Investigation of the $^{238}\mathrm{U} + {}^{209}\mathrm{Bi}$ MNT Reaction Using the GRAZING Code

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Abstract

We are looking for the angular and energy distribution of ^{211}Po, a nuclide produced by a multinucleon transfer reaction (MNT), which populates through the collison of ^{238}U beam on ^{209}Bi target. We compare the results obtained by using two distinct computational tools: the GRAZING_9 Fortran program, used for its capacity to estimate reaction outcomes for heavy-ion collisions, and the GRAZING code implemented in the Nuclear Reactions Video browser (NRV).

1. Introduction

MNT reactions could be a viable solution for generating heavy and superheavy neutron-rich nuclei, as the conventional approaches are either impractical or insufficient for transuranium nuclei. Another objective is to produce isotopes in the region near the $N = 126$ neutron shell, which holds astrophysical significance. As a result, production of neutron-rich exotic nuclei via MNT reaction mechnism has become a prominent area of research in various laboratories. The GRAZING code [1], which relies on Aage Winther's semi-classical model, is used as a model to explain MNT reactions. It's designed to explain inelastic scattering and nucleon transfer in close encounters between heavy-ions. This model is tailored to clarify scenarios involving the exchange of only a few nucleons while preserving most of the kinetic energy, and gives the best results for such problems. [2]

2. Calculations

We considered the MNT reaction involving the collision of ^{238}U beam on ^{209}Bi target, characterized by the following nuclear reaction:

$$^{238}\mathrm{U} + {}^{209}\mathrm{Bi} \rightarrow {}^{211}\mathrm{Po} + {}^{236}\mathrm{Pa}$$

In accordance with the fundamental principle of the conservation of energy, we can express the energy conservation equation as follows:

$$E_{\mathrm{projectile}} = \Delta\mathrm{TKE}_{\mathrm{loss}} + E_{\mathrm{Po}} + E_{\mathrm{Pa}}$$

Where E_{Po} and E_{Pa} represent the energies associated with the MNT reaction resultant products, namely, ^{211}Po and ^{236}Pa, respectively. Adding the reduced mass term for both the target-like (^{211}Po) and projectile-like product (^{236}Pa), the product energies can be calculated as:

$$E_{Pa} = \frac{m_{\mathrm{Po}}}{m_{\mathrm{Po}} + m_{\mathrm{Pa}}} \left(E_{\mathrm{projectile}} - \Delta\mathrm{TKE}_{\mathrm{loss}}\right)$$

$$E_{Po} = \frac{m_{\mathrm{Pa}}}{m_{\mathrm{Po}} + m_{\mathrm{Pa}}} \left(E_{\mathrm{projectile}} - \Delta\mathrm{TKE}_{\mathrm{loss}}\right)$$

By using the mentioned energy expressions, combined with the data obtained from the GRAZING code, we can ascertain the energies of the reaction products. These calculations span the energy range beginning at 1700 MeV, which is 31 MeV above the Coulomb barrier, and extend up to 2800 MeV. All calculations are done with standard initial parametrs and inelastic options. It's to be noted that the GRAZING code is not compatible for initial high projectile energies. For this particular problem, the unreliable results begin at about 2300 MeV.

3. Results

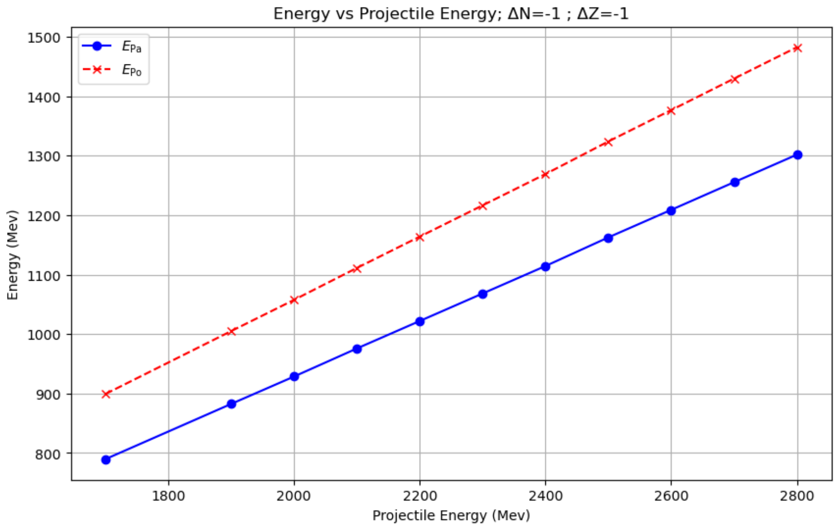
Regarding the comparison of the data acquired by the GRAZING_9 program and the NRV browser, three variables were compared:

a) Energy of ^{211}Po

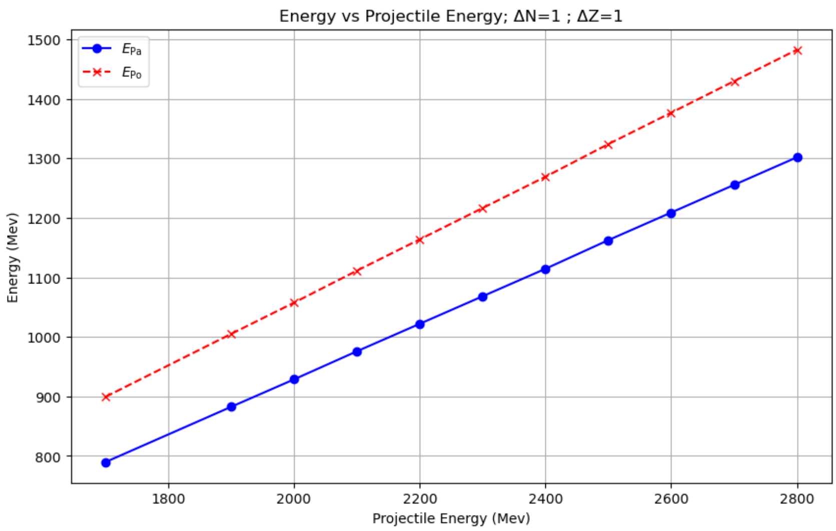
b) Cross-section for ^{211}Po

c) Angle for ^{211}Po

Both the GRAZING code and the NRV [3] browser have a flaw in their ability to differentiate between ^{211}Polonium (^{211}Po) produced via $\Delta Z = 1$ and $\Delta N = 1$ reactions versus those created through $\Delta Z = -1$ and $\Delta N = -1$ reactions. This is despite the fact that, theoretically, one of these reactions should result in a larger cross-section than the other, based on the angular distri-



(a)



(b)

Figure 1: MNT product energies for $\Delta Z = -1$ and $\Delta N = -1$ shown in (a) and for $\Delta Z = 1$ and $\Delta N = 1$ shown in (b). The energy values appear to be identical, showing no visible differences between the resulting products.

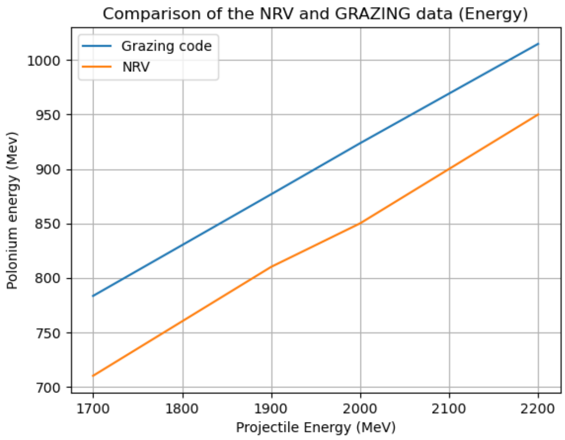
bution predicted by both tools.

In terms of energy distribution, the two versions follow the same trend, although the NRV browser doesn't allow for the specification of individual reaction products in the energy channel, which means the energy value provided by the browser represents the total kinetic energy rather than distinguishing between the two different product energies.

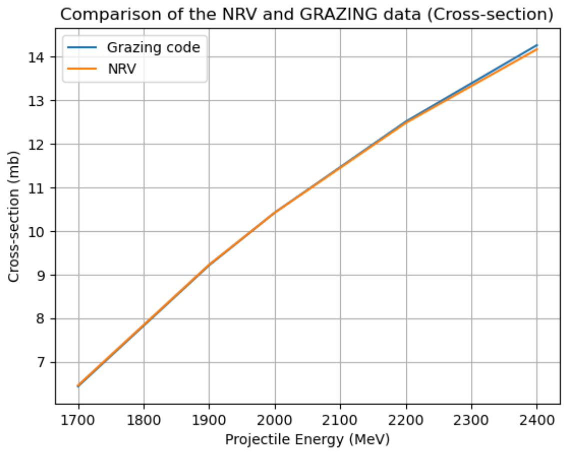
In the case of the angular distribution, it has been observed that as the bombarding energy increases, the angle at which the reaction products are emitted becomes progressively smaller. Theoretically, there should be an alignment between the angular distributions calculated by these two tools. However, that is not the case, which is perplexing, considering that both tools (of the same model) offer the option to specify the cross-section to be calculated in the angular distribution channel. The relative error ranges from 6% to 32%.

4. Conclusion

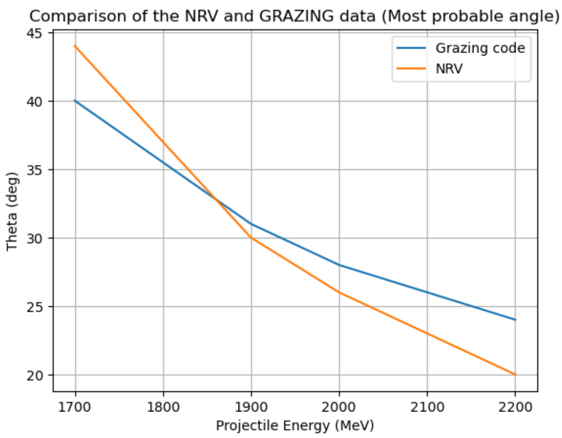
The GRAZING_9 program offers greater flexibility in terms of customization. It provides a wider array of options for setting initial parameters, including the energy of the projectile. It's worth noting that GRAZING_9 allows calculations to proceed even when the bombarding energy is exceptionally high, a feature not supported by the NRV browser. Furthermore, GRAZING_9 also offers a more extensive selection of output variables. One noteworthy example is the ability to obtain kinetic energy loss, a critical component when calculating the energy of the reaction products. This specific capability is not available in the NRV browser, making GRAZING_9



(a) Energy of ^{211}Po



(b) Cross-section of ^{211}Po



(c) Angle for ^{211}Po

Figure 2: Comparison between the GRAZING program and NRV browser. Only the results for $\Delta Z = -1$ and $\Delta N = -1$ are presented.

the preferred choice for those who need precise energy-related information in their calculations.

Acknowledgments

I would like to thank dr. Timo Dickel and dr. Deepak Kumar for their help during the project. I would also like to thank Dino Skrgic for his insight into the theoretical background of MNT reactions.

References

[1] A. Winther, *GRAZING_9*, The Niels Bohr Institute, Copenhagen, Denmark

[2] J. S. Barret et. al, ^{136}Xe+^{208}Pb *reaction: A test of models of multinucleon transfer reactions*. Phys. Rev. C 91, 064615 (2015)

[3] Grazing code of NRV, (http://nrv.jinr.ru/nrv/)