Neutron Flux and cross section – connection with nTOF experiment

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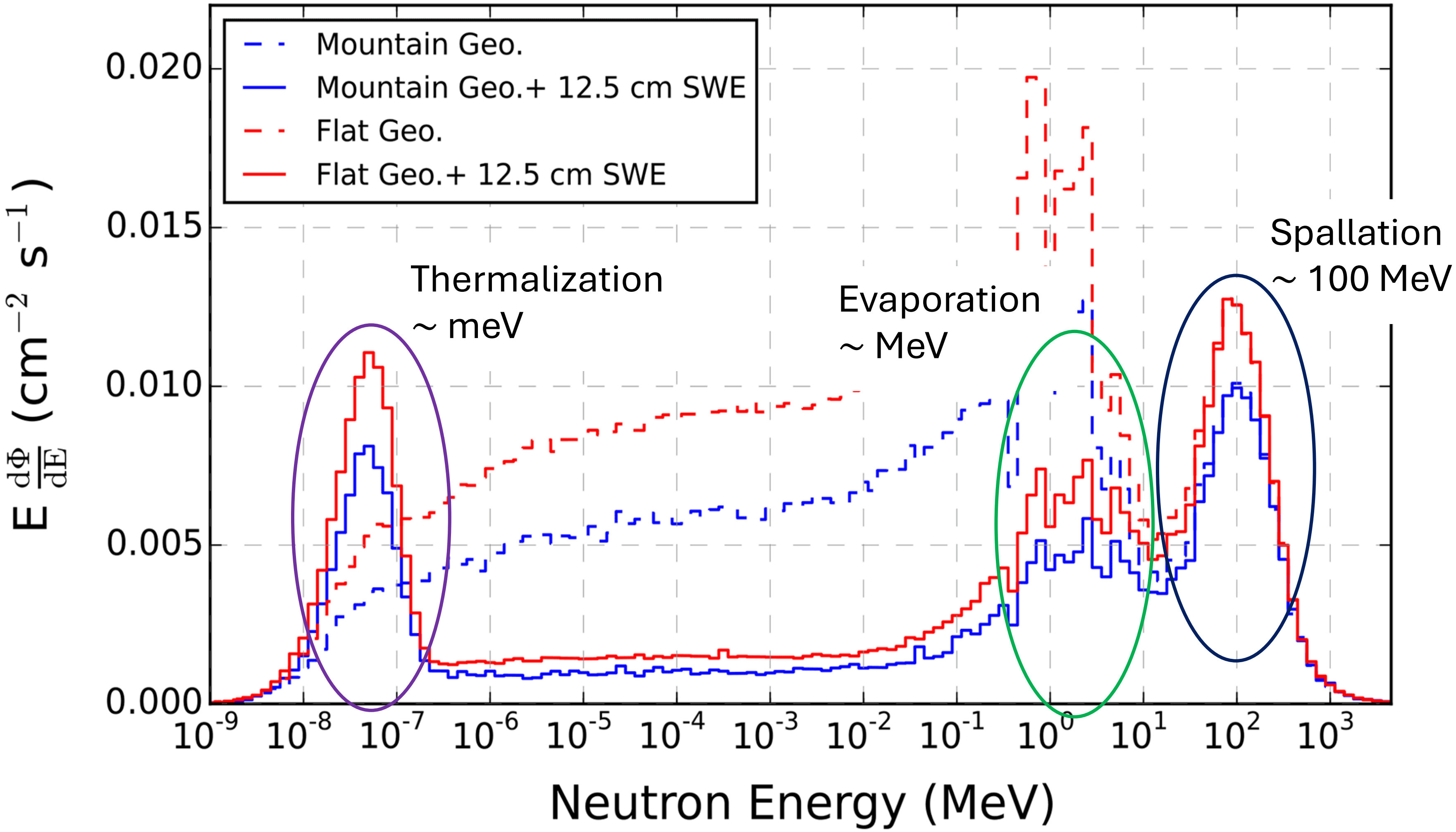
Neutron Flux

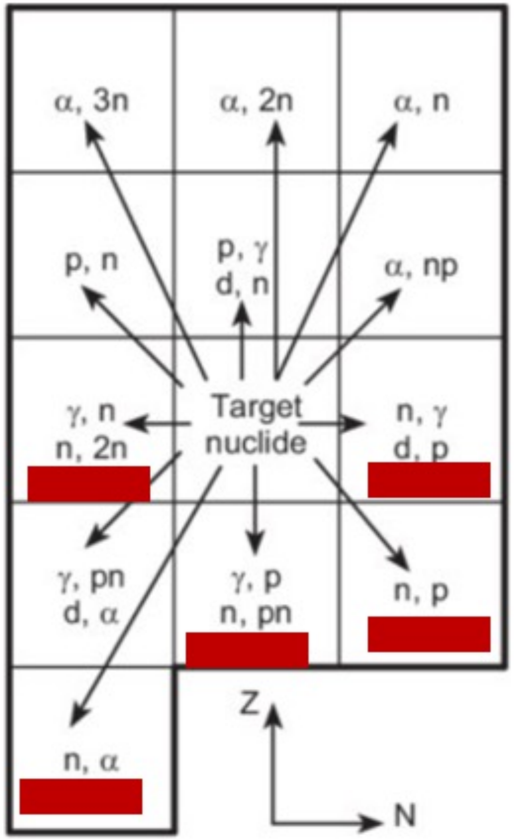


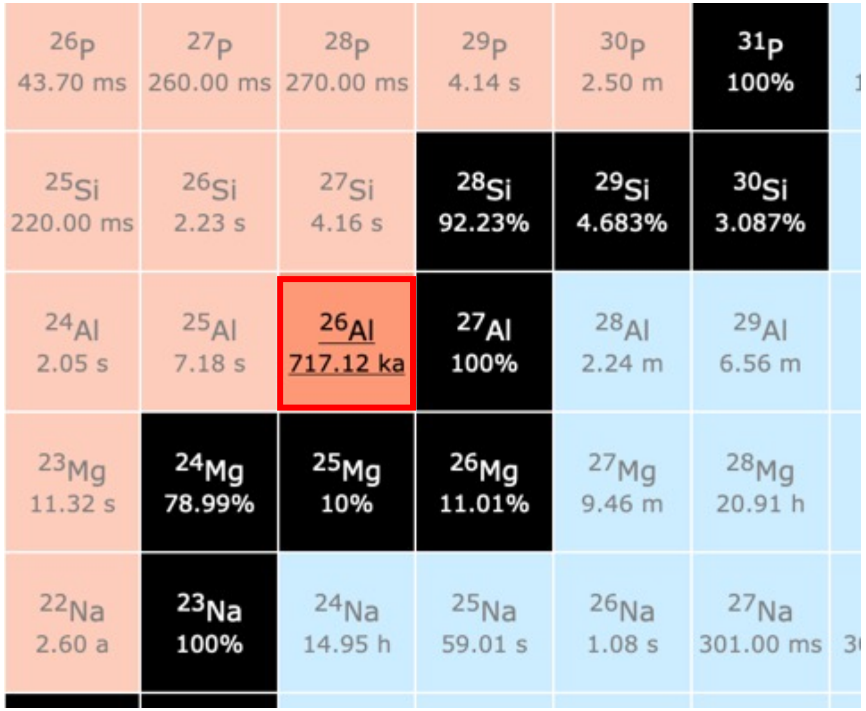
Typical neutron spectrum behavior:

- **Evaporation and spallation peak**: neutrons are produced inside showers induced by cosmic rays.
- **Thermal peak**: neutrons produced by evaporation and spallation are moderated by atmosphere.

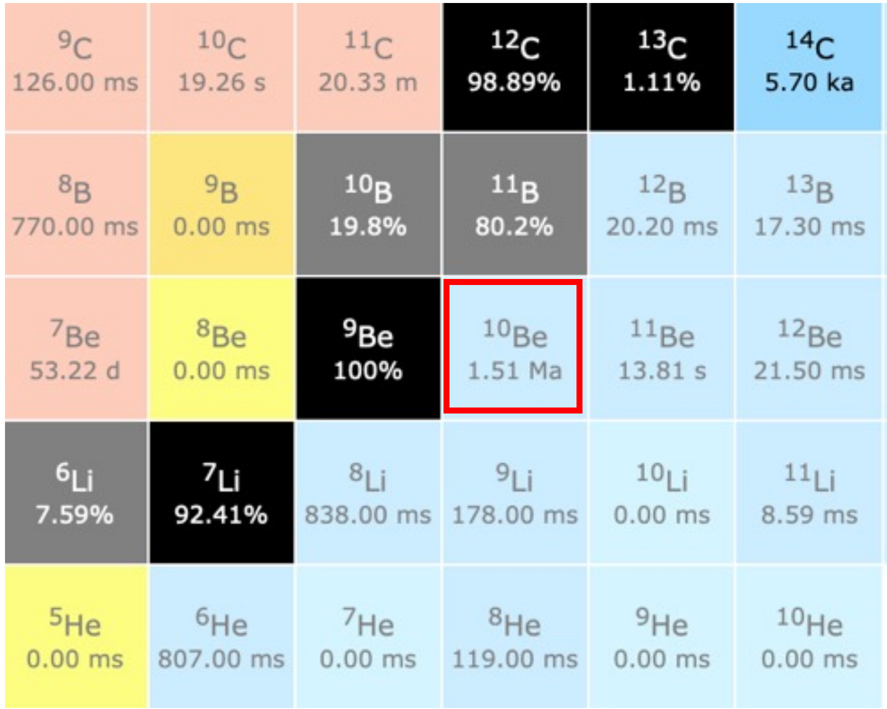
Typically, cross section for neutrons is proportional to 1/*v* ⟶ contribution of thermal neutrons to the production rate could be important to consider.

Reactions involving neutron, ^{26}Al and ^{10}Be





^{26}P 43.70 ms	^{27}P 260.00 ms	^{28}P 270.00 ms	^{29}P 4.14 s	^{30}P 2.50 m	^{31}P 100%
^{25}Si 220.00 ms	^{26}Si 2.23 s	^{27}Si 4.16 s	^{28}Si 92.23%	^{29}Si 4.683%	^{30}Si 3.087%
^{24}Al 2.05 s	^{25}Al 7.18 s	^{26}Al 717.12 ka	^{27}Al 100%	^{28}Al 2.24 m	^{29}Al 6.56 m
^{23}Mg 11.32 s	^{24}Mg 78.99%	^{25}Mg 10%	^{26}Mg 11.01%	^{27}Mg 9.46 m	^{28}Mg 20.91 h
^{22}Na 2.60 a	^{23}Na 100%	^{24}Na 14.95 h	^{25}Na 59.01 s	^{26}Na 1.08 s	^{27}Na 301.00 ms



^{9}C 126.00 ms	^{10}C 19.26 s	^{11}C 20.33 m	^{12}C 98.89%	^{13}C 1.11%	^{14}C 5.70 ka
^{8}B 770.00 ms	^{9}B 0.00 ms	^{10}B 19.8%	^{11}B 80.2%	^{12}B 20.20 ms	^{13}B 17.30 ms
^{7}Be 53.22 d	^{8}Be 0.00 ms	^{9}Be 100%	^{10}Be 1.51 Ma	^{11}Be 13.81 s	^{12}Be 21.50 ms
^{6}Li 7.59%	^{7}Li 92.41%	^{8}Li 838.00 ms	^{9}Li 178.00 ms	^{10}Li 0.00 ms	^{11}Li 8.59 ms
^{5}He 0.00 ms	^{6}He 807.00 ms	^{7}He 0.00 ms	^{8}He 119.00 ms	^{9}He 0.00 ms	^{10}He 0.00 ms

Black/Grey elements are the stable ones with the isotopic abundance

Reactions involving neutron, ^{26}Al and ^{10}Be

Production ^{26}Al:

- $^{27}Al(n,2n)^{26}Al$
- $[^{25}Mg(p,\gamma)^{26}Al]$

Destruction ^{26}Al:

- $^{26}Al(n,\alpha)$
- $^{26}Al(n,p)$

Cross section measured at nTOF

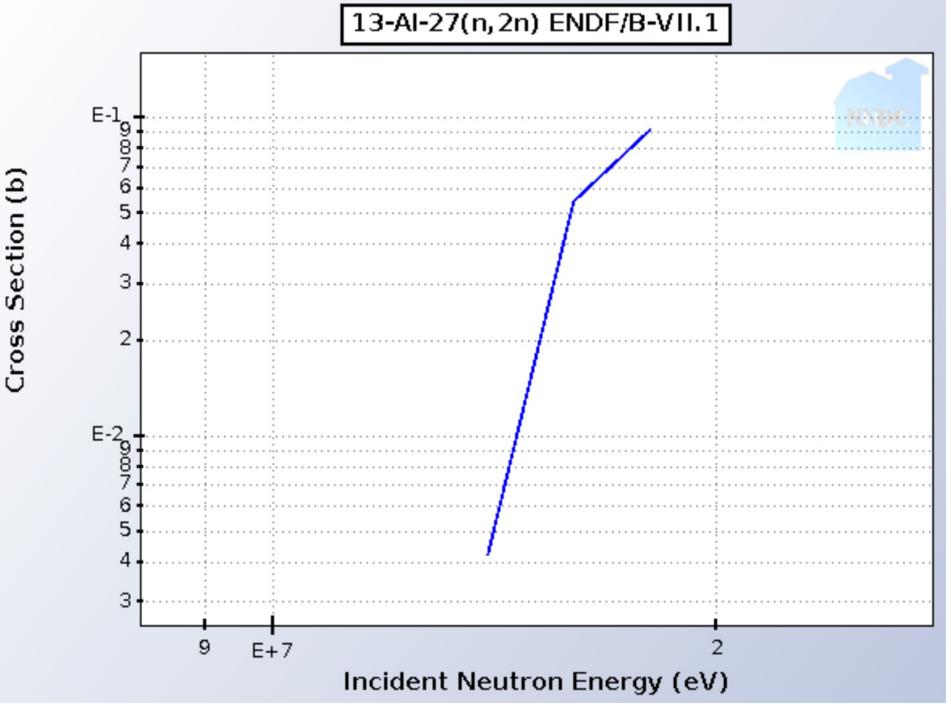
- $^{26}Al(n,\gamma)$

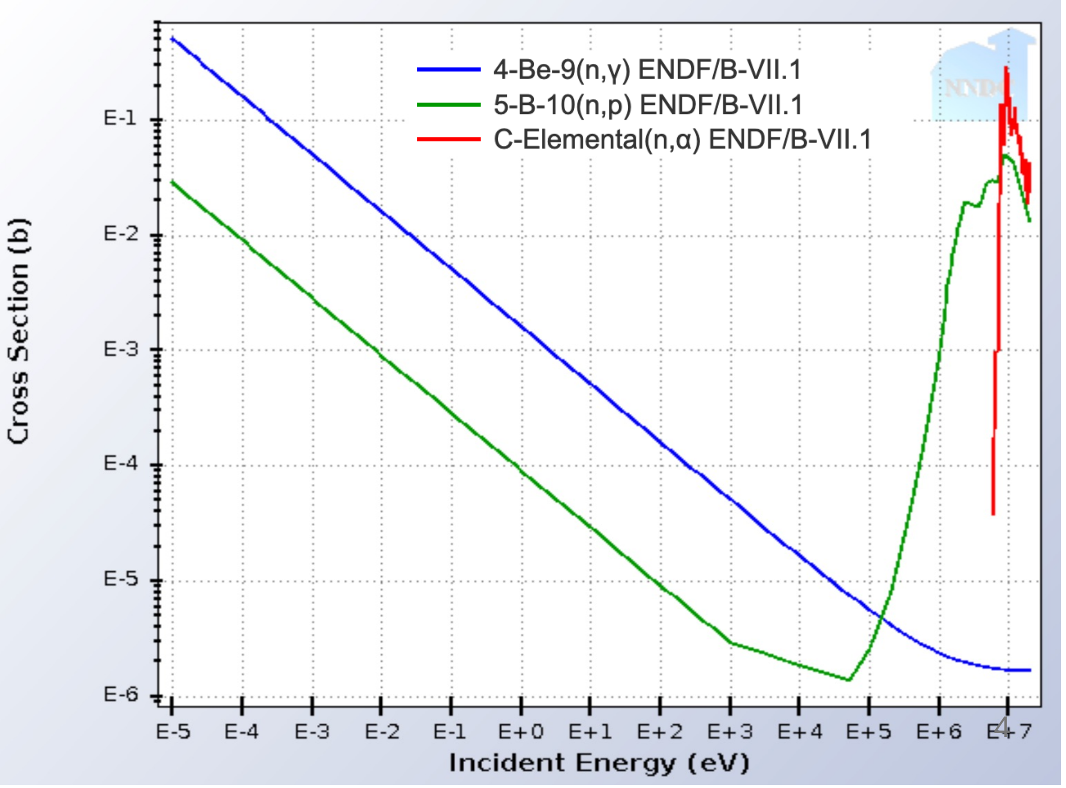
Production ^{10}Be:

- $^{9}Be(n,\gamma)^{10}Be$
- $^{10}B(n,p)^{10}Be$
- $^{13}C(n,\alpha)^{10}Be$

Destruction ^{10}Be:

- No experimental measurement, only predictions

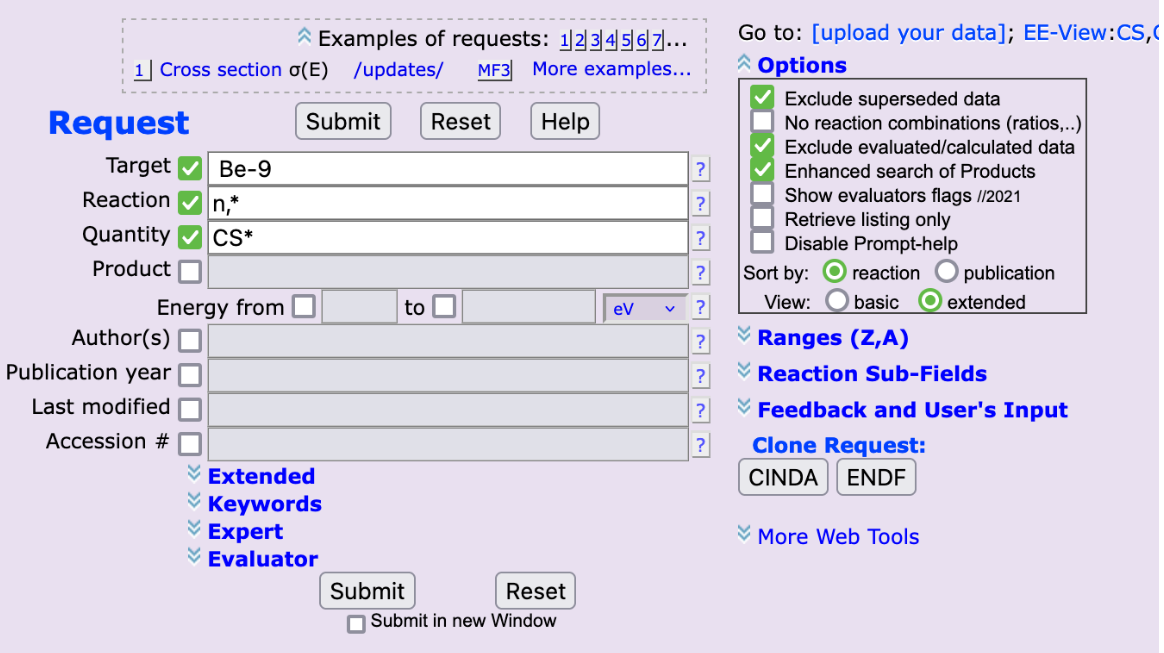




Some useful tools

Experimental Nuclear Reaction Data (EXFOR)

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

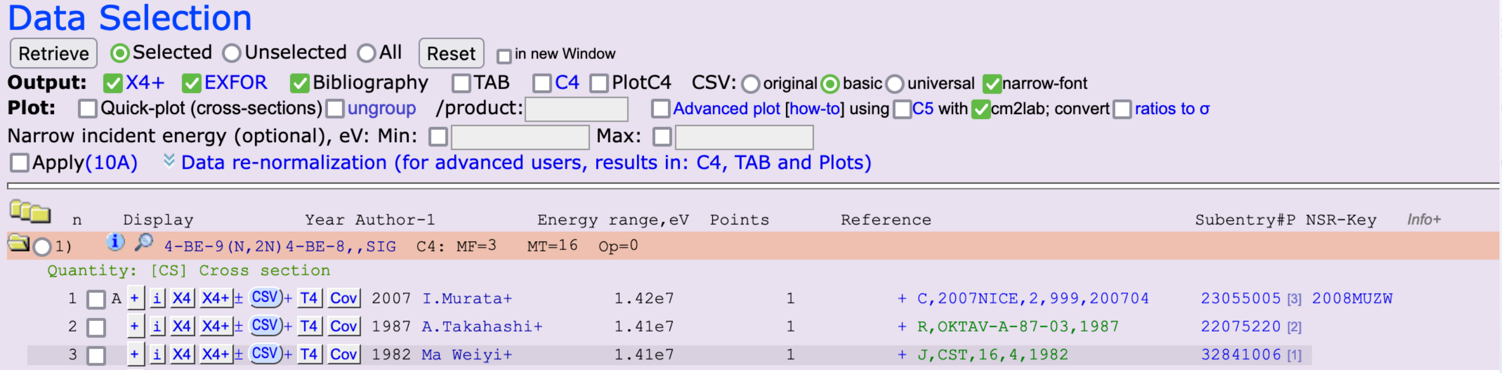


Target ☑ Be-9
Reaction ☑ n,*
Quantity ☑ CS*
Product ☐
Energy from ☐ to ☐ eV
Author(s) ☐
Publication year ☐
Last modified ☐
Accession # ☐

☑ Exclude superseded data
☐ No reaction combinations (ratios,..)
☑ Exclude evaluated/calculated data
☑ Enhanced search of Products
☐ Show evaluators flags //2021
☐ Retrieve listing only
☐ Disable Prompt-help

Sort by: ● reaction ○ publication
View: ○ basic ● extended

☐ Submit in new Window



● Selected ○ Unselected ○ All ☐ in new Window

Output: ☑ X4+ ☑ EXFOR ☑ Bibliography ☐ TAB ☐ C4 ☐ PlotC4 CSV: ○ original ● basic ○ universal ☑ narrow-font

Plot: ☐ Quick-plot (cross-sections) ☐ ungroup /product: ☐ Advanced plot [how-to] using ☐ C5 with ☑ cm2lab; convert ☐ ratios to σ

Narrow incident energy (optional), eV: Min: ☐ Max: ☐

☐ Apply(10A) Data re-normalization (for advanced users, results in: C4, TAB and Plots)

```
   n  Display        Year Author-1        Energy range,eV  Points       Reference                     Subentry#P NSR-Key   Info+
○1)  4-BE-9(N,2N)4-BE-8,,SIG  C4: MF=3   MT=16  Op=0
   Quantity: [CS] Cross section
   1 ☐ A + i X4 X4+± CSV+ T4 Cov 2007 I.Murata+      1.42e7   1   + C,2007NICE,2,999,200704   23055005 [3] 2008MUZW
   2 ☐   + i X4 X4+± CSV+ T4 Cov 1987 A.Takahashi+   1.41e7   1   + R,OKTAV-A-87-03,1987      22075220 [2]
   3 ☐   + i X4 X4+± CSV+ T4 Cov 1982 Ma Weiyi+      1.41e7   1   + J,CST,16,4,1982           32841006 [1]
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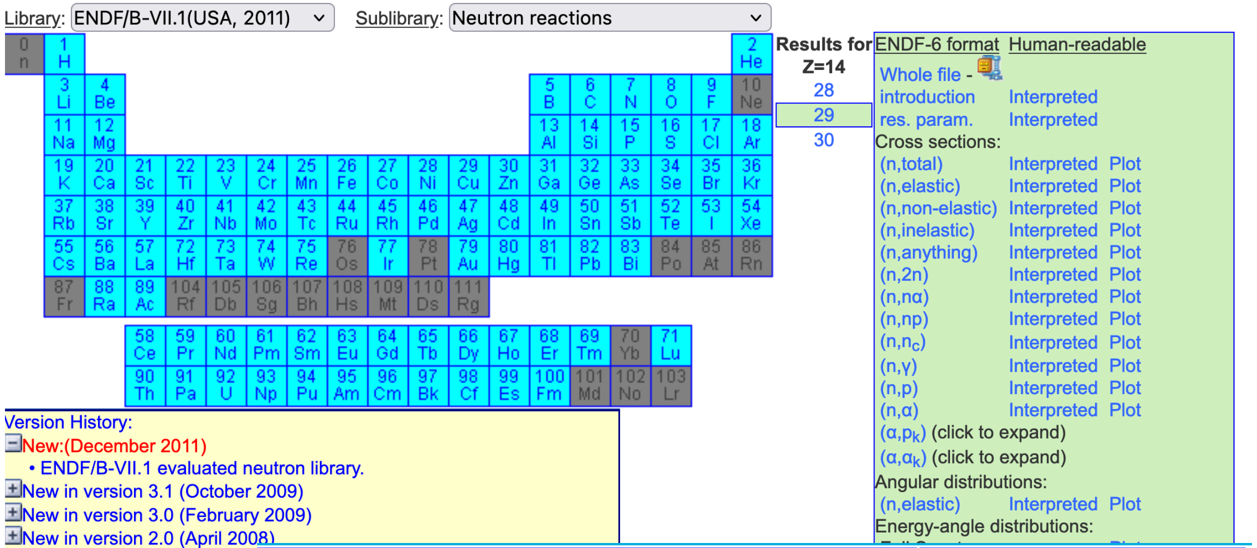
National Nuclear Data Center (NNDC)

https://www.nndc.bnl.gov/sigma/index.jsp?as=29&lib=endfb7.1&nsub=10

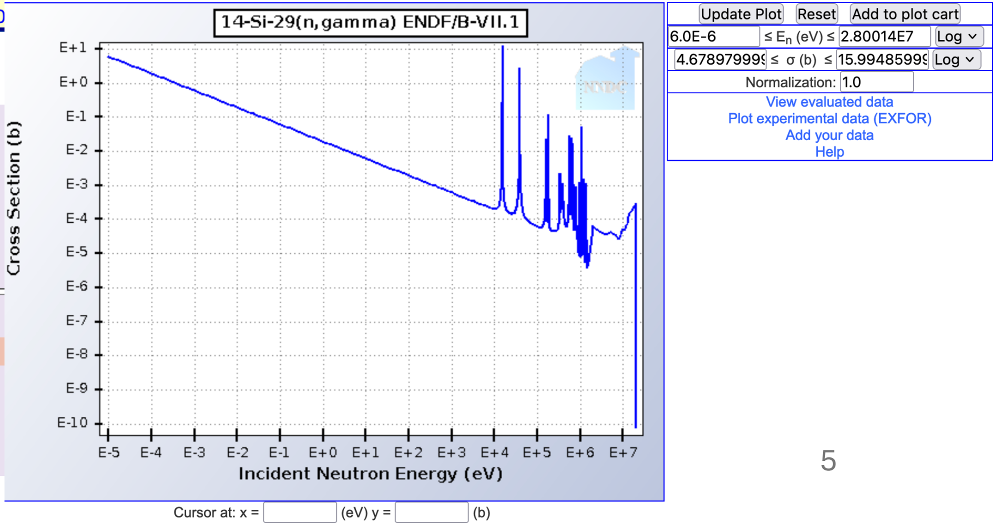


Library: ENDF/B-VII.1(USA, 2011) Sublibrary: Neutron reactions

Results for Z=14
28
29
30

ENDF-6 format	Human-readable	
Whole file -		
introduction	Interpreted	
res. param.	Interpreted	
Cross sections:		
(n,total)	Interpreted	Plot
(n,elastic)	Interpreted	Plot
(n,non-elastic)	Interpreted	Plot
(n,inelastic)	Interpreted	Plot
(n,anything)	Interpreted	Plot
(n,2n)	Interpreted	Plot
(n,nα)	Interpreted	Plot
(n,np)	Interpreted	Plot
(n,n_c)	Interpreted	Plot
(n,γ)	Interpreted	Plot
(n,p)	Interpreted	Plot
(n,α)	Interpreted	Plot
(α,p_k) (click to expand)		
(α,$α_k$) (click to expand)		
Angular distributions:		
(n,elastic)	Interpreted	Plot
Energy-angle distributions:		

Version History:
- New:(December 2011)
  - ENDF/B-VII.1 evaluated neutron library.
- New in version 3.1 (October 2009)
- New in version 3.0 (February 2009)
- New in version 2.0 (April 2008)
- New in version 1.0 (April 200



6.0E-6 ≤ E_n (eV) ≤ 2.80014E7 Log
4.678979999 ≤ σ (b) ≤ 15.99485999 Log
Normalization: 1.0
Cursor at: x = (eV) y = (b)

Production Rate

2 POSSIBLE APPROACHES:

1. Measurement of the different components and than calculation of production rate (same approach used for muons) ("Indirect method")
2. Direct measurement of the production rate @nTOF ("Direct method")

1- Indirect method

1. Measurement of the neutron flux at the site
2. Measurement of the cross sections for main production process
3. Evaluation of the abundance of the elements involved in the production of ^{10}Be and ^{26}Al

Count of thumb: to simulate 5 Myr of irradiation by neutron flux it's necessary about 30 days of irradiation at nTOF (realistic timescale for the use of nTOF detector)

2- Direct method

1. Measurement of the neutron flux at the site
2. Measurement of the production rate:
    - A. Collection of some samples of the rocks at the site
    - B. Measurement of the ^{10}Be and ^{26}Al concentration
    - C. Irradiation of the samples with a neutron flux tuned to be equal to the one measured experimental (@nTOF)
    - D. Measurement of the new concentration of ^{10}Be and ^{26}Al

Outlooks

MAIN QUESTION: Is the contribution of neutrons truly important for our purposes?

Few comments:

Inside Balco's code the contribution of neutron to the production rate is calculated through scaling schemes that moves the production rate calculated at some reference site to the interest site (ref. Balco et al. (2008)).

High uncertainty derived by this method

If the answer is YES, some possible steps to do:

1. Evaluation of Pros and Cons of the two approaches
2. Evaluation of the best way to measure the neutron spectrum:
   - I. Bonner spheres for the whole spectrum
   - II. Scintillator, more precise measurement but only parts of the spectrum

Studies on the contributions of different part of the neutron spectrum to the production rate. Focus on a specific part of the spectrum with more precise measurement.