EXFOR & Machine Readability

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U.S. DEPARTMENT OF ENERGY

Nuclear Reaction Data Compilations in USA & Worldwide

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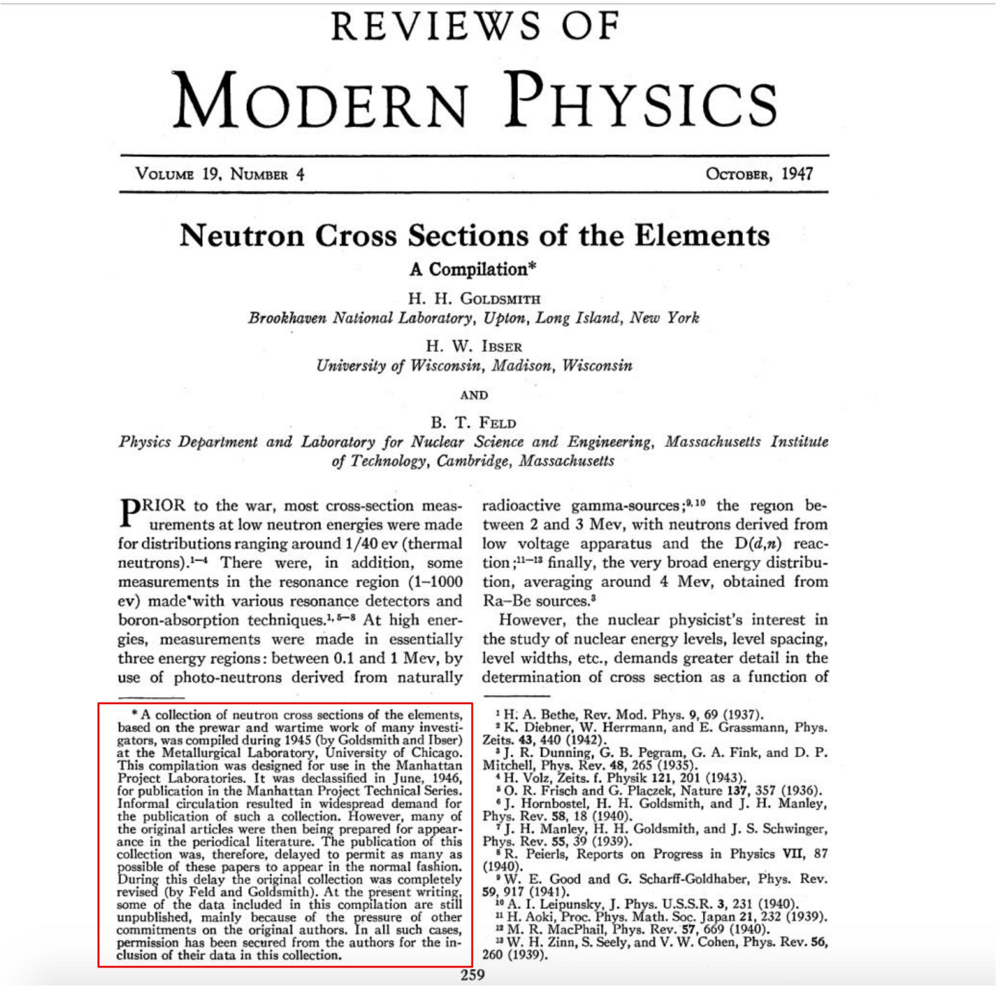

REVIEWS OF MODERN PHYSICS

VOLUME 19, NUMBER 4 OCTOBER, 1947

Neutron Cross Sections of the Elements

A Compilation*

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AND

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PRIOR to the war, most cross-section measurements at low neutron energies were made for distributions ranging around 1/40 ev (thermal neutrons).[1–4] There were, in addition, some measurements in the resonance region (1–1000 ev) made with various resonance detectors and boron-absorption techniques.[1, 5–8] At high energies, measurements were made in essentially three energy regions: between 0.1 and 1 Mev, by use of photo-neutrons derived from naturally radioactive gamma-sources;[9, 10] the region between 2 and 3 Mev, with neutrons derived from low voltage apparatus and the D(d,n) reaction;[11–13] finally, the very broad energy distribution, averaging around 4 Mev, obtained from Ra–Be sources.[3]

However, the nuclear physicist's interest in the study of nuclear energy levels, level spacing, level widths, etc., demands greater detail in the determination of cross section as a function of

* A collection of neutron cross sections of the elements, based on the prewar and wartime work of many investigators, was compiled during 1945 (by Goldsmith and Ibser) at the Metallurgical Laboratory, University of Chicago. This compilation was designed for use in the Manhattan Project Laboratories. It was declassified in June, 1946, for publication in the Manhattan Project Technical Series. Informal circulation resulted in widespread demand for the publication of such a collection. However, many of the original articles were then being prepared for appearance in the periodical literature. The publication of this collection was, therefore, delayed to permit as many as possible of these papers to appear in the normal fashion. During this delay the original collection was completely revised (by Feld and Goldsmith). At the present writing, some of the data included in this compilation are still unpublished, mainly because of the pressure of other commitments on the original authors. In all such cases, permission has been secured from the authors for the inclusion of their data in this collection.

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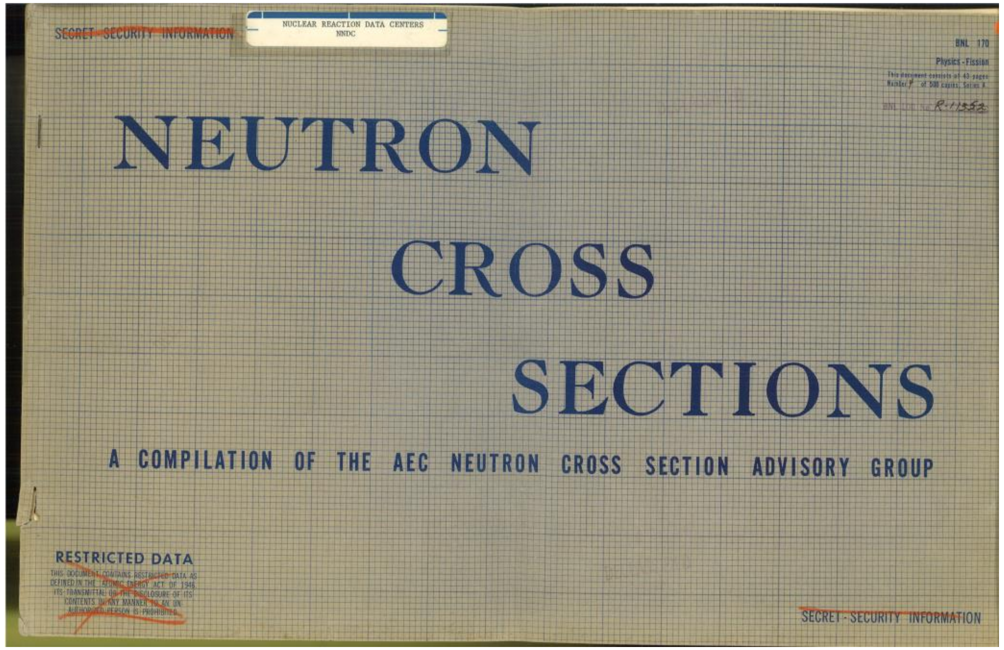

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Recent Cross Sections of Interest in Reactor Design

By Donald J. Hughes*

In 1955 the Geneva Conference provided an excellent opportunity to present and compare cross-section results that had never been available openly before, particularly with regard to the fissionable nuclides. For U^{233}, U^{235} and Pu^{239}, it was possible for the first time to compare results obtained at laboratories throughout the world and investigate the accuracy and agreement among the many measurements.

For some results, for example the thermal cross sections of U^{233}, U^{235} and Pu^{239}, the agreement was rather good; for other cases however, such as the resonance parameters for these nuclides, the data were not abundant and were only in poor agreement. For other cross sections important to reactors, in particular the various partial cross sections, such as capture and inelastic scattering, the information was scanty indeed.

At the second Geneva Conference there is no comparable release of a large mass of nuclear data from secrecy restrictions. Rather, the interest will be in the much greater variety of data available for consideration than there was at the first conference. The three years that have elapsed between the conferences have been devoted to the obtaining of more data by methods already in use at the first conference, to the increase in accuracy and resolving power, and the development of some entirely new methods. It is impossible to review adequately the data that have arisen in the last three years in a single paper. Rather the cross sections that are of particular interest to reactors will be considered, especially those for which significant new advances in knowledge have occurred since 1955.

SOURCES AND ACCURACY OF DATA

As recent developments in the instruments used for cross-section measurements are described in other papers of this conference,[1–3] the instrumental characteristics will not be considered here, but rather the quality and amount of data being furnished at the present time by the various techniques. It is not only the ultimate resolving power of a given instrument that is important but also its neutron intensity, which determines the amount of cross-section data that can be obtained with it. In order to make a rough estimate of the types of apparatus that have furnished the bulk of neutron cross-section data during the last few years, we can survey briefly the measured cross sections as functions of energy that appear in the recent second edition of BNL–325, "Neutron Cross Sections".[4]

As far as the instruments that have supplied the data appearing in the compilation there is a clear division according to energy. Examination of the source of experimental data shows that, with few exceptions, most of the information in various energy regions comes from single types of instruments. Thus, in the region of slow neutrons, the slow chopper provides most of the data below 0.1 ev. Above this energy, up to about 10 ev, the crystal spectrometer is the main instrument, giving way at the latter energy to the fast chopper. When an energy range of 10 kev is reached the fast chopper and the Van de Graaff provide data in equal abundance. It is in this region of energy that the pulsed accelerator has also been used for cross-section measurement, primarily in studies of separated isotopes. Above this energy the information is supplied principally by the Van de Graaff. A simple count of the energy decades for all the elements accounted for by the major instruments shows the Van de Graaff in the lead, with 33% of the data, followed by the fast chopper (27%), crystal spectrometer (20%) and slow chopper (20%).

When we consider the relative quality of the data supplied by the various instruments it is primarily a matter of resolving power that is of interest, for this determines the ability to analyze sharp fluctuations in cross section. The accuracy of the measured cross sections is usually a matter of statistics only, assuming that sample data are accurate. It is rather surprising that, in spite of the great variety of instruments, the resolving power is not greatly different in the energy regions in which the various instruments are best suited. This conclusion can be verified by Fig. 1, in which the resolving power is shown in terms of $E/\Delta E$, as given by the actual results in the compilation.

In the low energy region in which the slow chopper is the principal contributor, the resolving power shown in Fig. 1 decreases with increasing energy, as is typical of any time-of-flight instrument. When the energy is reached ($0.5 - 10$ ev) in which the crystal spectrometer predominates, the resolving power decreases slowly, as is characteristic of crystal spectrometers as well as the time-of-flight technique. The

* Brookhaven National Laboratory.

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- The EXchange FORmat (EXFOR) experimental nuclear reaction database and format for low- and intermediate-energy physics
  - 23,343 experimental works as of August 20, 2020
  - 174,951 reaction data tables
  - All compilations go through a quality assurance process
  - Nuclear Reaction Data Centers (NRDC) network
- EXFOR statistics, the IAEA official count of compilations: https://www-nds.iaea.org/public/exfor/x4compil/exfor_input.htm.
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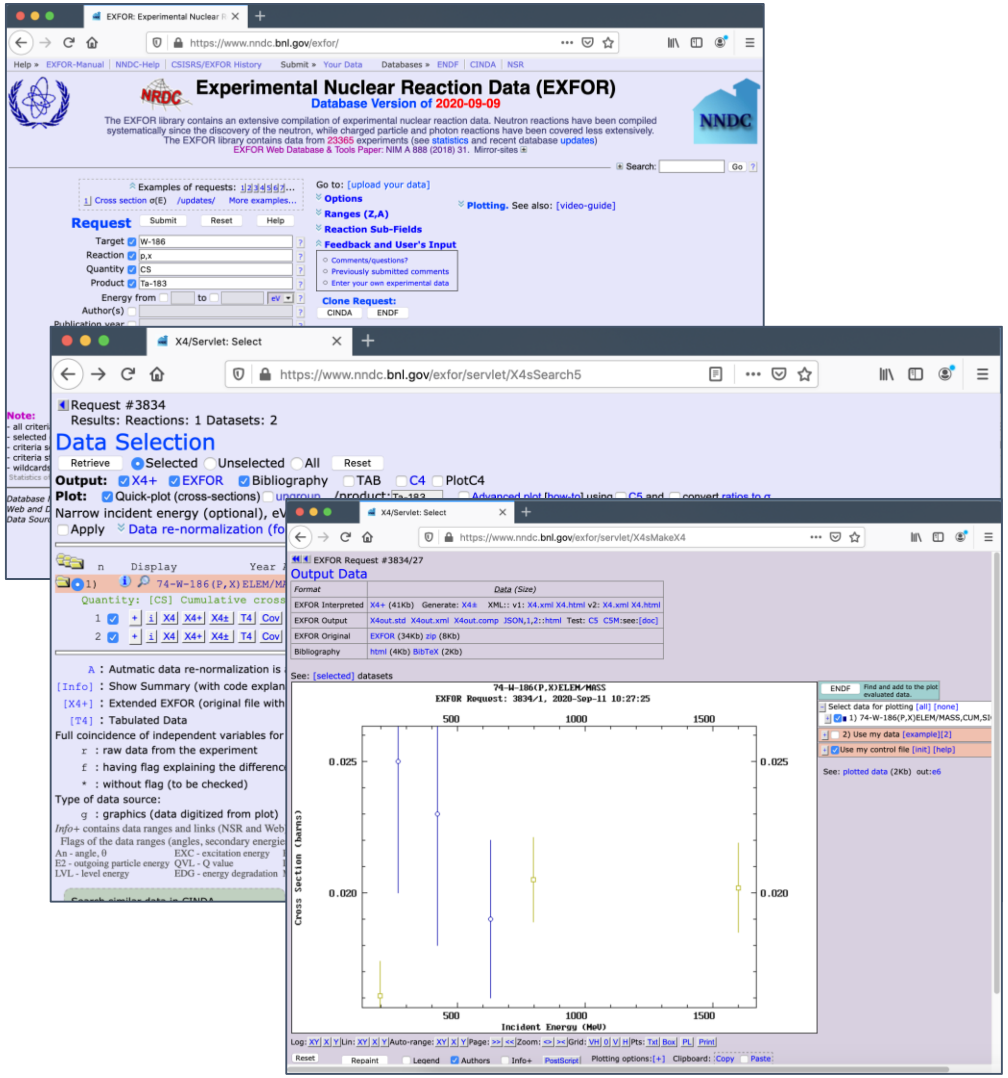

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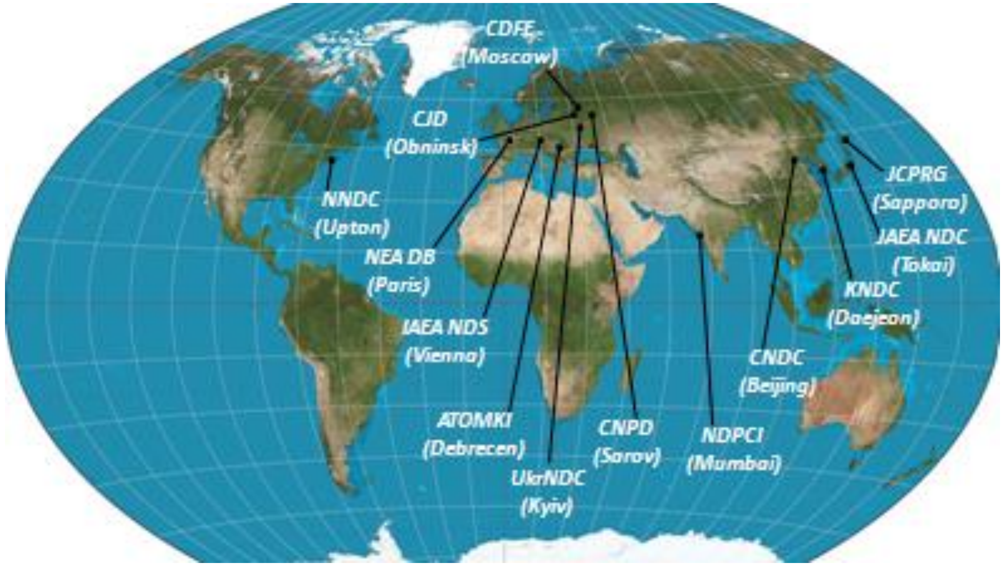

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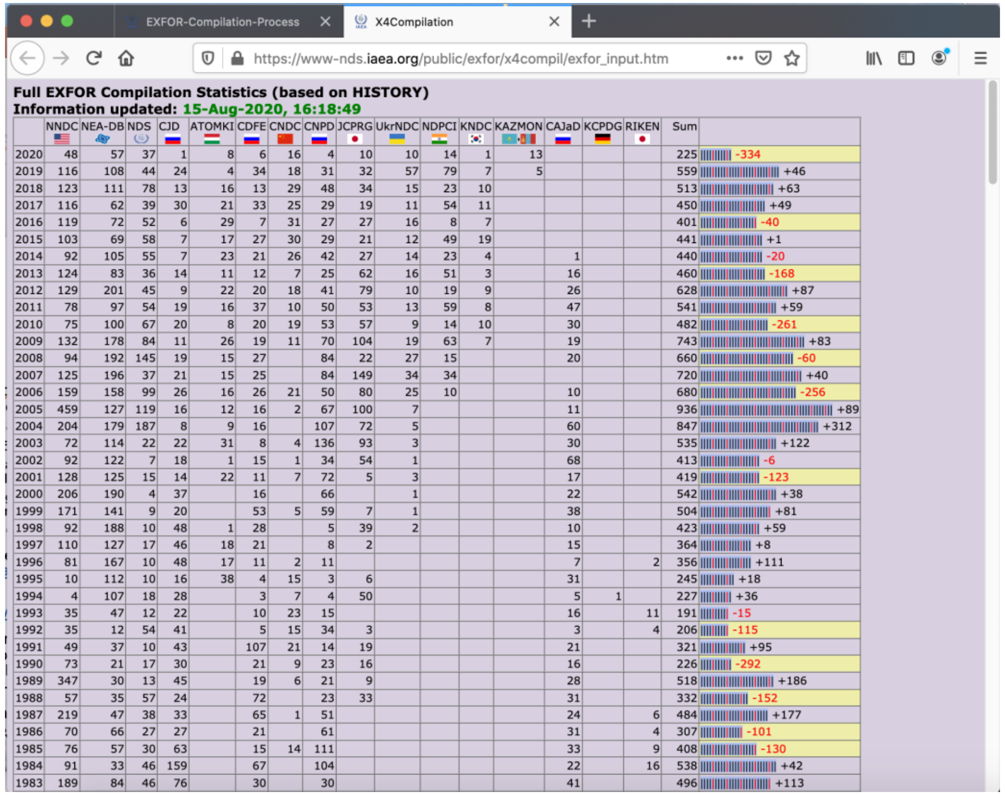

Full EXFOR Compilation Statistics (based on HISTORY)
Information updated: 15-Aug-2020, 16:18:49

	NNDC	NEA-DB	NDS	CJD	ATOMKI	CDFE	CNDC	CNPD	JCPRG	UkrNDC	NDPCI	KNDC	KAZMON	CAJaD	KCPDG	RIKEN	Sum	
2020	48	57	37	1	8	6	16	4	10	10	14	1	13				225	-334
2019	116	108	44	24	4	34	18	31	32	57	79	7	5				559	+46
2018	123	111	78	13	16	13	29	48	34	15	23	10					513	+63
2017	116	62	39	30	21	33	25	29	19	11	54	11					450	+49
2016	119	72	52	6	29	7	31	27	27	16	8	7					401	-40
2015	103	69	58	7	17	27	30	29	21	12	49	19					441	+1
2014	92	105	55	7	23	21	26	42	27	14	23	4		1			440	-20
2013	124	83	36	14	11	12	7	25	62	16	51	3		16			460	-168
2012	129	201	45	9	22	20	18	41	79	10	19	9		26			628	+87
2011	78	97	54	19	16	37	10	50	53	13	59	8		47			541	+59
2010	75	100	67	20	8	20	19	53	57	9	14	10		30			482	-261
2009	132	178	84	11	26	19	11	70	104	19	63	7		19			743	+83
2008	94	192	145	19	15	27		84	22	27	15			20			660	-60
2007	125	196	37	21	15	25		84	149	34	34						720	+40
2006	159	158	99	26	16	26	21	50	80	25	10			10			680	-256
2005	459	127	119	16	12	16	2	67	100	7				11			936	+89
2004	204	179	187	8	9	16		107	72	5				60			847	+312
2003	72	114	22	22	31	8	4	136	93	3				30			535	+122
2002	92	122	7	18	1	15	1	34	54	1				68			413	-6
2001	128	125	15	14	22	11	7	72	5	3				17			419	-123
2000	206	190	4	37		16		66		1				22			542	+38
1999	171	141	9	20		53	5	59	7	1				38			504	+81
1998	92	188	10	48	1	28		5	39	2				10			423	+59
1997	110	127	17	46	18	21		8	2					15			364	+8
1996	81	167	10	48	17	11	2	11						7		2	356	+111
1995	10	112	10	16	38	4	15	3	6					31			245	+18
1994	4	107	18	28		3	7	4	50					5	1		227	+36
1993	35	47	12	22		10	23	15						16		11	191	-15
1992	35	12	54	41		5	15	34	3					3		4	206	-115
1991	49	37	10	43		107	21	14	19					21			321	+95
1990	73	21	17	30		21	9	23	16					16			226	-292
1989	347	30	13	45		19	6	21	9					28			518	+186
1988	57	35	57	24		72		23	33					31			332	-152
1987	219	47	38	33		65	1	51						24		6	484	+177
1986	70	66	27	27		21		61						31		4	307	-101
1985	76	57	30	63		15	14	111						33		9	408	-130
1984	91	33	46	159		67		104						22		16	538	+42
1983	189	84	46	76		30		30						41			496	+113

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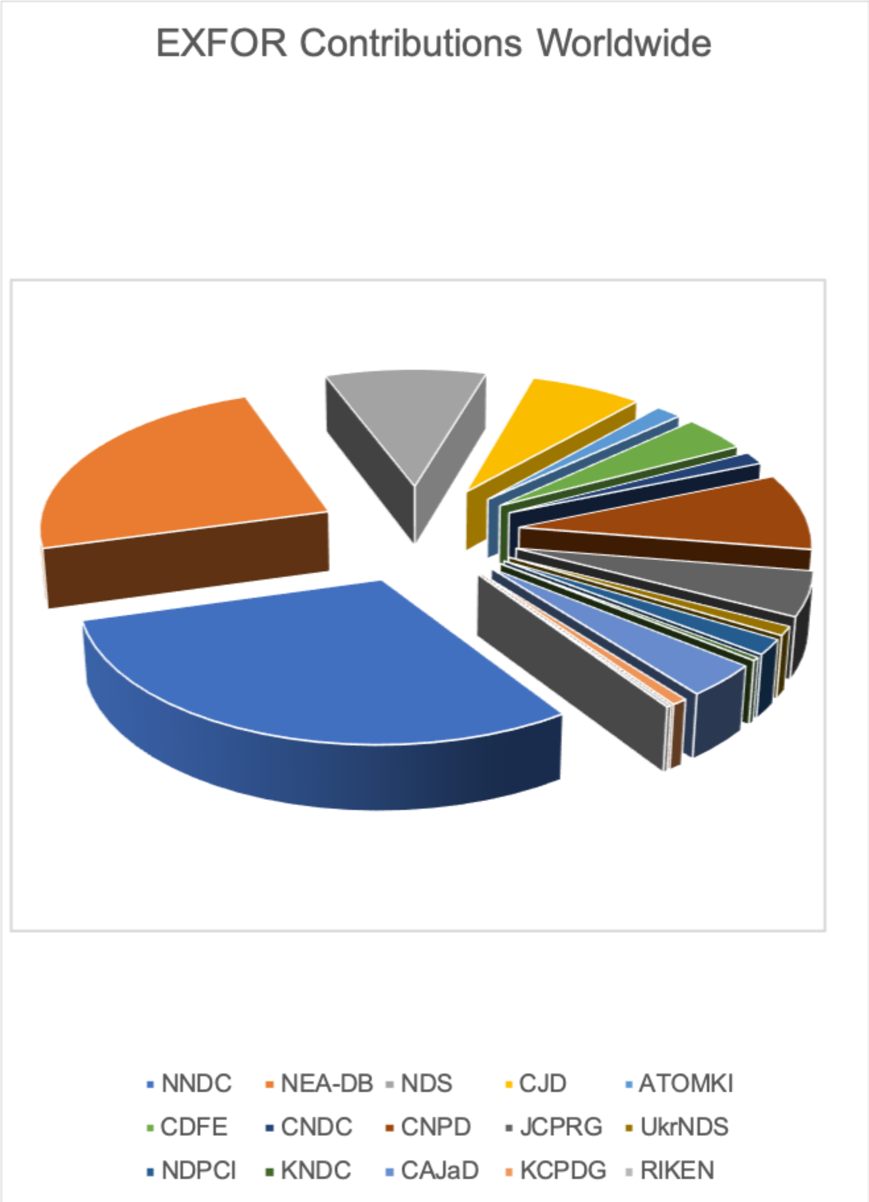

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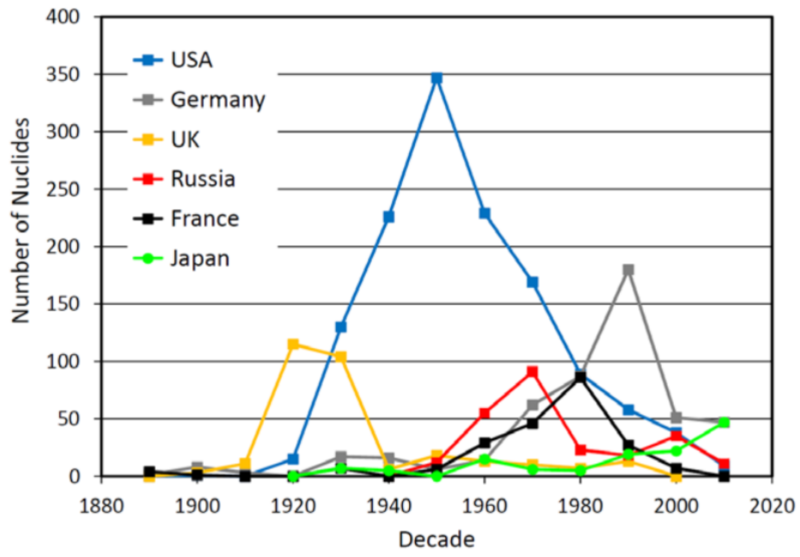
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Figure 2. *Number of nuclides discovered per decade at the top five countries: the United States, Germany, the United Kingdom, USSR/Russia, and France, as well as Japan. Japan is included because of the large number discovered during the last decade.*

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Evolving Project: Missing Data

- Not all experiments were compiled to SCISRS (Sigma Center Information Retrieval System) database at Brookhaven in 1950s for historical & technological reasons.
- EXFOR project started to compile neuron cross sections and spontaneous fission since 1970, no FY until 1976.
- EXFOR completeness: In spite of EXFOR Basics analysis, many important data sets were missed; comparison between EXFOR & Nuclear Science References (NSR) databases indicates that EXFOR could have 40,000+ experiments instead of 23,000.
- Present day cost of a single experiment, LBL 88” Cyclotron example:
  - $2,500 /hour beam time => $420 K/week
  - Cost of ^{36}S and ^{48}Ca for ECR source are $47 K/gram and $250 K/gram, respectively
  - Total price tag, conservatively, is $1 M
- It is cost effective to recover previous results than run new.
- EXFOR is a constantly-evolving project, it is driven by users’ needs; it is based on available computer technologies.

I. A Quick Guide to EXFOR

What is EXFOR?

EXFOR is the library and format for the collection, storage, exchange and retrieval of experimental nuclear reaction data. The library is the product of a worldwide co-operation, namely the international Network of Nuclear Reaction Data Centres (NRDC) which is co-ordinated by the IAEA Nuclear Data Section (NDS).

At present (May 2008), the EXFOR database contains about 17,000 works with around 129,000 data tables, representing

- a "complete" compilation of low-energy experimental neutron-induced reaction data,
- a less complete compilation of charged-particle-induced reaction data,
- a selected compilation of photon-induced, heavy-ion-induced, and high energy neutron-induced reaction data.

At present, compilation efforts concentrate on complete coverage of newly published data as well as, depending on the available manpower, on filling gaps in old measurements which are important for certain applications.

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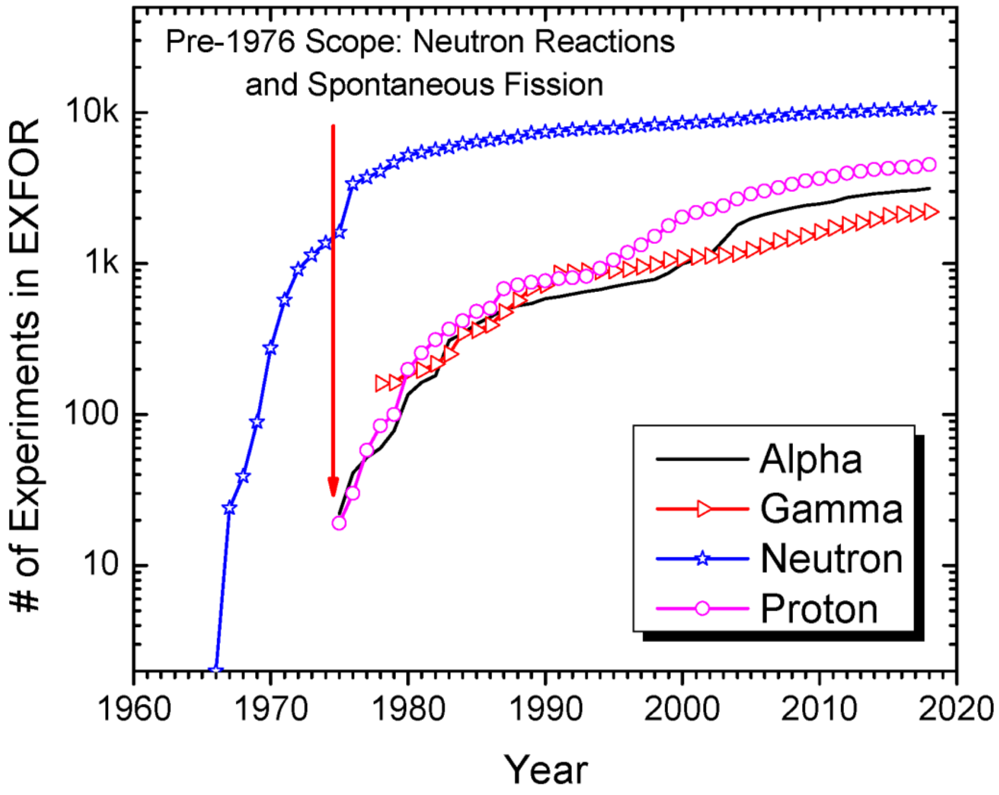

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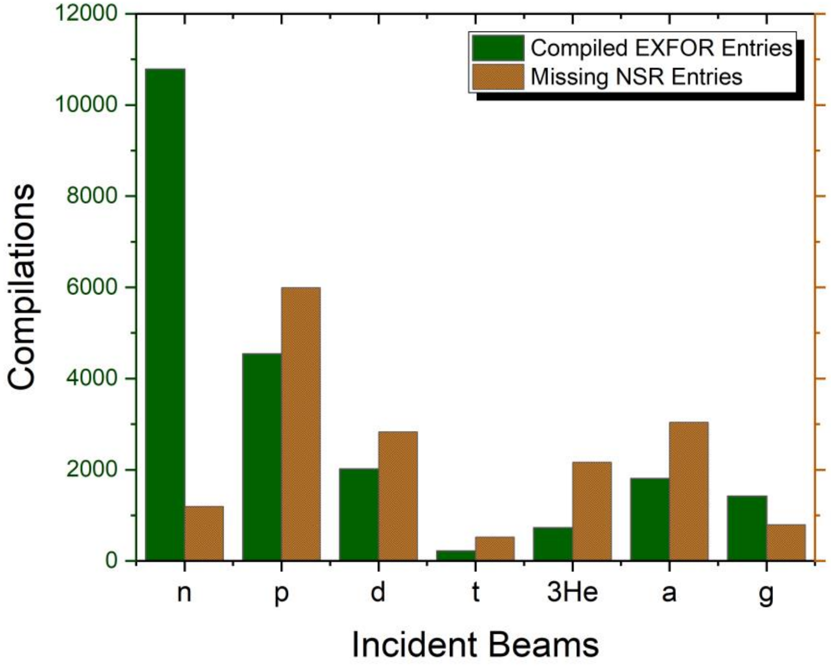
    - $2,500 /hour beam time => $420 K/week
    - Cost of ^{36}S and ^{48}Ca for ECR source are $47 K/gram and $250 K/gram, respectively
    - Total price tag, conservatively, is $1 M
- It is cost effective to recover previous results than run new.
- EXFOR is a constantly-evolving project, it is driven by users’ needs; it is based on available computer technologies.



EXFOR: ENDF validation

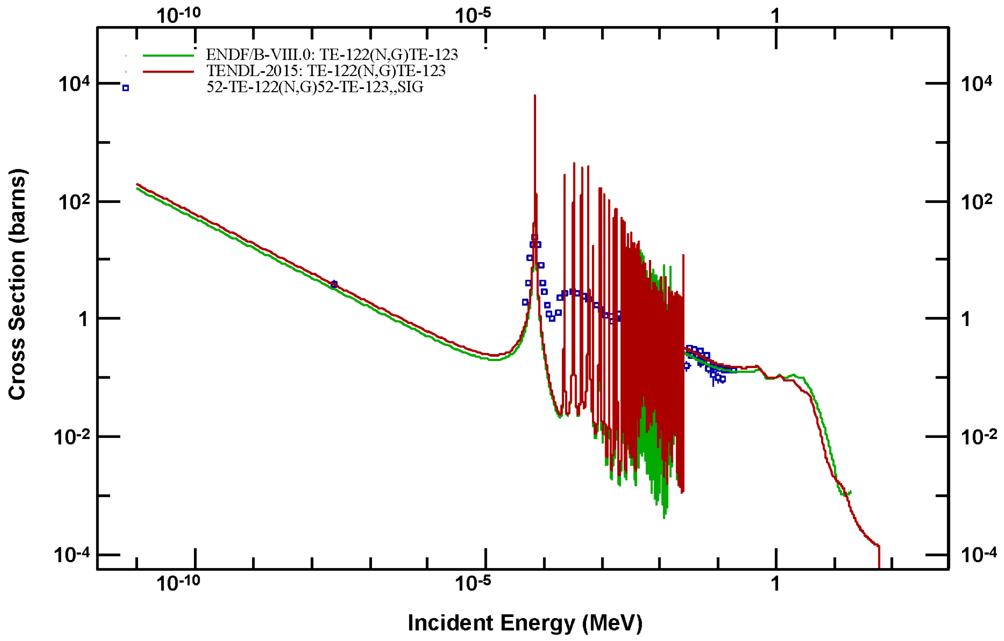
- ENDF library evaluations are based on theoretical calculations normalized to experimental data with an exception of neutron resonance region, where priority is given to experimental data.
- Importance of microscopic validation: Experimental $^{88}Zr(n,\gamma)$ thermal cross section is (8.61± 0.69) x10^5 barns [1] compared with the theoretically predicted 10 barns [2]:
    - [1] J.A. Shusterman, et al., “The surprisingly large neutron capture

  cross-section of ^{88}Zr,” Nature **565**, 328 (2019).

    - [2] A.J. Koning, D. Rochman, “Modern nuclear data evaluation with the

  TALYS code system,” Nucl. Data Sheets **113**, 2841–2934 (2012).

- EXFOR compilation of $^{88}Zr(n,\gamma)$ Nature article by Stanislav Hlavac (NNDC), #14520.
- FACILITY (REAC,1USAMIS) Neutron irradiations were performed using thermal-neutron flux in the graphite reflector of the University of Missouri Research Reactor (MURR).
- NRDC Rules: All experiments from USA & Canada are compiled by NNDC.



EXFOR: ENDF validation

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    - [1] J.A. Shusterman, et al., “The surprisingly large neutron capture

  cross-section of ^{88}Zr,” Nature **565**, 328 (2019).
    - [2] A.J. Koning, D. Rochman, “Modern nuclear data evaluation with the

  TALYS code system,” Nucl. Data Sheets **113**, 2841–2934 (2012).
- EXFOR compilation of $^{88}Zr(n,\gamma)$ Nature article by Stanislav Hlavac (NNDC), #14520.
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- NRDC Rules: All experiments from USA & Canada are compiled by NNDC.

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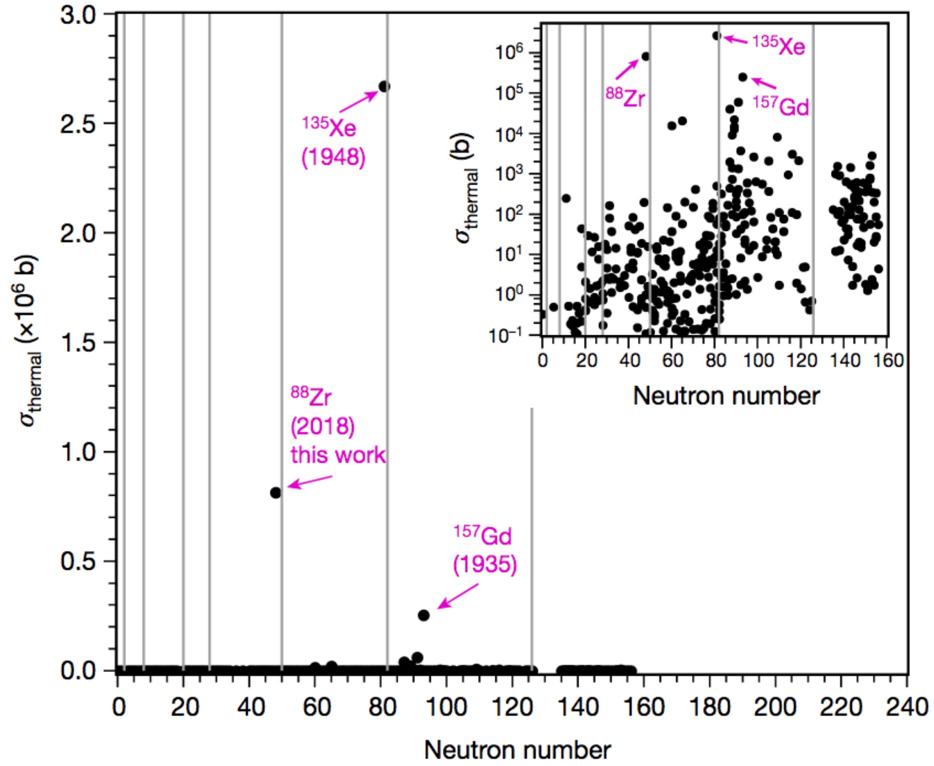

Fig. 3 | Measured thermal neutron capture cross-sections as a function of neutron number of the target. The main plot shows all the existing data on a linear scale, and the inset displays the same data on a logarithmic scale. The vertical lines indicate the neutron-shell closures, which occur for nuclei with 2, 8, 20, 28, 50, 82 and 126 neutrons. The three isotopes with cross-sections of more than 10^5 b are labelled along with the year of the measurement.

EXFOR: ENDF validation

- ENDF library evaluations are based on theoretical calculations normalized to experimental data with an exception of neutron resonance region, where priority is given to experimental data.
- Importance of microscopic validation: Experimental ^{88}Zr(n,γ) thermal cross section is (8.61± 0.69) x10^5 barns [1] compared with the theoretically predicted 10 barns [2]:
  - [1] J.A. Shusterman, et al., "The surprisingly large neutron capture cross-section of ^{88}Zr," Nature **565**, 328 (2019).
  - [2] A.J. Koning, D. Rochman, "Modern nuclear data evaluation with the TALYS code system," Nucl. Data Sheets **113**, 2841–2934 (2012).
- EXFOR compilation of ^{88}Zr(n,γ) Nature article by Stanislav Hlavac (NNDC), #14520.
- FACILITY (REAC,1USAMIS) Neutron irradiations were performed using thermal-neutron flux in the graphite reflector of the University of Missouri Research Reactor (MURR).
- NRDC Rules: All experiments from USA & Canada are compiled by NNDC.

```
ENTRY            14520   20190117   20190708   20190630       1448
SUBENT        14520001   20190117   20190708   20190630       1448
BIB                 12         40
TITLE      The surprisingly large neutron capture cross-section
           of 88Zr
AUTHOR     (J.A.Shusterman,N.D.Scielzo,K.J.Thomas,E.B.Norman,
           S.E.Lapi,C.S.Loveless,N.J.Peters,J.D.Robertson,
           D.A.Shaughnessy,A.P.Tonchev)
INSTITUTE  (1USALRL,1USAUCX,1USAUAL,1USAMIS)
           (1USAUSA) City University of New York,New York
REFERENCE  (J,NAT,565,328,2019)
FACILITY   (REAC,1USAMIS) Neutron irradiations were performed
           using thermal-neutron flux in the graphite reflector
           of the University of Missouri Research Reactor (MURR)
SAMPLE     (40-ZR-88,ENR=0.999) The 88Zr target material was
           produced via the 89Y(p,2n)88Zr reaction using a
           proton beam from the University of Alabama Cyclotron
           Facility at Birmingham.88Zr was chemically purified
           using anion-exchange chromatography and assayed before
           encapsulation as a salt residue in high-purity quartz
           tubes. The 37-kBq 88Zr samples and accompanying quartz
           encapsulated natural-metal foils (Fe, Zr, Mo and Y),
           which served as flux monitors,
           Each target contained 40.7 - 44.4 kBq of 88Zr at the
           beginning of irradiation
DECAY-DATA (40-ZR-88,83.4D,DG,392.87,0.9721)
           (40-ZR-89-G,3.267D,DG,909.15,0.9904)
DETECTOR   (HPGE) High-purity germanium detectors were used to
           measure induced activity in reaction products.
MONITOR    (26-FE-58(N,G)26-FE-59,,SIG)
           (40-ZR-90(N,2N)40-ZR-89,,SIG)
           (40-ZR-94(N,G)40-ZR-95,,SIG)
           (40-ZR-96(N,G)40-ZR-97,,SIG)
           (42-MO-98(N,G)42-MO-99,,SIG)
           Reactions (n,g) were used to determine neutron flux
           in thermal and resonance regions, (n,2n) reaction was
           used to determine the neutron flux above 12.5 MeV
INC-SOURCE The targets and monitors were irradiated simultaneously
           in the graphite reflector at MURR
INC-SPECT  Average thermal neutron flux  7.1E+13 n/cm2/s
           Resonance region neutron flux 2.7E+12 n/cm2/s
           neutron flux above 12.5 Mev   4.5E+9  n/cm2/s
HISTORY    (20190117C) Compiled by S.H.
ENDBIB              40
NOCOMMON             0          0
ENDSUBENT           43
SUBENT        14520002   20190117   20190708   20190630       1448
BIB                  6         25
REACTION   (40-ZR-88(N,G)40-ZR-89,,SIG,,SPA)
STATUS     (TABLE) Data taken from text p.329 of the reference
           (SUPPL,14520004) Neutron source spectrum
ANALYSIS   The neutron capture cross-section was determined from
           the dependence of the final-to-initial atom ratios on
           the neutron fluence.
ERR-ANALYS (ERR-1,0.2,11.) Systematic uncertainty in monitor mass
           (ERR-2,0.02,10.) Systematic uncertainty in irradiation
                            time
           (ERR-3) Systematic uncertainty in point source HPGe
                    efficiency used for monitor foils
           (ERR-4,0.,2.) Statistical uncertainty in neutron flux
           (ERR-5) Systematic uncertainty in reference cross
                      section data
           (ERR-6) Systematic uncertainty in sample geometry
           (ERR-7) Systematic uncertainty in point source HPGe
                   calibration used for sample foils
           (ERR-T) Total uncertainty
METHOD     (ACTIV) Activation method was used. Irradiation times
           varied between 0.08 and 50.15 hours. Cross section was
           measured by determining the quantities of 88Zr and of
           the reaction product 89Zr using gamma-ray spectroscopy
CORRECTION The Zr populations have been corrected for decay
           between the beginning of irradiation and the
           measurements performed after irradiation.
ENDBIB              25
COMMON               5          3
EN-DUMMY   ERR-3      ERR-5      ERR-6      ERR-7
EV         PER-CENT   PER-CENT   PER-CENT   PER-CENT
0.0253      1.          7.         6.         1.
ENDCOMMON            3
DATA                 2          1
DATA       ERR-T
B          B
    8.61E+5    0.69E+5
ENDDATA              3
ENDSUBENT           37
ENDENTRY             2
```

EXFOR Compilation Accession Number

- A unique compilation identifier, similar to NSR compilation keynumber or social security #.
- Each entry is assigned an accession number; each subentry is assigned a subaccession number (the accession number plus a subentry number).
- The subaccession numbers are associated with a data table throughout the life of the EXFOR system

```
ENTRY            14520 20190117   20190708   20190630       1448
SUBENT        14520001 20190117   20190708   20190630       1448
BIB                 12         40
TITLE      The surprisingly large neutron capture cross-section
           of 88Zr
AUTHOR     (J.A.Shusterman,N.D.Scielzo,K.J.Thomas,E.B.Norman,
           S.E.Lapi,C.S.Loveless,N.J.Peters,J.D.Robertson,
           D.A.Shaughnessy,A.P.Tonchev)
INSTITUTE  (1USALRL,1USAUCX,1USAUAL,1USAMIS)
           (1USAUSA) City University of New York,New York
REFERENCE  (J,NAT,565,328,2019)
FACILITY   (REAC,1USAMIS) Neutron irradiations were performed
           using thermal-neutron flux in the graphite reflector
           of the University of Missouri Research Reactor (MURR)
SAMPLE     (40-ZR-88,ENR=0.999) The 88Zr target material was
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           Facility at Birmingham.88Zr was chemically purified
           using anion-exchange chromatography and assayed before
           encapsulation as a salt residue in high-purity quartz
           tubes. The 37-kBq 88Zr samples and accompanying quartz
           encapsulated natural-metal foils (Fe, Zr, Mo and Y),
           which served as flux monitors,
           Each target contained 40.7 - 44.4 kBq of 88Zr at the
           beginning of irradiation
DECAY-DATA (40-ZR-88,83.4D,DG,392.87,0.9721)
           (40-ZR-89-G,3.267D,DG,909.15,0.9904)
DETECTOR   (HPGE) High-purity germanium detectors were used to
           measure induced activity in reaction products.
MONITOR    (26-FE-58(N,G)26-FE-59,,SIG)
           (40-ZR-90(N,2N)40-ZR-89,,SIG)
           (40-ZR-94(N,G)40-ZR-95,,SIG)
           (40-ZR-96(N,G)40-ZR-97,,SIG)
           (42-MO-98(N,G)42-MO-99,,SIG)
           Reactions (n,g) were used to determine neutron flux
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           Resonance region neutron flux 2.7E+12 n/cm2/s
           neutron flux above 12.5 Mev   4.5E+9  n/cm2/s
HISTORY    (20190117C) Compiled by S.H.
ENDBIB              40
NOCOMMON             0          0
ENDSUBENT           43
SUBENT        14520002   20190117   20190708   20190630       1448
BIB                  6         25
REACTION   (40-ZR-88(N,G)40-ZR-89,,SIG,,SPA)
STATUS     (TABLE) Data taken from text p.329 of the reference
           (SUPPL,14520004) Neutron source spectrum
ANALYSIS   The neutron capture cross-section was determined from
           the dependence of the final-to-initial atom ratios on
           the neutron fluence.
ERR-ANALYS (ERR-1,0.2,11.) Systematic uncertainty in monitor mass
           (ERR-2,0.02,10.) Systematic uncertainty in irradiation
                            time
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                    efficiency used for monitor foils
           (ERR-4,0.,2.) Statistical uncertainty in neutron flux
           (ERR-5) Systematic uncertainty in reference cross
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           (ERR-6) Systematic uncertainty in sample geometry
           (ERR-7) Systematic uncertainty in point source HPGe
                   calibration used for sample foils
           (ERR-T) Total uncertainty
METHOD     (ACTIV) Activation method was used. Irradiation times
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           the reaction product 89Zr using gamma-ray spectroscopy
CORRECTION The Zr populations have been corrected for decay
           between the beginning of irradiation and the
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ENDBIB              25
COMMON               5          3
EN-DUMMY   ERR-3      ERR-5      ERR-6      ERR-7
EV         PER-CENT   PER-CENT   PER-CENT   PER-CENT
0.0253      1.          7.         6.         1.
ENDCOMMON            3
DATA                 2          1
DATA       ERR-T
B          B
    8.61E+5    0.69E+5
ENDDATA              3
ENDSUBENT           37
ENDENTRY             2
```
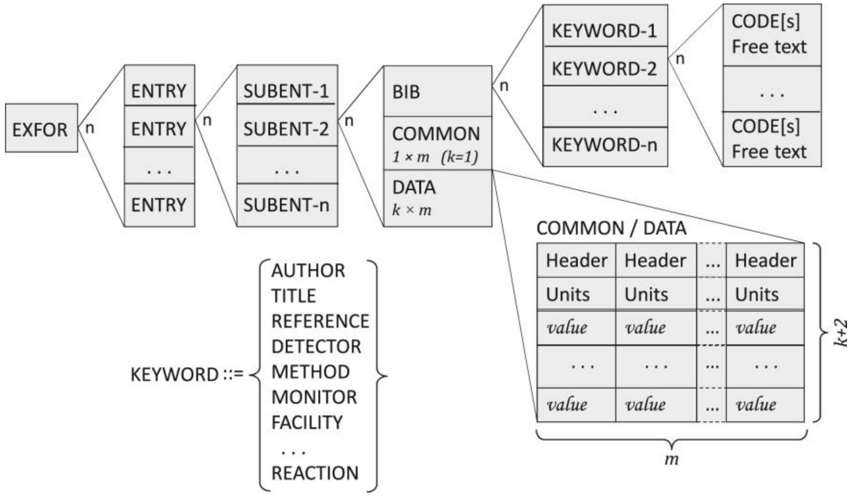

EXFOR Compilation Format

- EXFOR format for the data interchange between major centers was later adopted as the database format.
- EXFOR entry groups multiple publications from the same experiment and represents the final results.
- Each entry consists of the one bibliographical and multiple data subentries (experimental data sets).
- V.V. Zerkin, B.Pritychenko,`` *The Experimental Nuclear Reaction Data (EXFOR): Extended Computer Database and Web Retrieval System*,” Nucl. Instr. Meth. Phys. Res. A 888, 31 (2018); and references therein.
- O. Schwerer, “LEXFOR (EXFOR Compiler’s Manual)”, International Atomic Energy Agency Report IAEA-NDS-208, Rev. 2015/08(2015). 〈https://www-nds. iaea.org/nrdc/nrdcdoc/iaea-nds-0208-201508.pdf〉
- O. Schwerer, “EXFOR Formats Manual,” International Atomic Energy Agency Report IAEA-NDS-207, Rev. 2015/08 (2015);〈https://www-nds.iaea.org/ nrdc/nrdcdoc/iaea-nds-0207-201508.pdf〉



Well-Structured Format

- EXFOR Formats Description for Users (EXFOR Basics), originally written by Vicki McLane and updated by Otto Schwerer: https://www-nds.iaea.org/nrdc/nrdc_doc/iaea-nds-0206-200806.pdf.
- EXFOR system identifiers (ENTRY, DATA, …) may be combined with the modifiers (ENDENTRY, ENDDATA, NODATA,…).
- Essentially, data set start and end are hardcoded. Extremely helpful for EXFOR format readability!!!
- EXFOR had XML-like structures since 1970.
- Modern computer language (Java, ….) with advanced string handling is needed. Please forget about earlier languages like FORTRAN because it was designed for numbers only.

System Identifiers

Each of the following basic system identifiers refers to one of the hierarchy of units contained on an exchange file. Each of the following system identifiers indicates the beginning of one of these sections.

TRANS - A file is the unit *(only on files for exchange between data centres. In user retrieval files this identifier may be missing or be replaced by another keyword such as 'REQUEST')*
ENTRY - An entry (work) is the unit
SUBENT - A subentry (data set) is the unit
BIB - The Bibliographic Information section (hereafter referred to as the BIB section) of a complete work or sub-work is the unit
COMMON - The Common Data section of a complete work or sub-work is the unit
DATA - The Data Table section of a sub-work is the unit

These basic system identifiers may be combined with the modifiers

NO
END

to indicate three conditions:

- The beginning of a unit (basic system identifier only)
- The end of a unit (modifier **END** preceding the basic system identifier)
- A positive indication that a unit is intentionally omitted (modifier **NO** preceding the basic system identifier)

Well-Structured Format

- EXFOR Formats Description for Users (EXFOR Basics), originally written by Vicki McLane and updated by Otto Schwerer: https://www-nds.iaea.org/nrdc/nrdc_doc/iaea-nds-0206-200806.pdf.
- EXFOR system identifiers (ENTRY, DATA, …) may be combined with the modifiers (ENDENTRY, ENDDATA, NODATA,…).
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```
ENTRY            C1582   20181107   20190128   20190120       C181
SUBENT        C1582001   20181107   20190128   20190120       C181
BIB                 10         22
TITLE      Astrophysically important 31S states studied with
           the 32S(p,d)31S reaction
AUTHOR     (Z.Ma,D.W.Bardayan,J.C.Blackmon,R.P.Fitzgerald,
           M.W.Guidry,W.R.Hix,K.L.Jones,R.L.Kozub,R.J.Livesay,
           M.S.Smith,J.S.Thomas,D.W.Visser)
INSTITUTE  (1USATEN,1USAORL,1USANCA,1USATTU,1USACSM,1USARUT)
REFERENCE  (J,PR/C,76,015803,2007)
FACILITY   (VDGT,1USAORL) HRIBF Facility
SAMPLE     ZnS target with a thickness of 285 microgram/cm2
           deposited on 1 microgram/cm2 carbon for measurements
           at laboratory angles 17-48 deg. ZnS target with a
           thickness of 280 microgram/cm2 on 5 microgram/cm2
           carbon backing at laboratory angles 31-75 deg
DETECTOR   (SISD) Silicon detector array SIDAR operated in
           telescope mode with 300-micron-thick dE detectors
           backed by 500-micron-thick E detectors
METHOD     (EDE)
ERR-ANALYS (DATA-ERR) No information
HISTORY    (20071127C) compiled by S.H.
           (20100317A) SD: page number in ref. was corrected.
                                  15803 -> 015803
           (20181105U) OS. Minor BIB corrections
ENDBIB              22
COMMON               1          3
EN
MEV
32.0
ENDCOMMON            3
ENDSUBENT           29
SUBENT        C1582002   20071127   20080305   20080228       C083
BIB                  2          2
REACTION   (16-S-32(P,D)16-S-31,PAR,DA)
STATUS     (CURVE) Data taken from Fig 3 in the reference
ENDBIB               2
COMMON               1          3
E-EXC
KEV
4085.0
ENDCOMMON            3
DATA                 3          2
ANG        DATA       DATA-ERR
ADEG       B/SR       B/SR
  1.857E+01  6.427E-04  8.978E-05
  2.196E+01  5.616E-04  8.567E-05
ENDDATA              4
ENDSUBENT           15
```

Keywords & Codes

- The text part (bibliographic, experimental and bookkeeping information) is specified in variable length fields whose content is defined by keywords. An entry contains only those keywords relevant for the particular work. The information attached to a keyword may consist of "codes" (standard abbreviations taken from a "dictionary") and/or unstructured English "free text".
- The information-identifier keyword is used to define the significance of the information given in columns 12-66. The keyword is left adjusted to begin in column 1, and does not exceed a length of 10 characters).
- Codes for use with a specific keyword are found in the relevant dictionary.

ADD-RES	DETECTOR	**INSTITUTE**	**REFERENCE**
ANALYSIS	EN-SEC	LEVEL-PROP	REL-REF
ASSUMED	ERR-ANALYS	METHOD	RESULT
AUTHOR	EXP-YEAR	MISC-COL	SAMPLE
COMMENT	FACILITY	MOM-SEC	**STATUS**
CORRECTION	FLAG	MONIT-REF	**TITLE**
COVARIANCE	HALF-LIFE	MONITOR	
CRITIQUE	**HISTORY**	PART-DET	
DECAY-DATA	INC-SOURCE	RAD-DET	
DECAY-MON	INC-SPECT	**REACTION**	

Keywords & Codes

- The text part (bibliographic, experimental and bookkeeping information) is specified in variable length fields whose content is defined by keywords. An entry contains only those keywords relevant for the particular work. The information attached to a keyword may consist of "codes" (standard abbreviations taken from a "dictionary") and/or unstructured English "free text".
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- Codes for use with a specific keyword are found in the relevant dictionary.

```
INSTITUTE  (1USATEN,1USAORL,1USANCA,1USATTU,1USACSM)            C1582001    8
           (1USAUSA) Rutgers University, Piscataway, New Jersey C1582001    9
REFERENCE  (J,PR/C,76,15803,2007)                               C1582001   10
FACILITY   (VDGT,1USAORL) HRIBF Facility                        C1582001   11
SAMPLE     ZnS target with a thickness of 285 microgram/cm2     C1582001   12
           deposited on 1 microgram/cm2 carbon for measurements C1582001   13
           at laboratory angles 17-48 deg. ZnS target with a    C1582001   14
           thickness of 280 microgram/cm2 on 5 microgram/cm2    C1582001   15
           carbon backing at laboratory angles 31-75 deg        C1582001   16
DETECTOR   (SISD) Silicon detector array SIDAR operated in      C1582001   17
           telescope mode with 300-micron-thick dE detectors    C1582001   18
           backed by 500-micron-thick E detectors               C1582001   19
METHOD     (EDE)                                                C1582001   20
ERR-ANALYS (DATA-ERR) No information                            C1582001   21
```

Reaction String Sub-Fields & Dictionaries

- Nine reaction subfields: (SF1(SF2,SF3)SF4,SF5,SF6,SF7,SF8,SF9)
- Reaction: (1-H-1(N,G)1-H-2,,SIG,,MXW,DERIV)
- Decay Ratio: ((98-CF-254(0,F)ELEM/MASS,CUM,FY)/ (98-CF-254(0,F)MASS,CHN,FY))

Dictionary 3.	Institutes
Dictionary 4.	Reference Type
Dictionary 5.	Journals
Dictionary 7.	Conferences
Dictionary 15.	History
Dictionary 16.	Status
Dictionary 17.	Related Reference
Dictionary 18.	Facility
Dictionary 19.	Incident Source
Dictionary 20.	Additional Results
Dictionary 21.	Method
Dictionary 22.	Detectors
Dictionary 23.	Analysis
Dictionary 24.	Data Headings
Dictionary 30.	Process
Dictionary 33.	Particles
Dictionary 34.	Modifiers (REACTION SF8)
Dictionary 35.	Data-Type (REACTION SF9)
Dictionary 37.	Result
Dictionary 207.	Books
Dictionary 236.	Quantities (REACTION SF5-7)

EXFOR STATUS

- Any compilation contains status information.
- Gives information on the status of the data presented.

```
ENTRY            13467     900403              20050926       0000
SUBENT        13467001     900403              20050926       0000
BIB                  8         10
INSTITUTE  (1USALAS)
REFERENCE  (J,ACS,,(21),7404) NUCLEAR CHEM. AND TECHNOLOGY DIV.
            AMERICAN CHEM.SOC. NATIONAL MEETING, LOS ANGELES
AUTHOR     (K.WOLFSBERG,G.P.FORD)
TITLE      MASS YIELDS FROM SPONTANEOUS FISSION OF 254CF
METHOD     (RCHEM)
ERR-ANALYS STANDARD DEVIATION LESS THAN 10.% EXCEPT WHERE GIVEN
            ABSOLUTELY
STATUS     (RIDER) 74WOL3
HISTORY    (900207C) VM
ENDBIB              10
NOCOMMON             0          0
ENDSUBENT           13
SUBENT        13467002     900403              20050926       0000
BIB                  1          1
REACTION   (98-CF-254(0,F)MASS,CHN,FY)
ENDBIB               1
NOCOMMON             0          0
DATA                 5         26
MASS       DATA       DATA-ERR   DATA-ERR   DATA-MAX
NO-DIM     PC/FIS     PC/FIS     PER-CENT   PC/FIS
 93.         0.69                 10.
 97.         0.89                 10.
 99.         2.0                  10.
105.         4.88                 10.
109.         5.6        0.7
111.         5.3                  10.
112.         4.4                  10.
113.         5.2                  10.
115.         3.2                  10.
121.                                           0.5
127.                                           0.2
131.         2.6                  10.
132.         2.9                  10.
133.         4.9                  10.
134.         5.4                  10.
135.         4.6        0.6
139.         5.7                  10.
140.         5.9                  10.
141.         5.3        0.7
143.         5.9                  10.
145.         5.6        1.0
147.         4.7                  10.
149.         3.0                  10.
151.         2.6        0.3
153.         1.50                 10.
157.         0.60                 10.
ENDDATA             28
ENDSUBENT           34
```

EXFOR STATUS

- Any compilation contains status information.
- Gives information on the status of the data presented.

Dictionary 16: Status codes: used with the keyword STATUS.

APRVD	Approved by author
COREL	Data correlated with another data set
CPX	Data taken from data file of McGowan, et al.
CURVE	Data read from a curve
DEP	Dependent data
NACRE	Converted from NACRE files
NCHKD	Original reference not checked
NDD	Data converted from NEUDADA file
OUTDT	Normalization out-of-date
PRELM	Preliminary data
RCALC	Ratio to standard calculated by other than author
RIDER	Data converted from file of B.F. Rider
RNORM	Data renormalized by other than author
SCSRS	Data converted from SCISRS file
SPSDD	Data superseded
TABLE	Data received by center in tabular form
UNOBT	Data unobtainable from author

EXFOR Machine Readability

- EXFOR format was well ahead of its time.
- Good readability using modern computer languages for text string handlings.
- Complementary representations in the presentation of Viktor Zerkin (IAEA). :
  - C4 (X4toC4), X4$\pm$, C5, JSON, …
  - IAEA/NNDC Web Interfaces, Java/C/HTML/SQL technologies + wrapping of old FORTRAN codes.
- Results could be as good as an overall quality of underlying compilations.

Takeaways

- EXFOR is a unique experimental nuclear reaction database: J.L. Kammerdiener’s thesis.
- EXFOR effort is complex and well-organized.
- Combined international compilation and Quality Assurance (QA) efforts: relational database.
- Reading EXFOR compilations is relatively easy using modern computer languages.
- Some users criticize EXFOR for complexity; however, it is the “Holy Grail” after understanding compilation formats for EXFOR readability.

```
ENTRY            14329   20130820   20131120   20131111       1393
SUBENT        14329001   20130820   20131120   20131111       1393
BIB                 15         72
TITLE      Neutron Spectra Emitted by 239Pu, 238U, 235U, Pb, Nb,
           Ni, Al and C Irradiated by 14 MeV Neutrons
AUTHOR     (J.L.Kammerdiener)
INSTITUTE  (1USADAV)
REFERENCE  (R,UCRL-51232,1972) Ph.D.thesis
REL-REF    (O,10423001,L.F.Hansen+,P,USNDC-9,84,197311), Ni data.
           (O,V1004001,T.Kawano,W,KAWANO,2013)
             Angle-integrated spectra derived from present
             experiment
FACILITY   (ICTR,1USALRL) Insulated core transformer accelerator.
INC-SOURCE (D-T) Deuteron on tritium
DETECTOR   (SCIN,GLASD) NE-213 scintillator, 6Li glass detector.
PART-DET   (N,G)
METHOD     (TOF,PSD,RINGR) Time of flight, pulse shape ...
ANALYSIS   (REDUC) The entire data reduction process was ...
CORRECTION The data were corrected for effects due to ...
ERR-ANALYS (DATA-ERR) Data which has been corrected ...
           (ERR-S,,10.0) less than 10%.
COMMENT    From conversation of M.B. Chadwick with John ...
HISTORY    (20121207C) BP
           (20130712A) BP added reference to Los Alamos estimate
           by T. Kawano.
ENDBIB              72
COMMON               1          3
EN
MEV
14.0
ENDCOMMON            3
ENDSUBENT           79
SUBENT        14329002   20121207   20130502   20130429       1388
BIB                  3          3
REACTION   (13-AL-27(N,EL)13-AL-27,,DA)
STATUS     (CURVE) Fig.42.
REL-REF    (A,11322001,J.H.Coon+,J,PR,111,250,1958)
ENDBIB               3
NOCOMMON             0          0
DATA                 3         13
ANG-CM     DATA-CM    DATA-ERR
ADEG       MB/SR      MB/SR
  2.500E+01  2.238E+02
  3.000E+01  1.018E+02  6.049E+00
  3.500E+01  3.094E+01  3.807E+00
  4.000E+01  1.407E+01  2.260E+00
  4.500E+01  1.736E+01  1.867E+00
  5.500E+01  3.784E+01
  6.500E+01  4.469E+01
  7.500E+01  2.810E+01
  8.500E+01  1.181E+01  6.043E-01
  1.000E+02  1.000E+01  5.117E-01
  1.150E+02  1.181E+01  7.988E-01
  1.350E+02  1.082E+01  9.070E-01
  1.550E+02  1.121E+01  1.379E+00
ENDDATA             15
ENDSUBENT           23
ENDENTRY             2
```

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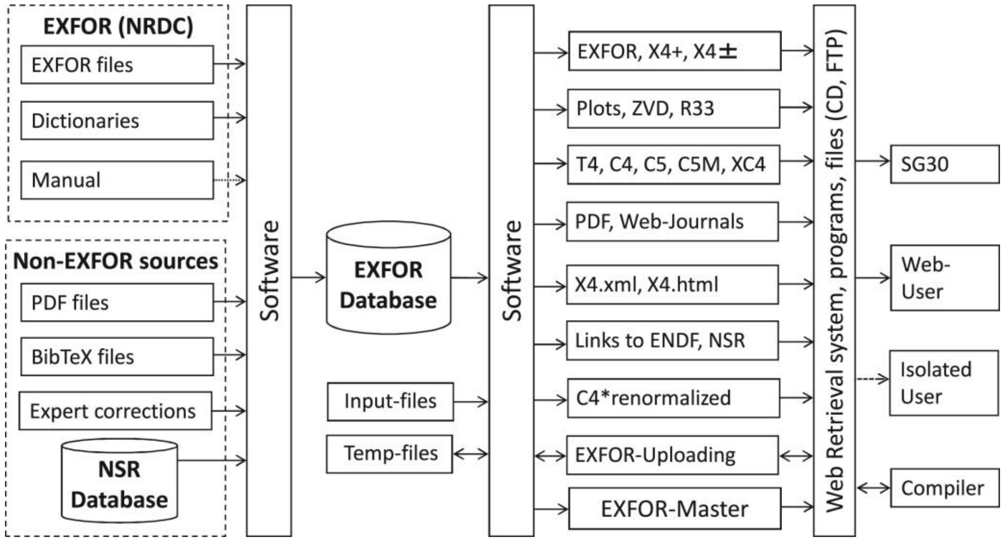

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The International Atomic Energy Agency: (https://www.iaea.org/about/mission)

- is an independent intergovernmental, science and technology-based organization, in the United Nations family, that serves as the global focal point for nuclear cooperation;
- assists its Member States, in the context of social and economic goals, in planning for and using nuclear science and technology for various peaceful purposes, including the generation of electricity, and facilitates the transfer of such technology and knowledge in a sustainable manner to developing Member States;
- develops nuclear safety standards and, based on these standards, promotes the achievement and maintenance of high levels of safety in applications of nuclear energy, as well as the protection of human health and the environment against ionizing radiation;
- verifies through its inspection system that States comply with their commitments, under the Non-Proliferation Treaty and other non-proliferation agreements, to use nuclear material and facilities only for peaceful purposes.