IAEA
International Atomic Energy Agency
Atoms for Peace and Development

Experimental nuclear data archaeology: Retroactive compilation of legacy data for EXFOR

Naohiko Otuka
presented by Paraskevi (Vivian) Dimitriou
Nuclear Data Section, IAEA, Vienna, Austria

Nuclear Reaction Data Centres (NRDC)

13 centres (China, Hungary, India, Japan, Korea, Russia, Ukraine, USA, NEA, IAEA) collaborating for **EXFOR compilation.**

NRDC 2023 meeting (Vienna)

All data measured in USA and Canada are compiled by NNDC .

Why there are legacy data missing in EXFOR?

SEARCH FOR STRUCTURE IN THE FAST-NEUTRON INTERACTION WITH U^{235}†

A. B. Smith and J. F. Whalen

Argonne National Laboratory, Argonne, Illinois

(Received 14 February 1966)

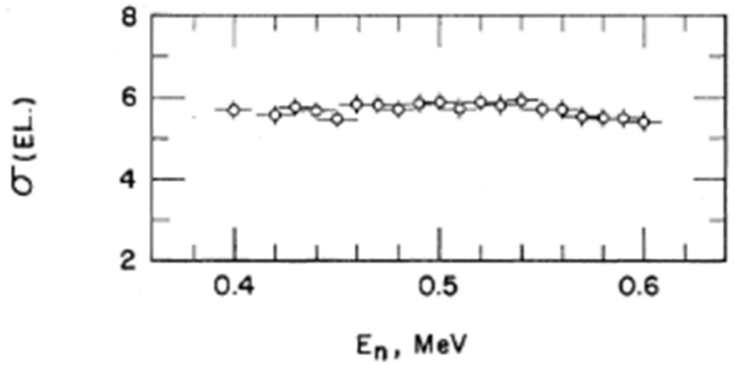

FIG. 2. Measured differential elastic-scattering cross sections of U^{235} expressed in the form of Eq. (1). Energy resolutions and relative uncertainties are indicated. Note the suppressed zeros.

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ENTRY            12369      820519
SUBENT        12369001      820519
BIB                  6           9
INSTITUTE   (1USAANL)
REFERENCE   (J,PRL,16,525,6603)
AUTHOR      (A.B.SMITH,J.F.WHALEN)
TITLE       SEACH FOR STRUCTURE IN THE FAST-NEUTRON INTERACTION
             WITH U-235.
STATUS      (UNOBT) MEASUREMENTS MADE TO EXAMINE STRUCTURE ONLY.
            DATA WILL NOT BE RELEASED.
HISTORY     (761006C)
            (820519A) CONVERTED TO REACTION FORMALISM
ENDBIB               9
NOCOMMON             0           0
ENDSUBENT           12
ENDENTRY             1
```

No reply to a data request (digitization from figure images was not a solution at NNDC until c.a. 2004)

Voluminous dataset (e.g., time-of-flight data) – not suitable for exchange by cards and tapes but now it is not a problem!

Unawareness of presence of legacy data (e.g., cartons kept in a storage or house)

N. Otuka, T. Kawano (2013) “Nuclear Data Archaeology”

核データニュース，No.106 (2013)

読者の広場

核データ考古学 Nuclear Data Archaeology

国際原子力機関　核データ課
大塚　直彦
n.otsuka@iaea.org
ロスアラモス国立研究所　理論部門
河野　俊彦
kawano@lanl.gov

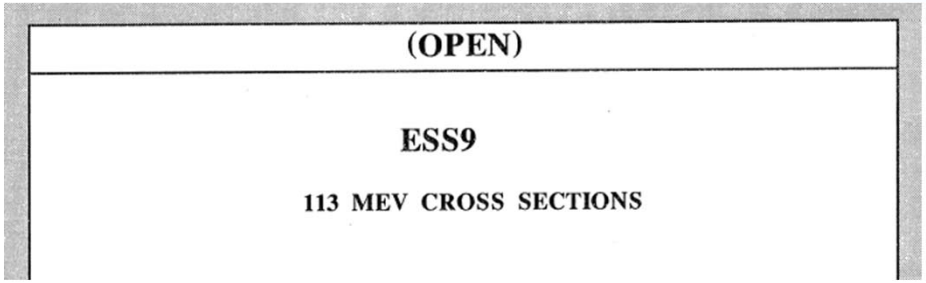
1. 緒言

MIT の教授、A. Kerman 氏とワイングラスを傾けつつ談笑していた時の話です。原子核理論の高名な方ではありますが、以下親しみも込めて Arthur と呼ばせて頂きます。大昔の出来事、Arthur が R. Feynman から「この論文原稿をチェックしてくれ」と数十枚の手書き（タイプライター？）原稿を渡されたそうです。複雑な角運動量が絡む面倒な計

Nuclear Data News **106** (2013) 72

Some examples presented in the next slides were originally collected for this 2013 article.

Meier's (p,n+x) dY/dΩdE (EXFOR# C0171, C1440)



(OPEN)

ESS9

113 MEV CROSS SECTIONS

Differential cross sections for run 372: Beryllium

Energy(MeV)	7.5 deg.		30 deg.		60 deg.		150 deg.	
0.5750e+00					0.3656e-02	0.1535e-03		
0.6250e+00			0.3537e-02	0.6236e-04	0.3613e-02	0.1389e-03		
0.6750e+00	0.3592e-02	0.8129e-04	0.3547e-02	0.6101e-04	0.3228e-02	0.1241e-03	0.2625e-02	0.5396e-04
0.7250e+00	0.3803e-02	0.8184e-04	0.3758e-02	0.5935e-04	0.3584e-02	0.1234e-03	0.2619e-02	0.5280e-04
0.7750e+00	0.3859e-02	0.8213e-04	0.3691e-02	0.6101e-04	0.3793e-02	0.1201e-03	0.2713e-02	0.5331e-04
0.8250e+00	0.3841e-02	0.7312e-04	0.3747e-02	0.5884e-04	0.3817e-02	0.1151e-03	0.2706e-02	0.5269e-04
0.8750e+00	0.3869e-02	0.8011e-04	0.3862e-02	0.5485e-04	0.3918e-02	0.1142e-03	0.2707e-02	0.5998e-04
0.9250e+00	0.4405e-02	0.8294e-04	0.4020e-02	0.5938e-04	0.4367e-02	0.1283e-03	0.2855e-02	0.5588e-04
0.9750e+00	0.3958e-02	0.8230e-04	0.3572e-02	0.6035e-04	0.3872e-02	0.1164e-03	0.2561e-02	0.5922e-04
0.1075e+01	0.3204e-02	0.5695e-04	0.3244e-02	0.3592e-04	0.3073e-02	0.7281e-04	0.2273e-02	0.3569e-04
0.1150e+01	0.3151e-02	0.5333e-04	0.3041e-02	0.4271e-04	0.3096e-02	0.6247e-04	0.2168e-02	0.3343e-04
0.1250e+01	0.3143e-02	0.5252e-04	0.3151e-02	0.3840e-04	0.3113e-02	0.6814e-04	0.2140e-02	0.3575e-04
0.1350e+01	0.2679e-02	0.4794e-04	0.2732e-02	0.3947e-04	0.2689e-02	0.5724e-04	0.1896e-02	0.3195e-04
0.1450e+01	0.2582e-02	0.4562e-04	0.2682e-02	0.3853e-04	0.2466e-02	0.5777e-04	0.1812e-02	0.3780e-04
0.1550e+01	0.2645e-02	0.4605e-04	0.2605e-02	0.3173e-04	0.2476e-02	0.5688e-04	0.1732e-02	0.2969e-04
0.1650e+01	0.2476e-02	0.4395e-04	0.2586e-02	0.4425e-04	0.2351e-02	0.5493e-04	0.1637e-02	0.2373e-04
0.1750e+01	0.2255e-02	0.4300e-04	0.2280e-02	0.3430e-04	0.2117e-02	0.4715e-04	0.1514e-02	0.3348e-04
0.1850e+01	0.2280e-02	0.3804e-04	0.2393e-02	0.3147e-04	0.2194e-02	0.5239e-04	0.1472e-02	0.2673e-04
0.1950e+01	0.2376e-02	0.4353e-04	0.2344e-02	0.4213e-04	0.2222e-02	0.4837e-04	0.1433e-02	0.2804e-04
0.2100e+01	0.2114e-02	0.2742e-04	0.2139e-02	0.2056e-04	0.1877e-02	0.3468e-04	0.1260e-02	0.1916e-04
0.2300e+								
0.2500e+								
0.2700e+								
0.2900e+								
0.3100e+								
0.3300e+								
0.3500e+								
0.3700e+								
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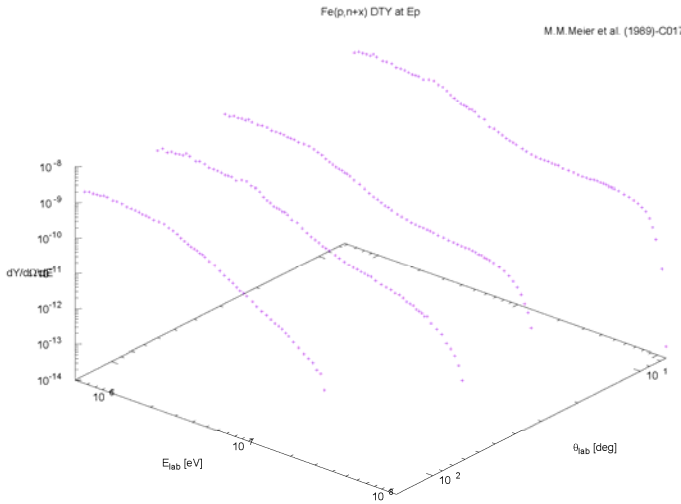
0.1750e+								
0.1850e+								
0.1950e+								
0.2100e+								
0.2300e+								
0.2500e+								
0.2700e+								



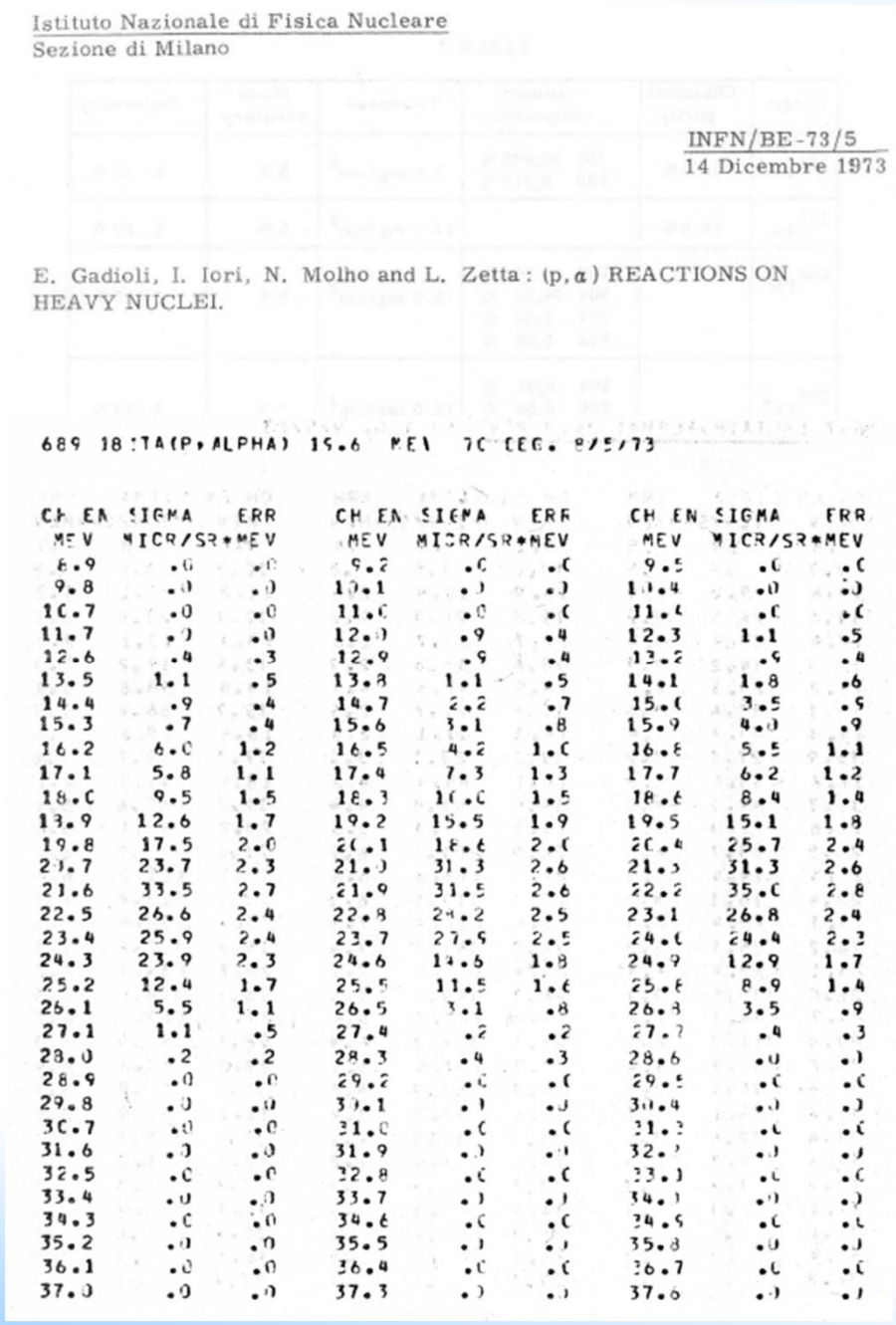
We noticed Larry Greenwood keeps its printout in a carton. Greenwood made a high resolution pdf file for EXFOR compilation (suitable for OCR) from the printout.

Boris Pritychenko made them machine readable (~4k data points).

OCR processing is not accurate for numbers in general.

Fe(p,n+x) double differential thick target yields (Ep=113 MeV)

Gadioli et al's (p,α+x) dσ/dΩdE (EXFOR# O2263)



Istituto Nazionale di Fisica Nucleare
Sezione di Milano

INFN/BE-73/5
14 Dicembre 1973

E. Gadioli, I. Iori, N. Molho and L. Zetta : (p,α) REACTIONS ON HEAVY NUCLEI.

689 18:TA(P,ALPHA) 19.6 MEV 7C CEG. 8/5/73

CH EN MEV	SIGMA MICR/SR*MEV	ERR	CH EN MEV	SIGMA MICR/SR*MEV	ERR	CH EN MEV	SIGMA MICR/SR*MEV	ERR
8.9	.0	.0	9.2	.0	.0	9.5	.0	.0
9.8	.0	.0	10.1	.0	.0	10.4	.0	.0
10.7	.0	.0	11.0	.0	.0	11.4	.0	.0
11.7	.0	.0	12.0	.9	.4	12.3	1.1	.5
12.6	.4	.3	12.9	.9	.4	13.2	.9	.4
13.5	1.1	.5	13.8	1.1	.5	14.1	1.8	.6
14.4	.9	.4	14.7	2.2	.7	15.0	3.5	.9
15.3	.7	.4	15.6	3.1	.8	15.9	4.0	.9
16.2	6.0	1.2	16.5	4.2	1.0	16.8	5.5	1.1
17.1	5.8	1.1	17.4	7.3	1.3	17.7	6.2	1.2
18.0	9.5	1.5	18.3	10.0	1.5	18.6	8.4	1.4
18.9	12.6	1.7	19.2	15.5	1.9	19.5	15.1	1.8
19.8	17.5	2.0	20.1	18.6	2.0	20.4	25.7	2.4
20.7	23.7	2.3	21.0	31.3	2.6	21.3	31.3	2.6
21.6	33.5	2.7	21.9	31.5	2.6	22.2	35.0	2.8
22.5	26.6	2.4	22.8	24.2	2.5	23.1	26.8	2.4
23.4	25.9	2.4	23.7	27.9	2.5	24.0	24.4	2.3
24.3	23.9	2.3	24.6	14.6	1.8	24.9	12.9	1.7
25.2	12.4	1.7	25.5	11.5	1.6	25.8	8.9	1.4
26.1	5.5	1.1	26.5	3.1	.8	26.8	3.5	.9
27.1	1.1	.5	27.4	.2	.2	27.7	.4	.3
28.0	.2	.2	28.3	.4	.3	28.6	.0	.0
28.9	.0	.0	29.2	.0	.0	29.5	.0	.0
29.8	.0	.0	30.1	.0	.0	30.4	.0	.0
30.7	.0	.0	31.0	.0	.0	31.3	.0	.0
31.6	.0	.0	31.9	.0	.0	32.2	.0	.0
32.5	.0	.0	32.8	.0	.0	33.1	.0	.0
33.4	.0	.0	33.7	.0	.0	34.0	.0	.0
34.3	.0	.0	34.6	.0	.0	34.9	.0	.0
35.2	.0	.0	35.5	.0	.0	35.8	.0	.0
36.1	.0	.0	36.4	.0	.0	36.7	.0	.0
37.0	.0	.0	37.3	.0	.0	37.6	.0	.0

NDS received a report copy (incl. ~15 k data points) from Australia by post.

NDS created a pdf copy (not good for OCR), sent pdf and original to Moscow.

The compiler (Svetlana Dunaeva) made them machine readable, checked the results against the original .

Svetlana sent the original back to Australia by post.

Data centres must keep an original hard copy until completion of final checking.

ORELA time of flight spectra (EXFOR# 14324 etc.)

IAEA International Atomic Energy Agency

INDC(NDS)-0647
Distr. AC/G/J/NC/ST

INDC International Nuclear Data Committee

Summary Report of the Consultants' Meeting on

EXFOR Data in Resonance Region and Spectrometer Response Function

IAEA Headquarters, Vienna, Austria

8 – 10 October 2013

Vienna Inte

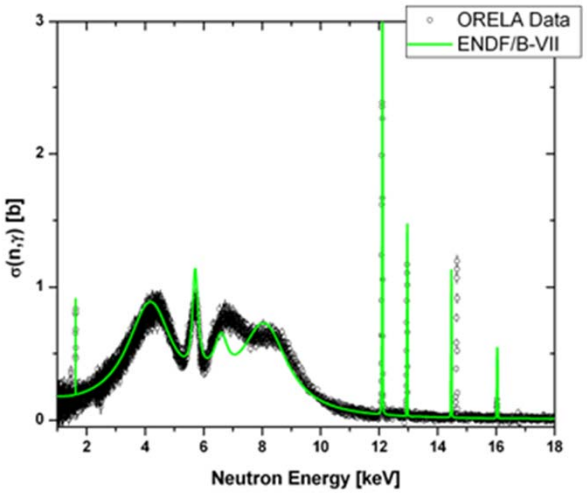


Fig. 4. (Color online) Neutron capture for ^{53}Cr oxide compared to ENDF/B-VII evaluation parameters.

These data are compared to the cross sections or transmission calculated using the most recent resonance parameter set from the ENDF/B-VII library. SAMMY [5] was used to calculate the neutron capture cross section and transmission, including all experimental effects. In

Not for direct comparison with ENDF resonance parameters because of experimental effects.

2013 IAEA Consultant Meeting discussed experimental descriptions for proper use of TOF spectra.

Boris Pritychenko worked with Klaus Guber in 2015 for release of many ORELA datasets in EXFOR.

Compilers should know what must be described in EXFOR for proper use of the data.

More TOF spectra missing in EXFOR?

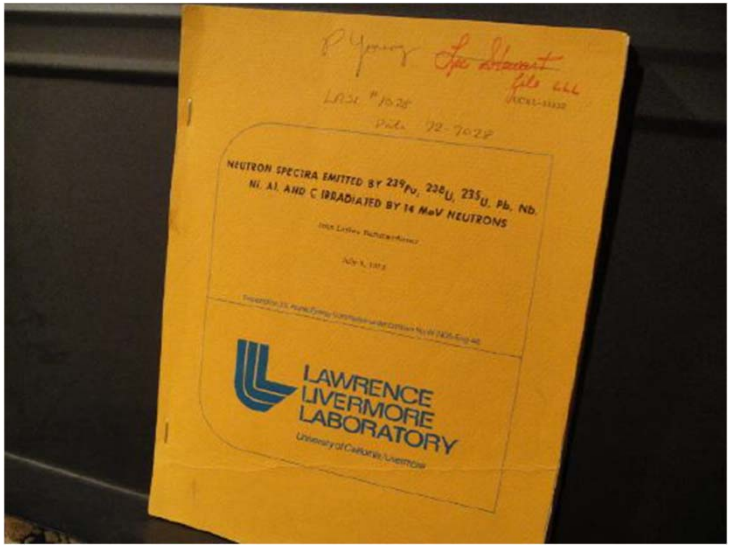
Mick Moxon's son informed NEA DB presence of printouts of "resonance data" from the Harwell linac.

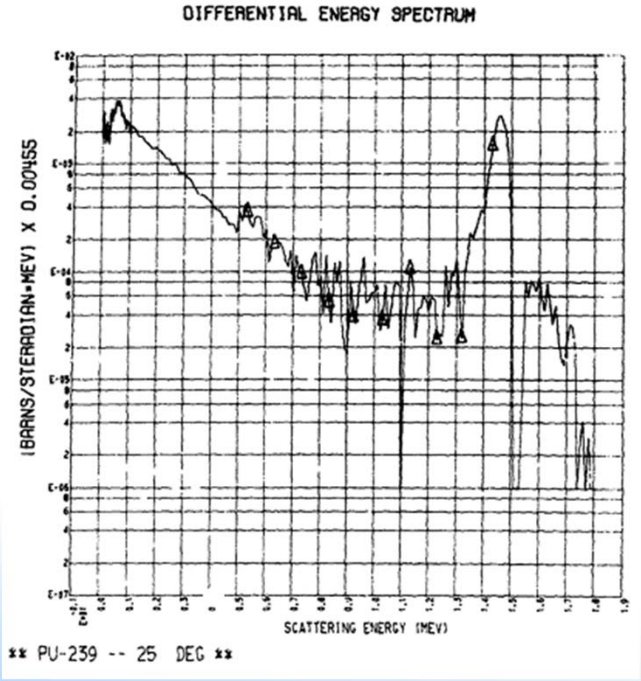
We have only ~10 EXFOR entries providing high resolution TOF spectra measured by him.

A Japanese researcher (retired) also has a pile of papers keeping transmissions from the JAERI linac in his house…

Extra resource needed to discover and digitize them for dissemination by EXFOR.

Kammerdiener's (n,n+x) dσ/dΩdE (EXFOR# 14329)





Very few actinide (n,n+x) DDX datasets in EXFOR before EXFOR# 14329.
(2 for ^{235}U, 1 for ^{239}Pu)

Boris Pritychenko digitized more than 8k data points from graph images as per request from Toshihiko Kawano.

Accurate digitization from log scale was challenging.

Data centres must monitor new publications routinely and send data requests in a timely manner. Otherwise, the data files may be lost .

Bair's $^{13}C(\alpha,n)^{16}O$ cross section (EXFOR# C0489.002)

PHYSICAL REVIEW C VOLUME 7, NUMBER 4 APRIL 1973

Total Neutron Yield from the Reactions $^{13}C(\alpha,n)^{16}O$ and $^{17,18}O(\alpha,n)^{20,21}Ne$†

J. K. Bair
Oak Ridge National Laboratory, Oak Ridge, Tennessee, 37830
and
F. X. Haas
Mound Laboratory, Miamisburg, Ohio
(Received 20 November 1972)

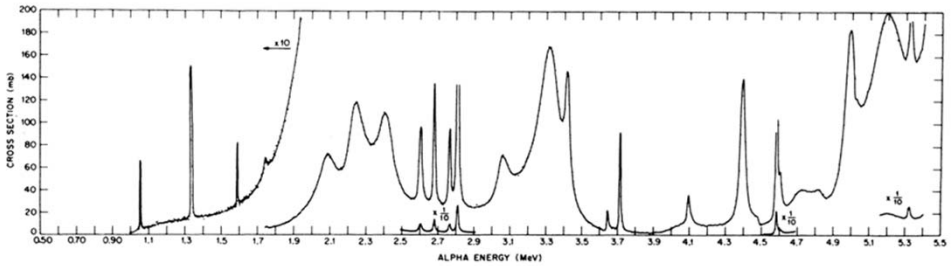
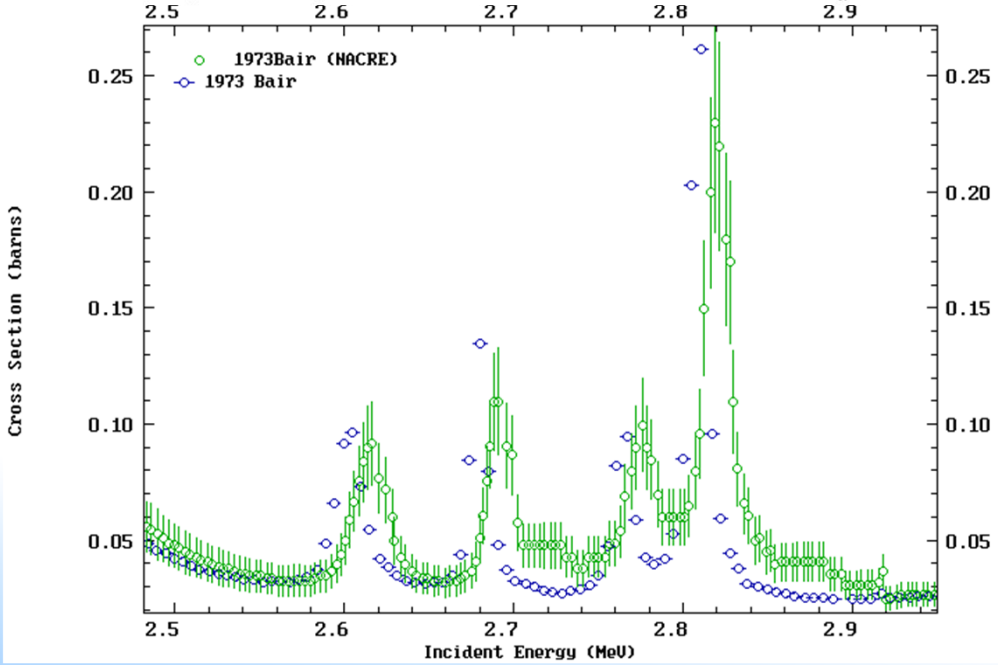


FIG. 3. These data show the $^{13}C(\alpha,n)^{16}O$ total neutron cross section. The target consisted of a layer of cracked (enriched) acetylene on a platinum backing. The target thickness was measured to be approximately 5 keV at the 1.057-MeV resonance. The energies are in the laboratory system and are corrected for target thickness. The cross-section scale is based on measurements made on the 1.057-MeV resonance using infinitely thick targets, of both enriched and natural elemental carbon, in conjunction with thin target measurements over this resonance and the wide resonance at about 2.4-MeV energy.



Important in the relation with $^{16}O(n,\alpha)^{13}C$ evaluation for CIELO.

In 1999, NNDC added in EXFOR a dataset digitized by the NACRE project.

In 2014, Gerry Hale shared with EXFOR 885 data points originally received from Duane Larson (not an author) around 1997.

Legacy data in your computer?

Tovesson's ^{240,242}Pu(n,f)cross sections (EXFOR# 14223)

PHYSICAL REVIEW C **79**, 014613 (2009)

Neutron induced fission of ^{240,242}Pu from 1 eV to 200 MeV

F. Tovesson, T. S. Hill, and M. Mocko
Los Alamos National Laboratory, Los Alamos, New Mexico 87545, USA

J. D. Baker and C. A. McGrath
Idaho National Laboratory, Idaho Falls, Idaho 83415, USA

(Received 19 June 2008; revised manuscript received 12 November 2008; published 29 January 2009)

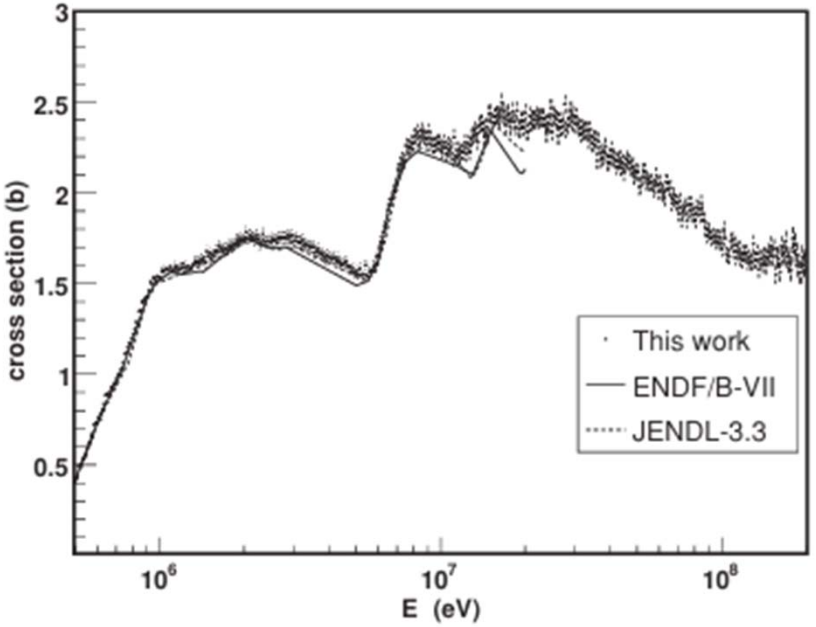


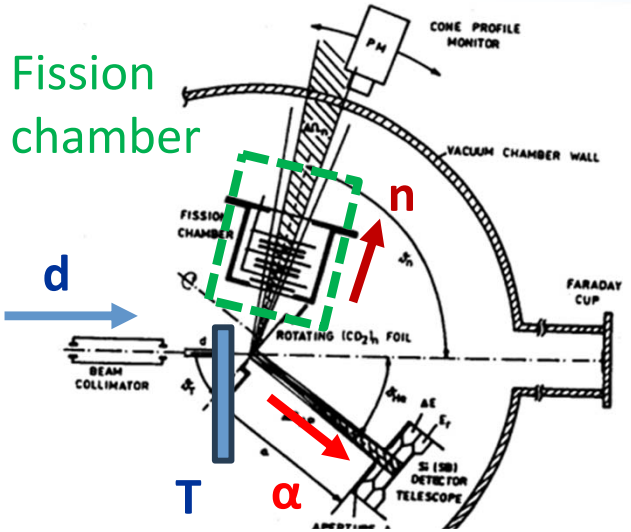
FIG. 11. Measured ^{240}Pu(n,f) cross section from threshold to 200 MeV. The 3% uncertainty in the overall normalization is not shown. The experimental data are compared with the ENDF/B-VII and JENDL-3.3 evaluations.

Series of measurements relative to ^{235}U(n,f) extended to 200 MeV (very useful!)

The article does not show ^{240,242}Pu(n,f)/ ^{235}U(n,f), and the compiler did not request the data, which are no longer available…

Data centres must have compilers having good nuclear data background and can judge what must be preserved.

Arlt et al's absolute σ_f measurements (EXFOR# 22304)



	Author	Reference	Alias, translation, source	Cross section (b)					
Laboratory				KRI	KRI	ZfK	ZfK	TUD	ZfK
E_n(MeV)				1.92	14.7	4.8	8.5	14.7	18.8
n.source				D-D	D-T	D-D	D-D	D-T	D-T
	EXFOR	22304.005	C,91JUELIC,,510,1991			1.773(33)	2.395(40)		2.473(59)
		22304.009	C,91JUELIC,,510,1991					2.449(27)	
		40927.006	J,YK,,(4),19,1986	2.01(5)					
		30706.006	S,ZFK-592,152,1986						*2.487(88)*
		30706.005	S,ZFK-592,152,1986				*2.350(44)*		
		30706.004	S,ZFK-592,152,1986			*1.740(35)*			
		40911.007	C,83MOSKVA,2,201,1983		2.309(28)				
		51001.003	J,AE,55,218,1983		2.309(29)				
		51001.003	J,AE,55,218,1983		2.349(45)				
		40547.017	C,79KNOX,,995,1979		2.505(51)				
		40547.009	R,YK-24,8,1977		*2.620(46)*				
199105	Merla+	C,91JUELIC,,510,1991				1.773(33)	2.395(40)	2.449(27)[a]	2.473(59)
198612	Shpakov	J,YK,,(4),19,1986	R,INDC(CCP)-302,33,1989	2.01(5)		1.740(35)	2.350(44)		2.487(88)
198604	Herbach+	S,ZFK-592,152,1986	S,INDC(GDR)-42,152,1986			1.740(35)	2.350(44)		2.487(88)
198510	Kovalenko+	J,IP,21,344,1985				1.739(34)[b]	2.406(70)[b]	2.394(24)	2.479(86)[b]
198506	Herbach+	R,INDC(GDR)-36,1985				1.740(35)[c]	2.350(44)[d]		2.487(88)[c]
198505	Herbach+	R,INDC(GDR)-35,1985				1.740(35)	2.350(44)		2.487(88)
198410	Arlt+	J,AE,57,249,1984	J,SJA,57,702,1985				2.40(7)		
198312	Alkhazov+	C,83MOSKVA,2,201,1983			2.309(28)[f]			[2.385][e]	
198310	Arlt+	C,83KIEV,2,129,1983					2.40(7)		
198310	Dushin+	J,AE,55,218,1983	J,SJA,55,656,1984		2.309(30)			2.377(23)	
198310	Dushin+	J,AE,55,218,1983	J,SJA,55,656,1984		2.349(45)			2.394(24)	
198212	Arlt+	S,ZFK-491,135,1982	S,INDC(GDR)-26,135,1982					2.394(24)	
198102	Arlt+	J,KE,24,48,1981			2.505(45)			2.394(24)	
198006	Arlt+	P,INDC(GDR)-12,9,1980			2.505(45)			2.394(24)	
198005	Arlt+	P,ZFK-408,26,1980	S,INDC(GDR)-14,26,1980		2.505(45)			2.394(24)	
198001	Arlt+	S,ZFK-410,122,1980	S,INDC(GDR)-133,122,1980		2.505(45)			2.394(24)	
197910	Arlt+	C,79KNOX,,990,1979			2.505(45)			2.394(24)[h]	
197910	Adamov+	C,79KNOX,,995,1979			2.505(51)[g]				
197906	Arlt+	P,ZFK-385,18,1979						2.360(26)	
197901	Arlt+	S,ZFK-382,180,1979	S,INDC(GDR)-9,180,1979					2.360(28)[f]	
197704	Alkhazov+	C,77KIEV,3,155,1977			2.620(46)				
197703	Adamov+	R,YFI-23,17,1977			2.620(46)				
197700	Adamov+	R,YK-24,8,1977			2.620(46)				

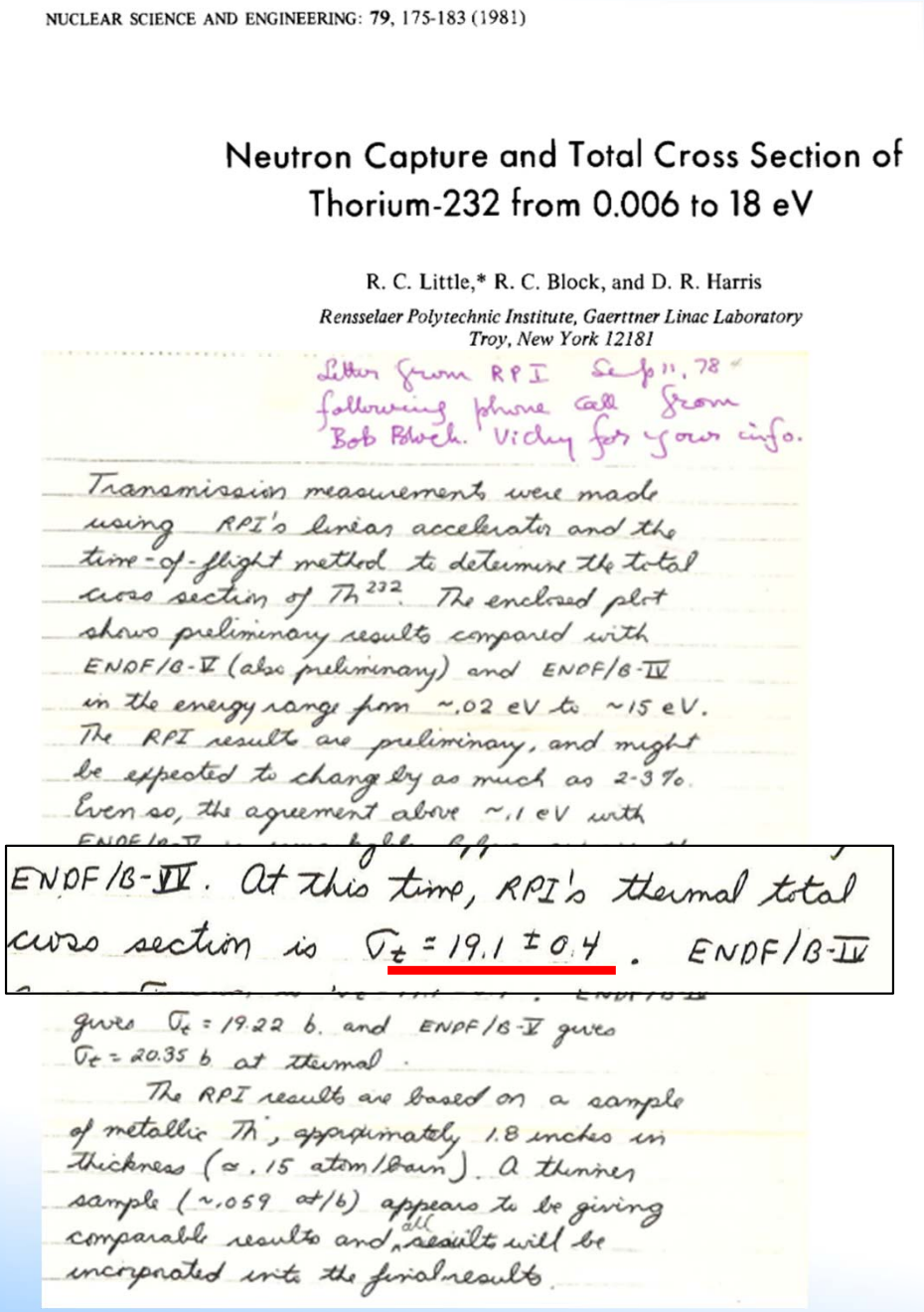
History for ^{239}Pu(n,f) at 6 energies (1977-1991)

D-D and D-T neutron fission cross sections measured at a few energies with ^{2}H(d,n)^{3}He and ^{3}H(d,n)^{4}He recoil detections.

Many publications in 1977-1991 without citations. It is very hard to know how many independent measurements were done.

Needs to trace history of each experimental project by the same compiler of the centre.

Little's σ_0 for ^{232}Th total (EXFOR #10956)



NUCLEAR SCIENCE AND ENGINEERING: 79, 175-183 (1981)

Neutron Capture and Total Cross Section of Thorium-232 from 0.006 to 18 eV

R. C. Little,* R. C. Block, and D. R. Harris

Rensselaer Polytechnic Institute, Gaerttner Linac Laboratory Troy, New York 12181

Letter from RPI Sept 11, 78 following phone call from Bob Block. Vicky for your info.

Transmission measurements were made using RPI's linear accelerator and the time-of-flight method to determine the total cross section of Th^{232}. The enclosed plot shows preliminary results compared with ENDF/B-V (also preliminary) and ENDF/B-IV in the energy range from ~.02 eV to ~15 eV. The RPI results are preliminary, and might be expected to change by as much as 2-3%. Even so, the agreement above ~.1 eV with ENDF/B-IV. At this time, RPI's thermal total cross section is $\sigma_t = 19.1 \pm 0.4$. ENDF/B-IV gives $\sigma_t = 19.22$ b. and ENDF/B-V gives $\sigma_t = 20.35$ b at thermal.

The RPI results are based on a sample of metallic Th, approximately 1.8 inches in thickness (~.15 atom/barn). A thinner sample (~.059 at/b) appears to be giving comparable results and all results will be incorporated into the final results.

EXFOR 10956.003 provides 19.1±0.04 b as the ^{232}Th+n thermal Total cross section interpolated from TOF data points from RPI. Looked too small for me.

Little's letter in Nov. 1981 was scanned (with other CSISRS archives in McLane's office) by NNDC. It shows the uncertainty must be 0.4 b.

Not only numerical data but private communications between data centres and authors must be preserved.

Summary

- Redoing an experiment is a waste of money. Worth spending money to add legacy data in EXFOR.

- Where are legacy data? In cartons in a warehouse? In your computers?

- The authenticity of the discovered legacy data is important if they are received via a third person not involved in the experiment.

- Compilers must have good nuclear data background so that they can judge what can/must be kept in EXFOR. (This requires proper training.)

- Centres are busy for regular compilation (e.g., ~450 articles are waiting compilation by NNDC). Legacy data compilation requires extra resource.

Thank you!

View of Vienna International Centre (VIC) Buildings from Kaiserwasser