The Abdus Salam
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IAEA
International Atomic Energy Agency

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Joint ICTP/IAEA School on Physics and Technology of Fast Reactors Systems

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Nuclear Data for Fast Reactor Systems - 1

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International Atomic Energy Agency

Nuclear Data for Fast Reactor Systems

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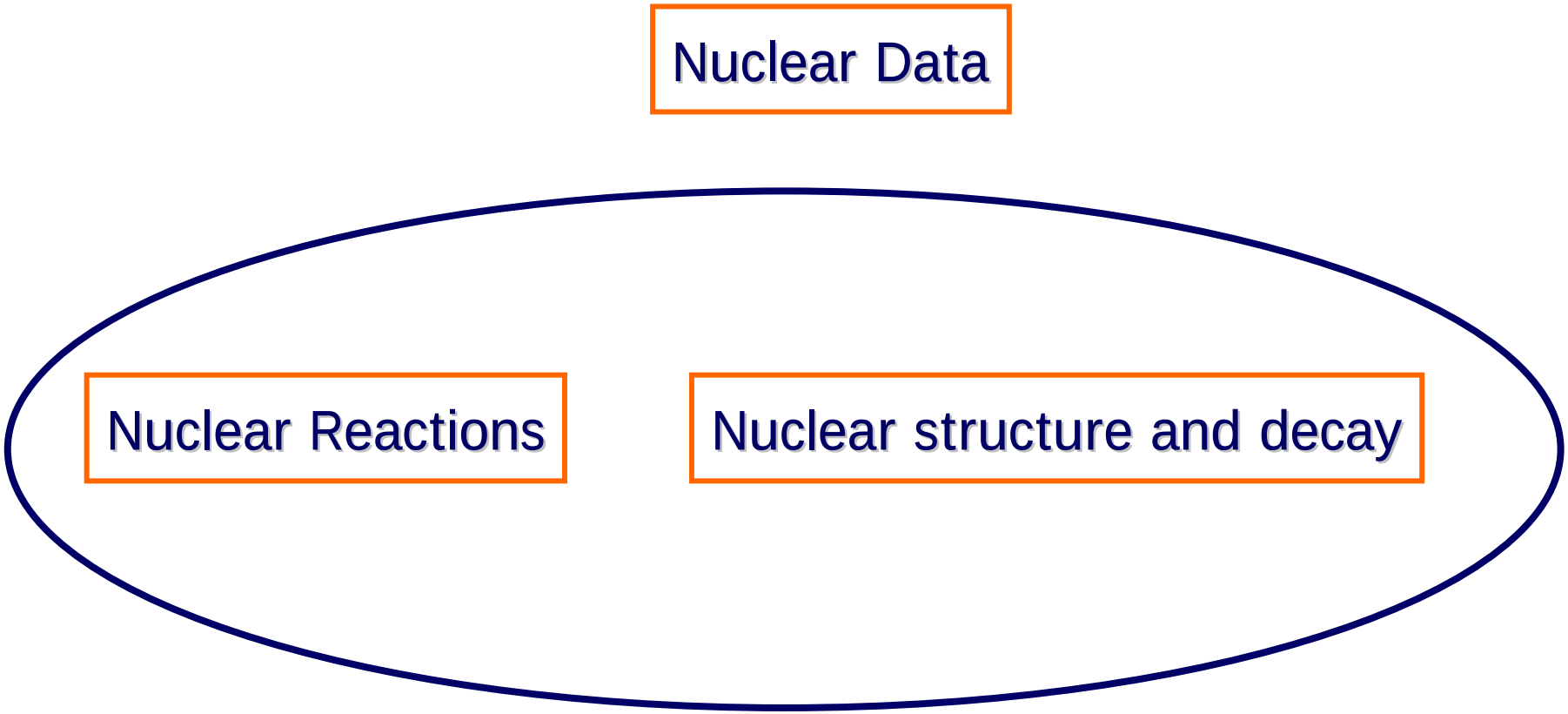
Department of Nuclear Sciences and Applications

ICTP Trieste, Nov. 2009

Nuclear Data for Fast Reactor Systems



Nuclear Data for Fast Reactor Systems

Nuclear Reactions

X (a , b) Y

X = Target a = Projectile

Y = Residual b = Ejectile

$$X = {}^{A}_{Z}X_{N}$$

$${}^{9}_{4}Be_{5} + {}^{4}_{2}He_{2} \rightarrow {}^{12}_{6}C_{6} + n \quad \text{or} \quad Be\ (\alpha, n)\ C$$

Nuclear Data for Fast Reactor Systems

Neutron-induced reactions

X (n , x) Y

X = Target n = Projectile

Y = Residual x = Ejectile

i.e if x = n the reaction is scattering

i.e. If x = γ the reaction is Radiative Capture

$$ {}^{1}_{1}H_{0} + {}^{1}n \rightarrow {}^{2}_{1}H_{1} + \gamma \quad \text{or} \quad H(n, \gamma) D $$

Nuclear Data for Fast Reactor Systems

The probability that a reaction occurs depends on Energy

Temperature (K)	Energy (eV)	Speed (m/s)
300	0.026	2200
1000	0.086	4000

“slow” or thermal neutrons → E ~ 0.03 eV

“fast” neutrons → E ~ 1 MeV

Nuclear Data for Fast Reactor Systems

For Slow neutrons

The most important reactions:

- **Scattering (ELA: (n,n) ; INE: (n,n'))**
- **Capture:**

  (n,γ)

  (n,α) only low Z

  (n,p) only low Z

  (n,f)

Nuclear Data for Fast Reactor Systems

For Fast neutrons

The most important reactions:

- **Scattering (ELA: (n,n) ; INE: (n,n'))**
- **Capture:**

  (n,γ)

  (n,α) ; (n,2n) ; (n,3n) …

  (n,p) ; (n,np) ; (n,2np)…

  (n,f)

Nuclear Data for Fast Reactor Systems

Cross Section

The probability of a particular reaction is proportional to its “cross section”

Let us assume a uniform beam of neutrons of intensity I (neutrons/cm2s)

The target is a layer “one atom thick” of Na atoms/cm2 and C is the number of interactions for example neutron captures per cm2s

Cross Section

Then the cross section σ is defined:

$$\sigma = \frac{C \text{ (n/cm2.s)}}{I \text{ (n/cm2.s)} \quad Na \text{ (nucleus/cm2)}}$$

Units:
(cm2 per nucleus)

Cross Section

Rearranging terms:

$$\sigma \quad Na \quad = \quad \frac{C}{I}$$

If every neutron falling on target reacted, then C=I fraction reacting =1 (100%)

σ **Na**

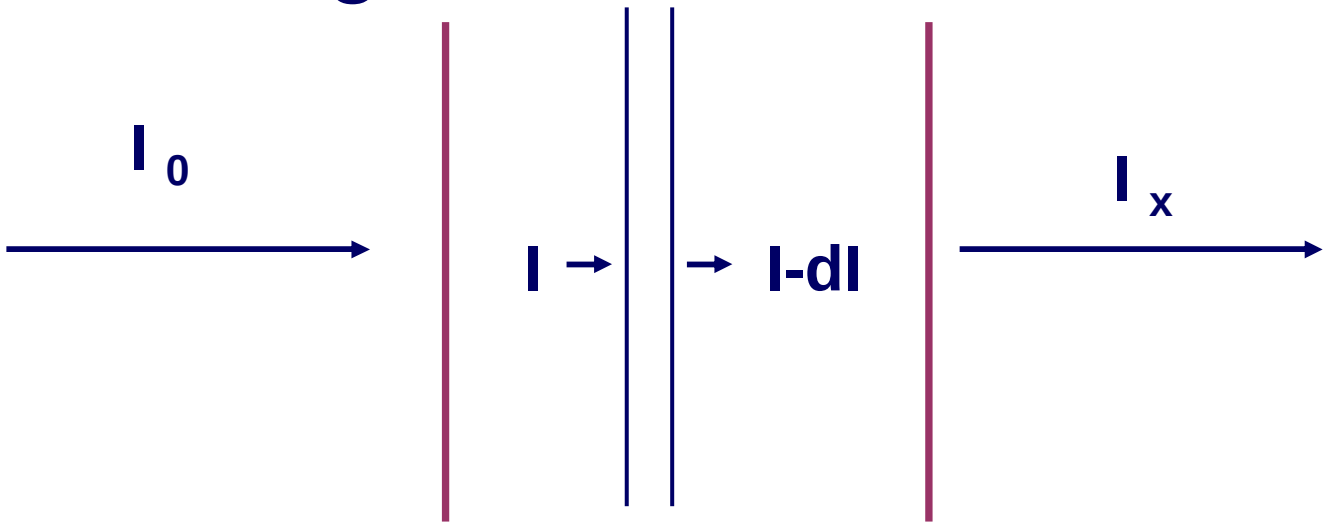
Represents the fraction of surface that undergoes capture. That is from one cm2

σ **Na cm2**

Cross Section

Now generalizing to any thickness:

N = #of target nucleus/cm3



$$-dI/I = N\ \sigma\ dx$$

Cross Section

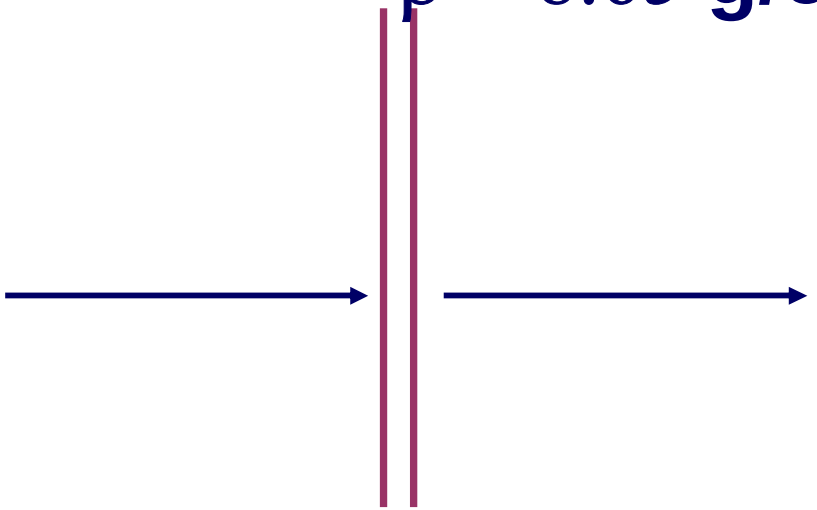
Integrating….

$$\frac{I_x}{I_0} = e^{-N \sigma x}$$

$$\frac{I_x}{I_0} = 0.30$$

Example: Cd

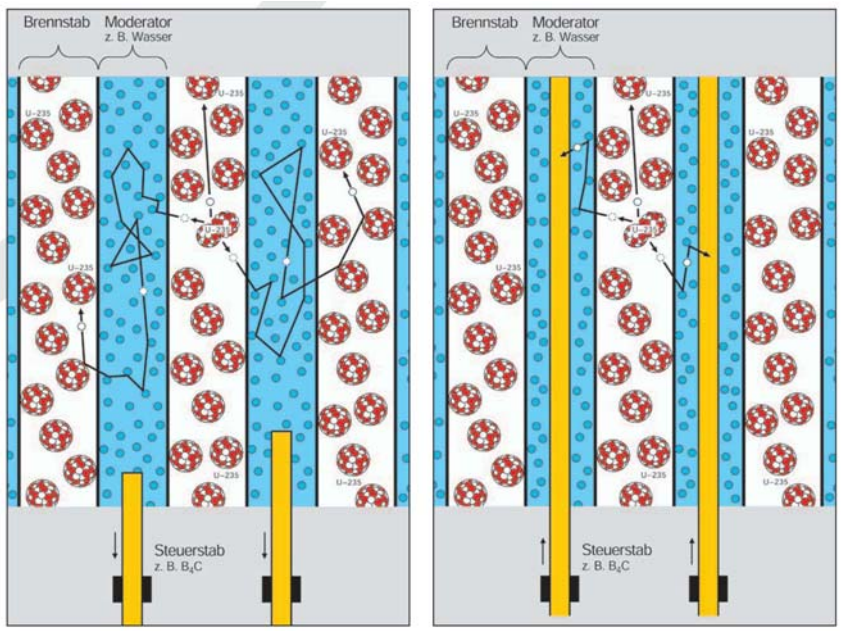
$\rho = 8.65$ **g/cm2**



dx =0.01cm

σ = ?

Neutron-induced reactions

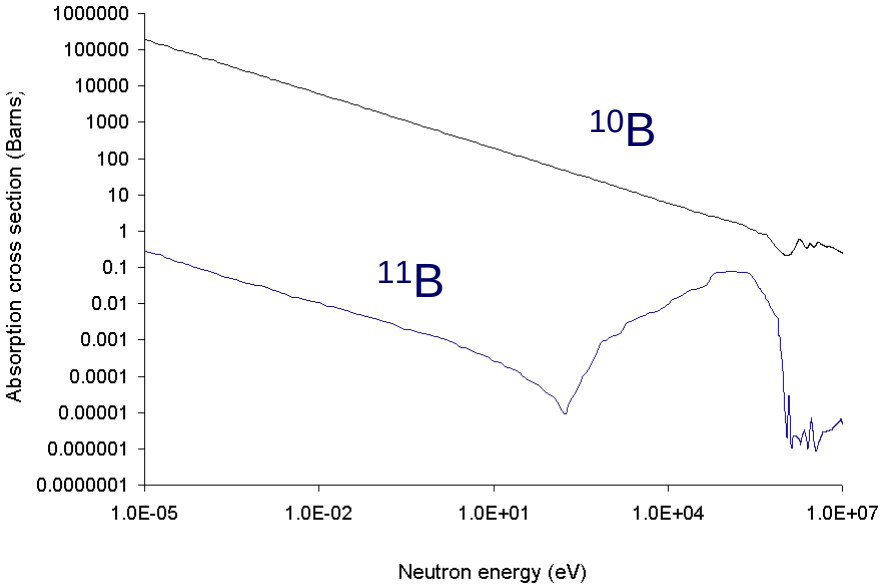


a) Anfahren eines Reaktors ($k > 1$)

b) Abschalten des Reaktors ($k < 1$)

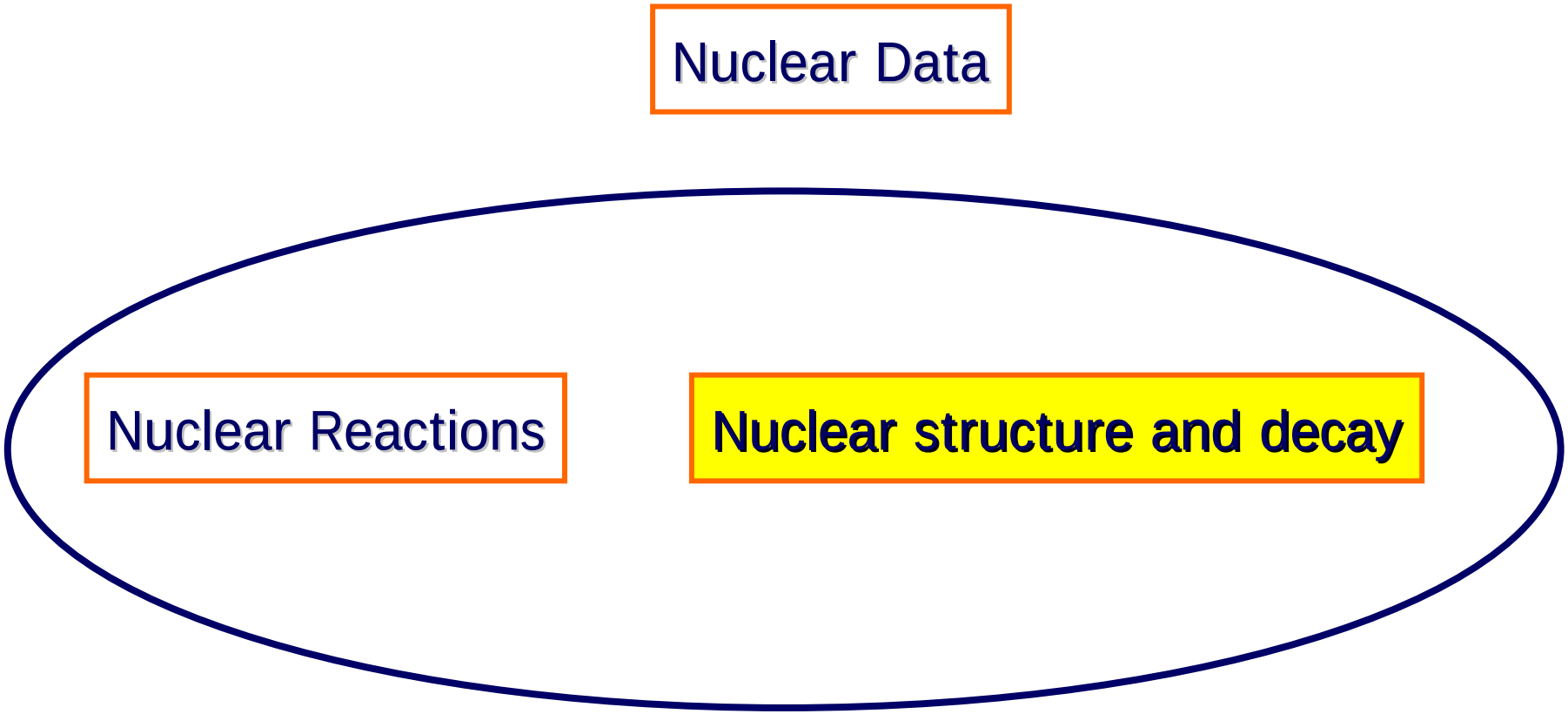
Abb. 5.10: Stellung der Steuerstäbe beim Anfahren und beim Abschalten eines Reaktors

Control Rod Insertion



Boron-10 Thermal Absorption Cross Section

Nuclear Data for Fast Reactor Systems



Nuclear structure and decay

Beta decay

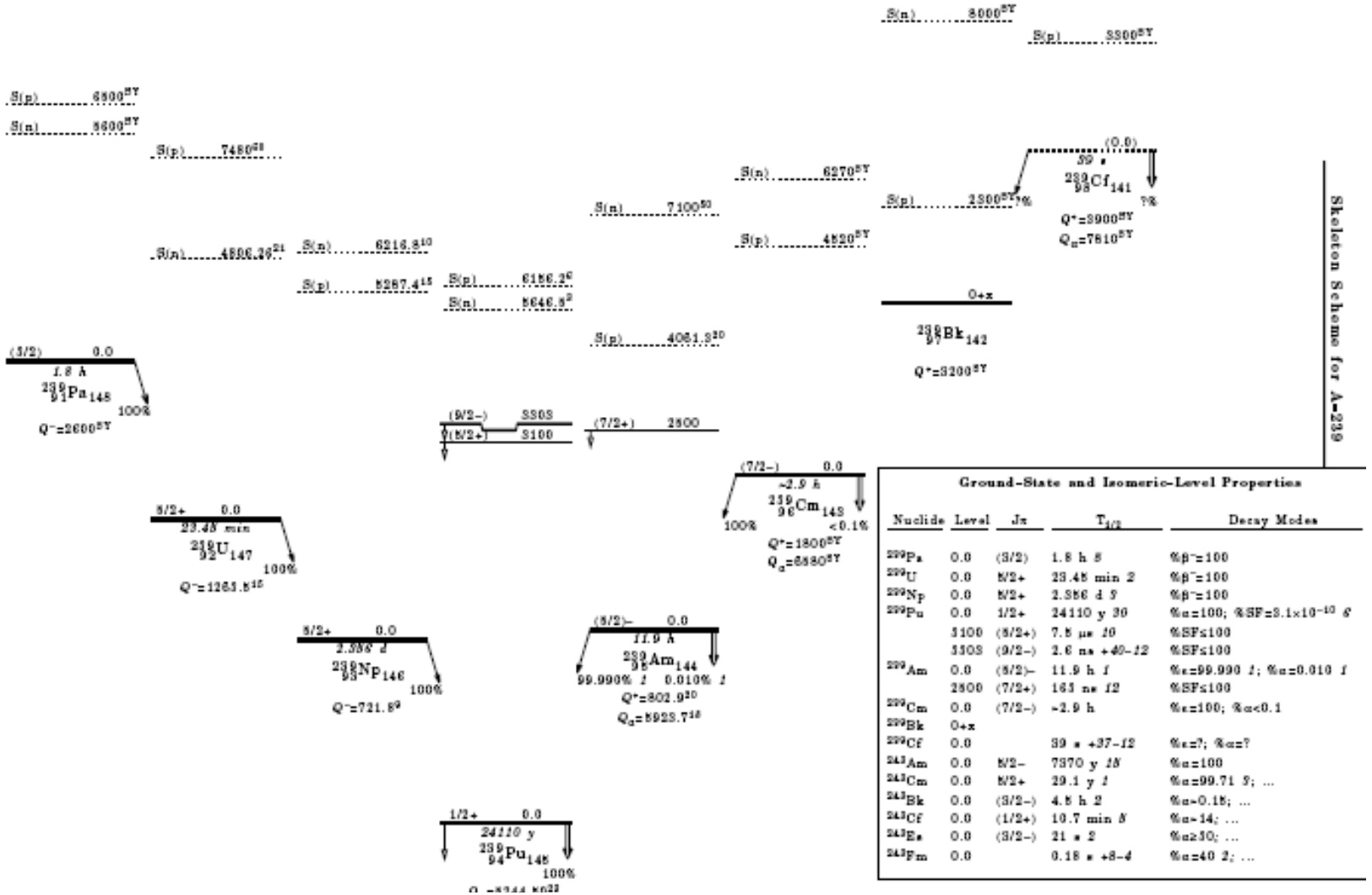
B-, B+

Beta-delayed neutrons

Alpha decay

Exotic decays...

Example: A=239



Where to get nuclear data?

Nuclear Data for Fast Reactor Systems

International Nuclear Data Centers

IAEA – Nuclear Data Section

www-nds.iaea.org

OECD – Nuclear Energy Agency Data Bank

www.nea.fr

CERN – Particle Data Group

www.cern.ch

Nuclear Data for Fast Reactor Systems

National Nuclear Data Centres

BNL – National Nuclear Data Center

JAEA – Japan Atomic Energy Agency

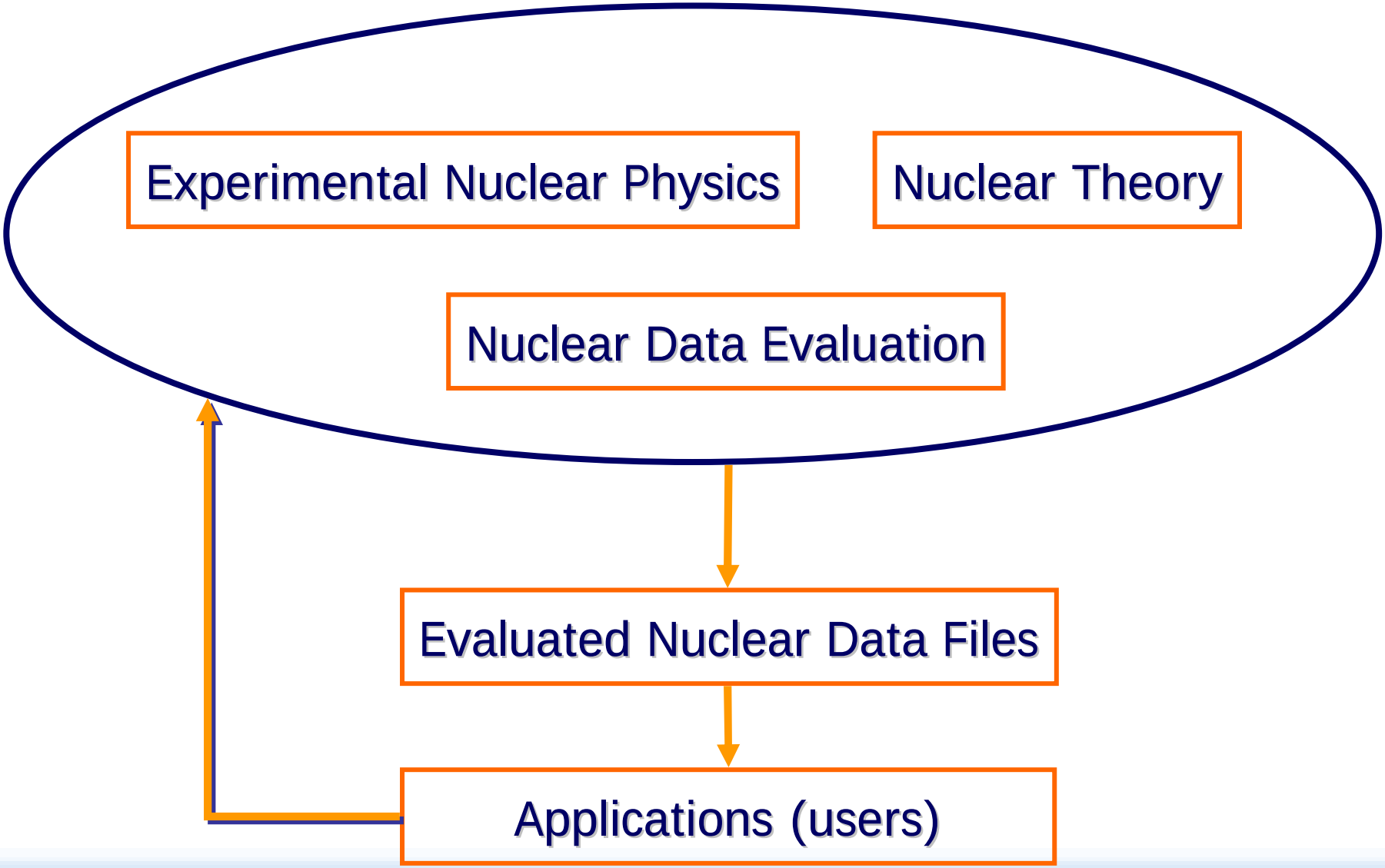
IPPE Obninsk – Nuclear Data Center

TUNL Nuclear Data Project

…(*)

* for a longer list see this **JAEA link**

Nuclear Data for Fast Reactor Systems



Nuclear Data: Libraries

Experimental : EXFOR

Evaluated : ENDF/B, JENDL, JEF, BROND, … (reactions)
ENSDF (nuclear structure)
FENDL (nuclear data for fusion applications)

Bibliographic : NSR, CINDA, …

Others : RIPL (nuclear model parameters)
IRDF (reactor dosimetry file)
IBANDL (ion beam analysis)
NACRE (nuclear astrophysics)
…

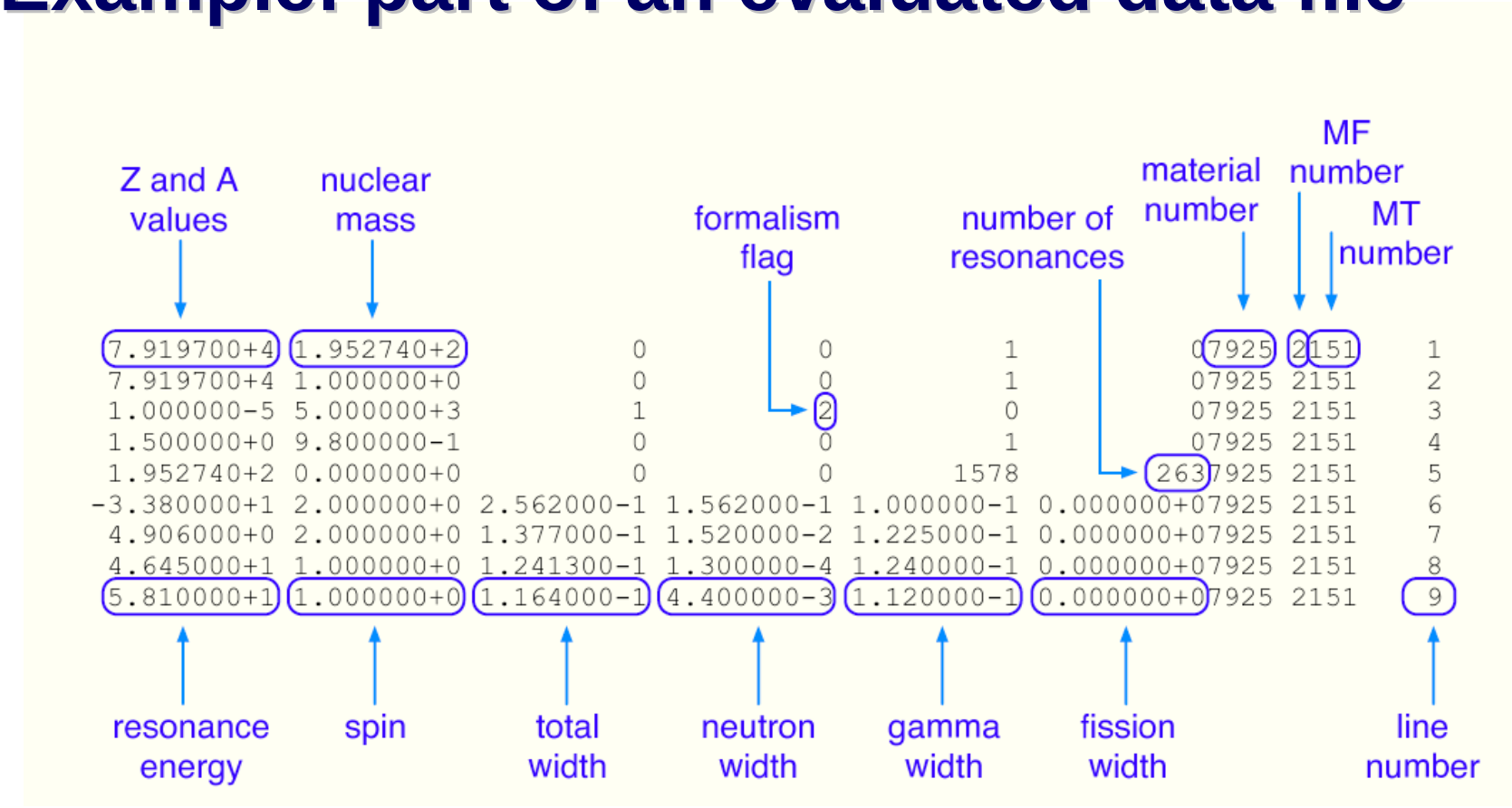
Nuclear Data: Libraries

Applications : ADS-lib, FENDL-2.1
: Medical radioisotope production
(charged-particles reactions)
: Prompt Gamma-ray Activation Analysis (PGAA)
: Photonuclear
: Thermal neutron capture gamma-ray

Nuclear Data: Libraries

Applications : ADS-lib, FENDL-2.1
: Medical radioisotope production
(charged-particles reactions)
: Prompt Gamma-ray Activation Analysis (PGAA)
: Photonuclear
: Thermal neutron capture gamma-ray

Example: part of an evaluated data file



Too complicated to be read by humans!

Nuclear Data for Fast Reactor Systems

Files for a material from report ENDF-102 (ENDF manual)

1 General information	9 Multiplicities for radioactive nuclide production	30 Data Covariances obtained from parameter covariances and sensitivities
2 Resonance parameter data	10 Cross sections for photon production	31 Data covariances for nubar
3 Reaction cross sections	12 Multiplicities for photon production	32 Data covariances for resonance parameters
4 Angular distributions for emitted particles	13 Cross sections for photon production	33 Data covariances for reaction cross sections
5 Energy distributions for emitted particles	14 Angular distributions for photon production	34 Data covariances for angular distributions
6 Energy-angle distributions for emitted particles	15 Energy distributions for photon production	35 Data covariances for energy distributions
7 Thermal neutron scattering law data	23 Photo-atomic interaction cross sections	39 Data covariances for radionuclide production yields
8 Radioactivity and fission-product yield data	27 Atomic form factors or scattering functions for photo-atomic interactions	40 Data covariances for radionuclide production cross sections

Nuclear Data for Fast Reactor Systems

Examples:

EXFOR : U-238 inelastic

ENDF : U-238 capture (example of plots of MF=3 as raw data)

ENSDF : Fe-56
IBANDL : p + C-12, calc for angle=175deg
IRDF : plots, MAT-MT list, Fe-54

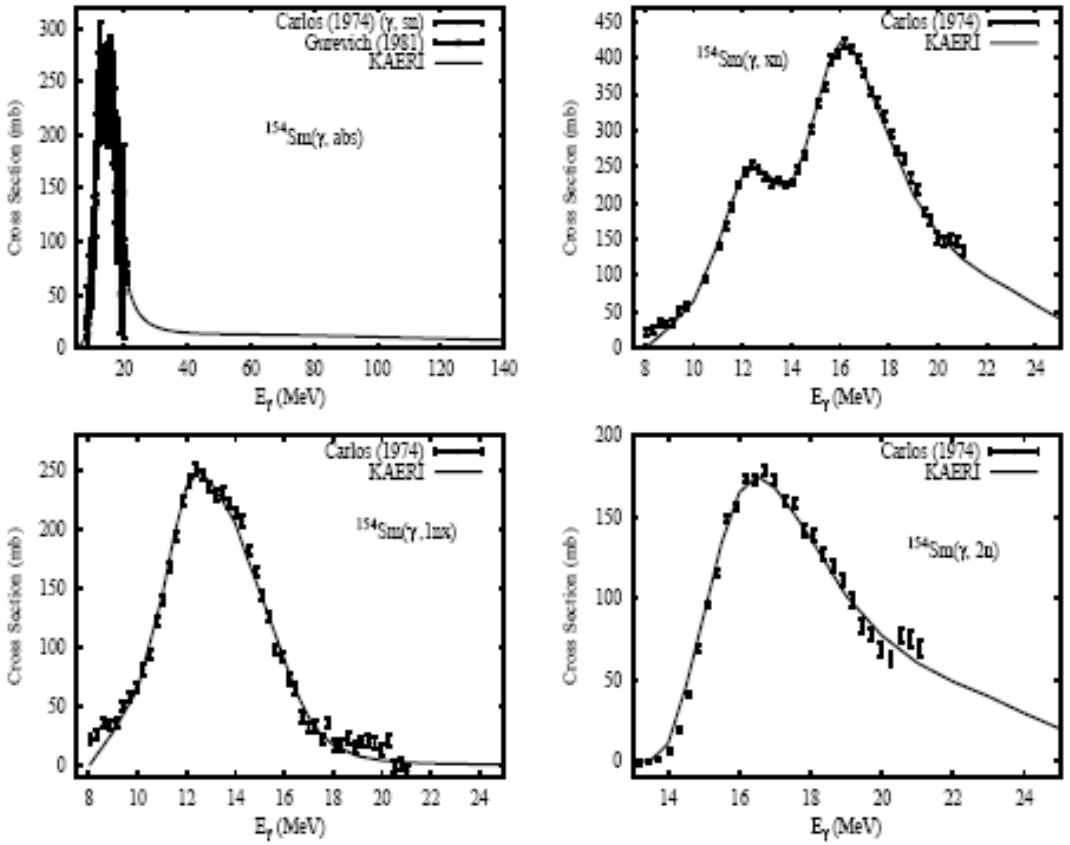
Others : delayed neutron emission (data, MT=455)
medical radioisotope production (gamma emitters)
PGAA (Al-27)
Photonuclear (Sm-154)

Nuclear Data for Fast Reactor Systems

Photonuclear

$\gamma + {}^{154}\mathrm{Sm}$

Abundance	Threshold Energies (MeV)								
(%)	γ,n	γ,p	γ,t	γ,He-3	γ,α	γ,2n	γ,np	γ,2p	γ,3n
22.70	7.97	9.09	14.02	16.44	1.20	13.83	16.56	16.88	22.09



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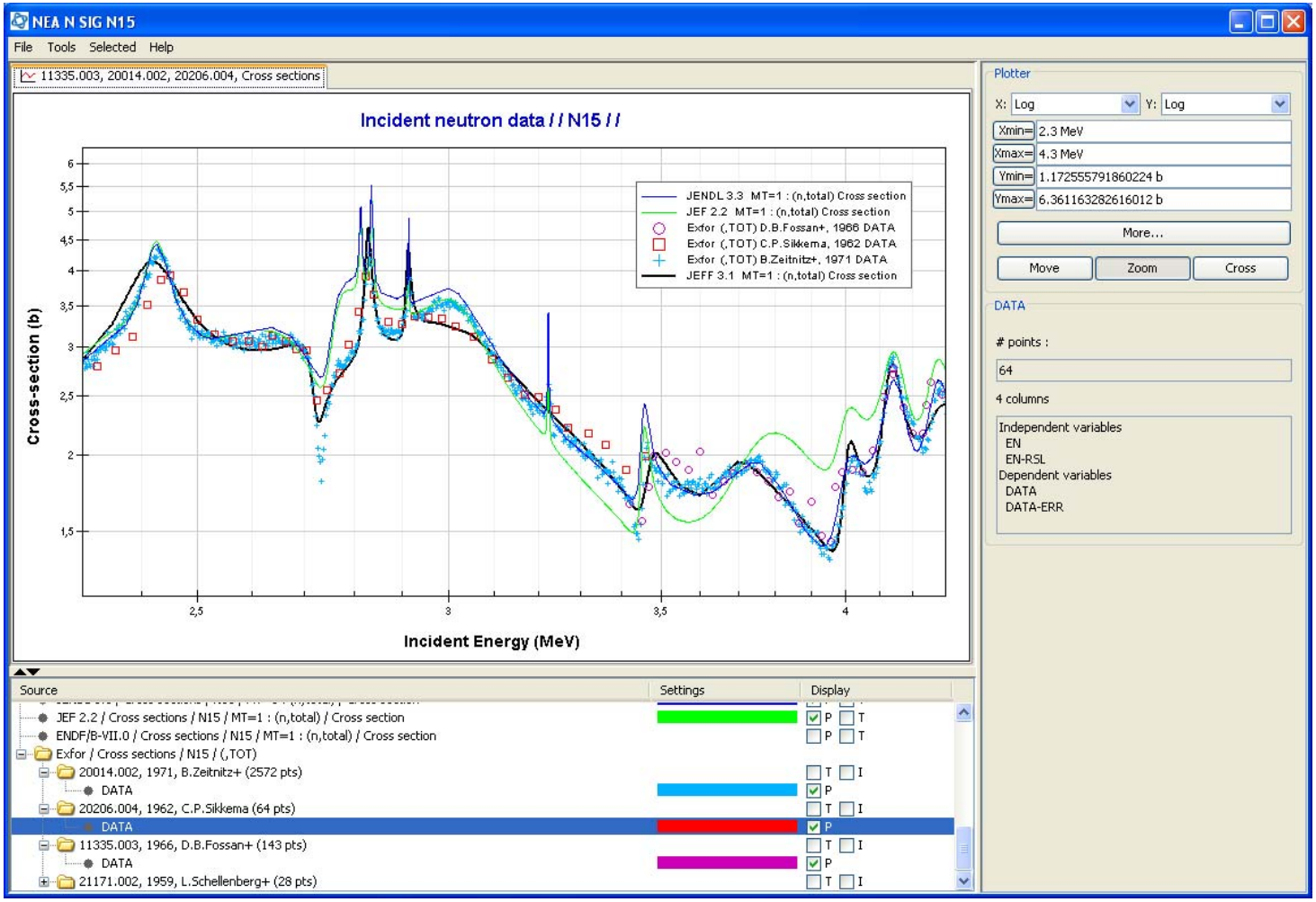
Nuclear Data for Fast Reactor Systems

JANIS 3.0



Q. Where to get Nuclear Data?

A. The Internet

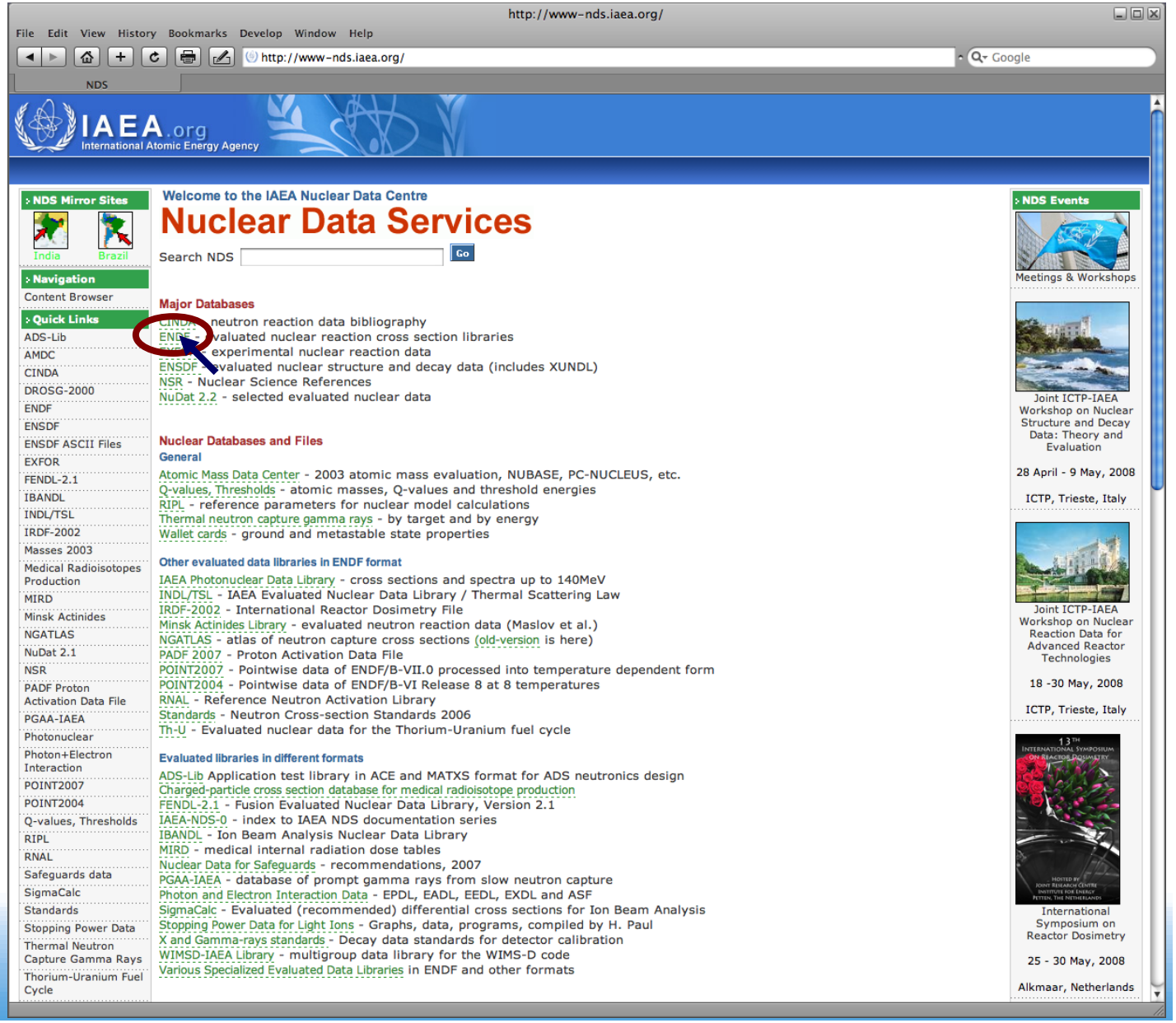
Example:

what is the capture cross section
of Zr-91 at E_n = 30 keV ?

Nuclear Data for Fast Reactor Systems

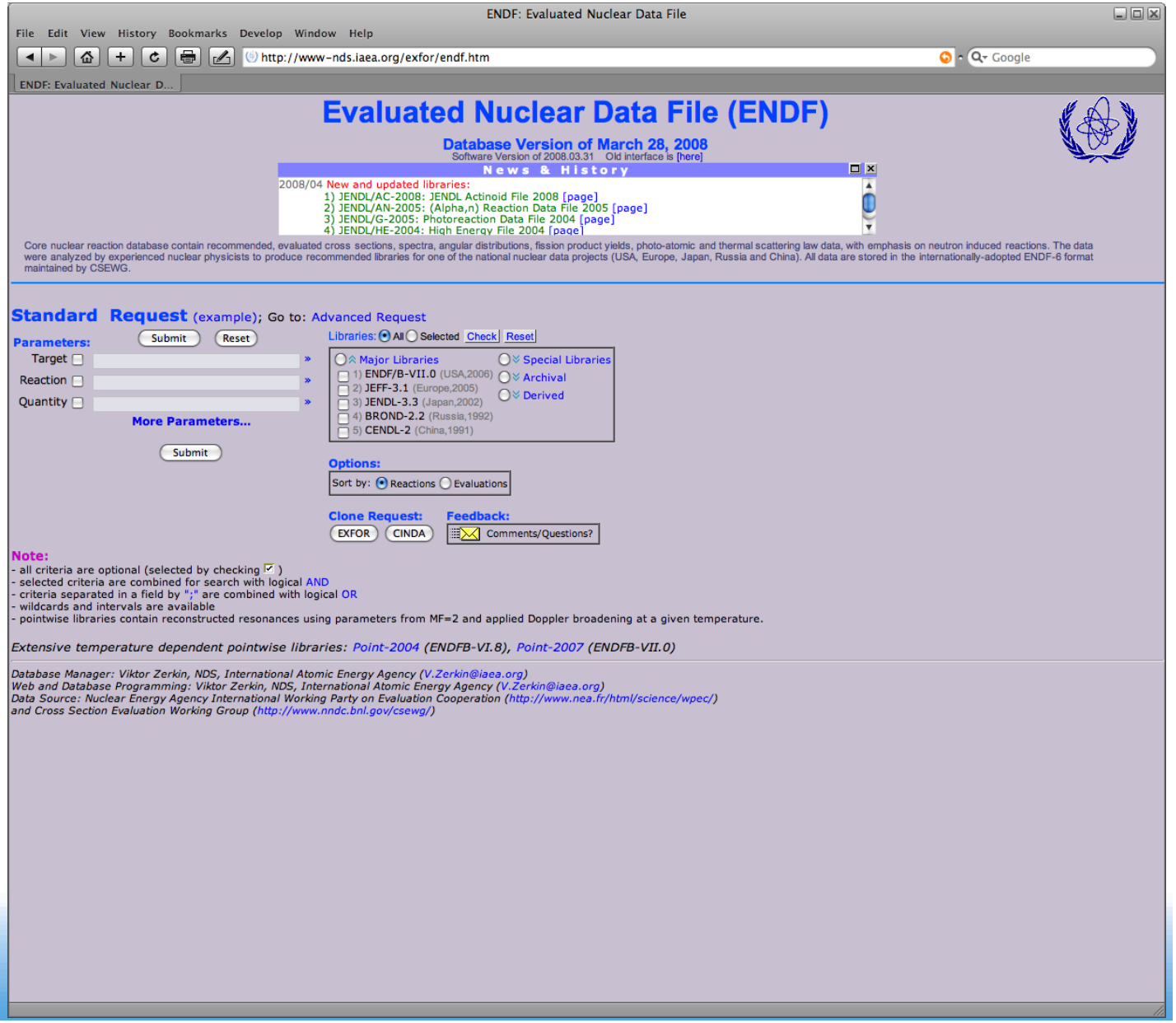
Nuclear Data Online

www-nds.iaea.org



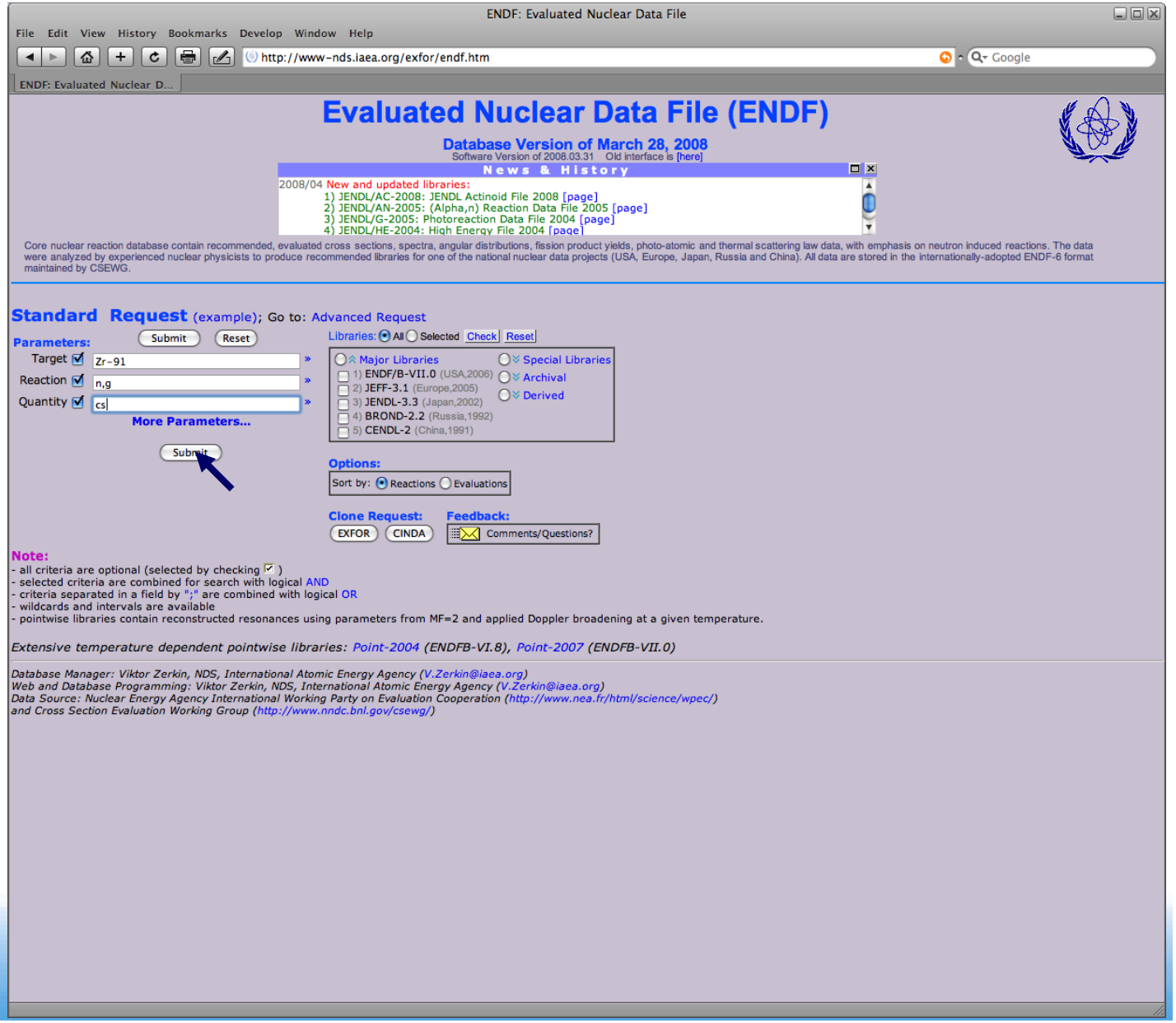
Nuclear Data for Fast Reactor Systems

Nuclear Data Online



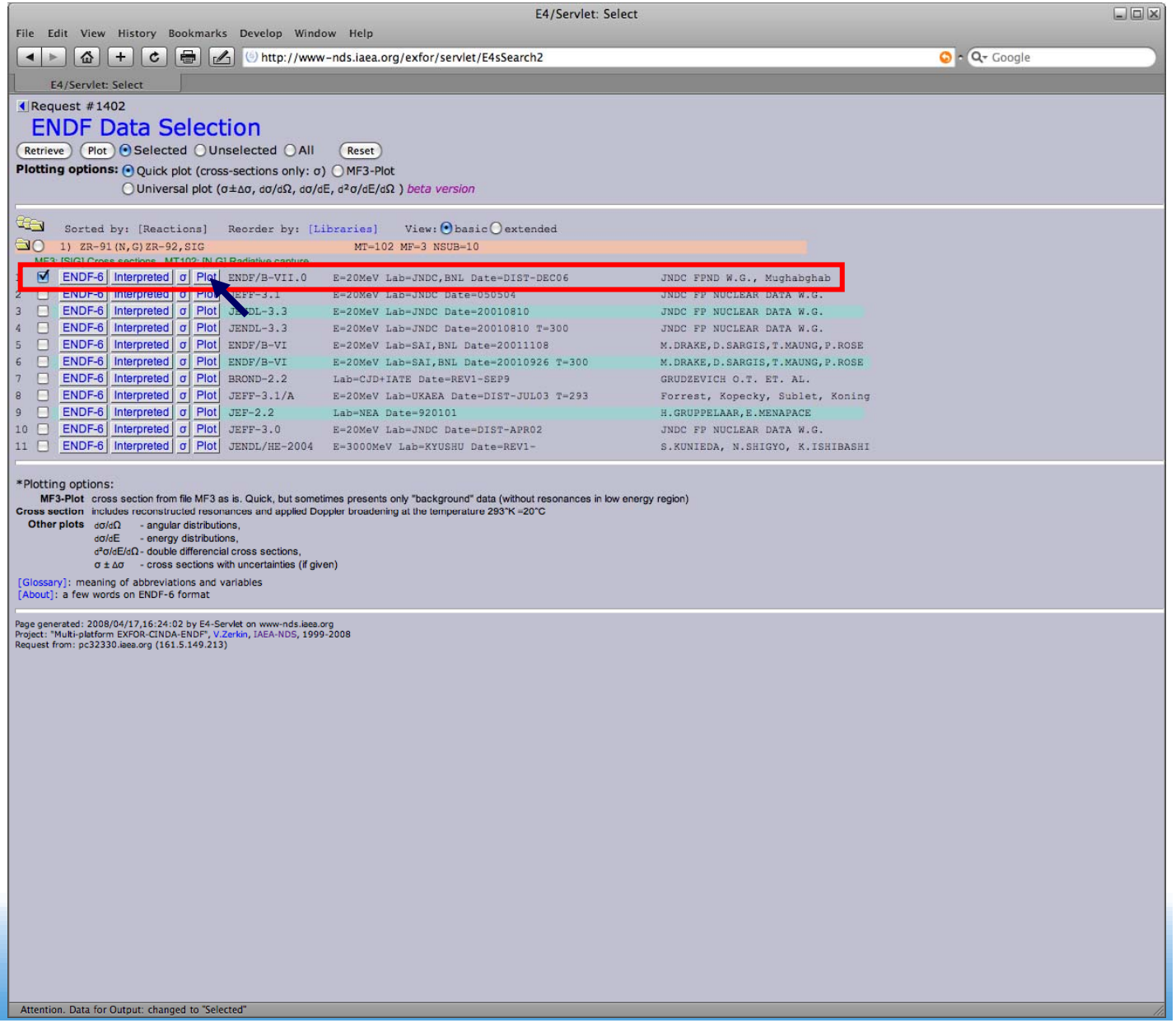
Nuclear Data for Fast Reactor Systems

Nuclear Data Online



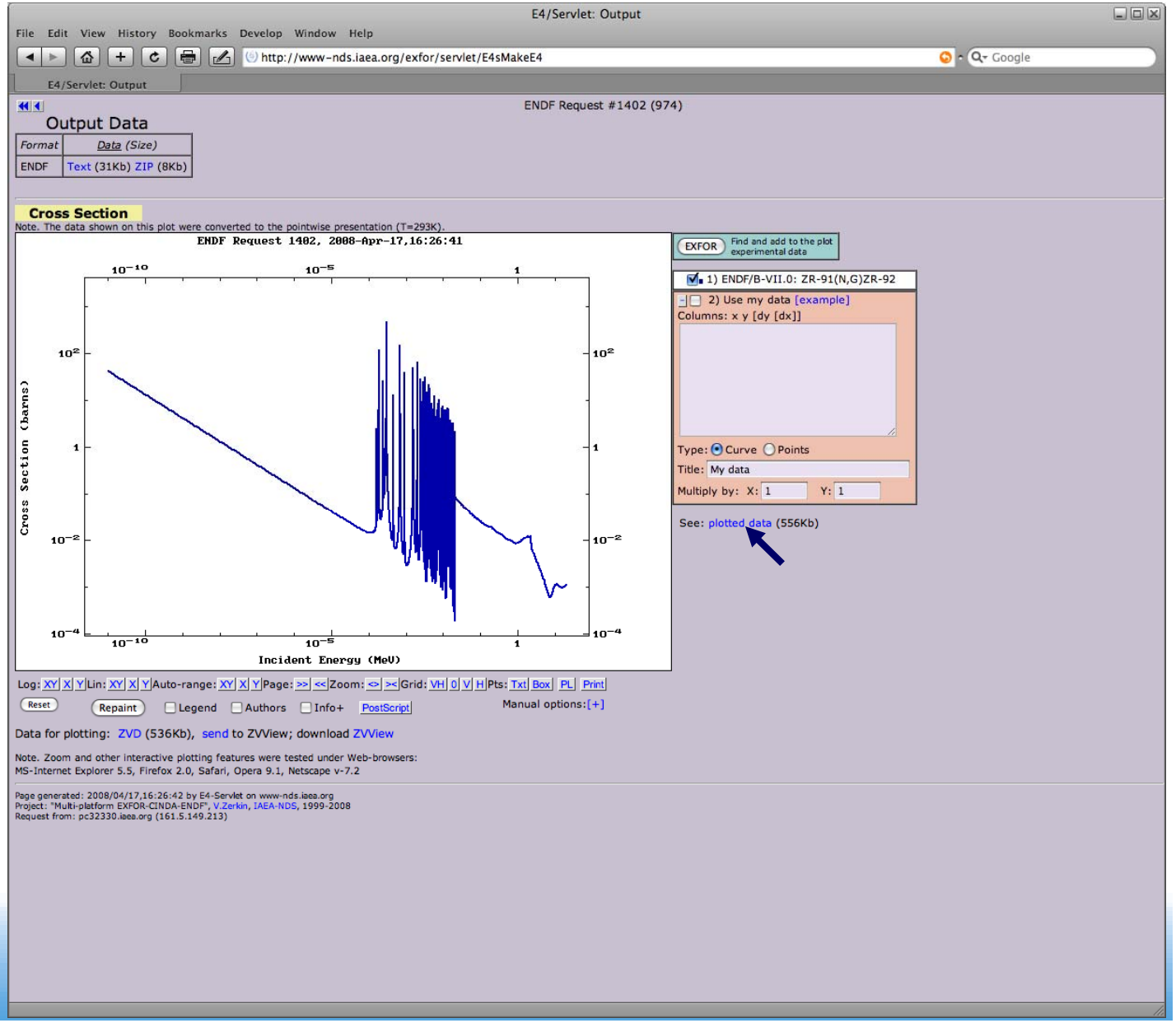
Nuclear Data for Fast Reactor Systems

Nuclear Data Online



Nuclear Data for Fast Reactor Systems

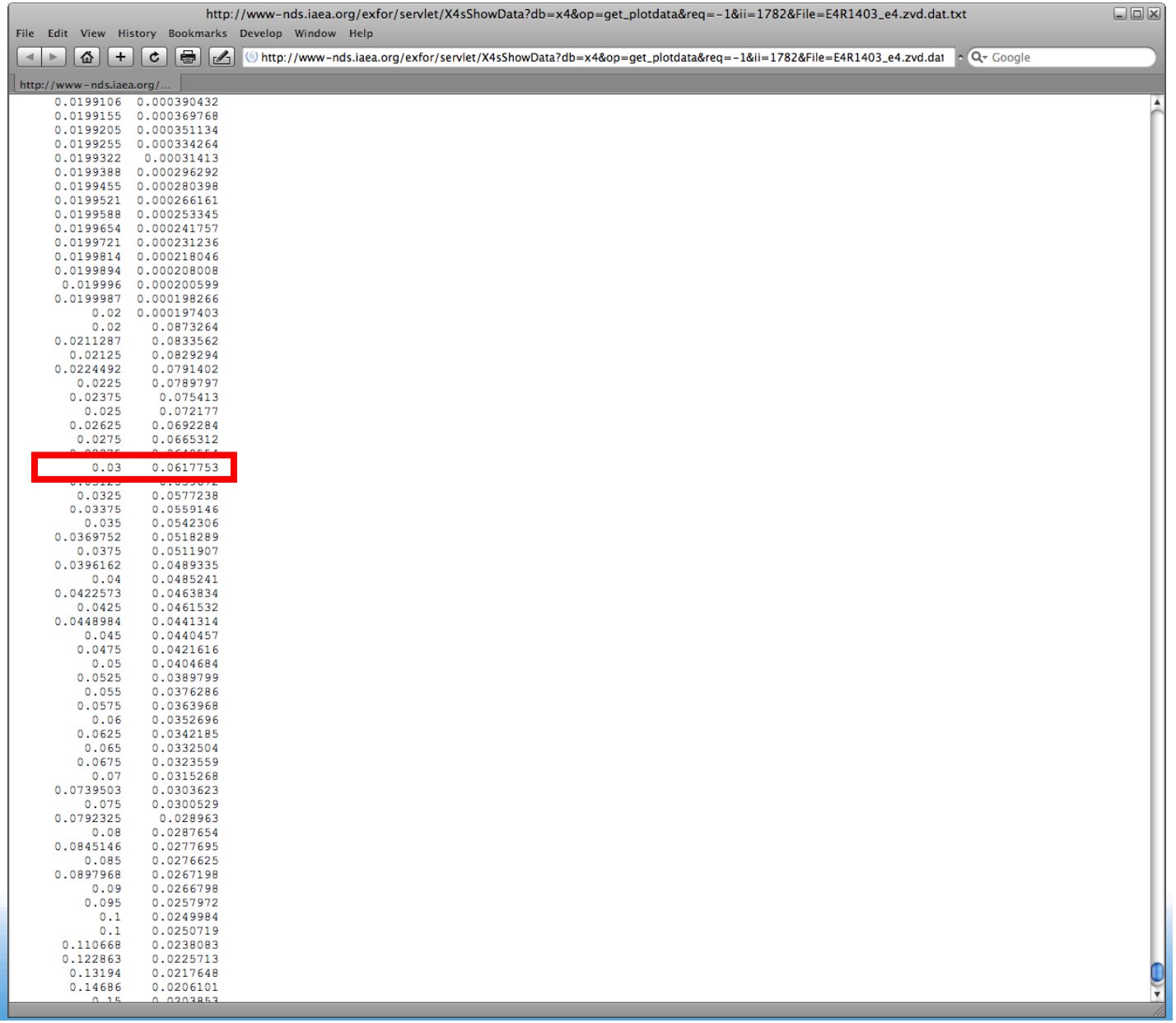
Nuclear Data Online



Nuclear Data for Fast Reactor Systems

Nuclear Data Online

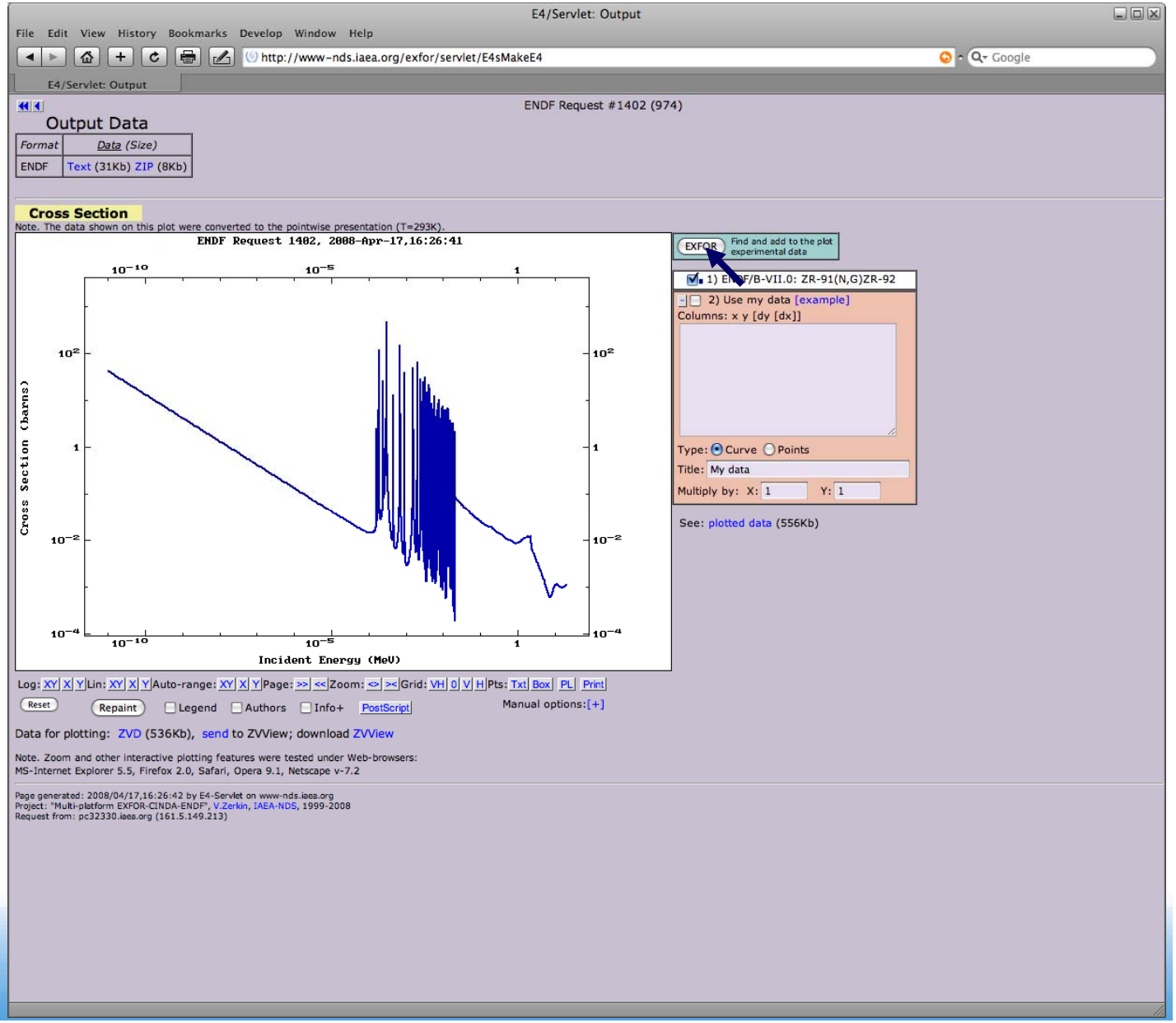
^{91}Zr capture cross section
at E_n=30 keV:
61.8 mb



Nuclear Data for Fast Reactor Systems

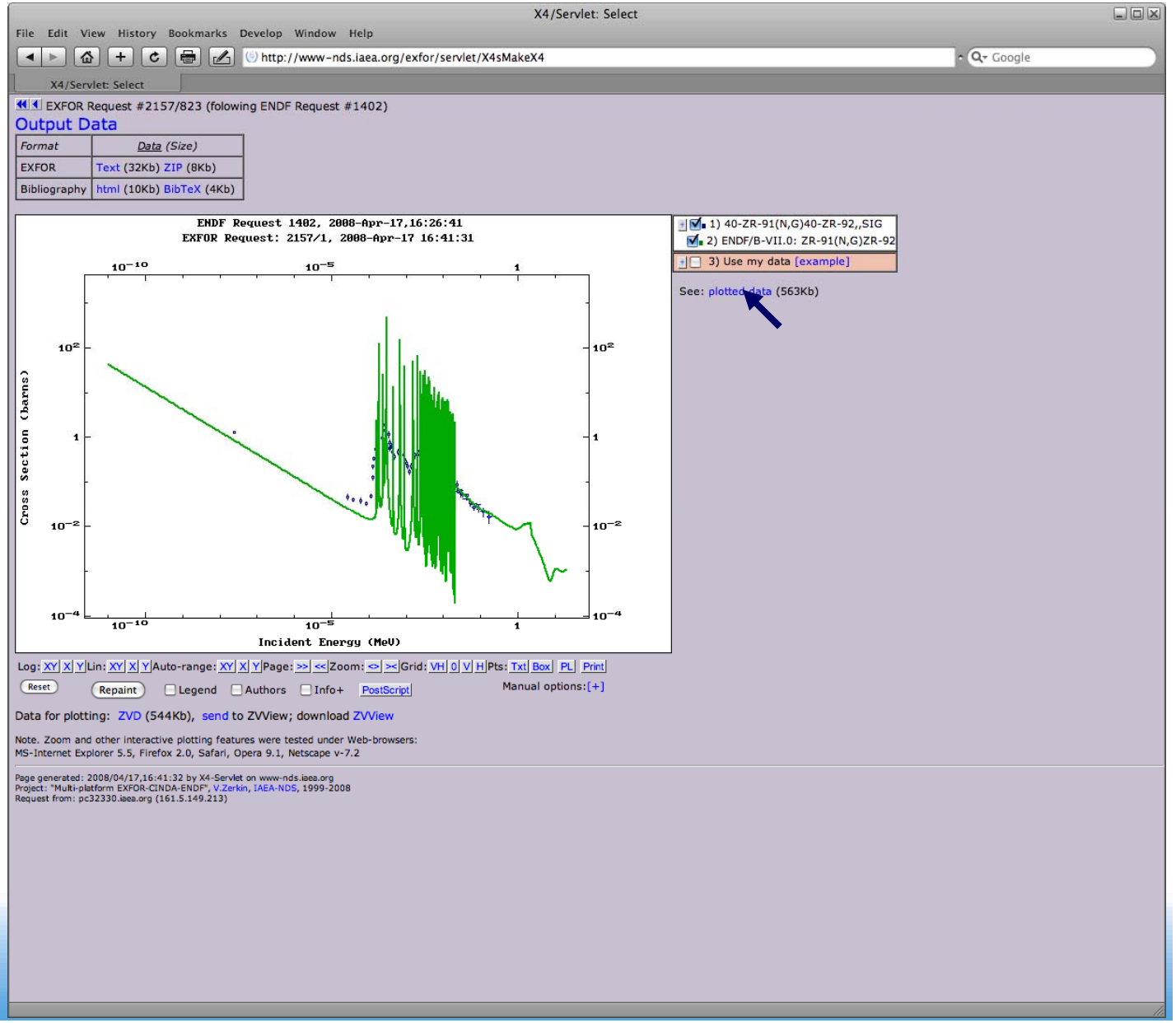
Nuclear Data Online

How about experimental data?



Nuclear Data for Fast Reactor Systems

Nuclear Data Online



EXFOR statistics

EXFOR General Statistics
Information updated: 02-Apr-2008, 13:22:52
Database as of: April 02, 2008

Number of ENTRY	17082	experimental works
Number of SUBENT	116011	data tables (can contain data of more than one reaction)
Number of Datasets	128649	data tables of reactions

Percent: [Counts]/[Number of ENTRY], i.e. = [Counts]/17082
Note. Σ[Percent] of a table below can be > 100% because one experimental work can contain many data tables with data of many types

EXFOR Quantity

#	Code	Quantity	Counts	Percent
1	CS	Cross section data	8833	51.7
2	DA	Differential data with respect to angle	3273	19.1
3	DAP	Partial differential data with respect to angle	2945	17.2
4	RP	Resonance parameters	1634	9.56
5	CSP	Partial cross section data	1402	8.2
6	POL	Polarization data	912	5.33
7	FY	Fission product yields	901	5.27
8	DAE	Differential data with respect to angle and energy	782	4.57
9	SP	Gamma spectra	416	2.43
10	MFQ	Miscellaneous fission quantities	413	2.41
11	RI	Resonance integrals	370	2.16
12	DE	Differential data with respect to energy	342	2
13	TT	Thick target yields	235	1.37
14	E	Kinetic energies	213	1.24
15	L	Scattering amplitudes	182	1.06
16	PY	Product yields	111	0.64
17	INT	Cross section integral over incident energy	107	0.62
18	NQ	Nuclear quantities	93	0.54
19	RR	Reaction rates	44	0.25
20	MLT	Outgoing particle multiplicities	39	0.22
21	TTD	Differential thick target yields	26	0.15
22	CST	Temperature dependent cross section data	16	0.093
23	SQ	Special quantities	12	0.07
24	COR	Secondary particle correlations	6	0.035
25	TTP	Partial thick target yields	6	0.035
26	DEP	Partial differential data with respect to energy	3	0.017

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EXFOR statistics

EXFOR Targets (el.)

#	Target	Counts	Percent
1	U	2243	13.1
2	C	1484	8.68
3	H	1251	7.32
4	Fe	1153	6.74
5	Al	1147	6.71
6	Ni	1099	6.43
7	Pb	1043	6.1
8	Cu	956	5.59
9	Li	873	5.11
10	Pu	852	4.98
11	O	775	4.53
12	Be	733	4.29
13	Th	688	4.02
14	Au	659	3.85
15	Si	658	3.85
16	Zr	647	3.78
17	B	608	3.55
18	Zn	596	3.48
19	Mg	591	3.45
20	Bi	588	3.44
21	Ca	563	3.29
22	Sn	546	3.19
23	Co	545	3.19
24	Mo	539	3.15
25	Ti	528	3.09
26	Ag	493	2.88
27	N	488	2.85
28	Ta	476	2.78
29	Nb	448	2.62
30	In	441	2.58
31	Cr	440	2.57
32	V	431	2.52
33	W	423	2.47
34	He	420	2.45
35	Cd	409	2.39
36	S	366	2.14
37	Mn	361	2.11
38	Na	350	2.04

EXFOR Targets

#	Target	Counts	Percent
1	U-235	1144	6.69
2	Al-27	1131	6.62
3	C-12	1031	6.03
4	U-238	942	5.51
5	Be-9	700	4.09
6	Au-197	650	3.8
7	Th-232	632	3.69
8	Pu-239	606	3.54
9	Bi-209	585	3.42
10	H-1	580	3.39
11	Ni-58	577	3.37
12	O-16	568	3.32
13	Fe-0	553	3.23
14	Cu-0	551	3.22
15	H-2	547	3.2
16	Co-59	530	3.1
17	Pb-0	516	3.02
18	Li-7	493	2.88
19	Li-6	467	2.73
20	Fe-56	452	2.64
21	Nb-93	445	2.6
22	Pb-208	435	2.54
23	U-233	404	2.36
24	Ni-0	371	2.17
25	Ta-181	360	2.1
26	Si-28	358	2.09
27	Zr-90	355	2.07
28	Mn-55	353	2.06
29	Cu-63	341	1.99
30	N-14	335	1.96
31	V-51	332	1.94
32	C-0	330	1.93
33	Na-23	329	1.92
34	F-19	322	1.88
35	B-10	321	1.87
36	Ca-40	304	1.77
37	Fe-54	302	1.76
38	Ni-60	299	1.75

EXFOR Incident particles

#	Projectile	Counts	Percent
1	N	9317	54.5
2	P	3231	18.9
3	D	1269	7.42
4	A	1207	7.06
5	G	896	5.24
6	HE3	493	2.88
7	0	328	1.92
8	6-C-12	158	0.92
9	T	155	0.9
10	8-O-16	119	0.69
11	3-LI-6	111	0.64
12	3-LI-7	97	0.56
13	2-HE-6	55	0.32
14	7-N-14	48	0.28
15	4-BE-9	35	0.2
16	5-B-11	34	0.19
17	8-O-18	30	0.17
18	9-F-19	30	0.17
19	10-NE-20	29	0.16
20	18-AR-40	29	0.16
21	E	21	0.12
22	14-SI-28	19	0.11
23	92-U-238	19	0.11
24	PIN	19	0.11
25	PIP	18	0.1
26	3-LI-8	16	0.093
27	4-BE-7	16	0.093
28	5-B-10	16	0.093
29	6-C-13	16	0.093
30	10-NE-22	14	0.081
31	3-LI-9	14	0.081
32	3-LI-11	13	0.076
33	9-F-17	13	0.076
34	2-HE-8	12	0.07
35	4-BE-11	12	0.07
36	9-F-18	12	0.07
37	16-S-32	11	0.064
38	5-B-8	11	0.064

EXFOR Reactions

#	Reaction	Counts	Percent
1	N,G	2423	14.1
2	N,EL	2026	11.8
3	N,F	1819	10.6
4	N,TOT	1646	9.63
5	N,INL	1179	6.9
6	N,0	1158	6.77
7	N,P	947	5.54
8	N,A	908	5.31
9	P,X	882	5.16
10	N,2N	840	4.91
11	P,EL	722	4.22
12	P,N	585	3.42
13	N,X	475	2.78
14	P,INL	458	2.68
15	D,P	427	2.49
16	A,EL	347	2.03
17	P,G	341	1.99
18	G,N	328	1.92
19	A,N	311	1.82
20	N,ABS	308	1.8
21	D,N	275	1.6
22	P,A	275	1.6
23	0,F	264	1.54
24	G,X	237	1.38
25	A,X	227	1.32
26	D,EL	214	1.25
27	P,F	210	1.22
28	D,A	196	1.14
29	A,2N	188	1.1
30	A,INL	181	1.05
31	N,THS	178	1.04
32	D,X	170	0.99
33	G,P	166	0.97
34	N,T	160	0.93
35	G,F	159	0.93
36	N,N+P	146	0.85
37	A,P	143	0.83
38	N,D	138	0.8

Done

Local intrane

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EXFOR database (present status):

- 63626 experimental data sets with results of microscopic and integral measurements
- 7369 data sets (12%) obtained with use of the reactor as a neutron source
- 1863 data sets (3%) contain results of integral (Maxwellian or other spectrum averaged) cross section measurements

Distributed by year of publication:

- **1946 – 1950 -> 22 datasets**

  first compiled work where reactor is used as a neutron source: G.T. Seaborg and collaborators (1946), measurements of ^{241}Am(n,γ), ^{10}B(n,α) and ^{158}Gd(n,γ)
- **1951 – 1960 -> 525 datasets**
- **1961 – 1970 -> 1700 datasets**
- **1971 – 1980 -> 2705 datasets**
- **1981 – 2000 -> 556 datasets**
- **2001 – present -> 611 datasets**

  ~200 – for fission products, ~400 – for actinides;

  from them

  14 – for target nuclides in metastable state

  12 – for long- and short-lived fission products

  16 – for short- and long-lived actinides

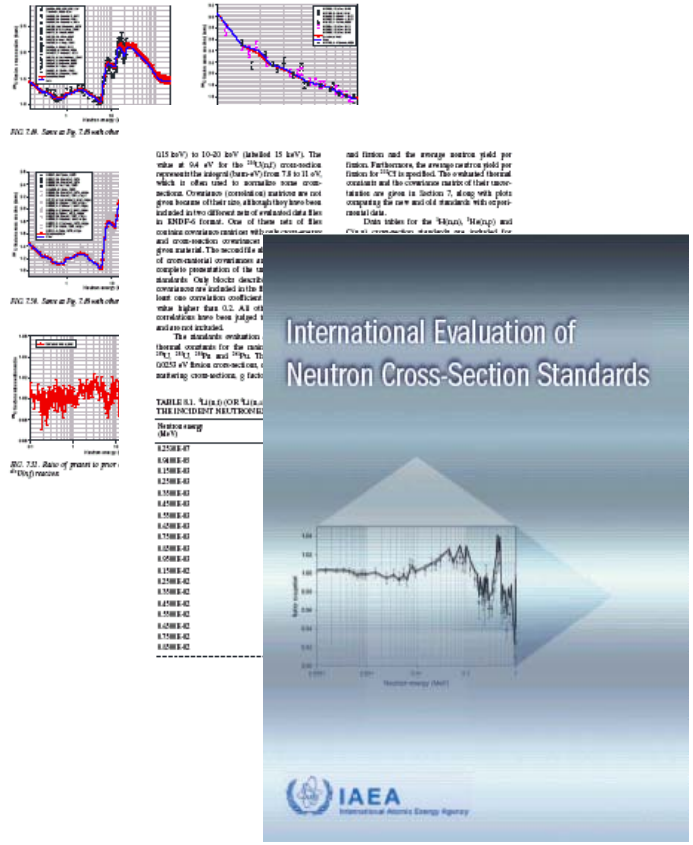
International neutron cross-section standards

- well documented (text, data tables and plots in IAEA Rep. STI/PUB/1291 (2006), will be published in Nucl. Data Sheets, 110 (12) (2009))
- achieved low uncertainties justified:

  in independent analysis (2007);

  by testing in integral

  experiments (2006-2008)



(free available at *http://www-nds.iaea.org/standards/*)

International neutron cross-section standards

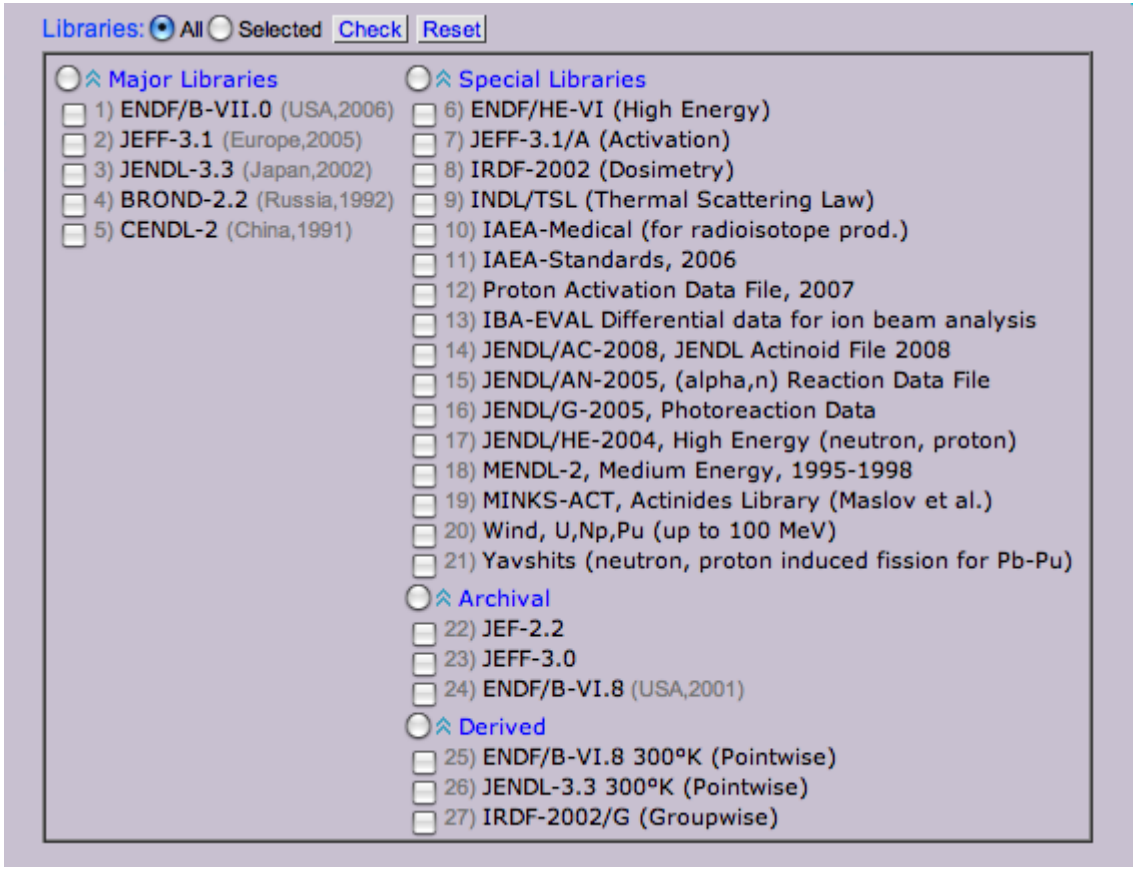
- include evaluation of 24 thermal constants:

  elastic scattering, capture and fission cross sections, Westcott g-factors and total fission neutron yields for ^{235,238}U and ^{239,241}Pu;

  their covariance matrix of uncertainties
- Axton's pre-evaluated values (1986) and new experimental data were used in the combined least-squares fit with all standard cross sections (2006)
- Independent Devadeenam's evaluation (1984) of thermal constants done with inclusion of integral measurements was used by Mughabghab in preparation of Atlas of Neutron Resonances (2006)

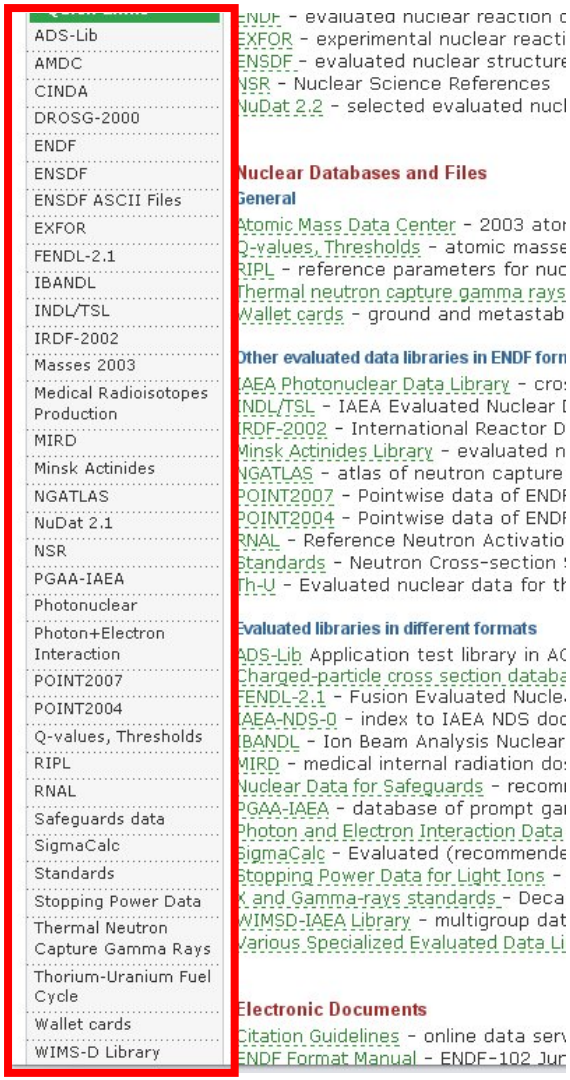
Providing On-line Services: Retrieval and Display Tools

Other Nuclear Data libraries available for display & retrieval:



a.mengoni@iaea.org

Providing On-line Services: Repository of Data Libraries



INTERNATIONAL ATOMIC ENERGY AGENCY

NUCLEAR DATA SERVICES

DOCUMENTATION SERIES OF THE IAEA NUCLEAR DATA SECTION

IAEA-NDS-7
2007/7

Index of Nuclear Data Libraries

available from the IAEA Nuclear Data Section

edited by

O. Schwerer

Abstract: This document lists more than 100 nuclear data libraries together with references that give more detailed information about these libraries. The data libraries include neutron cross-sections, resonance parameters, fission-product yields, nuclear structure and decay data, gamma-rays from radionuclides, data of nuclear reactions induced by charged particles or heavy ions, photonuclear data, photoatomic interaction data, and many others, partly with related data processing computer codes. All data and documentation references are available through WWW or on request from the IAEA Nuclear Data Section, free of charge, on CD-ROM or other computer media.

July 2007

Providing On-line Services: Repository of Data Libraries

Marco Verpelli

NDS Data Libraries

File Edit View History Bookmarks Develop Window Help

http://nds121.iaea.org/datalib/DocStore.html#Browse

iGoogle NDS n_TOF Corriere Repubblica LASTAMPA Yahoo! Google Maps YouTube Wikipedia News (275) Popular smr1944 AGE Spallations

NDS Data Libraries

by topic | by name | about | manage

Index of Nuclear Data Libraries

Search by keywords

» Expand all - 154 Libraries grouped in 27 topics

Help

- Data Libraries
  - » Neutron nuclear data, experimental
  - » ENDF format for evaluated nuclear data files
  - » ENDF data processing codes
  - » Evaluated neutron nuclear data: Comprehensive libraries
  - » Evaluated neutron nuclear data: Multigroup libraries
  - » Nuclear data standards for nuclear measurements
  - » Thermal neutron cross-sections, resonance-parameters and resonance-integrals
  - » Thermal neutron scattering law
  - » Actinides
  - » Fission product yields
  - » Neutron induced gamma-rays
  - » Neutron activation general application
  - Neutron activation for dosimetry
    - IRDF-2002
    - NMF-90, Neutron Metrology File
    - Neutron Excitation Function Guide for Reactor Dosimetry
    - RRDF-98. Russian Reactor Dosimetry File
    - Other dosimetry reaction files
  - » Miscellaneous specialized neutron data libraries
  - » Photonuclear data
  - » Photo-atomic interaction data
  - » Charged-particle nuclear reaction data
  - » Intermediate energy nuclear data
  - » Nuclear data for thermonuclear fusion
  - » Nuclear model parameters and codes
  - » Nuclear structure and decay data
  - » Gamma ray analysis
  - » Nuclear constants, Charts of Nuclides
  - » Atomic data
  - » Bibliographic files
- Selected Publications

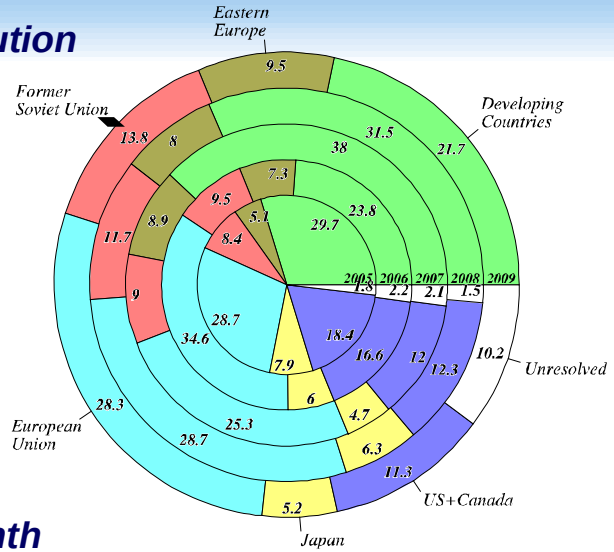
Description

Other dosimetry reaction files

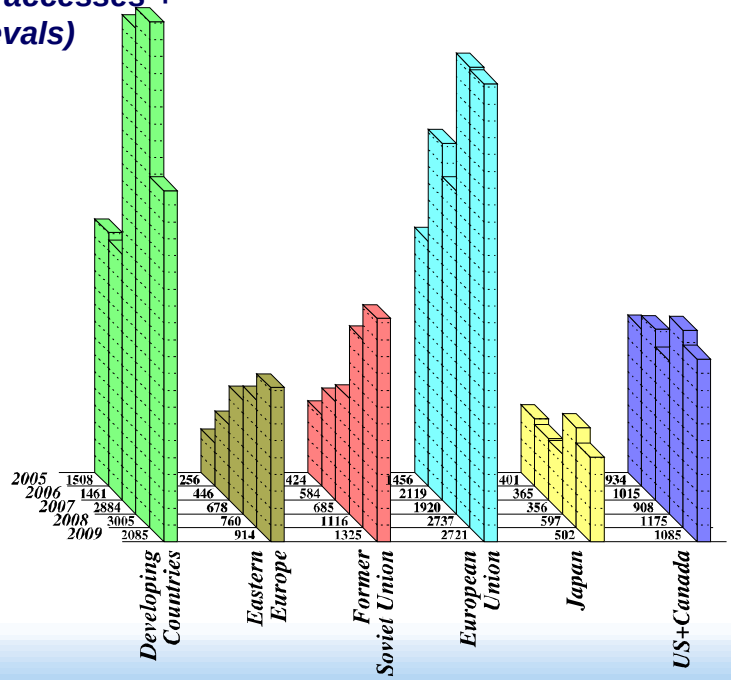
Other dosimetry reaction files may be included in the "General purpose evaluated neutron nuclear data".

Nuclear Data Services: Web Statistics

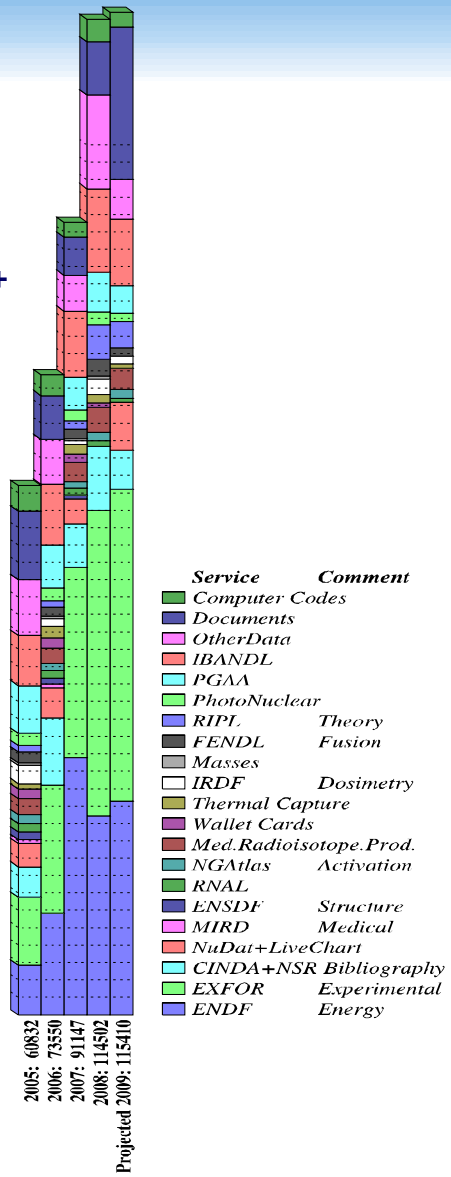
Geographical Distribution (%)



Average per Month (Number of accesses + retrievals)



Total per Year (Number of accesses + retrievals)



Conclusion

Nuclear Data Libraries are freely available from various international as well as national nuclear data centers.

The development of advanced nuclear technological devices benefits from this availability. Meanwhile, additional experimental, theoretical and evaluation activities are needed for continuous update and improvement of the quality of nuclear data libraries.