A discussion about how to estimate p-values for neutrons .

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As Luna knows I tried sometime ago to make a back of the envelope estimation of the p-value for neutrons..

I wanted to come back to this and try to do a bit better job but I have met two topics that I want to discuss with you with the hope that I/we will understand better after discussing ,,,,

- How to handle the neutron spectrum ?
- Contribution from thermal neutrons-
  I have found it negligible….but are my conclusions correct???

To estimate the p-value for a certain process i.e.

Be or Al atoms created /gr/year

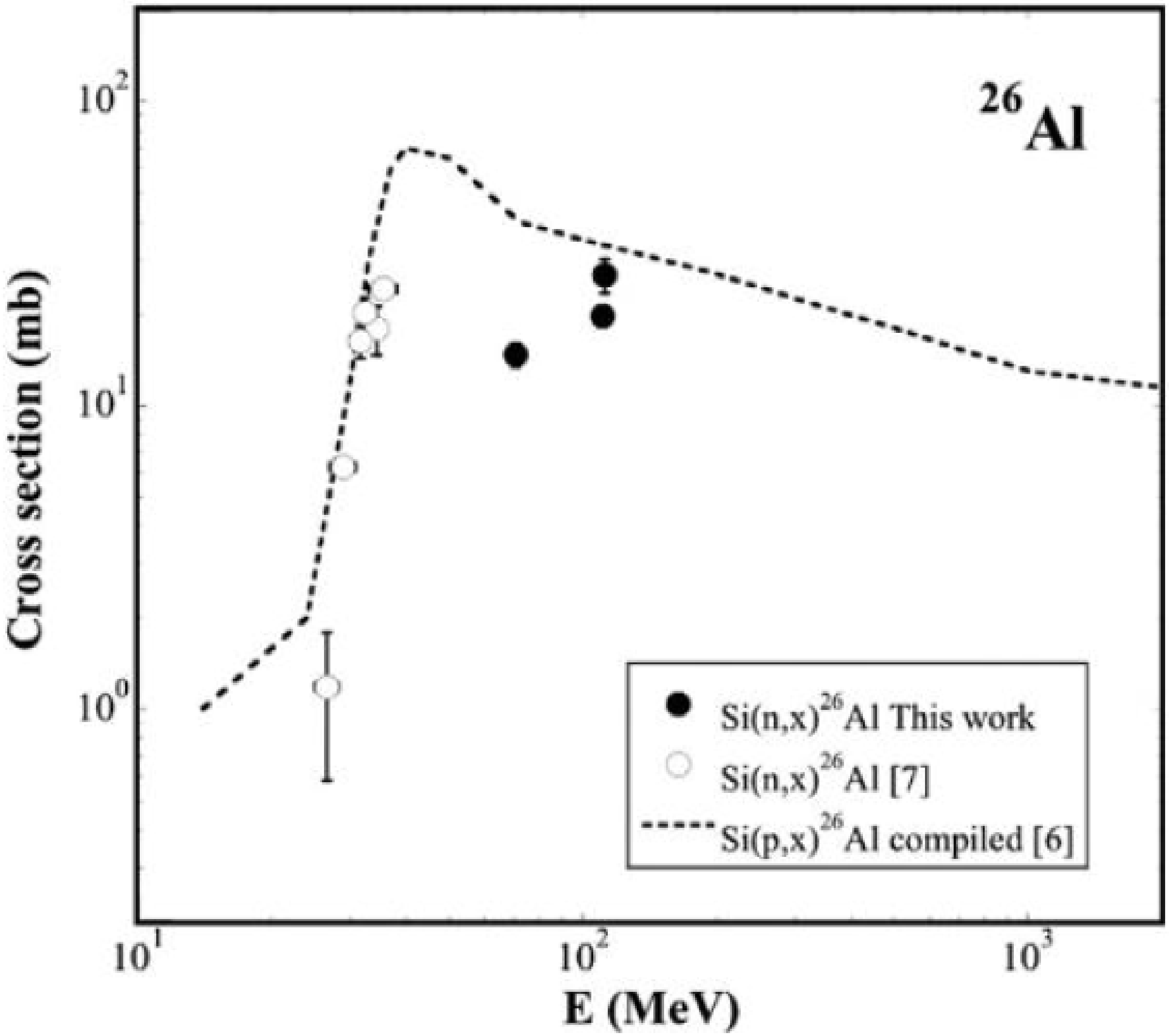
we need three ingredients

- the incoming flux neutrons/cm2 /sec
- the cross section cm2
- the number of target nuclei/ g

As a first exercise I will try to estimate the p-value for Al and the spallation process on quartz $Si(n,x)^{26}Al$

1. The cross section

My starting point to calculate the p-value for ^{26}Al was this plot from Luna giving the cross section to create ^{26}Al from the spallation process



Roughly between 50 MeV and 2000 MeV average σ is say 20 mb

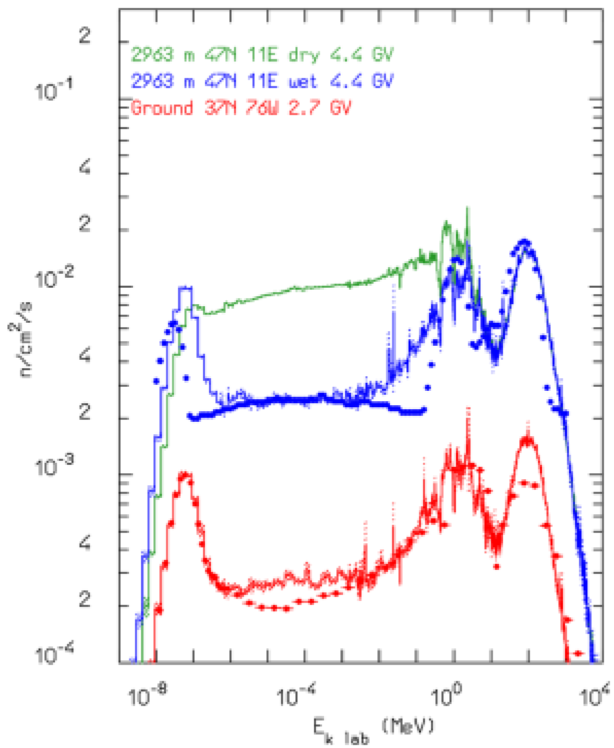
To go further we need to estimate the neutron flux in the energy range between 50 MeV and 2000 Mev

2. The flux

How to estimate the neutron flux in a given energy interval ?...

I need to calculate $\int d\Phi/dE$ where Φ is neutrons/cm2/sec/MeV and the integral from 50 MeV to 2000 MeV

Here I was confronted with some "problems"....

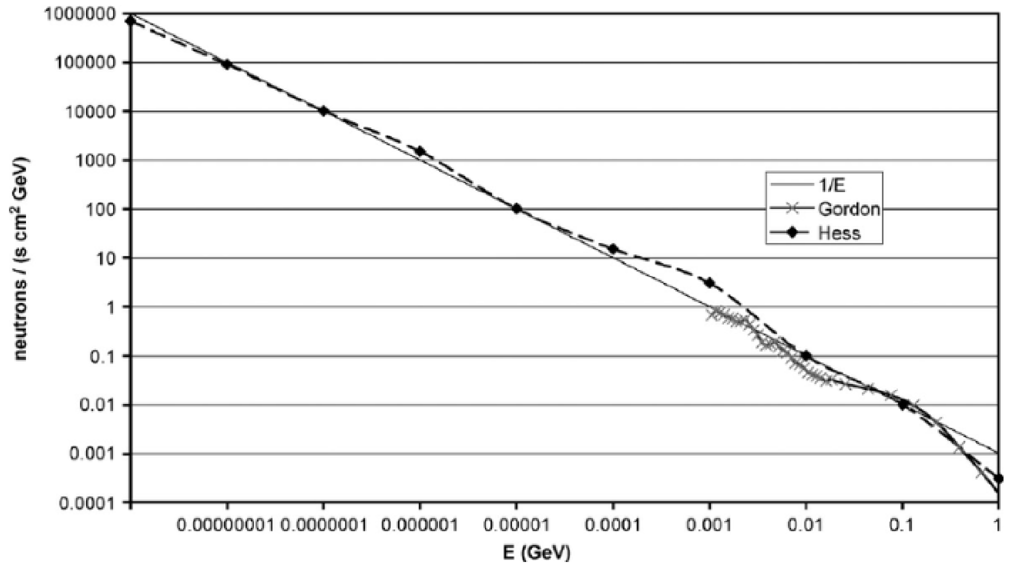


this is what we have

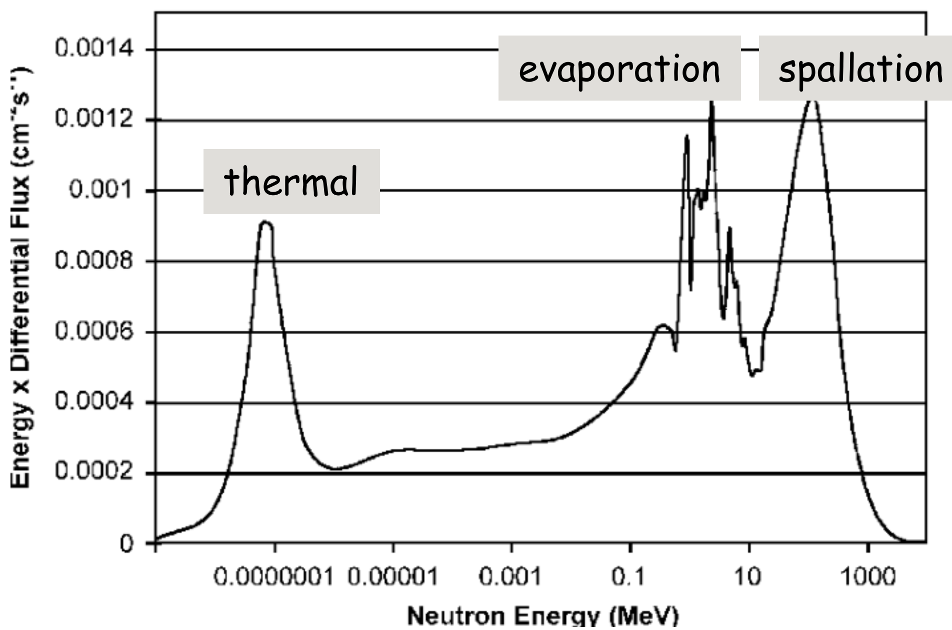
but what is plotted here is actually not the differential energy spectrum but E x Φ (E) ......

differential energy spectrum

$\Phi(E)$



$E \times \Phi(E)$

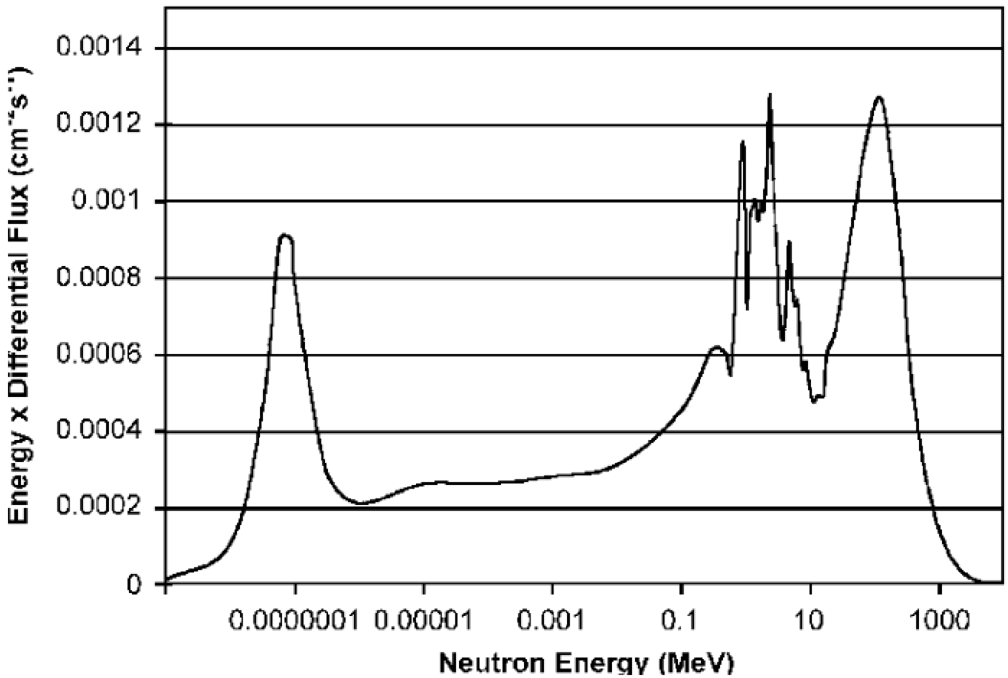


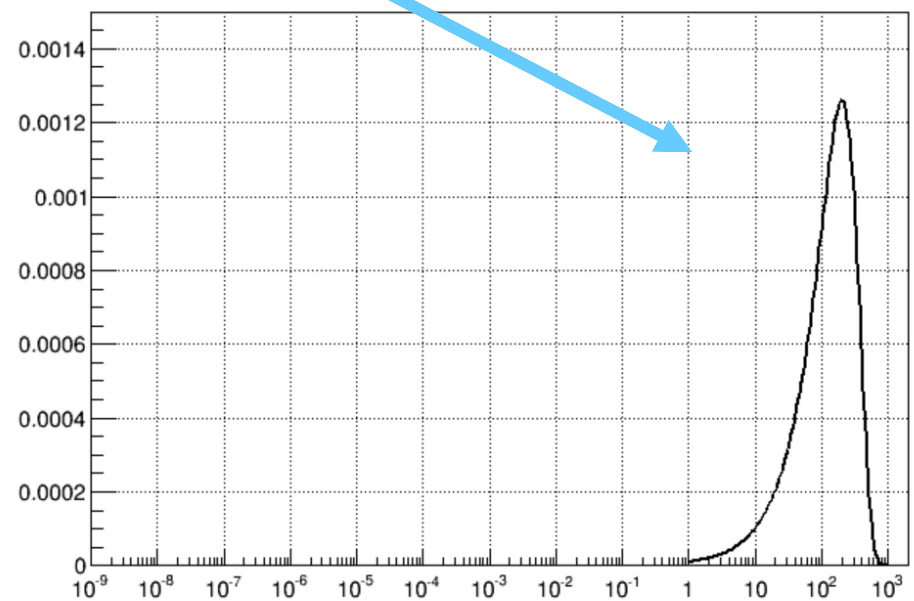
Typical neutron spectrum behavior:

- **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.

I need to know the neutron flux/cm2/sec in the spallation peak so what did I do ?

I adjusted the amplitude, mean and sigma of a gaussian for $\Phi(E)$ to get the $E \times \Phi(E)$ distribution for the spallation peak



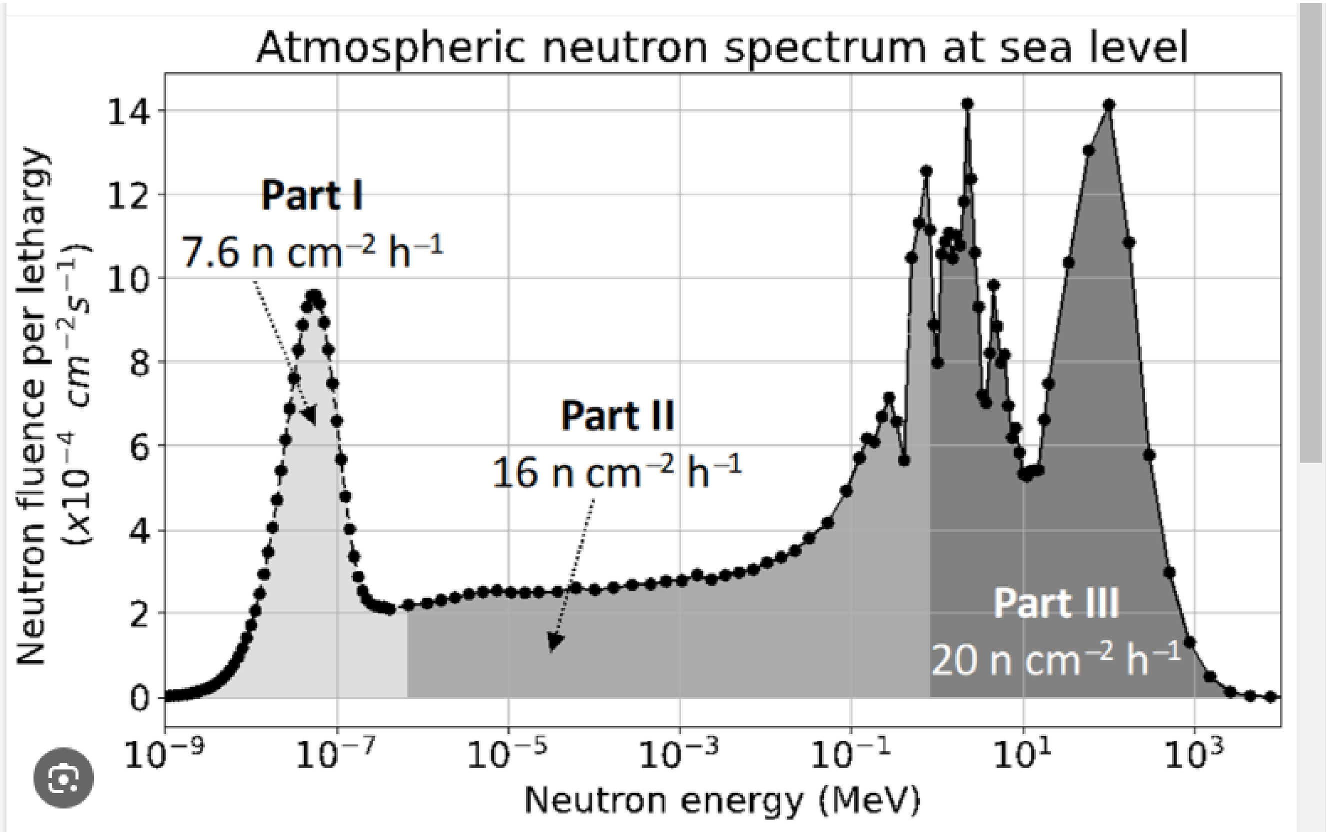


Afterwards I integrated the obtained $\Phi(E)$ distribution from 10 to 1000 MeV

integral 0.00249942

neutrons/cm2/sec → 9.0 neutrons /cm2/hour

Later I found this …thus I think my 9 neutrons/cm2/hour are in the correct ball park…..



may be there are more clever way to proceed knowing that

………$d\Phi/d(\log E) = E\, d\Phi/dE$!!

3. Target nuclei per gram

If the target is Si in quartz this is trivial using Avogadros number

Now as I have the flux and the cross section I can estimate the p26 -value for spallation neutrons

(p-value= flux(n/sec/cm2) * cross section(cm2)* Si atoms/ gr)

I will use as flux 12 neutrons/hour/cm2 and 20 mb as cross section

p26 (spallation) = **21 /atoms /g /year**

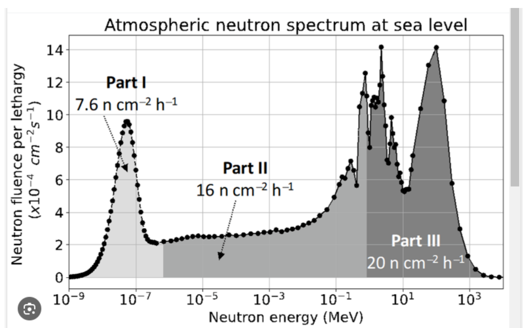
cf granger table 2 from exponential fits

P10 =4.5 at the surface

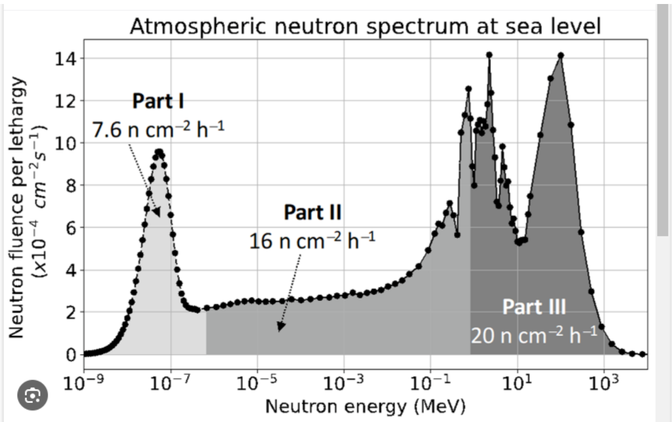
P26 = 4.5*6.8 = **30.6 atoms/gr/year** at sea level

Observe **21** atoms/g/year represents the spallation contribution and **30.6** is the total contribution

The contribution of Part I and Part II to the p-value remains to be estimated



Now I turn to an estimate a p-value for part I i.e. thermal neutrons

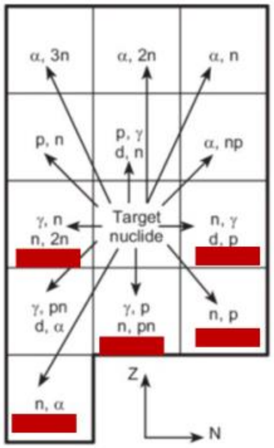


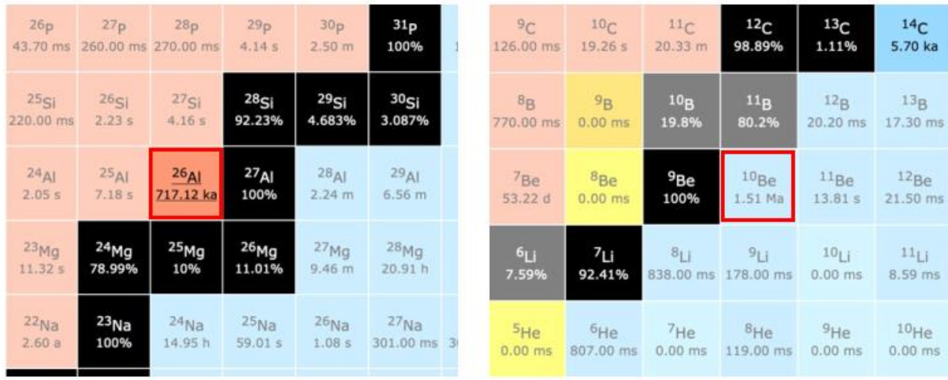
I redid my procedure for thermal neutrons
and found similar result as for spallation
in agreement with the 7.6 neutrons /cm2/h from
the plot

Now I need σ's for thermal neutrons creating Be10 or Al26 ?

lets look at Sara's slide

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





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,γ)^{26}Al]

Production ^{10}Be:

- ^{9}Be(n,γ)^{10}Be
- ^{10}B(n,p)^{10}Be
- ^{13}C(n,α)^{10}Be

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

Production ^{26}Al:

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

Production ^{10}Be:

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

Start with Be

1

- $^{9}Be(n,\gamma)^{10}Be$

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Measurement of the thermal neutron capture cross section by ^{9}Be using the neutron flux from a nuclear research reactor and the AMS technique

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We present the measurement of the thermal neutron capture cross section for the $^{9}Be(n,\gamma)^{10}Be$ reaction. The value we report of $\sigma = 9.7 \pm 0.53$ mb, indicates that previous publications underestimate this cross section. It is worthwhile to mention that, for this case, previous works are all indirect measurements, ours being the first direct one.

https://doi.org/10.1016/0375-9474(87)90514-8 ↗ Get rights and content ↗

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- $^{10}B(n,p)^{10}Be$

Abstract

Considering the varied geophysical applications of ^{10}Be, we have made an accurate measurement of the thermal neutron cross section for the reaction $^{10}B(n,p)^{10}Be$. In the literature, only upper and lower limit values have been reported for this cross section. Using the accelerator mass-spectrometric technique for the detection of ^{10}Be, we obtained a value of 6.8 ± 0.5 mb. This value is one order of magnitude lower than the cross section for the tritium channel in ^{11}B compound nucleus.

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- $^{13}C(n,\alpha)^{10}Be$

Has a negative Q-value of 3.7 keV and thus not possible with thermal neutrons

I use the EXFOR program indicated by Sara

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

Production ^{26}Al:

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

Production ^{10}Be:

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

Now Al

1

- $^{27}Al(n,2n)^{26}Al$

Has a negative Q-value of 1.3 MeV and thus not possible with thermal neutrons

2

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

Incoming proton

Thus no contribution to p26 from thermal neutrons

General question to discuss:
To what extent do we need to consider cosmic protons ??

To calculate the p-value for Be for thermal neutrons we need in addition to the flux and the cross section also the number of atoms per gram

I don't know how to calculate this but I see that

Be^9	represents	2-6 ppm	of earth crust
B^{10}	represents	10 ppm	of earth crust
SiO_2	represents	200000 ppm	of earth crust

From this assume that the number of Be9 and B10 atoms are down with order 10^{-4} relative quartz

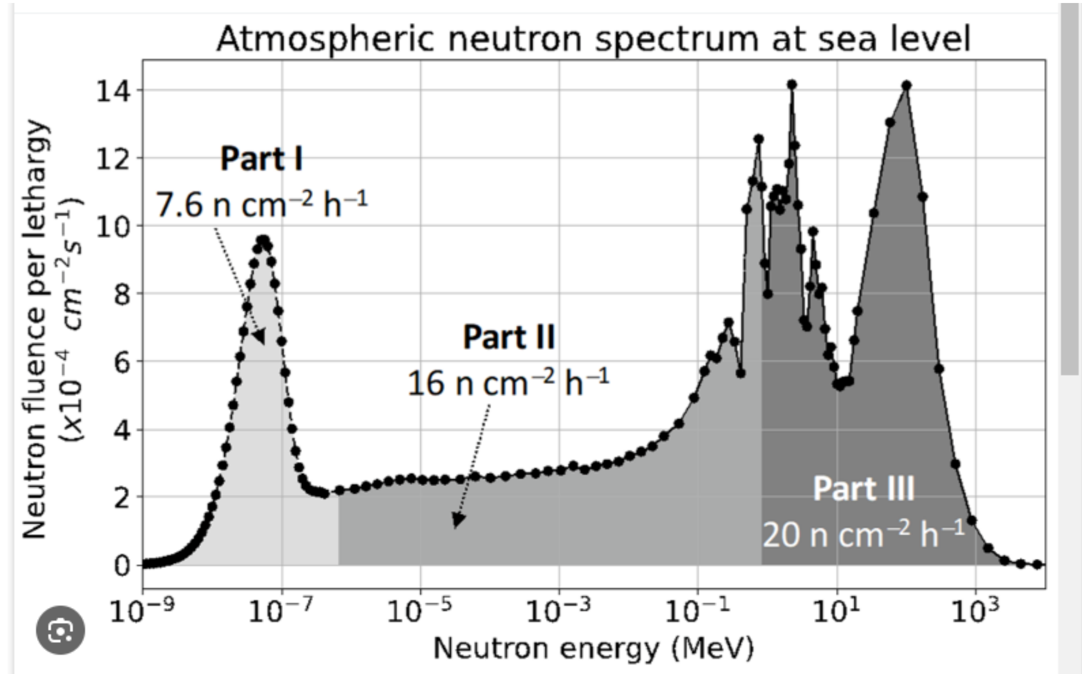
For spallation with a flux of 12 n/cm2/hour and a σ of 20 mb I got p26 = 21 /atoms /g /year

For thermal neutrons we have a flux of 7.6 n/cm2/hour and σ of order 10mb

BUT with order of 10^{-4} less target atoms

Thus I conclude that the contribution of thermal neutrons to the p-value is negligible next step…estimate contribution from part II ….

I have not yet tried this



Conclusion

- I have tried to estimate the p-value for the neutron induced spallation process and found a considerable contribution
- I have found that the contribution for thermal neutrons are negligible
- Estimates for the intermediate region have to be done
- All this have to be verified
- Are contributions from protons at the surface important?

Back up