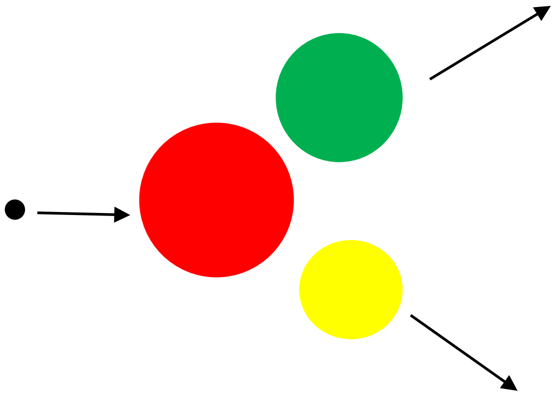
IAEA
International Atomic Energy Agency
Atoms for Peace and Development

Nuclear Reaction Databases

Paraskevi (Vivian) Dimitriou
Nuclear Data Section,
International Atomic Energy Agency,
Vienna, Austria

Nuclear reaction



$$a + A \rightarrow b + B$$

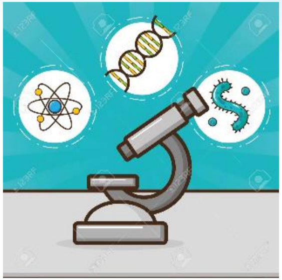
$$A(a,b)B$$

Q-value = masses (before) – masses (after)

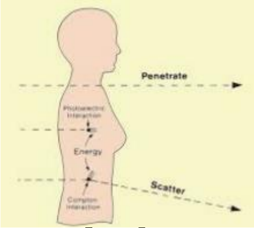
$$= M_a + M_A - M_B - M_b$$

Q-value > 0 : exothermic
Q-value < 0 : endothermic
Q = 0 : elastic scattering

Why do we study nuclear reactions?



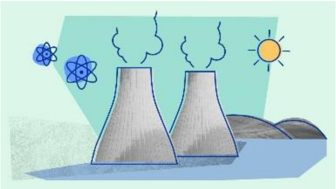
- Probe to nuclear structure properties of the nucleus

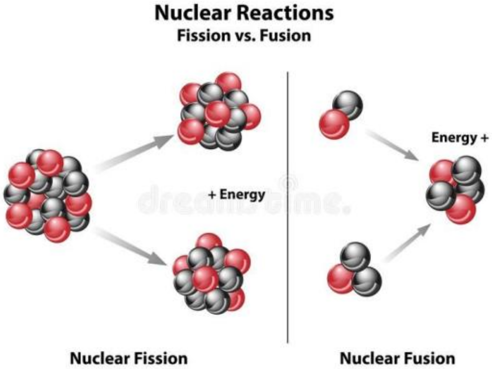


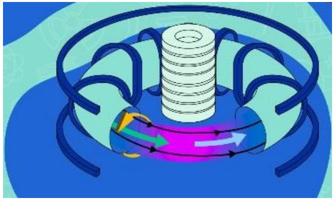
- Interaction of particles and radiation with matter
  - Inventories of particles and nuclei
  - Radiation transport

Nuclear fission and fusion

- Production of energy – safety and security (decay heat, waste management)



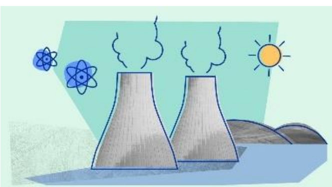




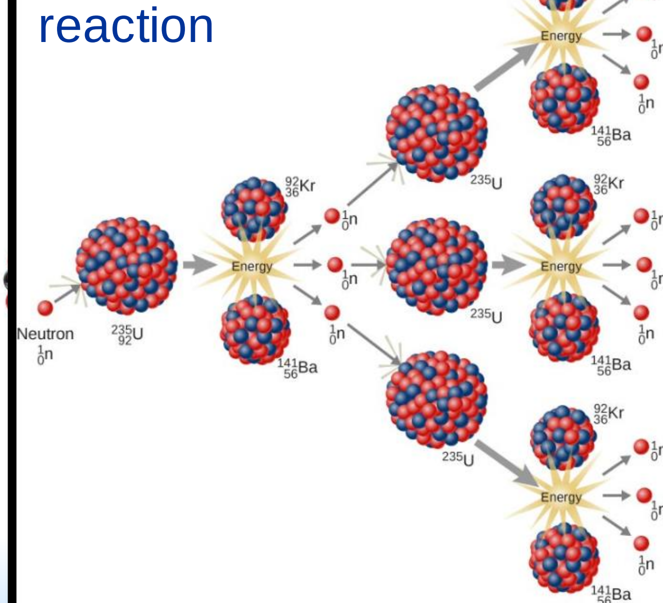
Images from web - IAEA

Chain reactions – nuclear inventories

- Production of energy – safety and security (decay heat, waste management)

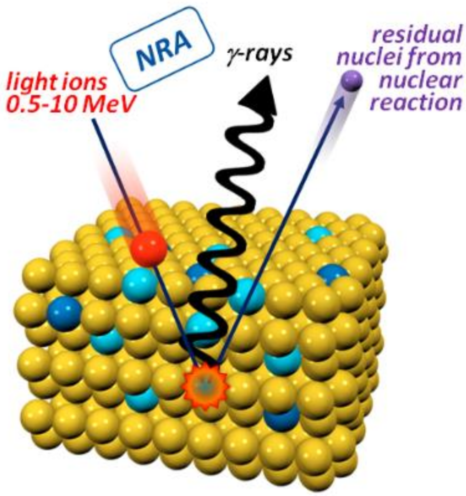


Fission chain reaction



Images from web - IAEA

Materials analysis



Ion Beam Analytical Techniques

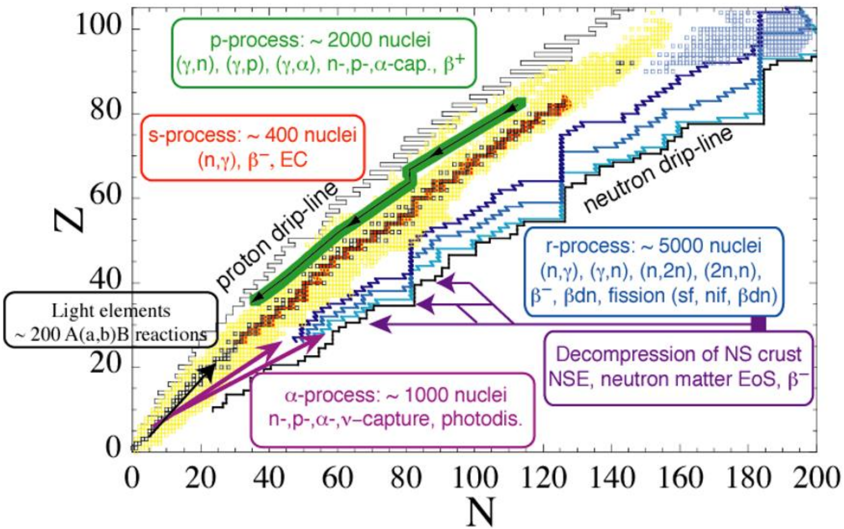
Surface composition

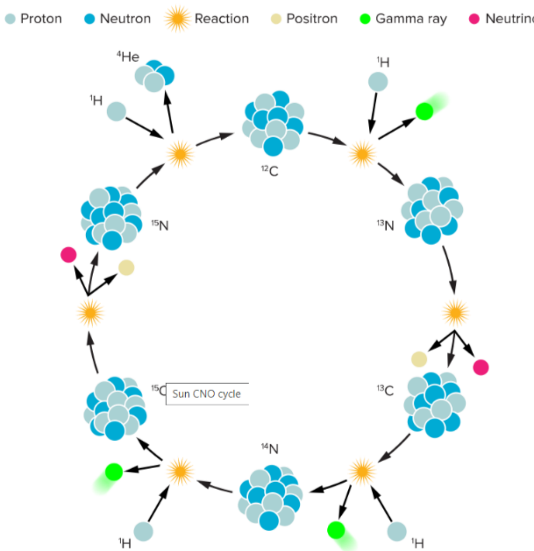
$$Y_\gamma(E_0,\theta) = \varepsilon_{\mathrm{abs}}(E_\gamma)\cdot N_p \cdot \int_0^{E_0} N_T \cdot \sigma(E_0,\theta)/S(E)\,\mathrm{d}E$$

Images from web - HZDR

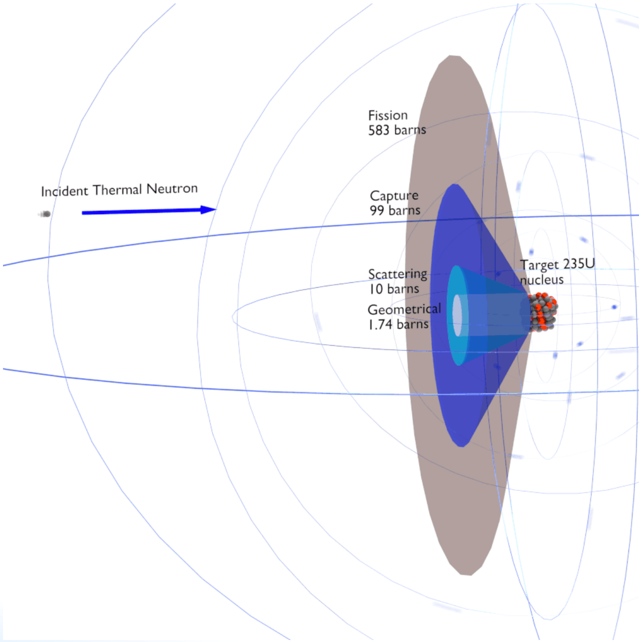
Nuclear reactions are the fuel of the stars

- Stellar Nucleosynthesis





Cross section σ



- Probability of a projectile to ‘hit’ a target nucleus and interact with it (scatter, break up, transfer a particle etc)
- Formal definition (Fermi Golden Rule)

$$\text{Probability} = n \cdot x \cdot \sigma$$

n = # nuclei per volume;

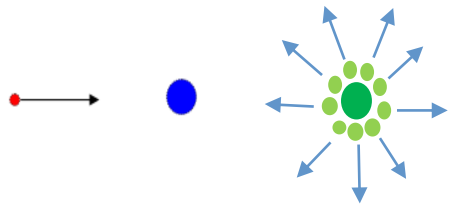
x = thickness;

σ = effective area of nucleus for reaction

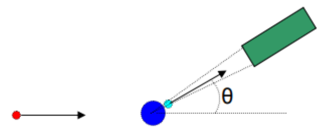
- σ (units = 10^{-24} cm^2 or 1 barn) – in nuclear physics mb (10^{-3} b) or μb (10^{-6} b)

Cross sections $\sigma(\theta)$, $\sigma(E,\theta)$

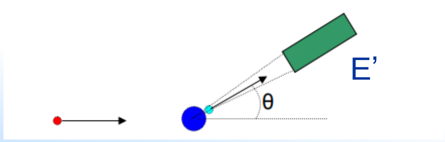
- Total cross sections σ_T (in 4π)



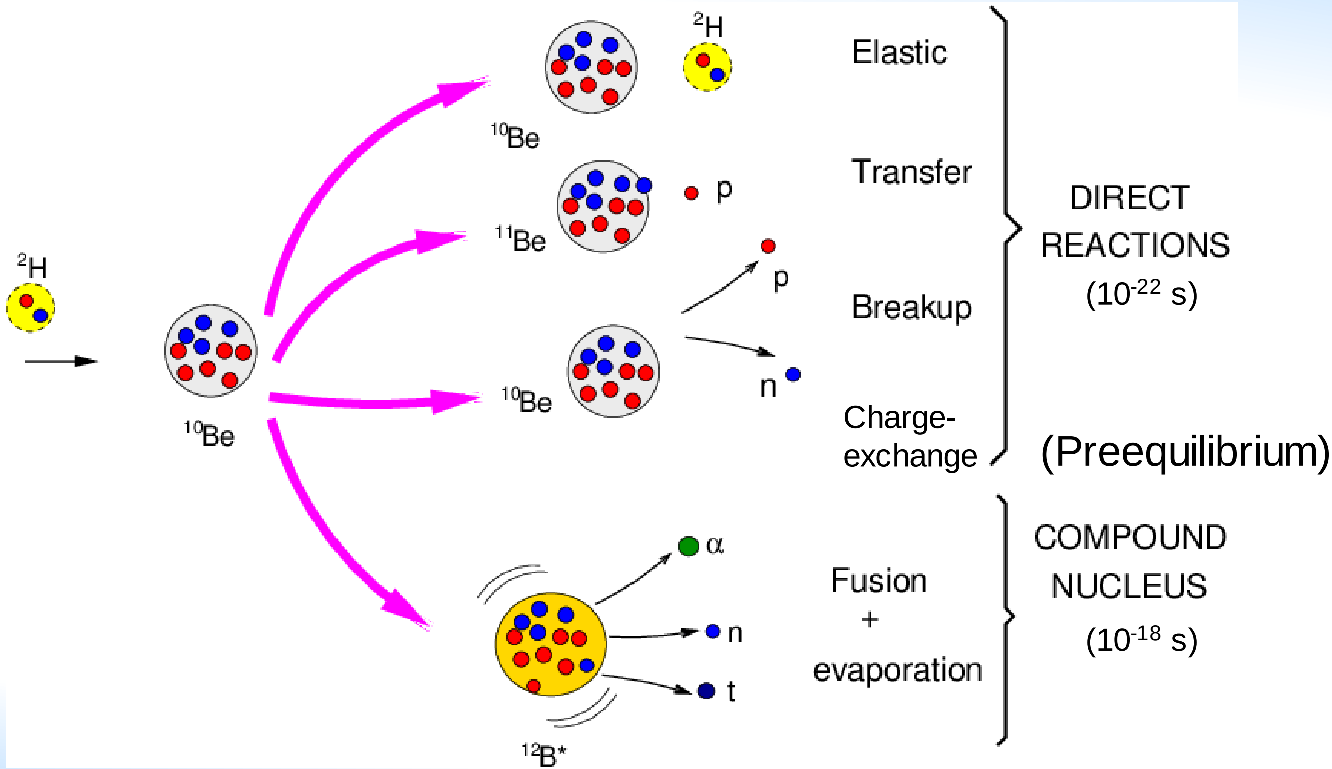
- Angular distribution $d\sigma/d\Omega$ (in $d\Omega$)



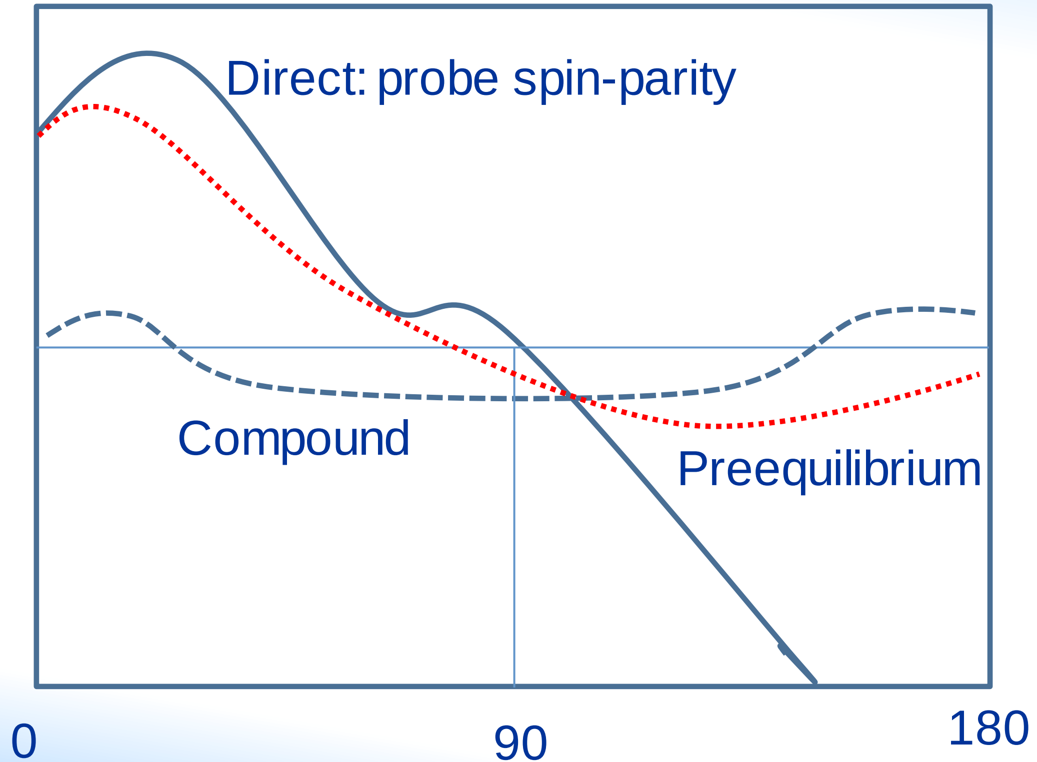
- Double-differential cross sections $d^2\sigma/dEd\Omega$ (emission spectrum: in $d\Omega$ with E’)



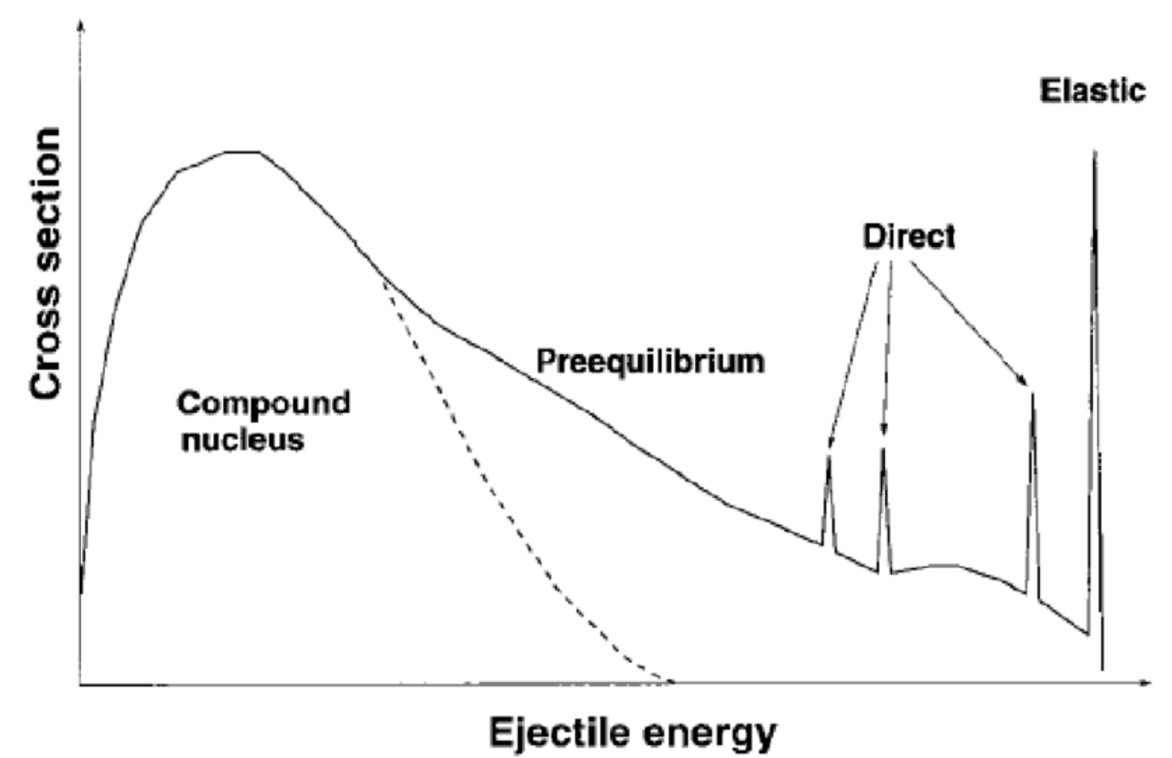
Reaction types



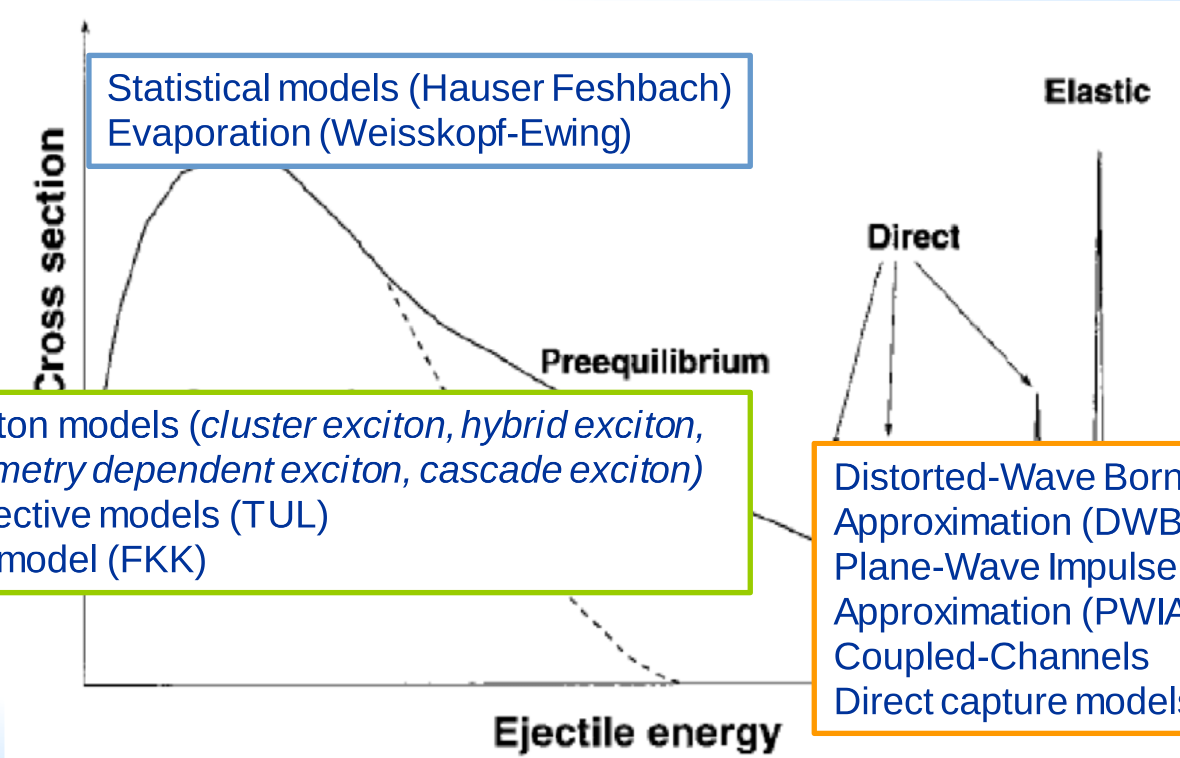
Angular distributions dσ/dΩ



Reaction Mechanisms



Reaction Models



Statistical models (Hauser Feshbach)
Evaporation (Weisskopf-Ewing)

Exciton models (*cluster exciton, hybrid exciton, geometry dependent exciton, cascade exciton)*
Collective models (TUL)
QM model (FKK)

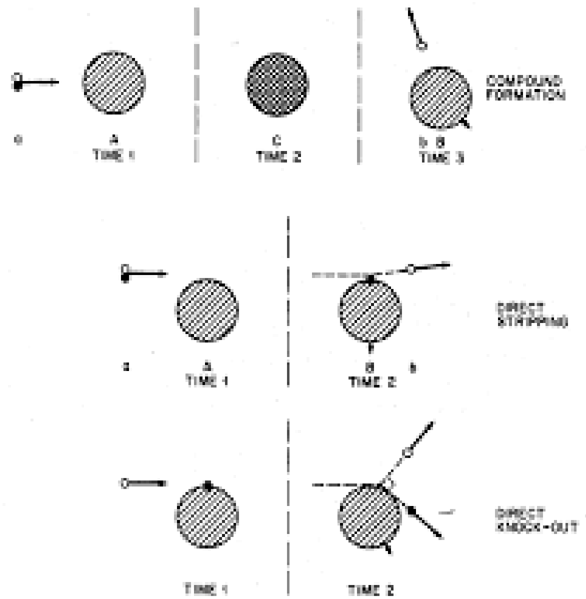
Distorted-Wave Born Approximation (DWBA)
Plane-Wave Impulse Approximation (PWIA)-HE
Coupled-Channels
Direct capture models

Cross section calculations

- Depending on incident energy more than one reaction mechanism may contribute
- Use different models to describe reaction mechanisms
- Models make use of parameters that have to be adjusted to experimental cross-section data
- Independent experimental information can be used to constrain the parameters

Direct reactions

- Inelastic scattering, transfer, knockout, breakup
- Only a few nucleons involved
- Periphery – forward angles
- Mainly one-step processes
- Selective – initial and final states connected by transferred angular momentum $l = \ell_\alpha - \ell_\beta$; parity conservation



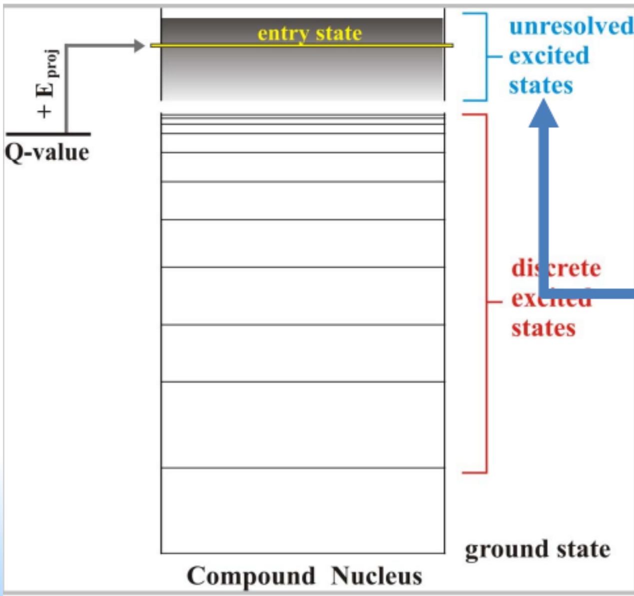
Spectroscopic factors: how much the wavefunction of a given state can be described by a single-particle motion within the nucleus

$$\left(\frac{d\sigma}{d\Omega}\right)_{\exp} = S_{(l_{Ax} j_{Ax})_{J_B}} \left(\frac{d\sigma}{d\Omega}\right)_{\mathrm{cal}}$$

Compound nucleus reactions

- Statistical model: excitation to energies where excited states are overlapping

$$\alpha + A \rightarrow C^* \rightarrow b + B \qquad \sigma_{bB} = \frac{\pi\lambda^2}{(2J_\alpha+1)\,(2J_A+1)} \sum_{J^\pi} (2J_C+1)\, T_{\alpha A}^{J^\pi} \frac{T_{bB}^{J^\pi}}{\sum_i T_i^{J^\pi}}$$



probability that **α** will cross the surface of **A** to form a compound state of **C** having spin ***J***

probability that **b** escapes from a state of the compound nucleus **C** with spin ***J***

: sum of probabilities over all exit channels ***i***

T's averaged over Nuclear Level Densities

$$\bar{T}_{\alpha A} = \sum_I \int \rho(E_\alpha, I)\, T_{\alpha A}^I(E_\alpha)\, dE_\alpha$$

Ingredients of HF cross sections

- Particle entrance/exit channels: $a + A$
  transmission coefficients T_{aA} are obtained by solving scattering of projectile a off target A using an Optical Model Potential (OMP):
  $U = V_c + V + i \cdot W$ (T's are related to scatt. amplitudes)

- Photon exit channel: $\gamma + A$
  transmission coefficient $T_{\gamma A}$ is obtained from Giant Resonances Strength Function (γSF) assuming E1/M1 transitions are important

- For excitations to phase space where levels are strongly overlapping and un-resolved: Nuclear Level Density (NLD) formulas are used to describe number of states per E and J

- Ground-state properties: masses, deformations, density distributions, single-particle level schemes are obtained from nuclear models

Ingredients of HF cross sections

Fission (n,f): compound nucleus formation

- Hill-Wheeler WKB form for T_f

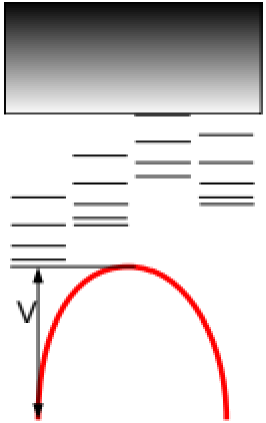
$$T_i(E) = \frac{1}{1 + \exp\left(2\pi \frac{V_i + E - E_0)}{\hbar\omega_i}\right)}, \qquad i = A, B,$$

Fission Barriers

- fission barrier height V_i, curvature $(\hbar\omega)_i$, for $i = 1, 2,$ and 3
- transition state parameters, band head energy, K^π, inertia $\hbar^2/2I$

Level Density

- normal level densities calculated internally
- tweaking parameters
  - level density parameter multiplier $(a \times c)$
  - fission level density scaling $(\rho_f \times c)$



Reference Input Parameter Library (RIPL)

- Produced by series of IAEA CRPs
- Recommends models and data for ingredients of direct, preequilibrium and compound nucleus reaction cross-section calculations
- Adopted by widely used reaction codes: Empire, TALYS, CCONE, COH2, etc.

Reference Input Parameter Library

IAEA

photon strength function models (Lorentzian, QRPA models)

Fission barriers, saddle-point level densities

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

Reference Input Parameter Library (RIPL-3)

R. Capote, M. Herman, P. Oblozinsky, P.G. Young, S. Goriely, T. Belgya, A.V. Ignatyuk, A.J. Koning, S. Hilaire, V.A. Plujko, M. Avrigeanu, O. Bersillon, M.B. Chadwick, T. Fukahori, Zhigang Ge, Yinlu Han, S. Kailas, J. Kopecky, V.M. Maslov, G. Reffo, M. Sin, E.Sh. Soukhovitskii and P. Talou

Nuclear Data Sheets - Volume 110, Issue 12, December 2009, Pages 3107-3214

Nuclear Data Sheets

RIPL discrete levels database updated in **September 2020** - it contains the correction for +X,.. levels

Introduction | MASSES | LEVELS | RESONANCES | OPTICAL | DENSITIES | GAMMA | FISSION | CODES | Contacts

Introduction

We describe the physics and data included in the Reference Input Parameter Library, which is devoted to input parameters needed in calculations of nuclear reactions and nuclear data evaluations. Advanced modelling codes require substantial numerical input, therefore the International Atomic Energy Agency (IAEA) has worked extensively since 1993 on a library of validated nuclear-model input parameters, referred to as the Reference Input Parameter Library (RIPL). A final RIPL coordinated research project (RIPL-3) was brought to a successful conclusion in December 2008, after 15 years of challenging work carried out through three consecutive IAEA projects. The RIPL-3 library was released in January 2009, and is available on the Web through *http://www-nds.iaea.org/RIPL-3/*. This work and the resulting database are extremely important to theoreticians involved in the development and use of nuclear reaction modelling (ALICE, EMPIRE, GNASH, UNF, TALYS) both for theoretical research and nuclear data evaluations.

The numerical data and computer codes included in RIPL-3 are arranged in seven segments: **MASSES** contains ground-state properties of nuclei for about 9000 nuclei, including three theoretical predictions of masses and the evaluated experimental masses of Audi *et al.* (2003). **DISCRETE LEVELS** contains 118 datasets (Z from 0 to 117) with all known level schemes, electromagnetic and γ-ray decay probabilities available from ENSDF in April 2014. **NEUTRON RESONANCES** contains average resonance parameters prepared on the basis of the evaluations performed by Ignatyuk and Mughabghab. **OPTICAL MODEL** contains 495 sets of phenomenological optical model parameters defined in a wide energy range. When there are insufficient experimental data, the evaluator has to resort to either global parameterizations or microscopic approaches. Radial density distributions to be used as input for microscopic calculations are stored in the MASSES segment. **LEVEL DENSITIES** contains phenomenological parameterizations based on the modified Fermi gas and superfluid models and microscopic calculations which are based on a realistic microscopic single-particle level scheme. Partial level densities formulae are also recommended. All tabulated total level densities are consistent with both the recommended average neutron resonance parameters and discrete levels. **GAMMA** contains parameters that quantify giant resonances, experimental gamma-ray strength functions and methods for calculating gamma emission in statistical model codes. The experimental GDR parameters are represented by Lorentzian fits to the photo-absorption cross sections for 102 nuclides ranging from ^{51}V to ^{239}Pu. **FISSION** includes global prescriptions for fission barriers and nuclear level densities at fission saddle points based on microscopic HFB calculations constrained by experimental fission cross sections.

masses, Qvlaues, etc AME, models

discrete levels and branchings (ENSDF)

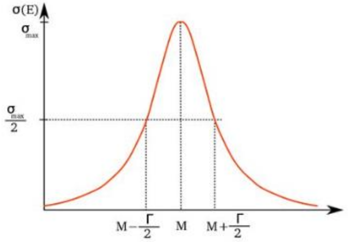
optical potentials (phenomenological, semi-microscopic, dispersive)

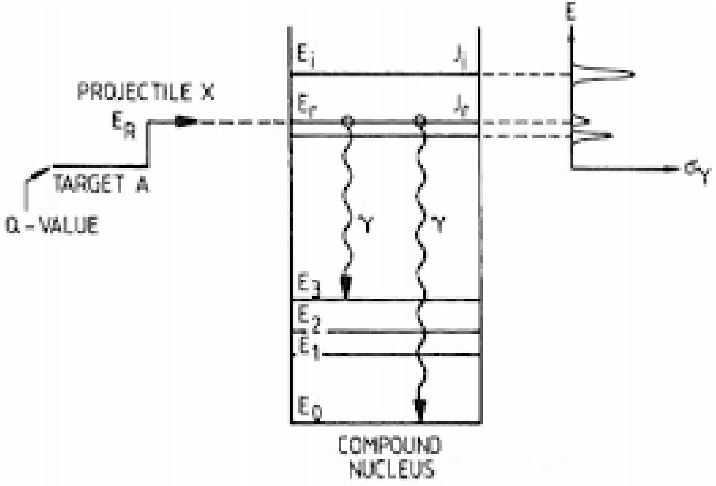
nuclear level density models, D0s, cumulative levels

Resonant reactions

Breit-Wigner formula

$$\sigma(J)=\frac{4\pi}{k^2}\frac{2J+1}{(2s_1+1)(2s_2+1)}\frac{\Gamma^2/4}{(E_R-E)^2+\Gamma^2/4}$$





R-matrix theory

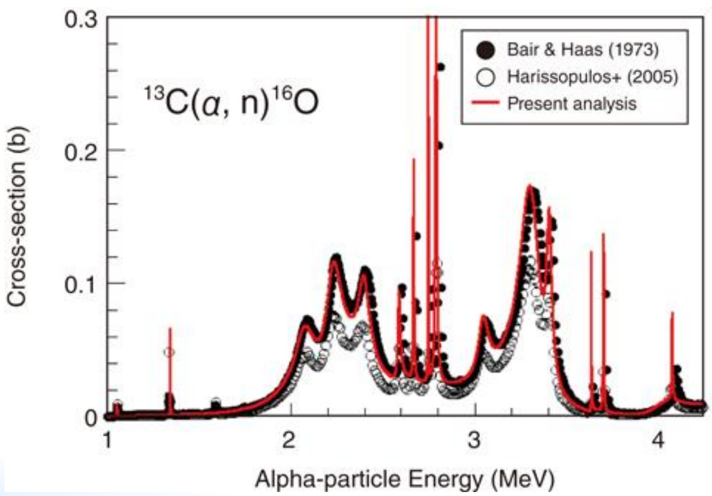
- The theory to describe individual resonances in A+B scattering, and the non-resonant background between them.

- Describes all the asymptotic properties of the A+B wave function outside some fixed radius, $R \geq a$, in terms of pole energies e_p and reduced width amplitudes γ_{np} for each channel n and pole p.
  - The γ_{np} are calculated from structure theory, or
  - or the γ_{np} are fitted to scattering data

$$R_{mn}(E) = \sum_{p=1}^{\infty} \frac{\gamma_{mp}\gamma_{np}}{E - e_p}$$

Use finite number of poles

E_R, Γ_R: initial values taken from ENSDF



Nuclear reaction codes

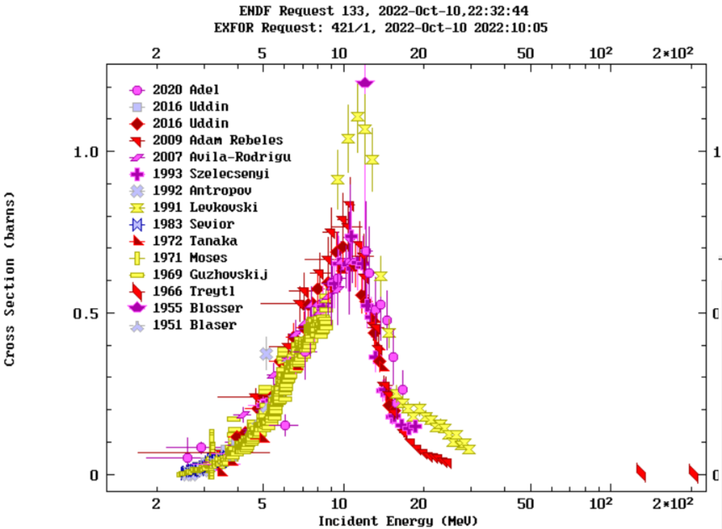
- R-matrix analysis codes (public)
  - AZURE2: https://azure.nd.edu/
  - SAMMY: RSICC (ORNL)
  - Other: EDA (LANL), CONRAD (CEA Cadarache), AMUR (JAEA), FRESCO (LLNL), RAC (Tsinghua), RFIT (GEEL)
- Nuclear reaction codes (public)
  - Empire: https://www-nds.iaea.org/empire

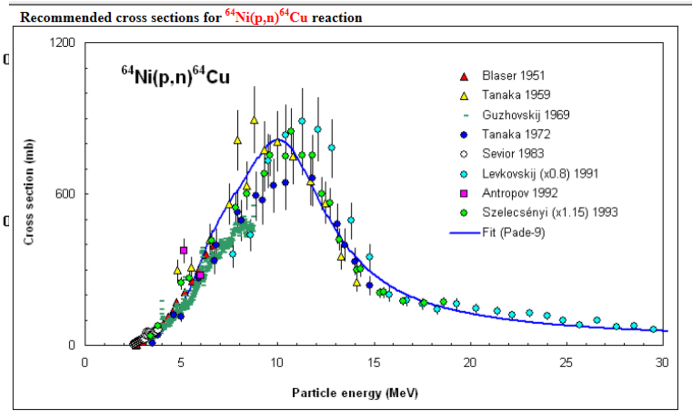
  - TALYS: https://www-nds.iaea.org/talys
- Direct reactions (transfer, inelastic, knockout, breakup)
  - FRESCO (Surrey, LLNL)

Nuclear reactions for applications

- Measured cross sections (total, ang. Distributions, double-differential cross sections
- Theoretical cross sections at any energy and angle
- Evaluated cross sections

Evaluation of nuclear cross sections





Evaluation methodology I

- Compile available exp. data for a specific incident particle on a target nucleus up to energy of interest – include all data in all open reaction channels (absolute cross sections, differential and double-differential, ratio cross sections, etc.)
- Assess exp. data: identify outliers; adopt final datasets
- Fit cross sections (total, angular distributions, partial cross sections) in open channels using suitable models
- *Correlation matrices (covariances) of parameters or cross sections*

Evaluation methodology II

- Compile available exp. data for a specific incident particle on a target nucleus up to energy of interest – include all data in all open reaction channels
- Assume a prior cross section (theory, previous evaluation)
- Fit experimental data using no model fit - Bayesian inference assuming known prior
- Include correlations in experimental data
- Produce recommended cross sections and covariances

Uncertainties

spread of the data

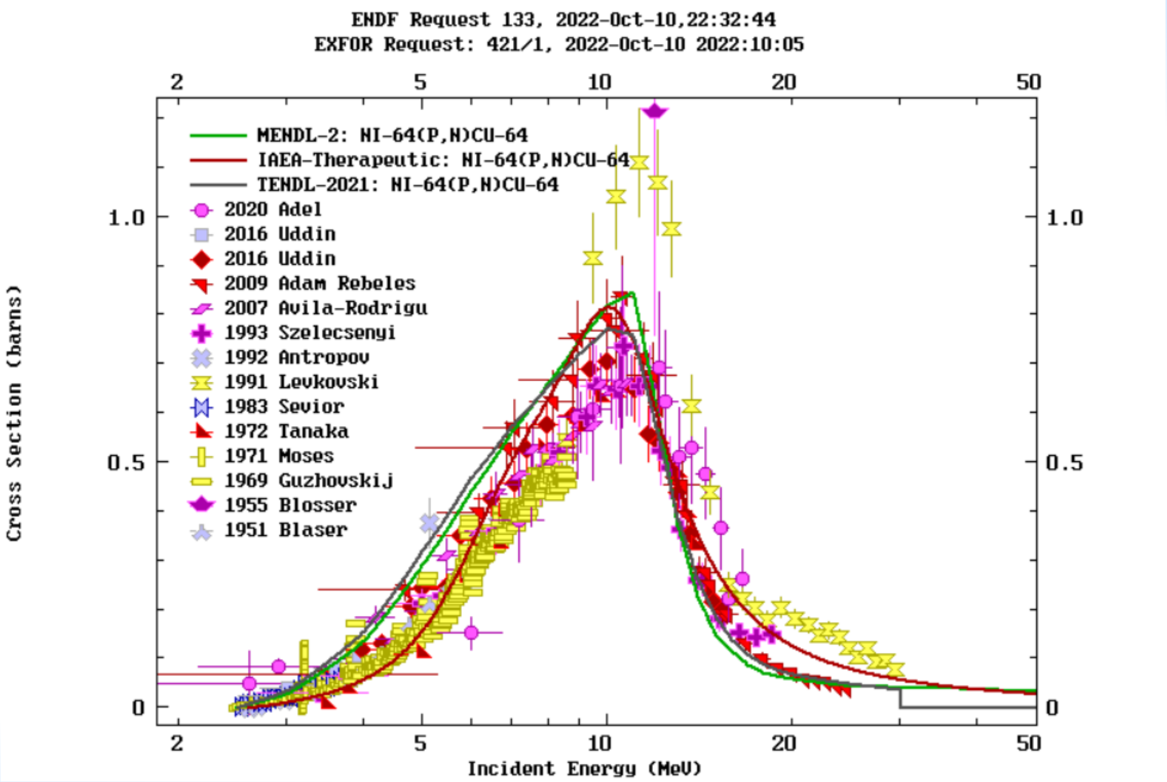
- Mean: $\mu = \frac{\sum x_i}{N}$
- Variance: $\sigma^2 = \frac{(x_1-\mu)^2 + \cdots + (x_N-\mu)^2}{N}$
- Standard deviation: $\sigma = \sqrt{\text{variance}} = \sqrt{\sigma^2}$
- Covariance: $cov(x,y) = \frac{\sum(x_i-\mu)(y_i-\nu)}{N-1}$

How two variables change together:
Positive
Negative

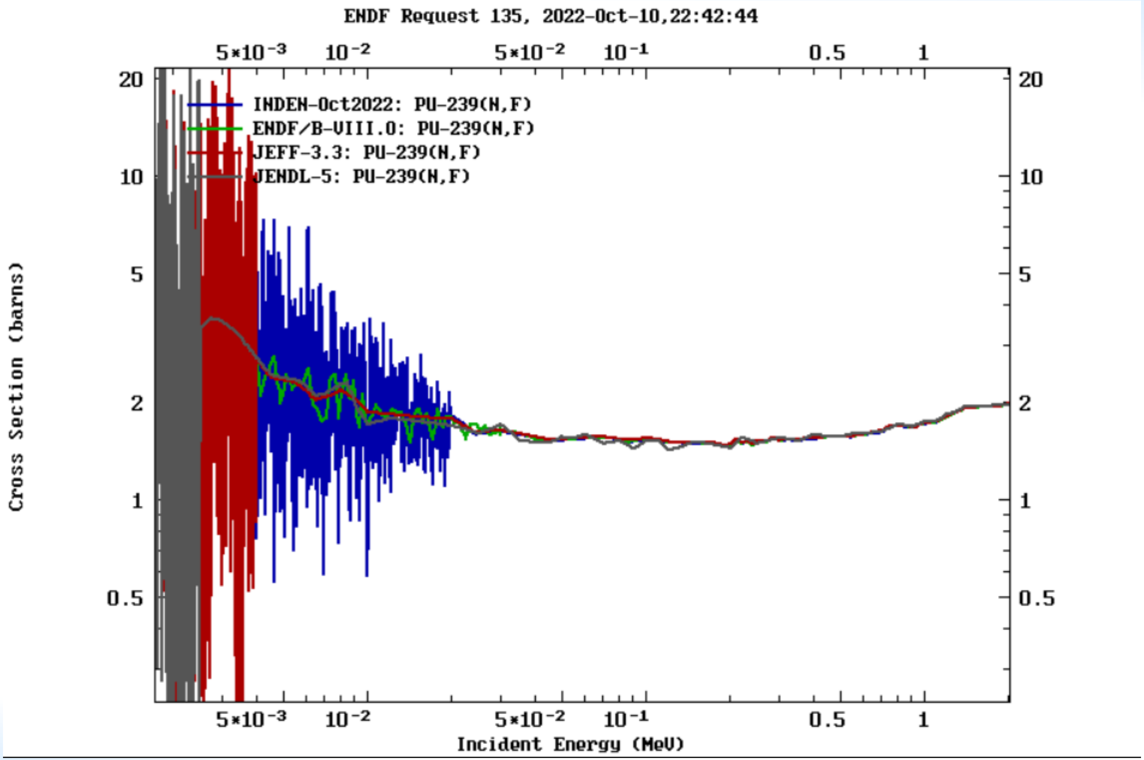
- Correlations: measure of the degree to which two variables move together :

  -1 to +1: 0 means they are not related

Different evaluations



Different evaluations cont'd



Databases

- **EXFOR: EXchange FORmat**

  contains experimental nuclear reaction data for incident neutrons, charged-particles and photons - 24,390 experiments

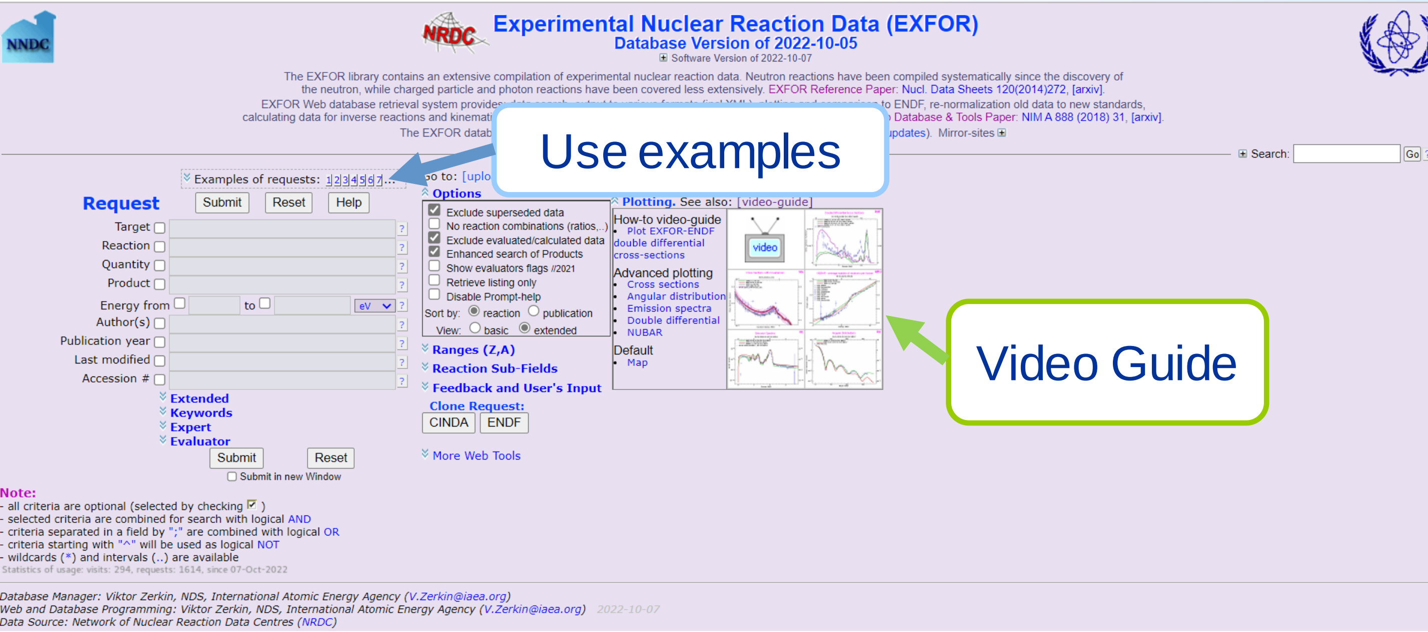
  – 1970: USA, NEA, IAEA, USSR agreed on format and established exchange between data centres
  – Nuclear Reaction Data Centres (NRDC): 13 data centres contribute ~ 500 entries per year
  – Central maintenance at IAEA – dissemination at IAEA, NNDC, and NEA
  – Distribution (EXFOR, X4+, C4, C5, XML, Html, plots): Web, CD/DVD ROM
  – Connection (import-export) to other databases: ENDF, CINDA, NSR

- **ENDF: Evaluated Nuclear Data File** is a collection of evaluated libraries

  – **ENDF-6**: format to store and exchange evaluated data
  – Fixed and well-defined, ("computer readable")
  – developed to be convenient for programming (Fortran)
  – The system offers "interpreted" and XML (GND) output formats
  – Contributors: *IAEA-NDS*, *WPEC*, *CSEWG*, *IPPE*, *CNDC*, *JAEA*, *NRG*, *CCFE*, *FZK*

EXFOR retrieval interface

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

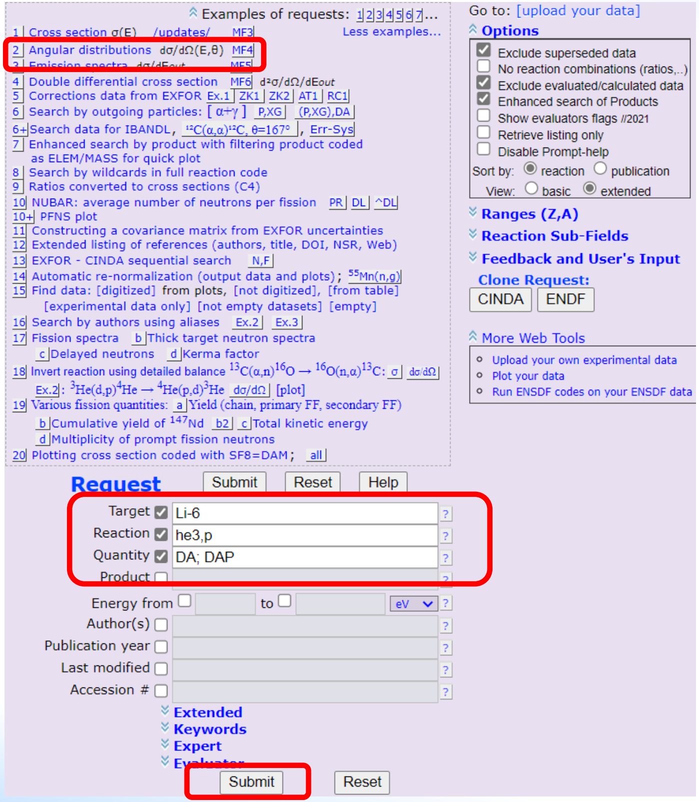


Use examples

Video Guide

Quick search: Examples, More examples

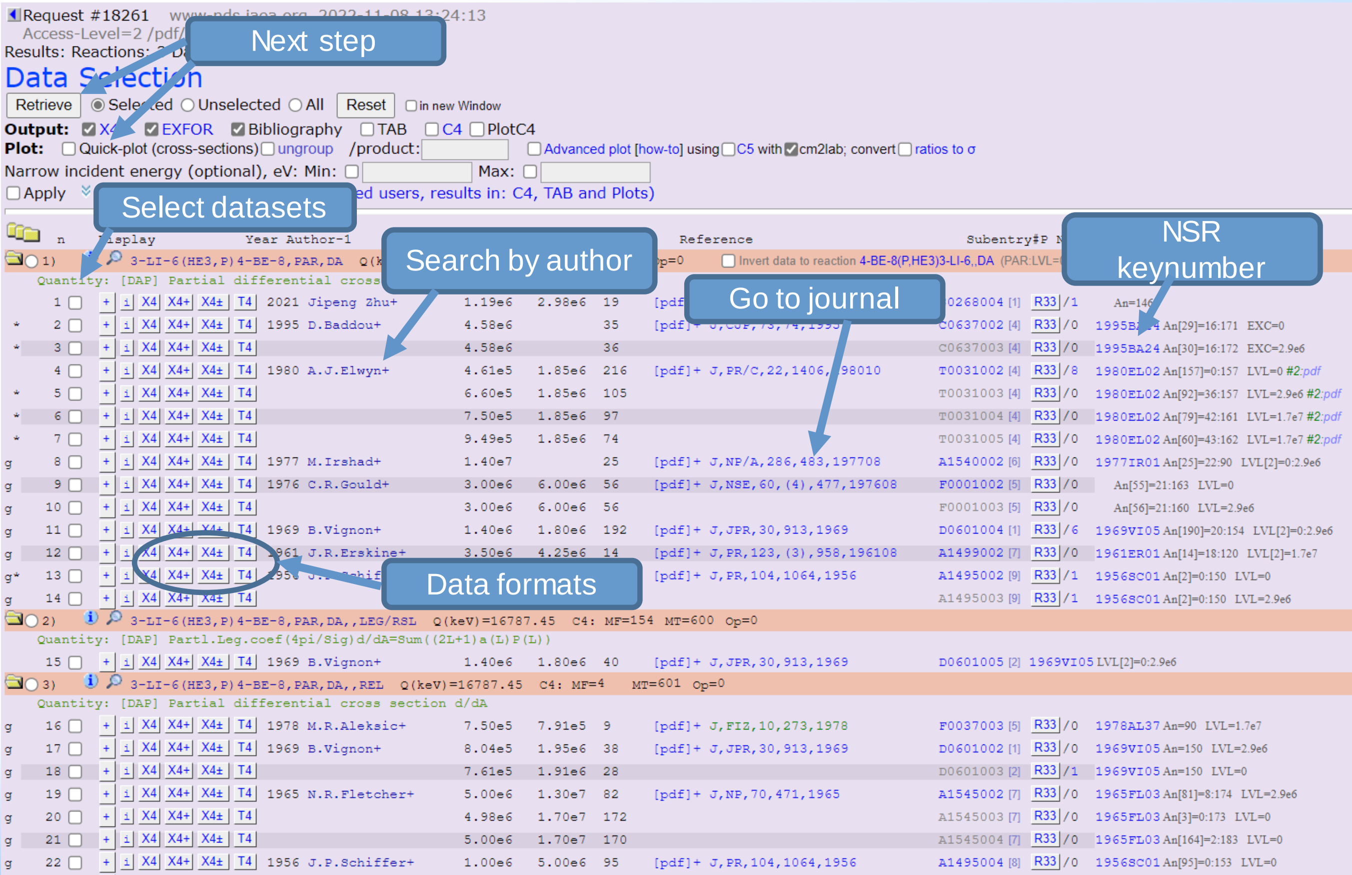
IAEA



- Examples of how to fill in the form

Data selection

IAEA



EXFOR plotting page

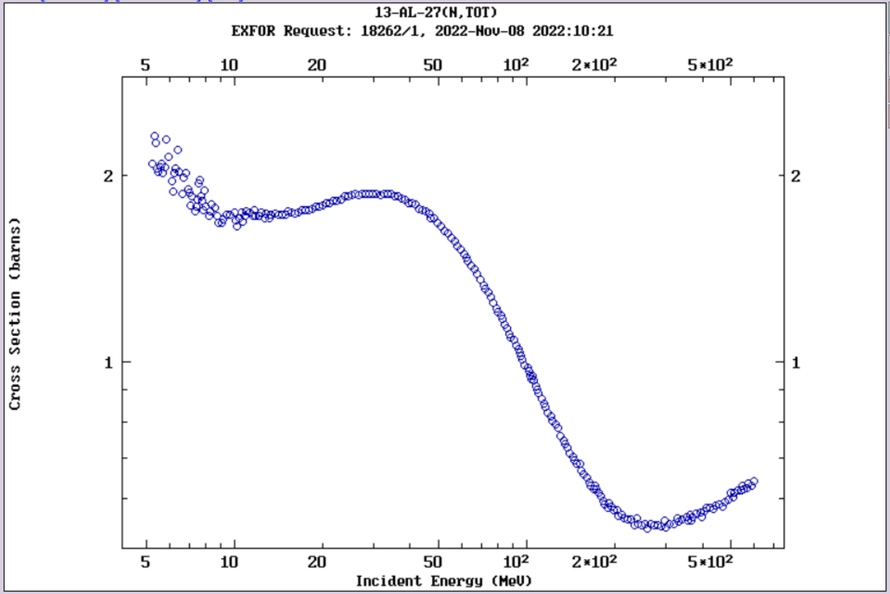
EXFOR Request #18262/630

Output Data

Format	*Data (Size)*
EXFOR Interpreted	X4+ (25Kb) Generate: X4± XML:: v1: X4.xml X4.html v2: X4.xml
EXFOR Output	X4out.std X4out.xml X4out.comp JSON,1,2::html JSON-FY new:x4z,x5z C5,A C5M:see:[doc]
EXFOR Original	EXFOR (41Kb) zip (8Kb)
Bibliography	html (3Kb) BibTeX (1Kb)

Output data formats

See: [selected] [unselected] [link] datasets



Similar search in ENDF

ENDF Find and add to the plot evaluated data.

- Select data for plotting [all] [none]
  - 1) 13-AL-27(N,TOT),,SIG
- 2) Use my data [example][2]
- Use my control file [init] [help]

See: plotted data (50Kb) out: e6 json:+ plotly2

Get plotted data in x,y format

Log: XY X Y Lin: XY X Y Auto-range: XY X Y Page: >> << Zoom: <> >< Grid: VH 0 V H Pts: Txt Box PL Print

Reset Repaint Legend Authors Info+ PostScript Plotting options:[+] Clipboard: Copy

Shift legend:x= 10 y= 10 Split: 0 1:xy;2:y Marker: Plot data or ratio: 0 0:data; 1:ratio to dataset-1; 2:ratio to 2-nd, etc.

Data for plotting: ZVD (39Kb); download ZVView; upload and plot your ZVD file

Select corresponding ENDF data

IAEA

Select and plot

Request #5762

ENDF Data Selection (Plot for EXFOR Request #1826)

Retrieve | Plot | Selected | Unselected | All | Reset

Plotting options: Quick plot (cross-sections only: σ)

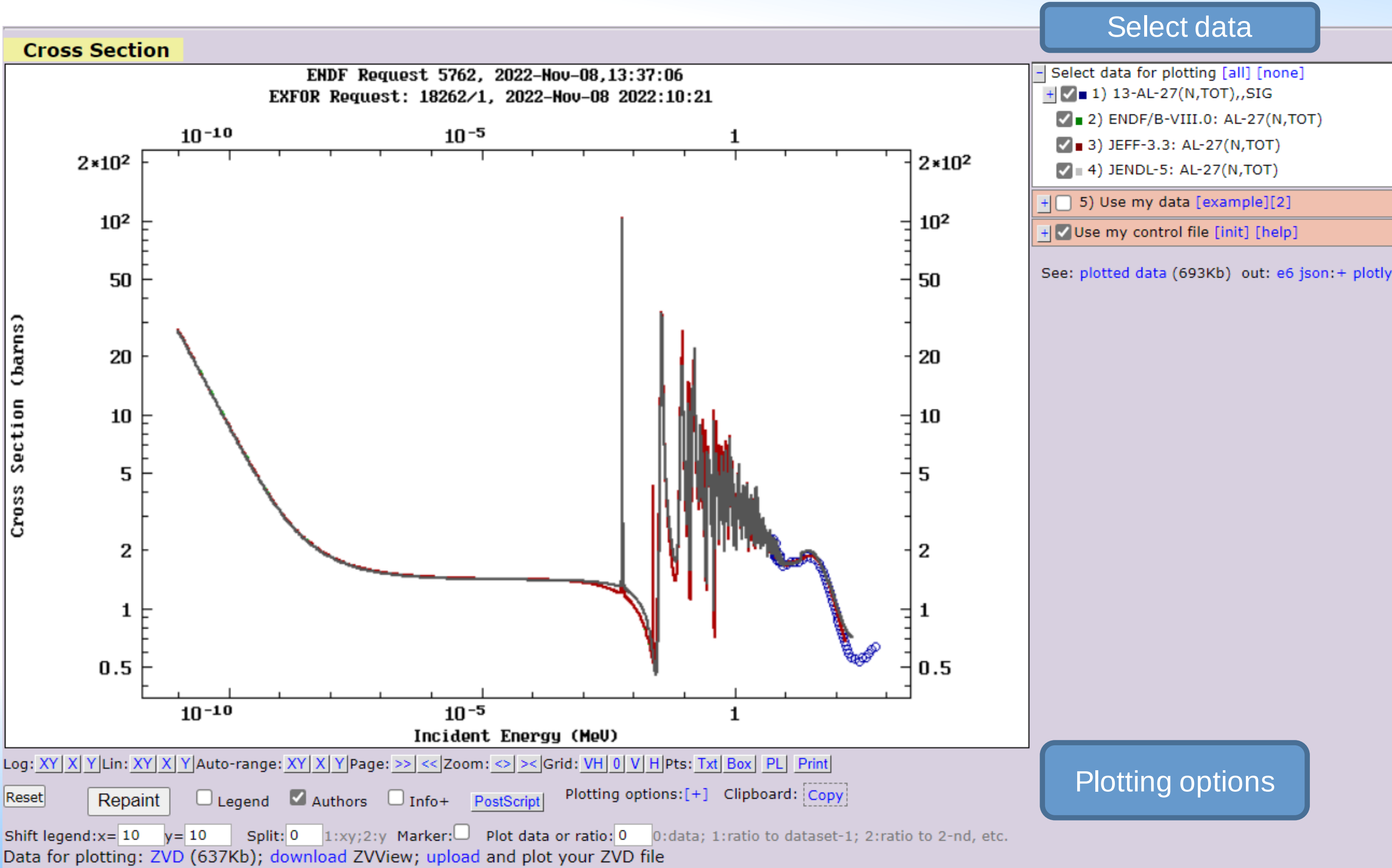
Sorted by: [Reactions] Reorder by: [Libraries] View: basic extended: get MAT, PEN, GND, run Inter: resonance integrals, etc.

1) AL-27(N,TOT),SIG MT=1 MF=3 NSUB=10

MF3: [SIG] Cross sections MT1: [N,TOT] Neutron total cross sections.

#	Links	Library	Info	Authors
1	ENDF-6 Interpreted σ js Plot	ENDF/B-VIII.0	E=150MeV Lab=LANL,ORNL Date=20111222	M.B.Chadwick+,Derrien+
2	ENDF-6 Interpreted σ js Plot	ENDF/B-VII.1	E=150MeV Lab=LANL,ORNL Date=20111222	M.B.Chadwick+,Derrien+
3	ENDF-6 Interpreted σ js Plot	ENDF/B-VII.0	E=150MeV Lab=LANL,ORNL Date=DIST-DEC06	M.B.Chadwick+,Derrien+
4	ENDF-6 Interpreted σ js Plot	JEFF-3.3	E=150MeV Lab=LANL Date=20171231	M.B.CHADWICK & P.G.YOUNG
5	ENDF-6 Interpreted σ js Plot	JEFF-3.2	E=150MeV Lab=LANL Date=090105	M.B.CHADWICK & P.G.YOUNG
6	ENDF-6 Interpreted σ js Plot	JEFF-3.1.2	E=150MeV Lab=LANL Date=090105	M.B.CHADWICK & P.G.YOUNG
7	ENDF-6 Interpreted σ js Plot	JEFF-3.1	E=150MeV Lab=LANL Date=090105	M.B.CHADWICK & P.G.YOUNG
8	ENDF-6 Interpreted σ js Plot	JENDL-5	E=200MeV Lab=TIT,JAERI Date=20090828	Y.HARIMA,H.KITAZAWA,T.FUKAHORI
9	ENDF-6 Interpreted σ js Plot	JENDL-4.0	E=20MeV Lab=TIT,JAERI Date=20090828	Y.HARIMA,H.KITAZAWA,T.FUKAHORI
10	ENDF-6 Interpreted σ js Plot	JENDL-3.3	E=20MeV Lab=TIT,JAERI Date=20010713	Y.HARIMA,H.KITAZAWA,T.FUKAHORI
11	ENDF-6 Interpreted σ js Plot	JENDL-3.3	E=20MeV Lab=TIT,JAERI Date=20010713 T=300	Y.HARIMA,H.KITAZAWA,T.FUKAHORI
12	ENDF-6 Interpreted σ js Plot	ENDF/B-VI	E=150MeV Lab=LANL Date=20011108	M.B.CHADWICK & P.G.YOUNG
13	ENDF-6 Interpreted σ js Plot	ENDF/B-VI	E=150MeV Lab=LANL Date=20010926 T=300	M.B.CHADWICK & P.G.YOUNG
14	ENDF-6 Interpreted σ js Plot	BROND-3.1	E=150MeV Lab=LANL,ORNL Date=DIST-DEC06	M.B.Chadwick+,Derrien+
15	ENDF-6 Interpreted σ js Plot	ROSFOND-2010	E=150MeV Lab=IPPE Date=DIST-DEC07	IGNATYUK A.V.
16	ENDF-6 Interpreted σ js Plot	ROSFOND-2008	E=150MeV Lab=IPPE Date=DIST-DEC07	IGNATYUK A.V.
17	ENDF-6 Interpreted σ js Plot	CENDL-3.2	E=20MeV Lab=CNDC Date=20150815	Y.L.HAN
18	ENDF-6 Interpreted σ js Plot	CENDL-3.1	E=20MeV Lab=CNDC,JNDC Date=DIST-DEC09	B.S.YU, S.CHIBA, Y.HARIMA
19	ENDF-6 Interpreted σ js Plot	JEFF-3.0	E=150MeV Lab=LANL Date=DIST-APR02	M.B.CHADWICK & P.G.YOUNG
20	ENDF-6 Interpreted σ js Plot	JEF-2.2	Lab=ECN Date=920101	EC BLANKET TECHNOLOGY, TASK B2
21	ENDF-6 Interpreted σ js Plot	JENDL-4.0/HE	E=200MeV Lab=SIT.SHIMZ Date=REV1-	K. Kosako
22	ENDF-6 Interpreted σ js Plot	JENDL/HE-2007	E=3000MeV Lab=SIT.SHIMZ Date=REV1-	K. Kosako
23	ENDF-6 Interpreted σ js Plot	JENDL/HE-2004	E=3000MeV Lab=KAERI Date=REV1-	Y. Lee
24	ENDF-6 Interpreted σ js Plot	JENDL-3.2	Lab=TIT,JAERI Date=REV2-DEC93	Y.HARIMA,H.KITAZAWA,T.FUKAHORI

Interactive plotting

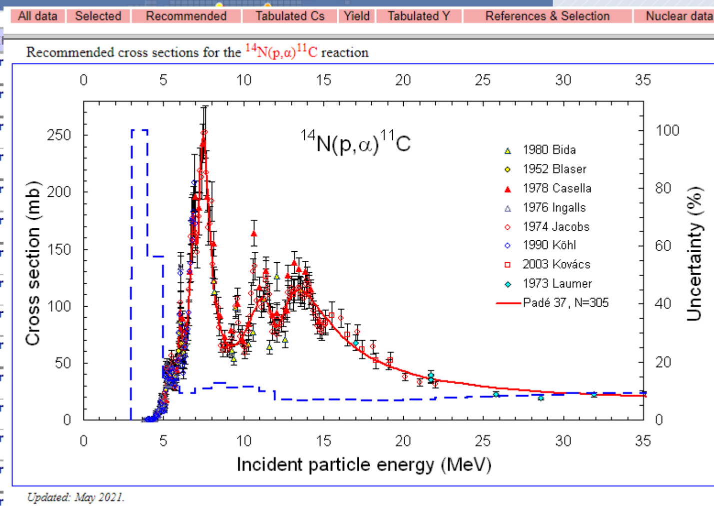


Other reaction databases

- Medical portal (evaluated): https://www-nds.iaea.org/medportal

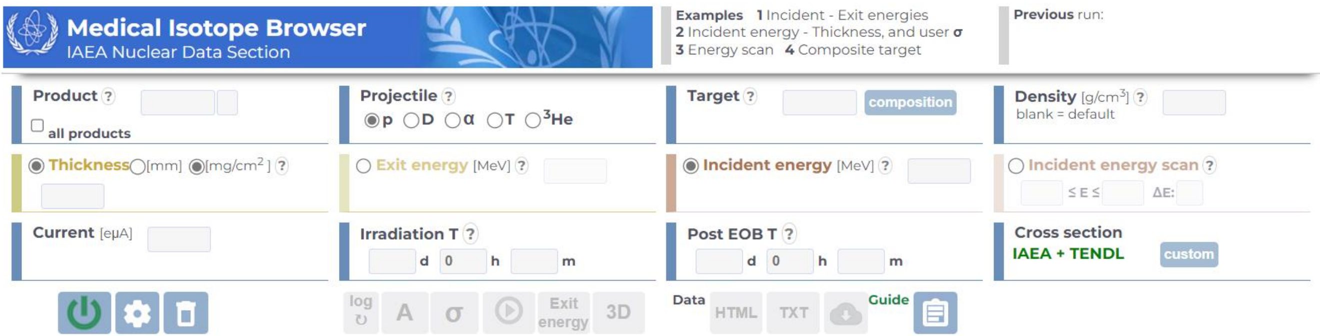
Decay data of nuclides denoted by green band were evaluated within IAEA CRPs.

Nuclide	Half-life	Decay %	Emission	Target	Reaction	Product	MI
$^{11}_{6}C_{5}$	20.364 min *14*	ec β+ 100 (β+ ≈ 99.8)	e^+	$^{14}_{7}N_{7}$	$^{14}N(p,\alpha)^{11}C$	$^{11}_{6}C_{5}$	mir
$^{13}_{7}N_{6}$	9.965 min *4*	ec β+ 100 (β+ ≈ 99.8)	e^+	$^{16}_{8}O_{8}$	$^{16}O(p,\alpha)^{13}N$	$^{13}_{7}N_{6}$	mir
$^{15}_{8}O_{7}$	122.24 s *16*	ec β+ 100 (β+ ≈ 99.9)	e^+	$^{15}_{7}N_{8}$	$^{15}N(p,n)^{15}O$	$^{15}_{8}O_{7}$	mir
				$^{14}_{7}N_{7}$	$^{14}N(d,n)^{15}O$	$^{15}_{8}O_{7}$	mir
$^{18}_{9}F_{9}$	109.77 min *5*	ec β+ 100 (β+ ≈ 96.7)	e^+	$^{18}_{8}O_{10}$	$^{18}O(p,n)^{18}F$	$^{18}_{9}F_{9}$	mir
				^{nat}Ne	$^{nat}Ne(d,x)^{18}F$	$^{18}_{9}F_{9}$	mir
$^{22}_{11}Na_{11}$	2.6018 y *22*	ec β+ 100 (β+ ≈ 90.0)		$^{27}_{13}Al_{14}$	$^{27}Al(d,x)^{22}Na$	$^{22}_{11}Na_{11}$	mir
				$^{27}_{13}Al_{14}$	$^{27}Al(\alpha,x)^{22}Na$	$^{22}_{11}Na_{11}$	mir
				$^{27}_{13}Al_{14}$	$^{27}Al(p,x)^{22}Na$	$^{22}_{11}Na_{11}$	mir
				$^{27}_{13}Al_{14}$	$^{27}Al(^{3}He,x)^{22}Na$	$^{22}_{11}Na_{11}$	mir
$^{24}_{11}Na_{13}$	14.997 h *12*	β- 100		$^{27}_{13}Al_{14}$	$^{27}Al(d,x)^{24}Na$	$^{24}_{11}Na_{13}$	mir
				$^{27}_{13}Al_{14}$	$^{27}Al(\alpha,x)^{24}Na$	$^{24}_{11}Na_{13}$	mir
				$^{27}_{13}Al_{14}$	$^{27}Al(p,x)^{24}Na$	$^{24}_{11}Na_{13}$	mir
				$^{27}_{13}Al_{14}$	$^{27}Al(^{3}He,x)^{24}Na$	$^{24}_{11}Na_{13}$	mir
$^{32}_{15}P_{17}$	14.268 d *5*	β- 100	e^-	$^{32}_{16}S_{16}$	$^{32}S(n,p)^{32}P$	$^{32}_{15}P_{17}$	mir



Medical isotope production

- TENDL (Talys Evaluated Nuclear Data Libraries
- Stopping powers



Other cont’d

- IBANDL (experimental): https://www-nds.iaea.og/ibandl

$^{12}C + p$

Type of data: ALL View: extended inverted Convert units for plotting: no ->mb/sr ->rr Plots: [reset]

No.	Reaction	Angle	Energy(keV)	Pts	Update	X4	Reference	File	Plot
1	$^{12}C(p,p_0)^{12}C$	179	360-7100	349	2012-01-01		Evaluated data from SigmaCalc archive (A.Gurbich, 2012) Evaluated data from current version of [SigmaCalc] >>> Calculate (timeout=5min)	View Save	mb
2	$^{12}C(p,p_0)^{12}C$	179.2°	4000-6600	55	2006-06-22	X4⁻	M. Tosaki et. al. Nucl. Instr. Meth. B168 (2000) 543 »	View Save	mb
3	$^{12}C(p,p_0)^{12}C$	178°	490-2500	61	2011-09-02	X4⁺	A.R.Ramos+(2002), Jour. Nucl. Instrum. Methods in Physics Res., Sect.B, Vol.190, p.95 »	View Save	rr
4	$^{12}C(p,p_0)^{12}C$	170°	1650-1800	31	2019-02-07	X4⁺	S.M.Duvanov+, JINR-P15-96-69, (1996). »	View Save	mb
5	$^{12}C(p,p_0)^{12}C$	170°	700-2500	29	2006-06-22	X4⁻	E.Rauhala Nucl.Instrum.Methods B12 (1985) 447 »	View Save	mb
6	$^{12}C(p,p_0)^{12}C$	170°	2700-3100	5	2020-04-07	X4⁻	Yang Guohua et al. Nucl.Instr.& Meth. v.B61 (1991) 175 »	View Save	rr
7	$^{12}C(p,p_0)^{12}C$	170°	1600-1790	22	2020-10-07	X4⁺	R.Salomonovic(1993), Jour. Nucl. Instrum. Methods in Physics Res., Sect.B, Vol.82, p.1 »	View Save	mb
8	$^{12}C(p,p_0)^{12}C$	170°	990-3500	78	2019-03-29	X4⁺	R.Amirikas+(1993), Jour. Nucl. Instrum. Methods in Physics Res., Sect.B, Vol.77, p.110 »	View Save	mb
9	$^{12}C(p,p_0)^{12}C$	170°	290-720	24	2020-04-10	X4⁺	J.Liu+(1993), Jour. Nucl. Instrum. Methods in Physics Res., Sect.B, Vol.74, p.439 »	View Save	rr
10	$^{12}C(p,p_0)^{12}C$	170°	710-2970	37	2020-04-10	X4⁺	J.Liu+(1993), Jour. Nucl. Instrum. Methods in Physics Res., Sect.B, Vol.74, p.439 »	View Save	rr
11	$^{12}C(p,p_0)^{12}C$	170°	290-2970	60	2020-04-10	X4⁺	J.Liu+(1993), Jour. Nucl. Instrum. Methods in Physics Res., Sect.B, Vol.74, p.439 »	View Save	rr
12	$^{12}C(p,p_0)^{12}C$	170°	340-3000	123	2019-03-29	X4⁺	S.Mazzoni+(1998), Jour. Nucl. Instrum. Methods in Physics Res., Sect.B, Vol.136-138, p.86 »	View Save	mb
13	$^{12}C(p,p_0)^{12}C$	170°	2690-7000	71	2020-04-19	X4⁺	D.Abriola+(2011), Jour. Nucl. Instrum. Methods in Physics Res., Sect.B, Vol.269, p.2011 »	View Save	mb
14	$^{12}C(p,p_0)^{12}C$	168.2°	380-4360	180	2020-04-07	X4⁺	H.L.Jackson+(1953), Jour. Physical Review, Vol.89, p.365 »	View Save	mb
15	$^{12}C(p,p_0)^{12}C$	165.2°	4350-6060	148	2021-12-07	X4⁺	N.Nikolic+(1963), Physical Review, Vol.132, p.2212		
16	$^{12}C(p,p_0)^{12}C$	165°	340-3000	123	2019-03-29	X4⁺	S.Mazzoni+(1998), Jour. Nucl. Instrum. Methods in Ph		
17	$^{12}C(p,p_0)^{12}C$	162.6°	4810-5590	25	2010-06-03	X4⁺	C.W.Reich+(1956), Jour. Physical Review, Vol.104, p.		
18	$^{12}C(p,p_0)^{12}C$	162°	1600-1790	37	2011-09-02	X4⁺	B.Fabre+(1994), Jour. Nuclear Physics, Section A, Vol.		
19	$^{12}C(p,p_0)^{12}C$	160°	1600-1790	22	2020-10-07	X4⁺	R.Salomonovic(1993), Jour. Nucl. Instrum. Methods in		
20	$^{12}C(p,p_0)^{12}C$	160°	340-3000	123	2019-03-29	X4⁺	S.Mazzoni+(1998), Jour. Nucl. Instrum. Methods in Ph		

ross-sections relevant to Ion Beam Analysis. Differential cross sections are presented both
lable in EXFOR retrieval system (see details of the algorithm here).

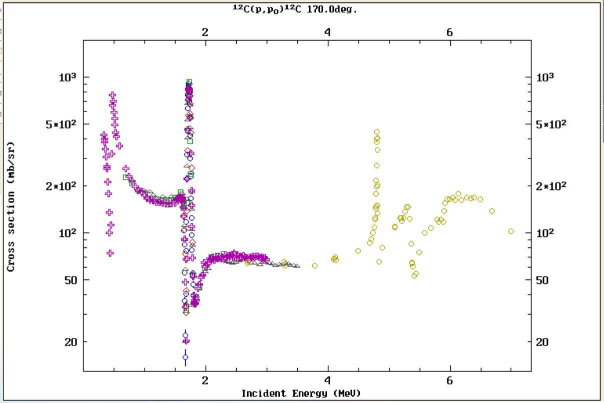
EA-TECDOC-1780), and the CRP on Development of a Reference Database for Particle-
ar data made available in IBANDL. The activity has been further supported by the IAEA
n the Resolved-Resonance Region.

: nds.contact-point@iaea.org (IAEA-NDS).

data produced by SigmaCalc up to October 2013 are available for easier access and
from SigmaCalc and imported into IBANDL. Users are cautioned however, that the 'on-the-
ge of this option.

s (mb/sr) can be converted to Ratio-to-Rutherford (rr) and vice versa. Press 'Convert units

terface. The codes include ERYA, NDF, SMNRA and PIGRECO. More details are available



Select data for plotting [all] [none]
- 1) 1996,Duvanov 12C(p,p0)12C 170deg
- 2) 1985,Rauhala 12C(p,p0)12C 170deg
- 3) 1993,Salomonovic 12C(p,p0)12C 170deg
- 4) 1993,Amirikas 12C(p,p0)12C 170deg
- 5) 1998,Mazzoni 12C(p,p0)12C 170deg
- 6) 2011,Abriola 12C(p,p0)12C 170deg

7) Use my data [example][2]

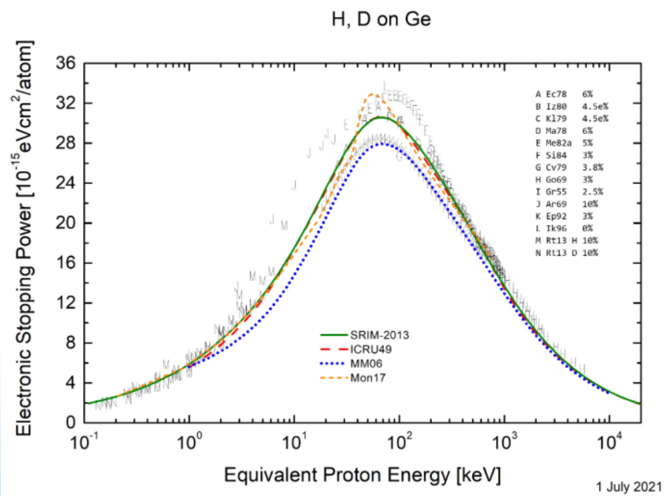
Use my control file [init] [help]

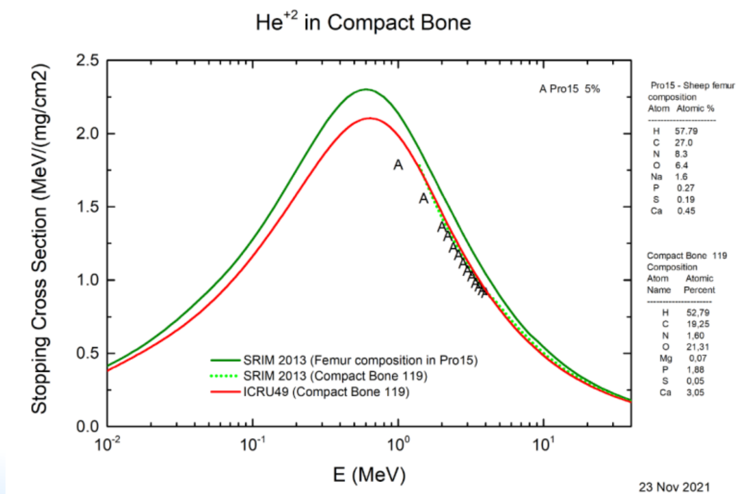
See: plotted data (18Kb) out: e6 json:+ plotly2

Other cont'd

- Stopping powers
  - Unique database of experimental electronic stopping powers

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





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Thank you!