International Atomic Energy Agency

Fission Product Yields in EXFOR
- Compilation and Dissemination -

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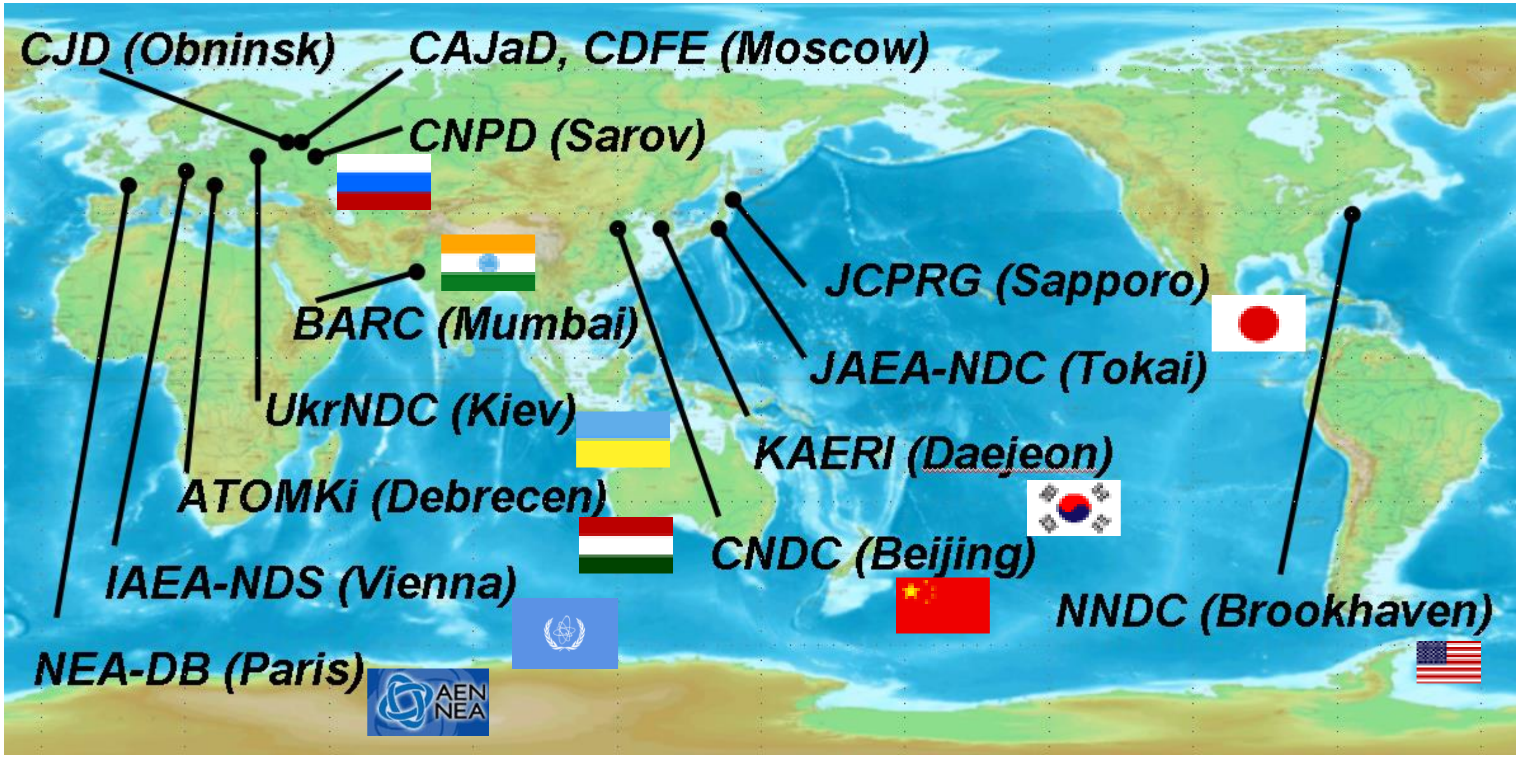
IAEA Nuclear Data Section

EXFOR Workshop 2018
22 – 25 October 2018, IAEA Vienna

1. Introduction

Nuclear Reaction Data Centres (NRDC)



13 centres from 8 countries and 2 international organisations

(China, Hungary, India, Japan, Korea, Russia, Ukraine, USA, NEA, IAEA)

NRDC – Centre Compiling Neutron-induced FY Quantities

Centre	Location of facility covered	New FY entries (2011-)
NNDC	USA and Canada	24
NEA DB	West Europe and Japan	16
NDS	"Rest of the world"	7
CJD	Former USSR (except for Ukraine)	4
CNDC	China	4
KNDC	Korea	0
NDPCI	India	22
UkrNDC	Ukraine	0

Vienna EXFOR Workshop (October 2016)

(as of 29 June 2018. Entries with SF2=N or 0 & SF6=FY counted.)

Fission Quantities Covered in EXFOR

- Fission product yield (FPY)
- Fission neutron multiplicity (prompt, delayed)
- Fission neutron spectrum (prompt, delayed)

major improvements in EXFOR in connection with IAEA CRPs

- Kinetic energy (fragment, neutron)
- Fission γ multiplicity, spectrum

etc.

JOURNAL OF NUCLEAR SCIENCE AND TECHNOLOGY
https://doi.org/10.1080/00223131.2018.1467288

Taylor & Francis

ARTICLE

Check for updates

^{235}U(n, f) Independent fission product yield and isomeric ratio calculated with the statistical Hauser–Feshbach theory

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ANS

NUCLEAR SCIENCE AND ENGINEERING · VOLUME 190 · 258–270 · JUNE 2018
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DOI: https://doi.org/10.1080/00295639.2018.1429173

Check for updates

Identifying Inconsistencies in Fission Product Yield Evaluations with Prompt Neutron Emission

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Received September 13, 2017
Accepted for Publication January 14, 2018

Quantities other than FPY (*e.g.*, ν, P(ν), TKE) also put useful constraints on FPY modelling.

Fission Product Yield Quantities in EXFOR

Process	Y(Z,A)	$Y(A) = \Sigma_Z Y(Z,A)$	$Y(Z) = \Sigma_A Y(Z,A)$
Fission			
		PRE: primary y.	
Prompt neutron emission			
	IND: independent y.	SEC: secondary y. = MAS: mass y.	CHG: charge y.
Delayed neutron and β emission			
	CUM: cumulative y.	CHN: chain y.	

Also

- Yield ratio (e.g., fractional independent / cumulative yield, R-value)
- Most probable charge (ZP) and mass (AP)
- Ternary yield - long-range α, triton (TER)

2. Coverage of FPY in EXFOR

Statements from IAEA TM on FY (IAEA(NDS)-713, 2016)

- "… 'historical' data* need to be revisited in light of the new measurements and models that have become available in recent years."

  (* Historical data mean those from radiochemical methods, classical mass spectrometry etc.)

- "It may be timely to look into the EXFOR database and check the completeness with respect to the compilations performed in the two previous IAEA CRPs on fission product yields."

TM on FPY data – current status and perspectives (23-26 May 2016, Vienna)

FPY in EXFOR in 1970s

- FPY was outside the EXFOR scope when Four Centre (4C) collaboration started in 1969.
- EXFOR coding rule for FPY was proposed by NDS (Memo 4C-3/42). It was reviewed by Crouch (Harwell), and accepted in the 1972 4C Meeting.
- However, the 4C manpower was not enough to start FPY compilation.

C) <u>Compilation of Fission Product Yields, Capture Gamma Ray Spectra and Other Data</u>

The problems of compiling both fission product yields and capture gamma ray spectra were discussed by the participants. The final decision was that <u>none of the centres have the manpower</u> to devote to these data yet.

Summary of 11th Four-Centre Meeting (1975)

Individual FPY Compilation

Some individual FPY compilations were available in 1970s, *e.g.*,

- M.E. **Meek**, B.F. Rider, NEDO-12154 (1972), -12154-1 (1974), -12154-2E (1978); B.F. Rider, NEDO-12154-3C (1981).
- E.A.C. **Crouch**, At.Data Nucl.Data Tables 19 (1977) 419.

They probably reduced motivation to maintain EXFOR complete for FPY.

1) Fission product yields and other important fission product data.

The original proposal by NDS for compilation of fission yield data, which had been previously distributed in Memo 4C-3/42, was adopted with only minor revisions. Until final manual pages are issued, compilation should proceed according to the proposals of Memo 4C-3/42. Since most of the large quantity of existing data are conveniently summarized in published review articles (e.g. Walker, AECL-3037, Part I), or in articles currently in preparation, only data which are not included in or which are produced subsequently to these review articles need be compiled with high priority.

Summary of 8th Four-Centre Meeting (1972)

IAEA Meetings on FPY in 1980s

Two IAEA meetings on FPY in 1980s:

- SM on Fission yield evaluation (September 1987, Studsvik, INDC(NDS)-208)
- CM on Compilation and evaluation of fission yield nuclear data (September 1989 ,Vienna, INDC(NDS)-261)

which were followed by the **IAEA CRP on "Compilation and evaluation of fission yield nuclear data" (1991-1996)**.

They definitely gave data centres strong motivation to improve the EXFOR coverage for FPY.

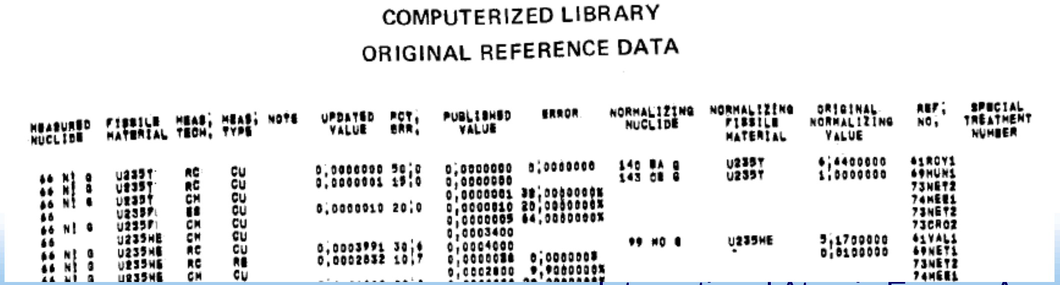
Individual Compilation – Meek's Compilation

- **"Compilation of Fission Product Yields, Vallecitos Nuclear Center"**

  M.E. Meek and B.F. Rider, NEDO-12154 (1972), -12154-1 (1974), -12154-2E (1978); B.F.Rider NEDO-12154-3C (1981).

- It tabulates both evaluated and experimental data (updated yield, original yield, original reference yield).

- Last version in 1993 (T.R. England & B.F. Rider, LA-UR-94-3106).
  They say files are on the anonymous ftp site - t2.lanl.gov/yields.



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ORIGINAL REFERENCE DATA

MEASURED NUCLIDE	FISSILE MATERIAL	MEAS. TECH.	MEAS. TYPE	NOTE	UPDATED VALUE	PCT. ERR.	PUBLISHED VALUE	ERROR	NORMALIZING NUCLIDE	NORMALIZING FISSILE MATERIAL	ORIGINAL NORMALIZING VALUE	REF. NO.	SPECIAL TREATMENT NUMBER
66 NI G	U235T	RC	CU		0.0000000	50.0	0.0000000	0.0000000	140 BA G	U235T	6.4400000	61ROY1	
66 NI G	U235T	RC	CU		0.0000001	15.0	0.0000000		143 CE G	U235T	1.0000000	69HUN1	
66 NI G	U235T	CH	CU				0.0000001	38.0000000%				73NET2	
66	U235F	SS	CU		0.0000010	20.0	0.0000010	20.0000000%				74MEE1	
66 NI G	U235F	CH	CU				0.0000005	64.0000000%				73NET2	
66	U235HE	CH	CU				0.0003400					73CRO2	
66 NI G	U235HE	RC	CU		0.0003991	30.6	0.0004000		99 MO G	U235HE	5.1700000	61VAL1	
66 NI G	U235HE	RC	RE		0.0002832	10.7	0.0000038	0.0000008			0.0100000	69NET1	
66 NI G	U235HE	CH	CU				0.0002800	9.9000000%				73NET2	

Individual Compilation – Meek's Compilation (cont)

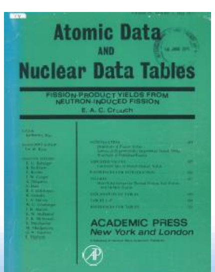
- V.McLane (NNDC) was asked to convert Meek & Rider's files into EXFOR in the 1987 Studsvik meeting.

- Her automatic conversion produced quasi-EXFOR entries which were further upgraded by M.Lammer (NDS), Wang Dao (CNDC) etc. with the source articles.

- Centres were asked to accelerate upgrading of quasi-EXFOR entries to normal EXFOR entries using STATUS=NCHKD (*original reference not checked*) in 11th NRDC meeting (1991).

Individual Compilation - Crouch's Compilation

- **"Fission-Product Yields from Neutron-Induced Fission"**
  - E.A.C Crouch, At. Data Nucl. Data Tables **19** (1977) 419, followed by
  - **Crouch 1, 2 and 3** (then Crouch retired in 1981),
  - **Crouch 4** (by E.A.C. Crouch, M.F. James, P.S. Whitworth, C. Dunn, 1985) - **394 exp. refs.**
  - **UKFY1** (→JEF1) by J. Banai, M.F. James (unpublished) – **16 additional exp. refs.**
  - **UKFY2** (by M.F. James, R.W. Mills, D.R.Weaver, Prog. Nucl. Energy 26(1991)1; AEA-TRS-1018 Part II, 1991) – **16 additional exp. refs.**
  - **UKFY3.0** (by R.W. Mills, PhD thesis in 1995) – **100 additional exp. refs.**
- Meek+Rider compilation were added to UKFY3 from EXFOR, and improved its coverage of early U.S. measurements.



A NO.	EL.	REF. NO.	EXPERIMENTAL YIELDS & SD		MEAN COMPONENT	R VALUE	CHI2/DF COMPONENT	DCHI2 EXTERNAL	CHI2	TOTAL INT.
77	GE	640	1.100E-02	15.0						3.3:
	AS	300	1.050E-01	50.0		1.83				
	CHAIN	2102	9.100E-03	20.0		-1.83				
78	GE	640	5.200E-02	15.0						

Individual Compilation - Crouch's Compilation (cont)

- Crouch's compilation was converted to **NEUDATA** by CCDN (Saclay) in 1977. But CCDN decided not to give high priority to its conversion to EXFOR (Memo 4C-2/89).

- Charlie Dunford (NNDC) said in 1977 that Meek+Rider's compilation contains ~1000 articles whereas Croach has ~300 articles only.

Mr. Schofield reported that CCDN converted the Crouch Library of experimental fission-product yield data to Neudada, and thus these data could well be transmitted after performing a simplified Exfor compilation procedure. (see Conclusion 12).

Mr. Dunford said that this converted Crouch Library should do it, although it is known that this does not contain all of the details required in Exfor. NNDC would have no manpower for reviewing the correctness of the Crouch Library. Mr. Dunford pointed out that Meek and Rider's compilation contains about 1000 references, whereas Crouch has about 300 references only, due to quality selections. NNDC could provide a list of references found missing in Crouch's Library (Action 52).

Summary of 2nd NRDC Meeting INDC(NDS)-90, 1977

Individual Compilation - Crouch’s Compilation (cont)

- P.D. Johnson (CCDN) compared Crouch’s 1977 compilation with EXFOR and CINDA in 1980.
- He concluded that of 394 references in Crouch’s compilation, 103 are missing in CINDA and 359 are missing in EXFOR.
- The situation could be better after Meek-to-EXFOR conversion in 1990s, but we do not know how many experiments are still not in EXFOR.

REFERENCE	DATE	LAB	AREA	EXFOR	CINDA
---AREA 1---					
58GENEVA15	4365809	MCM	1		
58GENEVA15	4445809	NRD	1		
58GENEVA15	4495809	NRD	1		
58GENEVA15	4595809	CRC	1		
65ATLANT	6500		1		NOT IN CINDA
65SALZB 1	4236507	NRD	1		
69VIENNA	9136907	MIS	1		
70LVEG	213067001	LAS	1		NOT IN CINDA
70MARBG	687009	LAS	1		NOT IN CINDA
75WASH	3787503	ACC	1		NOT IN CINDA
AD-62702	76500	NRD	1		NOT IN CINDA
AD-686041	6812	NRD	1		NOT IN CINDA
AECD-3551	5308	LAS	1		
AECD-3597	5300	LAS	1		NOT IN CINDA
ANDERSON	7200	TEX	1		NOT IN CINDA
ANL-4927	5200	ANL	1		
ANL-4928	5200	ANL	1		NOT IN CINDA
ANS 13	907007	ANL	1		
ANS 14	3707106	ANL	1		
ANS 15	4837200	ANL	1		
ANS 17	5317300		1		NOT IN CINDA
ANS 19	3977410	LRL	1		
ANS 22	6777500		1		
ANS 24	4587600	ANL	1		
BAYHURST	6000	LAS	1		NOT IN CINDA
BERGE	7200	MIS	1		NOT IN CINDA
BNWL-281	7300	BNW	1		NOT IN CINDA
CJC 31	485300	CRC	1		NOT IN CINDA
CJC 31	1205302	CRC	1		
CJC 31	2425300	CRC	1		
CJC 32	10175411	CRC	1		
CJC 33	8305505	MCM	1	EXFOR12086	
CJC 34	1935603	MCM	1		

not in EXFOR

Memo 4C-2/115 by Johnson

Checking of UK Database Against EXFOR

- We should know what are in the UK database but missing in EXFOR.
- Robert Mills is happy to share the latest version of his database with NDS and NEA DB (but he needs clearance at his side).
- Takanari Fukuda, Shin Okumura and O.N. (NDS) is checking existence of the references in Mill’s 1995 DB in EXFOR/CINDA.

Checking of UK Database Against EXFOR (Cont)

- Very preliminary result for the 1st part of UK list (1190 references): EXFOR/Mills~73%, CINDA/Mills~91%.

Added line	ref min	ref max	author	reference in EXFOR/CINDA format ([]: presence not confirmed)	EXFOR # (0: not in EXFOR, []: not in EXFOR but blocked in CINDA)	Lab (0: not in CINDA)	remarks	in EXFOR ? (Yes=1	in CINDA ? (Yes=1	Completeness
	1	3	K.A.Petrzhak+	R,AEC-TR-4696,1961	0	4RUSRI	Eng.of B,NEJTRONFIZ,,217,1961	0	1	
	4	12	B.P.Bayhurst	R,TID-5787,1957	13432	1USALAS		1	1	
	13	13	H.V.Weiss+	R,USNRDL-TR-943,1965	0	1USANRD	Superseded	0	1	
	14	14	J.M.Crook+	R,IS-558,1963	13200	1USAIOW		1	1	
	15	15	R.N.Ivanov+	J,JNE,9,46,1959	40730	4RUSITE	Eng.of J,AE,3,546,1957	1	1	
Added	15	15	R.N.Ivanov+	J,SJA,3,1436,1957	40730	3RUSITE	↑	1	1	
	16	16	M.P.Anikina+	J,JNE,9,167,1959	0	4RUSITE	Eng.of J,AE,4,198,1958	0	1	
	16	16	M.P.Anikina+	J,SJA,4,270,1958	0	4RUSITE	Eng.of J,AE,4,198,1959	0	1	
	17	20	M.P.Anikina+	C,58GENEVA,15,446,1958	40730	4RUSITE				
	21	27	D.C.Aumann+	J,JIN,31,1935,1969	13242	1USAANL				
	26	26	N.K.Aras+	J,JIN,28,763,1966	13085	1USAORL	Supersedes R,MIT-905-52,21,1965.			
Added	26	26	N.K.Aras+	R,MIT-905-21,1965	0	1USAMIT	↑			
	27	27	M.P.Anikina+	J,JNE,6,169,1957	0	4RUSITE	Eng.of J,AE,2,275,1957			
	28	28	A.T.Blades+	J,CJC,34,233,1956	13389, 13391	1CANMCM	Data also refered to in [401-402].			
	29	29	L.R.Bunney+	J,JIN,27,1183,1965	13214	1USANRD				
	30	30	O.Birgul+	J,RCA,8,9,1967	0	0	Corrected by O.Birgul+,J,RCA,16,103,1971	0	0	


Checking of Mill's DB against EXFOR/CINDA (Example)

```
**********************************************************
*   References from the Crouch Database                 *
*       COMPILED BY E.A. CROUCH                          *
*       LAST ADDITION 1981.                              *
**********************************************************
1_3. K A PETRZHAK ET AL. AEC TR 4696
4_12. B P BAYHURST. TID 5787
13. H V WEISS, W L REICHERT. AD 627027, TR 943.
14. J M CROOK, A F VOIGHT. IS 558
…
```

UK database
(received from Mills)

CINDA retrieval

```
1. K.A.Petrzhak+,R,AEC-TR-4696,1961
2. B.P.Bayhurst,R,TID-5787,1957
3. H.V.Weiss+,R,USNRDL-TR-943,1965
   (superseded by EXFOR 13083)
4. J.M.Crook+,R,IS-558,1963
…
```

EXFOR retrieval

1. Missing in EXFOR!
2. EXFOR 13432
3. (skipped)
4. EXFOR 13200

…

FPY Experiments in CINDA but not in EXFOR

The number of experiments in CINDA blocked with and without EXFOR for three fissioning systems.
(Only manually compiled CINDA records are used.)

Fission system	**FY experiments (total)**	**FY experiments without EXFOR**
^{235}U(n,f)	683	309
^{239}Pu(n,f)	273	116
^{252}Cf(sf)	145	85

Many FY experiments in CINDA are still missing in EXFOR.
Note that

- not all CINDA references are EXFORable.
- CINDA FY include quantities other than FYP.

3. Dissemination of FPY in EXFOR

Statement from IAEA TM on FY (IAEA(NDS)-713, 2016)

- “Dissemination of experimental and evaluated fission product yield data is another important point to be taken seriously by dissemination centers.”
- “Existing tools like JANIS (OECD/NEA Data Bank), should be upgraded to facilitate online display and retrieval of FPY data.”
- “Participants also expressed the need for improving the retrieval of FPY data from the EXFOR database.”

TM on FPY data – current status and perspectives (23-26 May 2016, Vienna)

Feedbacks from Shu Nengchuan

1. Standard data table:

The fission yield data table has many formats, it is better to give a standard format, such as :

`EN ELMENT MASS ISOMER DATA DATA-ERR DECAY-FLAG` …

2. Product retrieve:

When the product **MASS** and/or **ELMENT** are given in the data table, that will be failed through the retrieve system.

Suggestion:

Create a product index from data table, and add the function in the retrieve system. This is very important for fission yield data evaluation.

Feedbacks from Shu Nengchuan (cont)

3. Missing of the decay gamma intensity:

Many entries did not give the gamma intense in the **DECAY-DATA**, which is trouble to yield evaluation.

4. Add a covariance data block

5. Year format:

The year in the REFERENCE should be given in one format such as **`197808`** or **`1978`**, which year=1978 and month=08.

Feedback from Shu Nengchuan (cont)

6. XML output

XML lib is very good, but the structure is too complicate. For example, **my XML** for the data table is more simple :

```
<DATASET_13200002 HEADUNIT="ELEMENT:NO-DIM MASS:NO-DIM DATA:NO-DIM
DATA-ERR:NO-DIM"  ROW=2  COLS= 4 >
     <DATA DATA="1.058" DATA-ERR="0.018" ELEMENT="36" MASS="87" />
     <DATA DATA="1.115" DATA-ERR="0.011" ELEMENT="36" MASS="88" />
     <DATA>END</DATA>  #This line is needed.
</DATASET>
```

Dr Shu sent NDS these comments through Wang Jimin (CNDC).

FPY EXFOR Format

Flags like PRE, SEC, IND, CUM, … are seen in the EXFOR REACTION code.

Example:

- 92-U-235(N,F)MASS,PRE,FY (primary fragment mass yield table Y(A))
- 92-U-235(N,F)ELEM/MASS,CUM,FY (cumulative yield table Y(Z,A))

Product	FCY (%)
^{83}Kr	0.296(3)
^{84}Kr	0.477(5)
^{86}Kr	0.763(8)
…	…

```
REACTION    (94-PU-239(N,F)ELEM/MASS,CUM,FY,,SPA)
…
DATA                    4          33
ELEMENT     MASS        DATA        DATA-ERR
NO-DIM      NO-DIM      PC/FIS      PC/FIS
 36.         83.         0.296       0.003
 36.         84.         0.477       0.005
 36.         86.         0.763       0.008
…
```

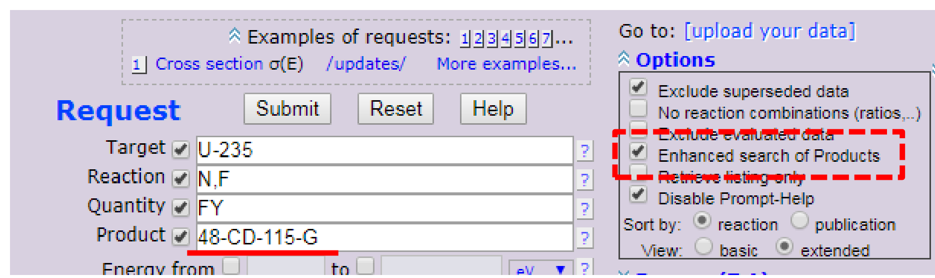
EXFOR Deficiency (1): FPY as a Variable of Table

We can search it by Product=48-CD-115-G on NDS website.

```
REACTION    (92-U-235(N,F)48-CD-115-G,CUM,FY)
DECAY-DATA  (48-CD-115-G,2.33D,B-)
…
DATA
PC/FIS
 0.011
ENDDATA                  3
```

We have to activate "*Enhanced search of Products*" to find it on NDS website.

```
REACTION    (92-U-235(N,F)ELEM/MASS,CUM,FY)
DECAY-DATA  (48-CD-115-G,2.33D,B-)
…
ELEMENT     MASS        ISOMER      DATA
NO-DIM      NO-DIM      NO-DIM      PC/FIS
…
 48.         115.         0.          0.011
…
ENDDATA                 3
```



EXFOR Deficiency (1): FPY as a Variable of Table (cont)

A subentry for a specific product nuclide

```
REACTION    (92-U-235(N,F)48-CD-115-G,CUM,FY)
DECAY-DATA (48-CD-115-G,2.33D,B-)
…
DATA
PC/FIS
 0.011
ENDDATA                   3
```

A subentry for several product nuclide

```
REACTION    (92-U-235(N,F)ELEM/MASS,CUM,FY)
DECAY-DATA (48-CD-115-G,2.33D,B-)
…
ELEMENT     MASS        ISOMER      DATA
NO-DIM      NO-DIM      NO-DIM      PC/FIS
…
 48.         115.        0.          0.011
…
ENDDATA                   3
```

This flexibility helps EXFOR compilers, but we know it is not convenient for end-users.

The NDS web system can provide a table in a unified style in the **C4** (as it has been also done for isotope production cross sections.)

Current C4 Format for FPY (EXFOR 10828.002)

Proj.	Targ.	MF	MT		Einc,eV	dEinc,eV	FPY/fis	dFPY/fis	Z(FPY)	A(FPY)
1	92235	801	18	A	6000000.	250000.0	0.011566	6.7545-3	35.00000	84.00000
1	92235	801	18	A	6000000.	250000.0	0.029404	5.9521-3	36.00000	87.00000
1	92235	801	18	A	6000000.	250000.0	0.038215	3.5542-3	38.00000	89.00000
1	92235	801	18	A	6000000.	250000.0	0.053087	5.8020-3	38.00000	91.00000
1	92235	801	18	A	6000000.	250000.0	0.058519	5.4426-3	40.00000	95.00000
1	92235	801	18	A	6000000.	250000.0	0.057187	6.2281-3	40.00000	97.00000
1	92235	801	18	A	6000000.	250000.0	0.061670	5.7356-3	42.00000	99.00000

Current "EXFOR REACTION – MF/MT Equivalence Table" for FPY

REACTION	MF	MT
(*,F)ELEM/MASS,CUM,FY	801	18
(*,F)ELEM/MASS,CUM,FY,,SPA	801	18
(*,F)ELEM/MASS,IND,FY,,MXW	801	18
(*,F)MASS,CHN,FY,,MXW	801	18
((*,F)ELEM/MASS,IND,FY,,MXW)/((*,F)MASS,CHN,FY,,	802	18

Not MF=8, MT=454/459?

(Must be improved and extended to make more FPY data available in C4.)

Computational Formats of FPY Proposed in 1980s

Proposal by P.D.Johnston (Memo 4C-2/113, 1980)

Computational Format for Fission Product Yields

Variable	FORTRAN Format	COBOL PL/I Format	Cols.	Description
DATA				
Z-TAR	I 3	9(3)	1-3	Z-number of target
A-TAR	A 3	X(3)	4-6	A-number of target
N-SPEC	A	X	7	Code for incident neutron spectrum (see A below)
N-ENER	E9.2	X(9)	8-16	Neutron energy (eV)
Z-PRO	I 3	9(3)	17-19	Z-number of product
A-PRO	A 3	X(3)	20-22	A-number of product
ISOM	A	X	23	Isomer state (m)
YIE-TYP	A 2	X(2)	24-25	Yield type (see B below)
YIELD	E10.3	X(10)	26-35	Yield (" " ")
YIE-ERR	E10.3	X(10)	36-45	Yield error(" " ")
DEC-PAR	A 2	X(2)	46-47	Decay particle (see C below)
HAL-LIF	A 8	X(8)	48-55	Half-life & units (free format)
DEC-EN	A 6	X(6)	56-61	Decay energy (keV)
BRA-RAT	A 4	X(4)	62-65	Branch ratio
NORMALISATION				
N-Z-TAR	I 3	9(3)	66-68	Z-number of target
N-A-TAR	A 3	X(3)	69-71	A-number of targe
N-N-SPEC	A	X	72	Code for incident neutron spectrum (see A below)
N-N-ENER	E9.2	X(9)	73-81	Neutron energy (ev)
N-Z-PRO	I 3	9(3)	82-84	Z-number of product
N-A-PRO	A 3	X(3)	85-87	A-number of product
N-ISOM	A	X	88	Isomer state (m)
N-YIE-TYP	A 2	X(2)	89-90	Yield type (see B below)
N-YIELD	E10.3	X(10)	91-100	Yield (" " ")
N-DEC-PAR *	A 2	X(2)	101-102	Decay particle (see C below)
N-HAL-LIF *	A 8	X(8)	103-110	Half-life & units (free format)
N-DEC-EN *	A 6	X(6)	111-116	Decay energy (keV)
N-BRA-RAT *	A 4	X(4)	117-120	Branch ratio
INDEX				
LAB	A 3	X(3)	121-123	Laboratory (as in CINDA dictionary)
ACCESS	I 5	9(5)	124-128	EXFOR accession number
SUB-ACCESS	I 3	9(3)	129-131	EXFOR sub-accession number
FILLER	A	X	132	Blanks

* Not currently implemented.

Proposal by V.McLane (Memo CP-C/189, 1989)

FISSION PRODUCT YIELD COMPUTATION FORMAT

Variable	Columns	FORTRAN Format
Data		
Target isotope Z,A,isomer	1 – 7	I3,I3,I1
Incident projectile	8	A1
Yield type/modifier	9 – 11	A2,A1
Energy (eV)	12 – 19	x.xxx±nn
Spectrum code	20	A1
Product isotope Z,A,isomer	21 – 27	I3,I3,I1 Z=0 for mass yields; A=0 for element yields
Decay half-life (min)	28 – 35	x.xxx±nn
Spin/parity†	36 – 38	±x.
Yield*	39 – 47	x.xxxx±nn
+Yield error*	48 – 56	x.xxxx±nn
−Yield error*	57 – 65	x.xxxx±nn
Error code	66	A1
Normalization		
Target isotope Z,A,isomer	67 – 73	I3,I3,I1
Incident projectile	74	A1
Yield type	75 – 76	A2
Energy (eV)	77 – 84	x.xxx±nn
Spectrum code	85	A1
Product isotope Z,A,isomer	86 – 92	I3,I3,I1 Z=0 for mass yields; A=0 for element yields
Decay half-life (min)	93 –100	x.xxx±nn
Yield*	101–109	x.xxxx±nn
Yield error*	110 – 118	A2
Method code	119	A1
Reference		
Institute	120 – 122	A3 (as in CINDA)
Date	123 – 124	A2
Accession #	125 – 129	A5
Subaccession #	130 – 132	I3

Both include monitor values (as MeeK+Rider's compilation), decay data etc.

EXFOR Deficiency (2): FPY Ratio

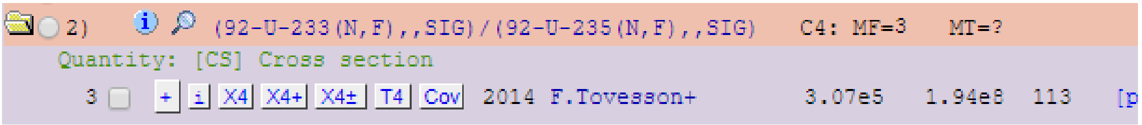
```
REACTION    ((92-U-235(N,F)48-CD-115-G,CUM,FY)/
            (92-U-235(N,F)42-MO-99,CUM,FY))
…
DATA        DATA-ERR
NO-DIM      PER-CENT
 0.402       26.3
ENDDATA               3
```

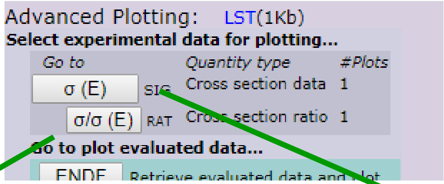
We know evaluators prefer to have the measured ratio to the FPY of monitor products (e.g., ^{99}Mo, ^{140}Ba).

But some end-users want to have the corresponding absolute FPY - Request from K.Tsubakihara (Tokyo Inst. Tech.)

EXFOR Deficiency (2): FPY Ratio (cont)

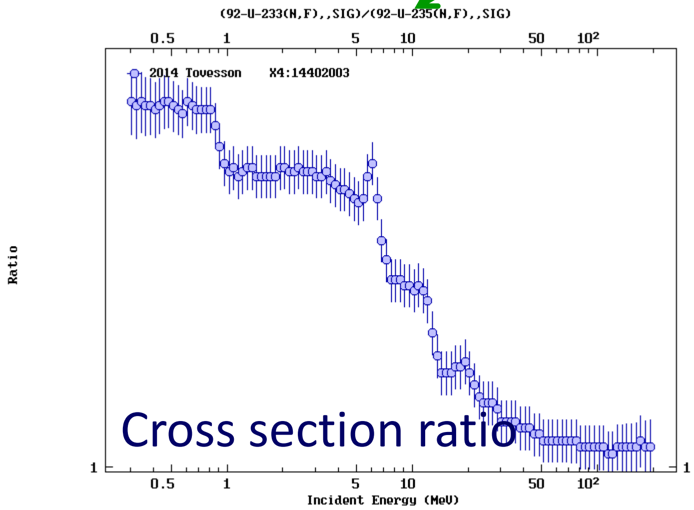
^{233}U(n,f)/^{235}U(n,f) cross section ratio (EXFOR 14402.003)

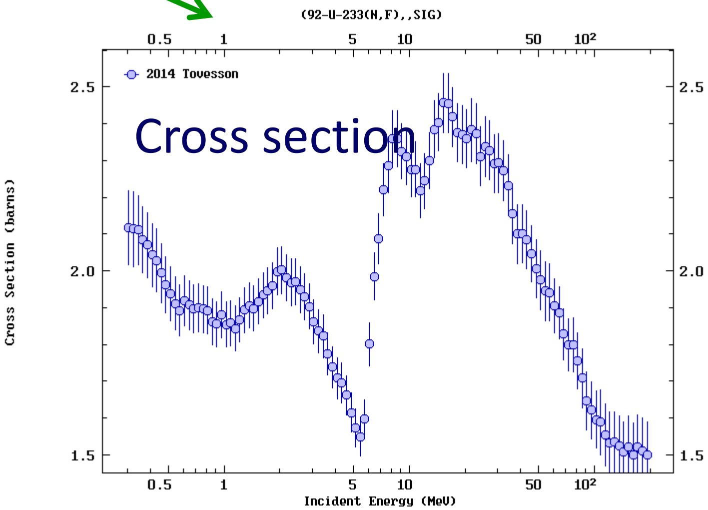




Plotted as the ratio provided by the authors

Plotted after conversion to absolute cross section by using the IAEA ^{235}U(n,f) standard stored in the system.





This can be extended to FPY (Monitor FPY values should be known!)

EXFOR Deficiency (2): FPY Ratio (cont)

Other major FPY ratios in EXFOR:

Fractional independent yield (FRIND)

```
((92-U-235(N,F)ELEM/MASS,IND,FY)/
(92-U-235(N,F)MASS,CHN,FY))
```

Fractional cumulative yield (FRCUM)

```
((92-U-235(N,F)ELEM/MASS,CUM,FY)/
(92-U-235(N,F)MASS,CHN,FY))
```

R-value (RVAL)

```
(((92-U-238(N,F)ELEM/MASS,CUM,FY,,FIS)/
(92-U-238(N,F)42-MO-99,CUM,FY,,FIS))//
((92-U-238(N,F)ELEM/MASS,CUM,FY,,MXW))
(92-U-238(N,F)42-MO-99,CUM,FY,,MXW)))
```

We should extend C4 to these ratios!

EXFOR Deficiency (3): Indirectly Measured FPY

Physics Letters B 761 (2016) 125–130

Contents lists available at ScienceDirect

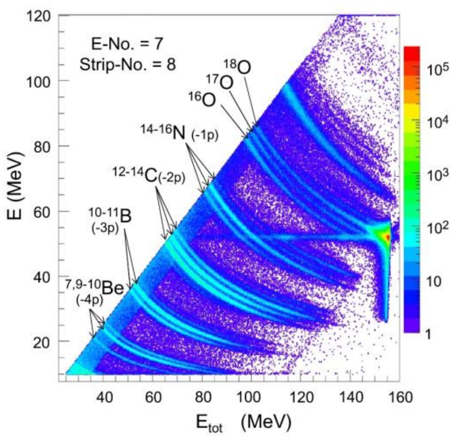
Physics Letters B

www.elsevier.com/locate/physletb

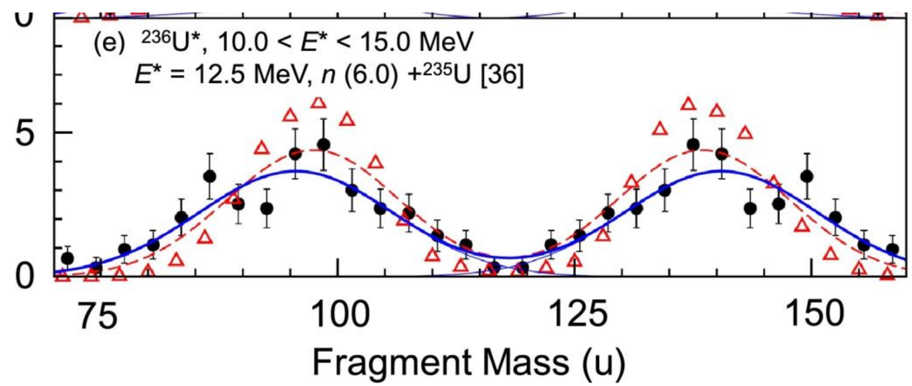
Fission fragments mass distributions of nuclei populated by the multinucleon transfer channels of the $^{18}O + ^{232}Th$ reaction

R. Léguillon [a], K. Nishio [a,*], K. Hirose [a], H. Makii [a], I. Nishinaka [a], R. Orlandi [a], K. Tsukada [a], I. Smallcombe [a,b], S. Chiba [c], Y. Aritomo [d], T. Ohtsuki [e], R. Tatsuzawa [f], N. Takaki [f]

$^{232}Th(^{18}O,^{14}C+f)$ to study FPY of $^{236}U^*$ fissioning system



PID of projectile-like particle



Mass distribution measured at JAEA Tandem
(△ is from $^{235}U(n,f)$ experiments)

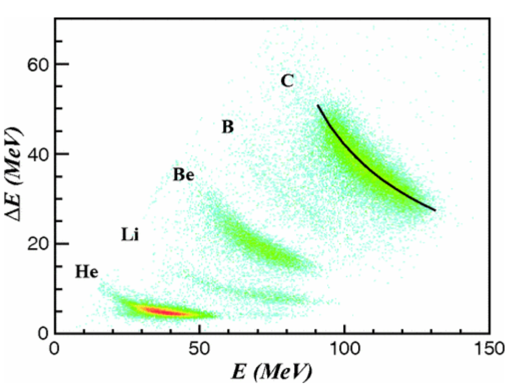
EXFOR Deficiency (3): Indirectly Measured FPY (cont)

PHYSICAL REVIEW C **88**, 024605 (2013)

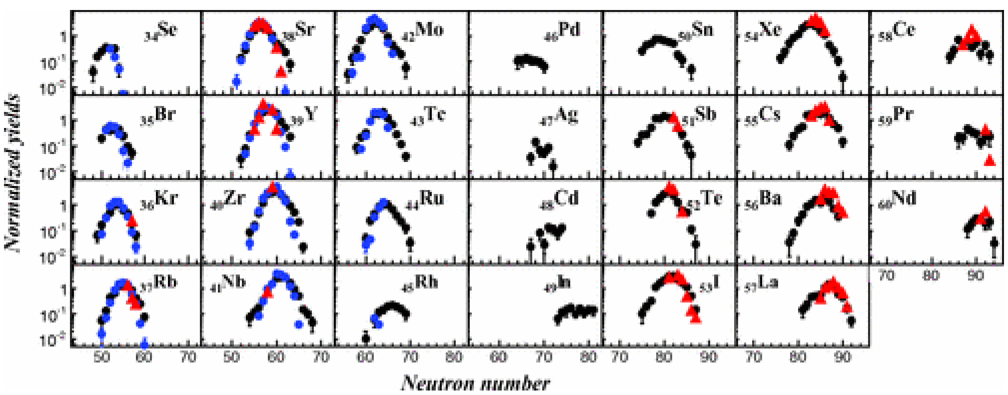
Isotopic yield distributions of transfer- and fusion-induced fission from ^{238}U + ^{12}C reactions in inverse kinematics

M. Caamaño,[1,2,*] O. Delaune,[1,†] F. Farget,[1,‡] X. Derkx,[1,§] K.-H. Schmidt,[1] L. Audouin,[3] C.-O. Bacri,[3] G. Barreau,[4]
J. Benlliure,[2] E. Casarejos,[5] A. Chbihi,[1] B. Fernández-Domínguez,[6] L. Gaudefroy,[7] C. Golabek,[1] B. Jurado,[4]

^{238}U(^{12}C,^{10}B+f) to study FPY of ^{240}Pu* fissioning system



PID of projectile-like particle



Isotopic yield measured by VAMOS @GANIL
(● and ● are from ^{239}Pu(n_{th},f) experiments)

EXFOR Deficiency (3): Indirectly Measured FPY (cont)

Indirect measurement of fission following

- Transfer reaction (e.g., JAEA, VAMOS@GANIL)
- Coulomb excitation (e.g., SOFIA@GSI)
- β-decay (e.g., ISOLDE@CERN)

(My thanks to Valentina Semkova for itemizing these cases!)

According to EXFOR rule, ^{235}U(n,n’f) second chance fission becomes

`92-U-235(N,N+F)`…

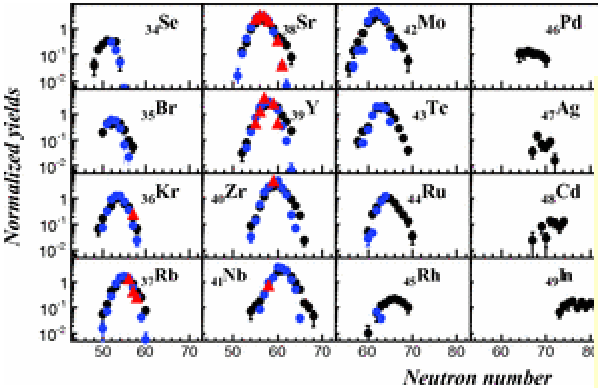
But probably users do not want to see

`92-U-238(6-C-12,5-B-10+F)`…

if the aim of the experiment is to provide ^{240}Pu* FPY data….

EXFOR Deficiency (3): Indirectly Measured FPY (cont)

^{238}U(^{12}C,^{10}B+f) to study FPY of ^{240}Pu* FPY (EXFOR O2160.003)




```
SUBENT        O2160003   20130828
BIB                  2          4
REACTION     (6-C-12(92-U-238,F)ELEM/MASS,IND,FY,,MSC)
             2p transfer-fission (fissioning system=
             Pu-240) part of the fission yield
…
DATA                 4         288
ELEMENT      MASS        DATA         ERR-S
NO-DIM       NO-DIM      ARB-UNITS    ARB-UNITS
 34.          82.        0.04         0.02
 34.          83.        0.16         0.04
…
```

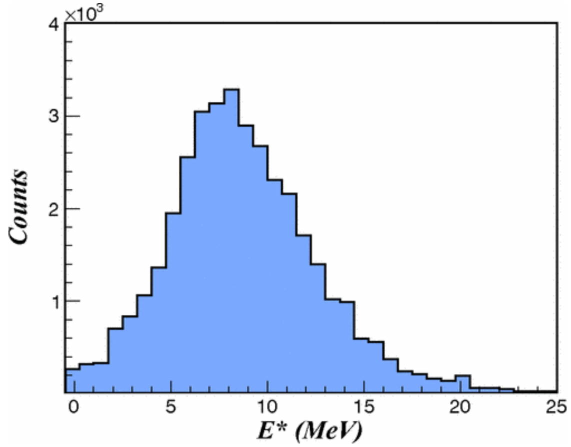
"Is there a way of specifying the compound nucleus and excitation energy for fission yields rather than the U238 on C reaction? Of course, this could be done in comments, but it would be better if this was searchable and extractable so that users could find the data." (Robert Mills, 7 May 2015)

EXFOR Deficiency (3): Indirectly Measured FPY (cont)

Possible solution: ^{240}Pu* (sf) instead of ^{238}U(^{12}C,^{10}B+f)

```
SUBENT        O2160003   20130828
BIB                  2          4
REACTION   (94-PU-240-X(0,F)ELEM/MASS,IND,FY)
           (6-C-12(92-U-238,F)ELEM/MASS,IND,FY,,MSC)
            2p transfer-fission (fissioning system=
            Pu-240) part of the fission yield
SAMPLE     240Pu* from 238U(12C,10B) reaction
…
EXC-TR
MEV
 ???
…
DATA                 4         288
ELEMENT    MASS       DATA        ERR-S
NO-DIM     NO-DIM     ARB-UNITS   ARB-UNITS
 34.        82.       0.04        0.02
 34.        83.       0.16        0.04
…
```

← Target excitation energy

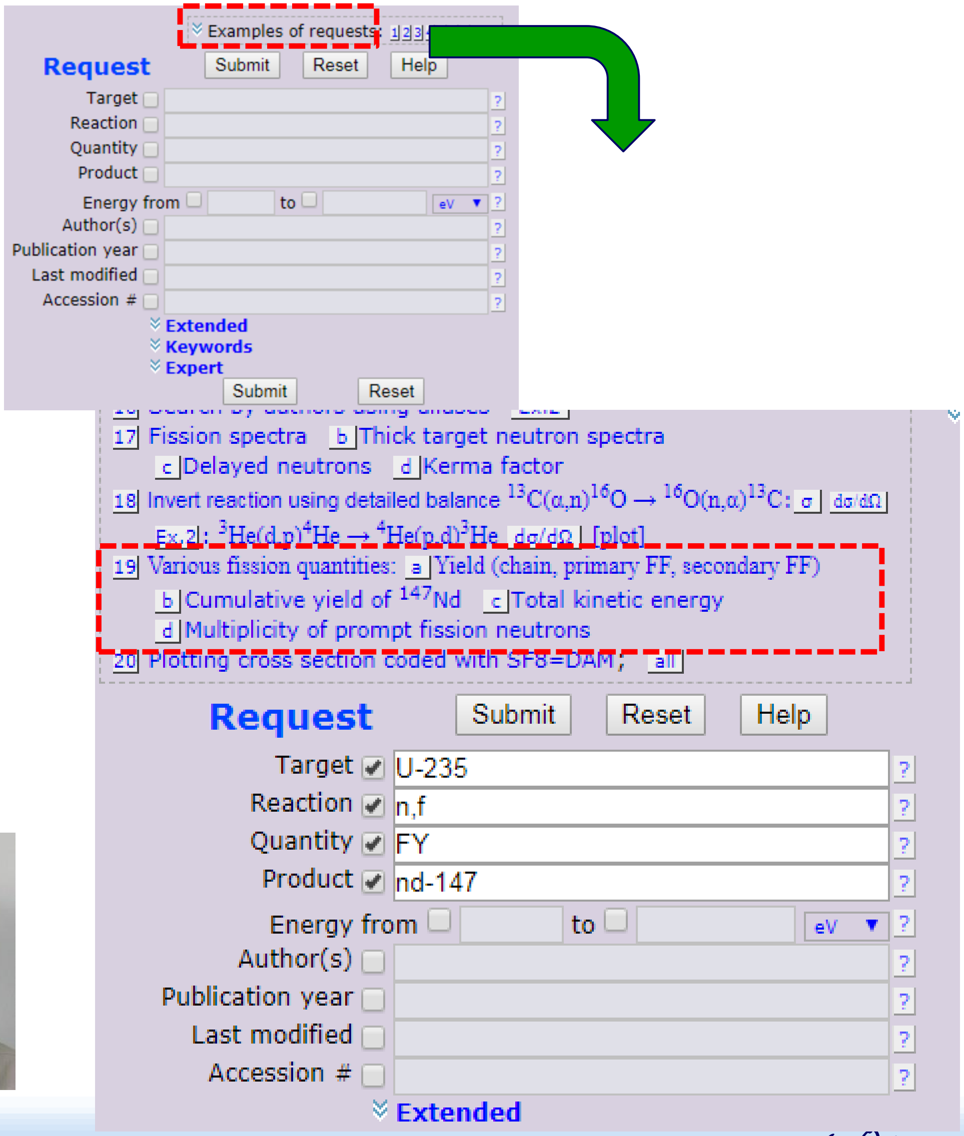


^{240}Pu excitation energy for the VAMOS data set.

Problem: <u>Excitation energy values</u> are not always seen in the literature.

EXFOR Deficiency (4): Web Retrieval

- EXFOR format of fission quantities becomes often complicated.
- It search also is therefore often challenging for users.
- Viktor Zerkin's strategy is to show more "examples".



4. A Few Additional Remarks on Compilation

Incident Energy Characterization in EXFOR

Requirement for documentation (Memo CP-D/199, 1989)

- **Thermal reactor** (where MXW and SPA are not coded in a consistent manner.)
  - Maxwellian temperature or mean energy
  - Epithermal neutron fraction (Westcott r-factor)
- **Fast reactor**
  - Mean energy of other spectral index
- **Fission spectrum**
  - Fission neutron source (e.g., ^{252}Cf(sf,), ^{235}U(n_{th},f))
- **Monoenergetic neutrons**
  - Neutron source description (e.g., T(d,n), ^{7}Li(p,n))
  - Spectral shape

Beam neutron spectrum characterization is important for cross section study, but probably less important for FPY study (?)

Decay Data and Decay Scheme Considered

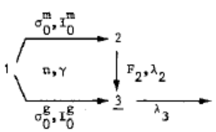
Requirement for documentation (Memo CP-D/199, 1989)

- precursor considered
- product isomers considered and spin of isomers for independent yields
- Nuclear data used and their uncertainties (capture cross section, decay data for corrections, decay data for spectrum analysis, delayed neutron data)

etc.

Are EXFOR FPY characterized by the same modifier (IND or CUM) always comparable directly? (I hope so...)

Decay Data and Decay Scheme Considered (cont)

Activation-decay type	Activation-decay scheme	"$\frac{\theta\sigma_0\gamma}{M}$" in k_0-definition [Eq.(I.3-14)]	"Q_0" in Eqs (I.3-18) (I.3-20) (I.3-21)	"$\frac{N_p/t_m}{SDC}$" in Eqs (I.3-18) – (I.3-21), to be divided by w for obtaining A_{sp} in Eqs (I.3-18) – (I.3-21)
III/b	Special case : $F_{24} = 0$	$\frac{\theta\sigma_0 F_2 F_3 \gamma_4}{M}$	$\frac{I_0}{\sigma_0}$	$(N_{p,4}/t_m)\cdot\left[S_2D_2C_2\frac{\lambda_4\lambda_3}{(\lambda_4-\lambda_2)(\lambda_3-\lambda_2)} - S_3D_3C_3\frac{\lambda_2\lambda_4}{(\lambda_4-\lambda_3)(\lambda_3-\lambda_2)} + S_4D_4C_4\frac{\lambda_2\lambda_3}{(\lambda_4-\lambda_2)(\lambda_4-\lambda_3)}\right]^{-1}$
III/c	Special case : $\lambda_3 \gg \lambda_2$ and λ_4, $D_3 = 0$ $F_3 = 1$, $F_2 + F_{24} = 1$ [e.g. ^{105}Rh from ^{104}Ru(n,γ)]	$\frac{\theta\sigma_0\gamma_4}{M}$	"	$(N_{p,4}/t_m)\cdot\frac{\lambda_4-\lambda_2}{\lambda_4S_2D_2C_2-\lambda_2S_4D_4C_4}$
IV/a **	 [e.g. ^{80}Br from ^{79}Br(n,γ)]	$\frac{\theta\sigma_0^g\gamma_3}{M}$	$\frac{I_0^g}{\sigma_0^g}$	$(N_{p,3}/t_m)\cdot\left[\frac{F_2\sigma_0^m}{\sigma_0^g}\frac{f+Q_0^m(\alpha)}{f+Q_0^g(\alpha)}\frac{\lambda_3S_2D_2C_2-\lambda_2S_3D_3C_3}{\lambda_3-\lambda_2} \ldots\right]^{-1}$
IV/b	Special case : $\lambda_2 \gg \lambda_3$ and $D_2 = 0$ [e.g. ^{60}Co from ^{59}Co(n,γ)]	$\frac{\theta(F_2\sigma_0^m+\sigma_0^g)\gamma_3}{M}$		
IV/c	Special case : $\lambda_2 < \lambda_3$ and $D_3 = 0$	$\frac{\theta F_2\sigma_0^m\gamma_3}{M}$		

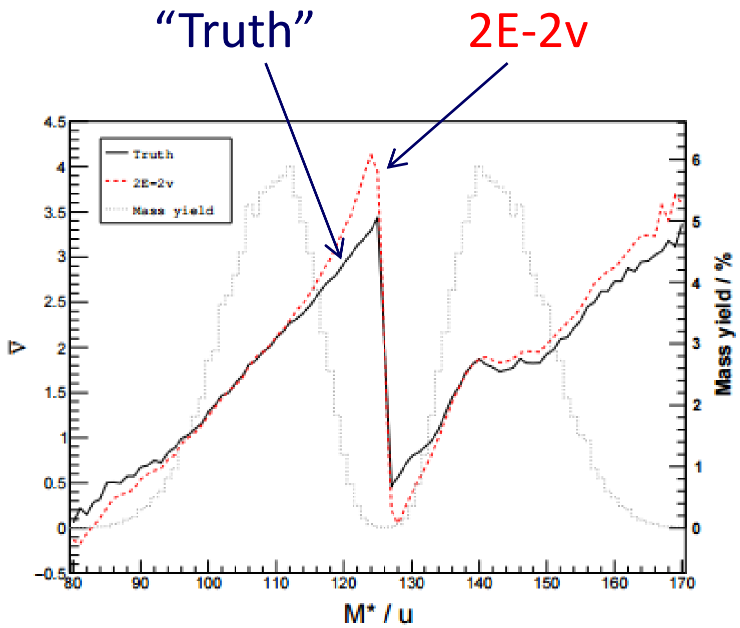
Element	Sample preparation	Isotope formed (Activation-decay type)	E_γ, keV	Measured $k_{0,Au}$ and relative error, %			
				KFKI "WWR-M"		INW "THET	
Cs	KFKI : 20 μg $CsNO_3$ (in H_2O) on Al-foil; pellet 6.4 mm diam. x 0.2 mm INW : CsCl (in H_2O) on W 41; 0.7 mg (CH 3), 1.7 mg (CH 15); pellet 10 mm diam. x 4 mm	^{134m}Cs (I)	127.5	$5.47.10^{-3}$(1.3)	$5.54.10^{-3}$(1.3)	$5.69.10^{-3}$(0.6)	5
		I.T. $F_2=1$					
		^{134}Cs (IV/b)	563.2	$4.22.10^{-2}$(2.6)	$4.09.10^{-2}$(3.2)	$4.26.10^{-2}$(0.6)	3
			569.3	$7.41.10^{-2}$(0.9)	$7.36.10^{-2}$(1.8)	$7.51.10^{-2}$(0.5)	7.
			604.7	$4.81.10^{-1}$(1.0)	$4.75.10^{-1}$(2.1)	$4.93.10^{-1}$(0.3)	4.
			795.8	$4.21.10^{-1}$(0.7)	$4.18.10^{-1}$(1.8)	$4.26.10^{-1}$(0.4)	3.
			801.9	$4.16.10^{-2}$(2.0)	$4.10.10^{-2}$(2.7)	$4.27.10^{-2}$(1.9)	3.
		131m					

Measured thermal data (k_0) tabulated by **Frans De Corte** with the decay scheme.
(k_0 is a quantity defined for neutron activation analysis.)

F.De Corte et al, J.Radioanal.Nucl.Chem.133(1989)3

Y(A): Correction for Prompt Neutron Emission

- Primary mass yield is often derived from secondary mass yield measured by 2E method, 2E-2v method.
- Various assumptions (e.g., v(A) value, isotropic emission of neutron)
- What EXFOR compilers can do is to describe derivation of the primary yield briefly in text (e.g., 2E, 2E-2v).



K.Jansson et al, arXiv:1709.07443v1 (2007)

Future Tasks for NDS and NRDC

- Centres could not put high priority to FPY compilation until 80s. NDS started X4-UKFY comparison to estimate X4 completeness.
- FPY data in EXFOR should be in a unified format. We need to extend the computational format (C4).
- The EXFOR format must be improved for FPY data measured by transfer reactions etc
- LANL workshop (20-23 August, 2018) and its follow up meeting (27-30 May 2019, Tokyo) to collect comments from evaluators.

Thank you for your attention!

First banana harvest at Nuclear Data Section (January 2018)

4C and CP Memo on FPY Compilation

Only memos archived on the NRDC website are listed:

- 4C-2/14, 89, 113 (112 is wrongly printed), 115
- 4C-3/122, 241, 317, 328, 341, 343, 363
- 4C-4/9, 13,
- CP-C/189
- CP-D/178, 185, 199