Neutron flux and cross sections

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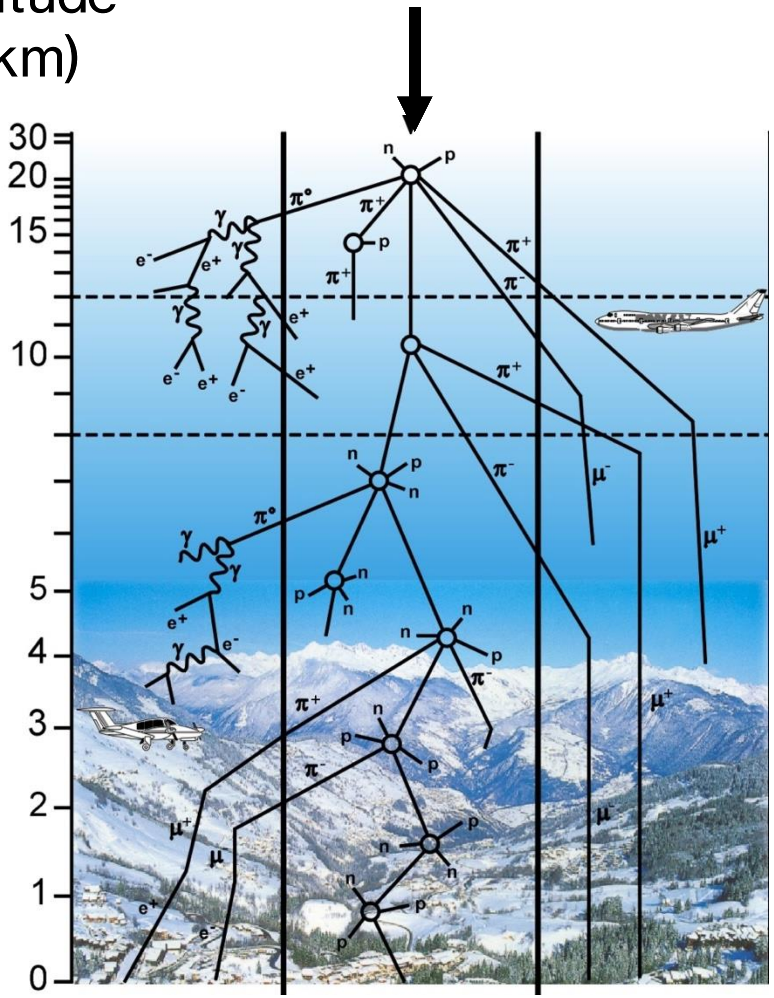
Neutron flux generated by cosmic rays

altitude (km)

cosmic ray proton

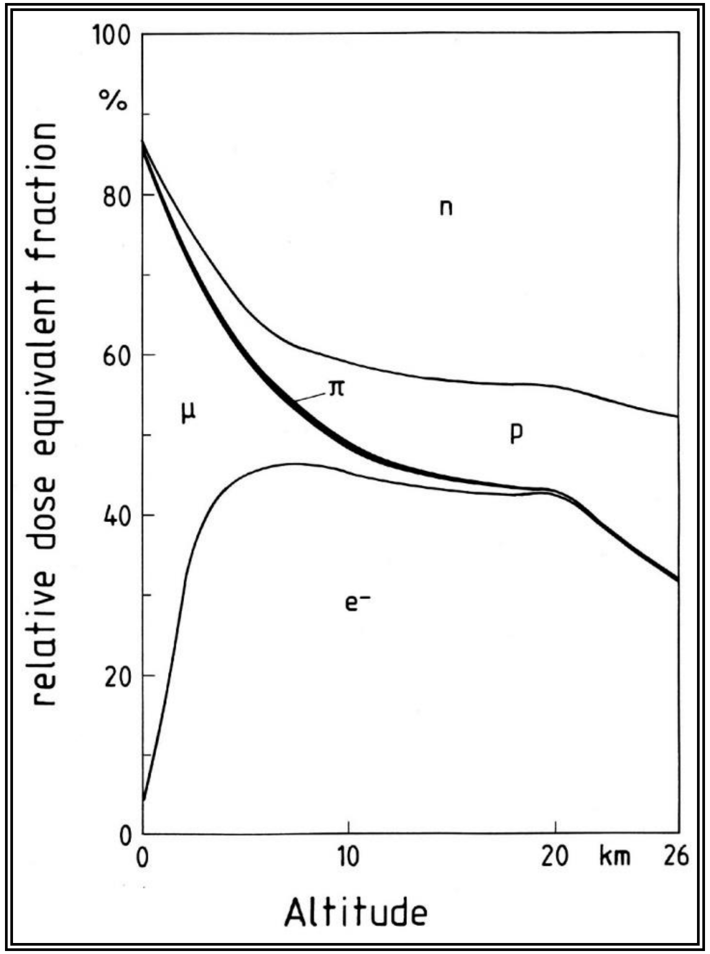


electrons and photons

pions, protons and **neutrons**

muons

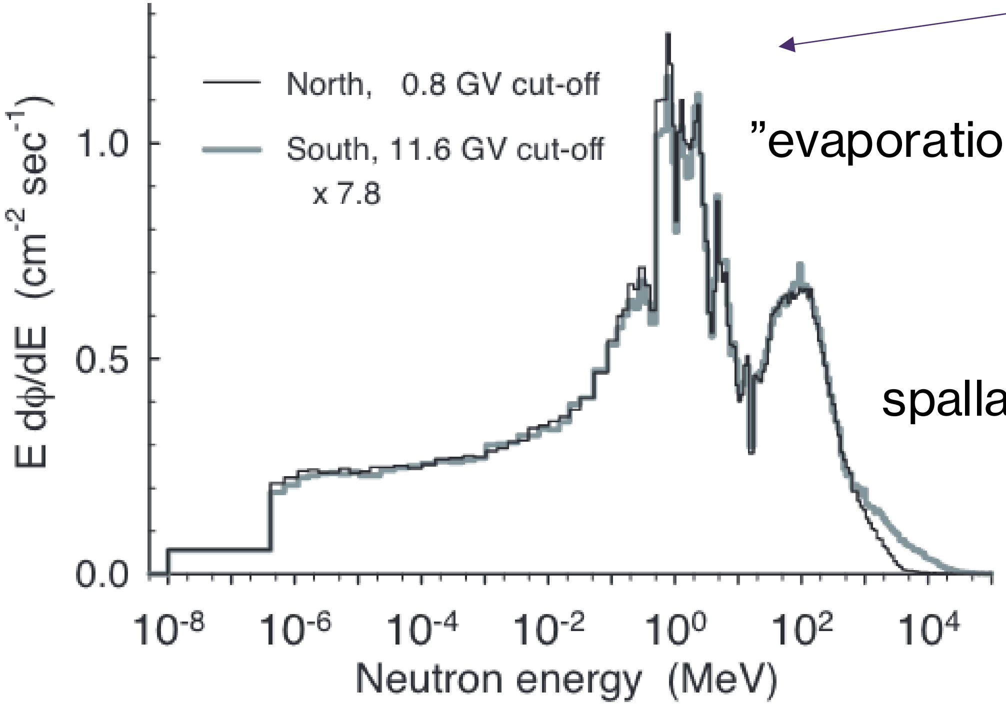
Secondary particles from spallation in earth's atmosphere



Neutron flux generated by cosmic rays

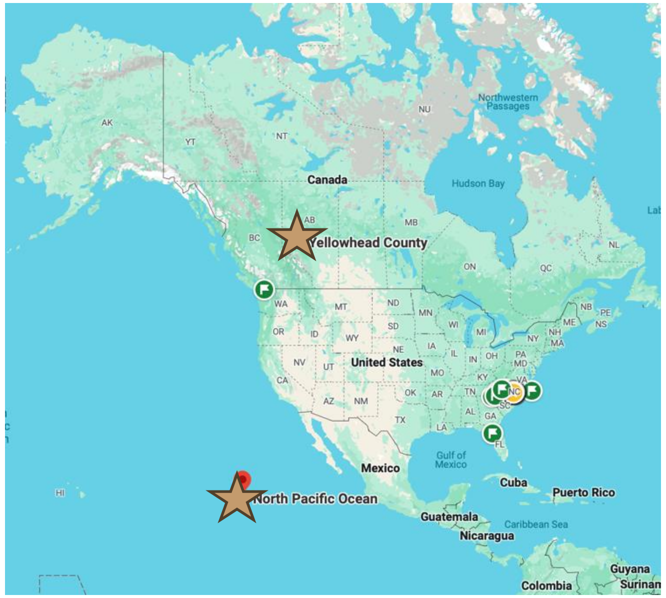
Intensity and energy distribution of different particles vary with **altitude, location in the geomagnetic filed and time in the sun's magnetic activity cycle.**

Neutron Flux @ 20 km altitude in two different locations



"evaporation peak"

spallation

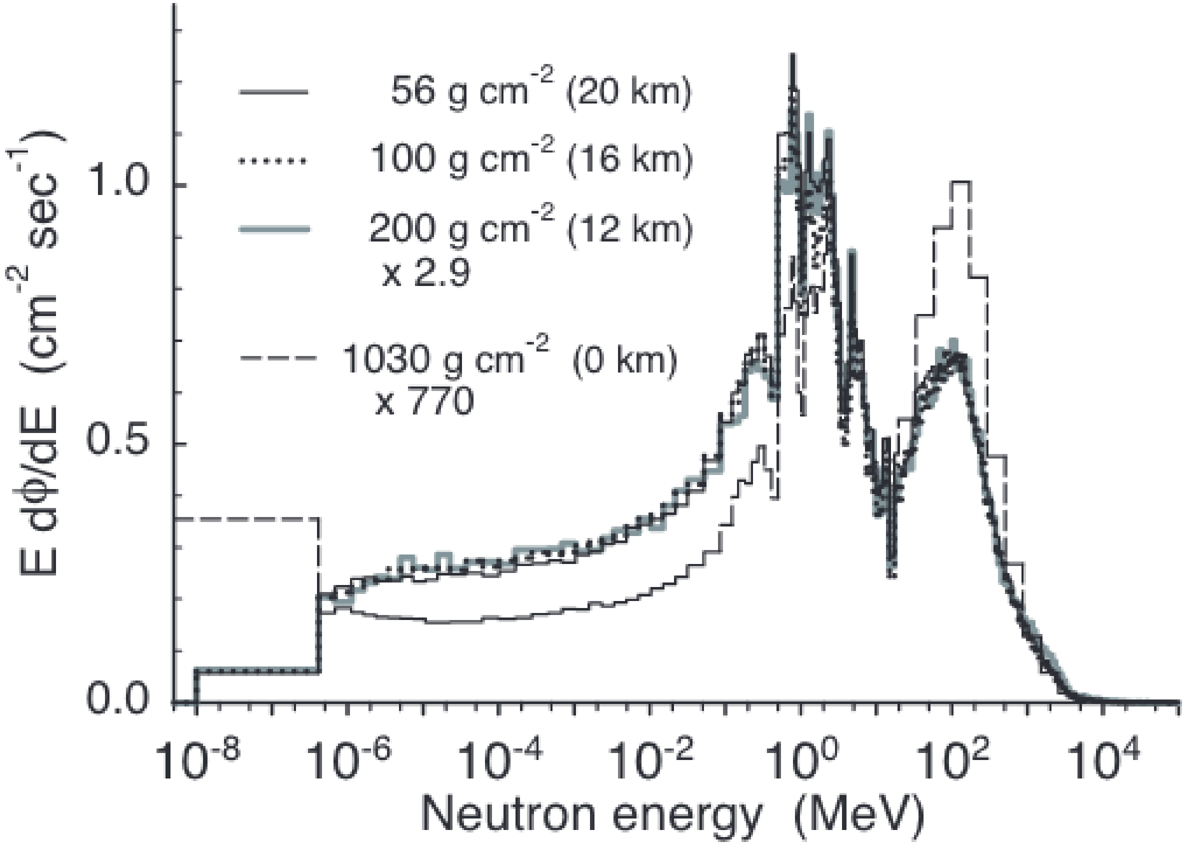


Strong dependence of neutron flux in different locations!

P. Goldhagen, J.M. Clem and J. W. Wilson, Radiation Protection Dosimetry (2004), Vol. 110, Nos 1-4, pp. 387±392 doi:10.1093/rpd/nch216

Flux Calculator → http://www.seutest.com/cgi-bin/FluxCalculator.cgi

The total neutron fluence rate at the northern location = 7.8 times the fluence rate at the southern location; The spectra have almost the same shape up to 1 GeV, but at high cut-off there is a significantly larger fraction of neutrons > 1 GeV.



P. Goldhagen, J.M. Clem and J. W. Wilson, Radiation Protection Dosimetry (2004), Vol. 110, Nos 1-4, pp. 387±392 doi:10.1093/rpd/nch216

At high altitude, **geomagnetic latitude small but measurable effect on the shape of the spectrum and a very large effect on neutron fluence rate.**

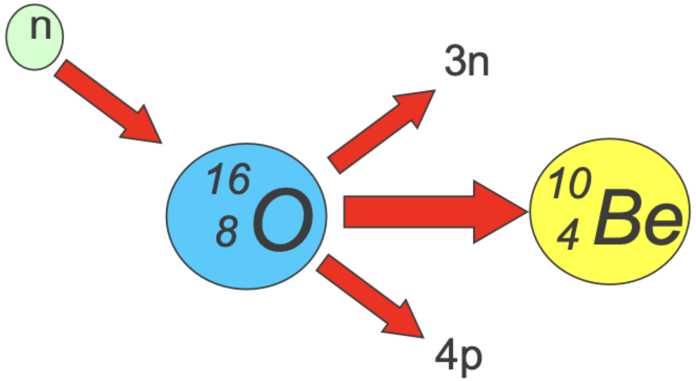
The shape of the cosmic-ray **neutron spectrum changes very slightly with altitude from 20 km down to 12 km** (56-201 gcm^{-2} atmospheric depth), **but it is very different on the ground.**

To my knowledge:
- No atmospheric neutron flux were measured in South Africa
- Can be measured with Bonner sphere of different dimensions and we could do it outside the Caves
- Developments of plastic scintillator to be used for measurements (UCT)

Cross sections for production of ^{26}Al and ^{10}Be

Quartz – SiO_2 ^{28}Si(Z=14, N=14) and ^{16}O(Z=8, N=8) → ^{26}Al(Z=13, N=13) and ^{10}Be(Z=4, N=6)

^{26}Al produce from Si → Si(n,x)^{26}Al
^{10}Be produced from O but also from Si → O(n,x)^{10}Be and Si(n,x)^{10}Be

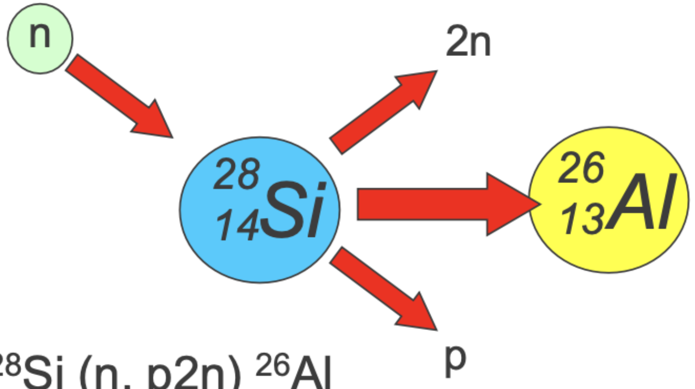


^{16}O (n, 4p3n) ^{10}Be

^{26}Al – 1st excited state is a short-lived isomer that beta decay to 26Mg

Ground and isomeric state information for $^{26}_{13}$Al

E(level) (MeV)	Jπ	Mass Excess (keV)	$T_{1/2}$	Decay Modes
0.0	5+	-12210.14 *7*	7.17E+5 y *17*	ε+β+ = 100%
0.2283	0+	-11981.83 *7*	6.34603 s *54*	ε+β+ = 100%



^{28}Si (n, p2n) ^{26}Al

^{10}Be – no isomers

Ground and isomeric state information for $^{10}_{4}$Be

E(level) (MeV)	Jπ	Mass Excess (keV)	$T_{1/2}$	Decay Modes
0.0	0+	12607.49 *8*	1.386E+6 y *12*	β^- = 100%

Cosmogenic-nuclide production rates

Basic calculation the production rate of a nuclide at one location depends:

- on the composition of the sample,
- the fluxes of the particles (mainly neutrons and protons) to which that sample is exposed,
- and the excitation functions (cross sections as a function of energy) for all important reactions.

AT THE EARTH'S SURFACE MAIN PRODUCTION VIA NEUTRON INTERACTION

Particle fluxes usually calculated using codes like MCNPX, GEANT4

Nuclides are produced by **neutron reactions**:

- **via capture reactions** (low energy neutrons 0.01 – 10 eV → capture cross sections are well determined)
- **spallation reactions** induced by neutrons with energy above 1 MeV up to GeV → **cross sections not known!**

R.C. Reedy, Nuclear Instruments and Methods in Physics Research B 294 (2013) 470–474
M.W. Caffee et al. Nuclear Instruments and Methods in Physics Research B 294 (2013) 479–483

Cosmogenic-nuclide production rates

Since cross sections are not known:
→ **cross sections for proton-induced reactions** are often used instead for neutron-induced reactions.

This assumption is **fairly good for nuclide** like ^{26}Al that are between **two stable nuclides or that are similar in binding energy per nucleon to an adjacent stable nucleus.** Occasionally, a particle-specific reaction such as ^{24}Mg(n,a)^{21}Ne, ^{39}K(n,a)^{36}Cl, or ^{56}Fe(p,a)^{53}Mn, needs to be added or deleted.

The assumption of approximately **equal proton and neutron cross sections fails for products far from the region of the stable isotopes**, such as neutron-rich ^{14}C and ^{10}Be.

Cross sections for analogous reactions of the same reaction type can be used to estimate cross sections, such as those for ^{58}Ni(n,2n)^{57}Ni and ^{59}Co(n,2n)^{58}Co reactions used for the ^{42}Ca(n,2n)^{41}Ca reaction. Some adjustments, such as for the threshold energies of the reactions, often are needed.

There are many formulae and codes → However, most formula and codes give cross sections for an individual nuclide that **typically differ from measured ones by factors of 2**, and the use of such codes for getting good cross sections is limited.

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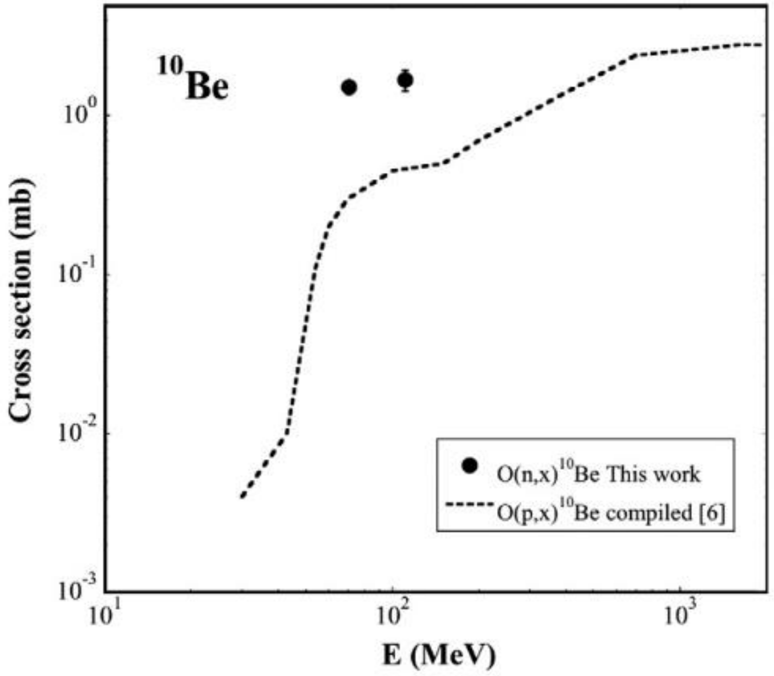
Neutron cross sections

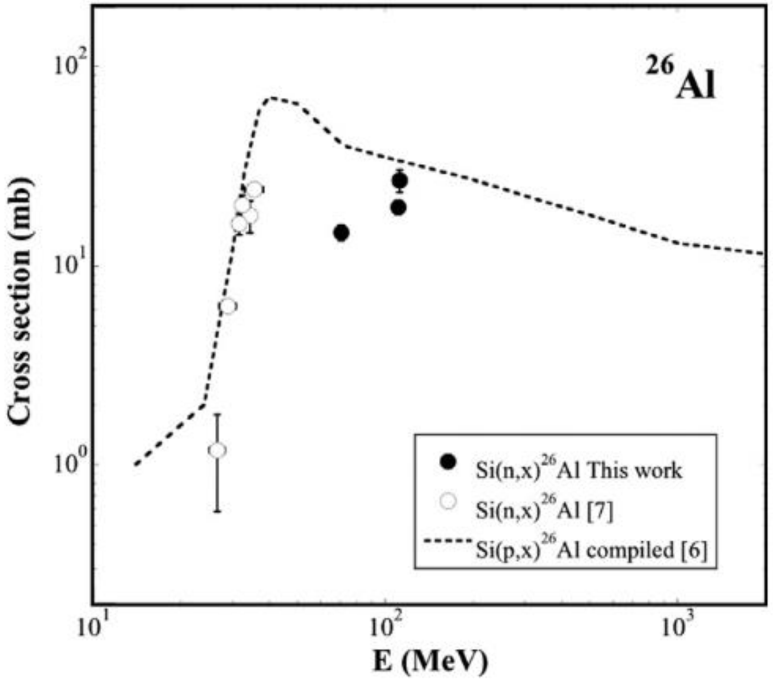
M.W. Caffee et al. Nuclear Instruments and Methods in Physics Research B 294 (2013) 479–483

Measurement performed at iThemba LABS with quasi-monoenergetic neutrons



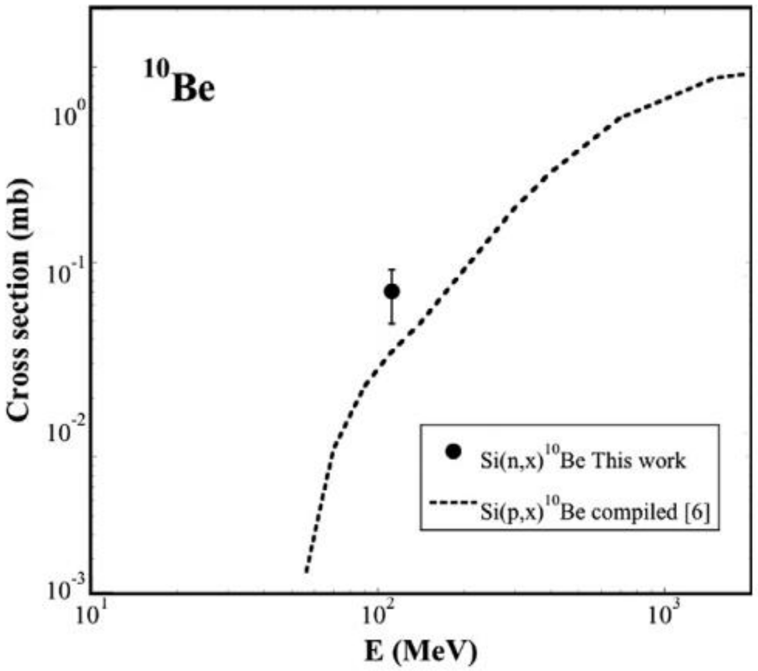
O(n,x)^{10}Be

Measured n-xs factor 3-5 higher but 30-50% lower than the one estimated by Monte Carlo models



Si(n,x)^{26}Al

Xs neutrons are similar to those from protons at low energies (<40 MeV) while at higher neutron energies the measured neutron cross sections from this experiment are lower than the corresponding proton cross sections.



Si(n,x)^{10}Be

The neutron induced cross section is slightly higher than the corresponding proton cross section.

Comments and questions

- Neutron flux varies with location and no measurements are available at Cave location. Might be interesting to investigating that.
- Cross sections for reactions for neutron energies above 30 MeV are needed → using quasi-monoenergietic neutron at iThemba LABS (and AMS measurements)

How much this uncertainties affect the production rates I am not sure. Need to do more reading and maybe understand better the calculation codes …

Which are the neutron flux and cross sections used in the calculations for the production parameters?