Optical Model Tuning Studies for Optimized Medical Isotope Production

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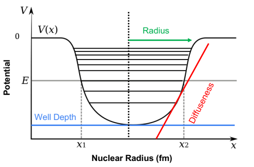
Motivation

The demand for medical radionuclides has increased significantly over the past decade, primarily due to their success in targeted theranostic cancer applications[12]. Therefore, knowledge regarding the methods to produce such isotopes is vital to aid in the success of the fight against cancer. Cross section data is a key component for informed production choices, However, this data is usually limited or non-existent for novel isotopes. Nuclear reaction modeling codes can predict cross section information but tend to break down for for complex reactions involving heavy nuclei targets or light ion incident particles. For this reason, improvement of nuclear reaction model parameters are required to determine the most effective manner in which to produce medical isotopes. To this end we have explored the effect of optical model parameter tuning on cross section prediction using the EMPIRE[1] nuclear modeling program.

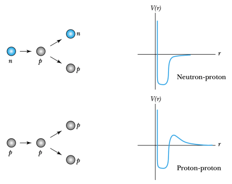
What is an Optical Model?

- Due to the attractive nuclear strong force, each proton or neutron existing in the nucleus acts on all surrounding nucleons with an individual potential[7]
- The optical model (OM) simplifies this complicated many body problem by modeling the nucleus as a **mean potential** of all nucleons[6]
- This mean potential describes how an incident particle will interact with the nucleus and ultimately how nucleons will be scattered out of the nucleus
- The most generalized OM is the Woods-Saxon potential[9]
- Nuclear reaction codes use parameterizations of the Woods-Saxon potential based on available experimental data[11]
- When little or no data exists, these parameters must be tuned to result in accurate cross section predictions

Woods-Saxon Potential



$$V(r) = -\frac{V_0}{1+\exp(r-R)/R}$$



Methods

- Modeled proton and ^{4}He induced reactions with EMPIRE[1]
- Chose reactions with limited or no experimental data and high disagreement with other codes (TALYS[2], PACE[3])
- Investigated effects of manual OM parameter tuning
- Adjusted three separate parameters of real and imaginary Woods-Saxon OM:
  1. **Radius**
  2. **Diffuseness**
  3. **Depth**
- Created custom python script for rapid output of OM change effect on cross sections
- Goal: minimize disagreement with experimental data or PACE predicted cross sections where no data existed

Reactions Modeled (EMPIRE):

$^{156}\mathrm{Gd}(p,2n)^{155}\mathrm{Tb}$
$^{157}\mathrm{Gd}(p,3n)^{155}\mathrm{Tb}$
$^{111}\mathrm{Cd}(p,n)^{111}\mathrm{In}$
$^{44}\mathrm{Ca}(p,2n)^{43}\mathrm{Sc}$
$^{153}\mathrm{Eu}(^4\mathrm{He},2n)^{155}\mathrm{Tb}$
$^{209}\mathrm{Bi}(^4\mathrm{He},2n)^{211}\mathrm{At}$

OM Parameterization:

A.J. Koning, J.P. Delaroche[4] – RIPL OMP Index: 5405

- The parameterization equations for the real and Imaginary depths are given below:

$$V_V(E) = v_1\left[1 - v_2(E-E_f) + v_3(E-E_f)^2 - v_4(E-E_f)^3\right],$$

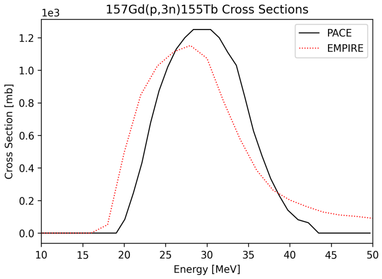
$$W_V(E) = w_1 \frac{(E-E_f)^2}{(E-E_f)^2 + (w_2)^2},$$

$$E_f^p = -\frac{1}{2}\left[S_p(Z,N) + S_p(Z+1,N)\right],$$

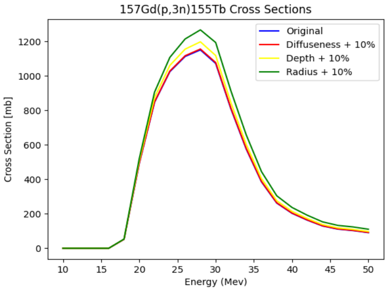
- S_p = proton separation energy
- Radius and Diffuseness are constants determined during their study

Results

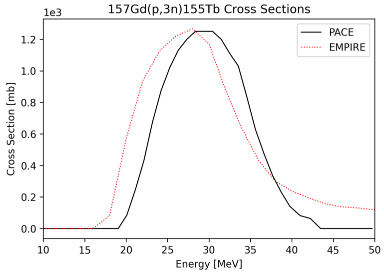
Case Study: $^{157}\mathrm{Gd}(p,3n)^{155}\mathrm{Tb}$



Individual Parameter Tuning Effects



Example of Manually Optimized Parameters



Conclusions

For proton induced reactions studied:

- OM diffuseness produces the least effect on cross section prediction
- OM radius has greatest impact on cross section prediction
- OM depth has low effect at lower energy but becomes more effective at high incident energy

For ^{4}He induced reactions studied:

- Inconclusive results due to added complexity of heavier incident nucleus
- More methodical testing protocol needed

Future work

- Extend manual optimization method to automatic chi-squared regression fitting protocol to achieve better cross section fits
- Explore optimization methods for level density, gamma strength functions in addition to OM
- More experimental cross section data needed to validate OM parameters and increase accuracy of cross section predictions

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