Neutron Production Rates in DM Detector Materials

Tia K. Martineau, University of Massachusetts Dartmouth – SULI Program
Alan E. Robinson, Fermilab

Background

Inferred properties of dark matter particles have suggested that particles beyond those described in the Standard Model, known as weakly interacting massive particles (WIMPs), are reasonable dark matter candidates. These dark matter particles can be detected directly by observing nuclear recoil from the interaction between WIMPs and a large target nucleus. [1] One of the sources of background radiation for direct detection dark matter experiments is neutrons produced by (α,n) nuclear reactions in detector materials. These (α,n) events are difficult to distinguish from those involving WIMPs.

Using the programming language Python, an open source calculator is being developed to calculate the anisotropic reaction rates from the (α,n) nuclear reaction process. It will also be able to calculate the angles and energies of outgoing neutrons produced in order to minimize the amount of background radiation present in these experiments.

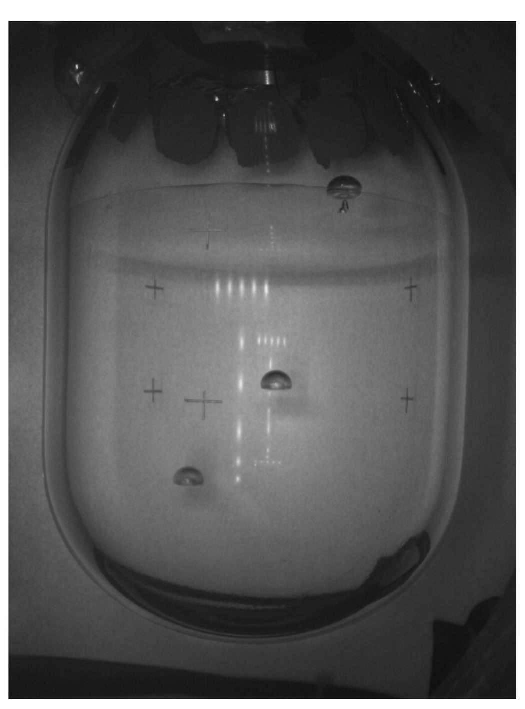

Figure 1 (left): Direct detection dark matter experiments detect nuclear recoils. This photo is of an event in COUPP-4kg with bubbles created by three nuclear recoils from neutrons produced in (α,n) nuclear reactions. Such neutron backgrounds that mimic dark matter are common to many different dark matter experiments. [3]

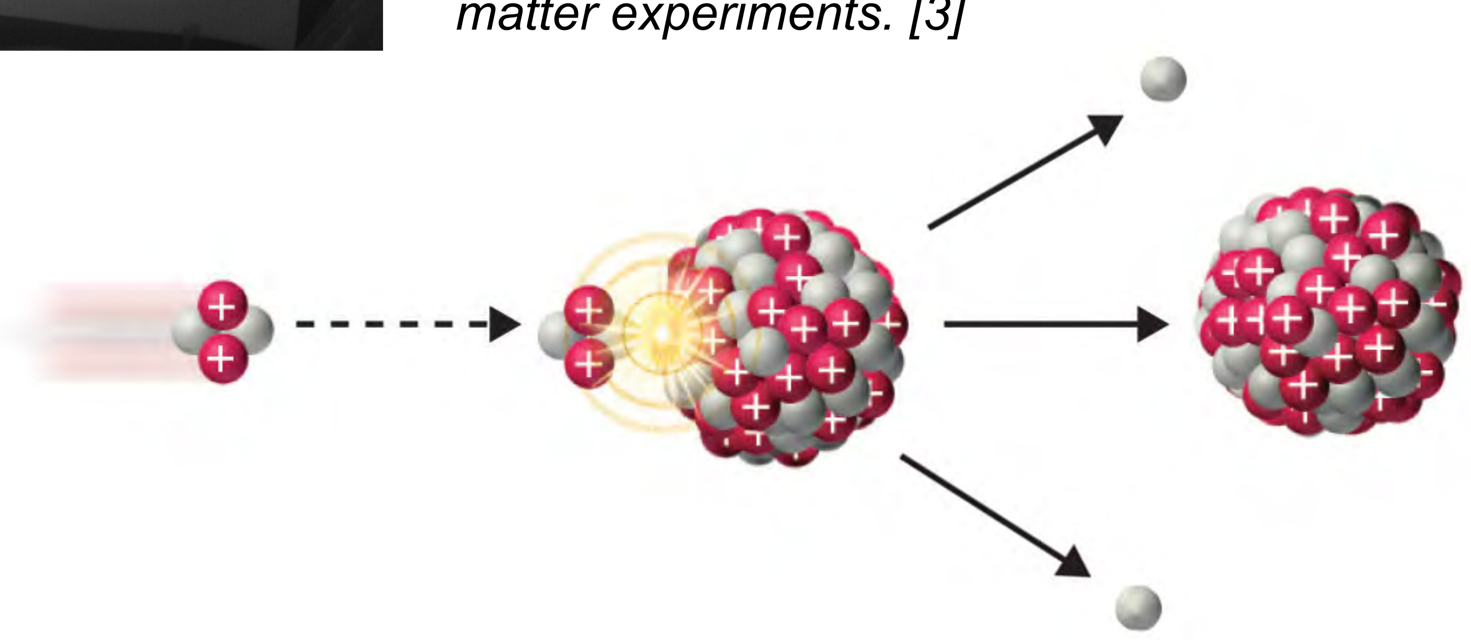

Figure 2 (above): An α-particle interacting with an atom of a given detector material and producing an α decay and a number of neutrons.

Algorithm

- Run a stopping power calculation in order to determine loss of energy in an alpha particle as it travels over a certain distance through a given material.
- The proportion of neutron-generating α-particles in the nuclear event can be calculated given a calculated stopping power and a reaction cross section when an integral of cross section over the stopping power is taken:

$$\frac{N_n}{N_\alpha} = \int_0^{E_{\alpha,max}} \frac{\sigma_{\alpha,n}}{\rho \frac{dE_\alpha}{dx}} (dE_\alpha)$$

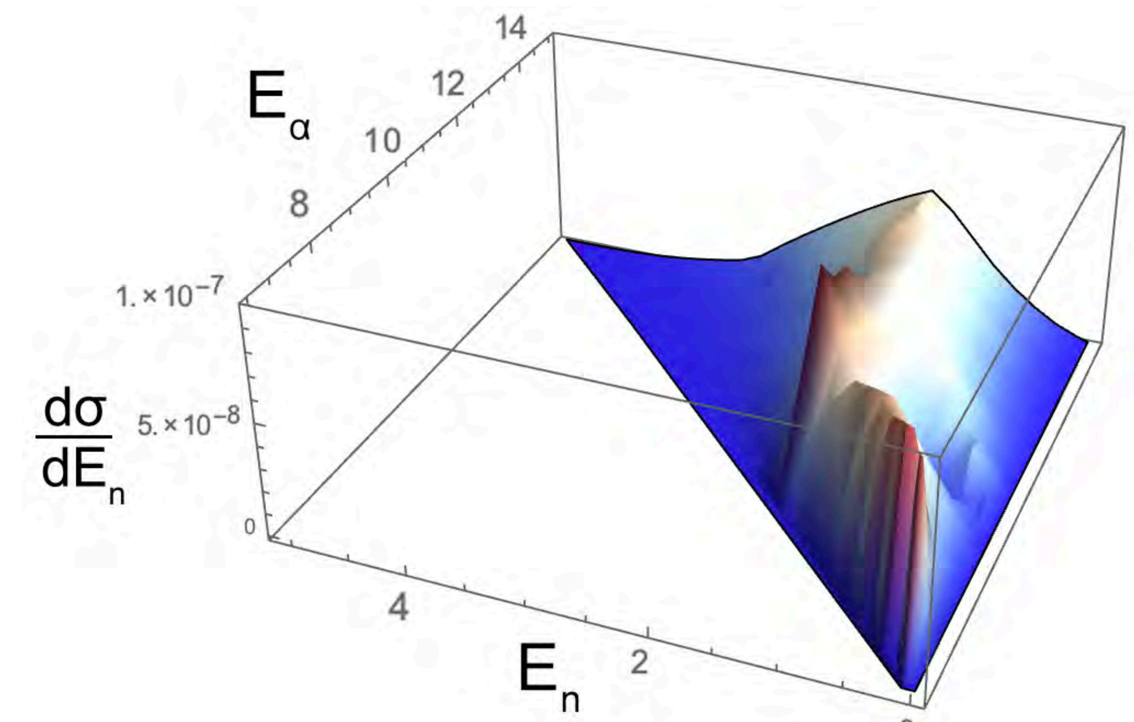

Figure 3 (left): A surface plot of the reaction's differential cross section in the laboratory frame of reference as a function of α-particle energy and neutron energy.

- Produce a range of the distribution of neutron energies emitted by running calculated values through a double integral over the energy of a stopping alpha particle.

$$\frac{\left(\frac{dN_n}{dE_{n,lab}}\right)}{N_\alpha} = \int_0^{E_{\alpha,max}} dE_\alpha \int d\Omega_{lab} \frac{\left(\frac{\partial \sigma_{\alpha,n}}{\partial E_{n,com} \partial \Omega_{com}}\right)\left(\frac{\partial \Omega_{com}}{\partial \Omega_{lab}}\right)\left(\frac{\partial E_{n,com}}{\partial E_{n,lab}}\right)}{\rho \frac{dE_\alpha}{dx}}$$

In order to construct the code that has been written thus far, data was used from the The Nuclear Data Center of the Japan Atomic Energy Agency. The Japanese Evaluated Nuclear Data Library, (JENDL), contains neutron-induced reaction data for approximately 406 nuclides, in the energy range from 10^{-5} eV to 20 MeV. [2]

Results

We intend to develop the calculator further so that it will take into account the possibility of detectors made of materials containing more than one element. We will also expand upon the number of target isotopes available in the calculator.

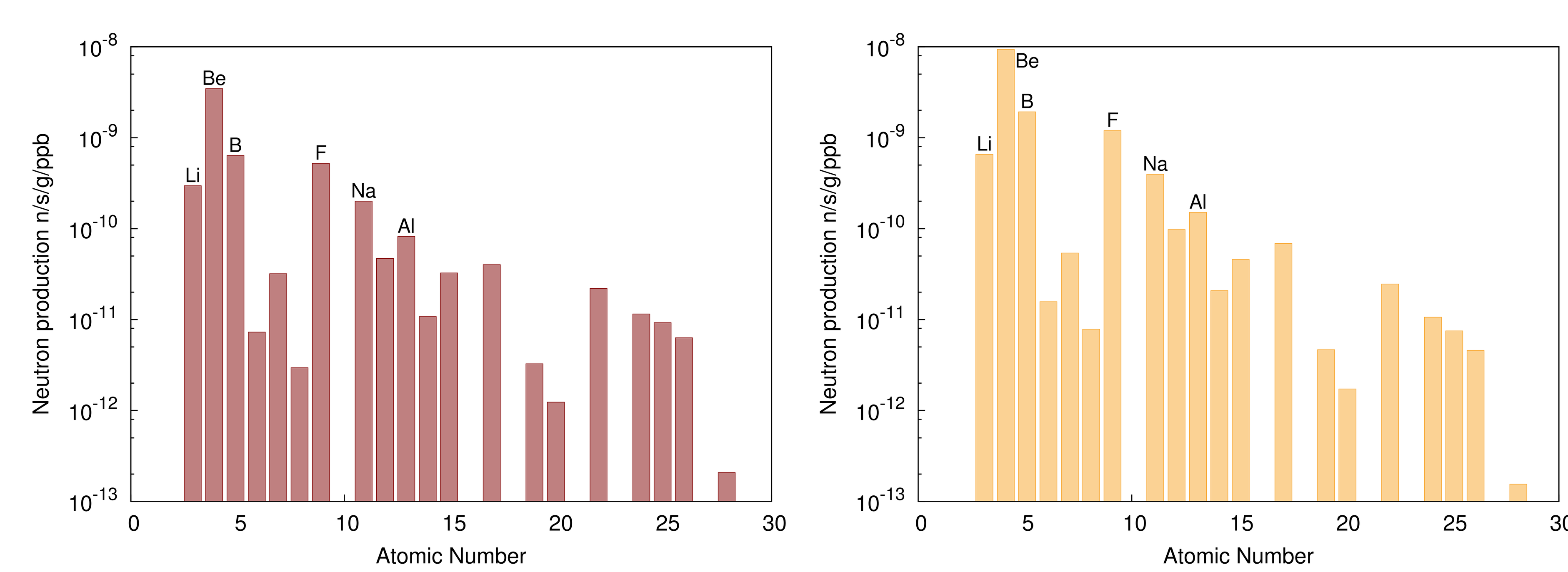

Figure 4 (above): A sample of (α,n) neutron yields from the Th-232 (left) and U-238 (right) decay chains for each element. [4]

References

[1] P. Cushman et al. Snowmass CF1 Final Summary Report: WIMP Dark Matter Direct Detection, arXiv:1310.8327 (2013).
[2] "JENDL," wwwndc.jaea.go.jp, 2016. [Online]. Available: http://wwwndc.jaea.go.jp/jendl/jendl.html. [Accessed: 22-Jul-2016].
[3] FCPA, private communication, July 2016.
[4] A. Robinson, Ph.D. thesis, University of Chicago (2015).

Acknowledgments

I would like to thank my mentor, Alan Robinson, and coordinators Erik Ramberg and Roger Dixon for their help throughout the internship. Ongoing research is supported in part by the U.S. Department of Energy, Office of Science, Office of Workforce Development for Teachers and Scientists (WDTS) as a part of the Science Undergraduate Laboratory Internship (SULI) Program at the Fermi National Accelerator Laboratory (FNAL).