Cosmic Ray Secondary Exposure Model for Low Background Detectors

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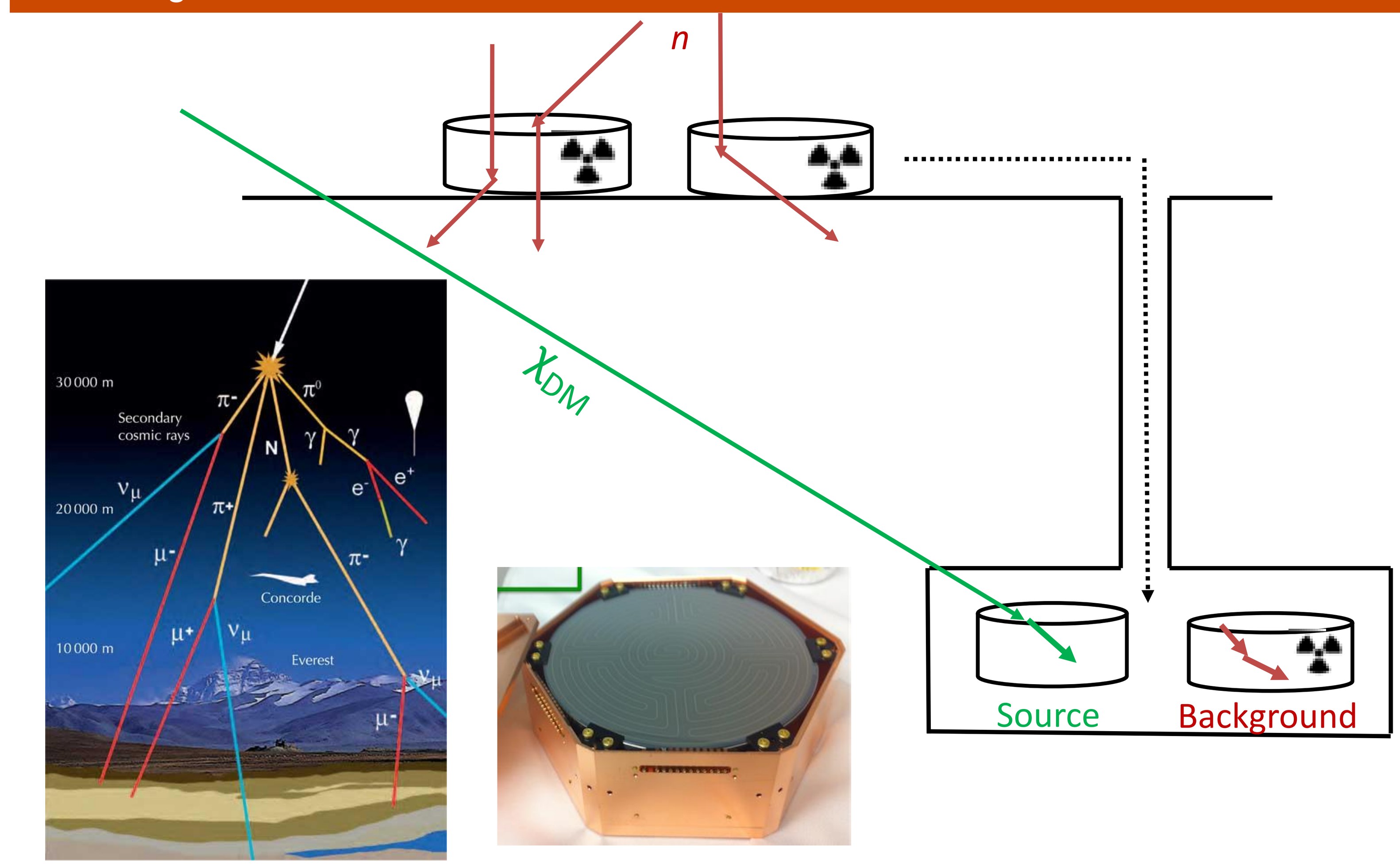
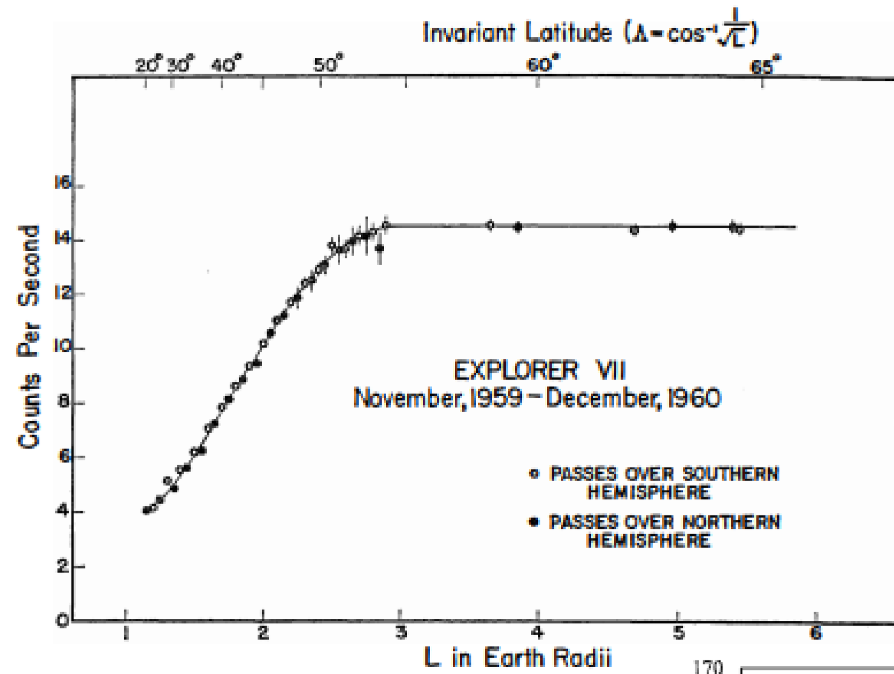
Dark Matter and Neutron Interactions:
The SuperCDMS experiment will attempt to detect dark matter particle interactions with germanium crystals by collecting recoil energies from particle collisions. Cosmic ray secondaries can produce radioactive isotopes in the germanium crystals during fabrication, which causes background energy signatures which may obscure the dark matter signal.



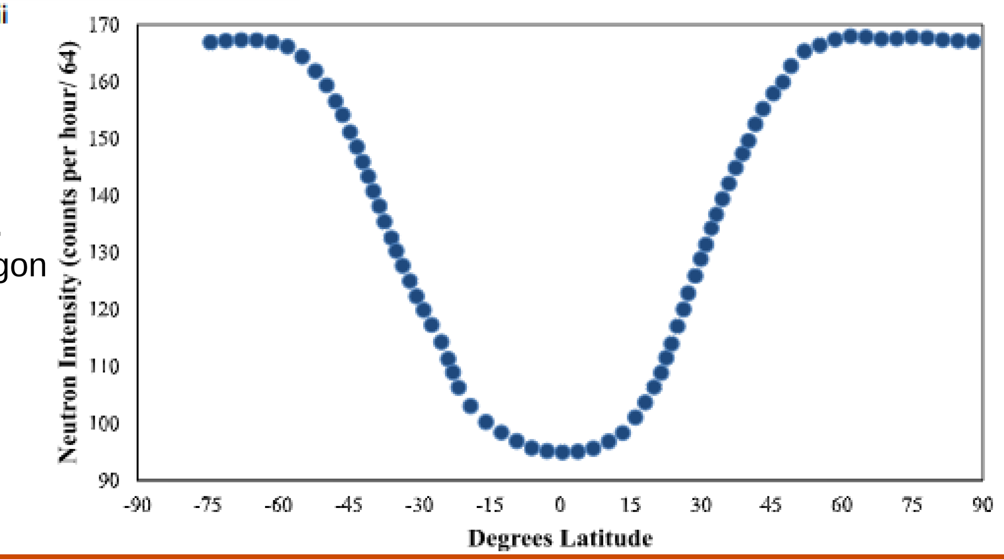
Bottom left: The germanium detectors used in the SuperCDMS detector and cosmic ray secondary showers showing multiple fundamental particles. Sources: Stanford National Accelerator Laboratory. PhysicsOpenLab.

Top right: Schematics showing how cosmic ray secondaries (red) can create radioactive isotopes in the SuperCDMS detectors, which will eventually decay, releasing energy that could be mistaken as a dark matter (green) particle interaction.

Impact of Geomagnetic Latitude:
The Earth's magnetic field impacts the probability of cosmic ray secondaries reaching sea level. When primary particles hit the Earth's magnetic field their initial path is bent, and the resulting secondaries' paths are also bent. The magnetic field can impact cosmic rays reaching sea level by a factor of up to two times. There is also a two times change in flux from the geomagnetic equator to the poles.

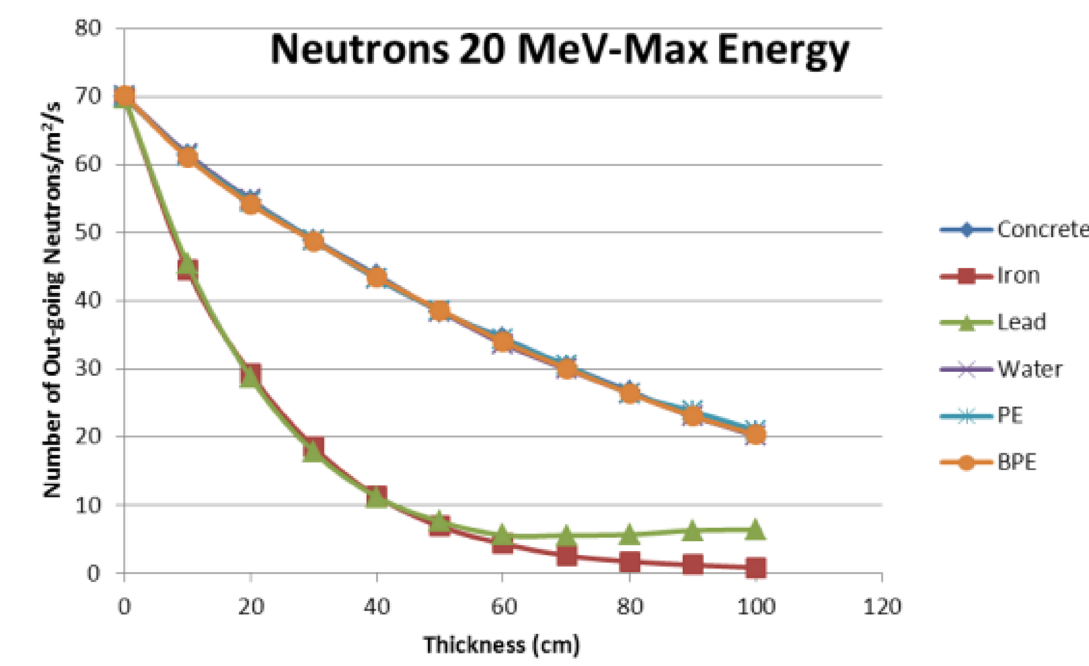


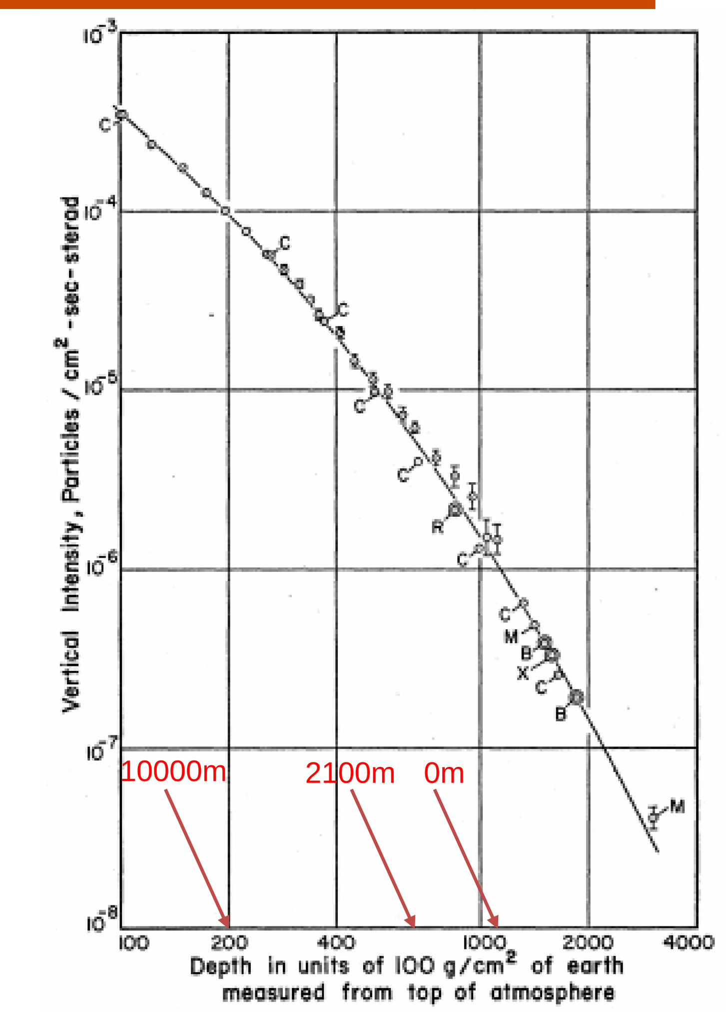
Earth's geomagnetic latitude compared to neutron interaction counts per second. Sources: W. C. Lin, Latitude Survey of Cosmic-Ray Intensity by Explorer 7, October 1959 to February 1961, Journal of Geophysical Research 68 (1963) 4885-4896.



Earth's geomagnetic latitude compared to neutron interaction counts per hour / 64. Sources: C. Johnson, Examination of radioargon production by cosmic neutron interactions, Journal of Environmental Radioactivity 140 (2015) 123-129.

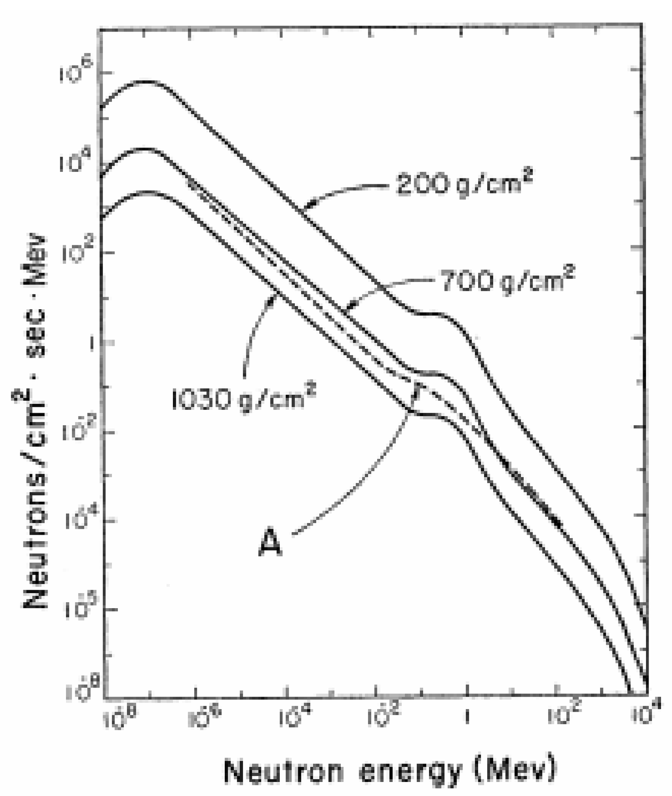
Impact of Shielding:
There are several factors that affect the shielding of a detector, including depth below ground and the materials used to surround the detector. Above 20 MeV, iron outperforms concrete, water, PE, and BPE in shielding secondaries by a factor of 20 and outperforms lead by a factor of 5. At depths greater than 1000 g/cm^2, neutron induced reactions are insignificant.

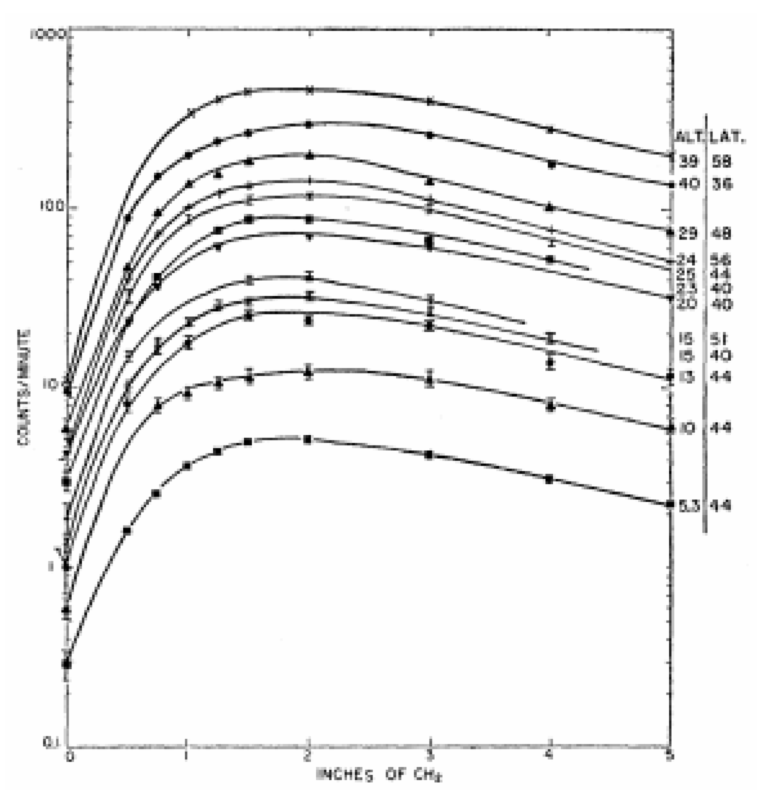




Comparison of shielding materials of various thicknesses compared to neutron counts per second and shielding depth in the earth compared to neutron counts per second. Sources: E. Aguayo, Cosmic Ray Interactions in Shielding Materials, Pacific Northwest National Laboratory PNNL-20693 (2011). P.H. Barrett, Interpretation of Cosmic-Ray Measurements Far Underground, Review of Modern Physics 24 (1952) 133-178.

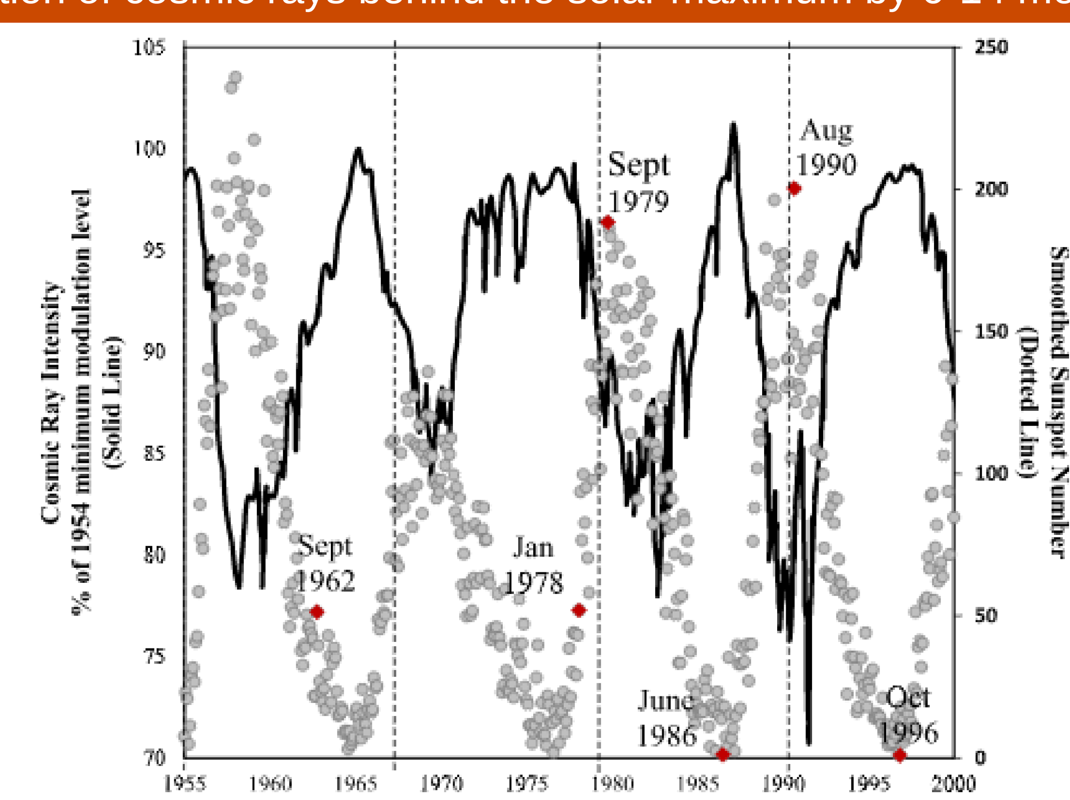
Impact of Elevation Above Sea Level:
Elevation above sea level has a large impact on neutron flux measurements. There is a 10x increase in the neutron flux at all energies at an elevation of 2100m (700 g/cm^2) compared to sea level (1030 g/cm^2) neutron flux.





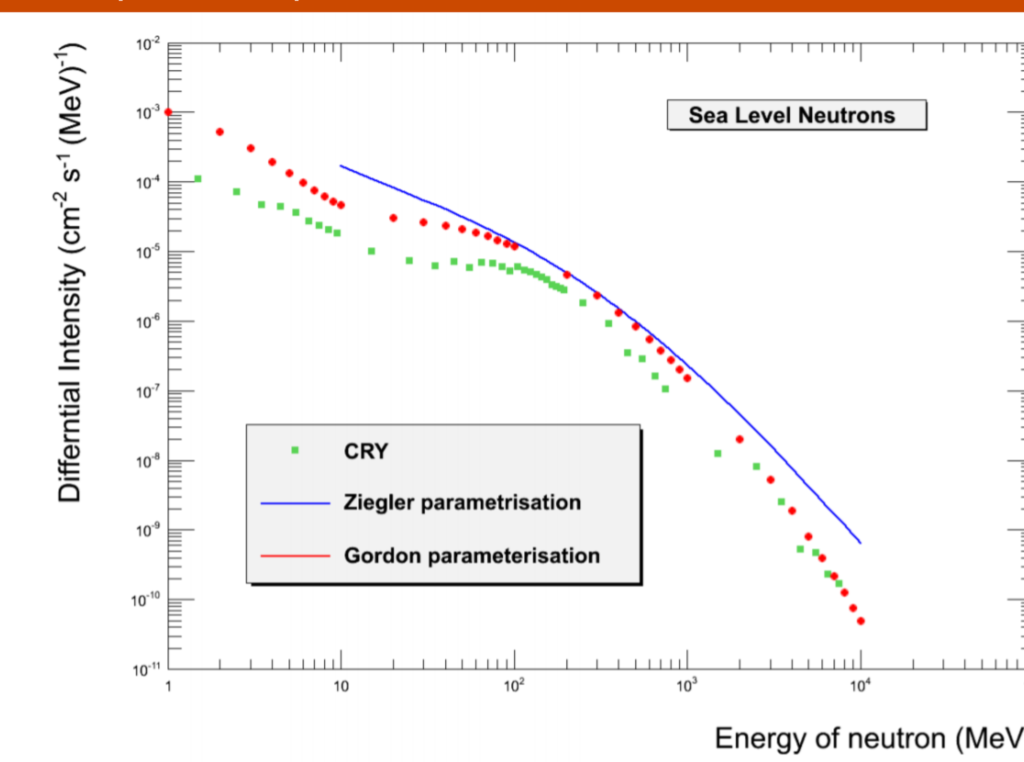
Neutron energy in MeV compared to counts per second for three different elevations (sea level, 2100m, and 10000m) and inches of shielding compared to counts per minute for several different altitudes and latitudes. Source: W.N. Hess et al., Cosmic ray neutron energy spectrum, Phys. Rev. 116 (1959) 445-457.

Impact of Solar Cycle:
Cosmic ray neutron flux and the solar activity cycle (approximated by sunspot number) are anti-correlated, meaning at solar maximum the cosmic ray flux at Earth is reduced and at solar minimum the cosmic ray flux at Earth is increased. There exists a time lag in the reduction of cosmic rays behind the solar maximum by 6-14 months.



Cosmic ray intensity compared to smoothed sunspot number, a measure of solar activity, from 1955 to 2000. Source: C. Johnson, Examination of radioargon production by cosmic neutron interactions, Journal of Environmental Radioactivity 140 (2015) 123-129.

Conclusions:
In comparing the various factors described, three models were determined to be the most successful at determining the rate of neutron exposure applied to dark matter detectors: CRY (2012), Ziegler (1998), and Gordon (2004). Future work will determine which model should be used for cosmic ray secondary exposure and how these models should be expanded upon.



Comparison of the three best neutron exposure models as a function of energy of neutrons in MeV and differential intensity. Source: V.A. Kudryavtsev, Cosmogenic activation: Recent results, AIP Conference Proceedings 1921 (2018) 090004.

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Acknowledgements
The 2019 STEM Teacher and Researcher Program and this project have been made possible through support from Chevron (www.chevron.com), the National Science Foundation through the Robert Noyce Program under Grant #1836335 and 1340110, the California State University Office of the Chancellor, and California Polytechnic State University in partnership with Pacific Northwest National Laboratory. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the funders.

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