Neutron Transport Studies in Fe using Pulsed Spheres

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Basic Motivations

- Neutron total cross sections on important materials are generally known to $\sim 1\%$.
- The uncertainty in the division between elastic and non-elastic is often 10% or more.

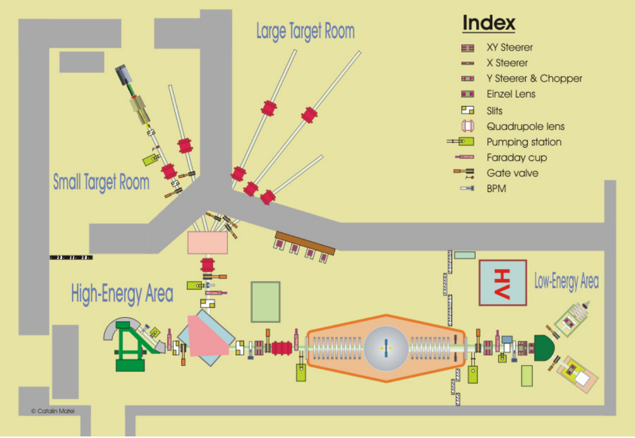
Idealized Scenario

- Consider a mono-energetic pulsed neutron source located at the center of a sphere of the material in question.
  - The material is a ∼few mean-free-paths thickness
  - The neutron energy may be measure by time of flight
- Attenuation of the mono-energetic neutrons may be measured by comparing sphere-on to sphere-off.
  - This provides a measure of the non-elastic cross section.
- Lower-energy neutrons are sensitive to (n, n') cross sections.
- This scenario can approximately realized using the $^{3}\mathrm{H}(d, n)$ reaction with deuteron energies below 0.5 MeV:
  - $E_n \approx 14$ MeV
  - $\approx$ isotropic

Real World Scenario

- Neutron sources are neither isotropic nor mono-energetic.
- For accelerator-based sources, the beam must reach a target at the center of the sphere.
- The total path length contributes to the time of flight.
- ...
- But we have MCNP simulations!
- We have focused on Fe (natural) and the D(d,n) neutron source, with $E_d \approx 7.0$ MeV, that provides $E_n \approx 10$ MeV at $0°$.

Edwards Accelerator Laboratory



- 4.5-MV Tandem Accelerator
- Pelletron charging system, upgraded to Alphatross He ion source
- Unique beam swinger and 30-m TOF tunnel
- Specializations: TOF techniques, neutrons
- `http://inpp.ohio.edu/~oual/`

ARUNA Association for Research at University Nuclear Accelerators

EAL

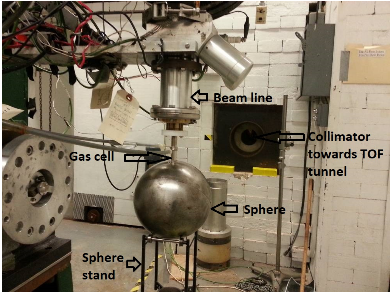
Beam Swinger

- Up to 30-m flight path
- Very well shielded (4’ concrete)
- Beamline is rotatable: $0^\circ \leq \theta_{\text{lab}} \leq 155^\circ$

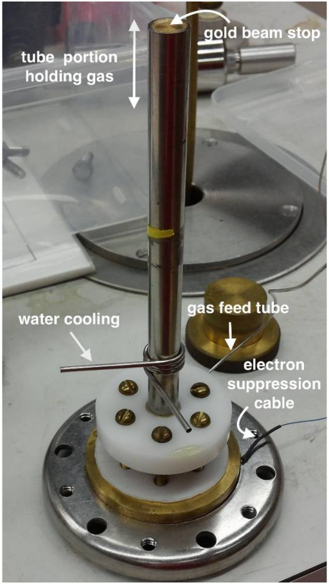
Iron Sphere Experiment

- D(d,n) neutron source:
  $E_d \approx 7.0$ MeV
  $E_n \approx 10$ MeV at $0°$
- 8-m flight path
- NE-213 liquid scintillator
- $0° \leq \theta_{\text{lab}} \leq 155°$
- "small" sphere:
  15.0-cm diameter
  3.0-cm thickness
- "large" sphere:
  21.0-cm diameter
  8.0-cm thickness

small sphere



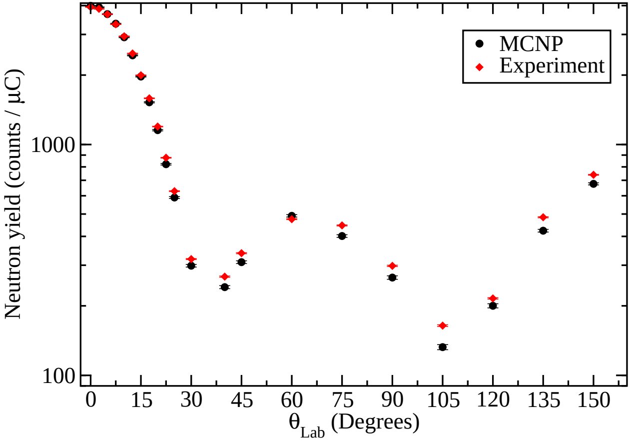
Gas Cell



gold beam stop
tube portion
holding gas
water cooling
gas feed tube
electron
suppression
cable

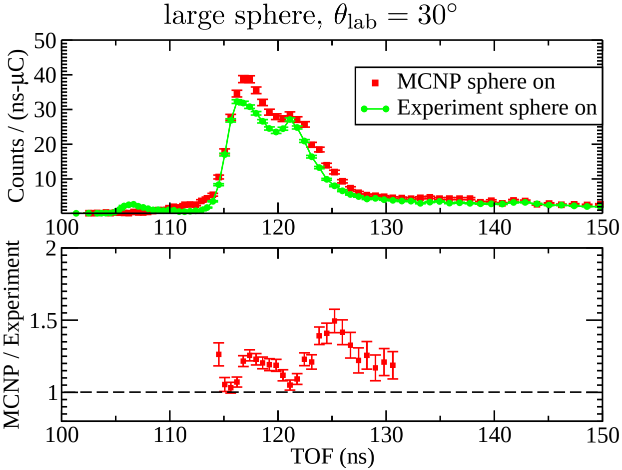
Small Iron Sphere

D(d,n) Source Yield



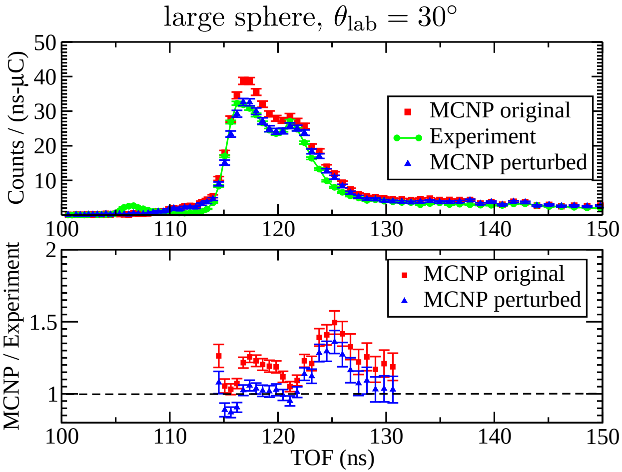
Simulation includes D(d,n) differential cross section, neutron detection efficiency, and many additional effects.

Typical Results



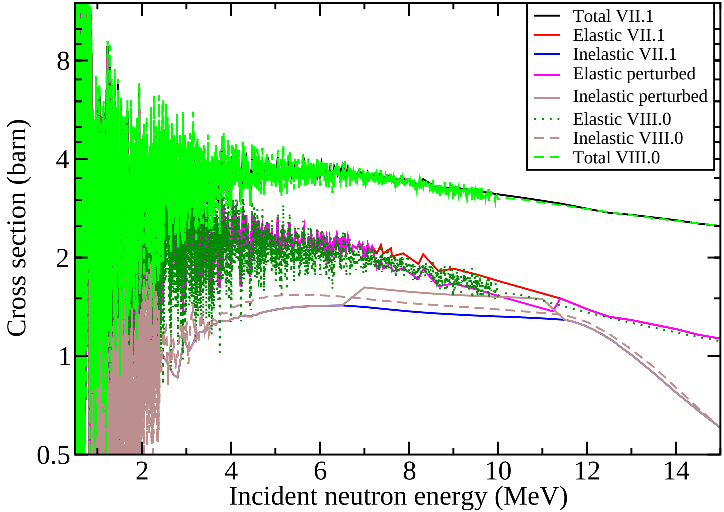
- MCNP simulation includes the ENDF/BVII.1 cross section library for iron.
- This results suggests that ENDF/BVII.1 over-estimates the elastic cross section.

Adjusting the Simulation



- Adjusting the ENDF/BVII.1 ^{56}Fe elastic cross section down by 10%, and the inelastic up by 15% (keeping the total cross section constant), leads to a much better description of the experimental data.
- Note that systematic errors in the data are estimated to be 3-5%.

ENDF Cross Sections



Documentation of Findings

- Results are published: Sushil Dhakal *et al.*, Nucl. Sci. Eng. **193**, 1033 (2019).
- Supplementary files include *all* of the data, as well as the MCNP input file and custom neutron source routine `source.f90`.
- This information is also available in Sushil Dhakal's thesis: `http://rave.ohiolink.edu/etdc/view?acc_num=ohiou1478097309006943`

^{56}Fe Neutron Cross Section

We are not alone in suggesting these changes:

- Cross section measurements of A.P.D. Ramirez *et al.*, Phys. Rev. C **95**, 064605 (2017).
- Ramsauer model predictions, e.g., R.W. Bauer *et al.*, Phys. Rev. C **130**, 348 (1998).
- The new ENDF/BVIII.0 evaluation.

Future Improvements and Directions

- Utilize longer flight paths.
- More robust time-of-flight calibration.
- Study additional materials:
  - C, Cr, Mn, Ni, Cu, Zr ?
- Partnerships between universities and national laboratories.

Two Workshops this Summer

Ohio University
@ Athens, Ohio:

- The 2020 R-matrix Workshop on Methods and Applications
  June 22-26, 2020
  http://indico.frib.msu.edu/event/29/overview
- T^3 Taking the Temperature: Workshop on Statistical Physics for Astrophysics and Applications
  July 13-16, 2020
  http://inpp.ohio.edu/~T3
- Student support available

Thank you for your attention.

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