International Atomic Energy Agency

The IAEA CRP on IRDFF validation and EXFOR

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Introduction: the IAEA CRP "Testing and Improving the International Reactor Dosimetry and Fusion File (IRDFF)"

https://www-nds.iaea.org/IRDFFtest/

- **Dosimetry reaction cross sections (XS) as a reference library allows to**
  - determine and monitor **neutron fluence and spectra in the high flux facilities** (fission and fusion reactors, accelerator driven sources)
  - predict **safe operation** (reactor vessel life time)

- **History**: 1993: IRDF-90 v. 2, 37 reactions, IAEA-NDS-141, 1993 } E < 20 MeV
  2006: IRDF-2002, 69 reactions, Rep.452, IAEA, 2006 } E < 20 MeV
  2012: IRDFF, v. 1.00, INDC(NDS)-0616, 2012 } E < 60 (200) MeV
  2014: IRDFF, v. 1.03 - it is an actual version } E < 60 (200) MeV
  (cf. IRDF-2002: 5 new ^{67}Zn(n,p), ^{113}In(n,n'), ^{169}Tm, ^{209}Bi(n,3n), ^{238}U(n,2n) and more than 32 updated reactions)

now Total = 76 dosimetry + 3 absorbing (cover materials) reactions: full List
- soon will be included ^{28}Si(n,p) {+ competing ^{29}Si(n,x)^{28}Al} – Fusion community request
- 1st RCM suggested new reactions: (n,γ) on ^{27}Al, ^{94,96}Zr, ^{70}Zn, ^{94}Nb, ^{113}In and ^{117}Sn(n,n')

- **The IAEA CRP on "IRDFF validation":**
  - expected **results -** updated and validated Dosimetry XS, Decay Data & Documentation
  - **started 1-5 July 2013** (1st RCM), Summary Report *INDC(NDS)-0639*

I. IRDFF relevant data and EXFOR: missed experimental data

- **IRDFF relevant data are**
  - SPectrum-averaged cross sections, *SPA or <σ>*
  - point-energy cross sections, σ(E)
  - neutron spectra generated by accelerator and reactor facilities

- **Working List of data found as missing in EXFOR** (≈ 10 articles):

  https://www-nds.iaea.org/IRDFFtest/CrossSectionsMissed.pdf

  -> list for compilation: Memo CP-D/838 "**EXFOR completeness for neutron dosimetry application**" (also WP2014-21)

  -> this Memo additionally includes a list of **International Symposiums on Reactor Dosimetry 1975 to 2011** (14), only partly cited in EXFOR

- **This work goes on -** examples on the next slides ->

I. SPA and EXFOR: example - status of SPA in ^{235}U(n$_{th}$,f) field

https://www-nds.iaea.org/IRDFFtest/SPA_Exp_U235.pdf

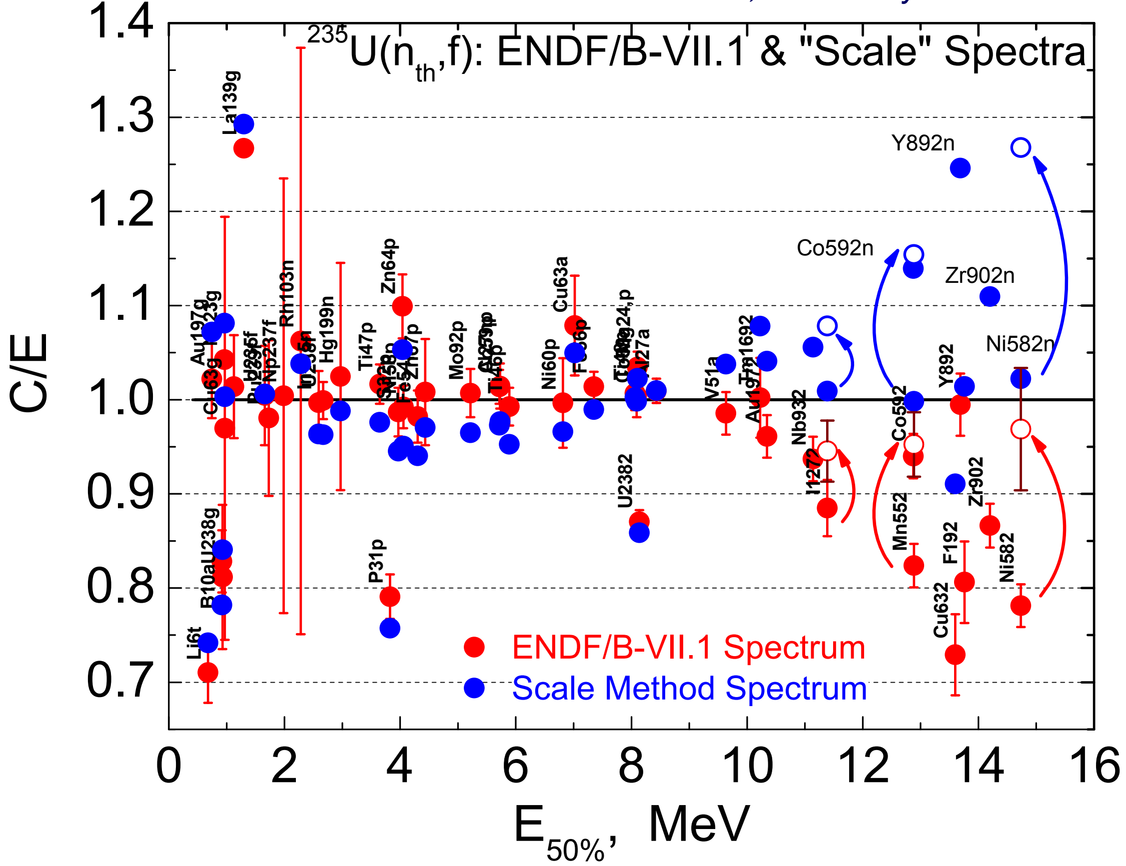
Available Experimental (evaluated or original) Spectrum Averaged Cross Sections (SPA) in U-235(ntherm,f) field sorted by E(50%)

N	Reaction Name			E(50%)	SPA	SPA Uncertainty		Reference for Recommended	Original Experiment	
N	Z	full	short	MeV	mb	%	mb	experimental SPA	Reference	EXFOR
1	21	Sc-45(n,γ)Sc-46	sc45g	0.591	NOT measured yet					
1	3	Li-6(n,t)He-4	li6t	0.662	4.560E+02	4.39	2.000E+01	NBSIR_85-3151,1986, p.66 =	B.Oliver	23226.000
2	41	Nb-93(n,γ)Nb-94	nb93g	0.692	NOT measured yet			J.Grundl,ND-1985,p.471		
2	79	Au-197(n,γ)Au-198	au197g	0.725	7.400E+01	4.05	3.000E+00		A.Fabry	20229.006
3	26	Fe-58(n,γ)Fe-59	fe58g	0.740	NOT measured yet					
4	47	Ag-109(n,γ)Ag-110m	ag109g	0.750	NOT measured yet					
5	92	U-235(n,γ)U-236	u235g	0.754	NOT measured yet					
3	25	Mn-55(n,γ)Mn-56	mn55g	0.771	3.820E+00				D.J.Hughes	13860.012
6	73	Ta-181(n,γ)Ta-182	ta181g	0.840	NOT measured yet					
4	5	B-10(n,a)Li-7	b10a	0.903	5.410E+02	4.44	2.400E+01	NBSIR_85-3151,1986, p.66 =	B.Oliver	23226.000
5	27	Co-59(n,γ)Co-60	co59g	0.914	1.100E+01			J.Grundl,ND-1985,p.471	D.Hughes	13860.014
7	90	Th-232(n,γ)Th-234	th232g	0.920	NOT measured yet					
6	92	U-238(n,γ)U-239	u238g	0.929	8.500E+01	9.41	8.000E+00		A.Fabry	20264.007
7	11	Na-23(n,γ)Na-24	na23g	0.962	2.600E-01				D.Hughes	30400.016
8	29	Cu-63(n,γ)Cu-64	cu63g	0.968	1.080E+01	23.15	2.500E+00		A.Fabry	20264.002
9	49	In-115(n,γ)In-116m	in115g	1.021	1.245E+02	4.25	5.290E+00	K.Zolotarev, INDC(NDS)-0657	A.Fabry	20229.004
8	74	W-186(n,γ)	w186g	1.033	NOT measured yet					
10	57	La-139(n,γ)La-140	la139g	1.294	5.300E+00			K.Zolotarev, INDC(CCP)-0431		11596.011
11	92	U-235(n,f)	u235f	1.650	1.217E+03	1.12	2.403E+01	W. Mannhart 2008		
12	94	Pu-239(n,f)	pu239f	1.730	1.831E+03	1.65	5.220E+01	W. Mannhart 2008		
13	93	Np-237(n,f)	np237f	2.010	1.350E+03	1.78	2.403E+01	W. Mannhart 2008		

SPA available: (1) individual measurements (a few are missed in EXFOR) and (2) recommended by experience evaluators - are really used in analysis ->

I. SPA and EXFOR: example - status of SPA in ^{235}U(n_{th},f) field

Ref. to S. Simakov et al. ISRD-15, 19-23 May 2014



- recommended experimental SPA for ^{127}I(n,2n), ^{55}Mn(n,2n) and ^{58}Ni(n,2n) reactions are different !!!
  (*curved arrows show how replacement of W. Mannhart' SPA with K. Zolotarev' ones will increase C/E by 8-15% for both PFNS spectra*)

- what could be a reason of difference between recommended SPA ?
  (next slide)

- proposal for HPRL which SPA has to be measured was formulated
  (https://www-nds.iaea.org/IRDFFtest/HPRL.pdf)

- EXFOR database has point-energy dosimetry σ(E) and corrections (from K. Zolotarev) !
- should we compile recommended spectrum-averaged <σ> and corrections ?

I. SPA and EXFOR: example - status of SPA in $^{235}U(n_{th},f)$ field

Expert opinion: "The reason for different recommended SPA could be different corrections applied. in particular, the difference in decay parameters"

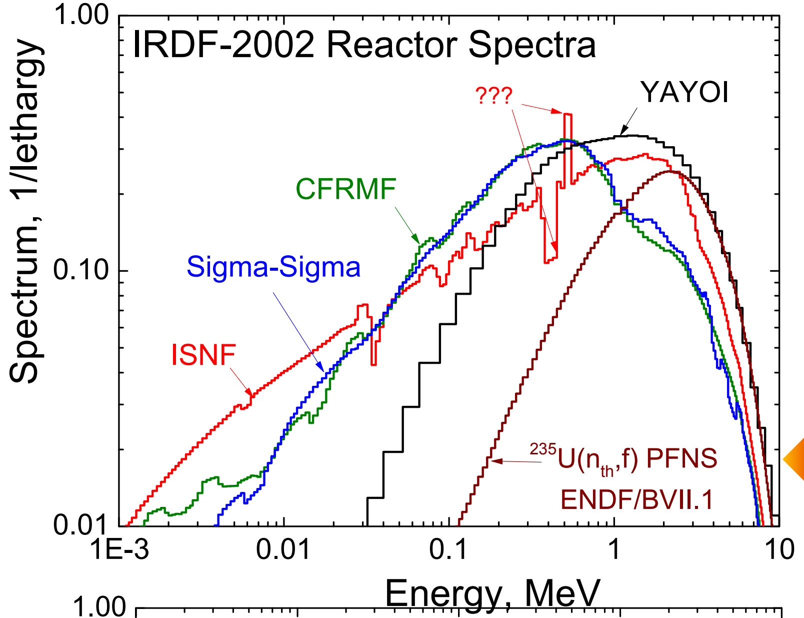
Let look in EXFOR:

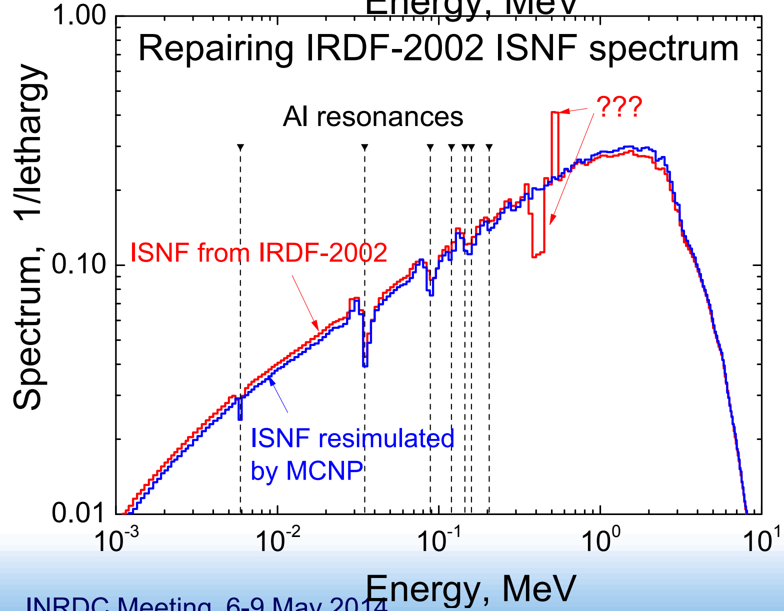
```
ENTRY      22020001    861212         20050926     0000

INSTITUTE  (2GERPTB)  Physikal. Techn. Bundesanst., Braunschweig, Germany

AUTHOR     (W.MANNHART)

TITLE      -SPECTRUM-AVERAGED NEUTRON CROSS SECTIONS MEASURED
            IN THE U-235 FISSION NEUTRON FIELD IN MOL.

FACILITY   (REAC,2BLGMOL) REACTOR BR1 AT MOL.

INC-SOURCE (REAC) THERMAL FISSION IN U-235.


REL-REF    (R,,W.L.ZIJP+,R,EUR-7164,75) DECAY PARAMETERS.
           (R,,W.MANNHART,C,84GEESTH,2,801,8409) DECAY PARAMETERS.

REACTION   (28-NI-58(N,2N)28-NI-57,,SIG,,FIS)

DATA       ERR-T
MB         MB
.00419     .00022
```

- Entry has no numerical DECAY-DATA (only reference)
- Decay data (from author) has to be compiled for completeness and corrections afterwards

I. SPA/Spectra and EXFOR: IRDF-2002 collection of Spectra

IRDF-2002 has a collection of S**pectra** for facilities:





EXFOR has **<σ>**:

Facility	First Author	EXFOR
ISNF (NBS, USA)	G. Lamaze	13153
	B. Oliver	13752
Σ-Σ (Mol, Belgium)	A. Fabry	20948
(NISUS, UK)	A. Hannan	20950
(ITN, Romania)	I. Garlea	30450 30568
CFRMF (ANC, USA)	A. Grundl	10479
(ANC, USA)	Y. Harker	10218
(ANC, USA)	E. Lippincott	13756
YAYOI (JAPAN)	K. Kobayashi	21589 20693

- **ISFN was re-simulated (**with ENDF/BVII.1**)**
  to recover facility spectrum
- **C/E agreement was found reasonable**
  for all these facilities except YAYOI
  (S. Simakov et al. ISRD-15, 19-23 May 2014)
- **How to keep new spectra (or MCNP models)**
  and refer to facility spectra from EXFOR Entries ?

II. IRDFF Decay Data sub-library https://www-nds.iaea.org/IRDFFtest/irdffnuclideslist.htm

Reference Decay library allows: - renormalization of XS to actual reference decay data and
- consistent use of same decay data in IRDFF evaluation and applications

List of Isotopes and Isomers produced by reactions included in IRDFF: version 1.00 (Oct 2012) - 82; version 1.03 (March 2014) - additional 6

#	Isotope	Decay Mode	Radiation used for detection	Producing reaction[1]	Source on Oct 2012	ENDF Mat	Latest ENSDF[2] (March 2014)	IRDFF new evaluations which replace ENSDF
			Whole Decay	**Library in ENDF**	irdf2012.endf		IRDFF2014.ENDF	
1	1-H-3	β-	β- 18.594 keV	6Li(n,t)4He	EVAL-JUL00	131	EVAL-JUL00	
2	9-F-18	β+	γ 511. keV	19F(n,2n)18F	EVAL-NOV96	922	EVAL-NOV96	
3	11-Na-22	β+,ε	γ 511. keV	23Na(n,2n)22Na	EVAL-DEC05	1122	EVAL-DEC05	
4	11-Na-24	β-	γ 1368.63 keV	23Na(n,γ)24Na 24Mg(n,p)24Na 27Al(n,α)24Na	EVAL-OCT07	1128	EVAL-OCT07	
5	12-Mg-27	β-	γ 843.76 keV γ 1014.44 keV	27Al(n,p)27Mg	EVAL-AUG11	1234	EVAL-AUG11	

Whole Decay library converted from ENSDF to ENDF by **SDF2NDF updated by M.Verpelli**

Link to LiveChart

Processing problem for ^{93m}Nb **not resolved yet**:

36	41-Nb-93M	IT (31 keV)	X 16.6 keV X 18.6 keV	93Nb(n,n')93mNb	NOT included	????	**EVAL-MAY11**	RadList does not calculate properly

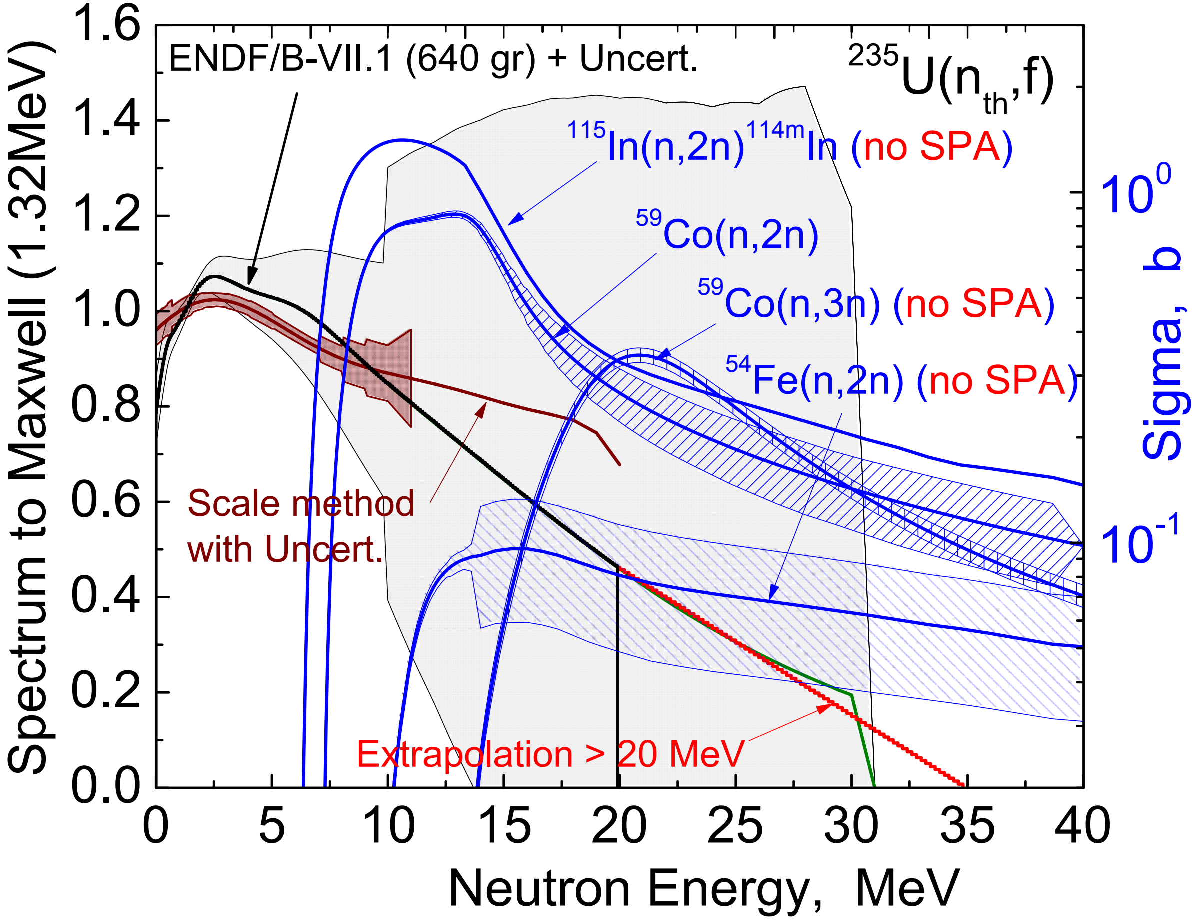
Replacement of ENSDF by actual new evaluations (DDEP, *V. Chechev*):

76	73-Ta-182	β-	γ 1121.3 keV γ 1189.0 keV γ 1221.4 keV	181Ta(n,γ)182Ta	EVAL-SEP10	7331	EVAL-SEP10	EVAL JAN 14 and pdf
						Iγ (1121 keV) =	35 (*?*)	35.17 (*33*) %/decay
						Iγ (1189 keV) =	16.49 (*6*)	16.58 (*16*) %/decay
83	79-Au-198	β-	γ 411.8 keV	197Au(n,γ)198Au	EVAL-OCT09	7928	EVAL-OCT09	EVAL JAN 14 and pdf
						Iγ (411 keV) =	96 (*?*)	95.62 (*6*) %/decay

Observation: e.g. ^{182}Ta and ^{198}Au - no significant difference, however *V. Chechev* gives uncertainties

III. Data retrieving from IRDFF: XS and Spectra covariancies

(*V. Zerkin' web-retrieval system: e.g. 235U(n_{th},f) PFNS spectra*)



Such retrievals and plots allow:

- **easy access to the ENDF-6 formatted XS and spectra (including covariancies)**
- **compare model uncertainties with experimental ones and make conclusions like:**
  too large ENDF/B-VII.1 uncertainties for ^{235}U(n_{th},f)PFNS and TENDL(>15 MeV) for ^{54}Fe(n,2n)

IV. Neutron Source data relevant for IRDFF

- Data for Neutron sources:

  - following IAEA Meeting "**Neutron Sources Spectra for EXFOR**", April 2011
    https://www-nds.iaea.org/index-meeting-crp/CM-2011_web/

  - we regular update (last – March 2014) Memo CP-D/700rev3
    "**Compilation of light-ion induced neutron spectra for applications**"

- Example of missing data found in 2014:

  Wang Xiaozhong et al. "*Measurement of Neutron Spectra from thick Be target bombarded with deuterons*", Nucl. Sci. and Tech. 5(1994)193

  Data presented as Table – CNDC compile them !

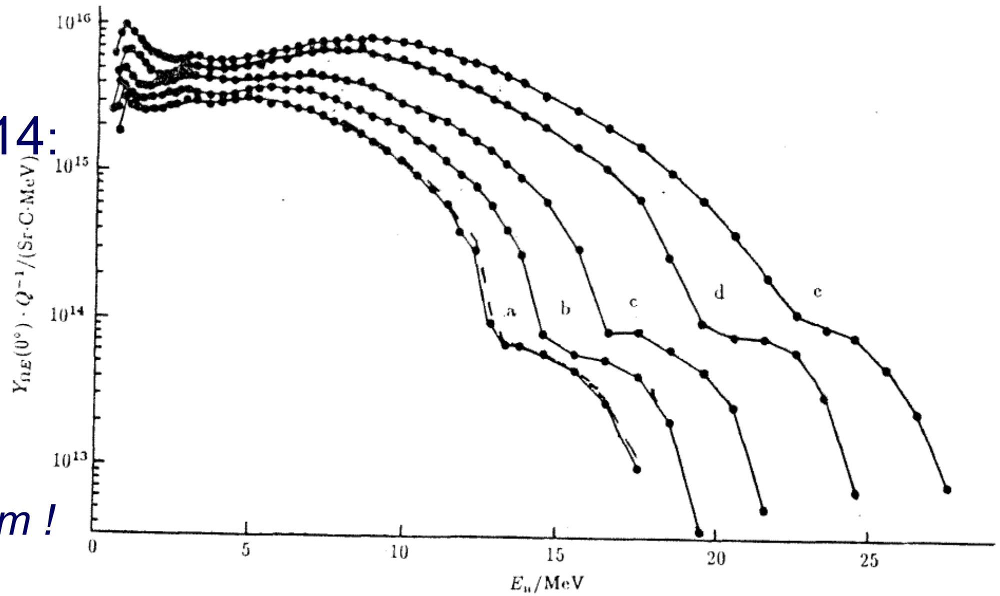


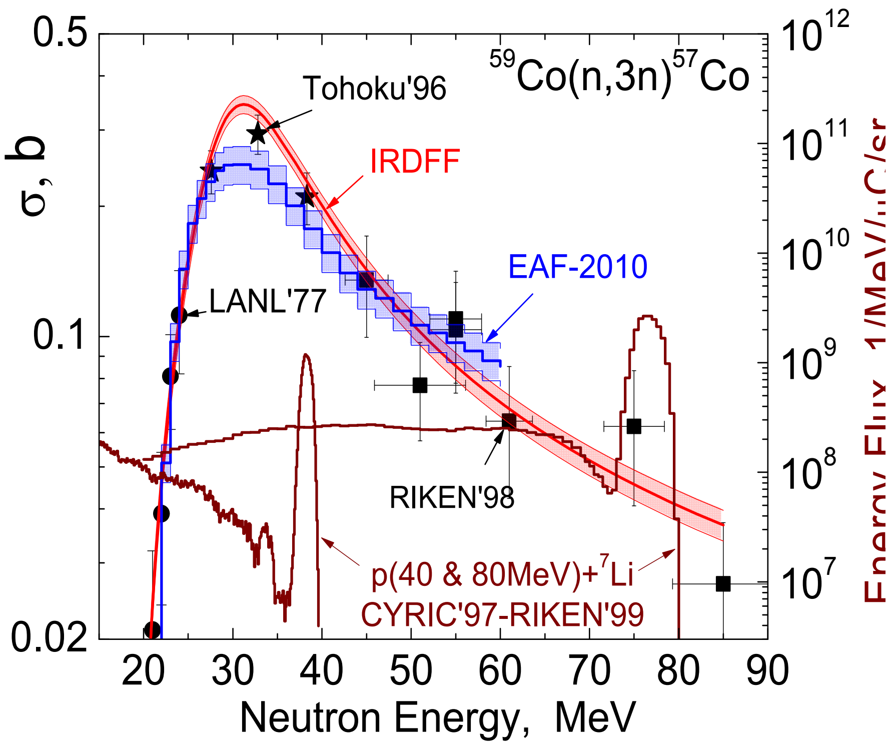
Fig.6 Spectral neutron yield per unit beam charge $Y_{\Omega E}(0°)/Q$ for thick Be target bombarded with deuterons of various energies

Curve a,b,c,d,e correspond to E_d =13.5, 15, 17, 20, 22 MeV; Previous data [4] at E_d =13.54 MeV are also shown here as a dashed line for comparison

V. Other IRDFF relevant data and EXFOR

High Energy (> 15-20MeV)

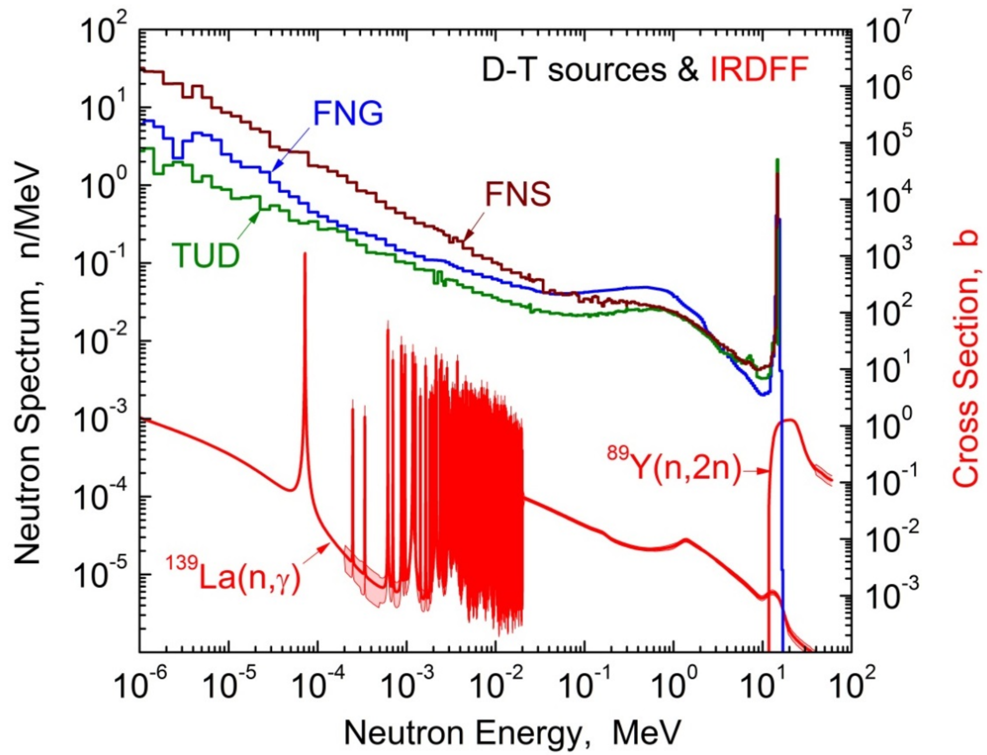
(n,3-6n) on ^{59}Co, ^{169}Tm, ^{209}Bi, ^{197}Au…
point data and broad spectra data



Task for NRDC/EXFOR:
- **compile new σ(E) and <σ(E)>**
- **compile neutron spectra**
  (we did it for L. Greenwood spectra)

D-T Fusion Energies (≤ 15 MeV):

such data were used for validation of EAF, but never for Dosimetry !



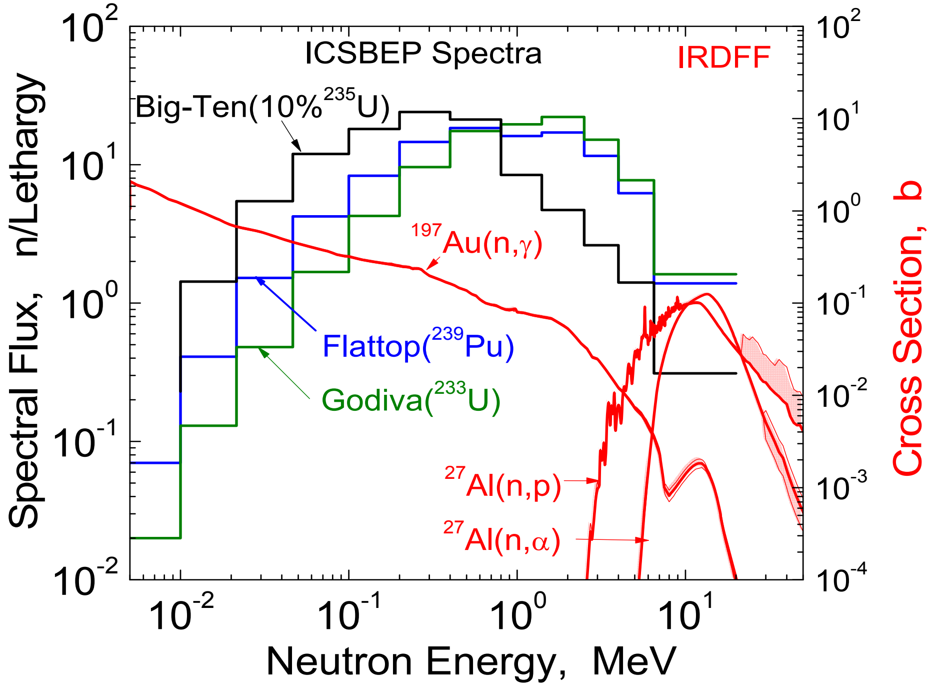
Task for NRDC/EXFOR:
- **distinguish between EXFOR and SINBAD**
- **compile <σ> and D-T neutron spectra relevant for EXFOR**

V. Other IRDFF relevant data and EXFOR

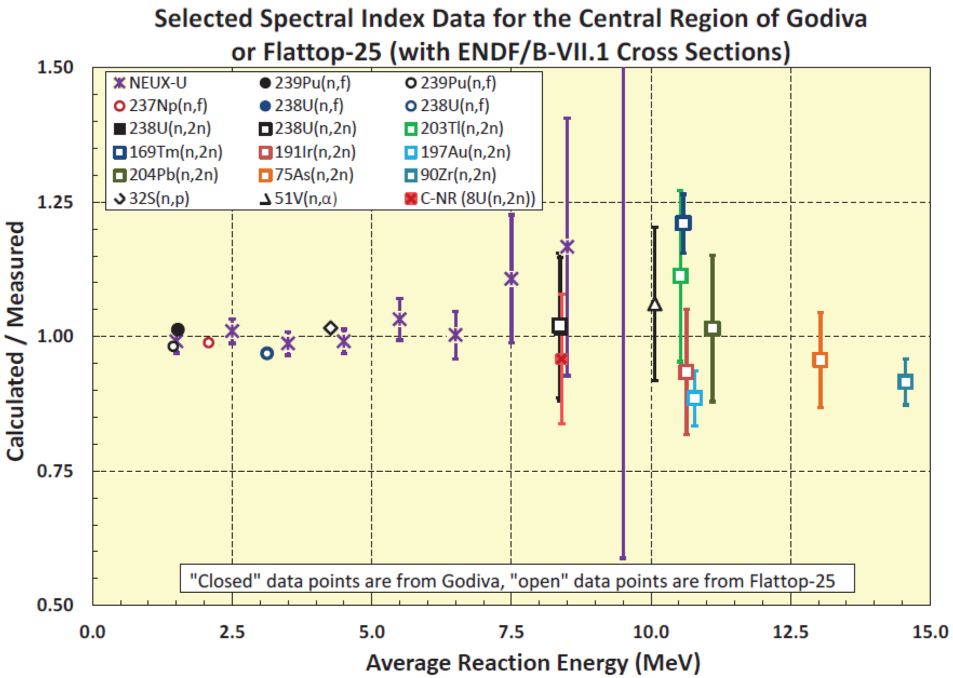
Reactors & Critical Facilities

already collected in ICSBEP and new ones will be produced during CRP

ICSBEP spectra and IRDFF XS



Validation: *M. Chadwick et al. CIELO papers:*



Task for NRDC/EXFOR:

- **distinguish between EXFOR and ICSBEP**
- **should we compile <σ> in EXFOR, whereas spectra/MCNP-models are in ICSBEP ?**

Conclusions: IRDFF relevant data and EXFOR

✓ **Current work:**

- compile EXFOR missed data collected in new MEMO CP-D/838
  and in updated MEMO CP-D/700rev3

- compile IRDFF data (σ(E), <σ>, spectra) appearing in new publications

- compile decay parameters, check them with authors
  (systematic inspection of suspicious $T_{1/2}$ in EXFOR (>1,000 entries) is ongoing)

✓ **Perspective work - following the needs of IAEA CRP on IRDFF consider and eventually take a decision on relation and sharing information between:**

- EXFOR (SPA) and IRDF-2002 (neutron research reactor facility spectra)

- EXFOR (XS or SPA) and SINBAD (14 MeV fusion benchmarks):

- EXFOR (SPA) and ICSBEP (critical facility benchmarks)