UPM contribution to WPEC/SG47

Oscar Cabellos
Universidad Politécnica de Madrid (UPM), Spain
oscar.cabellos@upm.es

INDUSTRIALES
ETSII | UPM

Outline

UPM aims to contribute to WPEC/SG47 in two objectives …

1. Collection of TOF Shielding Benchmarks for Nuclear Data validation

" … To participate in establishing the priority list of relevant benchmarks according to the needs of the nuclear data community, in particular among new and more recent benchmarks…"

2. Sensitivity Analysis in LLNL pulsed spheres

"… promote including the selected benchmarks in SINBAD;

contribute the available sensitivity profiles to be included in the database;"

1. TOF Shielding Benchmarks for Nuclear Data validation

- Ref: ***"JEFF/DOC-1852. Testing JEFF-3.3T3 in TOF Shielding Benchmarks",* K. Takise, O. Cabellos, April 24-27, 2017**

Testing JEFF-3.3T2/T3 (and other evaluations) in TOF Shielding Benchmarks

- FNS
- Oktavian
- MCNP6 shielding suite

References:

1. *JEFF/DOC1852. Testing JEFF-3.3T3 in TOF Shielding Benchmarks, K. Takise, O. Cabellos, April 24-27, 2017*
2. *SINBAD, DVD, 2016*
3. *F. Maekawa et al., "Collection of Experimental Data for Fusion Neutronics Benchmark", JAERI, 1994.*
4. *F. Maekawa et al., "Compilation of Benchmark Results for Fusion Related Nuclear Data", JAERI, 1998.*
5. *IAEA, "FENDEL-2 Benchmarks Sublibrary" [https://www-nds.iaea.org/fendl2/validation/benchmarks/jaerim94014/fns-tof/] (Accessed on 2017/April/19)*
6. *U. Fischer et al., "Benchmarking of the FENDL-3 Neutron Cross-Section Data Library for Fusion Applications", IAEA, 2014.*
7. *Russell D. Mosteller, "Validation Suites for MCNP", American Nuclear Society, for presentation at its 12th Biennial RPSD Topical Meeting (Santa Fe, April 14-17, 2002)*

2. TOF Shielding Benchmarks and materials in JEFF/DOC-1852

Z	Material	FNS_TOF	MCNP6 Shielding Suite	Oktavian
3	Li		X	
4	Be	X	X	
6	Graphite	X	X	
7	N2	X	X	
8	O2	X		
13	Al			X
14	Si			X
22	Ti			X
24	Cr			X
25	Mn			X
26	Fe	X	X	
27	Co			X
29	Cu			X
33	As			X
34	Se			X
40	Zr			X
41	Nb			X
42	Mo			X
74	W			X
82	Pb	X	X	
92	U235, U238		X	
94	Pu239		X	

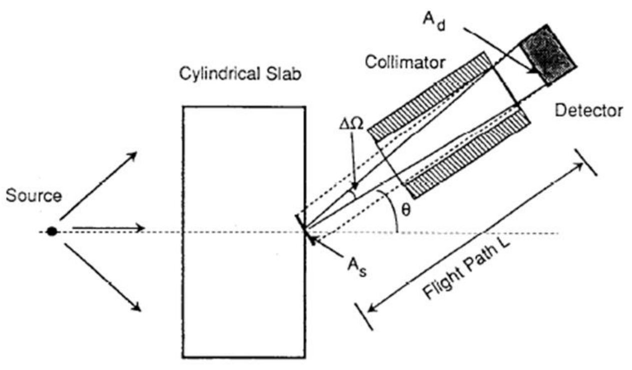
(23 elements and/or isotopes)

Compounds	FNS_TOF	MCNP6 Shielding Suite	Oktavian
Li2O	X		
Iron duct		X	
Iron duct+SS304		X	
Iron duct+SS304+PE		x	
Concrete		X	
Water		x	
LiF			X
Teflon (CF2)			X

(8 compounds/media)

3. FNS-TOF Benchmarks (17 cases x 5 angles)

1. FNS/TOF



Detector was located to observe leakage neutrons from <u>cylindrical slabs</u> at several angles.

2. FNS/In-situ

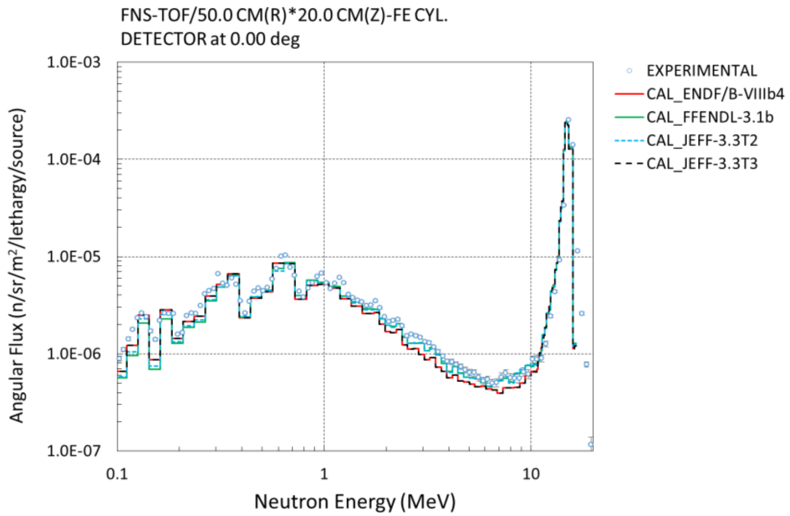
Detector was located inside of the slabs.

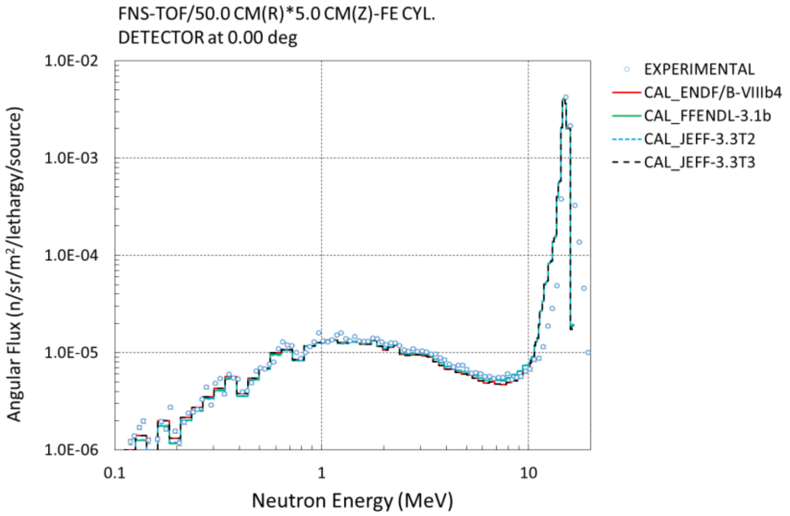
Geometry, materials		Detector Position
Beryllium	FNS-TOF/31.4 CM(R)*15.24 CM(Z)	Angle= 0.0 deg
	FNS-TOF/31.4 CM(R)*5.06 CM(Z)	Angle= 12.20 deg
Graphite	FNS-TOF/31.4 CM(R)*20.24CM(Z)	Angle= 24.90 deg
	FNS-TOF/31.4 CM(R)*40.48CM(Z)	Angle= 41.80 deg
	FNS-TOF/31.4 CM(R)*5.06CM(Z)	Angle= 66.80 deg
Iron	FNS-TOF/50.0 CM(R)*20.0 CM(Z)-Iron	
	FNS-TOF/50.0 CM(R)*40.0 CM(Z)-Iron	
	FNS-TOF/50.0 CM(R)*5.0 CM(Z)-Iron	
	FNS-TOF/50.0 CM(R)*60.0 CM(Z)-Iron	
Li2O	FNS-TOF/31.4 CM(R)*20.0 CM(Z)-Li2O	
	FNS-TOF/31.4 CM(R)*40.0 CM(Z)-Li2O	
	FNS-TOF/31.4 CM(R)*4.8 CM(Z)-Li2O	
N2	FNS-TOF/ N2 SLAB-TOF	
O2	FNS-TOF/ LO2 SLAB-TOF	
Lead	FNS-TOF/31.4 CM(R)*20.32CM(Z)-Lead	
	FNS-TOF/31.4 CM(R)*40.64CM(Z)-Lead	
	FNS-TOF/31.4 CM(R)*5.06CM(Z)-Lead	

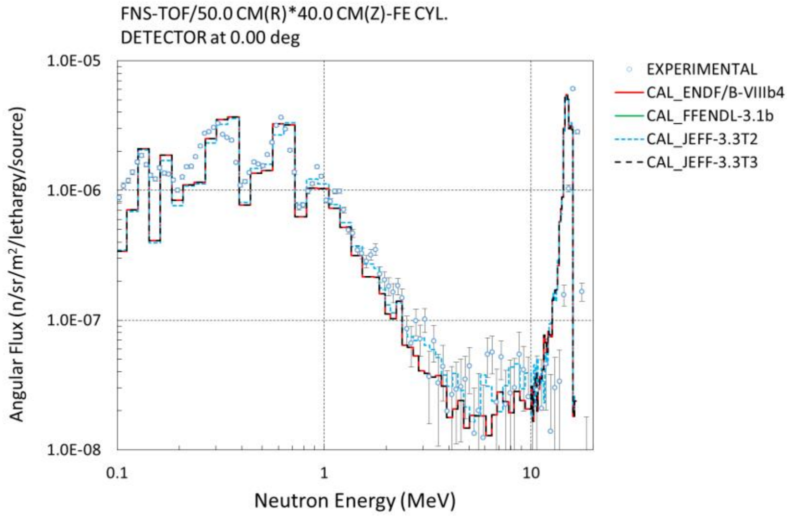
Ref. F. Maekawa et al., "Collection of Experimental Data for Fusion Neutronics Benchmark", JAERI, 1994.

3.1 FNS-TOF Benchmarks for Iron

Figures. Results obtained for the **<u>Fe (iron)</u>** ToF-experiment at FNS showing angular neutron leakage spectra for thick slabs <u>at 0 degrees</u>







3.2 FNS-TOF Benchmarks for Iron

INDUSTRIALES
ETSII | UPM

FNS-TOF/50.0 CM(R)*5.0 CM(Z)-Iron

Angle= 0 deg	ENDF/B-VIIIb4	FENDL-3.1b	JEFF-3.3T2	JEFF-3.3T3
10 MeV < E < 16 MeV	0.95	0.95	**0.95**	0.95
5 MeV < E < 10 MeV	0.93	1.01	**1.02**	0.93
1 MeV < E < 5 MeV	0.95	0.96	**0.96**	0.95
0.5 MeV < E < 1 MeV	0.96	0.94	**0.93**	0.96
0.1 MeV < E < 0.5 MeV	1.06	1.00	**1.00**	1.06

Angle= 24.90 deg	ENDF/B-VIIIb4	FENDL-3.1b	JEFF-3.3T2	JEFF-3.3T3
10 MeV < E < 16 MeV	1.20	1.26	1.27	1.20
5 MeV < E < 10 MeV	0.95	0.98	1.00	0.95
1 MeV < E < 5 MeV	0.92	0.95	0.95	0.92
0.5 MeV < E < 1 MeV	1.03	0.99	1.00	1.03
0.1 MeV < E < 0.5 MeV	1.23	1.09	1.12	1.23

Angle= 41.80 deg	ENDF/B-VIIIb4	FENDL-3.1b	JEFF-3.3T2	JEFF-3.3T3
10 MeV < E < 16 MeV	0.77	0.83	0.82	0.77
5 MeV < E < 10 MeV	0.84	0.85	0.86	0.84
1 MeV < E < 5 MeV	0.89	0.91	0.91	0.89
0.5 MeV < E < 1 MeV	1.02	0.98	0.99	1.02
0.1 MeV < E < 0.5 MeV	1.20	1.07	1.09	1.20

Angle= 66.80 deg	ENDF/B-VIIIb4	FENDL-3.1b	JEFF-3.3T2	JEFF-3.3T3
10 MeV < E < 16 MeV	0.62	0.59	0.58	0.62
5 MeV < E < 10 MeV	0.74	0.74	0.75	0.74
1 MeV < E < 5 MeV	0.87	0.90	0.89	0.87
0.5 MeV < E < 1 MeV	0.95	0.91	0.91	0.95
0.1 MeV < E < 0.5 MeV	1.00	0.90	0.91	1.00

FNS-TOF/50.0 CM(R)*40.0 CM(Z)-Iron

Angle= 0 deg	ENDF/B-VIIIb4	FENDL-3.1b	JEFF-3.3T2	JEFF-3.3T3
10 MeV < E < 16 MeV	0.95	0.96	**0.94**	0.95
5 MeV < E < 10 MeV	0.65	0.97	**0.93**	0.65
1 MeV < E < 5 MeV	0.96	1.15	**1.08**	0.96
0.5 MeV < E < 1 MeV	1.01	1.10	**1.02**	1.01
0.1 MeV < E < 0.5 MeV	0.96	0.94	**0.93**	0.96

Angle= 24.90 deg	ENDF/B-VIIIb4	FENDL-3.1b	JEFF-3.3T2	JEFF-3.3T3
10 MeV < E < 16 MeV	0.93	0.92	0.95	0.93
5 MeV < E < 10 MeV	0.80	0.97	0.94	0.80
1 MeV < E < 5 MeV	0.95	1.15	1.11	0.95
0.5 MeV < E < 1 MeV	0.98	1.07	1.01	0.98
0.1 MeV < E < 0.5 MeV	0.97	0.96	0.96	0.97

Angle= 41.80 deg	ENDF/B-VIIIb4	FENDL-3.1b	JEFF-3.3T2	JEFF-3.3T3
10 MeV < E < 16 MeV	0.86	0.81	0.87	0.86
5 MeV < E < 10 MeV	0.42	0.46	0.46	0.42
1 MeV < E < 5 MeV	0.86	1.07	1.02	0.86
0.5 MeV < E < 1 MeV	0.93	1.02	0.97	0.93
0.1 MeV < E < 0.5 MeV	0.91	0.90	0.91	0.91

Angle= 66.80 deg	ENDF/B-VIIIb4	FENDL-3.1b	JEFF-3.3T2	JEFF-3.3T3
10 MeV < E < 16 MeV	0.67	0.63	0.63	0.67
5 MeV < E < 10 MeV	0.00	0.00	0.00	0.00
1 MeV < E < 5 MeV	0.74	0.94	0.88	0.74
0.5 MeV < E < 1 MeV	0.87	0.97	0.92	0.87
0.1 MeV < E < 0.5 MeV	0.84	0.82	0.85	0.84

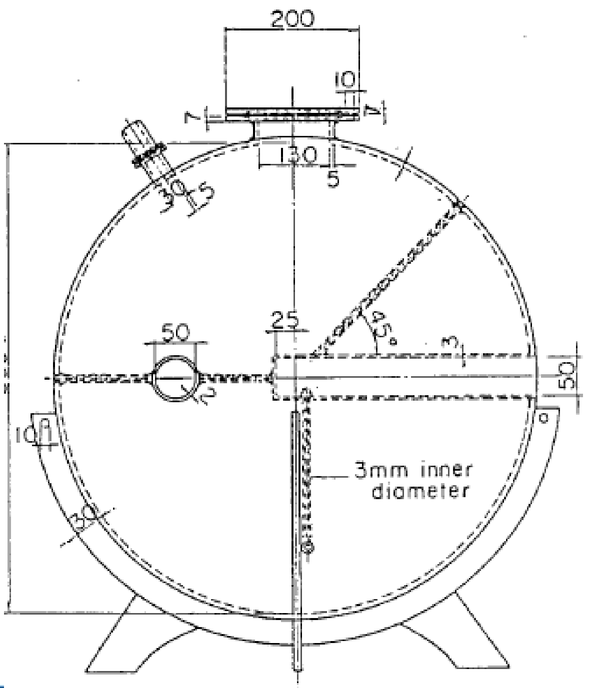
3.3 Conclusion for FNS-TOF Benchmarks

Material	Conclusion FENDL report	Our conclusion
Be	*"All calculations reproduce very well"*	JEFF-3.3 T2 and T3 underestimate from 5-10 MeV
Graphite	*"All calculations reproduce very well"*	Large differences between FENDL-31b and JEFF-3.3 T2/T3 at high angles for 50 mm and 200mm below 1 MeV
Fe	*"50 and 200 mm assemblies: all calculations very well above 0.1 MeV, 400 and 600 mm assemblies: less good agreement below 1 MeV"*	*Slightly better agreement in T2*
Li_2O	*"All calculations reproduce very well"*	T2 and T3 similar to FENDL/3.1b
N_2	*""All calculations reproduce very well except for the angle 66.6 deg"*	T2 and T3 similar to FENDL/3.1b
O_2	*"All calculations underestimate at larger angles"*	*Slightly better agreement in T3*
Pb	*"All calculations reproduce very well except for JENDL-4.0 which, at the neutron energy around 10 MeV, produces a smaller peak than the measured one"*	Better T2/T3

Ref: *U. Fischer et al., "Benchmarking of the FENDL-3 Neutron Cross-Section Data Library for Fusion Applications", IAEA, 2014 (https://www-nds.iaea.org/publications/indc/indc-nds-0631/)*

4. OKTAVIAN TOF Benchmarks (15 cases)

Neutron leakage from OKTAVIAN pulsed sphere
Ex) 61 cm sphere: Type I

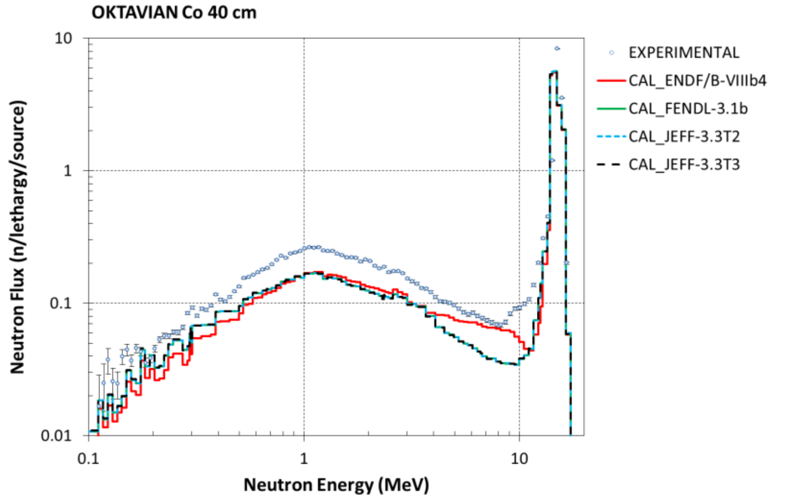


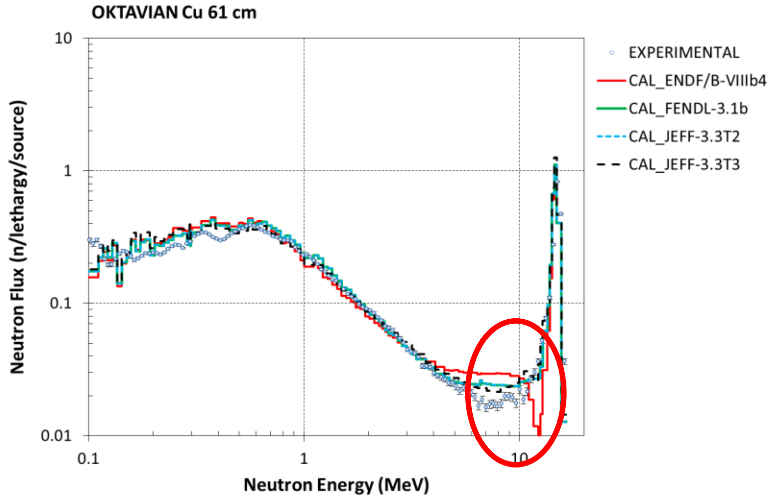
Geometry	Type-I 61 cm diameter vessel	Type-II 40 cm diameter vessel	Type-III 60 cm diameter vessel	Type –IV 28 cm diameter vessel
	Cu	Al	Si	Nb
	LiF	As		
	Mn	Co		
	Mo	Cr		
	Zr	Se		
		Teflon		
		Ti		
		W		

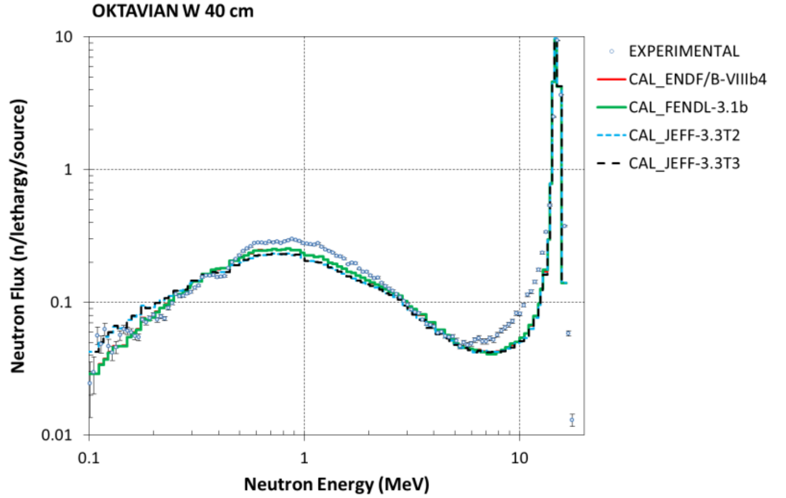
Neutron source spectra	
CASE 1 (Table 4.2)	LiF, Mn , Cu, Mo, W
CASE 2 (Table 4.3)	Teflon, Si, Co
CASE 3 (Table 4.4)	Al
CASE 4 (Table 4.5)	Ti, As, Se, Zr
CASE 5 (Table 4.6)	Cr, Nb

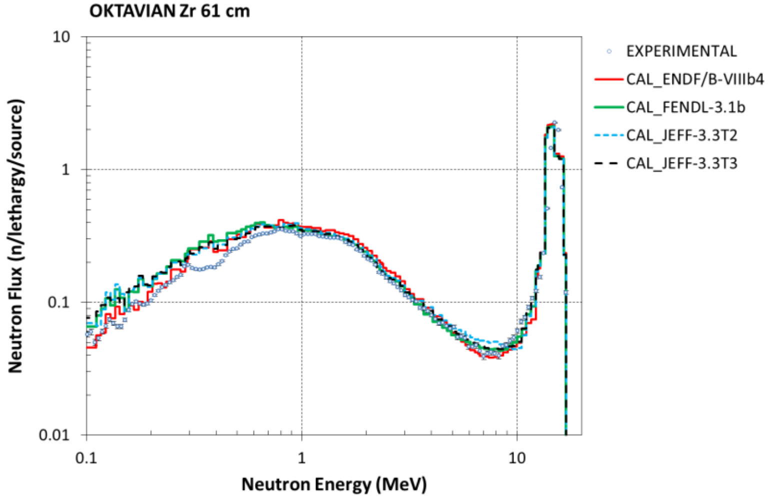
Ref.: F. Maekawa et al., "Collection of Experimental Data for Fusion Neutronics Benchmark", JAERI, 1994.

4.1 OKTAVIAN TOF Benchmarks









4.2 OKTAVIAN TOF Benchmarks

Table. <C>/<E> values

	ENDF/B-VIIIb4	FENDL-3.1b	JEFF-3.3T2	JEFF-3.3T3		ENDF/B-VIIIb4	FENDL-3.1b	JEFF-3.3T2	JEFF-3.3T3
	Oktavian Al-40 cm					Oktavian As-40 cm			
10 MeV < E < 16 MeV	1.01	1.01	1.01	1.01		0.82	-	0.83	0.83
5 MeV < E < 10 MeV	0.91	0.90	0.90	0.90		0.88	-	0.92	0.92
1 MeV < E < 5 MeV	0.91	0.91	0.91	0.91		1.22	-	1.14	1.14
0.5 MeV < E < 1 MeV	0.93	0.93	0.93	0.94		1.12	-	1.08	1.08
0.1 MeV < E < 0.5 MeV	1.41	1.38	1.38	1.41		1.23	-	1.27	1.27
	Oktavian Co-40 cm					Oktavian Cr-40cm			
10 MeV < E < 16 MeV	0.81	0.83	0.83	0.83		0.92	0.93	0.93	0.93
5 MeV < E < 10 MeV	0.89	0.55	0.55	0.55		1.18	1.06	1.07	1.07
1 MeV < E < 5 MeV	0.69	0.64	0.64	0.64		1.17	1.12	1.14	1.14
0.5 MeV < E < 1 MeV	0.58	0.61	0.61	0.62		1.15	1.25	1.23	1.23
0.1 MeV < E < 0.5 MeV	0.64	0.77	0.77	0.78		1.16	1.07	1.05	1.05
	Oktavian Cu-61cm					Oktavian LiF-61 cm			
10 MeV < E < 16 MeV	0.91	1.02	1.02	1.15		1.05	1.05	1.05	1.05
5 MeV < E < 10 MeV	1.58	1.31	1.31	1.28		0.87	0.88	0.88	0.87
1 MeV < E < 5 MeV	1.01	1.12	1.12	1.07		0.88	0.88	0.88	0.88
0.5 MeV < E < 1 MeV	0.99	1.01	1.01	0.93		0.67	0.65	0.67	0.67
0.1 MeV < E < 0.5 MeV	1.15	1.11	1.11	1.16		0.85	0.82	0.85	0.85

4.3 Conclusion for OKTAVIAN TOF Benchmarks

Material	Conclusion FENDL report	Our conclusion
Al	*“FENDL-3 is slightly better than FENDL-2.1 and JENDL-4”*	*All libraries showed similar results (0.5 – 10 MeV). Overestimation below 0.5 MeV*
As	-	*JEFF-3.3T2/T3 slightly better than ENDF/B-VIIIb4*
Co	*“FENDL-3 is the same as FENDL-2.1. The JENDL-4 is better than FENDL-3 (4 - 11 MeV)”*	*All libraries high underestimation*
Cr	*“FENDL-3 is better than FENDL-2.1 and JENDL-4 except for neutrons from 0.5 to 1 MeV for which FENDL-3 gives a larger overestimation”*	*All similar results. Overestimation from 0.5 to 1 MeV for ENDF/B-VIIIb4*
Cu	*“FENDL-3 is the same as FENDL-2.1. JENDL-4 is better than FENDL-3 (1 to 11 MeV)”*	*Slightly better T2=FENDL-3.1b. From 1 to 5 MeV overestimation, and large overestimation for ENDF/B-VIIIb4*
LiF	-	*All same results.*
Mn	*“FENDL-3 is better than FENDL-2.1 for neutrons above 1 MeV. Worse agreement is obtained for neutrons below 1 MeV”*	*JEFF-3.3T2/T3 overestimation 1MeV to 5 MeV*
Mo	*“FENDL-3 is better than FENDL-2.1 for neutrons from 0.5 to 10 MeV”*	*T2/T3 good agreement*

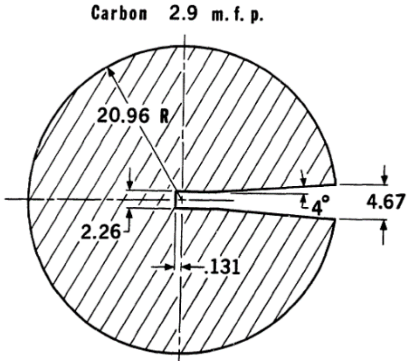
Ref: *U. Fischer et al., “Benchmarking of the FENDL-3 Neutron Cross-Section Data Library for Fusion Applications”, IAEA, 2014 (https://www-nds.iaea.org/publications/indc/indc-nds-0631/)*

5. MCNP6-TOF Suite (14 cases))

Leakage neutrons from

- FNS: <u>Cylindrical slab</u> Configuration
  1: Iron duct
  3: Duct + SS-304
  7: Duct + SS-304 + Polyethylene

- LLNL: <u>Pulsed sphere</u>



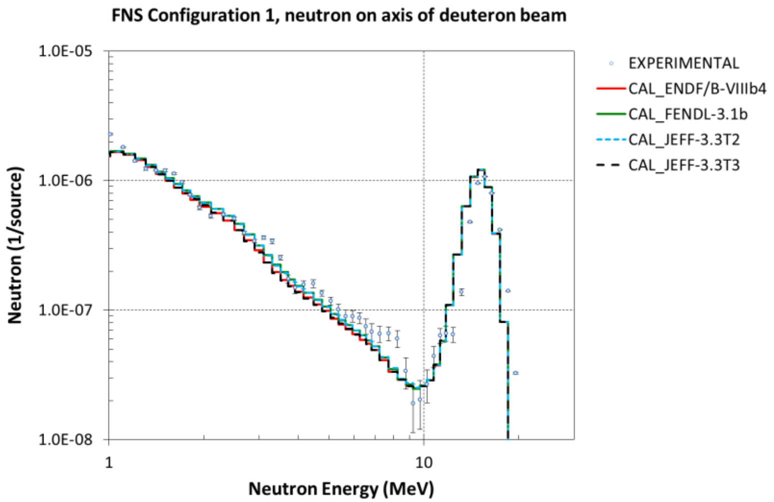
Geometry, FNS	
Fusion Spectra Problem Configuration 1 On Axis	
Fusion Spectra Problem Configuration 3 Off Axis	
Fusion Spectra Problem Configuration 7 On Axis	
LLNL pulsed spheres	
Beryllium	: 0.8 mfp, fwhm=4.0 ns, Pilot-B bias=1.6, FP=765.20 cm, 30-deg
Carbon	: 2.9 mfp, fwhm=4.0 ns, NE213-A bias=1.6, FP=766.00 cm, 30-deg
Concrete	: 2.0 mfp, fwhm=3.0 ns, NE213-A bias=1.6, FP=975.40 cm, 120-deg
Iron	: 0.9 mfp, fwhm=3.0 ns, NE213-A bias=1.6, FP=766.00 cm, 30-deg
Lead	: 1.4 mfp, fwhm=3.0 ns, NE213-A bias=1.6, FP=766.00 cm, 30-deg
Lithium	: 1.6 mfp, fwhm=4.0 ns, Pilot-B bias=1.6, FP=765.20 cm, 30-deg
Nitrogen	: 3.1 mfp, fwhm=4.0 ns, Pilot-B bias=1.6, FP=765.20 cm, 30-deg
Pu-239	: 0.7 mfp, fwhm=3.0 ns, NE213-A bias=1.6, FP=766.00 cm, 30-deg
U-235	: 0.7 mfp, fwhm=3.0 ns, NE213-A bias=1.6, FP=766.00 cm, 30-deg
U-238	: 0.8 mfp, fwhm=4.0 ns, Pilot-B bias=1.6, FP=765.20 cm, 30-deg
Water	: 1.9 mfp, fwhm=5.0 ns, Pilot-B bias=1.6, FP=754.00 cm, 30-deg

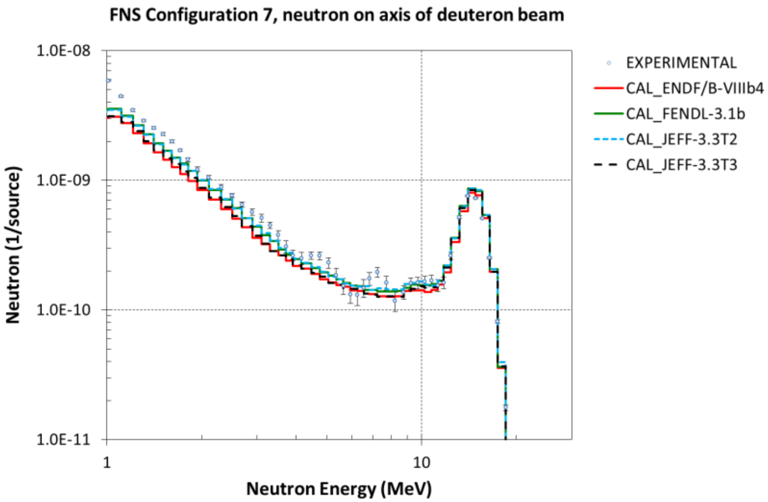
Ref. MCNP6 Benchmark suite

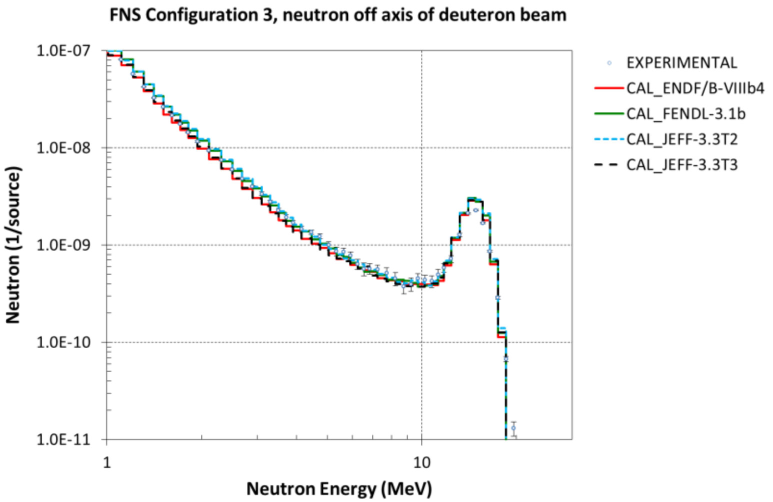
5.1 MCNP6-FNS Suite

Figure. Fusion Spectra Problem Configuration 1/3/7 - On/Off Axis

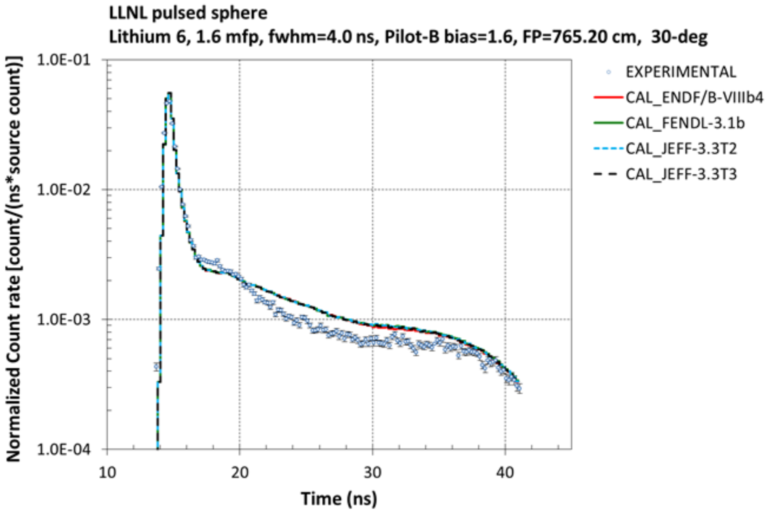
- FNS, FENDL-3.1b and JEFF-3.3T2 show slightly better agreement than ENDF/B-VIIIb4 and JEFF-3.3T3 (1 – 10 MeV)

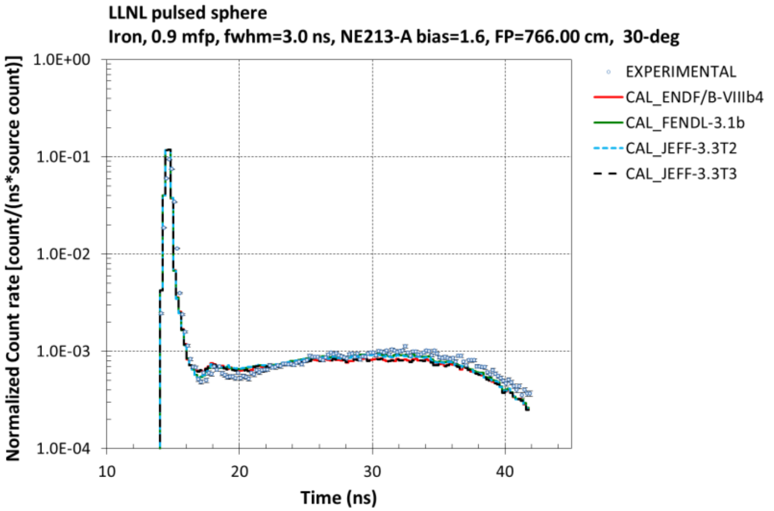


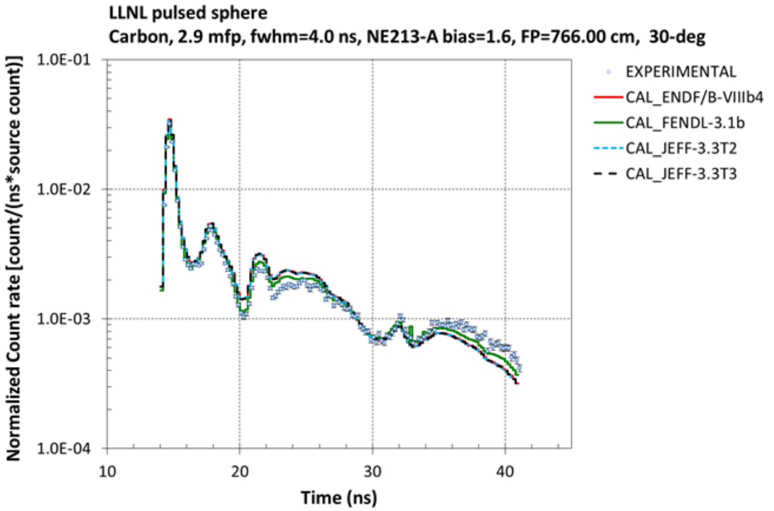


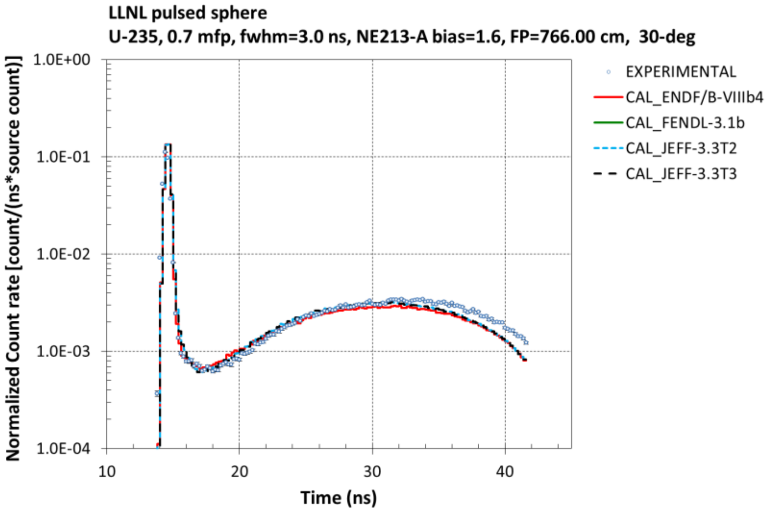


5.2 LLNL Pulsed Spheres









6. LLNL Pulsed sphere Transmission Integral Benchmarks

❑ LLNL-235U pulsed sphere

Calculations: MCNP6.1.1 and ^{235}U/TENDL2014 random files

- U-235, 0.7 mfp, fwhm=2.0 ns, NE213-B bias=1.6, FP=945.54 cm, 26-deg

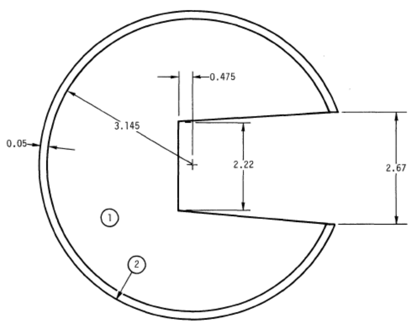
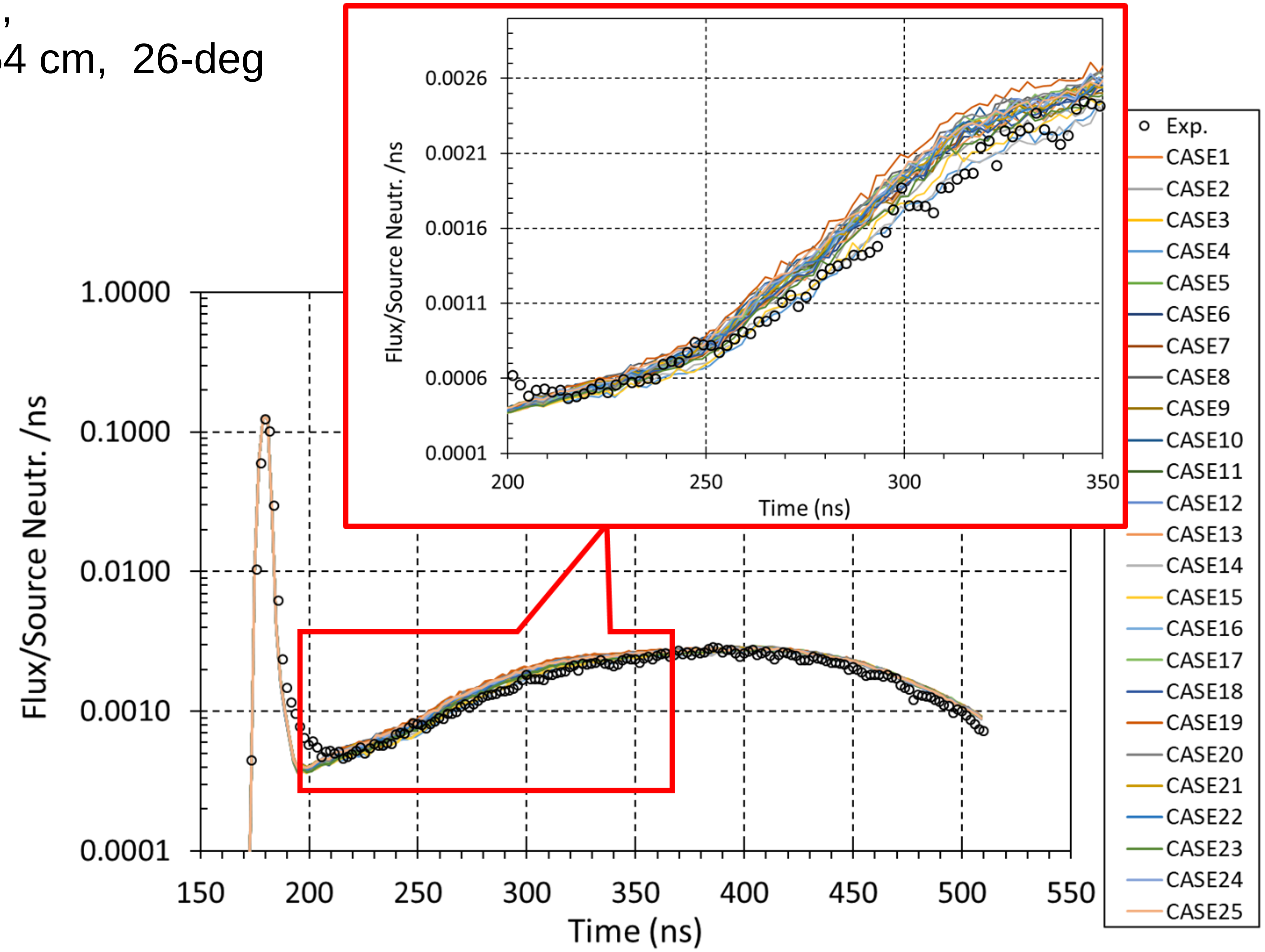


Fig. Dimensions of the small 235U solid spherical target , Report: LLNL UCID-17332

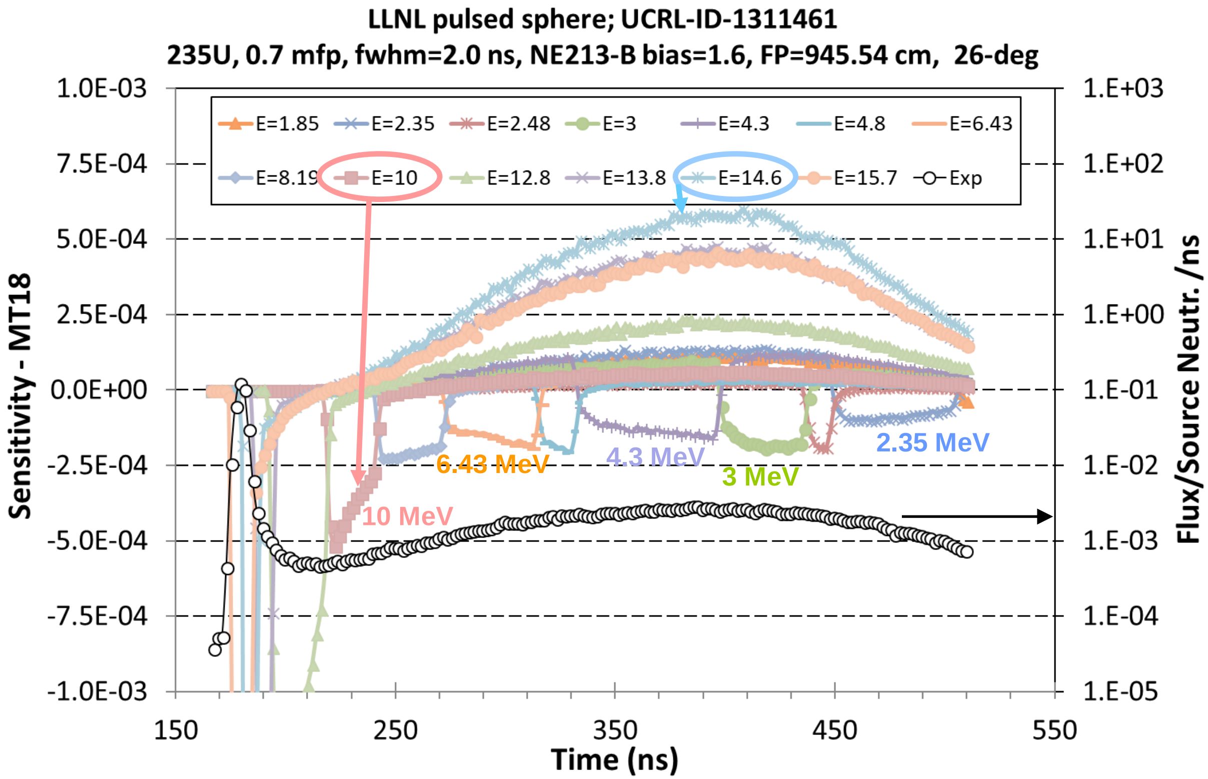


❑ Ref: *"Examples of Monte Carlo techniques applied for nuclear data uncertainty propagation"*, O. Cabellos, L. Fiorito, WONDER2018

7. Sensitivity Analysis in LLNL pulsed spheres

- Sensitivity Analysis : "LLNL- 235U" pulsed sphere
  - **Fission** mainly around 14 MeV, other terms with lower values

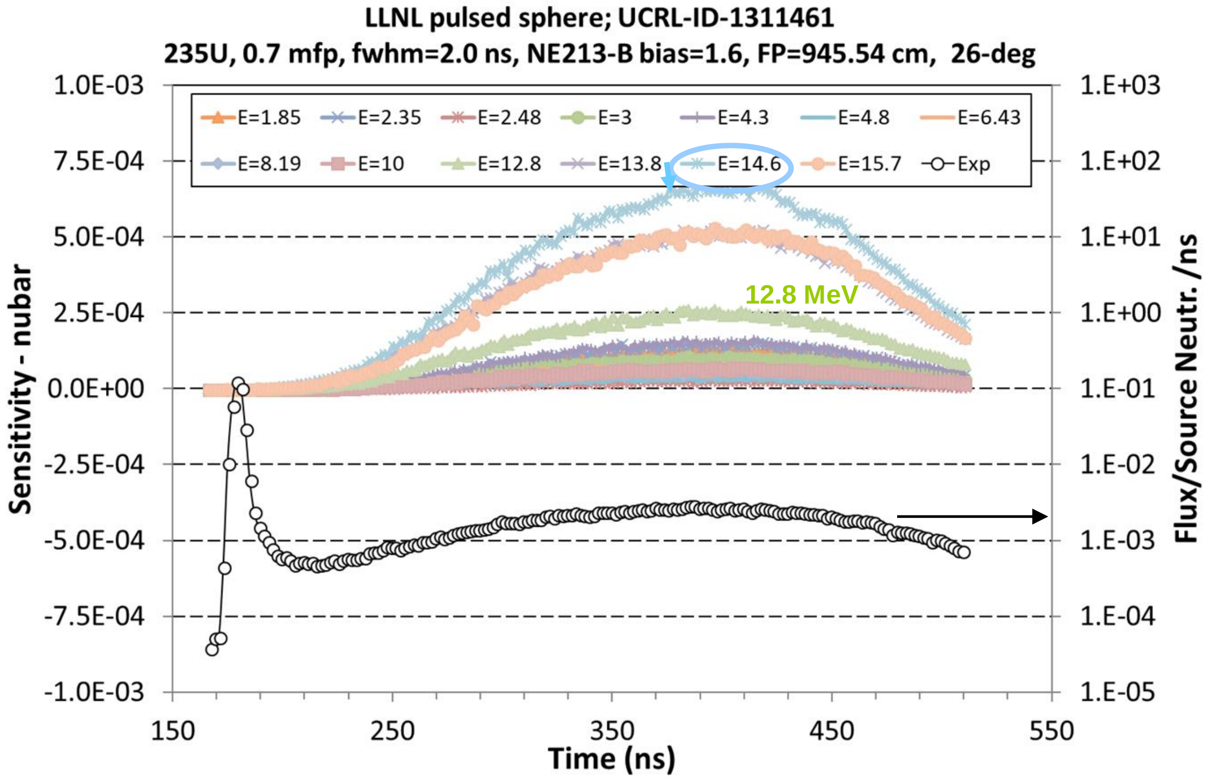
Note: Sensitivities predicted with MCSEN code



7. Sensitivity Analysis in LLNL pulsed spheres

- Sensitivity Analysis : “LLNL- 235U” pulsed sphere
  - **Nu-bar** mainly 14 MeV

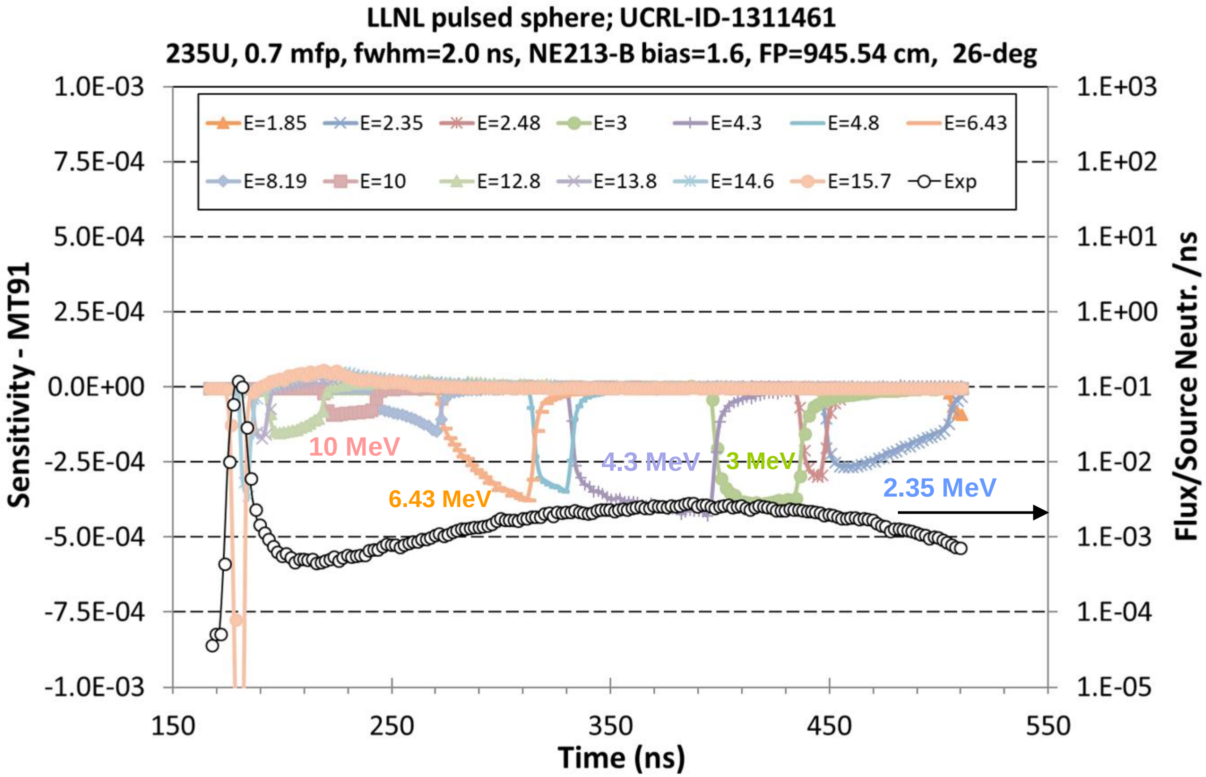
Note: Sensitivities predicted with MCSEN code



7. Sensitivity Analysis in LLNL pulsed spheres

- Sensitivity Analysis : “LLNL- 235U” pulsed sphere
  - **MT91**, between 1.8-14 MeV

Note: Sensitivities predicted with MCSEN code



8. Conclusion

- Collection of MCNP inputs/exp.data: FNS and Oktavian
  - Problems/errors in some inputs **… additional efforts are needed in the refining of the inputs**
    - MCNP4 → MCNP6
    - Neutron source spectra
  - Inputs and experimental data
    - Experimental data normalization

- Important Benchmarks for ND validation… that are not yet in SINBAD
  - LLNL pulsed spheres

- Sensitivity Analysis using MCSEN5 code for LLNL pulsed spheres
  - MCSEN5 -> MCNP5.1.30 (some restrictions for new ND)
    - Ref. : R.L. Perel, J.J. Wagschal, Y. Yeivin, "Monte Carlo Calculation of Point-Detector Sensitivities to Material Parameters", Nuclear Science and Engineering, 124 (1), 197–209 (1996)
    - Ref.: R.L. Perel, "Upgrading of the MCSEN sensitivity software to comply with the current standard of the MCNP-5 Monte Carlo code", F4E-GRT-168.01, March 2014

Acknowledgments

- This work is funded by the SANDA Project ("Supplying Accurate Nuclear Data for Energy and non-Energy Applications") under EURATOM HORIZON2020 Grant Agreement No. 847552