OpenMC simulations of the UoB HF-ADNeF for Medical Isotope Production

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HIGH FLUX ACCELERATOR-DRIVEN NEUTRON FACILITY

Introduction

The **high-flux accelerator driven neutron facility** (HF-ADNeF) at the University of Birmingham can produce neutron fluxes of up to $\mathbf{10^{12}\ n\ s^{-1}\ cm^{-2}}$ [1].

An OpenMC simulation has been produced to investigate the possibility of **producing novel medical isotopes** at this facility, under various irradiation conditions [2].

Holmium-166 is an exciting medical isotope, emitting both **beta** and **gamma** (80.6 keV) radiation, making it suitable for both **therapy** and **imaging** [3].

Holmium-166 Production

Production of ^{166}Ho ($t_{1/2}$ = 26.6 hours) can be via **two routes** [3]:

$$^{165}\text{Ho} + n \longrightarrow {}^{166}\text{Ho}$$

$$^{164}\text{Dy} + n \longrightarrow {}^{165}\text{Dy} + n \longrightarrow {}^{166}\text{Dy} \xrightarrow{\beta^-} {}^{166}\text{Ho}$$

The first is simple and produces **high yields**, since natural holmium is 100% ^{165}Ho.

Although the second route requires double neutron capture, the **cross sections** for both reactions are very high.

Since ^{166}Dy has an 81.5 hour half-life, a **^{166}Dy/^{166}Ho generator** can be produced, which is more convenient.

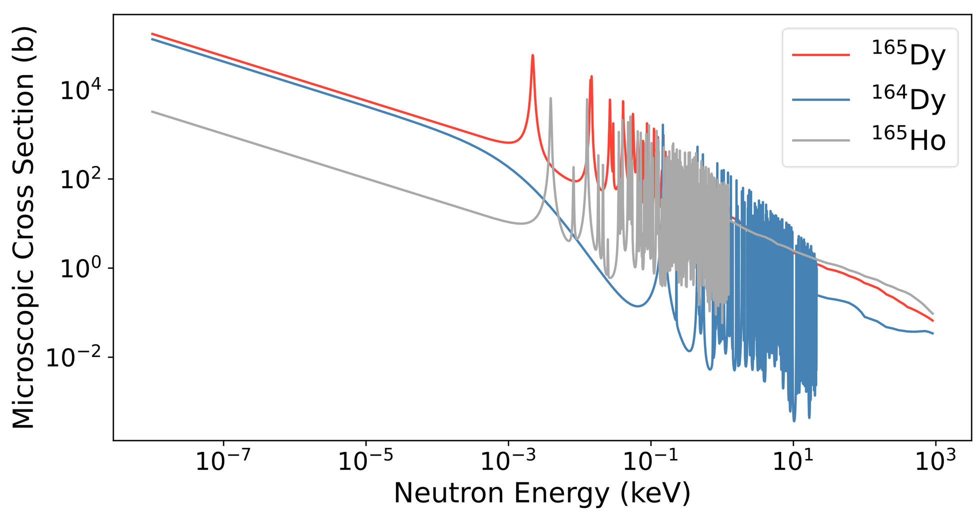

Figure 6) TENDL-2019 cross sections of (n,γ) in ^{165}Ho, ^{164}Dy and ^{165}Dy.

Model Overview

Figure 1) Photograph of HF-ADNeF target room.

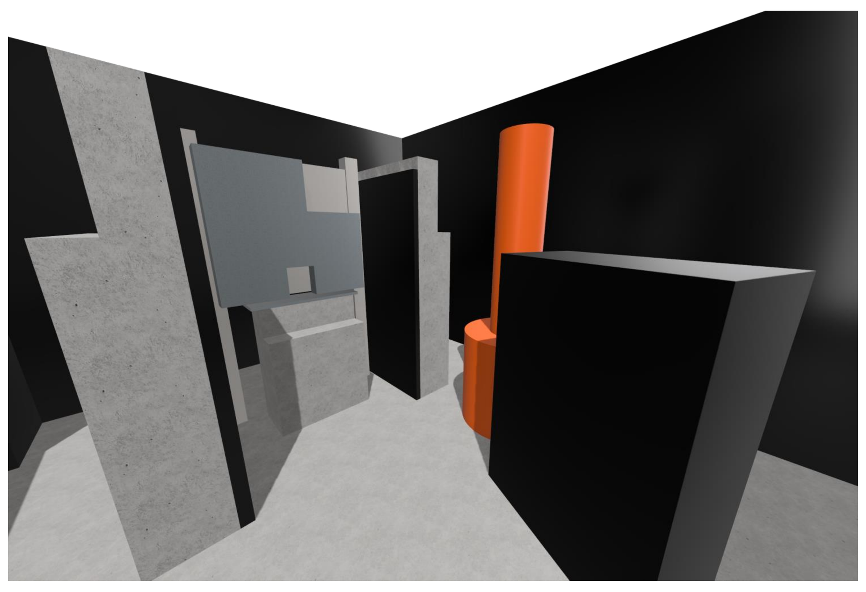

Figure 2) 3D CAD model of HF-ADNeF target room.

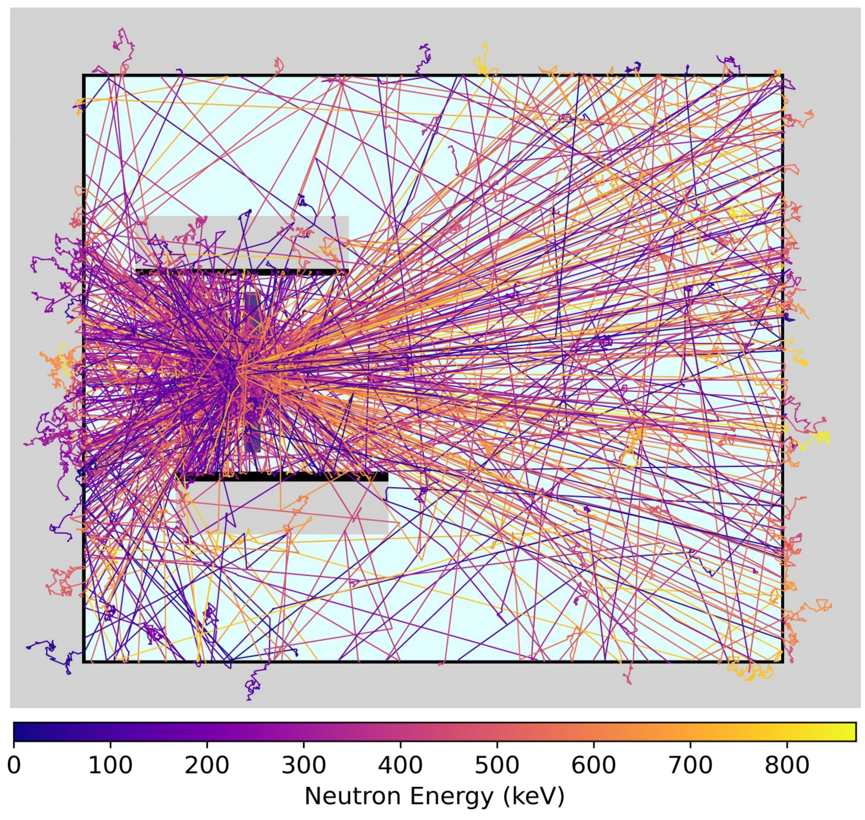

Figure 3) Top-down view of neutron tracks in target room, colour coded by initial neutron energy.

Geometry

- A **3D model** of the **HF-ADNeF** target room has been developed in **OpenMC** and can be imported as a **Python package**.
- Activation foils, moderating materials and more can be added using **functions** to prevent boundary clashes.

Starting Neutron Information

- A **source file** is defined for each **proton energy**, based on MCNP input cards [4].
- A **neutron energy** is first sampled from an **energy distribution** via **linear interpolation**.
- Based on this neutron energy, the relevant **angular distribution** is sampled for the **lab emission angle**.

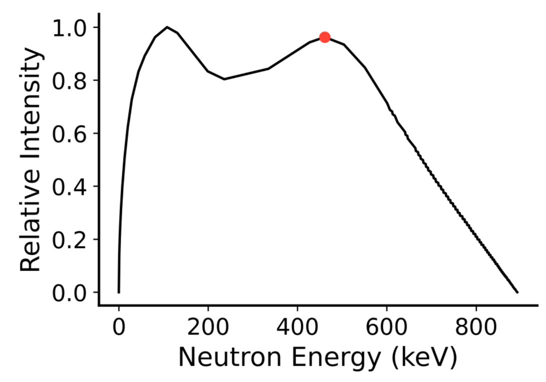

Figure 4) Neutron energy distribution for 2.6 MeV protons incident on target.

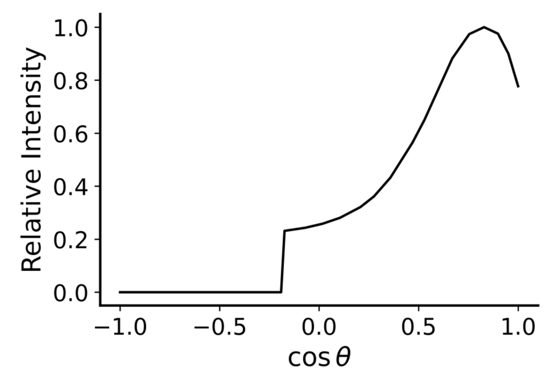

Figure 5) Angular distribution for 461 keV neutron sampled in Figure 4.

Neutron Tracks

- A **track file** contains position and energy information at each step.
- This allows for validation of the neutron transport in the problem.

Tally Normalisation

- Tallies such as **flux** and **(n,γ)** are output per source particle.
- Multiplying by a **source strength** term gives the number of neutrons per mC of proton beam at a given energy, based on theoretical yield.

Activity Calculations

The irradiation of a **natural holmium** foil was **simulated**, consisting of 100% ^{165}Ho.

The **normalised (n,γ)** tally within the foil gives the **reaction rate**, R, of ^{166}Ho production.

The **activity** of ^{166}Ho at a given time, t, can then be calculated for a desired irradiation time, t_{irr},

$$A = R\left(1 - e^{-\lambda t_{irr}}\right)e^{-\lambda t}.$$

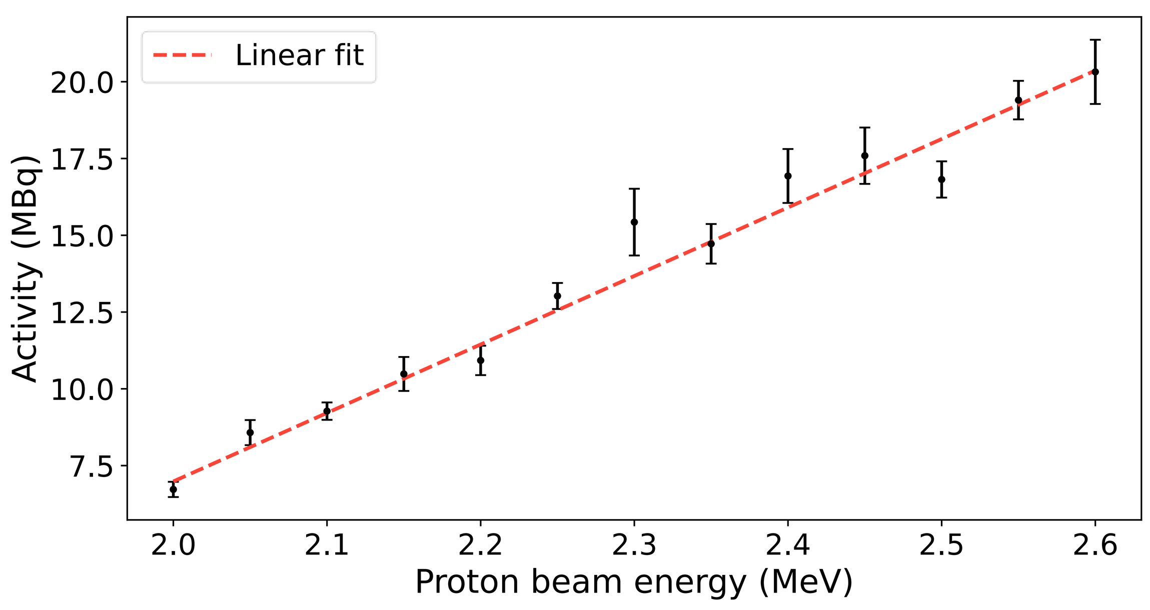

Figure 8) Predicted activities of ^{166}Ho from irradiation of natural Ho foil at fluxes from increasing proton energy at HF-ADNeF. Errors are statistical.

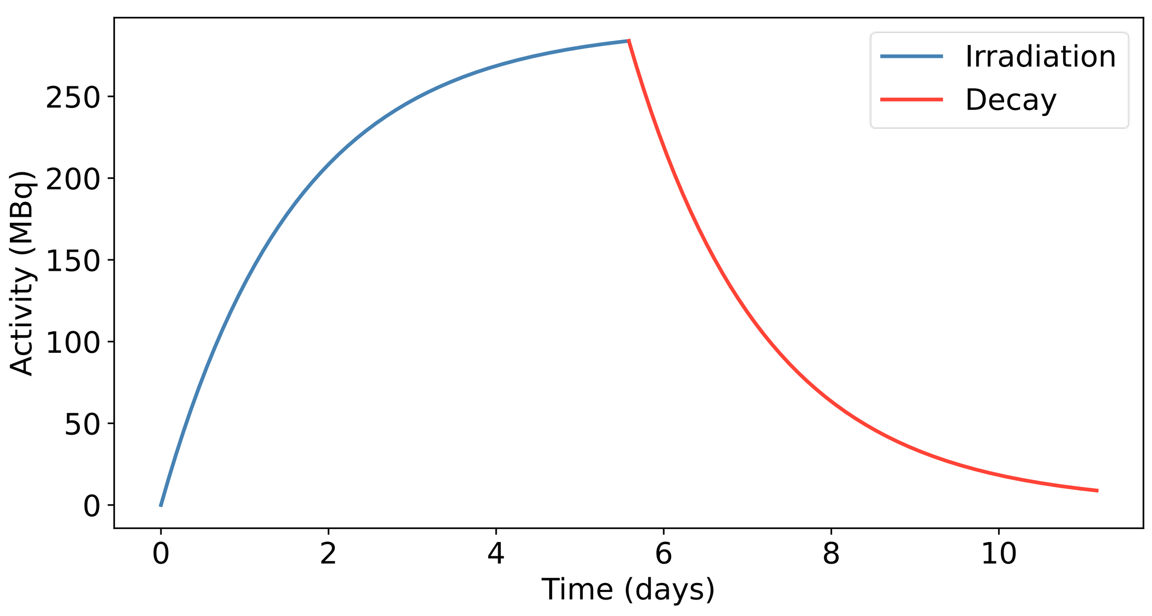

Figure 7) Activity of a natural holmium foil during and after neutron irradiation.

Reaction rates were calculated at **increasing proton energies**, resulting in different neutron yields and flux profiles.

Activities were calculated for **3-hour irradiations** at proton currents of **34 mA**.

A **linear trend** reflects the increase in neutron flux with proton energy [1].

Experimental Work

Both natural **holmium** and **dysprosium** foils were irradiated at **HF-ADNeF**.

Activation foils were also irradiated for simulation benchmarking.

Gamma spectroscopy was performed to analyse the activity of ^{166}Ho present in the foils.

Figure 9) MnAl (left) and Ho (right) foil attached to holder to be irradiated.

Preliminary results show an **order of magnitude agreement** between simulated and measured activities.

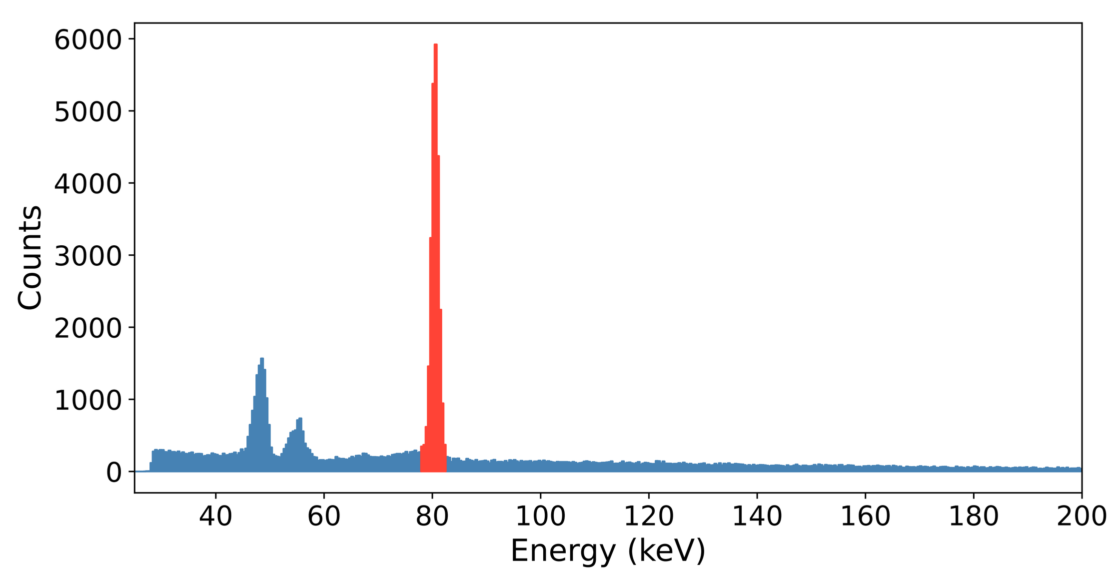

Figure 10) Spectrum of activated Ho foil taken on HPGe detector, showing 80.6 keV peak from ^{166}Ho decay.

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Conclusion and Outlook

- An OpenMC model has been created to facilitate activity calculations at HF-ADNeF.
- Predicted activities agree with preliminary experimental results to an order of magnitude.
- Code will be developed to allow (2n,γ) calculations.
- Future comparisons will be made to MCNP and other codes, as well as more experimental data.

References

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4) D. M. Minsky , AB-BNCT beam shaping assembly based on ^{7}Li(p,n)^{7}Be reaction optimization, Appl. Rad. and Isotopes, 69, 12 (2011)