What are nuclear data?

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Various nuclear problems

How do we design a nuclear reactor? Neutronics ruling the chain reaction, reactor control, isotopic evolution of the fuel, neutron damage to the structural materials…

How do we design a fusion reactor? Fusion reactions, tritium breeding reactions, monitoring…

How do we produce isotopes for medical applications (imaging, therapy, monitoring)?

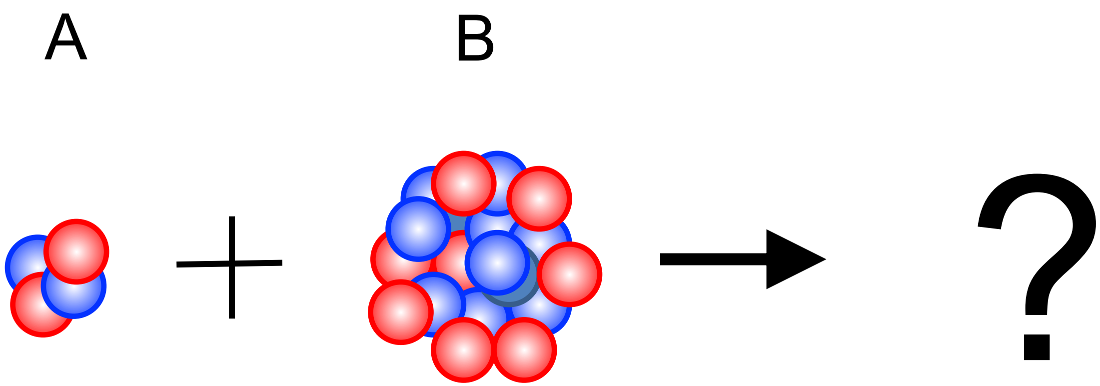
What is the dose due to neutrons in a conventional radiotherapy treatment? Neutrons produced in photonuclear reactions.

What is the far from field dose in a proton therapy treatment? Biological effect of secondary particles produced in proton induced nuclear reactions.

How are the elements produced in stars? s-process, r-process, p-process…

How do we improve our nuclear and nuclear reaction models?

Nuclear reactions



How probable is a A + B nuclear reaction?

What are the possible reaction channels and the distributions of the reaction products (isotopic, energy, angle…)

What are the half-lives, masses … of the decay products?

Nuclear reaction models

Nuclear reaction models

- Direct + compound nucleus (resonances)
- Statistical models (Hauser Feshbach…)
- Optical model
- Preequilibrium model
- Intranuclear cascade
- Spallation

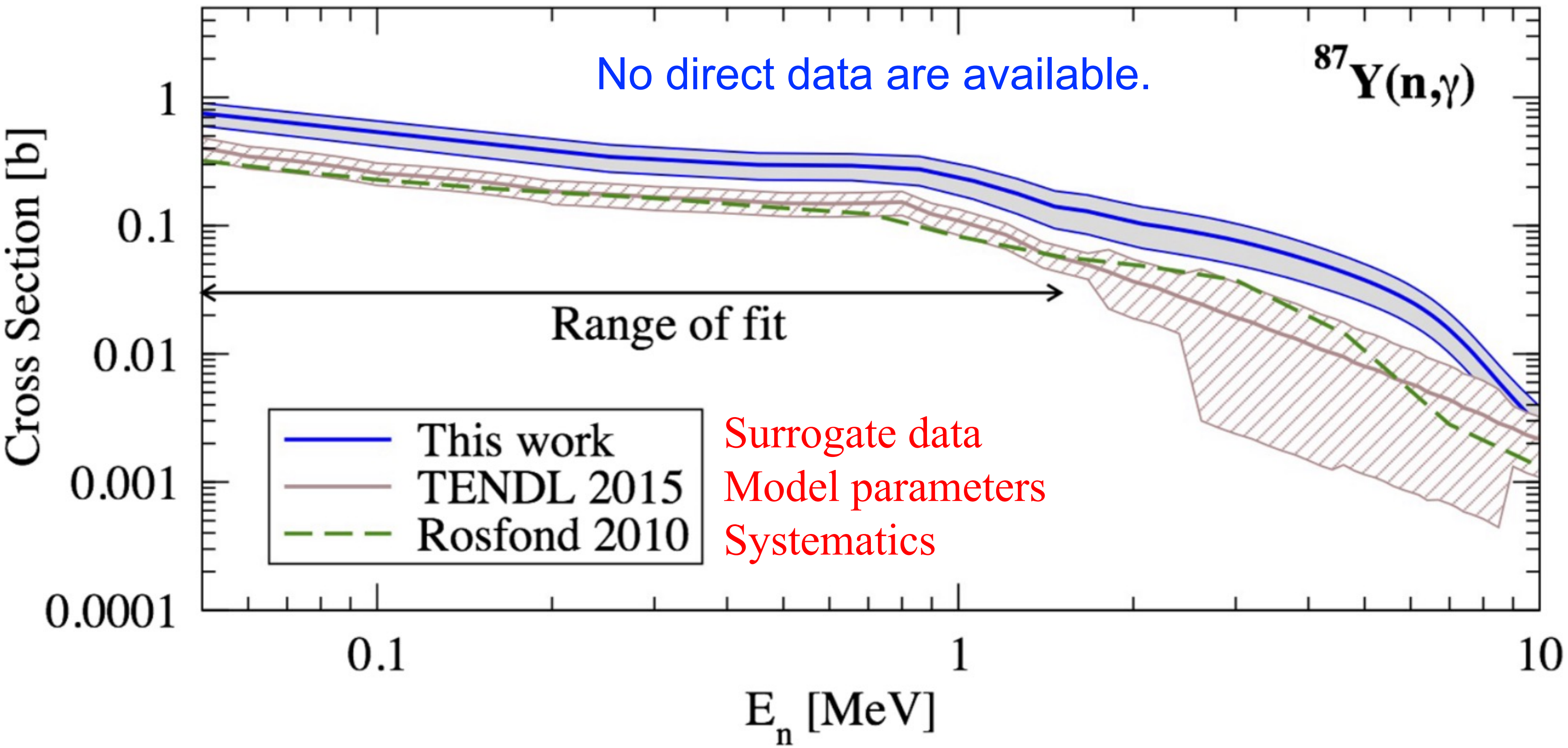
…

- Liquid drop model for fission

Neutron induced reactions, excitation energy = S_n + …

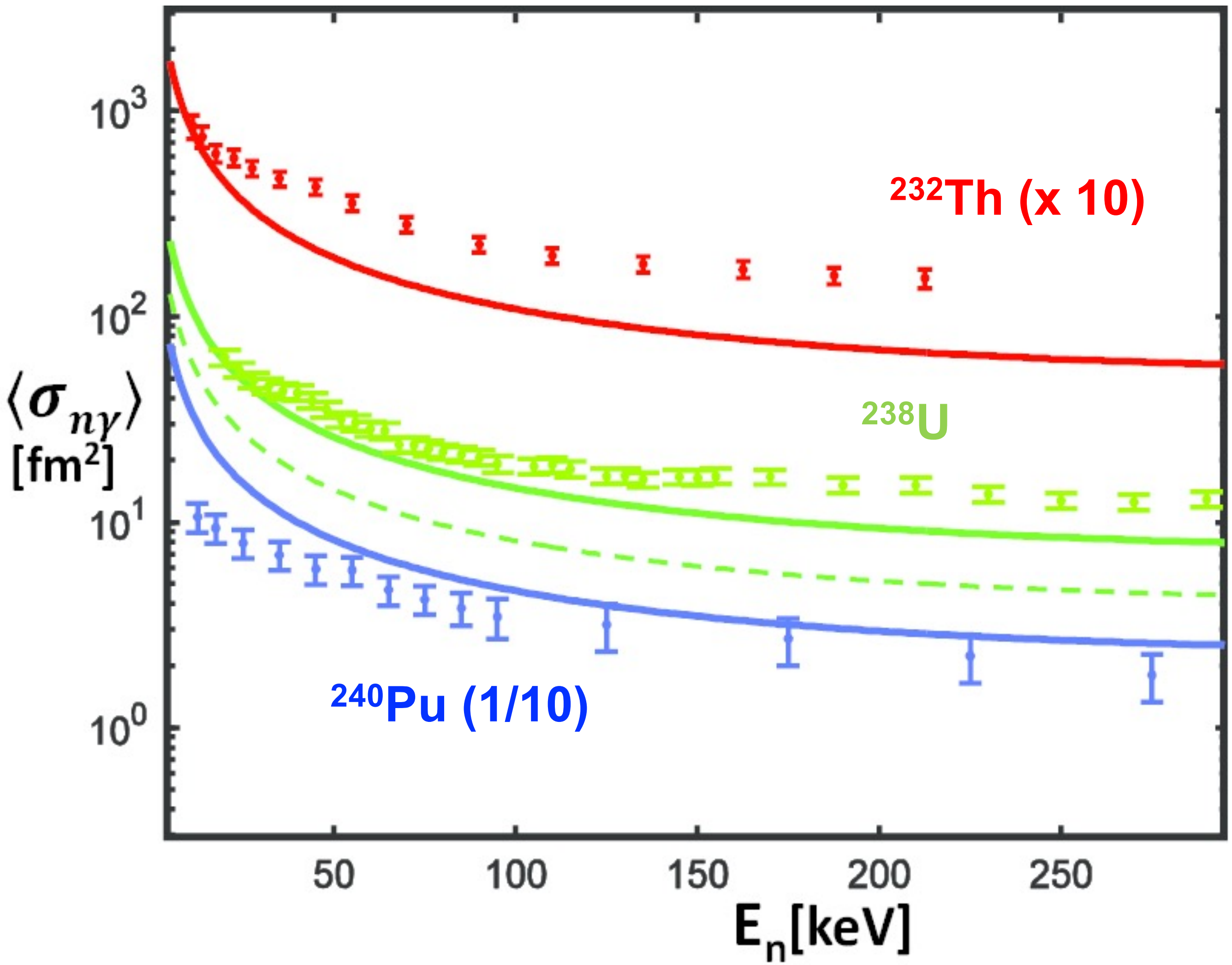
meV – keV
keV – 100 keV
MeV
10 MeV
100 MeV
1 GeV

The (in) accuracy of the models



J. E. Escher et al., Phys. Rev. Lett. 052501 121 (2018)

The (in) accuracy of the models



E. Grosse et al., Physics Procedia 64 (2015)

The required accuracies

The **target accuracy** required for a given problem will depend on its nature and the imposed safety margins: criticality, dose to public, isotopic inventory calculation, nucleosynthesis in astrophysical scenarios...

Accuracies required for nuclear technologies are usually very demanding (i.e. linked to safety). **For example,** the **uncertainty Δ*k* in the neutron multiplication *k*** for a reactor needs to be calculated with **1000 pcms** or less

$$\frac{\Delta k_{calc}}{k_{calc}} \approx 0.01$$

Nuclear theory is not good enough. We need to:

- Measure the nuclear properties and use the experimental results in our calculations.
- Constrain the nuclear models with the data.

Types of nuclear data

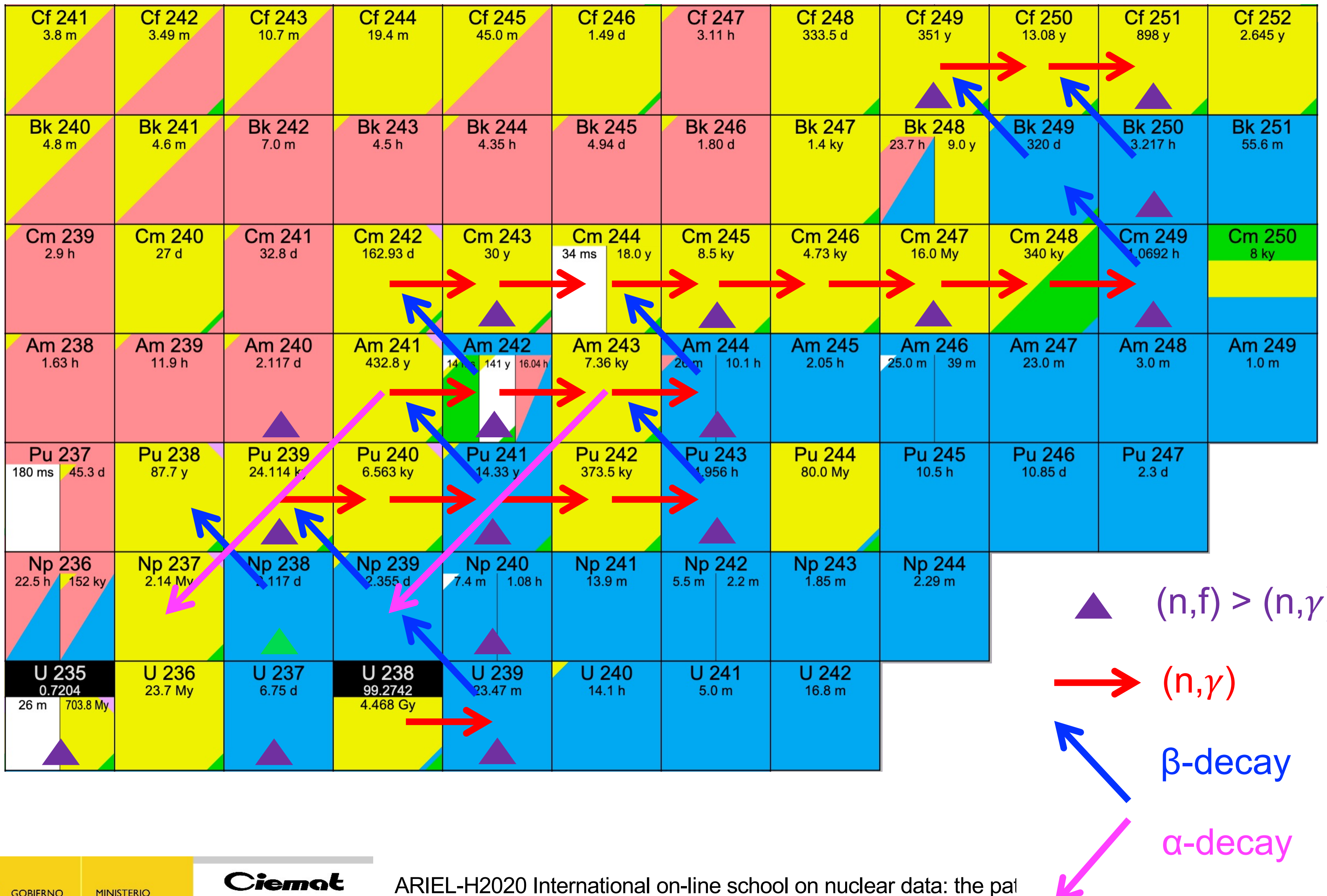
Every nuclear application that requires minimal precision must be supported by well-validated experimental data. Nuclear models are not able to predict (by themselves) accurately the microscopic properties of nuclei.

Differential data

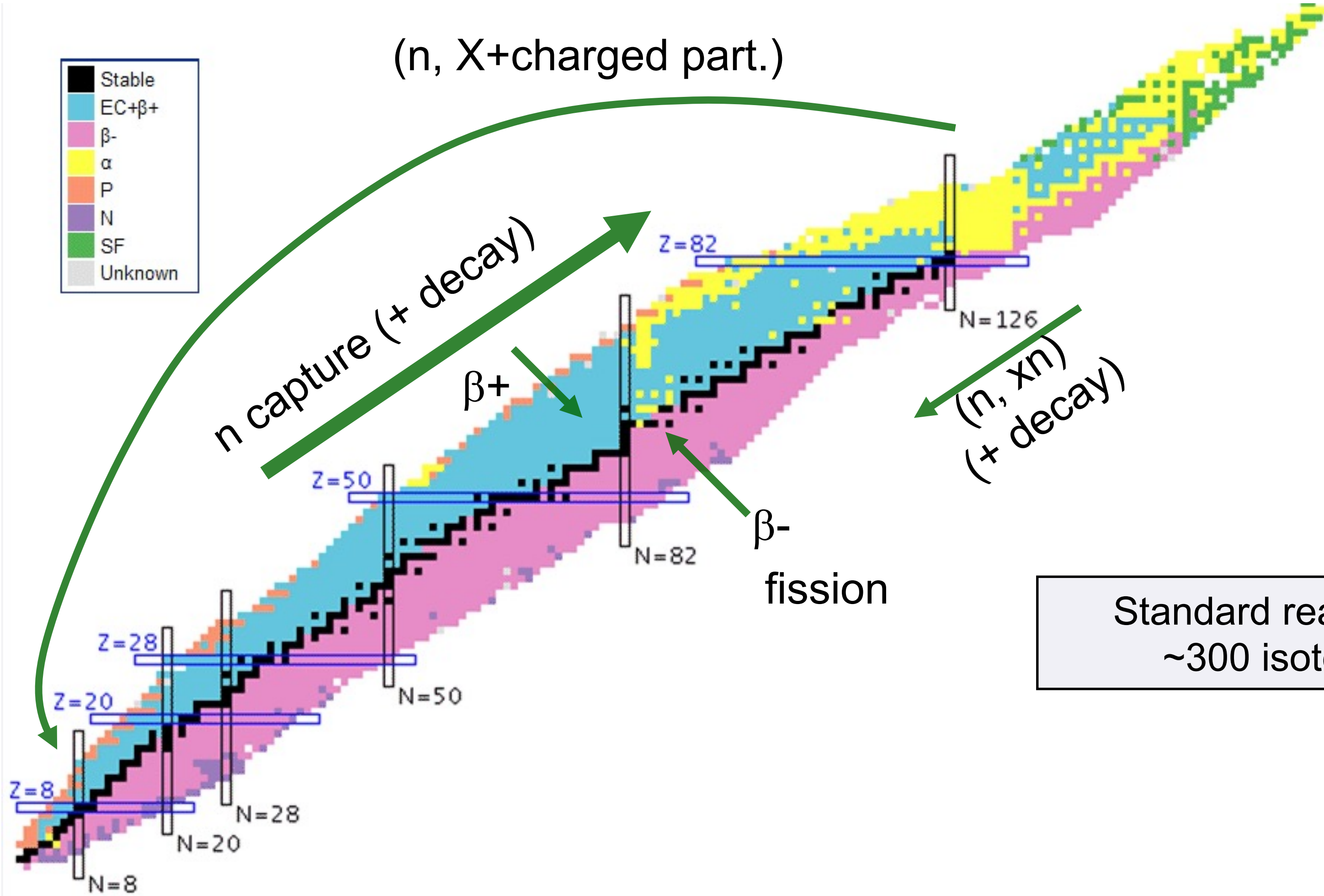
- Nuclear reaction data: cross sections (probability of reaction as a function of energy), energy distributions, multiplicity and angular distributions of reaction products ...
- Decay and nuclear structure data: modes of disintegration, half-lives, probabilities of emission of particles (multiplicities, energies, angular correlations), information on the nuclear structure (energy, spin and parity) ...

- Integral data. Macroscopic properties of nuclear systems, some of them measured or determined with high accuracy. They are typically used for the test and validation of microscopic data.

Nuclear processes inside a nuclear reactor



Data for nuclear reactors, waste management…



Standard reactor
~300 isotopes

Nuclear data for nuclear technologies

Cross sections:

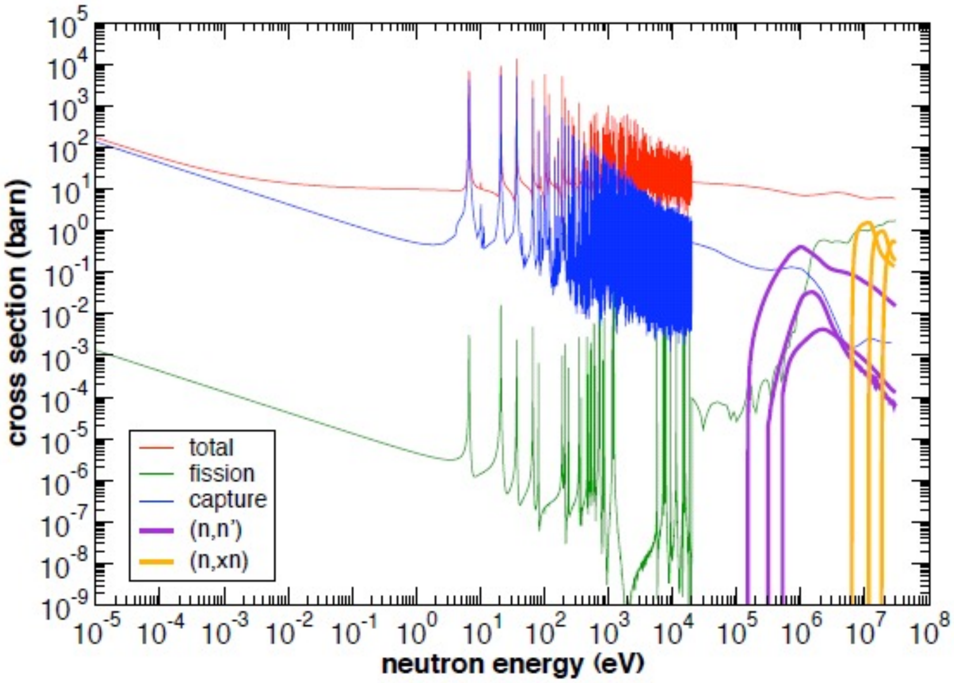
- Fission (n,f) and neutron capture (n,γ) of actinides, structural materials and some fission fragments ...
- Reactions (n, n), (n, n'γ), (n, xn), for fuel and other reactor materials: coolants, moderators, vats, control rods ...
- Emission probabilities and secondary particle spectra: prompt neutrons, prompt γ-rays, fission fragment distribution ...
- Fission fragments.

Beta disintegration of fission fragments:

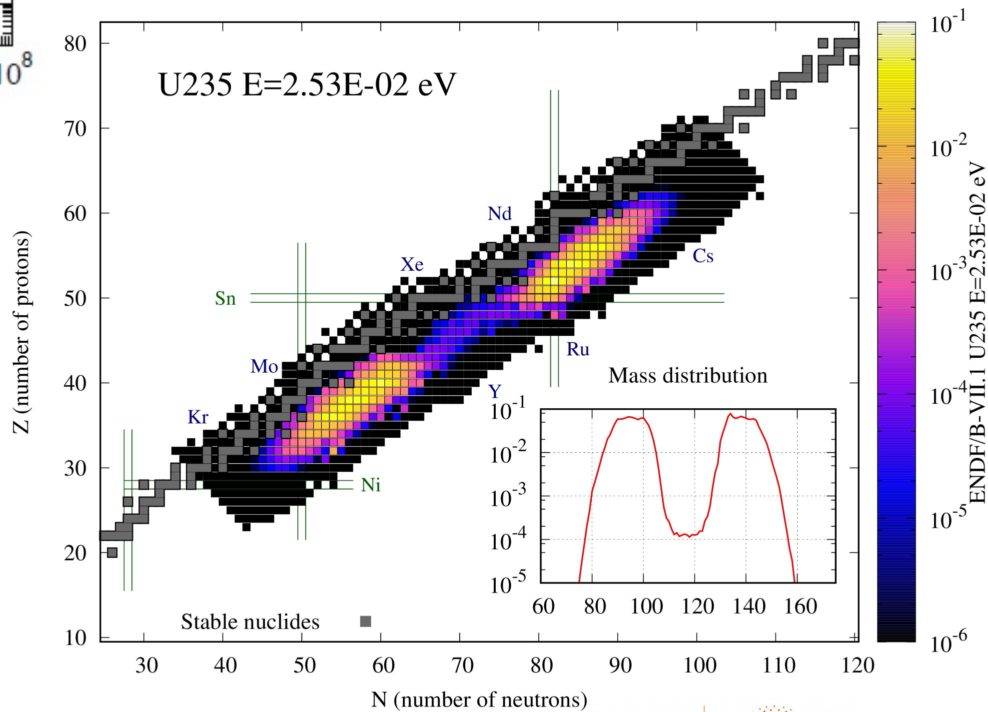
- decay and emission schemes of delayed neutrons, γ's, β's, (neutrinos) …

See seminars by:

- E. González Romero on ***Nuclear data for nuclear technologies and applications***
- F. Álvarez on ***Nuclear data for reactor physics (thermal and fast systems)***
- F. Álvarez on ***Nuclear fuel cycles***



Cross section data for ^{238}U



Fission yield distributions calculated with FISPACT (https://fispact.ukaea.uk/)

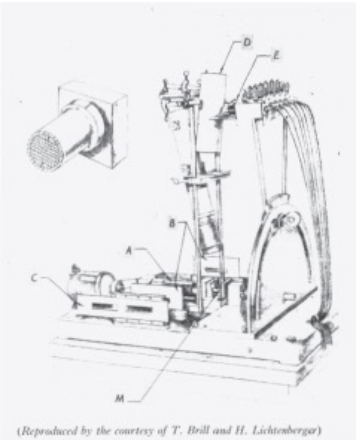
PHYSICAL REVIEW VOLUME 72, NUMBER 3 AUGUST 1, 1947

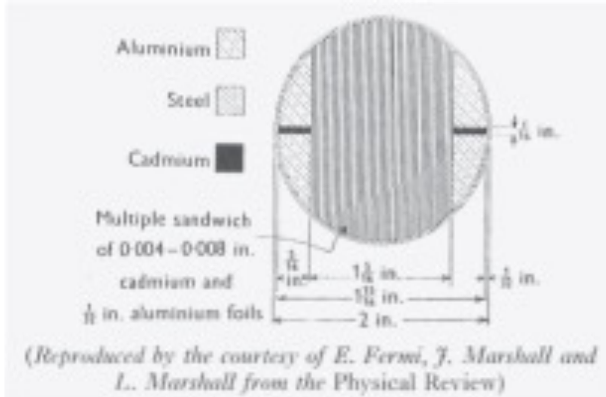
A Thermal Neutron Velocity Selector and Its Application to the Measurement of the Cross Section of Boron

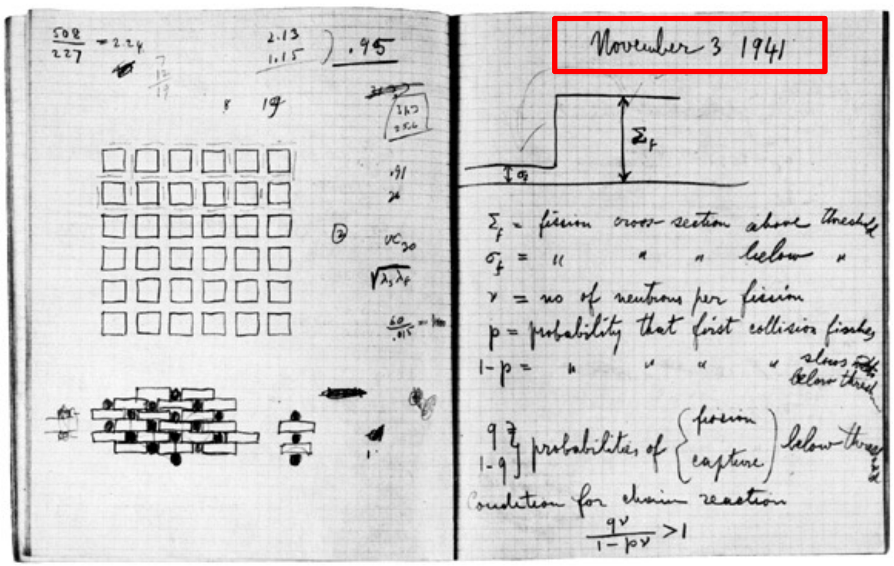
E. Fermi, J. Marshall, and L. Marshall
Argonne National Laboratory, University of Chicago, Chicago,** Illinois*

(Received April 25, 1947)

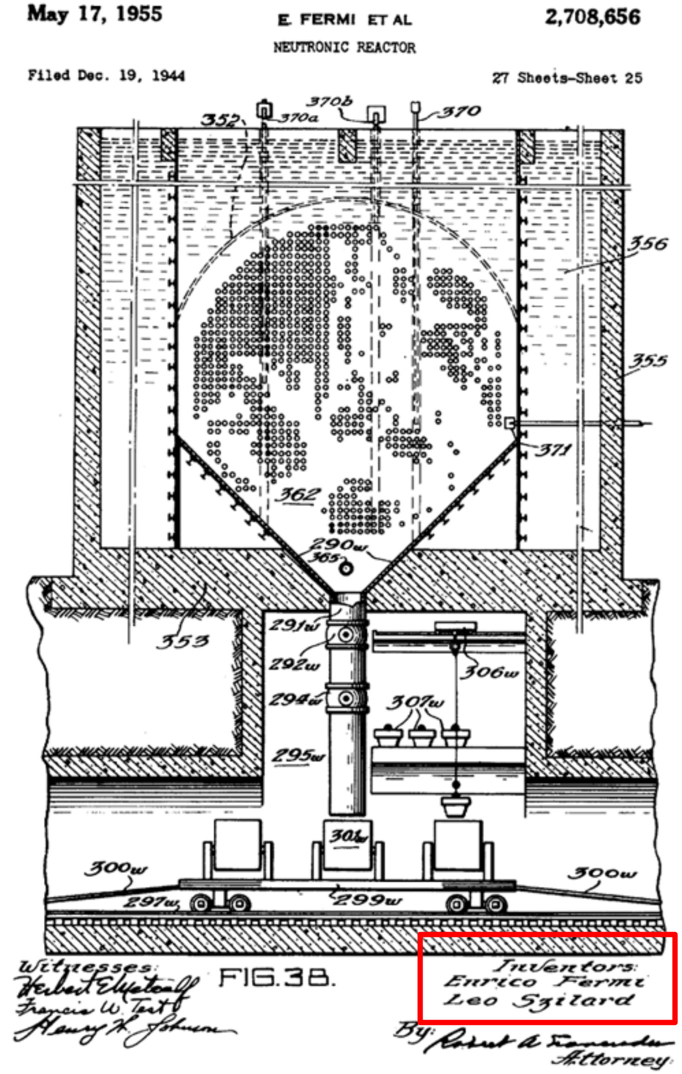
During the Manhattan project







(1941) FERMI's logbook about the design of Chicago PILE-1 (1942)



(1945) Patent on Fermi-Szilard reactor design.

Nuclear Science for the Manhattan Project and Comparison to Today's ENDF Data

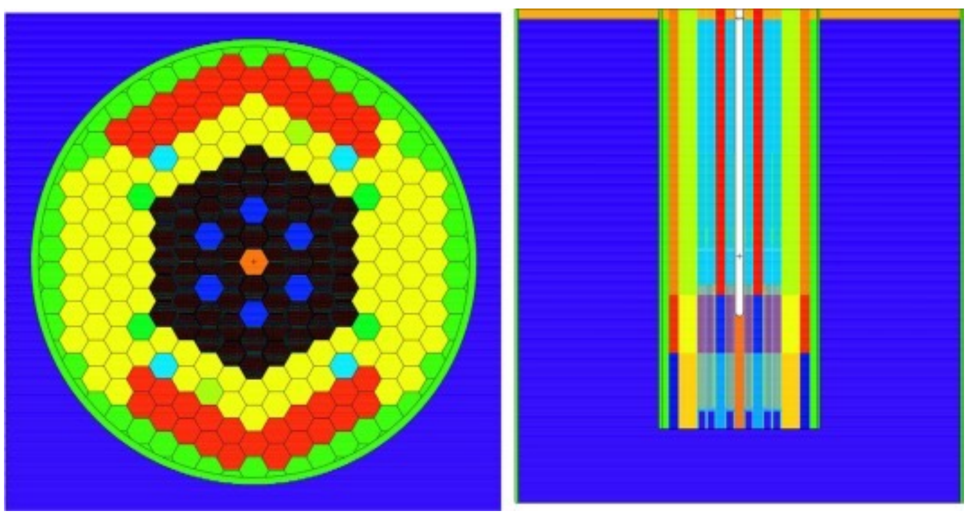
by M. B Chadwick

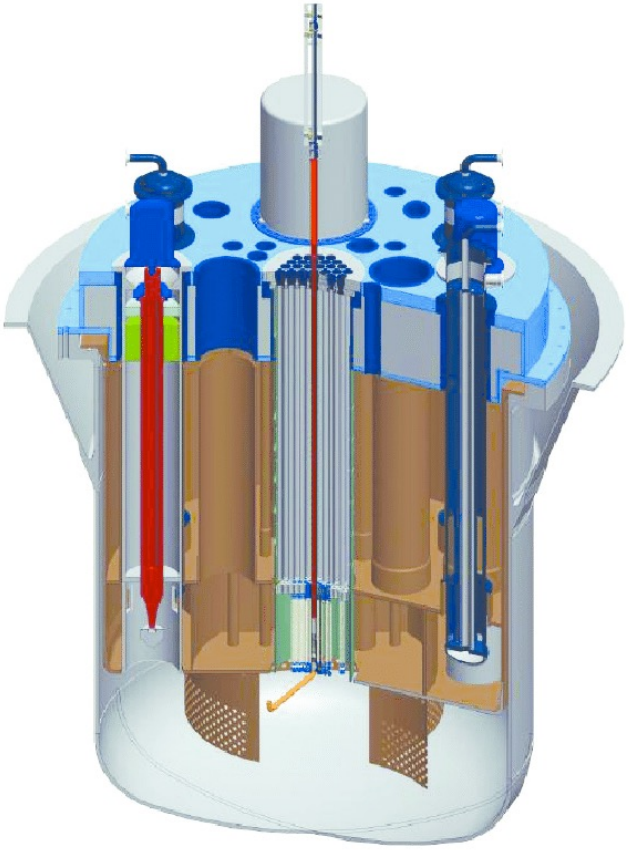
https://doi.org/10.1080/00295450.2021.1901002

State of the art nowadays

1. Better Monte Carlo simulation tools and computers.
2. Powerful and well characterised neutron sources.
3. More advanced detectors and data acquisition systems.

Unfortunately, we don't have Fermi!





The MYRRHA Accelerator Driven System

See seminar by:

- O. Cabellos on ***Simulation codes and data processing tools***

Which data are prioritary?

Identification of nuclear data priorities: which data contribute largest to the uncertainty in the parameter calculated.

$$\frac{\Delta k}{k} = \mathbf{SC}\boldsymbol{S}^{\boldsymbol{T}}$$

k ≡effective multiplication factor in the reactor
$\mathbf{S}$ ≡ vector of sensitiviy coefficients
$\mathbf{C}$ ≡covariance matrix

The sandwich rule

$$S_{k,\alpha} = \frac{\alpha}{k}\frac{\partial\alpha}{\partial k}$$

α ≡reaction cross section

Sensitivity coefficient

See seminar & hands-on lectures:

- V. Bécares on ***nuclear data and sensitivity analyses***

NEA Nuclear Data High Priority Request List

HPRL Main	High Priority Requests (HPR)	General Requests (GR)	Special Purpose Quantities (SPQ)		New Request	EG-HPRL (SG-C)
			Standard	Dosimetry		

ID	View	Target	Reaction	Quantity	Energy range	Sec.E/Angle	Accuracy	Cov	F:
2H		8-O-16	(n,a),(n,abs)	SIG	2 MeV-20 MeV		See details	Y	Fi
3H		94-PU-239	(n,f)	prompt g	Thermal-Fast	Eg=0-10MeV	7.5	Y	Fi
4H		92-U-235	(n,f)	prompt g	Thermal-Fast	Eg=0-10MeV	7.5	Y	Fi
8H		1-H-2	(n,el)	DA/DE	0.1 MeV-1 MeV	0-180 Deg	5	Y	Fi
15H		95-AM-241	(n,g),(n,tot)	SIG	Thermal-Fast		See details		Fi
18H		92-U-238	(n,inl)	SIG	65 keV-20 MeV	Emis spec.	See details	Y	Fi
19H		94-PU-238	(n,f)	SIG	9 keV-6 MeV		See details	Y	Fi
21H		95-AM-241	(n,f)	SIG	180 keV-20 MeV		See details	Y	Fi
22H		95-AM-242M	(n,f)	SIG	0.5 keV-6 MeV		See details	Y	Fi
25H		96-CM-244	(n,f)	SIG	65 keV-6 MeV		See details	Y	Fi
27H		96-CM-245	(n,f)	SIG	0.5 keV-6 MeV		See details	Y	Fi
32H		94-PU-239	(n,g)	SIG	0.1 eV-1.35 MeV		See details	Y	Fi
33H		94-PU-241	(n,g)	SIG	0.1 eV-1.35 MeV		See details	Y	Fi
34H		26-FE-56	(n,inl)	SIG	0.5 MeV-20 MeV	Emis spec.	See details	Y	Fi
35H		94-PU-241	(n,f)	SIG	0.5 eV-1.35 MeV		See details	Y	Fi
37H		94-PU-240	(n,f)	SIG	0.5 keV-5 MeV		See details	Y	Fi
38H		94-PU-240	(n,f)	nubar	200 keV-2 MeV		See details	Y	Fi
39H		94-PU-242	(n,f)	SIG	200 keV-20 MeV		See details	Y	Fi
41H		82-PB-206	(n,inl)	SIG	0.5 MeV-6 MeV		See details	Y	Fi
42H		82-PB-207	(n,inl)	SIG	0.5 MeV-6 MeV		See details	Y	Fi
45H		19-K-39	(n,p),(n,np)	SIG	10 MeV-20 MeV		10	Y	Fu
97H		24-CR-50	(n,g)	SIG	1 keV-100 keV		8-10	Y	Fi
98H		24-CR-53	(n,g)	SIG	1 keV-100 keV		8-10	Y	Fi
99H		94-PU-239	(n,f)	nubar	Thermal-5 eV		1	Y	Fi
102H		64-GD-155	(n,g),(n,tot)	SIG	Thermal-100 eV		4	Y	Fi
103H		64-GD-157	(n,g),(n,tot)	SIG	Thermal-100 eV		4	Y	Fi
114H		83-BI-209	(n,g)Bi-210g,m	BR	500 eV-300 keV		10	Y	AD
115H		94-PU-239	(n,tot)	SIG	Thermal-5 eV		1	Y	Fi
116H		3-LI-0	(d,x)Be-7	SIG	10 MeV-40 MeV		10	Y	Fu
117H		3-LI-0	(d,x)H-3	SIG,TTY	5 MeV-40 MeV		10	Y	Fu
118H		68-ER-167	(n,g)	SIG,RP	0.01 eV-100 eV		2	Y	Fi

https://www.oecd-nea.org/dbdata/hprl/index.html

NEA Nuclear Data High Priority Request List, HPRL

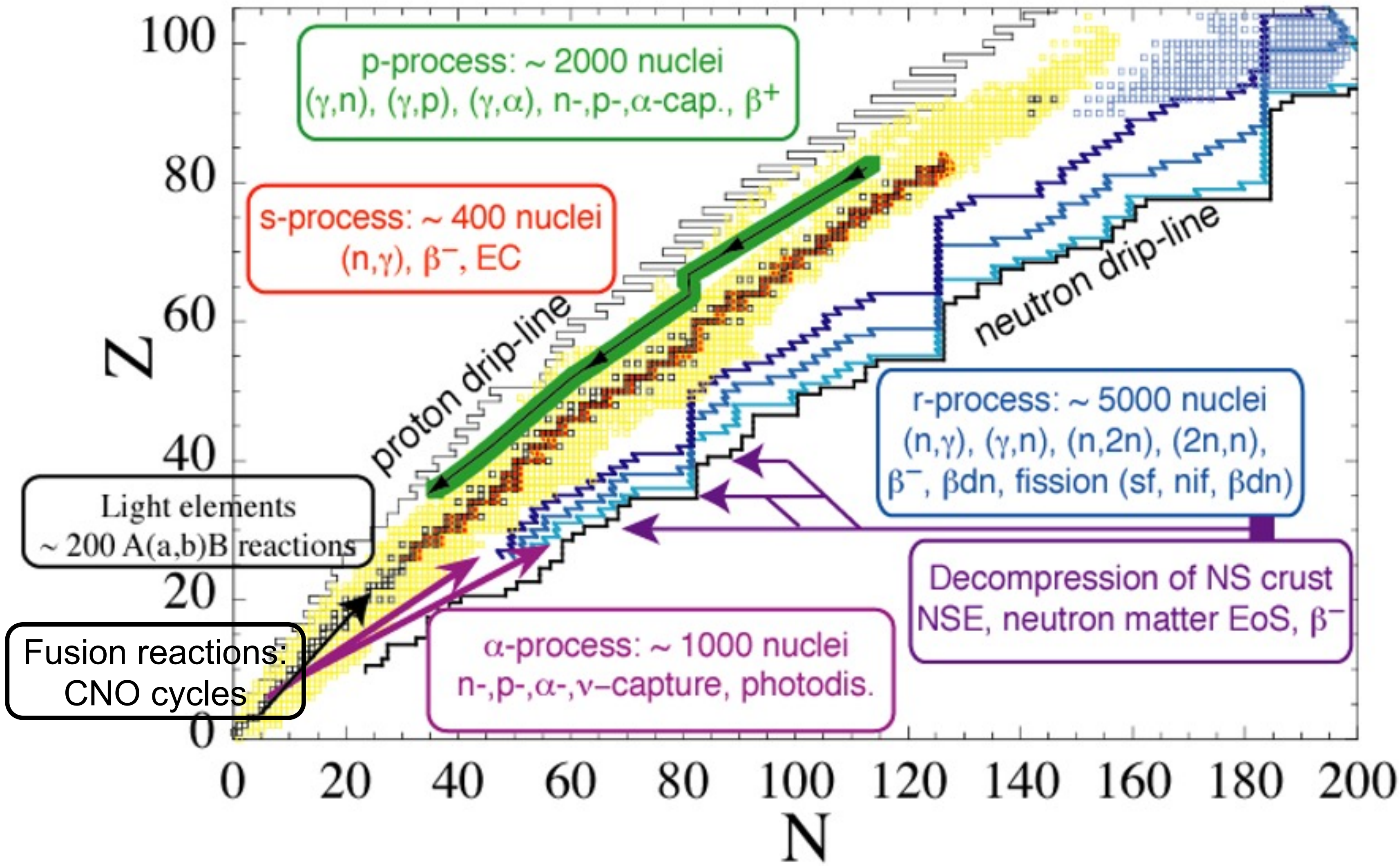
HPRL Main	High Priority Requests (HPR)	General Requests (GR)	Special Purpose Quantities (SPQ)		New Request	EG-HPRL (SG-C)
			Standard	Dosimetry		

Request ID	32		**Type of the request**	High Priority request	
Target	**Reaction and process**	**Incident Energy**	**Secondary energy or angle**	**Target uncertainty**	**Covariance**
94-PU-239	(n,g) SIG	0.1 eV-1.35 MeV		See details	Y
Field	**Subfield**	**Created date**	**Accepted date**	**Ongoing action**	**Archived Date**
Fission	Fast Reactors (VHTR)	04-APR-08	12-SEP-08	Y	

Requested accuracies:

1 keV –100 keV : ~5%

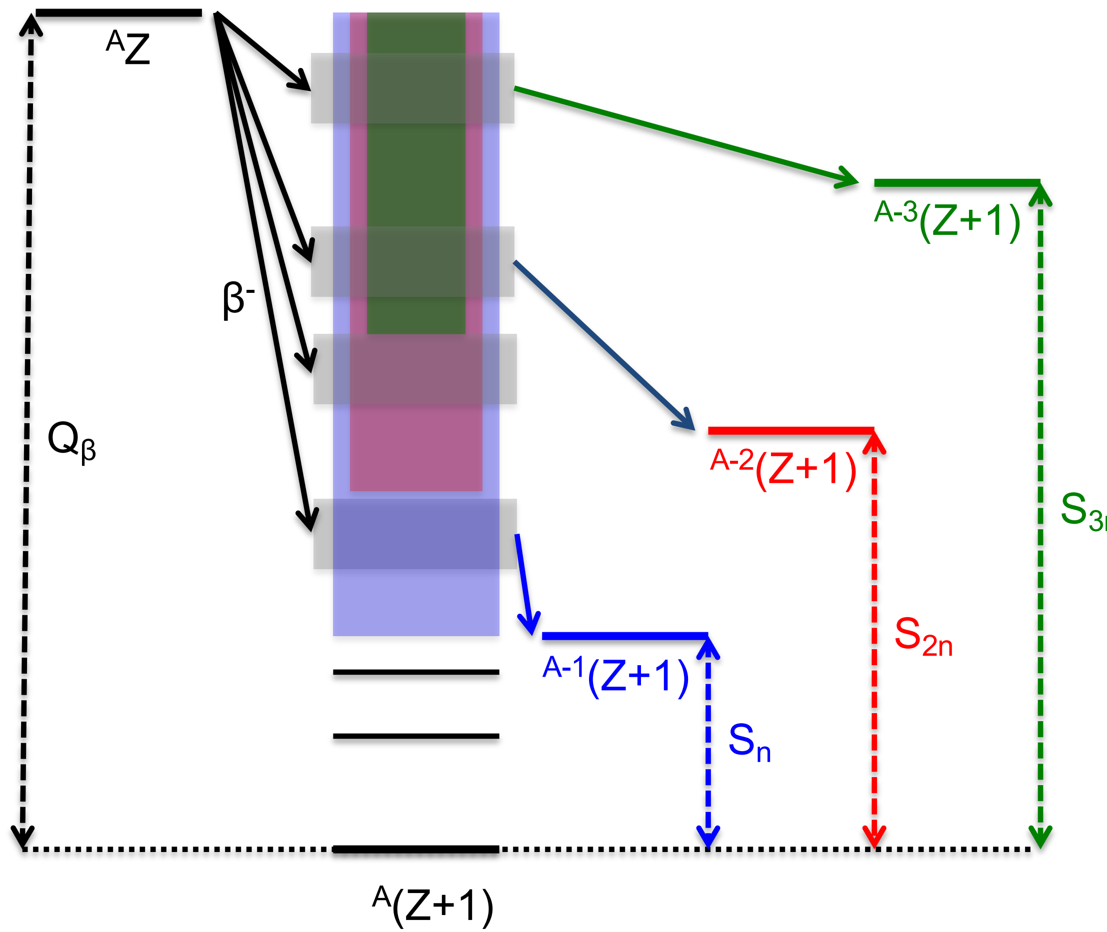
Nuclear data for nuclear astrophysics



β-decay data

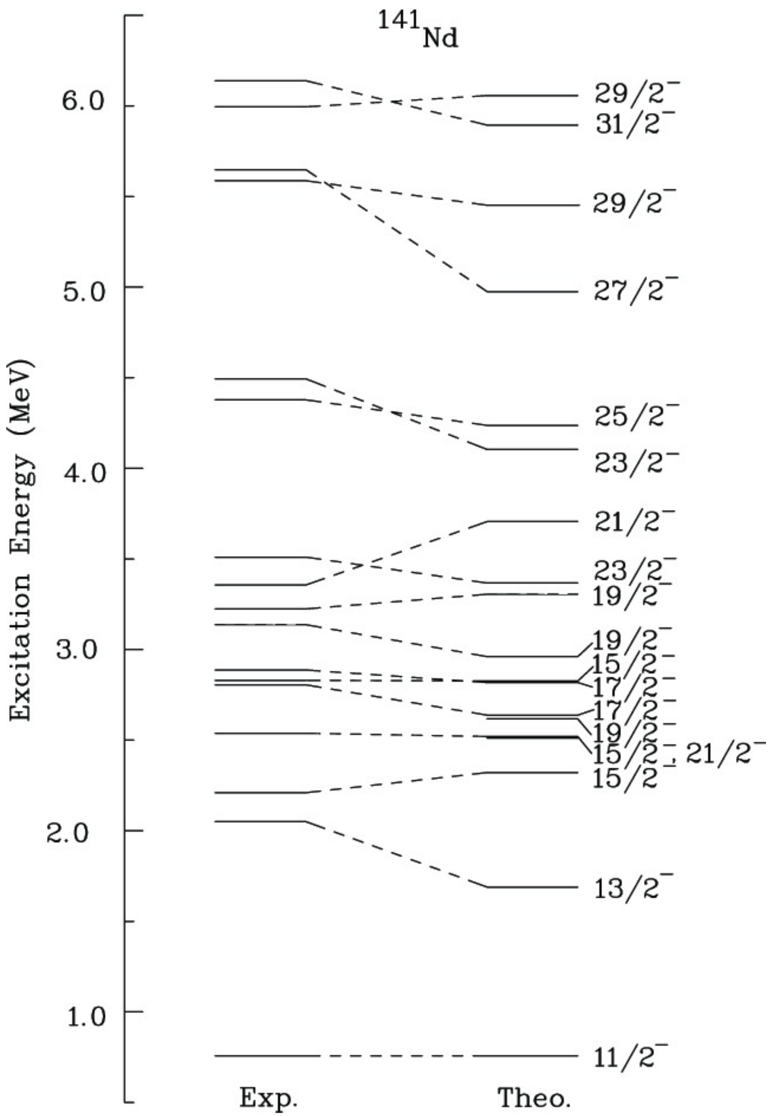
Typical data:

- Half lives $T_{1/2}$
- Q-values
- γ-ray energies and transition probabilities
- β-decay probabilities
- Delayed neutron emission probabilities and spectra



See seminar by B. Rubio ***Facilities and experimental techniques: decay data (accelerators and separators)***

Nuclear data for nuclear structure



Comparison of a Shell Model calculation and the experimental level scheme of ^{141}Nd.

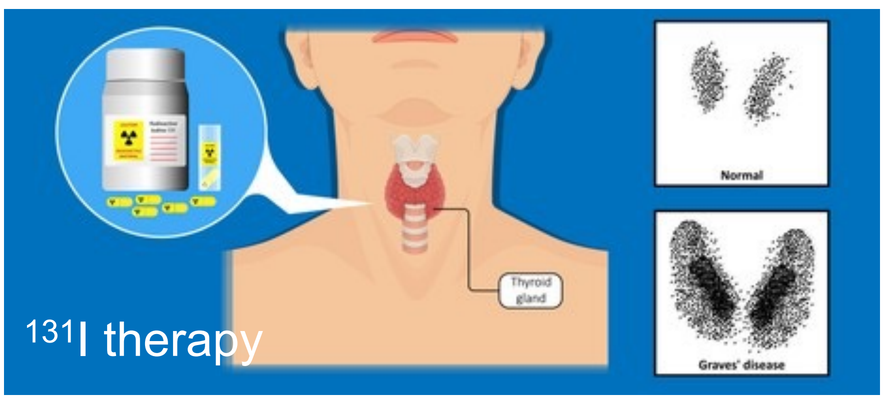
- Excitation energies and spin / parities.
- γ-ray energies and transition probabilities

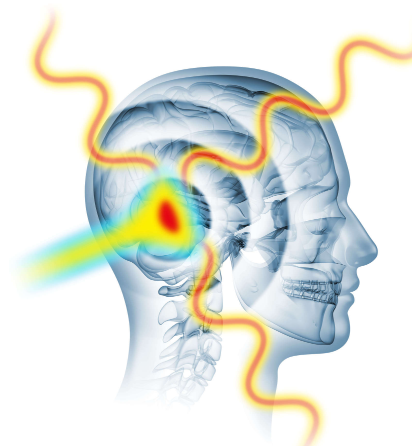
See seminar by:

- B. Rubio ***Facilities and experimental techniques: decay data (accelerators and separators)***

Nuclear data for medical applications

PET imaging





Proton therapy

Proton cross sections with C,N,O and other materials < 250 MeV

See seminar by:

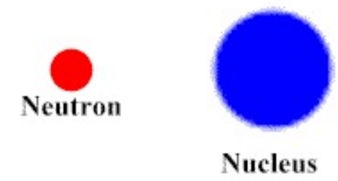
- R. Capote ***Nuclear data priorities for non-energy applications***

Some basics about neutron reactions

Neutron reactions at "low" energies (i.e. < 10 MeV)

A neutron is absorbed to form a "compound nucle

$$n + {}^{A}Z \rightarrow {}^{A+1}Z^{*}$$



which lives for a short time and decays:

${}^{A+1}Z^{*} \rightarrow n + {}^{A}Z$ (elastic)

${}^{A+1}Z^{*} \rightarrow {}^{A+1}Z^{*\prime} + \gamma$ (radiative capture)

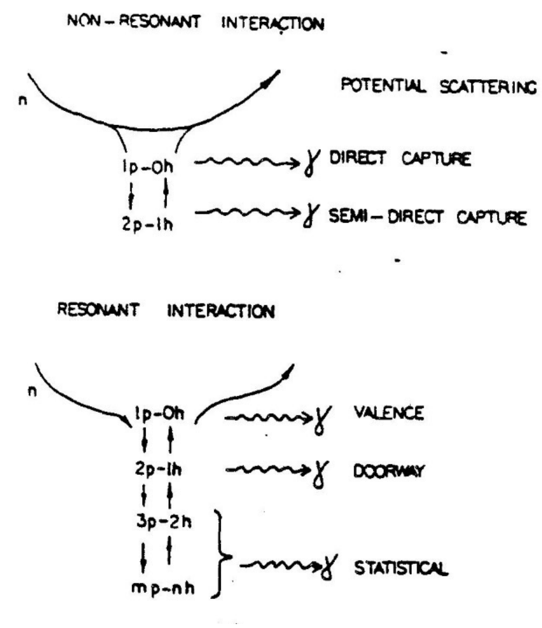
${}^{A+1}Z^{*} \rightarrow {}^{A1}Z_{1}^{*} + {}^{A2}Z_{2}^{*} + xn$ (fission)

${}^{A+1}Z^{*} \rightarrow n + {}^{A}Z^{*}$ (inelastic)

${}^{A+1}Z^{*} \rightarrow {}^{A+1-x}Z^{*} + xn$ (neutron multiplication)

…

Other contributions:



The compound nucleus (CN)

The CN formation probability is higher for certain neutron energies E_n corresponding to quasi-bound or virtual states: **resonances**

S_n : neutron separation energy of CN (<10MeV) ⇨ level separation D_0 ~ 1 eV – 100 keV

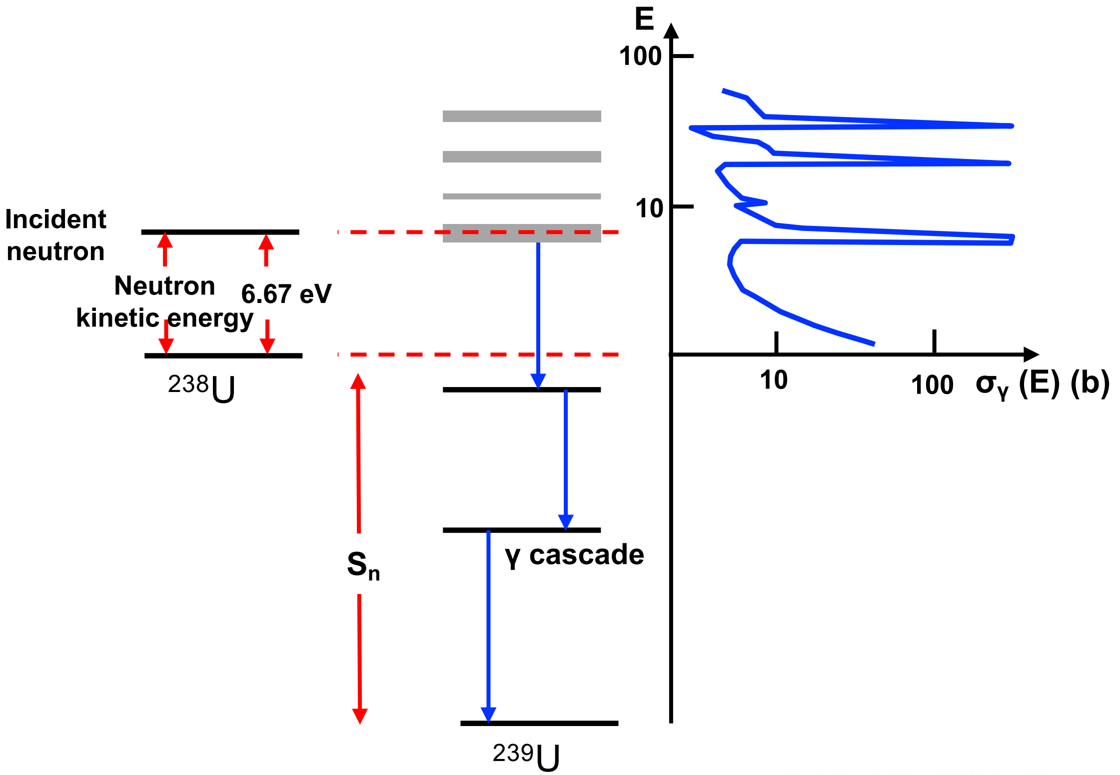
$$E_R = S_n + \frac{A}{A+1} E_n$$

Life-time ↔ Energy-width: Γ

$$\Gamma = \Gamma_n + \Gamma_\gamma + \Gamma_f + \ldots$$

$$(\sigma = \sigma_n + \sigma_\gamma + \sigma_f + \ldots)$$

Γ ~ 1 meV – 100 keV



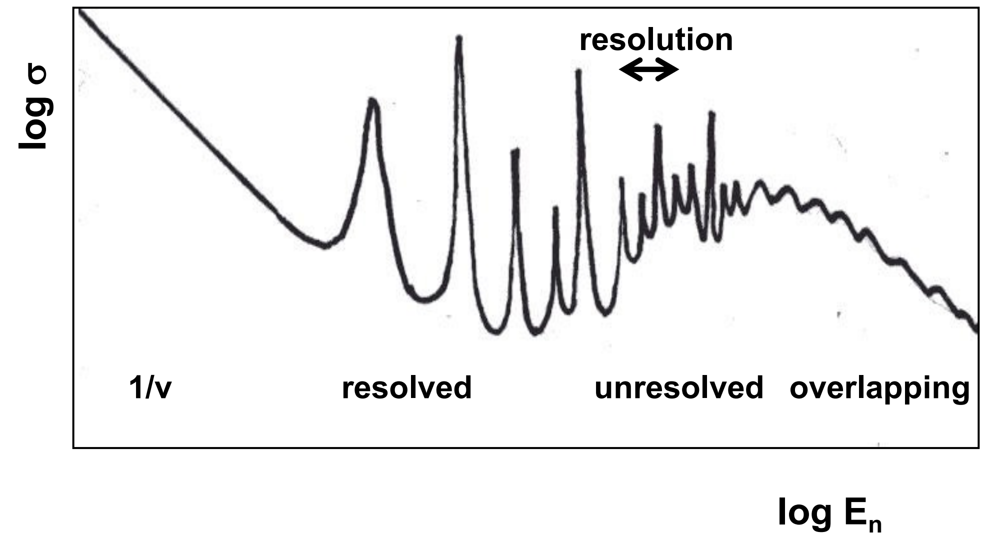
The shape of a neutron cross-section

1/v: thermal

$\Gamma < D_0$, $\Gamma > \Delta E$: resolved resonance region (RRR)

$\Gamma < D_0$, $\Gamma < \Delta E$: unresolved resonance region (URR)

$\Gamma > D_0$: overlapping resonances

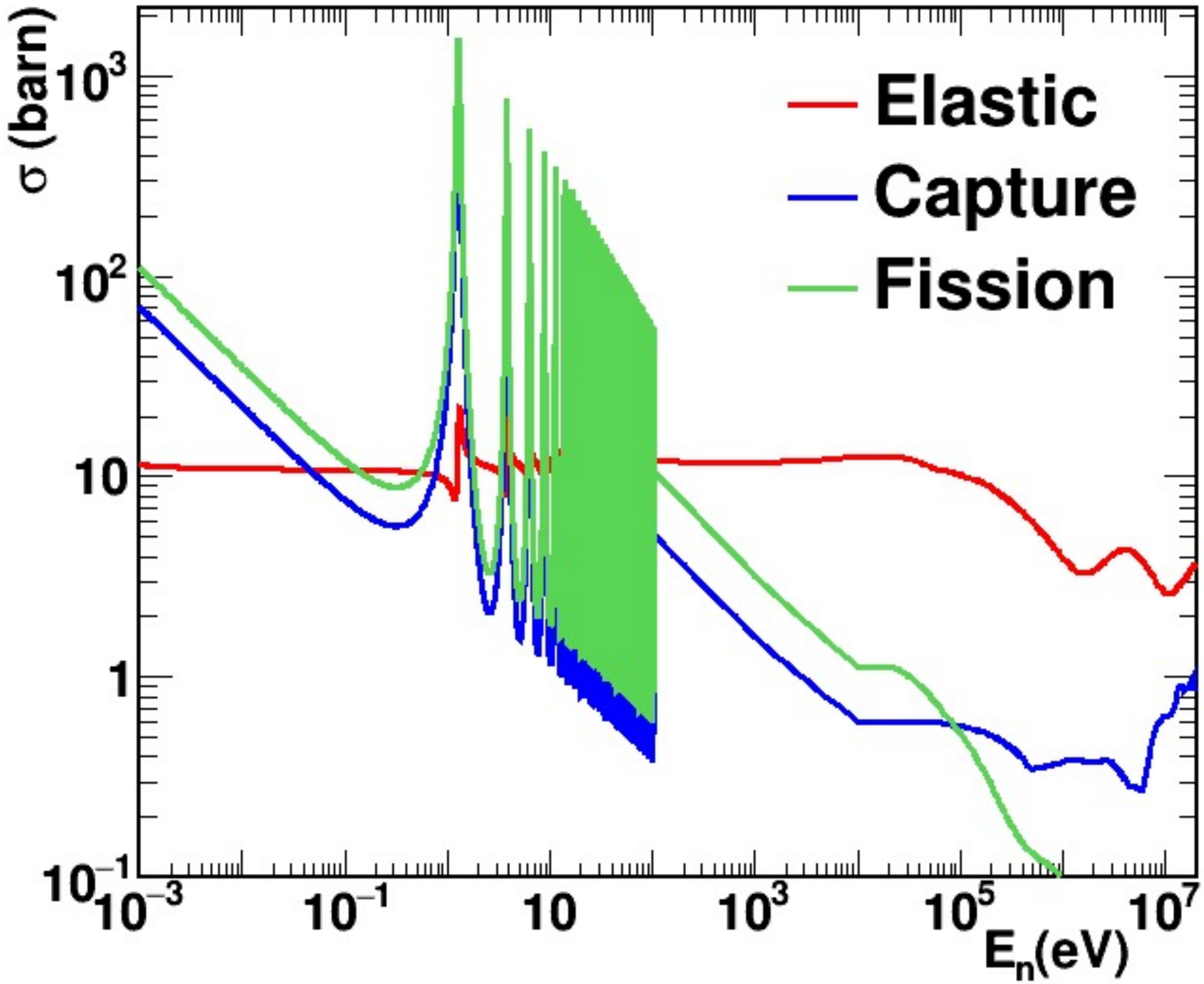


- In the resolver resonance region (RRR), σ is described using the R-Matrix formalism, in one of its usual approximations.
- In the unresolved resonance region (URR), average σ are described by Hauser-Feshbach statistical theory
- At higher energies cross section are described using Optical Model and other reaction models

It is a parametric approach since nuclear theory cannot predict the values.

Experimental information is absolutely necessary.

The case of ^{239}Pu

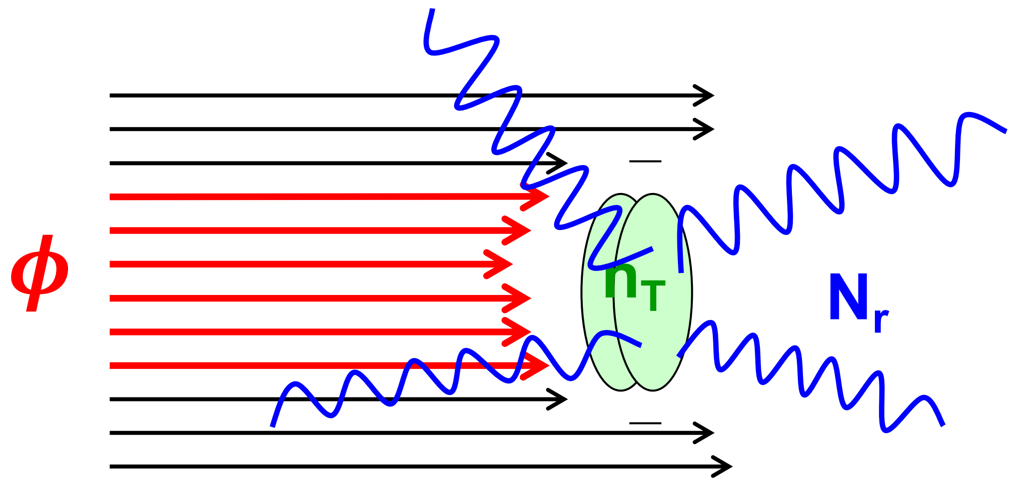


Measurement of differential cross-sections

$$\sigma_x(E) = \frac{\text{Number of reactions}}{\text{Number of target nucleus per unit area} \times \text{Number of neutrons of energy E}}$$

The proportionality constant σ is the reaction cross section.

It has units of area, and is usually expressed in *barns = 10^{-24}cm^2.*



$$\sigma_x(E)[barn] = \frac{N_x(E)[reactions \cdot s^{-1}]}{n_T\,[atoms \cdot barn^{-1}] \cdot \phi(E)[neutrons \cdot s^{-1}]}$$

Measuring the neutron cross sections requires:

- **A facility** providing a well characterized neutron beam.

Seminar by A. Junghans on ***Facilities and experimental techniques: reactions (neutron beams, reactors)***

- **A detection system** for counting the reactions (i.e. detecting the reaction secondaries.

Seminar by C. Guerrero on ***Detectors and experimental techniques***

-A highly pure **sample**.

Seminar by E. Maugeri on ***Samples for nuclear data experiments***

- A **theoretical framework and analysis codes** to express the cross sections (*R*-matrix formalism).

See the seminars by

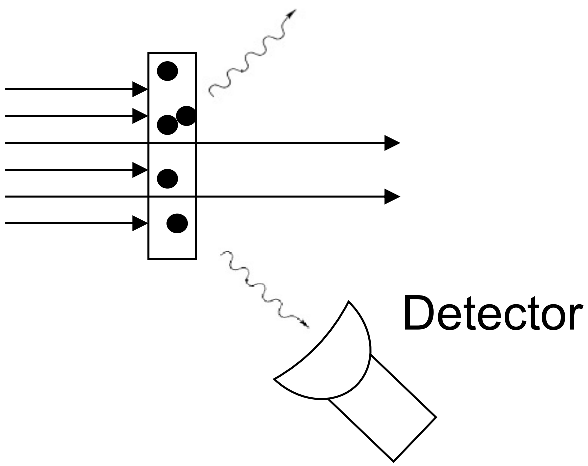
- L. Leal on ***Nuclear data evaluation***
- D. Rochman on ***Automatized nuclear data evaluation***

How to measure cross sections as a function of the energy

Reaction Measurements (n,x)

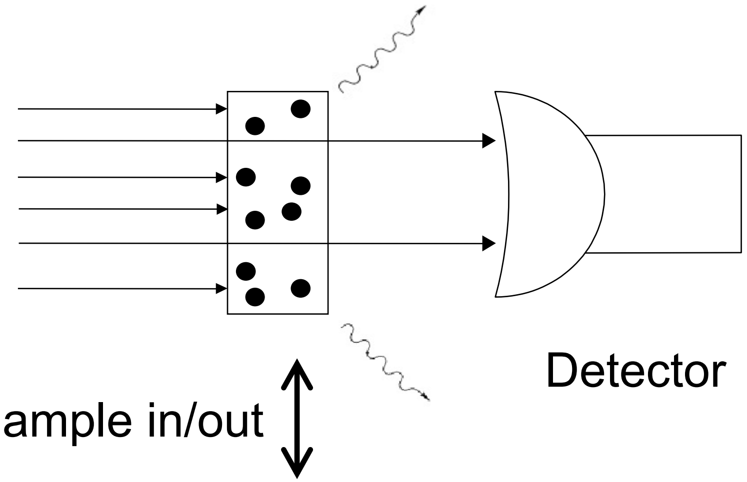
$$C_x = \epsilon_x \cdot Y_x \cdot I_n$$ **Counting rate**

$$Y_x \cong (1 - e^{-n\sigma_{tot}}) \frac{\sigma_x}{\sigma_{tot}}$$ **Yield**

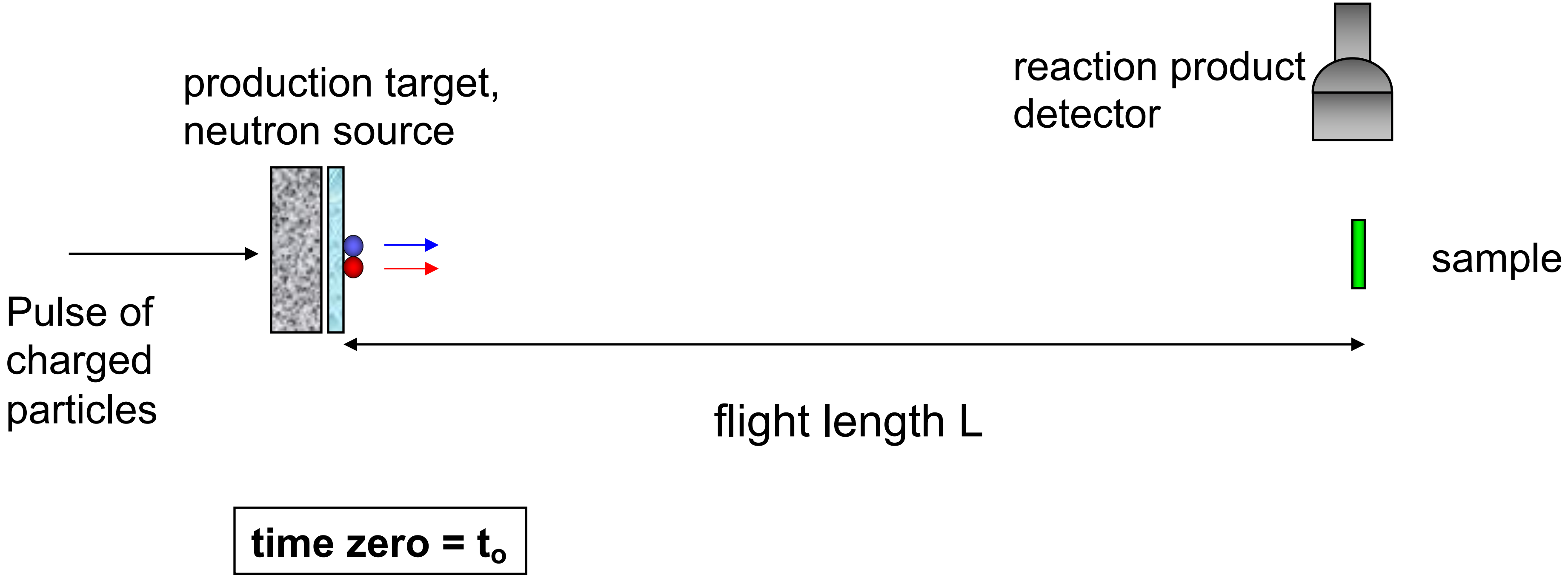


Transmission (n,tot)

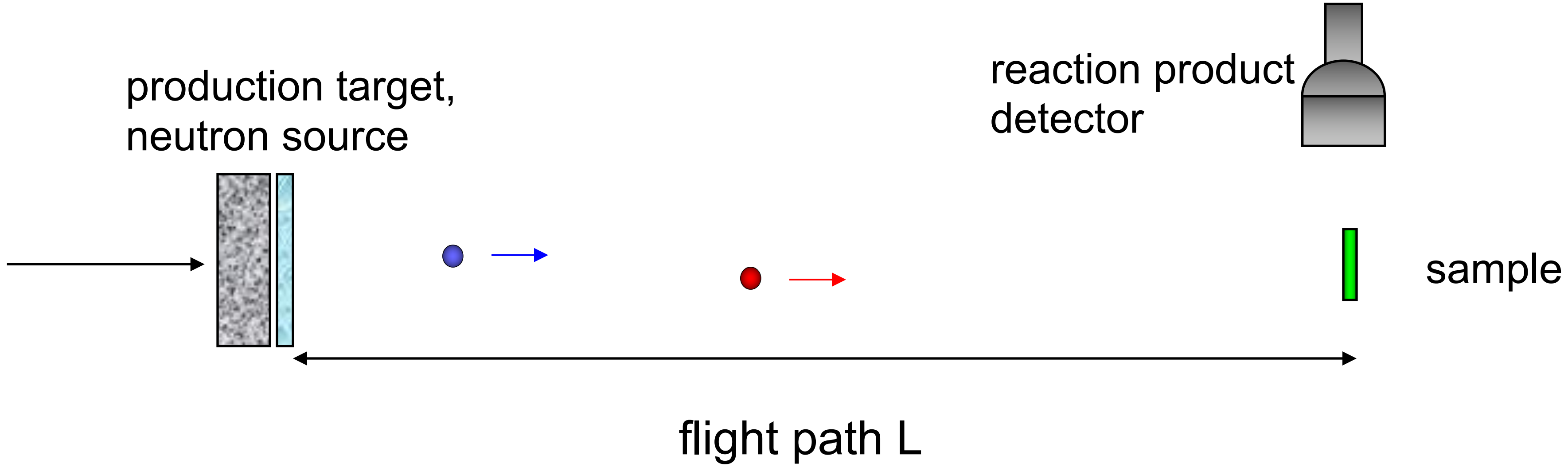
$$T = \frac{C_{in}}{C_{out}} \cong e^{-n\sigma_{tot}}$$



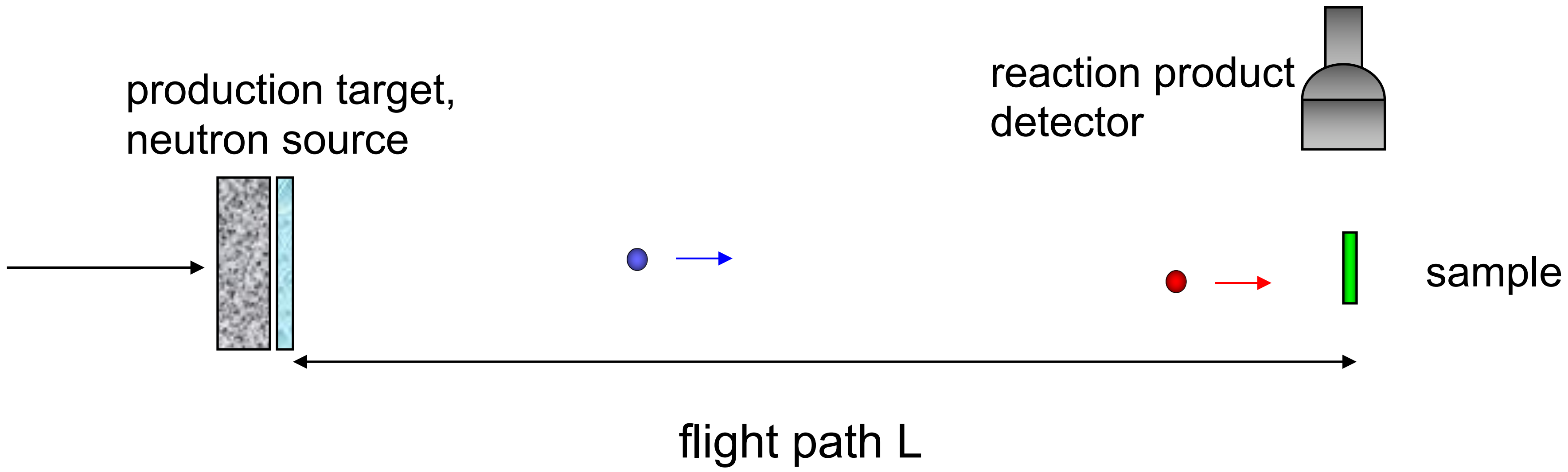
Time – Of – Flight technique



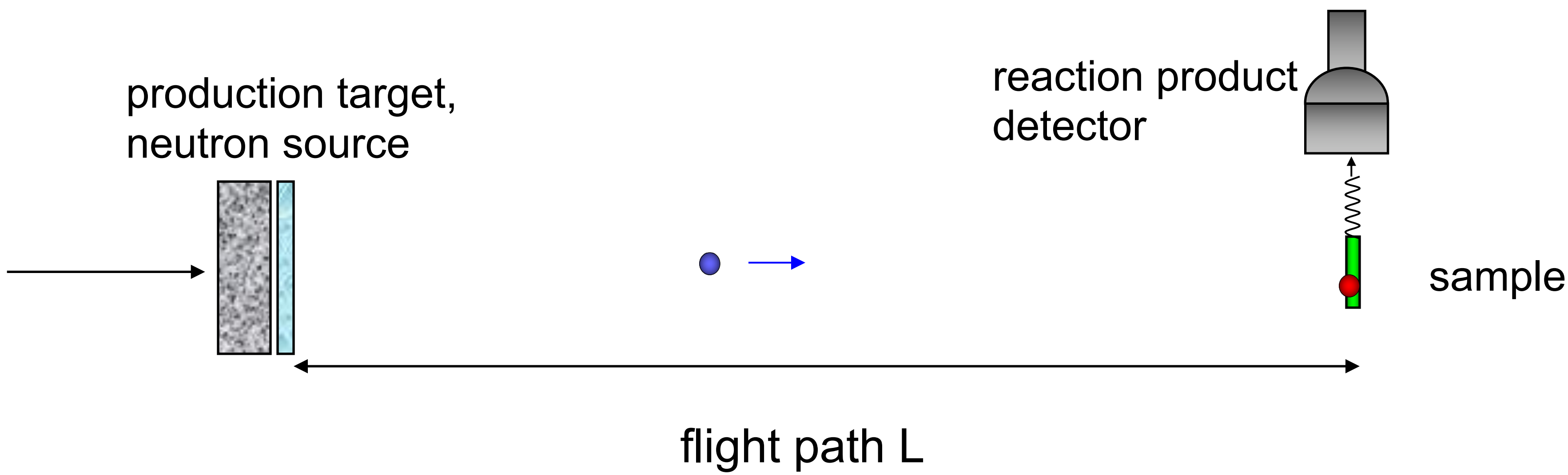
Time – Of – Flight technique



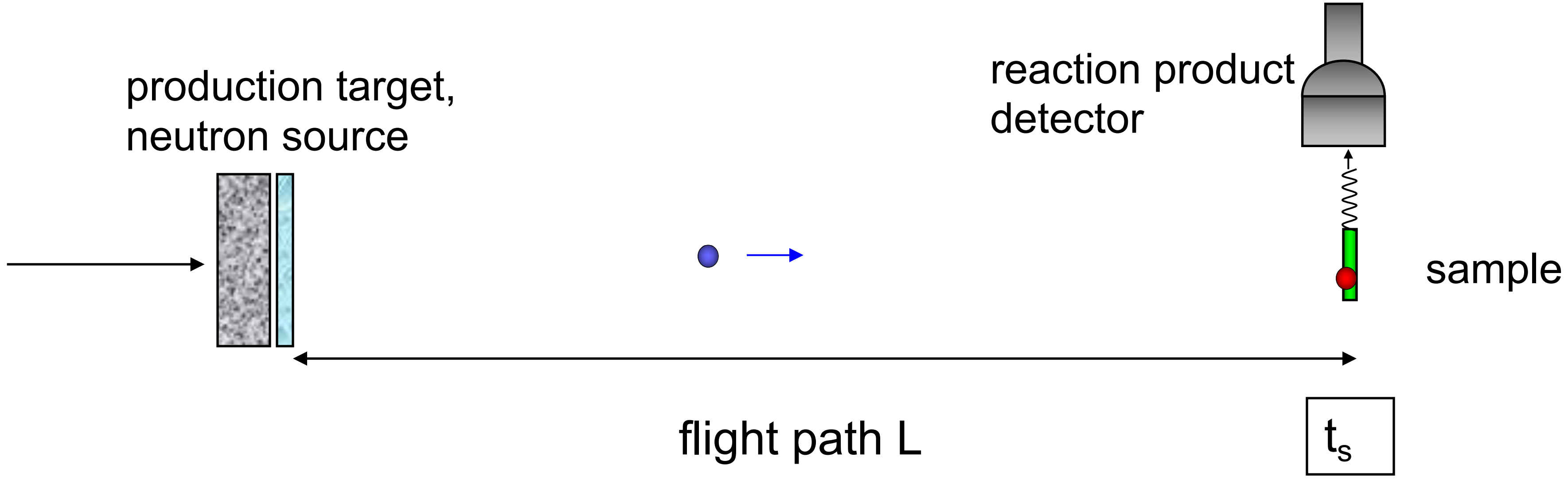
Time – Of – Flight technique



Time – Of – Flight technique

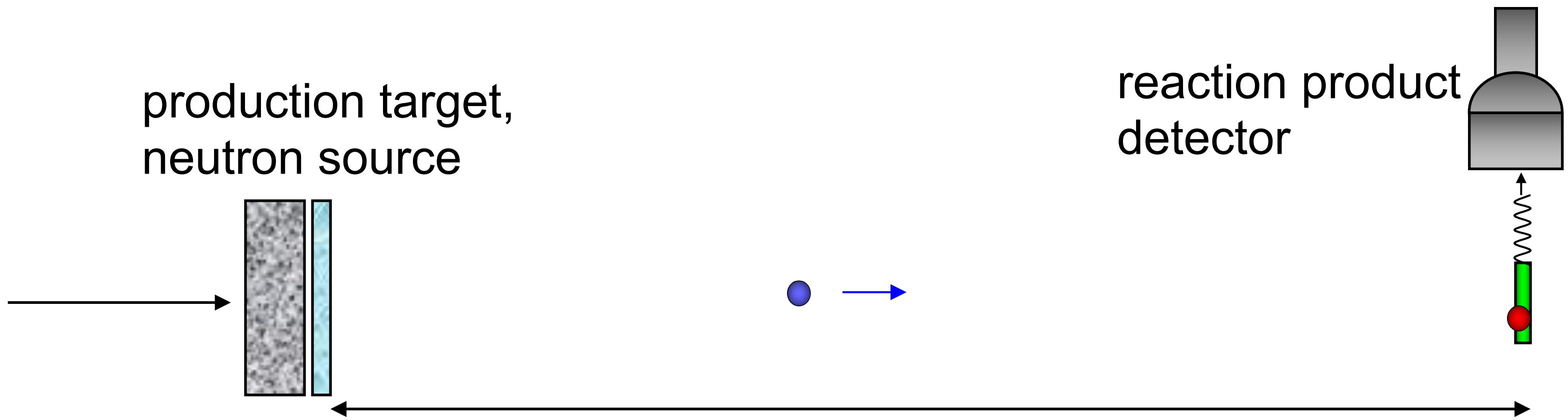


Time – Of – Flight technique



$t_n = t_s - t_o$

Time – Of – Flight technique



flight path L

$t_n = t_s - t_o$

Kinetic energy of the neutron by time-of-flight

$$E_n = m_n c^2 \left(\frac{1}{\sqrt{1-(v_n / c)^2}} - 1 \right)$$

$$v_n = \frac{L}{t_n}$$

There will be hands-on lectures with a **TOF experiment simulator** on:

- Transmission
- Capture cross sections
- Fission cross sections

Integral data and integral experiments

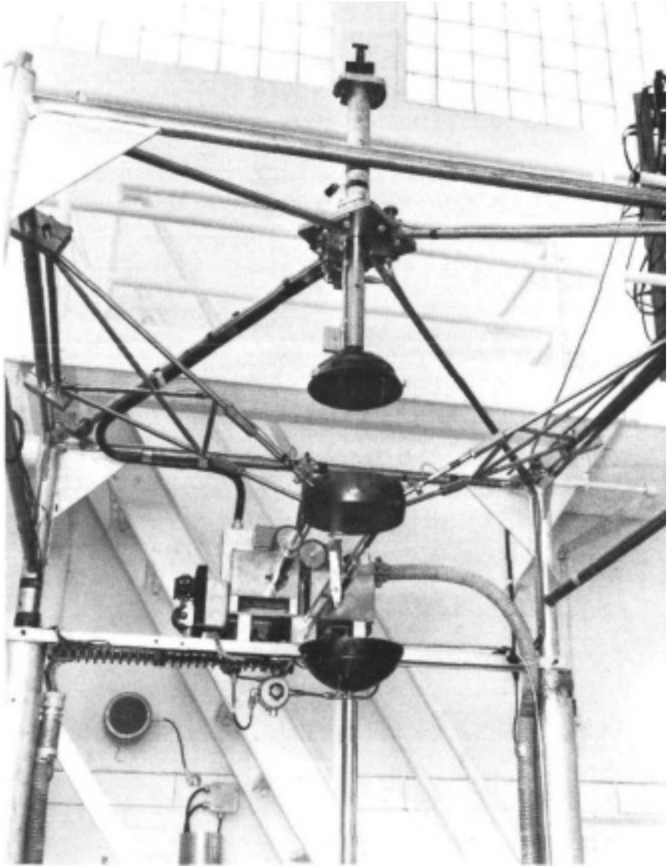
Calculation results (e.g. critical masses, reactor parameters, shielding attenuation lengths…) obtained using measured nuclear data need to be validated in systems representative of the intended applications → ***integral vs. differential experiments***.

For reactor physics applications, integral experiments are usually conducted in simple, very low ("zero") power, well characterized reactors → (sub)critical assemblies, reactor mock-ups.

In the past, integral experiments constituted the main source of nuclear data.

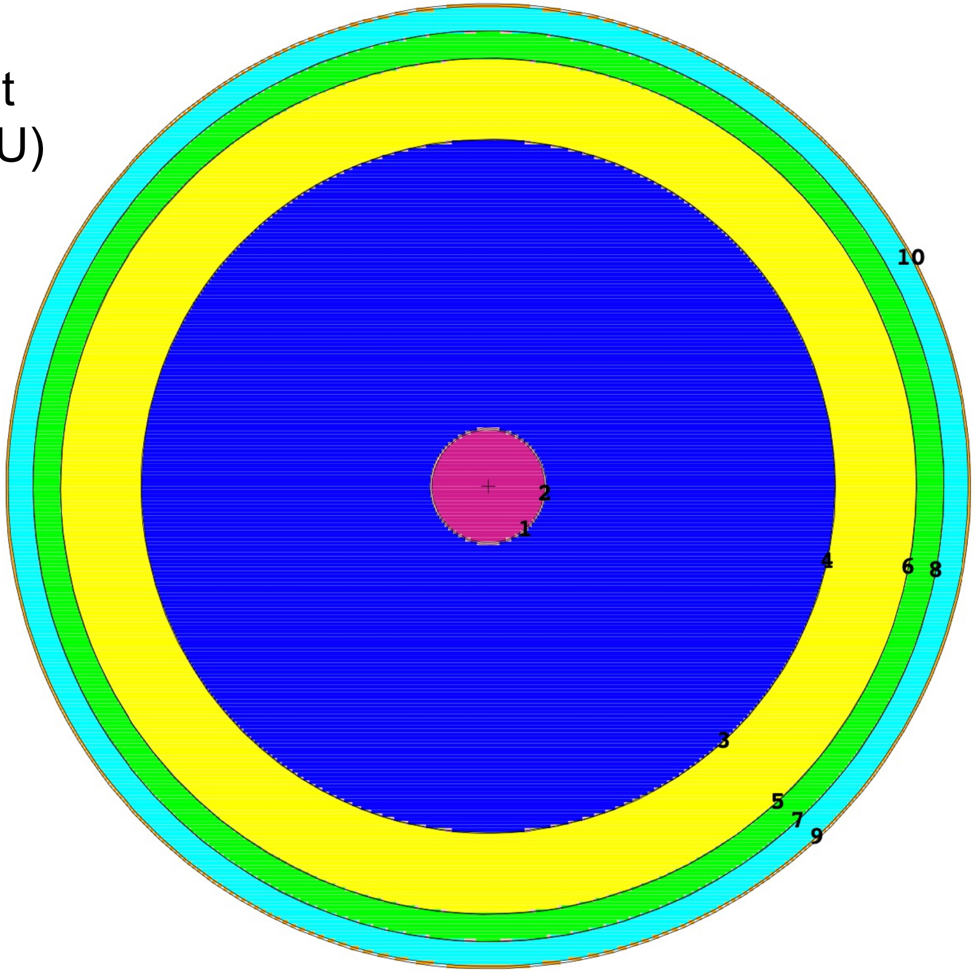
Example: **Godiva reactor**.

- Los Alamos National Lab (USA).
- First assembled in 1951.
- Bare Highly Enriched Uranium (HEU) sphere (1.02% ^{234}U, **93.71% ^{235}U**, 5.27% ^{238}U).
- k_{eff} = 1.000 ± 0.001.



The Godiva model

^{235}U layers with slightly different isotopic compositions (^{234}U, ^{238}U)



Integral experiments (II)

Databases of integral experimental data:

- International Criticality Safety Benchmark Evaluation Project (**ICSBEP**)

  https://www.oecd-nea.org/jcms/pl_24498/international-criticality-safety-benchmark-evaluation-project-icsbep

International Handbook of Evaluated Reactor Physics Benchmark Experiments (IRPhE)

  https://www.oecd-nea.org/jcms/pl_20279/international-handbook-of-evaluated-reactor-physics-benchmark-experiments-irphe

- Spent Fuel Isotopic Composition (**SFCOMPO**)

  https://www.oecd-nea.org/jcms/pl_21515/sfcompo-2-0-spent-fuel-isotopic-composition

- Shielding Integral Benchmark Archive and Database (**SINBAD**)

  https://www.oecd-nea.org/jcms/pl_32139/shielding-integral-benchmark-archive-and-database-sinbad

Seminar by O. Cabellos on **Reference integral experiments databases and validation of nuclear data**

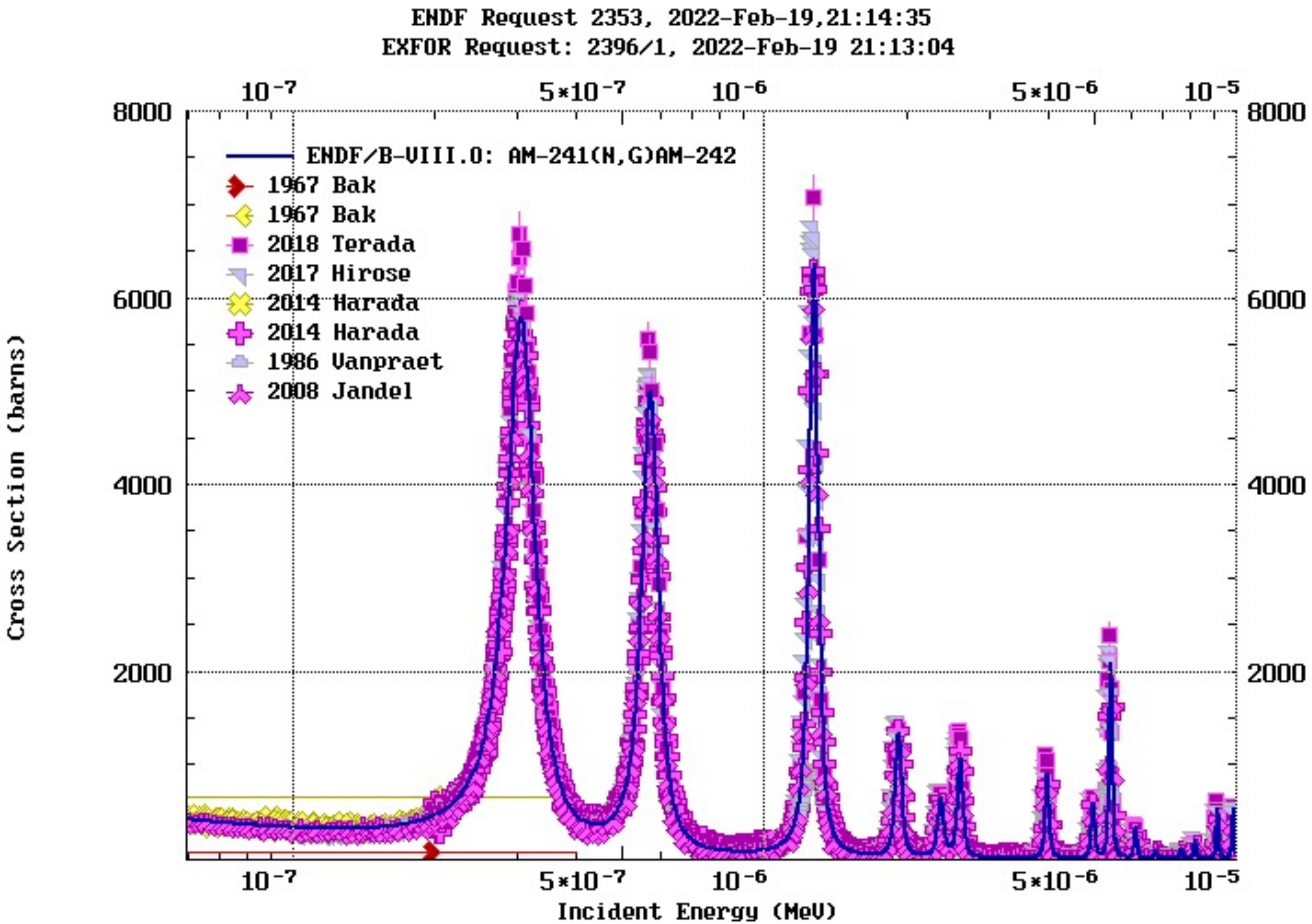
Nuclear data evaluation

An **evaluation** is the process of

- **analysing measured nuclear data sets** (cross sections, secondary particles, nuclear structure) and their uncertainties.
- **combining them with the predictions** of nuclear model calculations
- validating them with **integral data** / well known macroscopic assemblies,
- **Estimating the true value** (of a cross section, a particle yield, double differential cross section…)

See the seminars by

- A. Plompen on the ***The JEFF project – A. Plompen***
- P. Schillebeeckx on ***Identification and propagation of uncertainties***
- L. Leal on ***Nuclear data evaluation***
- D. Rochman on ***Automatized nuclear data evaluation***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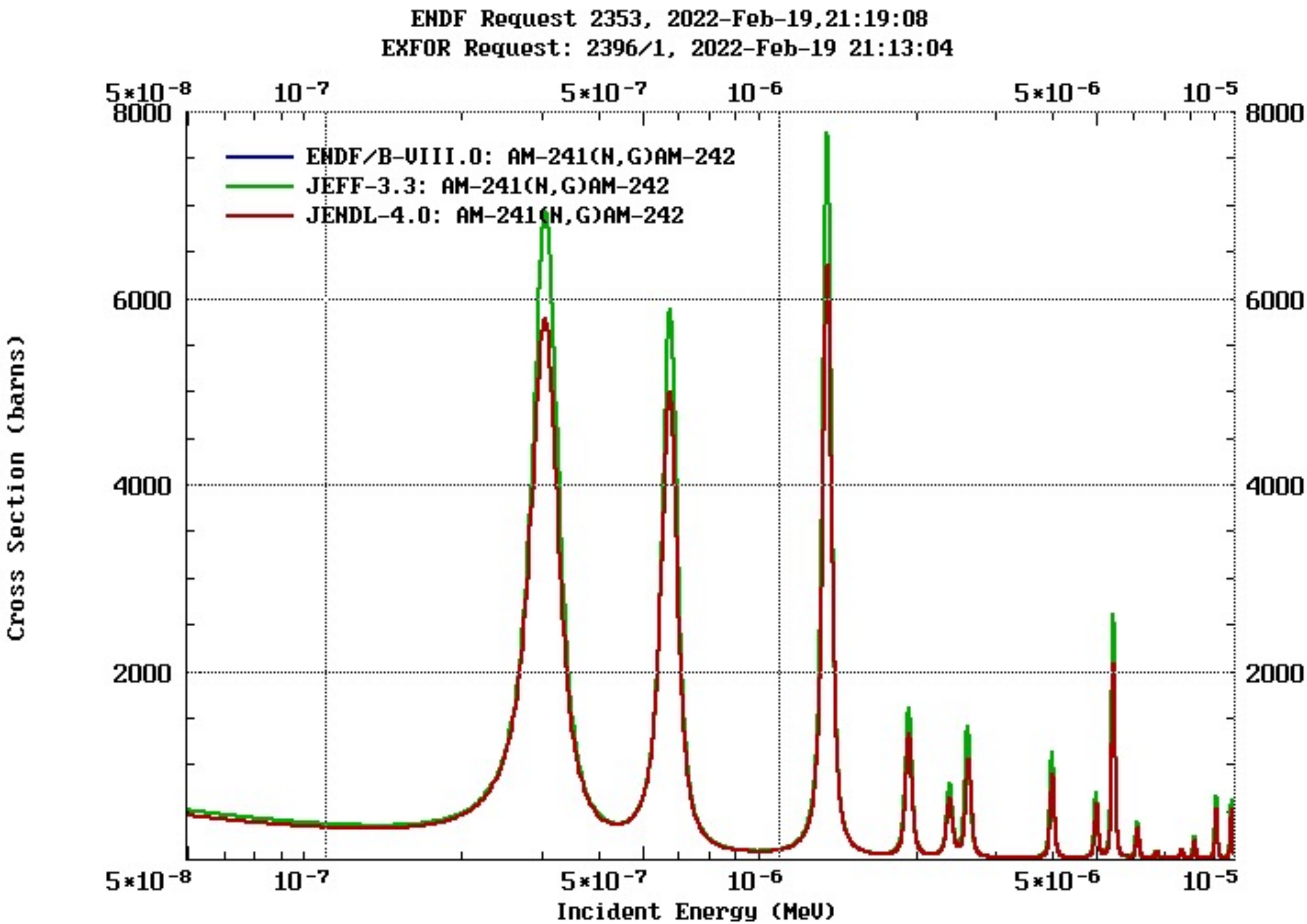
1967 Bak
1967 Bak
2018 Terada
2017 Hirose
2014 Harada
2014 Harada
1986 Vanpraet
2008 Jandel
Cross Section (barns)
Incident Energy (MeV)
8000
6000
4000
2000
10⁻⁷
5*10⁻⁷
10⁻⁶
5*10⁻⁶
10⁻⁵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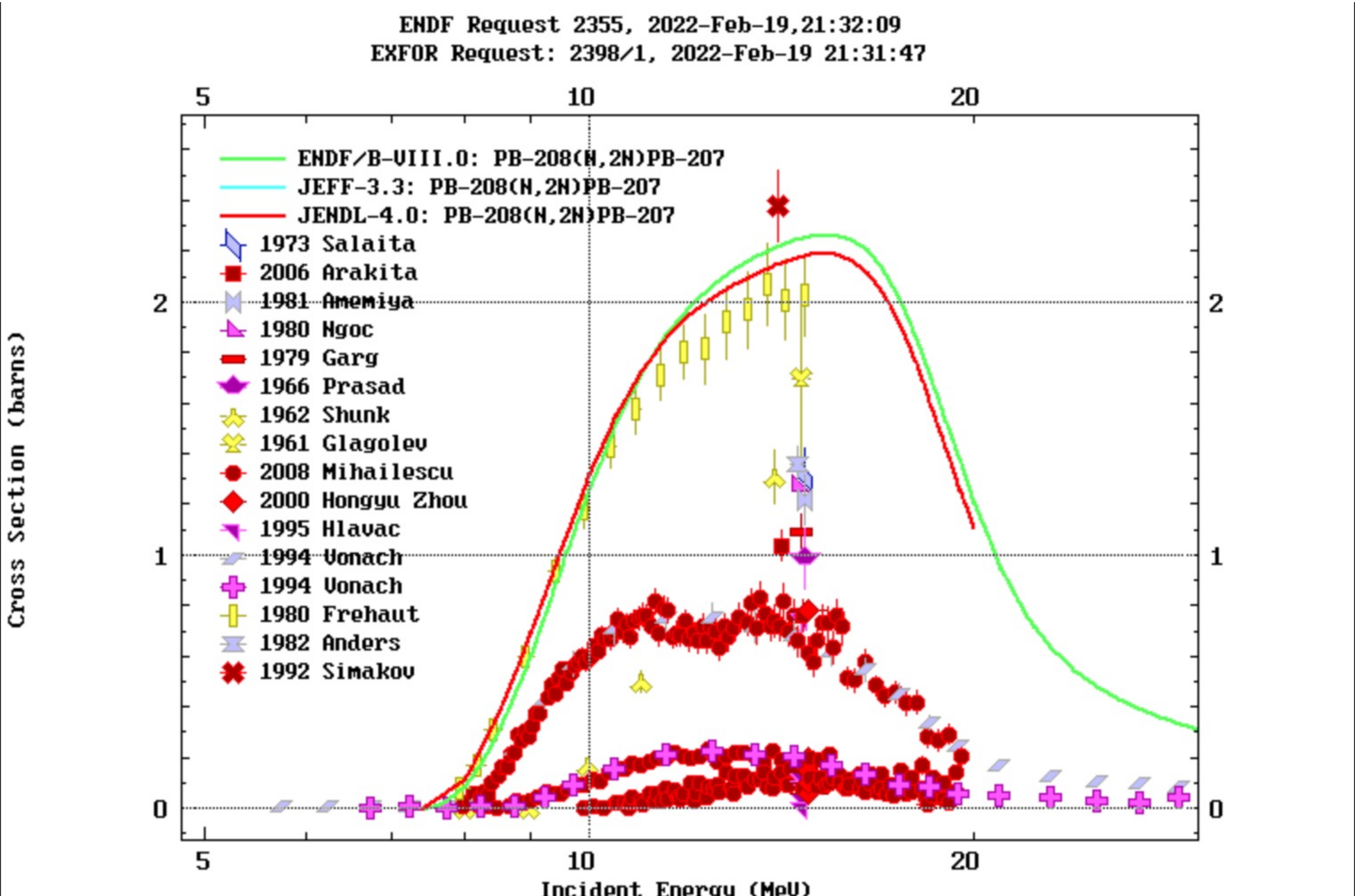
EXFOR Request: 2396/1, 2022-Feb-19 21:13:04
ENDF/B-VIII.0: AM-241(N,G)AM-242
JEFF-3.3: AM-241(N,G)AM-242
JENDL-4.0: AM-241(N,G)AM-242
Cross Section (barns)
Incident Energy (MeV)
5*10^-8
10^-7
5*10^-7
10^-6
5*10^-6
10^-5
8000
6000
4000
2000



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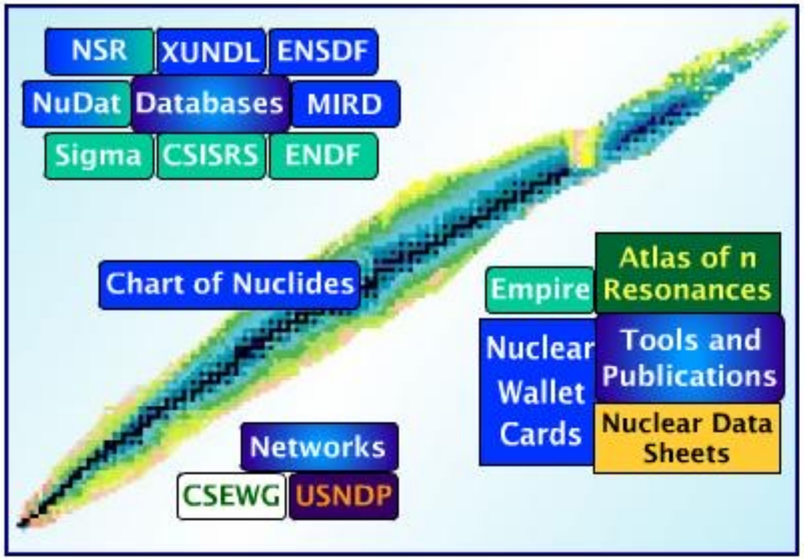
EXFOR Request: 2398/1, 2022-Feb-19 21:31:47
ENDF/B-VIII.0: PB-208(N,2N)PB-207
JEFF-3.3: PB-208(N,2N)PB-207
JENDL-4.0: PB-208(N,2N)PB-207
1973 Salaita
2006 Arakita
1981 Amemiya
1980 Ngoc
1979 Garg
1966 Prasad
1962 Shunk
1961 Glagolev
2008 Mihailescu
2000 Hongyu Zhou
1995 Hlavac
1994 Vonach
1994 Vonach
1980 Frehaut
1982 Anders
1992 Simakov
Cross Section (barns)
Incident Energy (MeV)
5
10
20
0
1
2

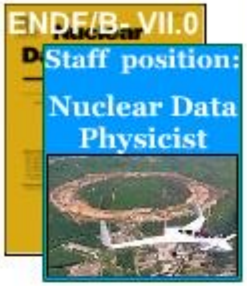


National Nuclear Data Center

NNDC

BROOKHAVEN NATIONAL LABORATORY

- Nuclear Structure and Decay Databases
- Nuclear Structure and Decay Tools
- Nuclear Reaction Databases
- Nuclear Reaction Tools
- Bibliography Databases
- Networks and Links
- About the Center
- Publications
- Meetings



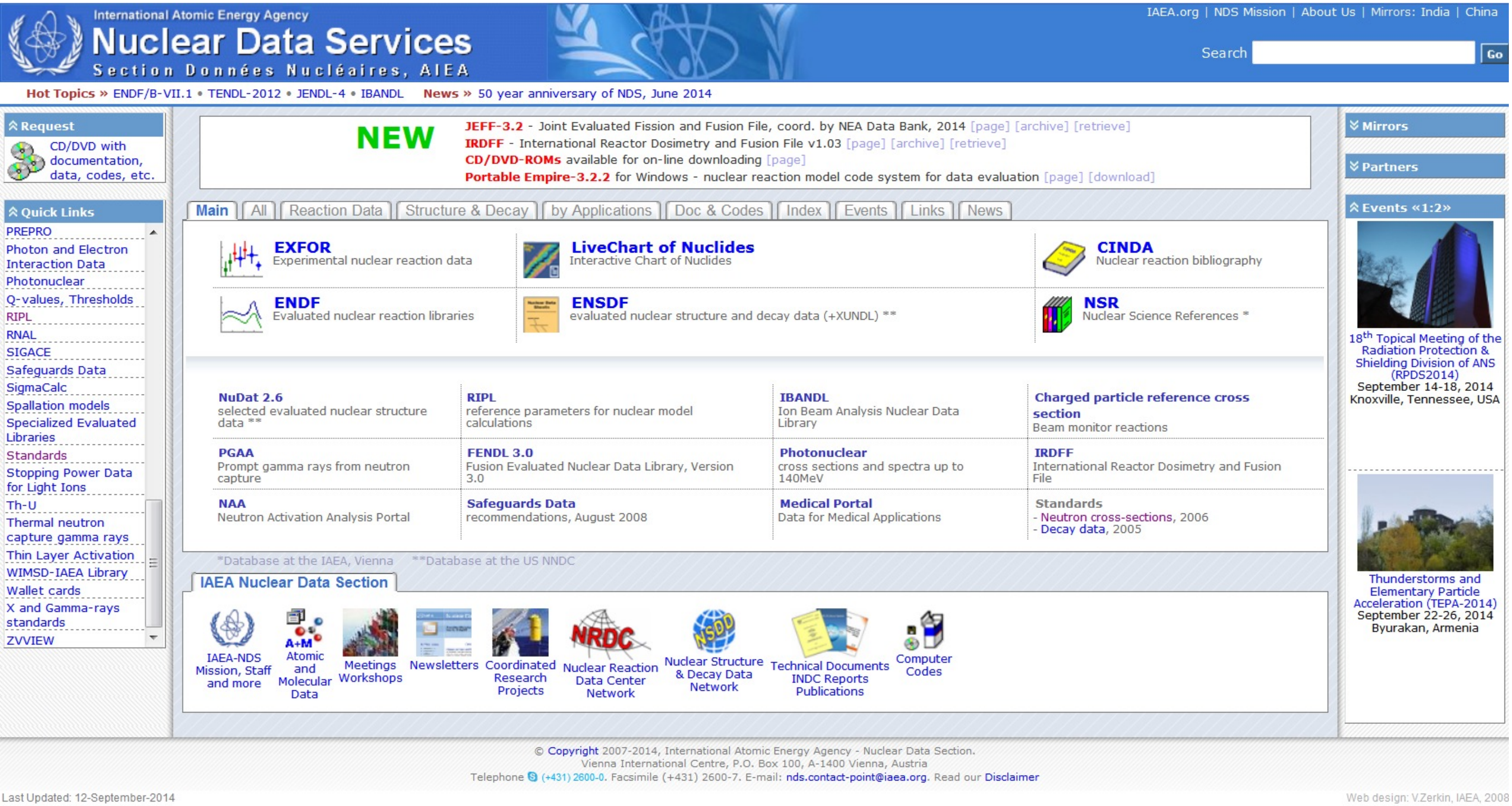
Low-Fidelity Covariances New ENDF Checking Codes

Site Index - Search the NNDC: Go

AMDC Atomic Mass Data Center, *Q-value Calculator*	**Atlas of Neutron Resonances** Parameters & thermal values	**CapGam** Thermal Neutron Capture γ-rays	**Chart of Nuclides** Basic properties of atomic nuclei
CINDA Computer Index of Nuclear (reaction) Data	**CSEWG** Cross Section Evaluation Working Group	**CSISRS alias EXFOR** Nuclear reaction experimental data	**Empire** Nuclear reaction model code system, *Reference paper*
ENDF Evaluated Nuclear (reaction) Data File, *Sigma*	**ENSDF** Evaluated Nuclear Structure Data File	**IRDF** International Reactor Dosimetry File	**MIRD** Medical Internal Radiation Dose
NMMSS & DoE NMIRDC Safeguards & inventory decay data standards	**NSR** Nuclear Science References	**Nuclear Data Sheets** Nuclear structure & decay data journal, *Special Issues on reaction data*	**Nuclear Wallet Cards** Ground & isomeric states properties, *Homeland Security version*
NucRates MACS & Astro-physical reaction rates	**NuDat** Nuclear structure & decay Data	**USNDP** U.S. Nuclear Data Program	**XUNDL** Experimental Un-evaluated Nuclear Data List

Sponsored by the Offic https://www.nndc.bnl.gov/ S. Department of Energy

Acknowledgments - Comments/Questions - Disclaimer



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

NEA NUCLEAR ENERGY AGENCY

ABOUT US TOPICS NEWS AND RESOURCES LEARNING AND TOOLS DATA BANK

Nuclear Data Services

Developing, compiling, testing and disseminating nuclear data and tools

Evaluated files Search ENDF-6 | Experimental entries Search EXFOR | Bibliographical entries Search CINDA

The **Joint Evaluated Fission and Fusion** (JEFF) Nuclear Data Library is a collaboration between NEA Data Bank participating countries. The JEFF library combines the efforts of its different Working Groups to produce sets of evaluated nuclear data, for fission and fusion applications.

» More information

Contact

For more information on Nuclear Data Services contact the NEA Data Bank Nuclear Data Service team

Last modified: 21 January 2022

https://www.oecd-nea.org/dbdata/

NEA Tools and Databases

- HPRL
- ICSBEP/DICE
- IRPHE/IDAT
- JANIS
- NDAST
- NDEC
- SFCOMPO
- SINBAD

Nuclear Data Links

- IAEA NDS (Vienna)
- NNDC (Brookhaven)
- NRDC

More info on

- Evaluated nuclear data
- Experimental nuclear data

Latest JEFF Libraries

- JEFF-3.3

Evaluated Releases

- BROND-3.1
- ENDF/B-VIII.0
- JEFF-3.3
- JENDL-4.0
- TENDL-2017
- Other Libraries (description)
- **Evaluated Archive**

2020 Events

- [Remote] 27-30 April - JEFF Meetings (Zoom)
- [Remote] 24-27 November - JEFF Meetings (Zoom)

2019 Events

Seminar by R. Capote on ***Dissemination of nuclear data***

Hands-on lecture on ***Nuclear data visualization tools***

The ENDF evaluated nuclear data format

ENDF (currently ENDF-6) was developed for the storage and retrieval of evaluated nuclear data to be used for applications of nuclear technology.

International cooperative effort: the ENDF formats and libraries are decided by the Cross Section Evaluation Working Group (CSEWG).

The ENDF system is logically divided into **formats** and **procedures**:

> **Formats** describe how the data are arranged in the libraries and give the formulas needed to reconstruct physical quantities such as cross sections, secondary particle distributions (energy, energy – angle)
>
> **Procedures** are restrictive rules that specify what data types must be included and which format can be used.

Each ENDF evaluation is identified by a set of key parameters organized into a hierarchy.

- Library **NLIB**, a collection of evaluations from a specific evaluation.
- Version **NVER**, updates to a library in ENDF format. The versions have a revision number.

NLIB	Library Definition
0	**ENDF/B** - United States Evaluated Nuclear Data File
1	**ENDF/A** - United States Evaluated Nuclear Data File
2	**JEFF** - NEA Joint Evaluated Fission and Fusion File (formerly JEF)
3	**EFF** - European Fusion File (now part of JEFF)
4	**ENDF/B** High Energy File
5	**CENDL** - China Evaluated Nuclear Data Library
6	**JENDL** - Japan Evaluated Nuclear Data Library
17	**TENDL** - TALYS Evaluated Nuclear Data Library
18	**ROSFOND** - Russian evaluated neutron data library
21	**SG-23** - Fission product library of the Working Party on Evaluation Cooperation Subgroup-23 (WPEC-SG23)
31	**INDL/V** - IAEA Evaluated Neutron Data Library
32	**INDL/A** - IAEA Nuclear Data Activation Library
33	**FENDL** - IAEA Fusion Evaluated Nuclear Data Library
34	**IRDF** - IAEA International Reactor Dosimetry File
35	**BROND** - Russian Evaluated Nuclear Data File (IAEA version)
36	**INGDB-90** - Geophysics Data
37	**FENDL/A** - FENDL activation evaluations
41	**BROND** - Russian Evaluated Nuclear Data File (original version)

Sublibrary **NSUB**. Set of evaluations for a particular data type.

NSUB = 10***IPART**+ITYPE with **IPART**=1000*Z+A

NSUB	IPART	ITYPE	Sub-library Names
0	0	0	Photo-Nuclear Data
1	0	1	Photo-Induced Fission Product Yields
3	0	3	Photo-Atomic Interaction Data
4	0	4	Radioactive Decay Data
5	0	5	Spontaneous Fission Product Yields
6	0	6	Atomic Relaxation Data
10	1	0	Incident-Neutron Data
11	1	1	Neutron-Induced Fission Product Yields
12	1	2	Thermal Neutron Scattering Data
19	1	9	Neutron Standards Data
113	11	3	Electro-Atomic Interaction Data
10010	1001	0	Incident-Proton Data
10011	1001	1	Proton-Induced Fission Product Yields
10020	1002	0	Incident-Deuteron Data
10030	1003	0	Incident-Triton Data
20030	2003	0	Incident-Helion (^{3}He) Data
20040	2004	0	Incident-Alpha data

Material **MAT**. The target (isotope or a collection of isotopes) in a reaction sub-library, or the radioactive (parent) nuclide in a decay sub-library:

Z01-Z99 for materials from Z=1 to 99 (special numbers for Z >= 100)

Z00 for natural elements

File **MF** subdivision of a material (**MAT**); each file contains data for a certain class of information. MF runs from 1 to 99.

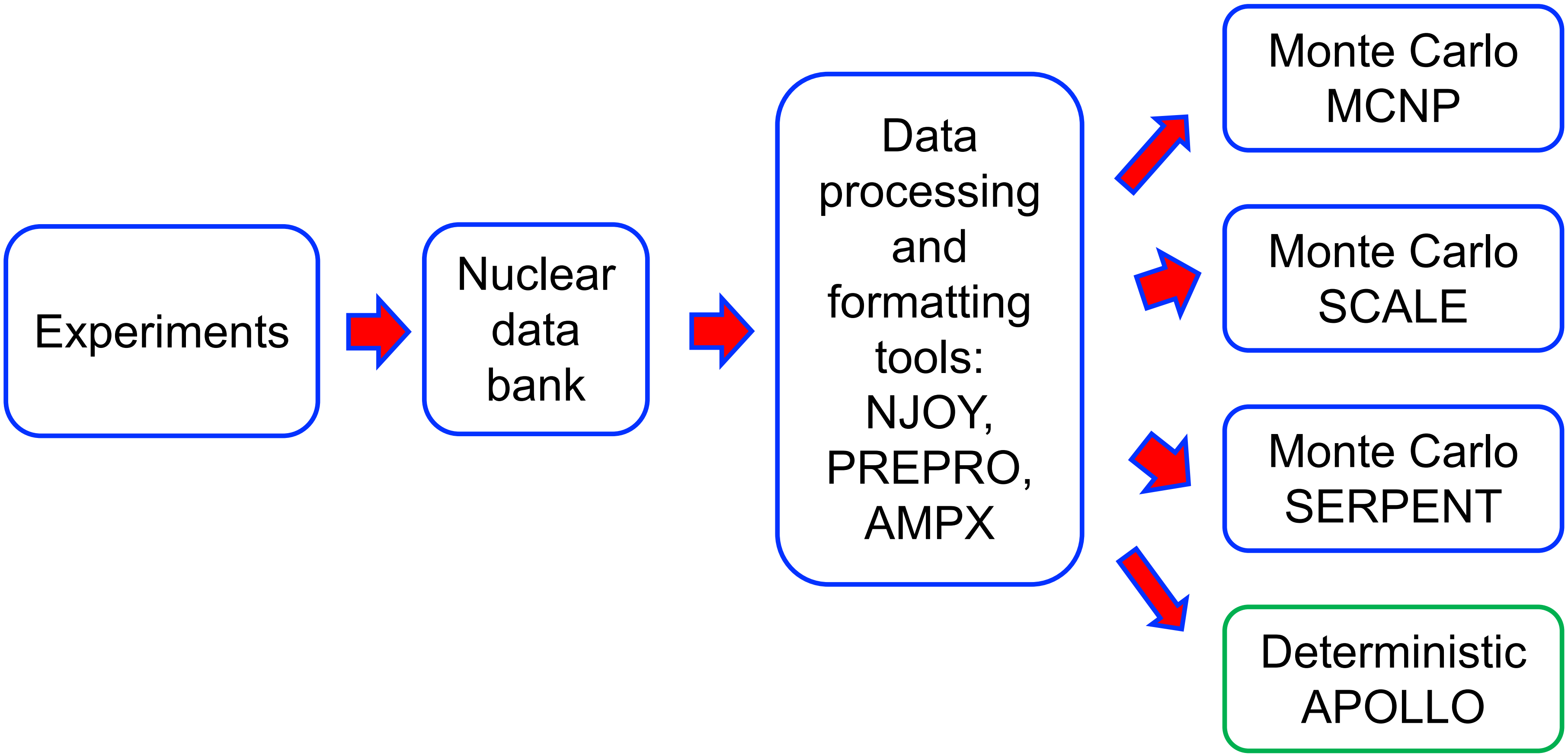
MF	Description
1	General information
2	Resonance parameter data
3	Reaction cross sections
4	Angular distributions for emitted particles
5	Energy distributions for emitted particles
6	Energy-angle distributions for emitted particles
7	Thermal neutron scattering law data
8	Radioactivity and fission-product yield data
9	Multiplicities for radioactive nuclide production
10	Cross sections for radioactive nuclide production
12	Multiplicities for photon production
13	Cross sections for photon production
14	Angular distributions for photon production
15	Energy distributions for photon production
23	Photo- or electro-atomic interaction cross sections

Section **MT** subdivision of a file (**MF**) ; each section describes a particular reaction or a particular type of auxiliary data. MT runs from 1 to 999.

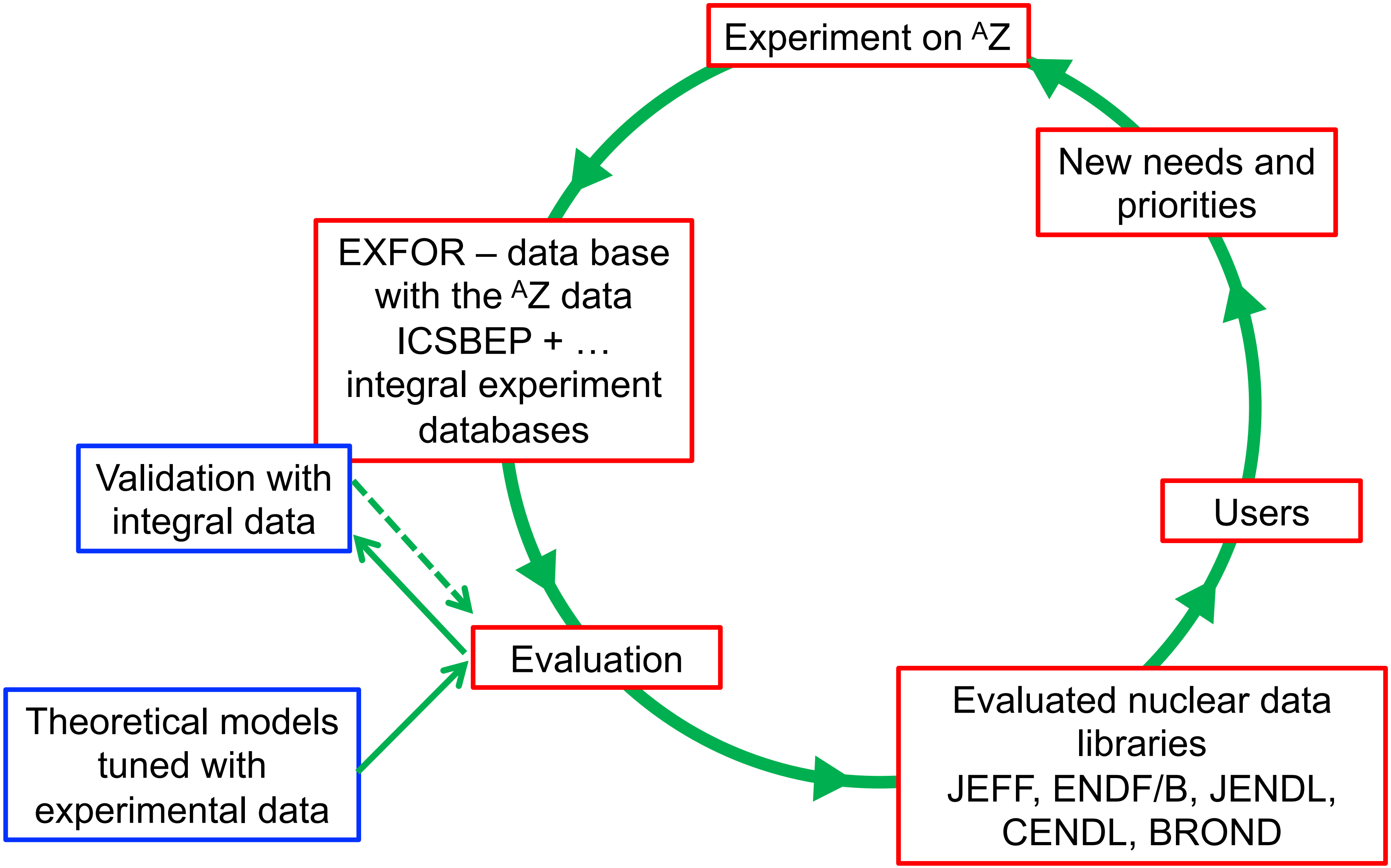
Examples for incident neutrons (could be any incident particle)

MT	Reaction	Description
1	(n,total)	Total cross section
2	(z,z0)	Elastic cross section
4	(z,n)	Inelastic cross section (1st excited state + 2nd excited state…)
16	(z,2n)	Production of 2 neutrons and a residual
18	(z,f)	Neutron induced fission
102	(z,γ)	Radiative capture
107	(z,α)	Neutron induced alpha emission

The nuclear data path



The nuclear data cycle



ENJOY the school!