Benchmark analyses of Pb JEFF-3.1T data for fusion applications

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Objective and Content

- Objective:
  - validation of the JEFF-3.1T, ENDF-B6.8 and FENDL-2.1 files for Lead against fusion relevant benchmarks

- Content:
  - available experimental data base at 14 MeV
  - available evaluations for Pb isotopes,
  - comparison of transport calculations with experiments
  - conclusions.

Integral and Cross Sections Experimental Data relevant for Pb evaluated data validation at 14 MeV /T(d,n) source/

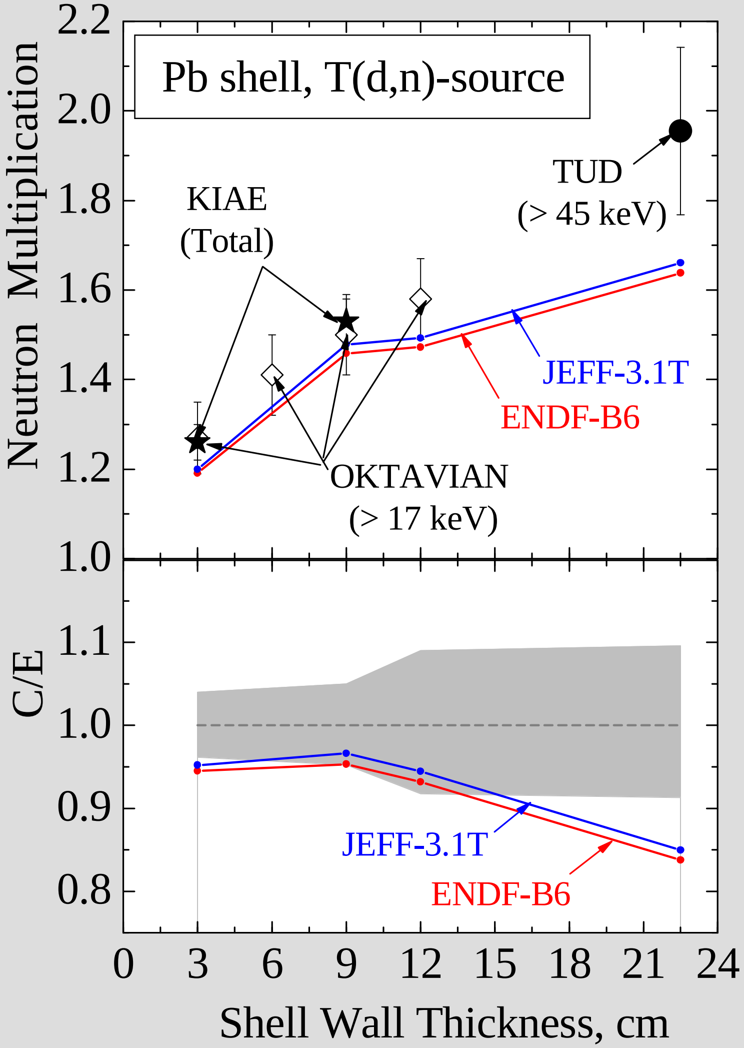
Shape: Wall thickness (sizes), cm	Method	Laboratory	Year	Analyses
Total Neutron Leakage (Multiplication) with T(d,n)-Source in the Center				
Shell: t = 3.0 (R = 12, r = 9.0) t = 9.0 (R = 12, r = 3.0)	4π-Boron Tank, no detector threshold	KIAE, Moscow	1989	+
Box: t = 10.0 (60×(35×35 - 15×15))	4π-Polypropyl. Block, BF_3	BARC, Bombay	1986	-
Neutron Leakage Spectra with T(d,n)-Source in the Center				
Shell: t = 5.6 (R = 12, r = 4.5) t = 9.0 (R = 12, r = 4.5)	Time-of-Flight, $\Theta = 26^o$, E > 1 MeV	LLL, Livermore	1986	-
Shell: t = 7.5 (R = 12, r = 4.5)	Time-of-Flight, 0^o, 30^o, 60^o	IPPE, Obninsk	1988	+
Shell: t = 7.5 (R = 12, r = 4.5)	Proton recoil, 0^o, E>1.2MeV	IRD, Prague	1993	+
Shell: t = 22.5 (R = 25, r = 2.5)	TOF, p-recoil, 90^o, E>45keV	TUD, Dresden	1987	+
Shell: t = 3.0 (R = 8, r = 5.0) t = 6.0 (R = 11, r = 5.0) t = 9.0 (R = 14, r = 5.0) t = 12.0 (R = 17, r = 5.0)	n-TOF, Detector angles: 0^o, 50^o, E > 17keV	OKTAVIAN, Osaka	1984	+/-
Angular Neutron Spectra from Slab with T(d,n)-Source and Detector on different sides of Slab				
Slab: t = 5.08 (R = 31.5) 20.3 (R = 31.5) 40.6 (R = 31.5)	Time-of-Flight, Detector angles: $0^o – 67^o$ E > 100 keV	JAERI, Tokai-mura	1991	+
Gamma-ray Leakage Spectra with T(d,n)-Source in the Center				
Shell: t = 10.0 (R = 20, r = 10)	NaI-pulse-height spectr.	OKTAVIAN, Osaka	1989	+
Energy-Angular Differential Cross Sections at 14 MeV				
^{208}Pb(n,xn) & ^{208}Pb(n,n'γ)	Time-of-flight, n- γ coin.	IPPE, Obninsk	1993	+
^{nat}Pb(n,xn)	Time-of-Flight	OKTAVIAN, Osaka	1984	+
^{nat}Pb(n,γ)	Scint. pair spectroscopy	NJS, Lublana	1979	+

Pb evaluated cross sections files selected for validation

	JEFF-3.1T (2004)	ENDF-B6.8 (1996)	FENDL-2.1 (2004)
	E < 200 MeV	E < 150 MeV	E < 150 MeV
	Pb-204 Pb-206 Pb-207 Pb-208	- Pb-206 (mod 2) Pb-207 (mod 3) Pb-208 (mod 3)	- Pb-206 = ENDF-B6.8 mod 2 Pb-207 = ENDF-B6.8 mod 3 Pb-208 = ENDF-B6.8 mod 3

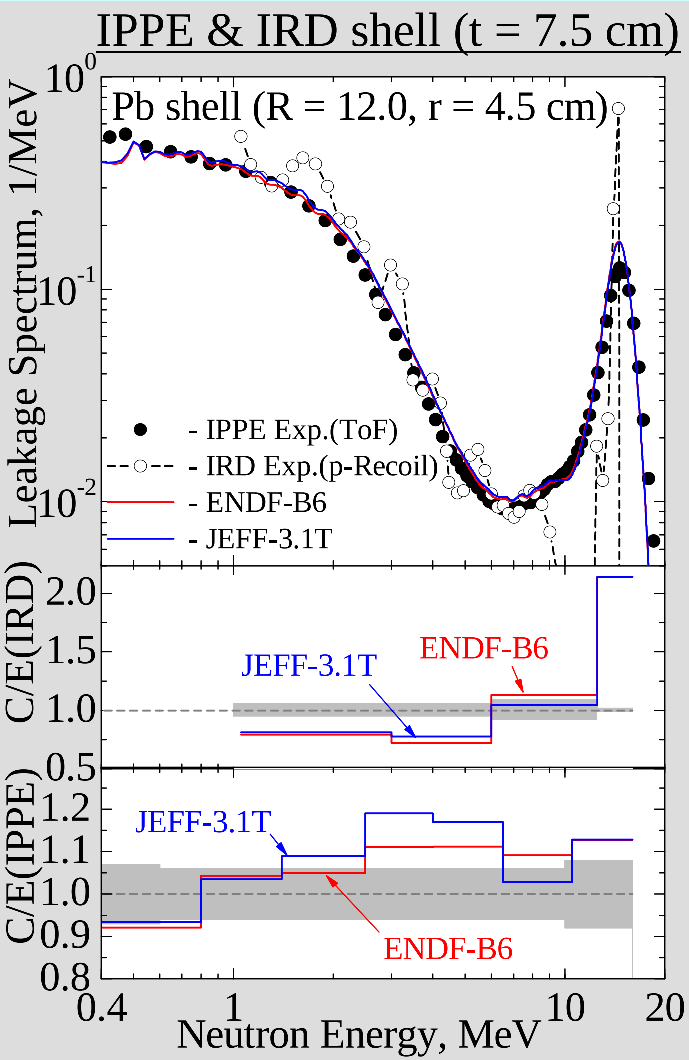
- Two independent libraries ENDF-B6.8 and JEFF-3.1T were validated, since FENDL-2.1 = ENDF-B6.8

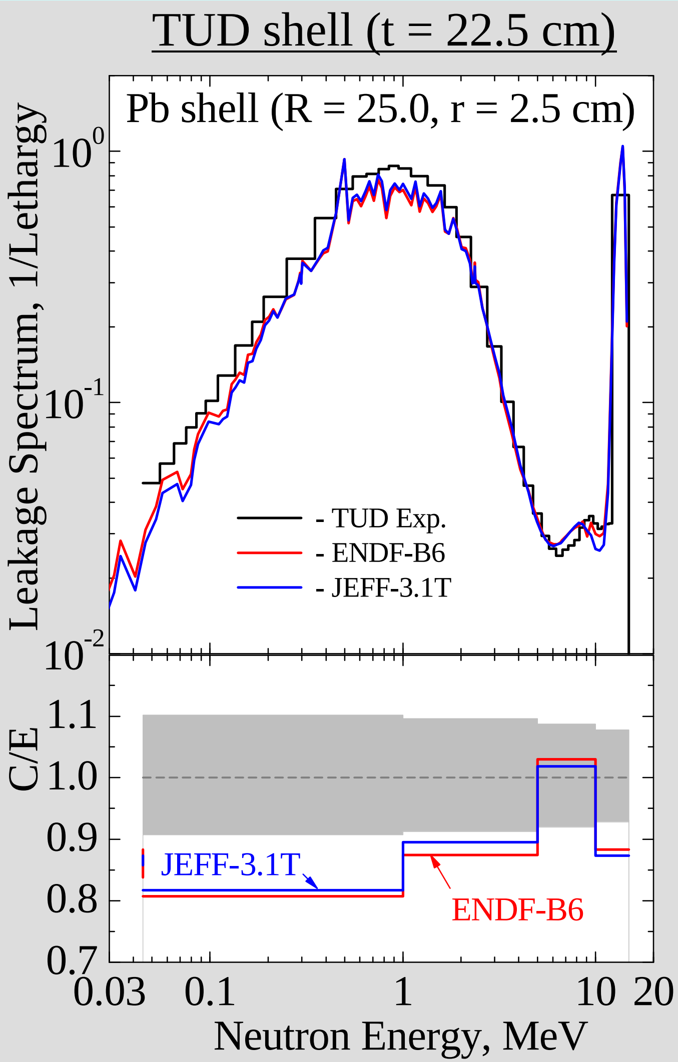
Validation against Total Neutron Leakage from Pb-Shells
(Neutron Multiplication)



***Findings*: ≈ 15% underestimation by both ENDF-B6 & JEFF-3.1T for Pb thickness 22.5cm**

Validation against Neutron Leakage Spectra from Pb-shells at 14 MeV



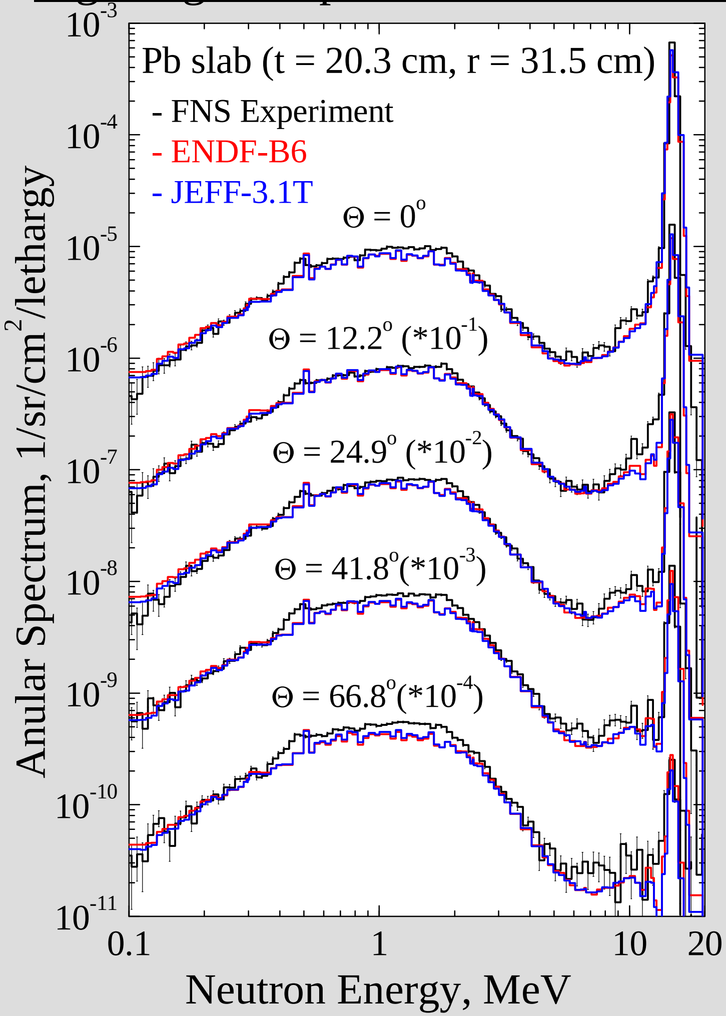


<u>Findings</u>: - deviations up to 20% (double of experimenral uncertainties) for the neutron leakage spectra measured in IPPE & TUD

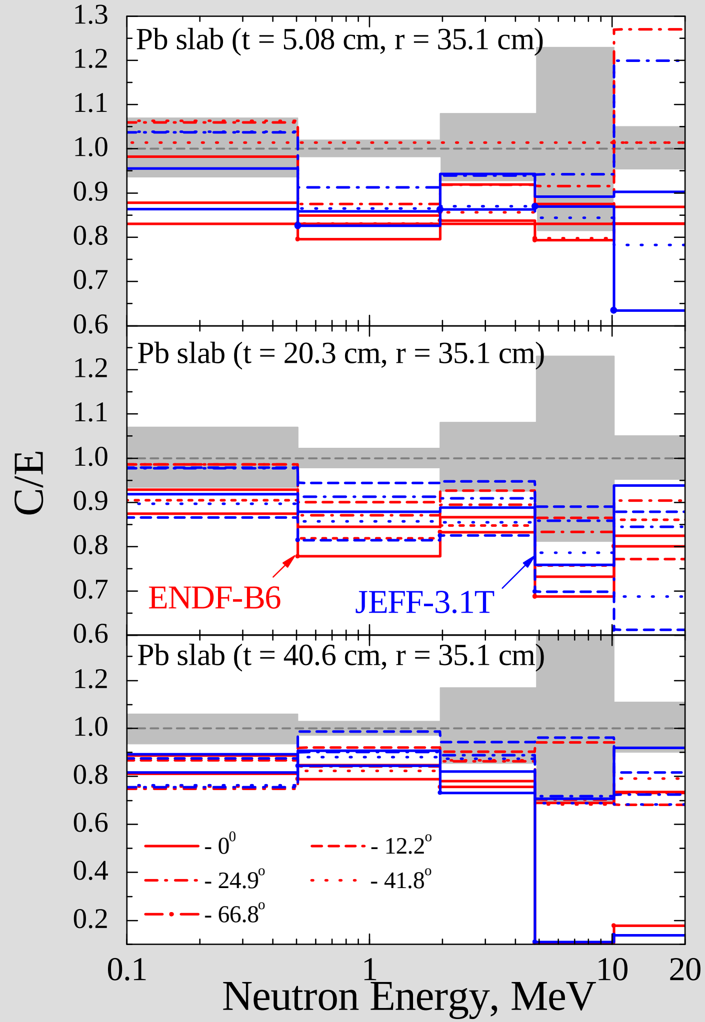
- deviation up to 100% for the case of IRD experiment

Validation against Angular Neutron Spectra from Pb-slab (FNS-experiment)

E.g.: angular Spectra for slab t = 20 cm



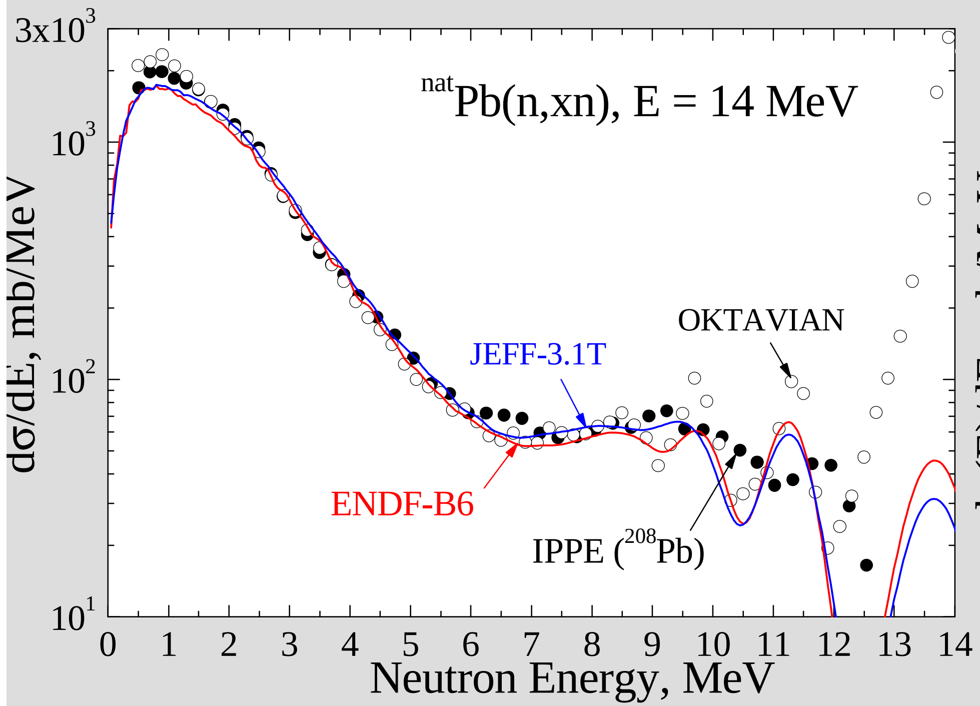
C/E (t = 5, 20 , 41 cm)



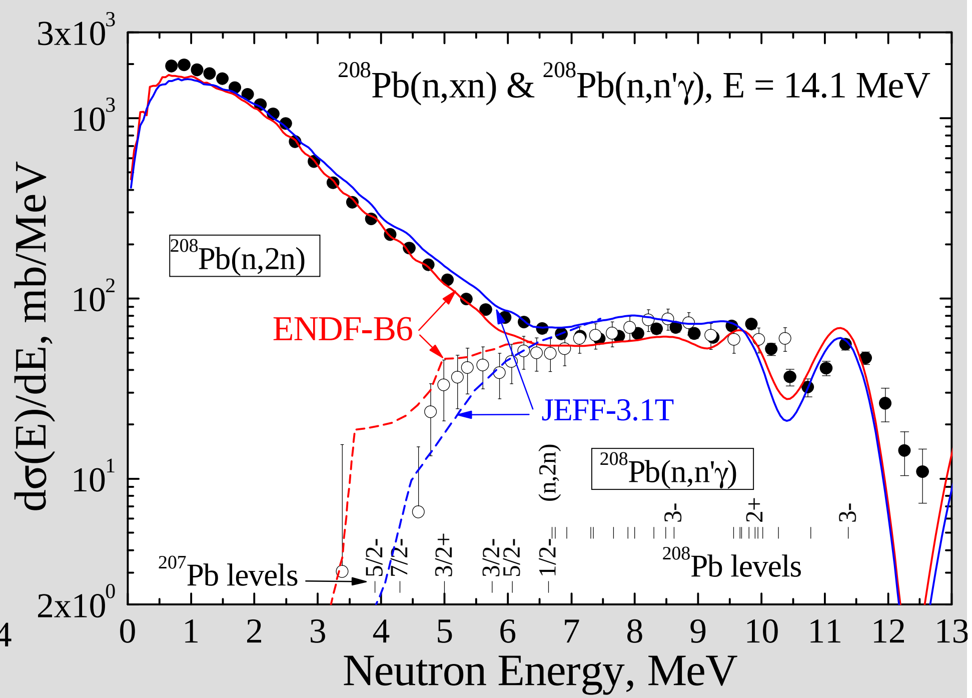
***Findings*: - up to 10-20% underestimation for neutrons below 5 MeV**
- much larger deviations for 14 MeV-group (elastic)

Validation against Secondary neutron Energy Distributions (SED) from Pb(n,xn) reaction at 14 MeV

Neutron emission for natural Lead

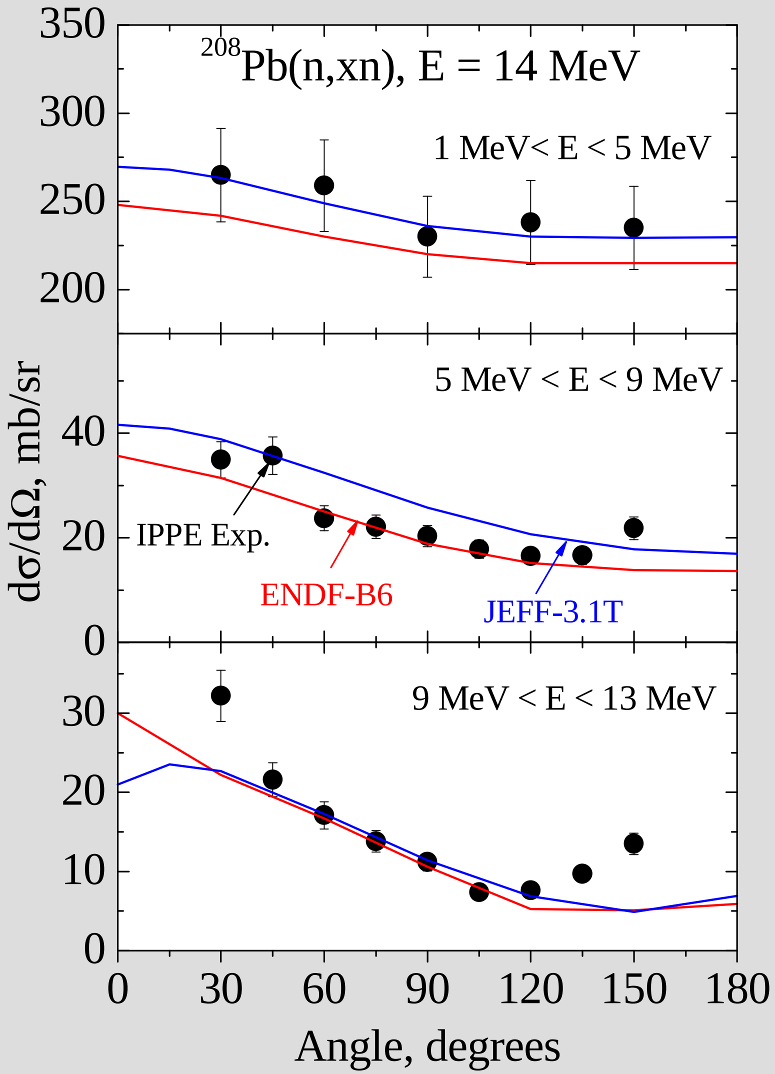


Neutron emission and inelastic for Lead-208



<u>Findings</u>: reasonable agreement for energy differential cross section for 000Pb(n,xn) and 208Pb(n,xn) or 208Pb(n,n'g) reactions at 14MeV

Validation against Secondary neutrons Angular Distribution (SAD) from $^{208}Pb(n,xn)$ reaction at 14 MeV

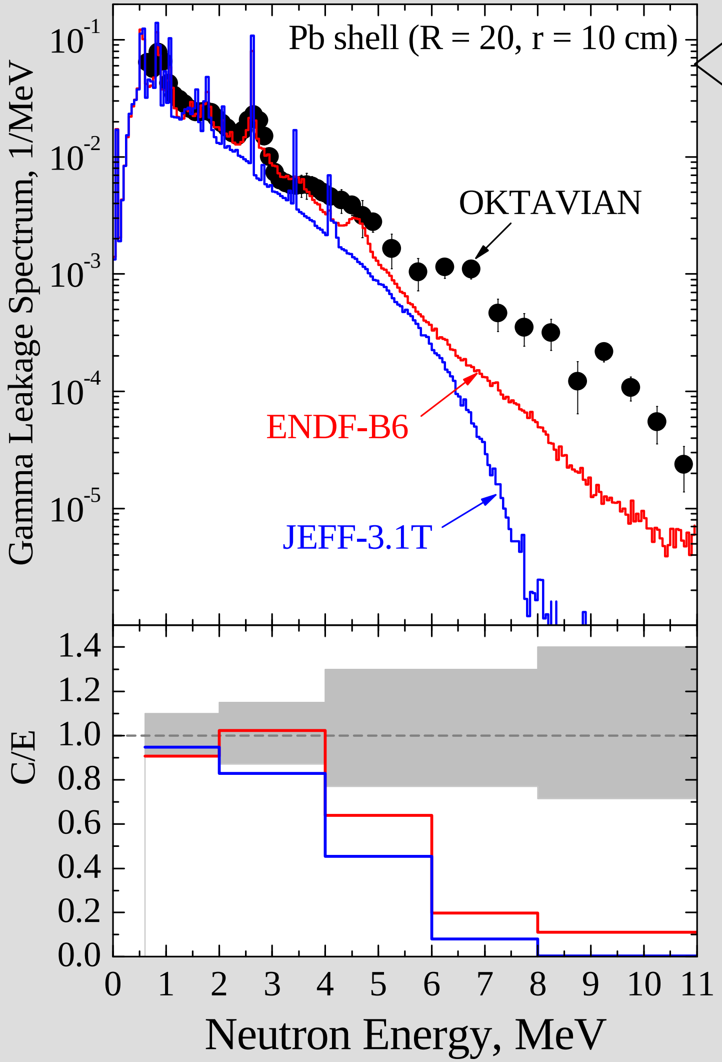


Findings:

Reasonable prediction of the secondary neutron angular distributions for the $^{208}Pb(n,xn)$ reaction

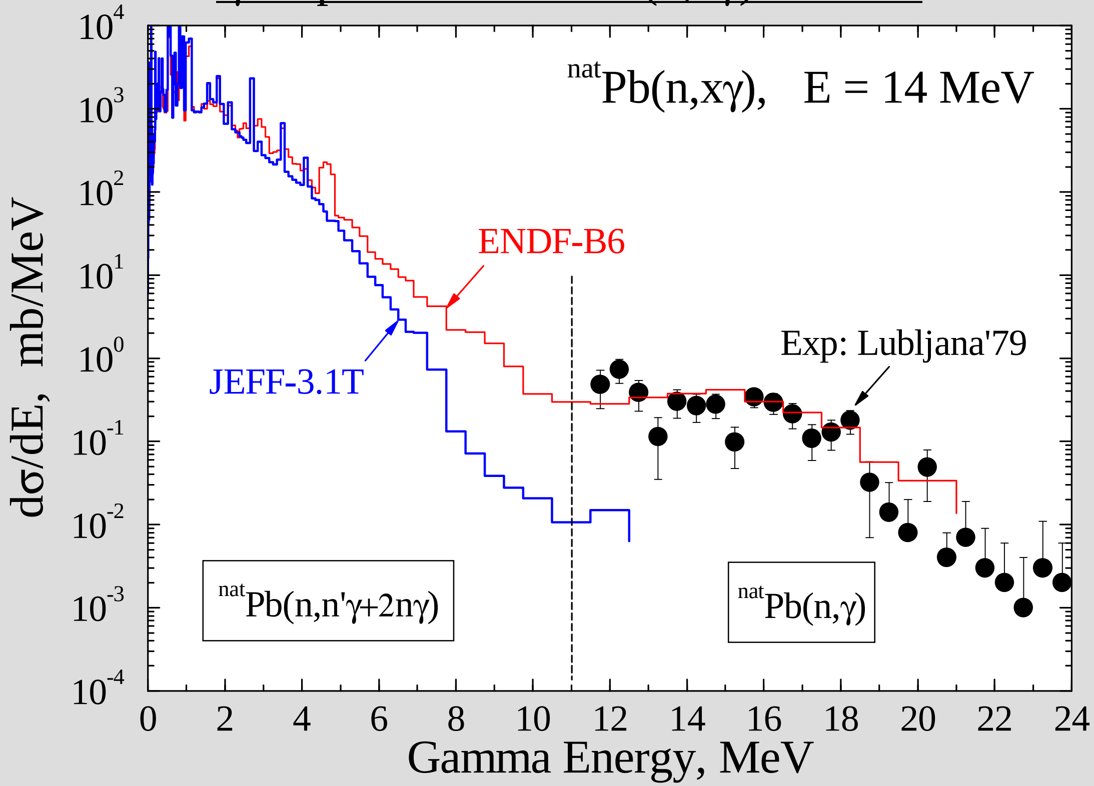
by ENDF-B6 and JEFF-3.1T

Gamma Leakage from Pb shell & γ-spectra from Pb(n,xγ) reaction



γ - Leakage Spectrum from Pb-Shell

γ - Spectrum from Pb(n,xγ) reaction



***Findings**: - large underestimation of g-ray leakage above 5MeV by JEFF-3.1T & ENDF-B6.8*
***Most likely reason**: - wrong presentation of Pb(n,xg) energy differ. cross section at 14 MeV*

Conclusions on status of JEFF-3.1 and ENDF-B6.8 (FENDL-2.1) Pb data derived from fusion benchmarks

- **Transport of Neutrons:**
  - JEFF-3.1T and ENDF-B6.8 are close each other
  - they underestime by 15% neutron multiplication at lead thickness ≈ 20 cm,
  - diviate by 20% in predicting the energy distribution of leaking neutrons in spherical symmetry (shells), and more – fo the case of "elastic" scattering on lead slabs,
  - correct present the energy and angular distributions of secondary neutrons for (n,xn) and (n,n'γ) reaction on Pb and ^{208}Pb.
- **Transport of Secondary Gammas:**
  - large underestimation of leakage spectrum above 5 MeV (JEFF-3.1T worse than ENDF-B6.8)
  - large underestimation of secondary γ-rays with energies 5-10 MeV from Pb(n,xγ) reaction (JEFF-3.1T worse than ENDF-B6.8)