Neutron irradiations at the University of Birmingham High Flux Accelerator Driven Neutron Facility (HF-ADNeF)

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High-Flux Accelerator Driven Neutron Facility (HF-ADNeF)

HF-ADNeF Overview

- Neutron Therapeutics machine
- Hyperion type: 0.4-2.6 MV single-ended electrostatic acceleration
- Easily achievable and stable > 30 (up to 50) mA protons delivered onto (600 rpm) rotating Li target
- Solid Li target, 0.3-mm-thick, copper backed and water cooled to produce neutrons via $^{7}\mathrm{Li}(p, n)$

Broad applications

- Nuclear materials research under neutron irradiation
- Nuclear fission/fusion data e.g. neutron capture cross section data
- Nuclear waste management, understanding the long term effects of radiation on material characteristics
- High power target development
- Medical physics:
  - BNCT developments: **Kiran Nutter - Wednesday III Session A (14:30)**
  - Medical isotope production: **Max Conroy - Monday Poster Session**
  - Radiobiology
- Industrial and space research on the effect of radiation
- Nuclear metrology, calibrated and controllable neutron source availability and testing of new radiation monitoring systems
- Nuclear astrophysics

Target room

- $\approx$ 3x3 m^2 of space in the room
- Lead shielding to protect from ^{7}Be accumulated in the target ($\sim$ TBq)
- 42 mm from target to outside of vacuum vessel (incl. 3 mm Cu, 7 mm graphite, 6 mm Ti)

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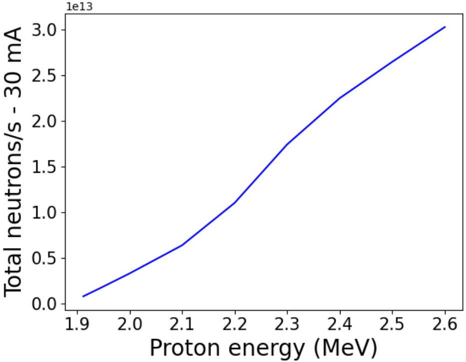
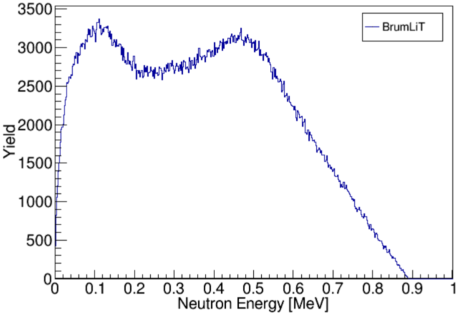
Neutron yields - 30 mA protons



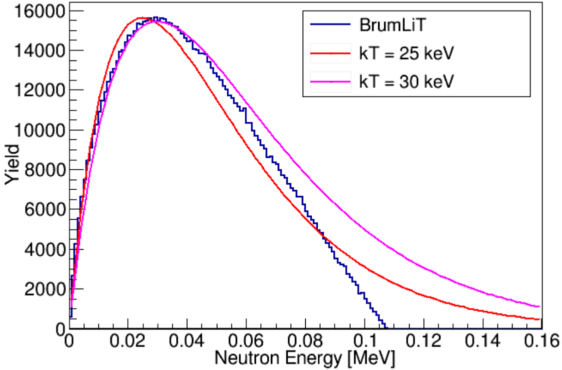
$E_p = 2.6$ MeV



PLUS: Deuteron beams coming in the future will allow for a factor of ~5 increase in intensity and energies of ≈ 14 MeV (DT neutron energies)

s-process studies

Choosing the right energy of protons ($E_p = 1.912$ MeV) gives a neutron energy spectrum with roughly kT=30 keV - perfect for s-process studies



Calculate the Maxwellian Averaged Cross Section (MACs) directly for (n,γ)

Masters project: Studies of gamma-ray signature in stars, ^{60}Co

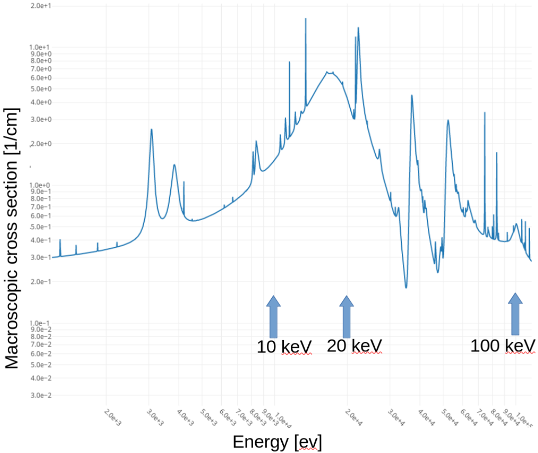
- Irradiate to do: $^{59}\mathrm{Co}(n,\gamma)^{60}$Co
- Abundance from ^{60}Co β-delayed gamma rays
- Get MACs for $^{59}\mathrm{Co}(n,\gamma)^{60}$Co (known)
- Breeding ^{60}Co in the target allows us to study:
  - $^{60}\mathrm{Co}(n,\gamma)^{61}$Co (not known)

Tim Williams & Patrick Galvin

- ^{61}Co half life of 1.65 hours shows need for high intensity to reach realistic equilibrium activity for background - 67 keV gamma (or 3.6% 917.5 keV)
- Activity of cobalt measured relative to Mo, Mn and Au
- Big discrepancies found in measured vs. expected MACS

Target flange scattering effects

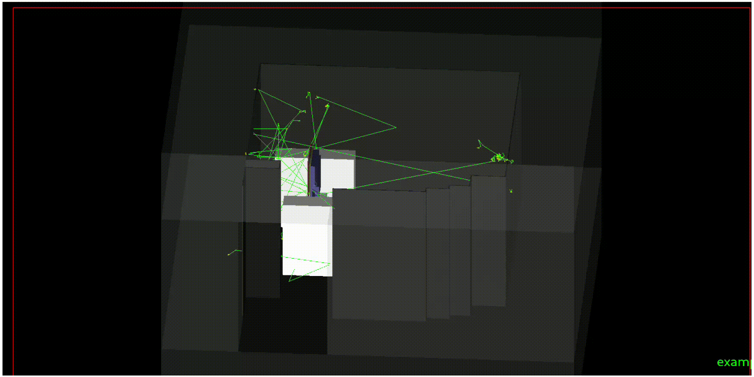
Neutrons travel through 6 mm of titanium (vacuum vessel)
Energy range of interest: 0-100 keV



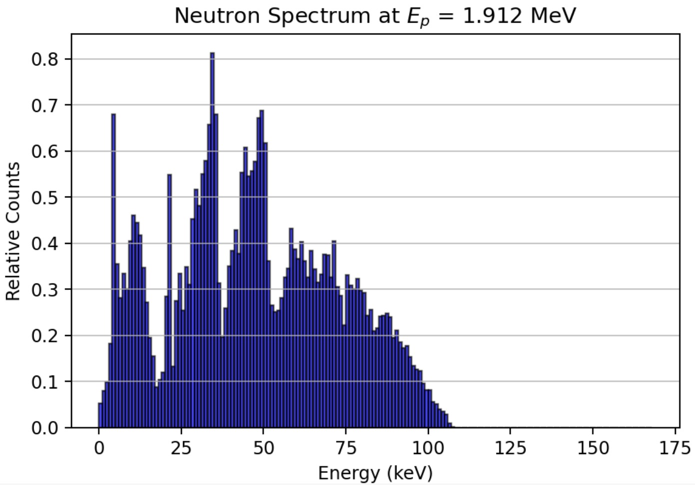
- Large resonances around 20 keV cause significant attenuation/scattering (6/cm)→ 3.6 interaction lengths!
- Neutron (elastic) scattering off titanium vacuum vessel therefore loses neutrons of certain energies

GEANT4 simulations

GEANT4 simulation developed - bespoke $^{7}\mathrm{Li}(p,n)$ PrimaryGeneratorAction class created with correct differential and total cross sections (vanilla GEANT4 did not reproduce expected results)



Simulated neutron spectrum



Resolving the issues

Solution 1

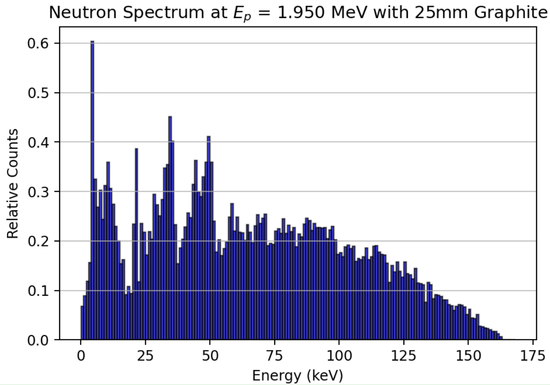
Find a material that counter-acts the Ti attenuation to flatten out the spectrum

- Too many resonances - can only make the spectrum more confusing
- Not a viable option

Resolving the issues

Solution 2

Run with higher energy neutrons + graphite to backscatter neutrons to lower energies



Resolving the issues

Solution 2

Run with higher energy neutrons + graphite to backscatter neutrons to lower energies

- Works well to smooth spectrum but Maxwell Boltzmann shape is not well-maintained
- Run at multiple energies and unfold to get XS(E)
- Increase in overall neutron intensity due to multiple scatters and higher proton energy
- ^{59}Co(n,γ) MACS value of 34.2 $\pm$ 1.3 mb against expected 27.1 $\pm$ 2.7 mb (kT = 60 keV)
    - Not MACS-like spectrum yet!

Resolving the issues

Solution 3

Use GEANT4 to understand and correct for the energy spectrum

- Only works as a verification step - impossible for isotopes with XS(E) data
- Using this technique for ^{59}Co(n,γ) reproduced a spectrum-averaged cross section (SACS) value of 24.9 $\pm$ 1.5 mb vs expected 25.7 mb

Resolving the issues

Solution 4

Replace the titanium vacuum vessel with a resonance-less material (carbon fibre/graphite)

- Long term ideal plan - need to work with manufacturers on warranty-proof solution
- Carbon has no resonances in this region so would be ideal - just mechanical/vacuum concerns to consider

Overview

- High-intensity neutron source up to 0.9 MeV maximum energy
- Up to 3×10^{13} neutrons/s
- Running at lower energy allows direct s-process astrophysical studies
- Suite of Monte Carlo codes developed to model neutron spectra
- Validation study with cobalt shows corrections needed for titanium flange
- Multiple solutions are possible to allow for a campaign of measurements
- High neutron fluence allows for double-activation or long-lived isotopes studies
- Preliminary experiment paves the way for a suite of neutron-activation studies with a well understood energy spectrum

Facility Info

NNUF National Nuclear User Facility

UKRI Engineering and Physical Sciences Research Council

UNIVERSITY OF BIRMINGHAM

HIGH FLUX ACCELERATOR-DRIVEN NEUTRON FACILITY

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Get in touch with the team!

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