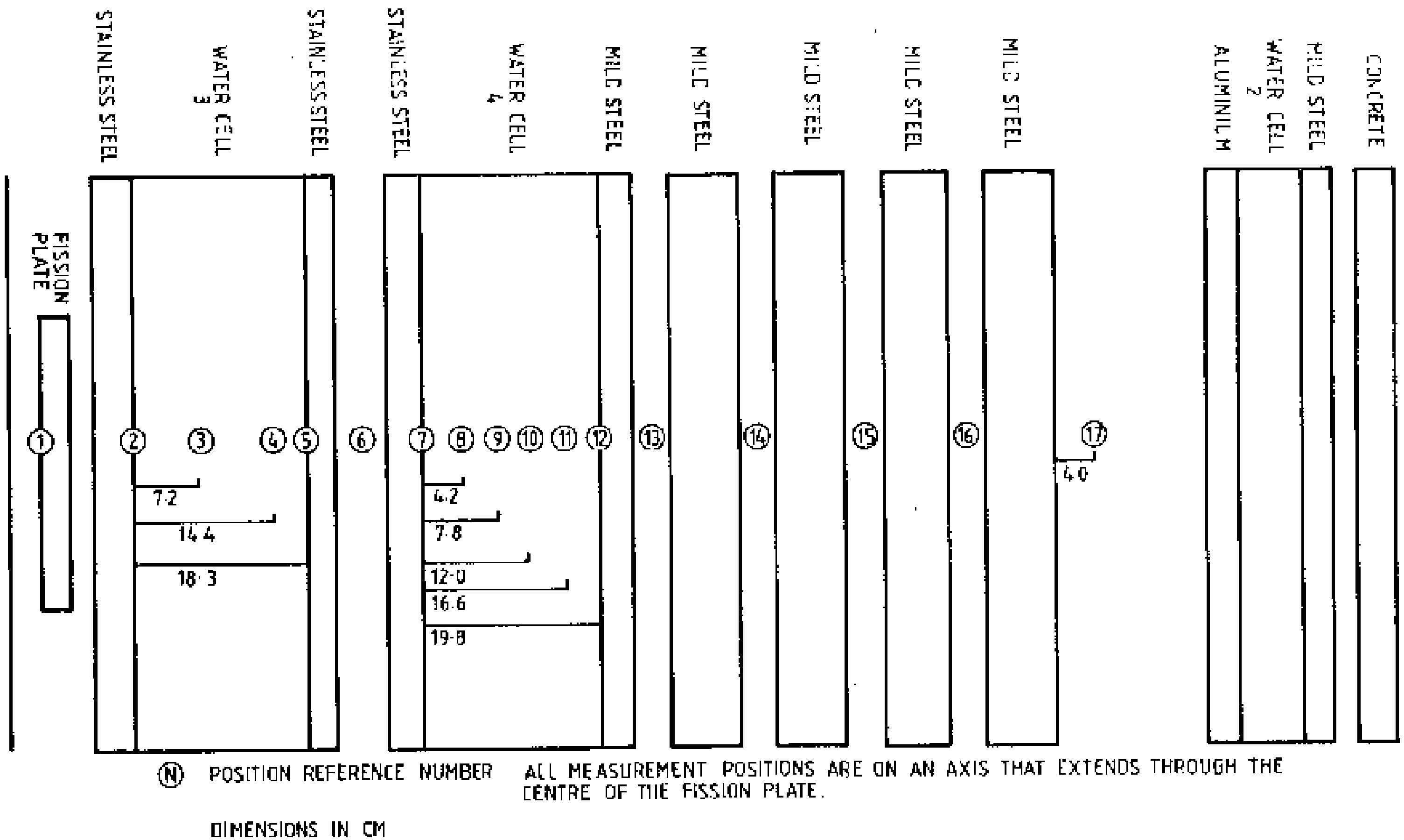
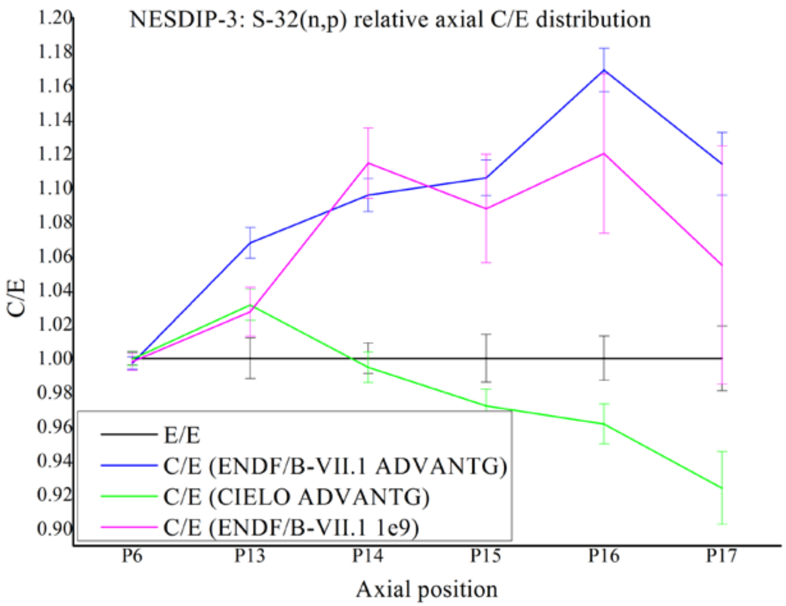
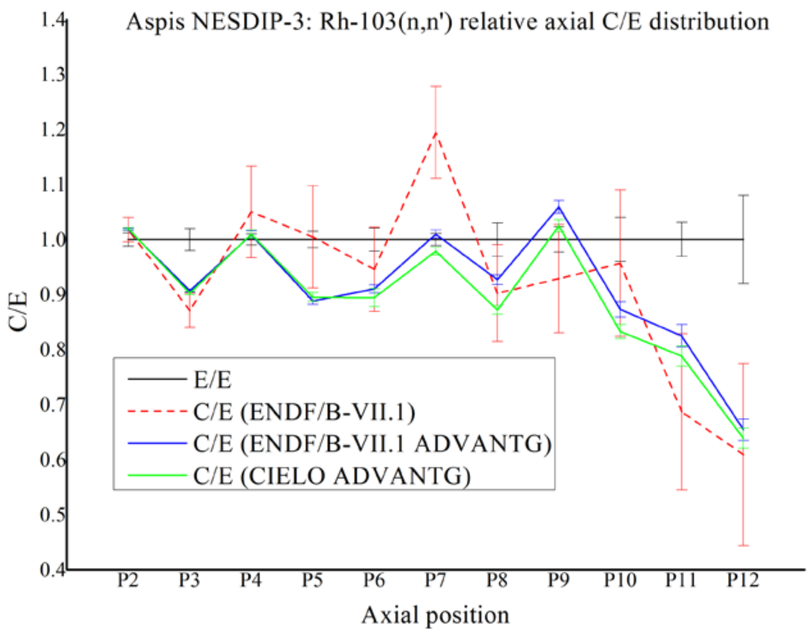


FIGURE 2
MEASUREMENT LOCATIONS IN THE 18/20 NESDIP ARRAY


NESDIP-3: S-32(n,p) relative axial C/E distribution
C/E
1.20
1.18
1.16
1.14
1.12
1.10
1.08
1.06
1.04
1.02
1.00
0.98
0.96
0.94
0.92
0.90
E/E
C/E (ENDF/B-VII.1 ADVANTG)
C/E (CIELO ADVANTG)
C/E (ENDF/B-VII.1 1e9)
P6
P13
P14
P15
P16
P17
Axial position


Aspis NESDIP-3: Rh-103(n,n') relative axial C/E distribution
C/E
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
E/E
C/E (ENDF/B-VII.1)
C/E (ENDF/B-VII.1 ADVANTG)
C/E (CIELO ADVANTG)
P2
P3
P4
P5
P6
P7
P8
P9
P10
P11
P12
Axial position

EURACOS Fe

- TRIGA thermal column n. source, converted to fast by fission plate
- Attenuation in Fe
- Reaction rate axial distributions (as a function of depth in Fe):
  - $^{32}S(n,p)$
  - $^{197}Au(n,\gamma)$ under Cd
  - *$^{103}Rh(n,n')$ - measurements normalized to the first value*
  - $^{115}In(n,n')$
- Experimental uncertainties:
  - Source (spectrum and spatial distribution)
  - Room return

EURACOS MCNP model (recent progress)

- Re-definition of the neutron source
- Improved variance reduction techniques
- Sensitivity study:
  - Source fission spectrum
  - Source positioning (in fission plate, before the fission plate, . . .)
  - Source (radial) distribution
  - Impurities in Fe
- Modelling of new activation detectors
- Neutron spectra calculations

EURACOS - Experimental setup

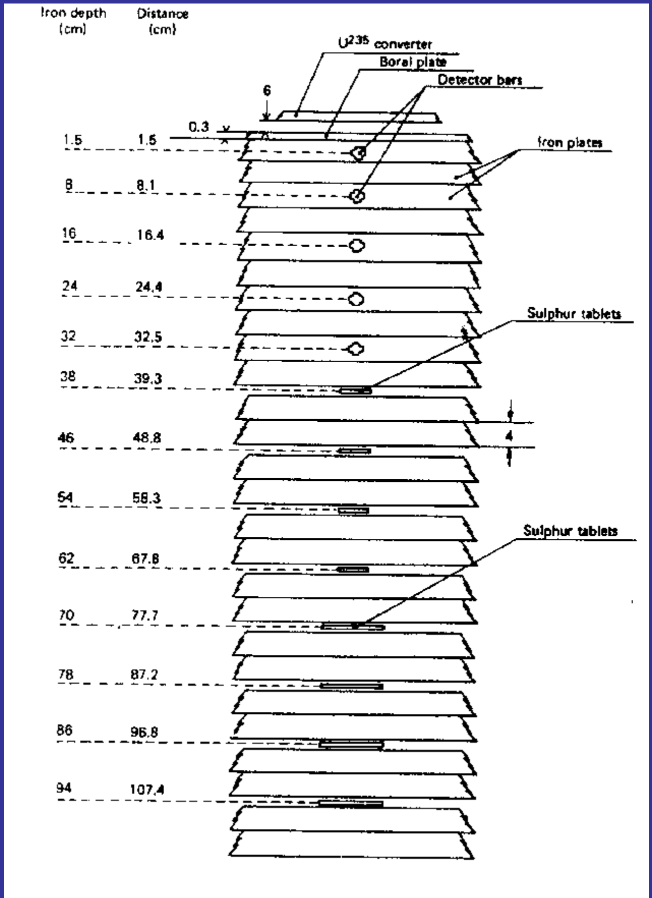


Fig. 4: SULPHUR DETECTOR POSITIONS IN THE IRON ASSEMBLY

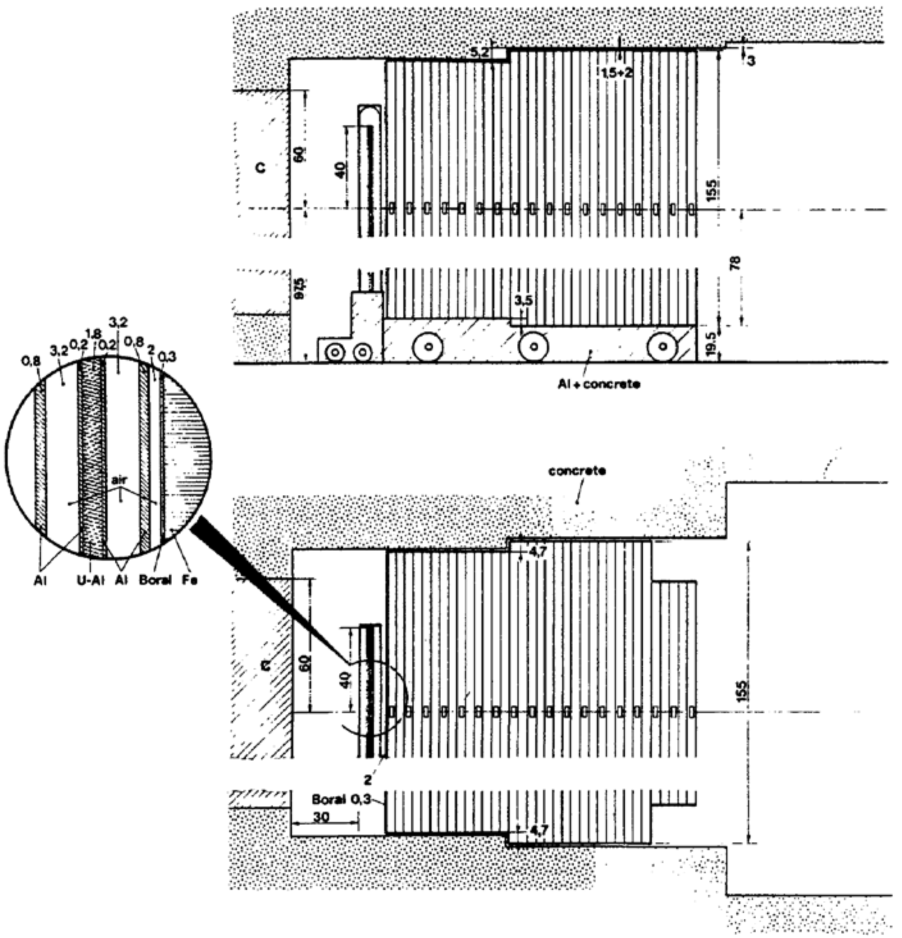
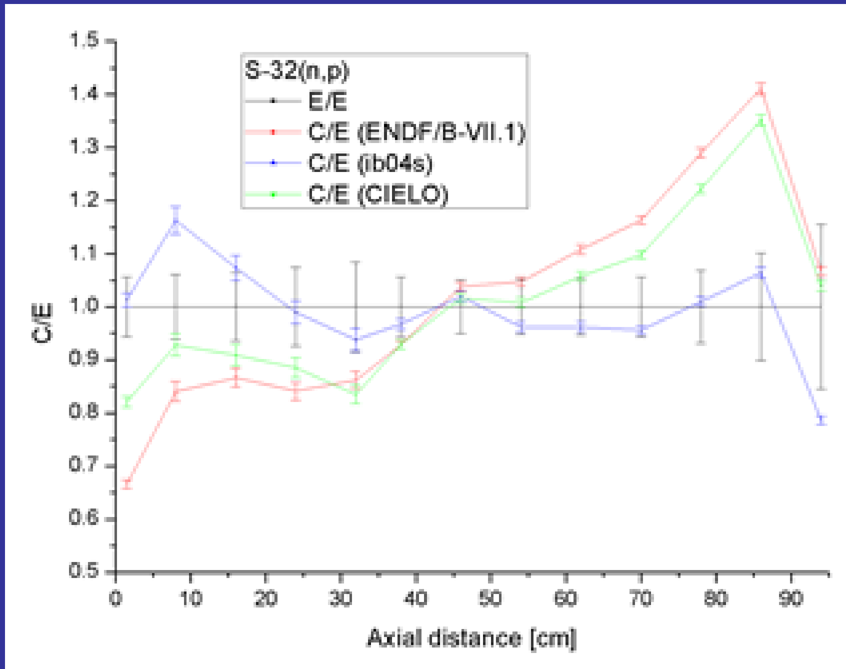
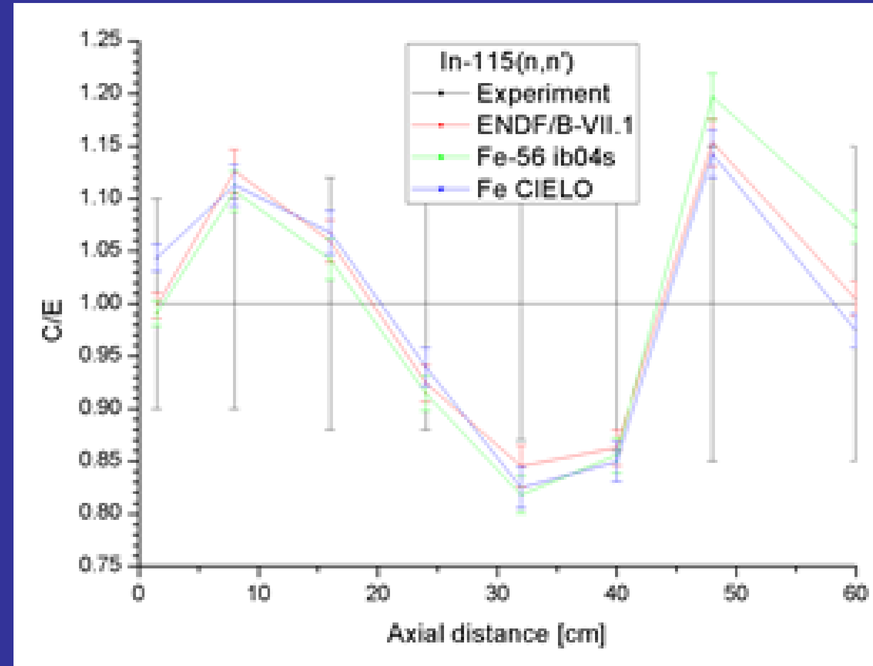
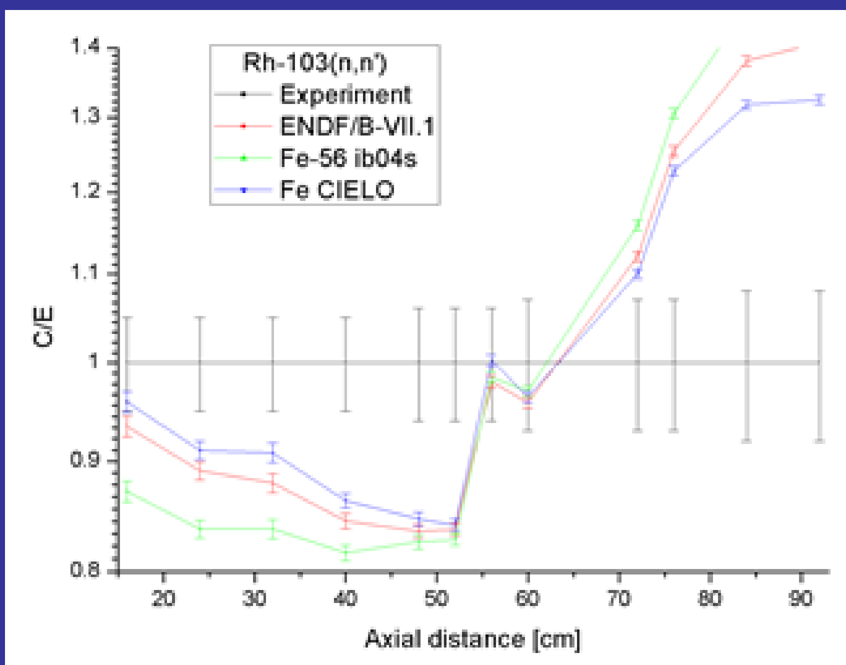
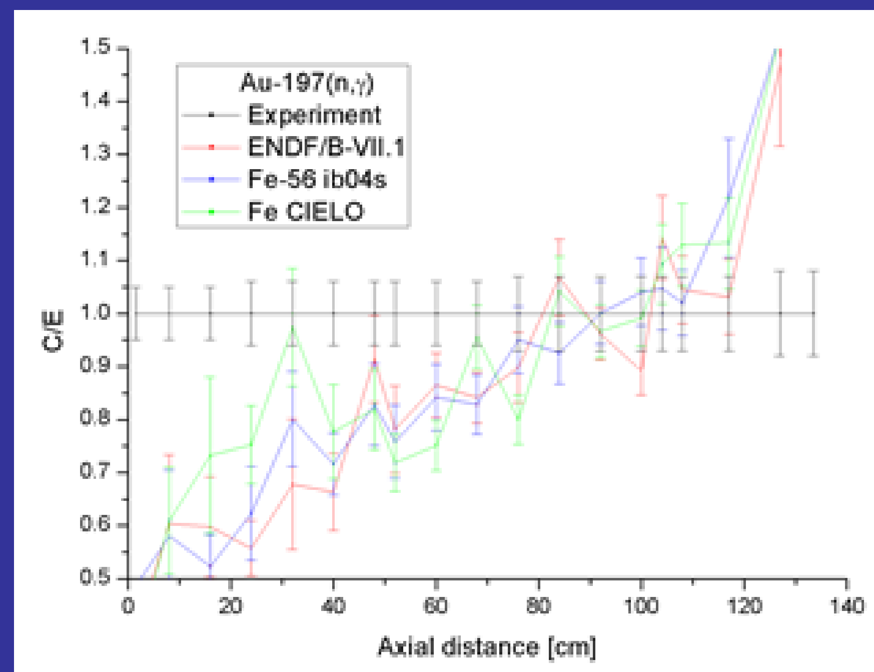


Fig. 2 Vertical and horizontal cross section of iron assembly including the Euracos II facility


S-32(n,p)
E/E
C/E (ENDF/B-VII.1)
C/E (ib04s)
C/E (CIELO)
C/E
Axial distance [cm]


In-115(n,n')
Experiment
ENDF/B-VII.1
Fe-56 ib04s
Fe CIELO
C/E
Axial distance [cm]

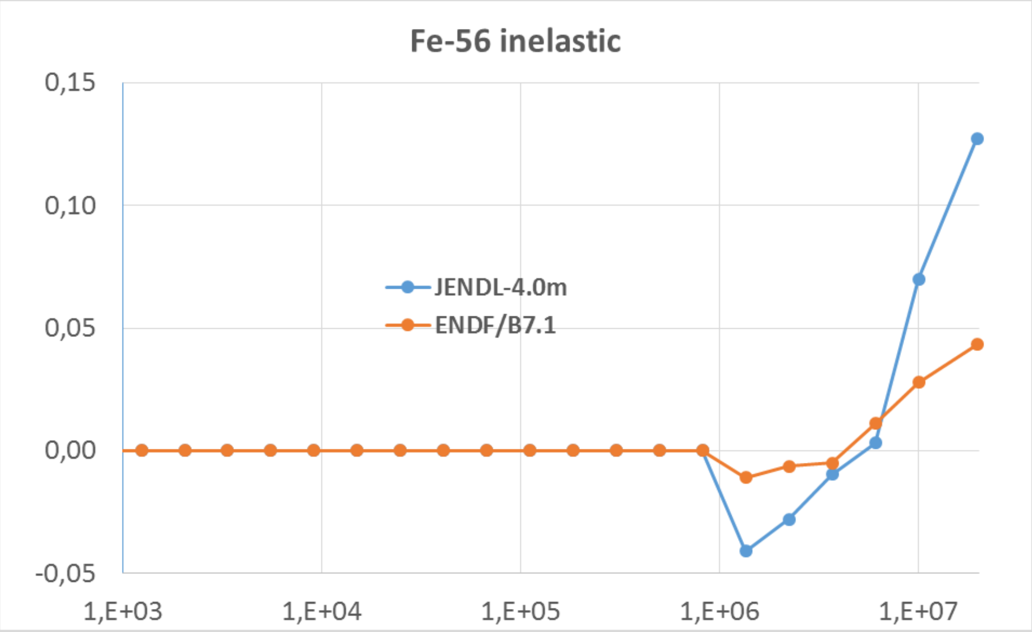

Rh-103(n,n')
Experiment
ENDF/B-VII.1
Fe-56 ib04s
Fe CIELO
C/E
Axial distance [cm]

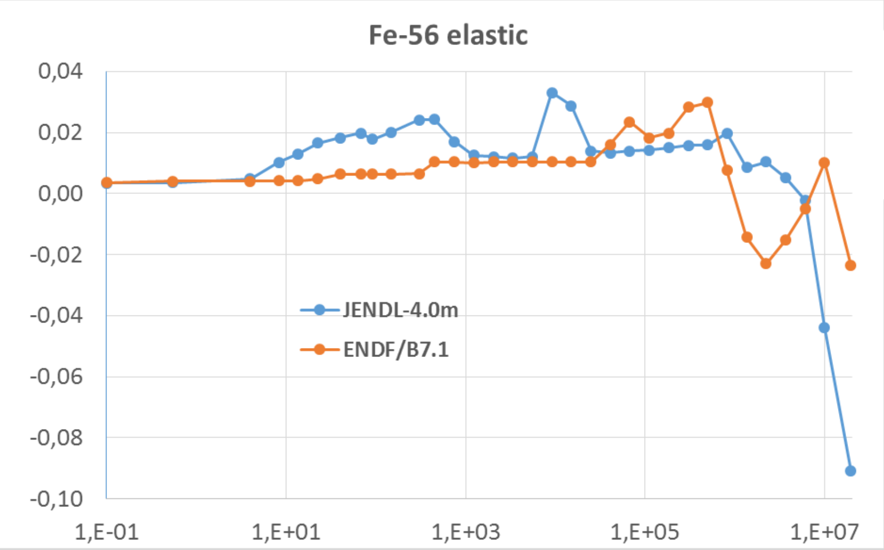

Au-197(n,γ)
Experiment
ENDF/B-VII.1
Fe-56 ib04s
Fe CIELO
C/E
Axial distance [cm]

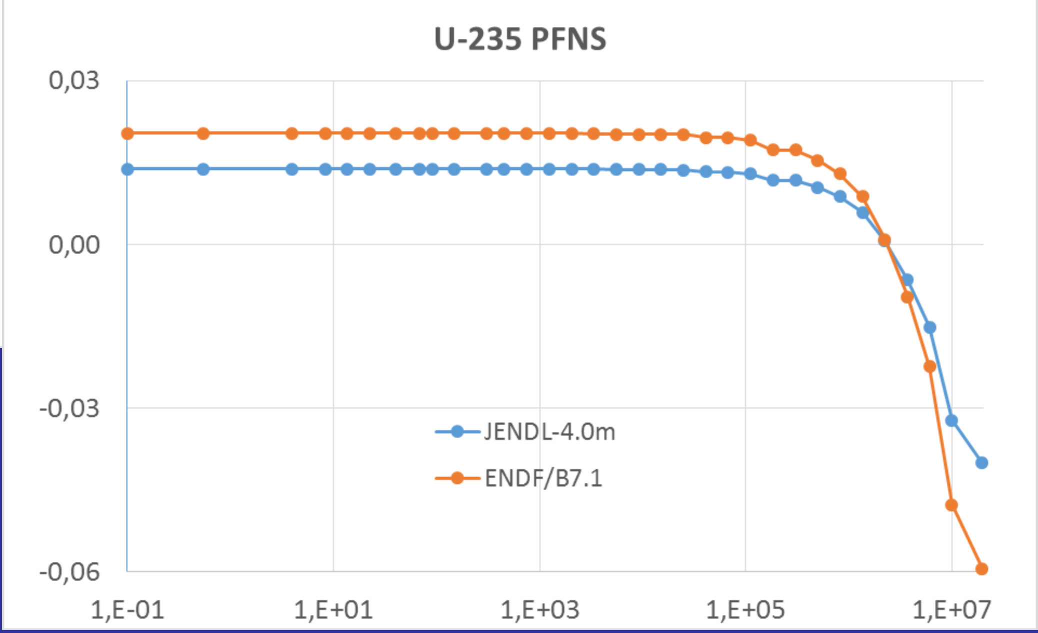
WPEC WG39 adjustment exercise

- SINBAD ASPIS FE-88
- k_{eff} & β_{eff}: SNEAK-7A & 7B, FLATTOP-Pu

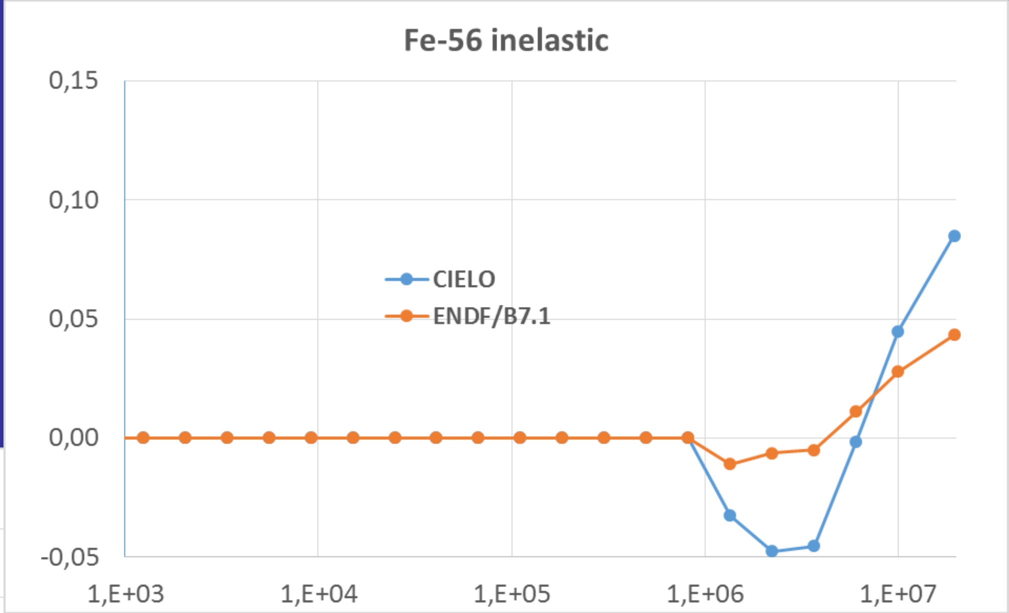
Results of adjustment exercise: adjustments of ENDF/BVII.1

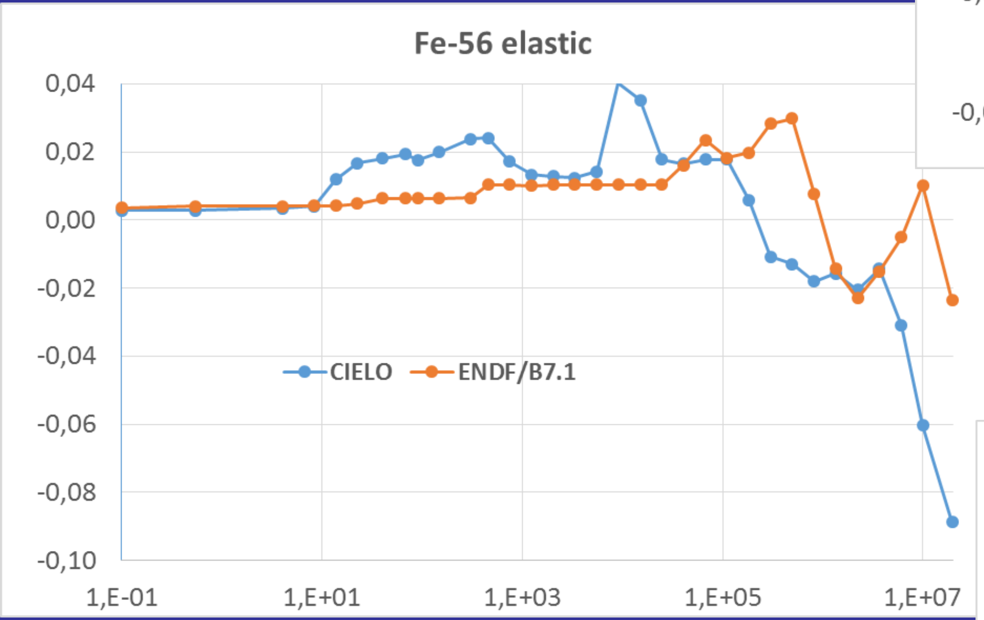


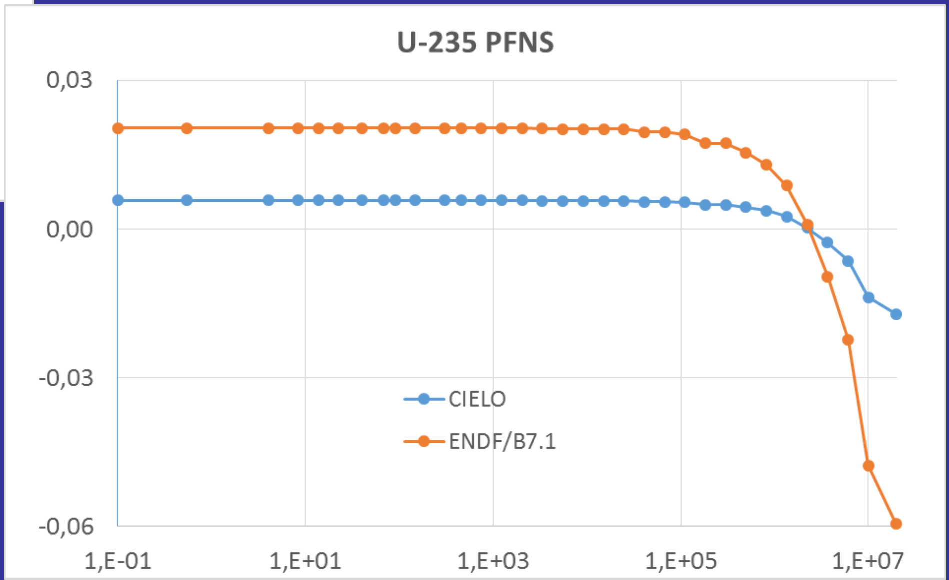


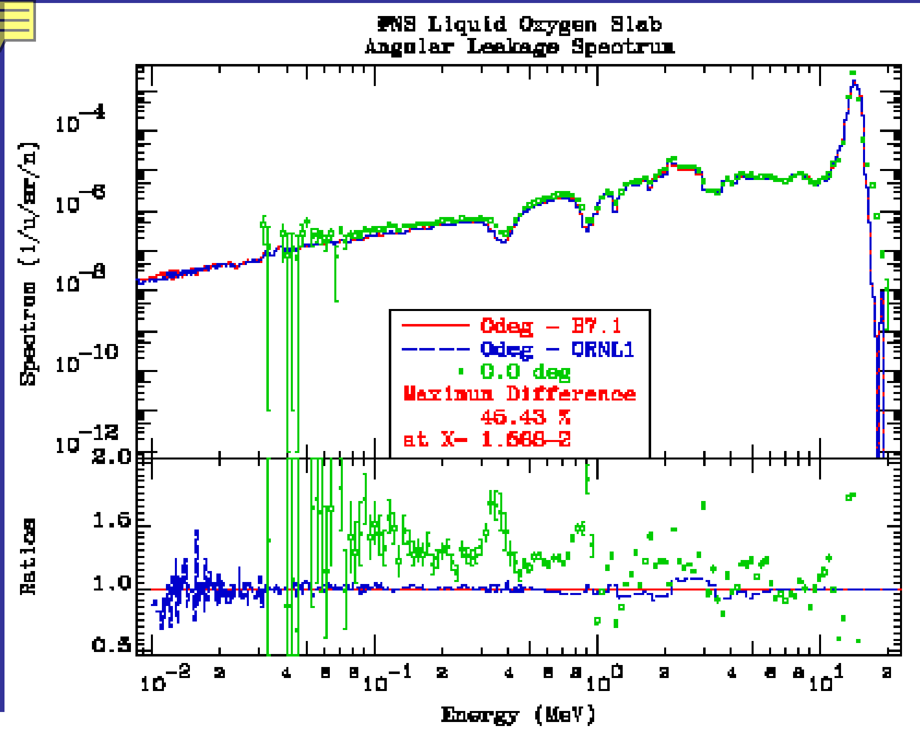


Adjustment exercise: ENDF/BVII.1 vs. CIELO

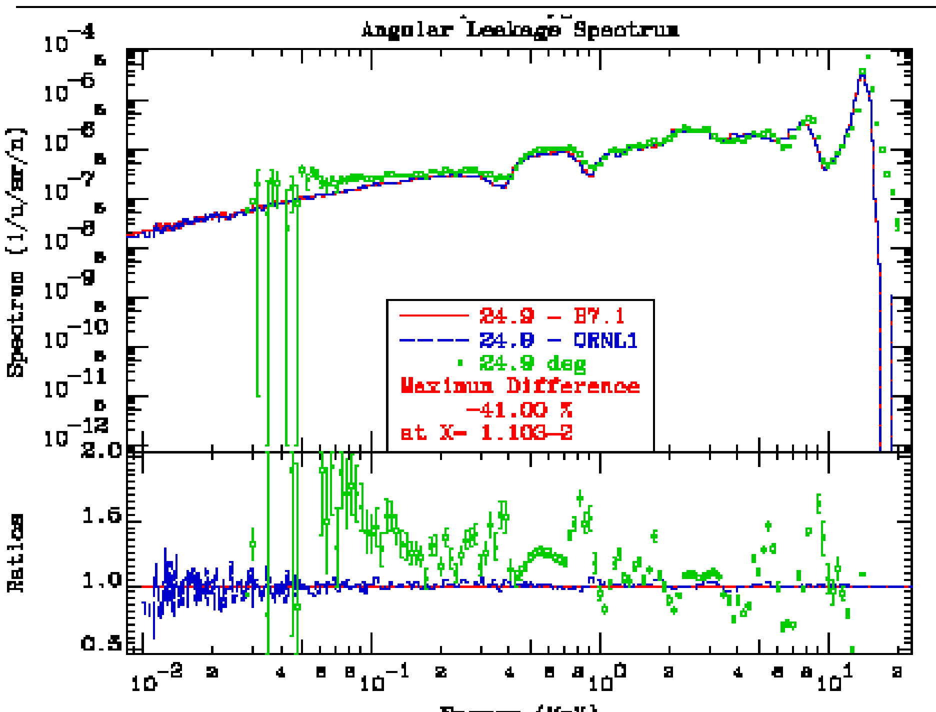


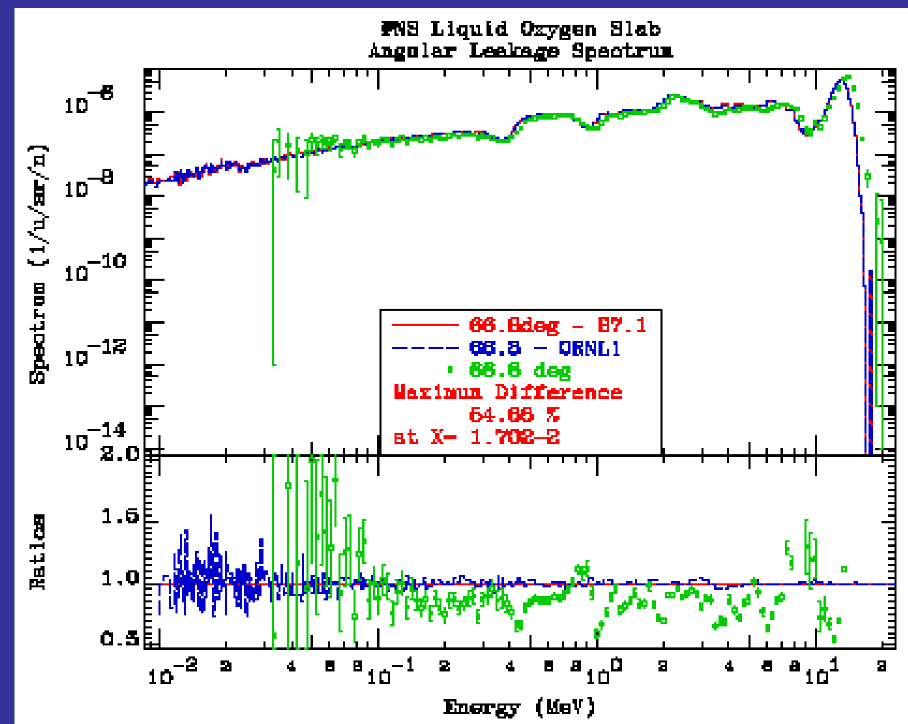






FNS Oxygen (CIELO)





Conclusions

- **Combined use of shielding, criticality & kinetics benchmarks offers a more complete picture needed for ND validation.**
- The SINBAD database currently contains compilations and evaluations of experiments for 46 reactor shielding problems, 31 for fusion neutronics shielding and 23 for accelerator shielding cases. 25 benchmarks include Iron or steel as shielding material.
- Four shielding benchmarks performed in the 1980-ies, ASPIS Iron88, JANUS phase I, ASPIS NESDIP 3 and EURACOS Iron, were selected among the recently re-evaluated SINBAD experiments for the validation of the new iron cross section evaluations.
- ASPIS-Fe88 was successfully used and **demonstrated to be useful for validation of modern nuclear data evaluations and codes.**

Conclusions

- The validation revealed general good performance of the new iron data. For several reaction rate measurement and benchmarks, the new data agree better or comparable to the reference ENDF/B-VII.1 cross-sections. Few reaction rates measured in the ASPIS Iron-88 benchmark (**^{32}S and ^{115}In**), sensitive predominantly to the iron inelastic and elastic scattering **(~1 to ~5 MeV**) indicate underestimation of the calculation comparing to the measured values and a possible overestimation of $\sigma_{el}/\sigma_{inel}$ at the above fast energy ranges.
- JENUS-1 and NESDIP-3 (analysis still ongoing),
- k_{eff}, β_{eff} and RR sensitivities prepared and used for **SG-39 adjustment exercise**,
- **FNS-Oxygen** can be used for validation of other evaluations than ORNL1 & -2.