Incident energies coded for ^{238}U(n,f) FPY datasets

(N. Otsuka, 2025-05-21, Memo CP-D/1139)

Uranium-238 is not fissile, and its fission events induced by reactor neutrons do not represent the quantity of interest at the thermal energy. Namely, EN-DUMMY=0.0253 eV is questionable for uranium-238 neutron-induced fission. The purpose of this paper is to share suggestion on better coding of the representative energy with Andrea Mattera (NNDC).

I received comments on incident energies coded for ^{238}U(n,f) fission product yields from Andrea Mattera (NNDC) [1]. Below I introduce three typical comments.

13327.004 (fast reactor spectrum)

Current coding: EN-MEAN=0.4 MeV with SF8=FST.

Sample was irradiated in the Idaho experimental first breeder reactor (EBR-II):

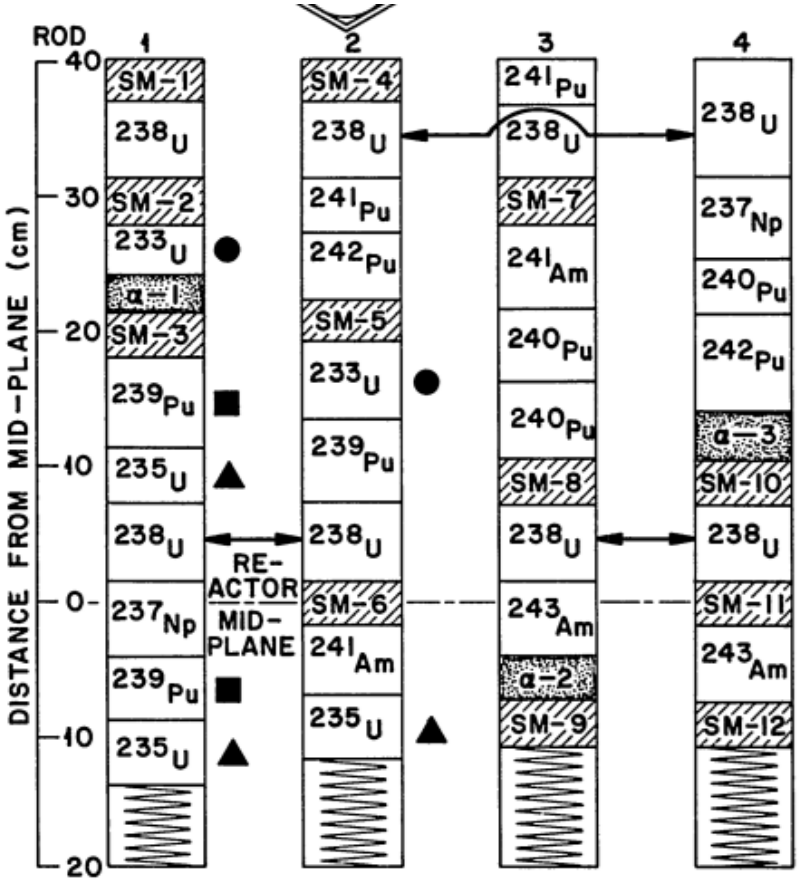

Fig. 1 EBR-II Irradiation Package-Location of Fission Yield, Spectrum Monitor and Capture-to-Fission Ratio Capsules.
- 5 -

These four sample packages contain ^{238}U capsules and spectrum monitor capsules ("SM"). Based on gamma spectroscopy of these monitor capsules after irradiation, the authors calculated the "mean neutron energy" as well as "mean fission energy" of ^{238}U:

TABLE VIII

SUMMARY OF NEUTRON ENERGIES FOR EBR-II IRRADIATION PACKAGE AND COMPARISON TO THE DESIGN NEUTRON SPECTRA FOR FTR AND CONCEPTUAL 1000 MW_e LMFBR (ENERGY IN KeV)

	EBR-II Unshielded Irradiation Assembly								
	SM-1	SM-3	SM-5	SM-10	SM-6	SM-9	SM-12	FTR	1000 MW_e LMFBR
Axial Position (midplane = 0)	+38 cm	+19 cm	+19 cm	+10 cm	0 cm	-10 cm	-10 cm		
Mean Neutron Energy	248	439	401	454	487	457	421	482	448
Median Neutron Energy	74	147	128	152	146	141	100	200	243
Mean Fission Energy for ^{233}U	154	291	261	291	322	298	265	325	355
Mean Fission Energy for ^{235}U	151	290	260	293	324	299	265	338	360
Mean Fission Energy for ^{238}U	3020	2990	3030	3040	2930	2110	2010	2530	3420
Mean Fission Energy for ^{239}Pu	227	427	388	440	481	446	407	476	451
Mean Fission Energy for ^{241}Pu	149	285	255	288	318	293	260	320	348

The "mean neutron energy" and "mean fission energy for ^{238}U" correspond to

$$\langle E \rangle = \int \mathrm{d}E\, E\, \varphi(E) \Big/ \int \mathrm{d}E\, \varphi(E)$$

$$\langle E \rangle = \int \mathrm{d}E\, E\, \sigma(E)\varphi(E) \Big/ \int \mathrm{d}E\, \sigma(E)\varphi(E)$$

where φ(E) is the neutron fluence and σ(E) is the ^{238}U(n,f) cross section. This table shows the mean neutron energy (i.e., *first* definition) is about **0.4 MeV** while the ^{238}U mean fission energy (i.e., *second* definition) is about **2.5 MeV**. This difference is due to presence of the ^{238}U(n,f) threshold energy around 1 MeV.

Question: Replace EN-MEAN=0.4 MeV (first definition) with EN-MEAN=2.5 MeV (second definition)?

13379.002 (fission neutron spectrum)

Current coding: EN-DUMMY=1 MeV with SF8=FIS.

Sample was irradiated by neutrons in a uranium rod in an ORNL reactor. The authors say they are nearly unmoderated fission spectrum neutrons and the average neutron energy effecting fission in ^{238}U is estimated to be ~**2.8 MeV**.

Question: Adopt KT-DUMMY=1.32 MeV (energy commonly used SF8=FIS for pure ^{235}U prompt fission neutron spectrum) or EN-MEAN=2.8 MeV (second definition)?

30496.008-009 (thermal neutron spectrum)

Current coding: EN-DUMMY=1 MeV with SF8=SPA.

Sample was irradiated by neutrons for neutrons from the APSARA reactor. The sample is wrapped by a Cd foil. Use of **SF8=EPI and EN-MIN=0.5 MeV** is the current practice by NDPCI for FY measured with a Cd foil in BARC research reactors.

The authors do not provide any representative energy though they give the fractions of fast neutrons for several dosimetry reactions. Andrea Mattea found the spectrum in Fig. 1 of H. Naik+, J,RCA,75,69,1996 (EXFOR 31518), and he estimated the representative neutron energy as **4.2 MeV** according to the *second* definition.

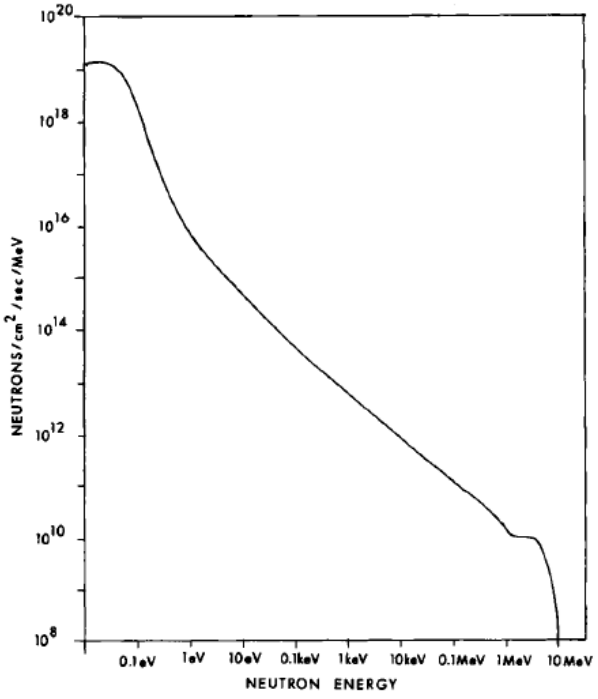

Fig. 1. Differential neutron flux vs. energy at the irradiation position used in APSARA reactor.

Question: Do we use EN-DUMMY=4.2 MeV (mean energy calculated by other than the authors) instead of EN-MIN=0.5 eV?

The original comments are appended to this memo.

Reference

[1] A. Mattera et al., "Reviewing incident neutron energy assignments in ^{238}U(n,f) fission yield data", Report # BNL-228181-2025-INRE, Brookhaven National Laboratory (2025).

Appendix

EXFOR #	Neutron source	Current	Comments by Andrea Mattera (2025-03-21)
13317	Critical assembly	EN-DUMMY= 1 MeV	EN could probably be changed to 2.9 MeV (as reported in 14584 for the same CRASS)
13327	Fast reactor	EN-MEAN= 0.4 MeV	Here, I believe that as the EN-MEAN (mean fission energy) one could use the values reported in Table VIII of 1975MAWY. For U-238, this would be 2.903 MeV - 3.020 MeV based on the location of the U-238 irradiated assemblies.
13379	Reactor core	EN-DUMMY= 1 MeV	EN-DUMMY could be changed to something else. The mean fission energy is ~2.8 MeV, as reported in 1954KE37: "The average neutron energy effecting fission in U-238, [...], is estimated to be approximately 2.8 MeV."
21736	Reactor core	EN-DUMMY= 1.5 MeV	Spectrum in the thesis [CEA-R 2442 — BRETHE Pierre EXPERIMENTAL MEASUREMENT OF NEUTRON SPECTRUM IN THE REFLECTOR OF A LIGHT WATER REACTOR. at https://inis.iaea.org/records/y0mcb-ark30] from which the neutron energy inducing fission can be estimated in 3 +/- 1 MeV
22334	Fast reactor	EN-DUMMY= 1 MeV	Approximate energy based on [Nilsson, Ragnar, and Erkki Aalto. Tests of Neutron Spectrum Calculations with the Help of Foil Measurements in a D_2O and in an H_2O-Moderated Reactor and in Reactor Shields of Concrete an Iron. No. AE--155. AB Atomenergi, 1964.] Possible information on energy spectrum from https://inis.iaea.org/records/9p2k6-mr524 [Etemad, B. Measurement of fast neutron spectrum in fuel irradiation rig in R2 reactor using activation detectors and unfolding techniques. No. STUDSVIK-BR--78-1. Aktiebolaget Atomenergi, 1978.] Average XS-weighted energy is ~4 +/- 2 MeV
23597	Reactor core	EN-DUMMY= 0.5 MeV	Fast reactor spectrum given in Fig. 7 of the main reference. Average XS-Weighted energy is ~850 keV +/- 100 keV using data in the plot; it's probably higher, considering that the plot is cut at 1 MeV

23796	^{12}C(d,n) at 26 MeV	EN-MEAN= 10 MeV	26 MeV deuterons delivered to the PARRNe line was fully stopped in a 3 mm thick graphite converter details from [Lau, C., et al. "Production of neutron-rich surface-ionized nuclides at PARRNe." Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms 204 (2003): 257-260.] Average neutron energy effecting fission (calculated from the spectrum in the reference above): 13.5 +/- 5 MeV
30496	Thermal reactor +Cd foil	EN-DUMMY= 1 MeV	Fission spectrum for APSARA reactor can be found in [Naik, H., et al. "Absolute Fission Yields in the Fast Neutron Induced Fission of 99.9997 Atom % Pure 238U Using Track Etch-cum Gamma Spectrometric Technique." Radiochimica Acta 75.2 (1996): 69-76.] from which the neutron energy inducing fission can be estimated in 4.2 +/- 2 MeV
30752	Σ-Σ thermal-fast couple	EN-DUMMY= 450 keV	The energy spectrum of ITN Sigma-Sigma available in [T. Angelescu et al. /Nucl. Instr and Meth. in Phys . Res. A 345 (1994) 303-307] from which the neutron energy inducing fission can be estimated in 3.0 +/- 1.5 MeV
31571	^{7}Li(p,n) at 25.5 MeV	EN-MIN/MAX= 1.5/3.5 MeV	From the main reference: "This arrangement produced a beam of neutrons confined within a forward cone of half angle 23◦ and with energies between 1.5 and 3.5 MeV. The average neutron energy was about 2.5 MeV." EN-AVG could better represent this instead of EN-MIN / EN-MAX
32668	Reactor core	EN-DUMMY= 1 MeV	In the reference (Chung, Chien, and Ming-Yung Woo. "Fission product yields in the fast-neutron fission of 238 U." Journal of Radioanalytical and Nuclear Chemistry 109.1 (1987): 117-131.) the authors report the effective average energy inducing fission. "If one assumes a Watt neutron energy spectrum in a swimming-pool type research reactor such as the THOR facility, the effective average energy of neutrons inducing ^{238}U(n, f) reaction is about 3.2 MeV; the use of neutron shields would also reduce the number of low-energy neutrons such that the effect of average neutron energy would be slightly greater than 3.2 MeV."
33166	Thermal reactor+ Cd foil	EN-MIN=0.5 MeV	Fission spectrum for CIRUS reactor can be found in [R. H. Iyer, H. Naik, A. K. Pandey, P. C. Kalsi, R. J. Singh, A. Ramaswami & A. G. C. Nair (2000) Measurement of Absolute Fission Yields in the Fast Neutron–Induced Fission of Actinides: 238U, 237Np, 238Pu, 240Pu, 243Am, and 244Cm by Track-Etch-cum-Gamma spectrometry, Nuclear Science and Engineering, 135:3, 227-245, DOI: 10.13182/NSE00-A2136]

			from which the neutron energy inducing fission can be estimated in 2.6 +/- 1.1 MeV
40206	Reactor “active zone” (core?)	EN-DUMMY= 1 MeV	There is a spectrum in [Krezhov, K., et al. "The reference neutron field-a standard neutron source for neutron measurements at the research reactor IRT-2000 in Sofia; Oporno pole-obraztsov iztochnik za neutronni izmervaniya na reaktora IRT-2000 v Sofia." (1993).] -- BUT: the paper is in Russian
40489	Reactor core	EN-MEAN= 1.3 MeV	There is an unfolded spectrum for BR-1 in [Doroshenko, J. J., et al. "New methods for measuring neutron spectra with energy from 0.4 eV to 10 MeV by track and activation detectors." Nuclear Technology 33.3 (1977): 296-304.]. In [1977GUZJ] there is a reference to another irradiation at BR-1 with Average neutron energy of 1.8 MeV, so that EN-MEAN could be closer to 1.8 MeV than 1.3 MeV