The European Commission's science and knowledge service

Joint Research Centre

European Commission

The Joint Evaluated nuclear data library for Fission and Fusion - JEFF

Arjan Plompen

SANDA and ARIEL kick-off meetings, Brussels, 9-12 September 2019

European Commission

For and with

Member States

OECD-NEA
IAEA

International
partners

Challenge: Climate Change - carbon free energy

Nuclear energy can be an important component in the mix

2016	CO2	CO2-free	Nuclear	Bio+waste
world	81%	19%	5%	10%
EU 28	72%	**28%**	14%	10%
Belgium	71%	29%	20%	7%
France	47%	**53%**	42%	7%
Germany	79%	21%	7%	10%
Sweden	29%	**71%**	33%	25%

Countries with a high percentage CO_2-free energy use (nuclear) electricity for heating.

Still a lot to do for CO_2-free transport.

Data International Energy Agency, Total primary energy supply

Challenges for nuclear energy

- Cost of construction
- Perception of risk & public opinion

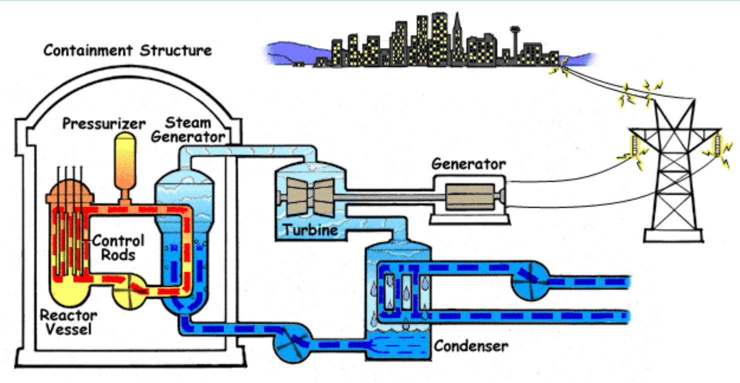
  Legacy of historical major accidents, Fukushima and Chernobyl, and the shadow they project over the future.
- Communication in a difficult era

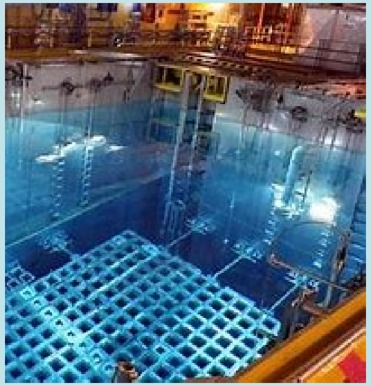
Nuclear data and applications of JEFF

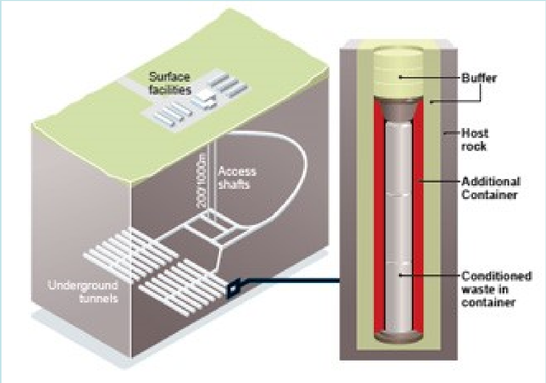
Towards a general purpose library

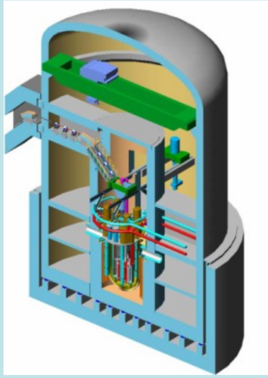
Applications: fission and fusion, radiation protection, nuclear medicine, (nuclear) security, object and materials analysis

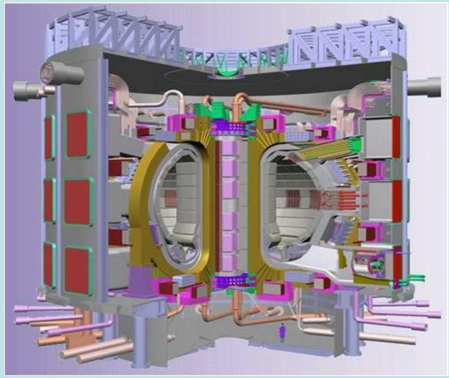
Science: reactions and structure of nuclei, astrophysics, basic physics

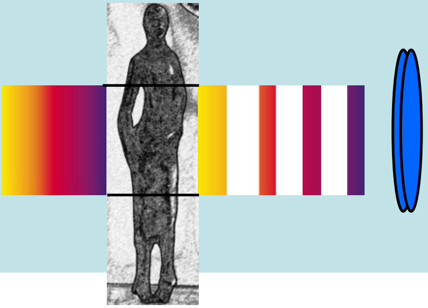


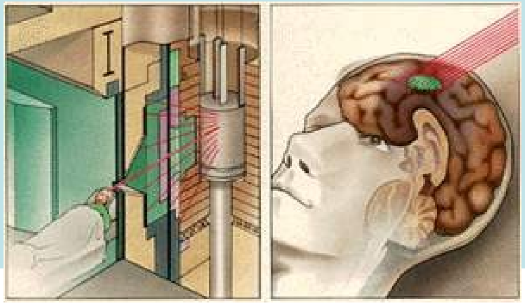












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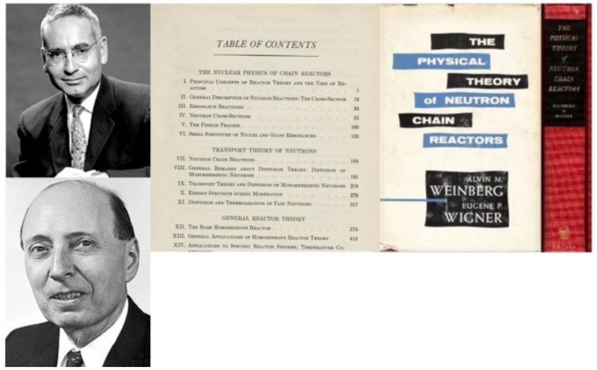
Modeling for cost reduction

- Reliable predictions with credible uncertainty margins.
- We are a far cry from that in the nuclear field
- Lots of expert judgement and ad-hoc methods and codes.
- Lots of tests needed for innovative ideas.
- Knowledge management through data libraries, codes and procedures can make major steps forward with modern software technology
- JEFF-4 development goal for 2018-2024

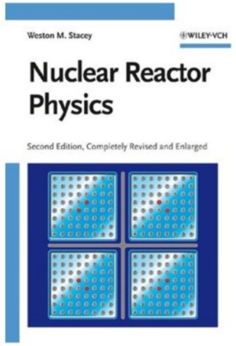
The physical theory of neutron chain reactors

Alvin M. Weinberg and Eugene P. Wigner, University of Chicago Press (1958)



Nuclear Reactor Physics

Weston M. Stacey, Wiley-VCH, 2nd ed. (2007)



- One set of data for all applications
- One suite of modeling codes

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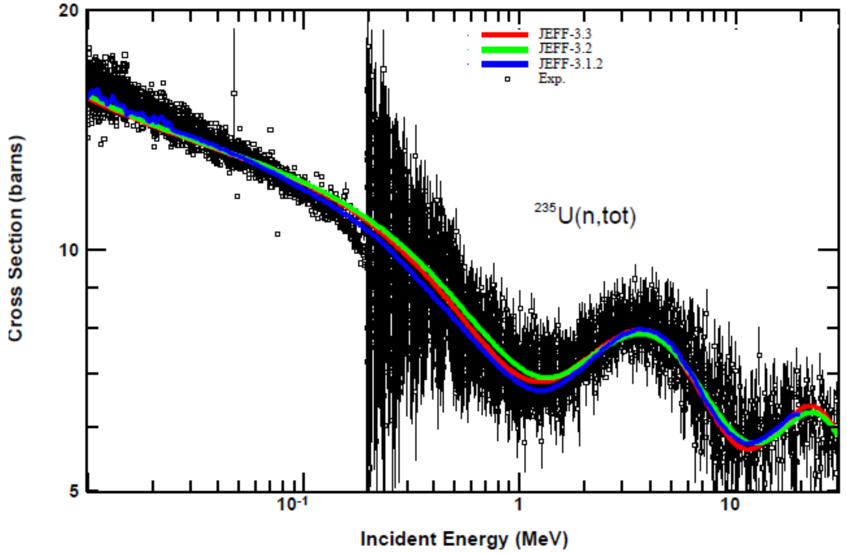
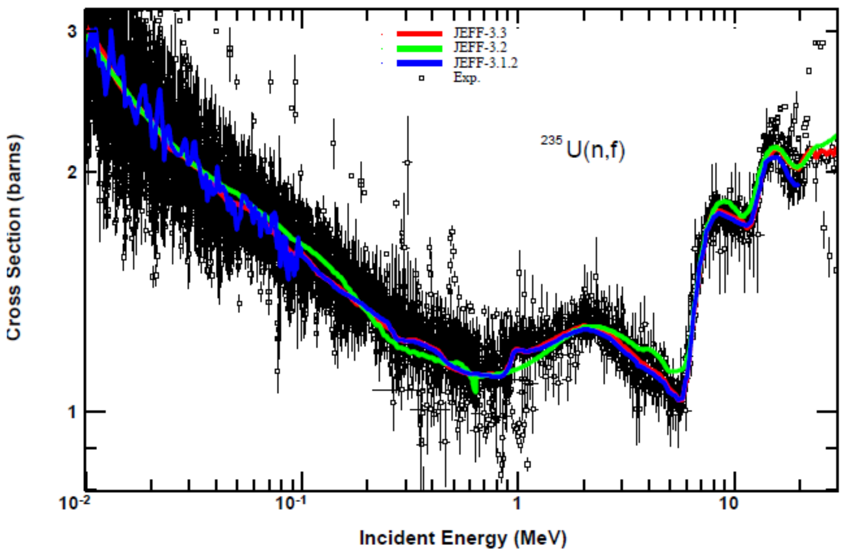
JEFF – 3.3, 20 November 2017

- New major actinides (CEA Cadarache & Bruyeres-le-Chatel, IRSN)
- FY beta file UKFY3.7 (NNL)
- Radioactive Decay Data File (CEA Saclay)
- New covariances
- Increased reliance on TENDL for completeness and decay heat (D. Rochman, M. Fleming)
- New Cu files (Pereslavtsev, Leal) solved important issue with JEFF-3.2
- Improved gamma-emission data (C. Jouanne, R. Perry, G. Noguere, O. Serot, …)
- Restoration of 8 group structure for delayed neutrons (P. Leconte)
- New thermal scattering data (Cantargi, Granada, Marquez Damian, Noguere)
- Removal of legacy files, update of adopted files to latest release
- Many issues resolved (many contributors)

JEFF-3.3 U-235





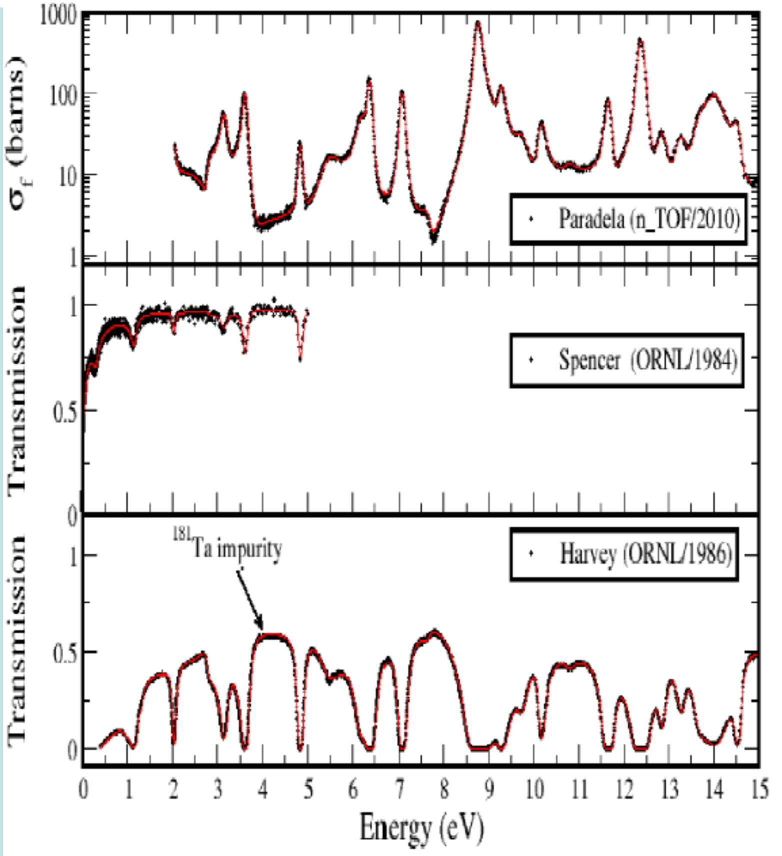


Table 3: Standard values and resonance parameters results for 0.0253 eV

Parameter	Standard Values (b)	Values obtained with the new resonance parameters (b)
σ_f(b)	584.4 ± 1.0	584.4
σ_γ(b)	99.30 ± 0.73	99.23
σ_s(b)	14.09 ± 0.22	14.09
Fission integral in the 7.8-11 eV range (b eV)	246.4 ± 1.2	246.9

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JEFF-3.3 Pu-239

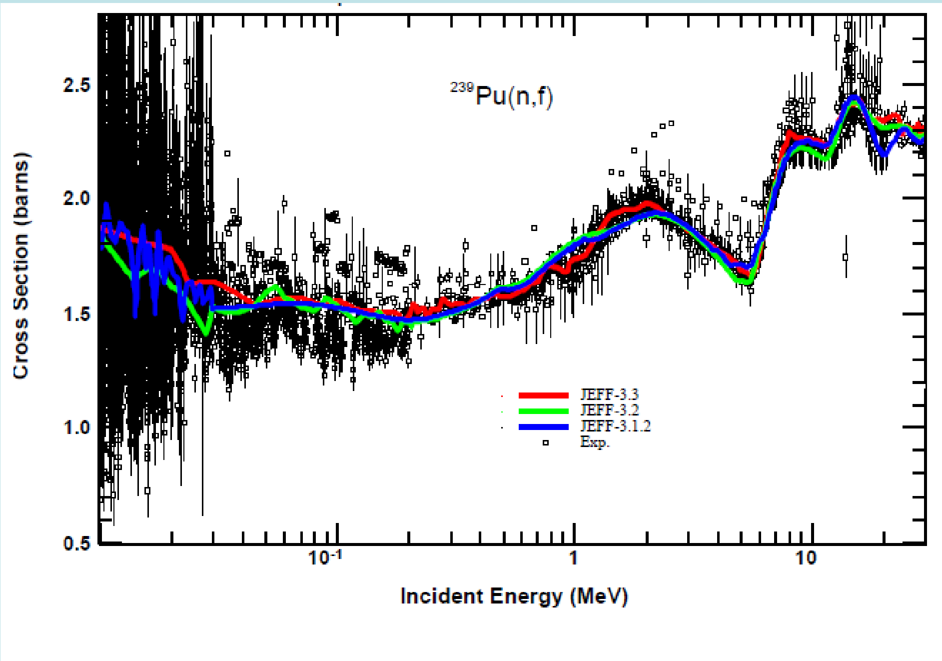
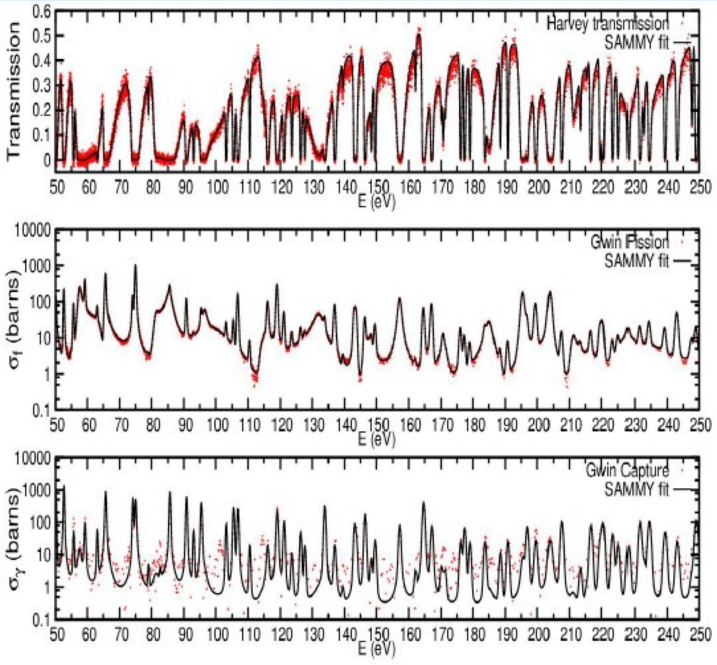


Table 7: Standard average fission integral

Energy Interval (eV)	Standard recommended values and uncertainties (barns)	Average fission cross section obtained with the new resonance parameter (barns)
100 - 200	18.709 (93)	18.547
200 - 300	17.859 (89)	17.832
300 - 400	8.562 (51)	8.309
400 - 500	9.567 (48)	9.564
500 - 600	15.489 (77)	15.495
600 - 700	4.523 (27)	4.286
700 - 800	5.654 (34)	5.508
800 - 900	5.039 (30)	4.859
900 - 1000	8.384 (50)	8.496
1000 - 4000	4.515 (31)	4.369



	ANR	JEFF-3.1.1	JEFF-3.2	JEFF-3.3
σ_γ	269.1 ± 2.9	272.61	270.06	271.3
σ_f	748.1 ± 2.0	747.08	747.19	749.0
σ_s	7.94 ± 0.36	8.0	8.1	7.76

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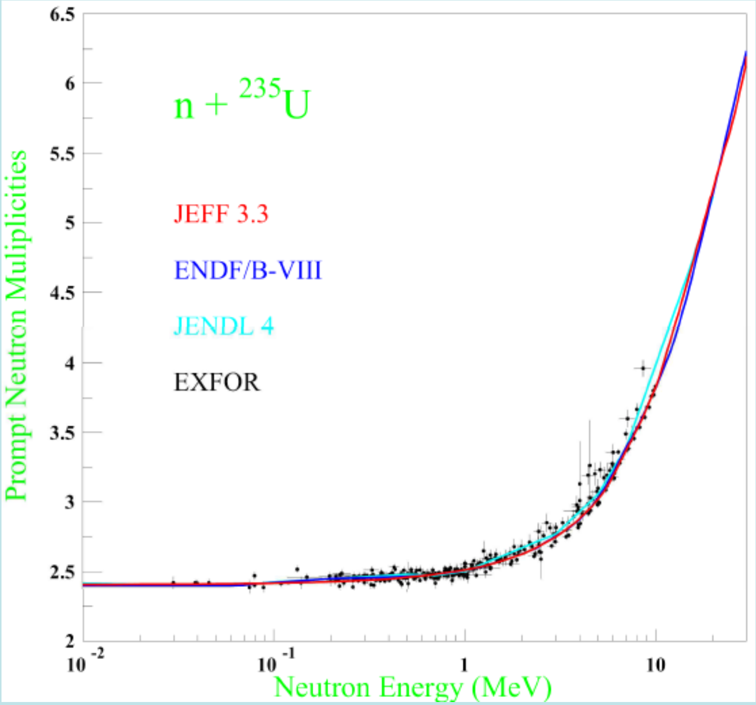
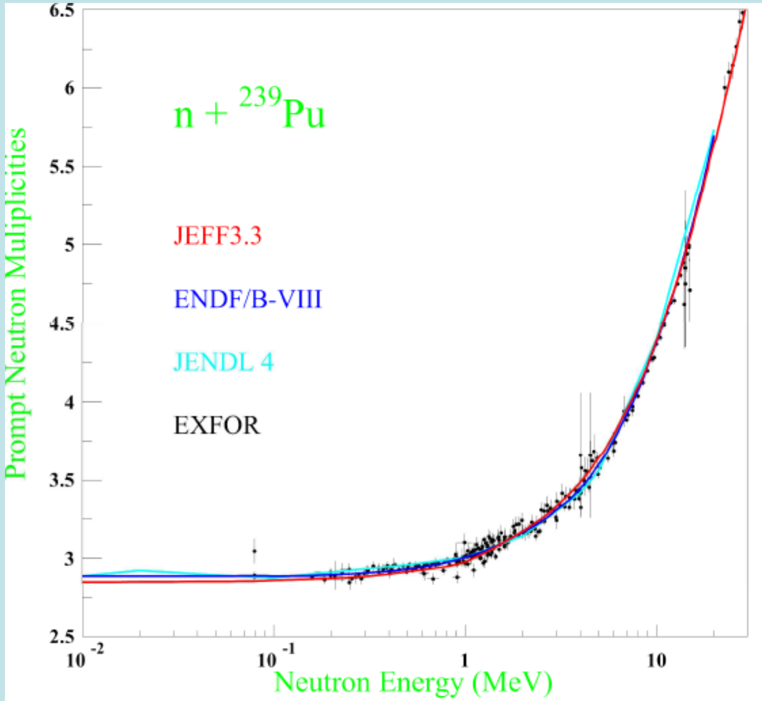
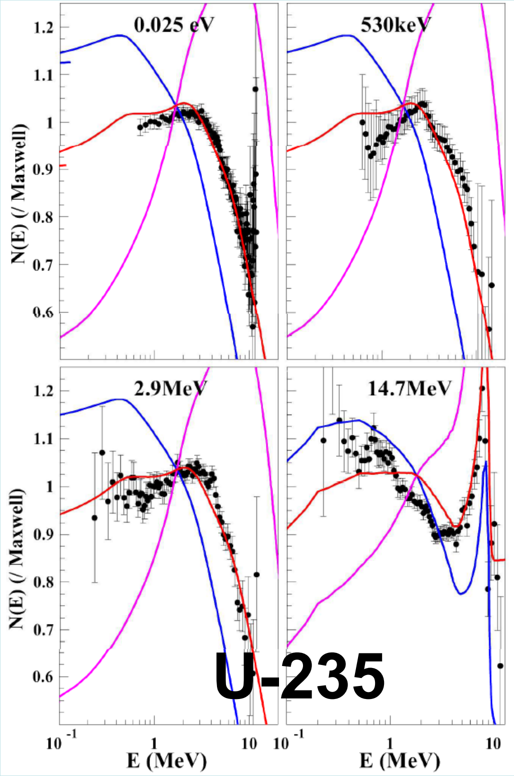
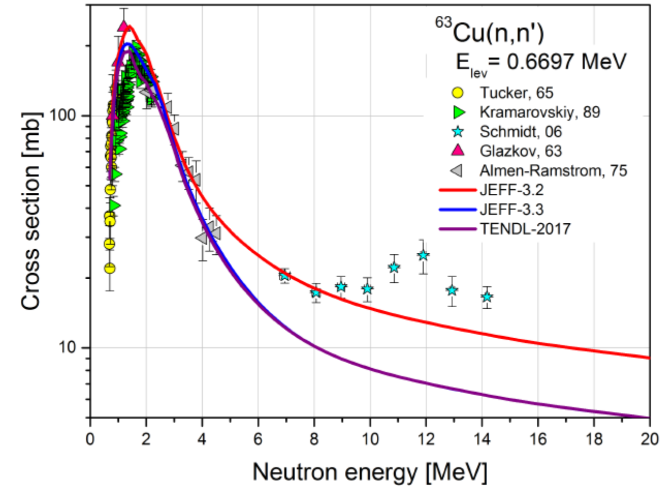
U-235, Pu-239 nu-bar and pfns

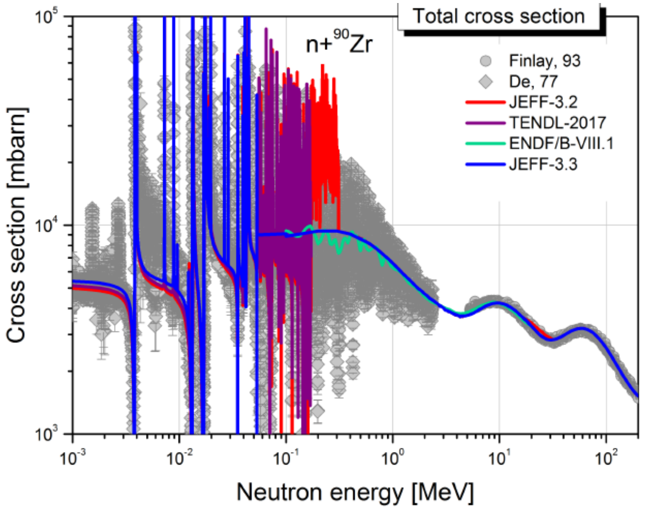






Structural materials, coolants





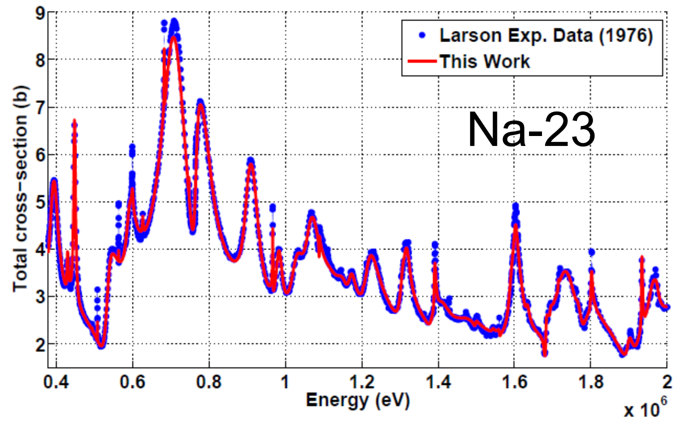
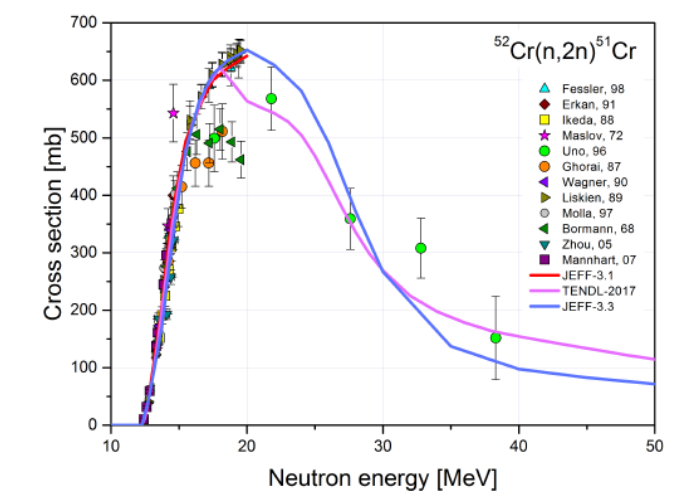
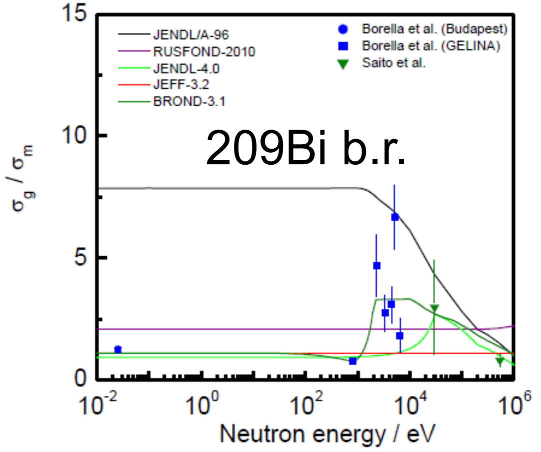
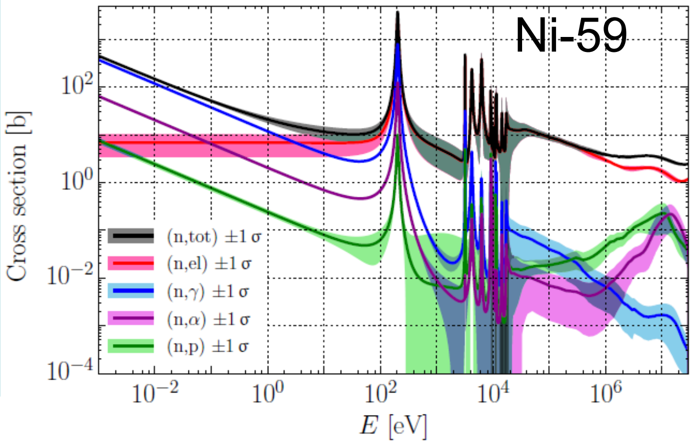


Fig. 31: Evaluated ^{23}Na total cross-section (red) compared to Larson experimental data (blue dots)



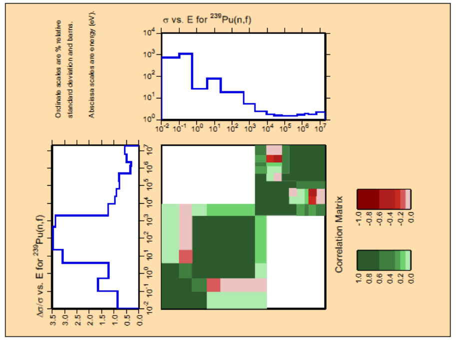




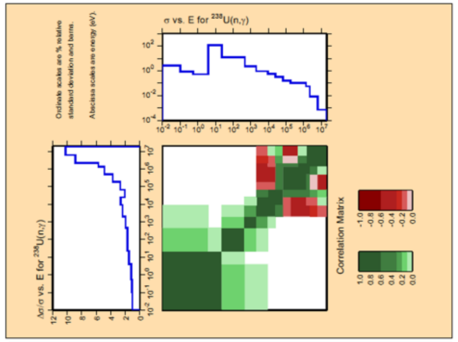
Cyrille De Saint Jean

	^{239}Pu	^{238}U	^{23}Na

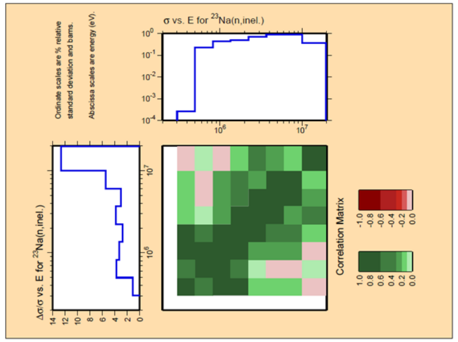
(n,f)



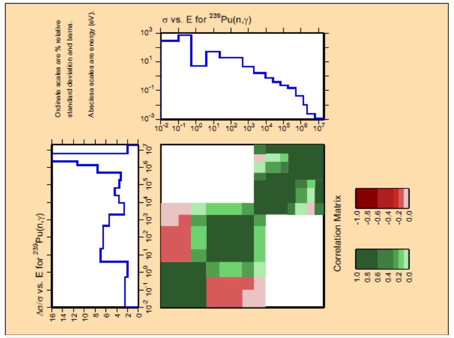
(n,g)



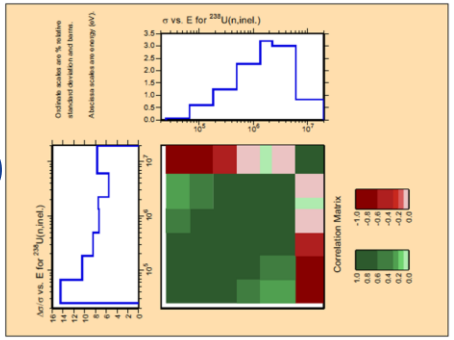
(n,inl)



(n,g)



(n,inl)

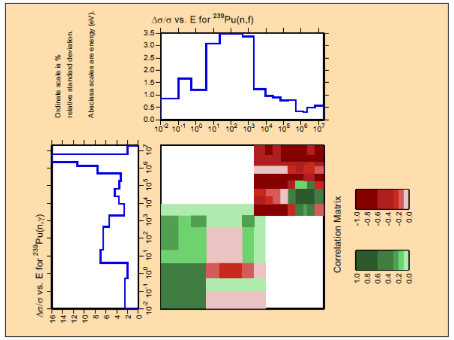


Further covariances for Hf

Many from TENDL (D. Rochman)

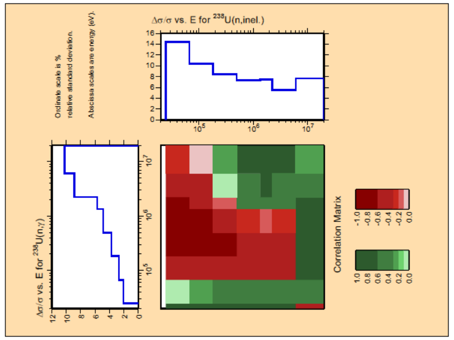
(n,f) x

(n,g)



(n,g) x

(n,inl)



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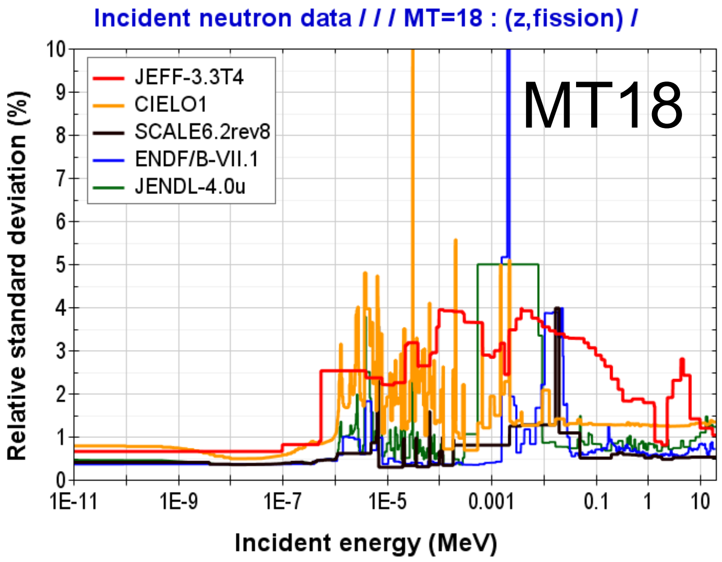
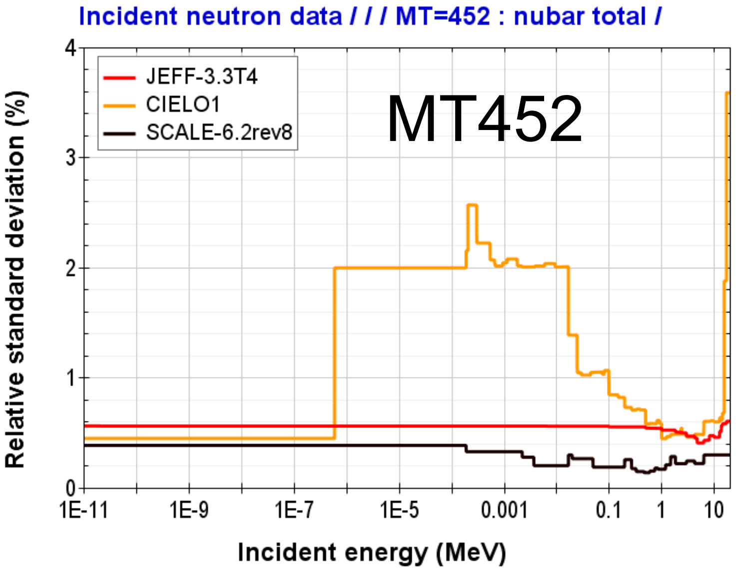
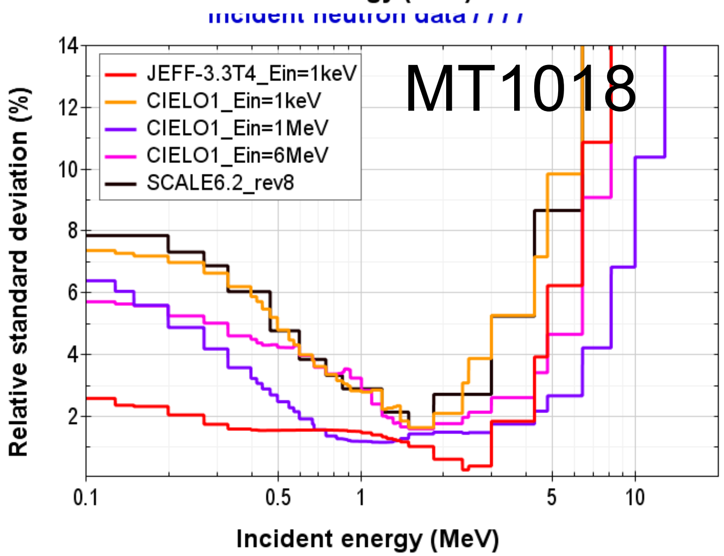
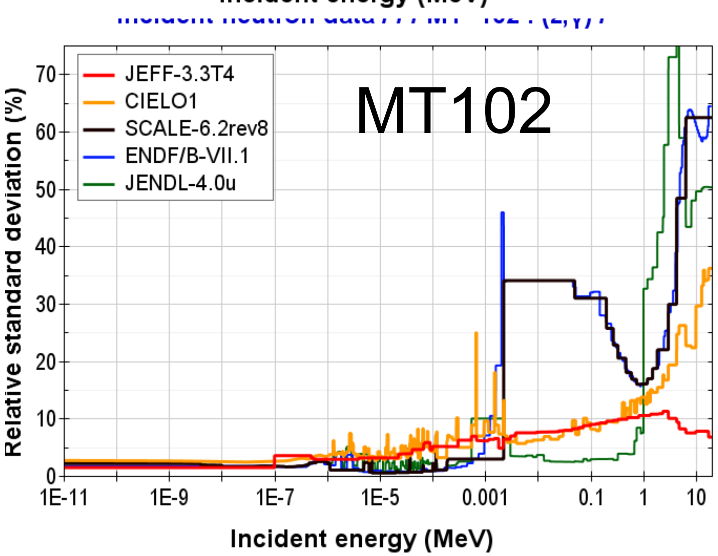
❑ U-235


Incident neutron data / / / MT=18 : (z,fission) /
MT18
JEFF-3.3T4
CIELO1
SCALE6.2rev8
ENDF/B-VII.1
JENDL-4.0u
Relative standard deviation (%)
Incident energy (MeV)
10
9
8
7
6
5
4
3
2
1
0
1E-11
1E-9
1E-7
1E-5
0.001
0.1
1
10


Incident neutron data / / / MT=452 : nubar total /
MT452
JEFF-3.3T4
CIELO1
SCALE-6.2rev8
Relative standard deviation (%)
Incident energy (MeV)
4
3
2
1
0
1E-11
1E-9
1E-7
1E-5
0.001
0.1
1
10


MT1018
JEFF-3.3T4_Ein=1keV
CIELO1_Ein=1keV
CIELO1_Ein=1MeV
CIELO1_Ein=6MeV
SCALE6.2_rev8
Relative standard deviation (%)
Incident energy (MeV)
14
12
10
8
6
4
2
0.1
0.5
1
5
10


MT102
JEFF-3.3T4
CIELO1
SCALE-6.2rev8
ENDF/B-VII.1
JENDL-4.0u
Relative standard deviation (%)
Incident energy (MeV)
70
60
50
40
30
20
10
0
1E-11
1E-9
1E-7
1E-5
0.001
0.1
1
10

Robert Mills, UKFY-3.7 = JEFF-3.3 FY

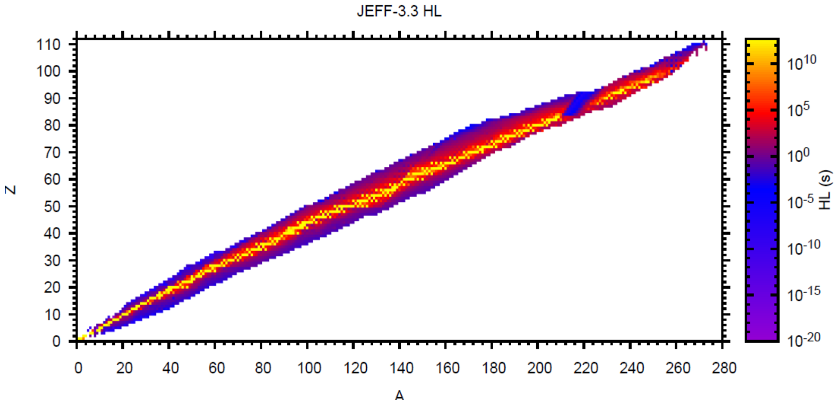
Max. Fraction of Fission Rate			
>10%	1-10%	0.1%-1%	Spont. fission
nuclides: 5	2	12	3
*^{233}U TFH *^{235}U TFH *^{238}U FH *^{239}Pu TF *^{241}Pu TF	*^{240}Pu F ^{245}Cm TF	*^{232}Th FH ^{234}U F ^{236}U F ^{237}Np TF ^{238}Np TF ^{238}Pu TF ^{242}Pu F ^{241}Am TF ^{242m}Am TF ^{243}Am TF ^{243}Cm TF ^{244}Cm TF	^{252}Cf Sp ^{242}Cm Sp ^{244}Cm Sp

* Nuclides in UKFY1 and previous UK libraries.
T Thermal fission.
F Fast fission.
H 14Mev Fission.
Sp Spontaneous fission.

Neutron spectra	Fissioning nuclide	UKFY3.6	New data	UKFY3.7
Thermal	Th229	337	72	409
Thermal	U233	757	188	945
Thermal	U235	2390	151	2541
Thermal	Np238	115	63	178
Thermal	Pu239	861	225	1086
Thermal	Pu241	334	63	397
Thermal	Cm245	161	219	380
Thermal	Cf249	305	239	544
Fast	U235	724	5	729
Fast	Pu239	390	5	395
Fast	Pu241	111	5	116

New JEFF-3.3 DD file, Mark Kellett, CEA Saclay

Olivier Bersillon, Alan Nichols



- **FROM JEFF-3.1.1 TO JEFF-3.3**

JEFF-3.3 (released October 2016):

Complete re-assessment and update to all 900 evaluations coming from ENSDF

Assessment of IAEA actinide decay data (85 nuclei)

Assessment of IRDFF decay data library (~80 nuclei)

Inclusion of updated UKPADD-6.12 library (~50 additional nuclei)

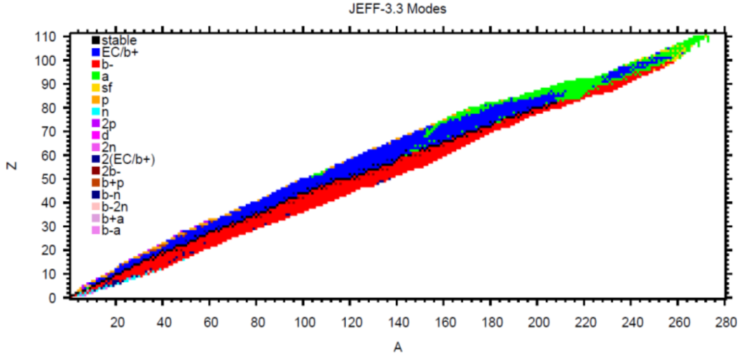
Assessment of new DDEP evaluations (~30 additional nuclei)

Inclusion of initial TAGS results from University of Valencia *(2010)*

Inclusion of first TAGS results from University of Nantes *(2015)*

Inclusion of further TAGS results from University of Valencia *(2016)*

Corrections based on limited feedback to JEFF-3.1.1



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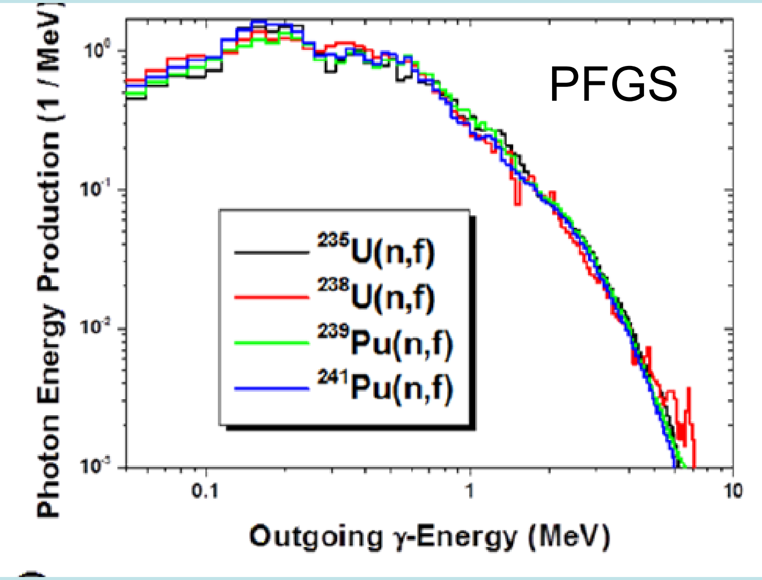
JEFF-3.3 Gamma yields

- Prompt fission (Serot)
- Capture (Perry, Noguere, Serot)
- Inelastic (Jouanne)



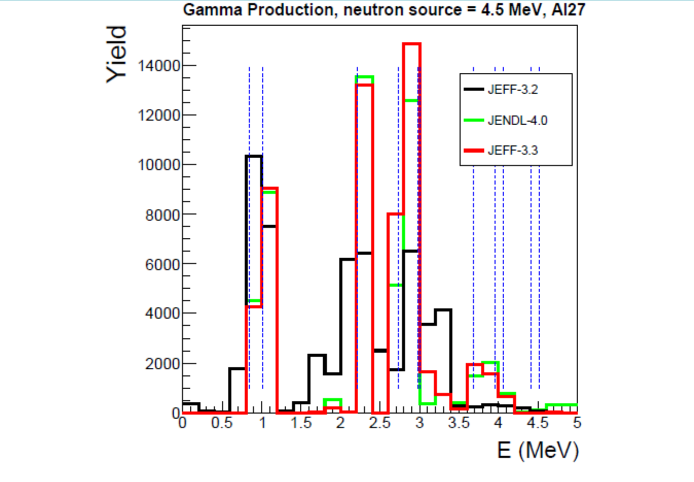
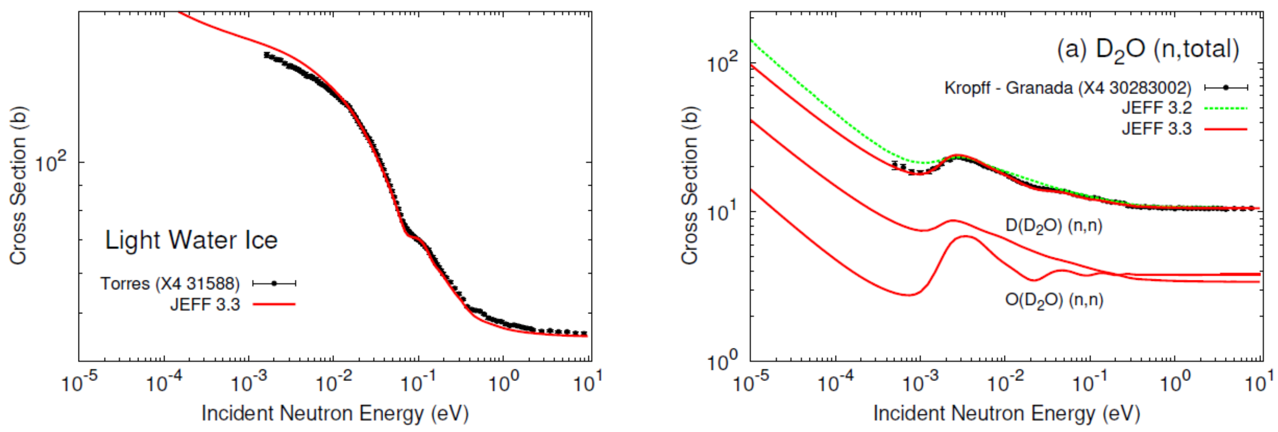


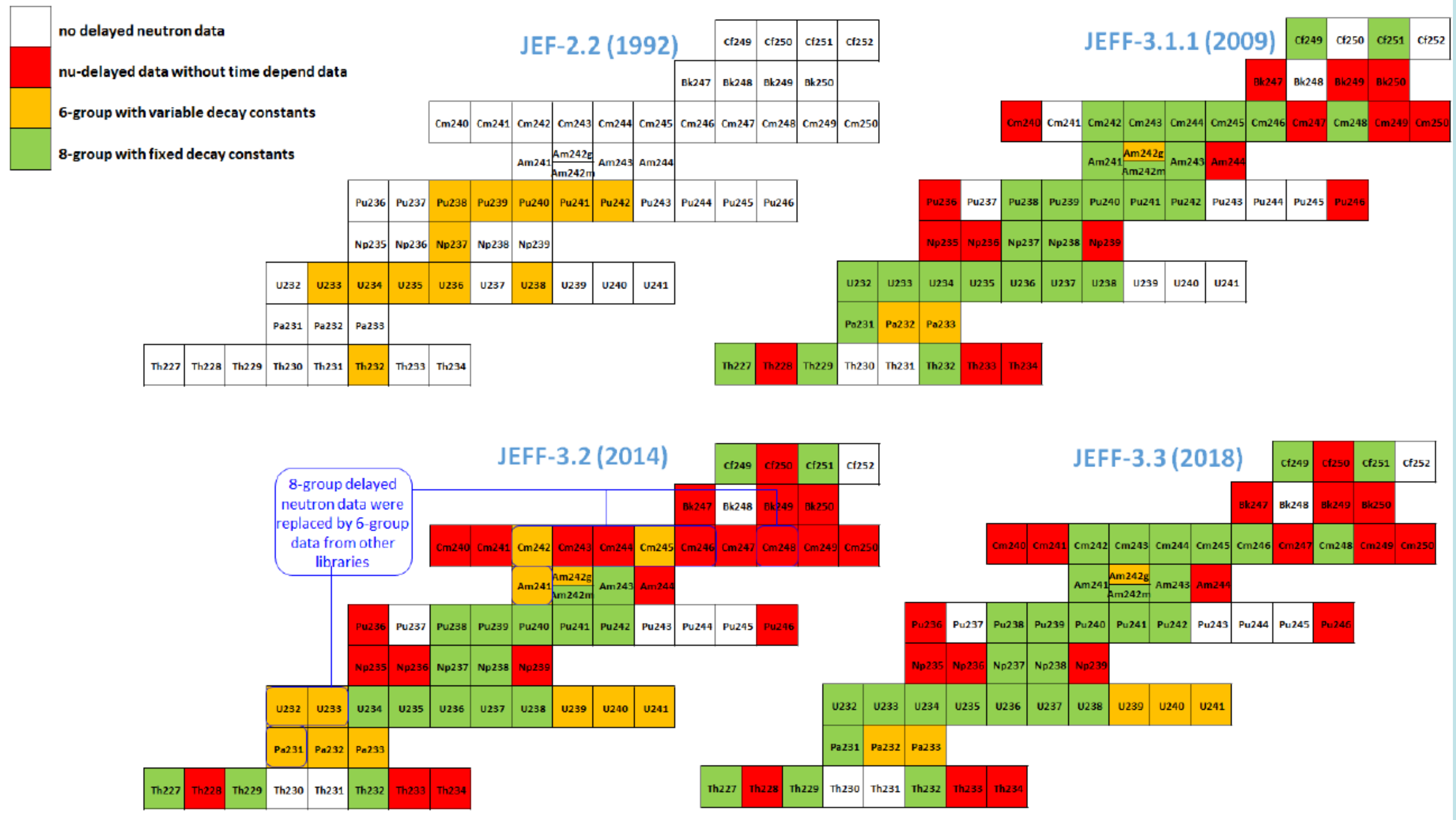
Fig. 71: Monte-Carlo simulations of gamma spectra from Al-27 inelastic scattering with 4.5 MeV neutrons, with excited level energies of Al-27 shown in blue.

Thermal scattering

- 20 files, 14 new, first covariances for H in H_2O.
- Cantargi, Granada, Marquez Damian
  - D in D_2O, Ortho D_2, Para D_2
  - H in ice, mesitylene, Ortho H_2, Para H_2, toluene
  - O-16 in D_2O, Al_2O_3
  - Al in $Al2O_3$
  - Si in Si
- Mg in Mg (Mounier)
- H in CaH_2, Ca in CaH_2 (Serot)
- Keinert, Mattes
  - H in H_2O, CH_2, ZrH (Keinert, Mattes)
  - Be in Be (Keinert, Mattes)
  - C in graphite (Keinert, Mattes)

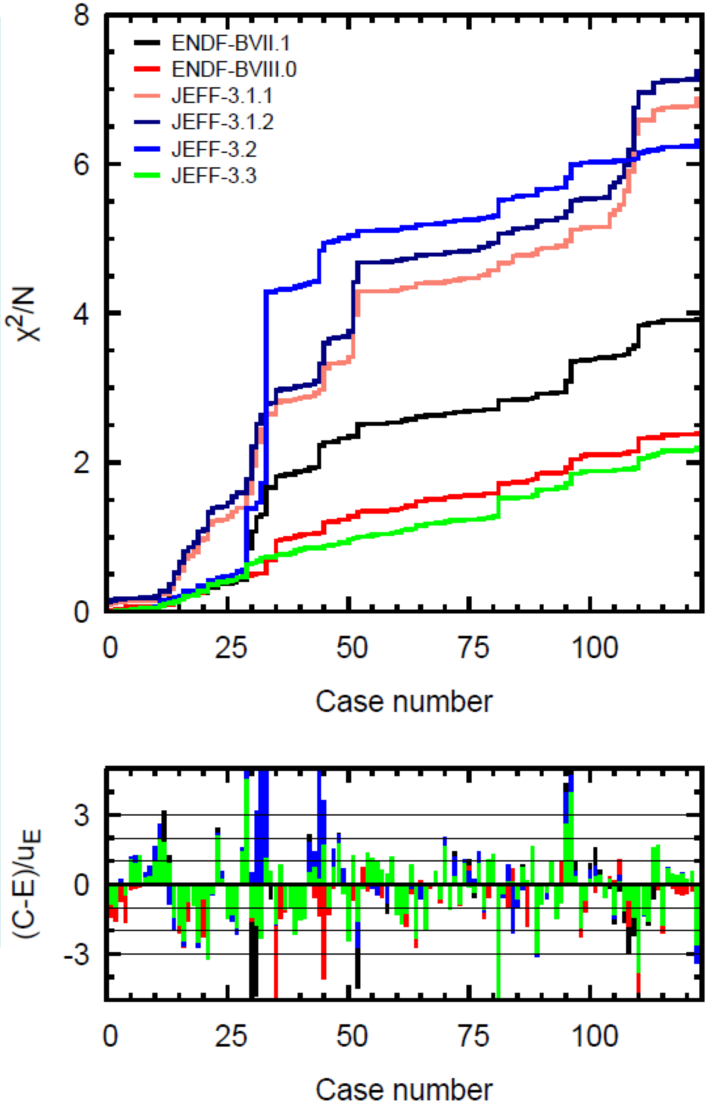


Delayed neutrons – 8 groups structure

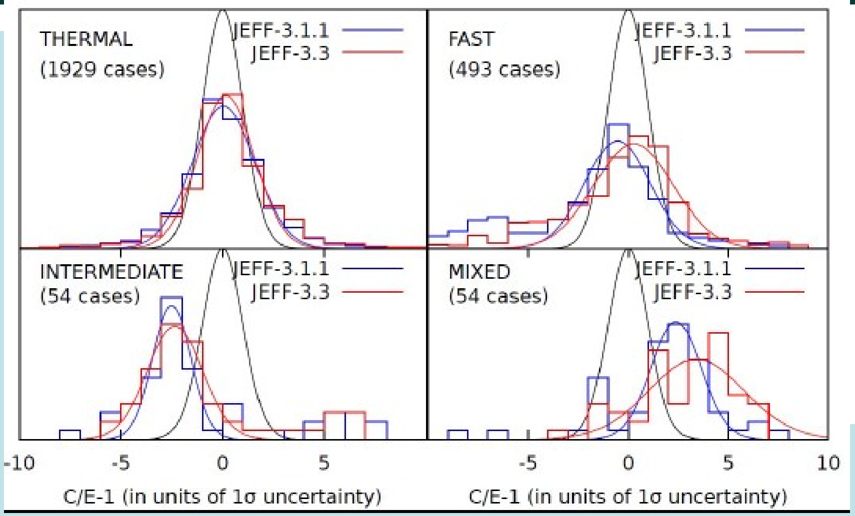


Benchmarking

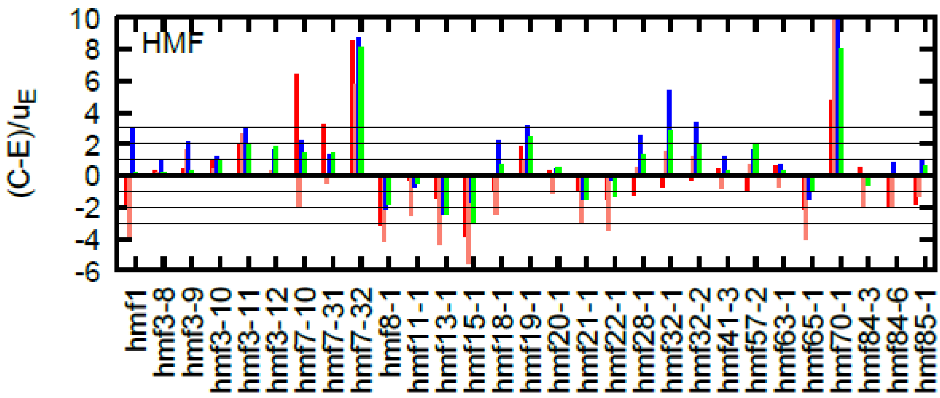
NEA-Mosteller

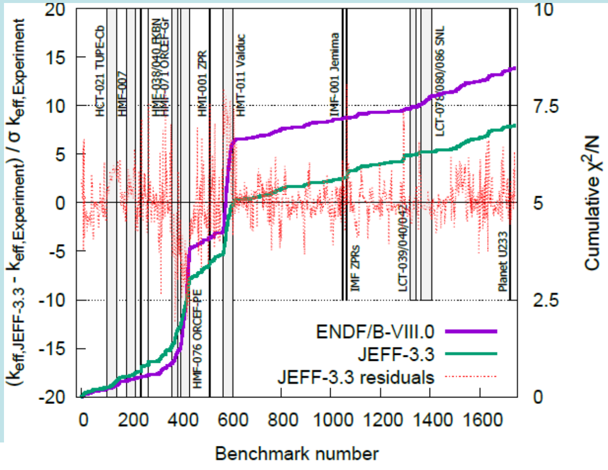


NRG - Van der Marck



IRSN - Leclaire





Trkov - Fleming

JEFF-3.3 is considerably better than JEFF-3.2 and JEFF-3.1.1&2

JEFF-3.3 is comparable to ENDF/B-VIII.1

Distributions over benchmarks are strongly affected by outliers

Leads to a non-Gaussian distribution!

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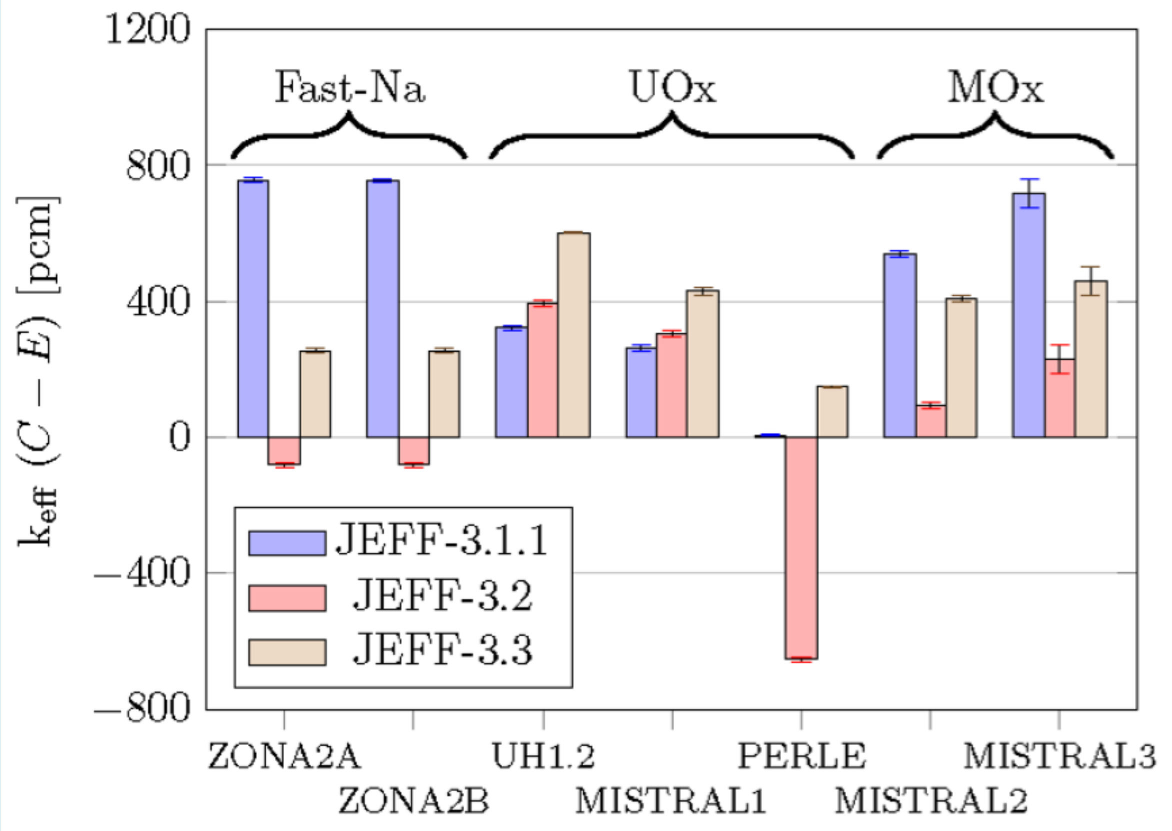
Outlier analysis

- NEA+IRSN suite implied materials other than actinides (2-3s and **>3s**)
- The remainder of outliers (16 out of 45) are **actinide+water+oxygen** only.
- IAEA suite: 1/3 of cases is an outlier > 2s. Many due to small benchmark unc.
- PE, Be/BeO, F, Al, concrete, S, steel, Cu, Er, W, Pb, Th
- (D2O, C, Hf, Np) … (Gd, Cr).

- Most important remain the major actinides

mat.	N	Cases
PE	2	**lmt5-1**, pmf31-1
D_2O	1	hst20-5
Be&BeO	5	hmf9-2, **hst46-1**, **pmf21-2**, **hmf38-1**, **hci4-1**
C	3	hmf19-1, hmi6-3, hst46-1
F	2	**hmf7-32**, hst20-5
Al	3	**hmf70-1**, imf6-1, **lmt5-1**
concrete	1	**hst7-1**
S	1	**hst46-1**
Steel	4	hmf13, hmf7-1, lct34-17, **hmi1-1**
Cu	2	**hmf73**, hmi6-1
Er	1	**lmt5-1**
Hf	1	lct29-8
W	2	**umf4-2**, **hmf70-1**
Pb	5	hmf57-2, **lct27-1 to** -4,
Th	1	**pmf8-1**
Np	1	smf8-1

Additional critical experiments



VENUS-F

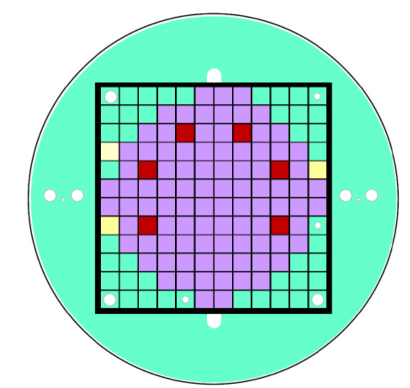
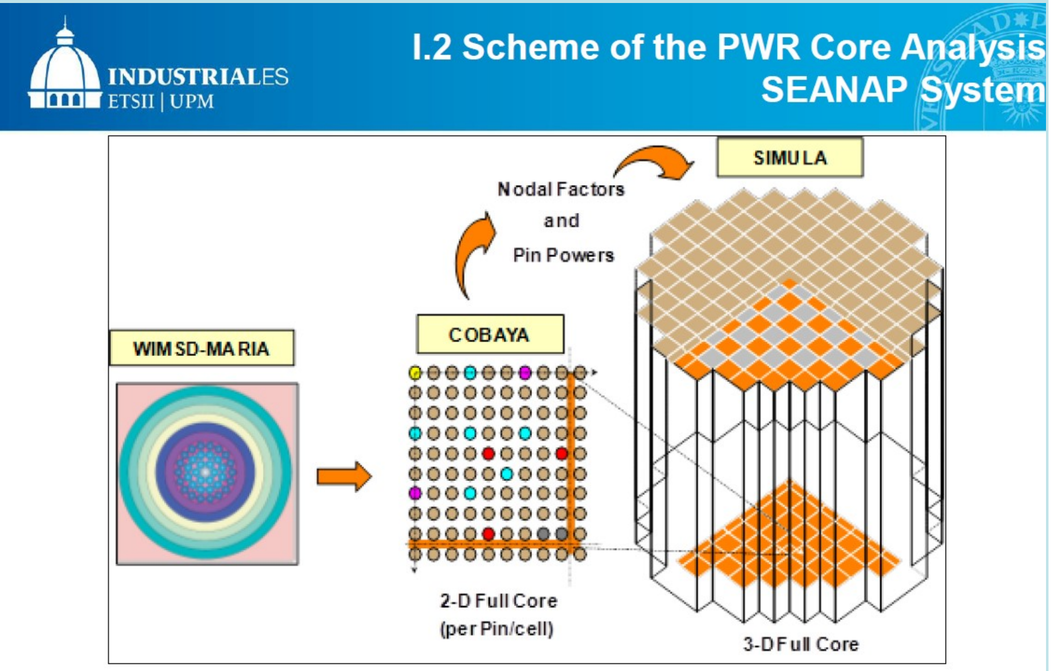


Table 32: Calculated k_{eff} -values for the VENUS-F CR0 core. The statistical uncertainty of the calculated values is less than 5 pcm.

library	k_{eff}	library	k_{eff}
JEFF-3.1.2	1.0059	JENDL-4.0	1.0031
JEFF-3.2	1.0083	ENDF/B-VII.1	1.0069
JEFF-3.3	1.0073	ENDF/B-VIII.0	1.0054

Application to PWR – UPM – SEANAP

Boron concentration and axial offset



SEANAP: WIMS-D4 (ND-1981+some updates (e.g. Gadolinium)) + COBAYA + SIMULA

			Boron concentration (ppm)		Axial Offset (%)		
Power (%)	Burnup (GWd/tM)	Meas. (ppm)	SEANAP Original Calculated (ppm)	SEANAP Upgraded Calculated (ppm)	Meas. (%)	SEANAP Original Calculated (%)	SEANAP Upgraded Calculated (%)
50	0.015	1200	1150	1165	7.7	5.6	5.9
75	0.031	1113	1071	1085	3.8	3.7	3.9
100	0.134	985	1000	1011	-0.7	0.7	0.8
100	1.34	870	897	896	-1.6	-1.2	-1.2
100	2.487	779	806	797	-2.4	-2.9	-2.9
100	2.842	755	778	768	-2.8	-3	-3.1
100	3.591	688	714	701	-3.8	-4.9	-5
100	4.441	604	645	629	-3.2	-3.8	-3.9
100	5.549	504	544	526	-3.9	-4.4	-4.6
100	6.692	412	439	420	-4.2	-4.4	-4.5
100	7.716	319	340	321	-4.7	-5.1	-5.2
100	8.823	227	239	219	-3.6	-2.8	-2.8
100	10.284	101	100	79	-3.5	-1.6	-1.5
100	11.351	4	-7	-29	-3.4	-2.1	-2.1

- JEFF-3.3 does very well when applied to an actual PWR code system

Delayed neutron testing

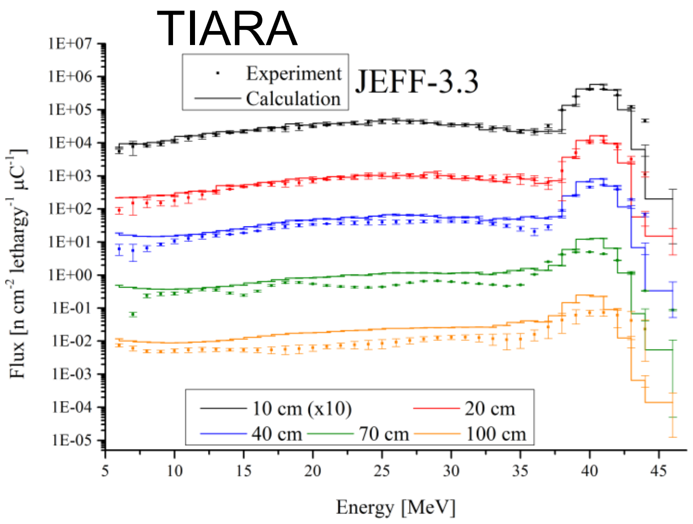
- Beta-eff versus 20 cases in literature and VENUS-F
- JEFF-3.3 comes out well (JEFF-3.1.1 somewhat better)

	Experiment β_{eff}		JEFF 3.3	JEFF 3.1.1
TCA	771	(2.2%)	2.3±0.8	3.9±0.7
IPEN/MB01	742	(0.9%)	4.2±0.9	4.6±1.0
Masurca/R2	721	(1.5%)	2.1±1.1	2.9±1.1
Masurca/ZONA2	349	(1.7%)	2.6±1.7	1.1±1.7
FCA/XIX-1	742	(3.2%)	3.0±1.2	3.6±1.2
FCA/XIX-2	364	(2.5%)	3.3±1.6	3.8±1.6
FCA/XIX-3	251	(1.6%)	4.4±1.9	-1.2±2.0
SNEAK/9C1	758	(3.2%)	-1.8±1.1	-0.8±1.1
SNEAK/7A	395	(5.1%)	1.0±1.5	-1.0±1.5
SNEAK/7B	429	(4.9%)	3.5±1.4	3.7±1.3
SNEAK/9C2	426	(4.5%)	-4.9±1.5	-5.4±1.5
ZPR-9/34	667	(2.2%)	0.7±2.2	4.2±2.2
ZPR-U9	725	(2.3%)	2.6±1.9	0.8±1.9
ZPPR-21/B	381	(2.4%)	-8.9±2.3	-4.5±2.2
ZPR-6/10	222	(2.3%)	5.9±3.8	3.9±0.7
Godiva	659	(1.5%)	0.3±1.1	-1.7±1.1
Topsy	665	(2.0%)	4.1±1.0	2.4±1.0
Jezebel	194	(5.2%)	-3.1±1.6	-1.0±1.6
Popsy	276	(2.5%)	7.6±1.7	4.3±1.4
Skidoo	290	(3.4%)	0.7±1.4	1.7±1.4
Flattop	360	(2.5%)	3.1±1.3	4.2±1.3

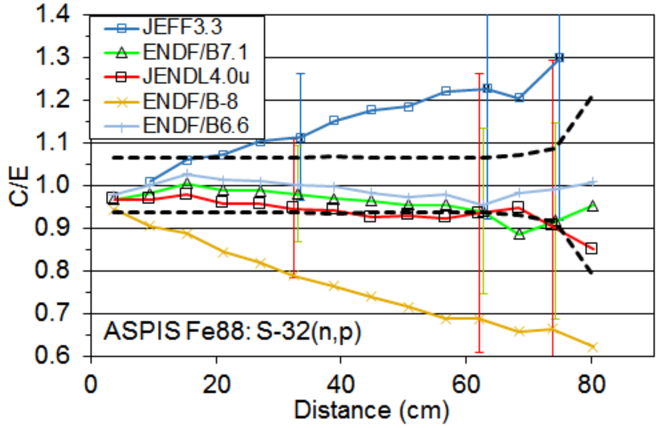
	Experiment Rossi$-\alpha$		JEFF 3.3	JEFF 3.1.1
SHE/core8	6.53e-3	(5.2%)	-1.5±1.0	-3.5±1.0
Sheba-II	200.3e-6	(1.8%)	-4.4±1.4	4.7±1.4
Stacy/run-029	122.7e-6	(3.3%)	-2.9±1.2	3.5±1.2
Stacy/run-033	116.7e-6	(3.3%)	-0.6±1.2	0.2±1.2
Stacy/run-046	106.2e-6	(3.5%)	-0.1±1.1	0.7±1.1
Stacy/run-030	126.8e-6	(2.3%)	-1.1±1.2	0.9±1.2
Stacy/run-125	152.8e-6	(1.7%)	-4.1±1.2	3.2±1.2
Stacy/run-215	109.2e-6	(1.6%)	-4.6±1.1	0.0±1.2
Winco	1109.3e-6	(0.1%)	-4.4±1.0	0.7±1.0
Big Ten	117.0e-6	(0.9%)	0.1±1.4	-0.3±1.5

library	β_{eff}	library	β_{eff}
JEFF-3.1.2	730	JENDL-4.0	724
JEFF-3.2	733	ENDF/B-VII.1	727
JEFF-3.3	729	ENDF/B-VIII.0	727
Experiment	730(11)		

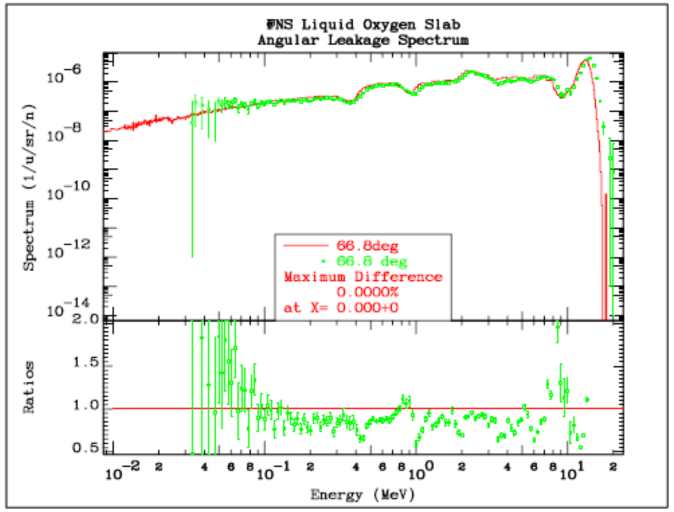
Cross section validation using shielding benchmarks from SINBAD Ivo Kodeli I443



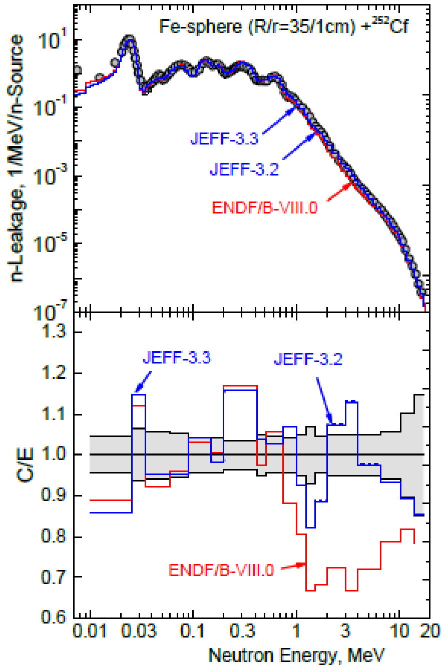
ASPIS IRON-88

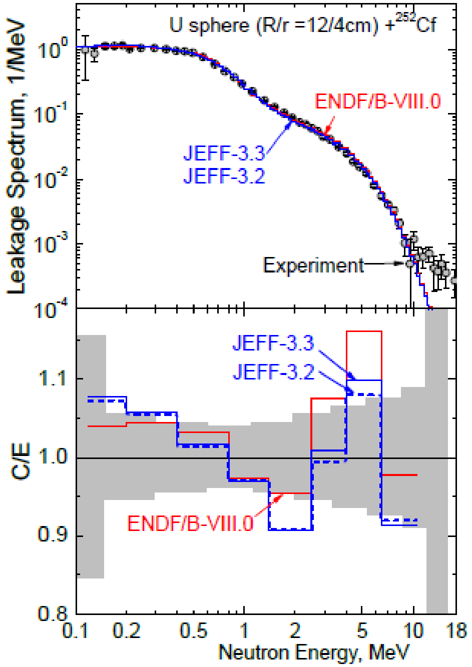


FNS Oxygen



Cf-252 leakage spectra Fe and U - IPPE





Decay Heat, Pu-239 & Inconel-600 examples

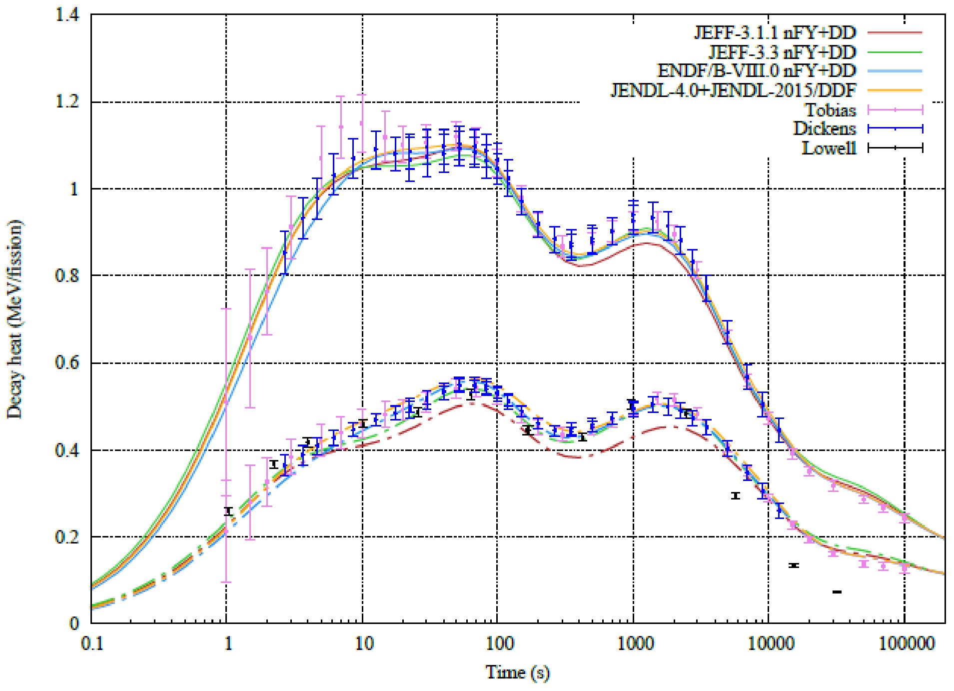


Fig. 98: Total and gamma fission decay heat pulse for ^{239}Pu, showing simulations with a range of nuclear data files, as calculated by FISPACT-II. Note the significant under-prediction of gamma heat for JEFF-3.1.1, over a range of cooling periods from 10 to 2000 seconds.

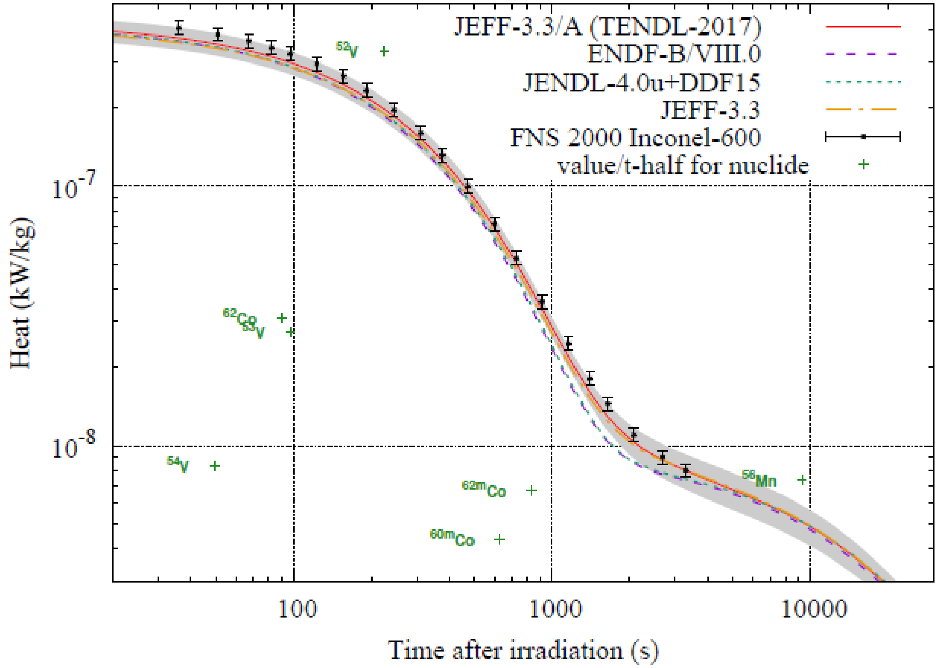


Fig. 100: Decay heat simulations and measurements from the JAEA Fusion Neutron Source, considering Inconel-600 irradiation and the most recent nuclear data libraries. Dominant nuclides are labeled at (x,y) coordinates that are their half-life and post-irradiation quantity, respectively.

JEFF-4.0

- We want JEFF-4 to be a fundamental change
- Best knowledge for users – best physics
- Completeness – large reliance on TALYS and TENDL
- Agreed ways of integrating contributions
- Version and documentation control
- Use modern tools for inspection and checking
- Use modern tools for benchmarking and validation
- Eliminate limitations (formats, correlated emissions)
- Method development 2018-2020
- JEFF-4 development 2021-2024

JEFF Stakeholders meeting

- Focus on applications side
    - Accelerator applications
    - Advanced reactors
    - Running power plants
    - Waste storage at various stages
    - Reprocessing and conditioning
    - Long term storage/final repositories
    - Transport
- Medical and dosimetry (not in the meeting)

Cooperation

- JEFF values output of EU projects contributing (to) new evaluations
- JEFF wants to be up-to-date on new data for evaluations
- Joint meetings
- Follow the model of the EU fusion projects? They meet at JEFF meetings in parallel sessions and contribute to plenary sessions. They store their documents on the JEFF webpage at the OECD-NEA.
- Involvement in the organization of SANDA and ARIEL

Remarks

- Meeting schedule
  - Separate scientific/technical meetings from project administration meetings.
  - Scientific/technical meetings only on content, possibly with one overview presentation of project/status.
  - Executive Committee meetings deal with project administration by VC or otherwise.
  - Only remaining concern is when we need Governing Board decision (attach half day to sci.meeting).
  - For good project organization we should fix the meeting schedule now. This could simply be done annually.
- Mailing list
  - We need a server that automatically forwards to the correct mailing list
  - Participants should complete the mailing list to meet their needs
  - NEA has this set up for JEFF, …, so has the competence.