A STUDY OF POTENTIAL ACCELERATOR PRODUCTION OF RADIOISOTOPES FOR BOTH DIAGNOSTICS AND THERAPY

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Abstract

There is currently much interest in accelerator based replacements for radioisotope production. The primary focus is the use of compact low energy (<30 MeV) proton accelerators that can provide local on-site production of short lived isotopes and as a replacement for the current reactor production of important isotopes such as Ga-68.

As part of a study into the viability of this production method this work undertakes a benchmarking study the GEANT4 code using the new low energy data-driven physics list QGSP_BIC_AllHP for the production of significant diagnostic and therapy isotopes such as F-18 and Ga-68. Results from these simulations will be compared to experimental cross-sections and other codes to determine reliability before being used to further asses the activity producible using these reactions.

INTRODUCTION

There is currently much interest in new methods of production of medical isotopes, for both therapy and diagnostics. Here we are interested in the use of low energy accelerators to provide on-site production of short lived isotopes to improve the supply and availability of therapeutic and diagnostic techniques at smaller medical facilities e.g. local hospitals. In this work we focus on a few of the relevant isotopes: F-18, Sc-44, Cu-62, Cu-60 and Ga-68. We will study the obtainable activity of each isotope due to the irradiation of a target with protons. The yields of each isotope due to the bombardment of protons on to a specific target material have been obtained from simulation using GEANT4 and two high precision proton transport models, the exploratory model QGSP_BIC_PHP and the newly released model QGSP_BIC_AllHP. The new model QGSP_BIC_AllHP expands upon the previous Binary cascade models such as QGSP_BIC_HP which includes high precision neutron transport by the use of experimental cross-section libraries for low energy protons. Previous work [1, 2] has shown the limits of the previous HP models, producing poor results at incident proton energies below 100 MeV and target masses below A = 100. From this a new exploratory model QGSP_BIC_PHP was created and tested [1]. It was shown to work well in these limits although for limited cases. After further testing QGSP_BIC_HP and QGSP_BIC_PHP were combined, and improved, to give the new model QGSP_BIC_AllHP which is available with the standard release.

BENCHMARKING

A limited benchmarking study of the QGSP_BIC_PHP model was undertaken in previous work [1] and some further work has been undertaken using the new QGSP_BIC_AllHP model. While this work has only been able to carry out a limited benchmarking, often reduced to a small range or single energy for each production reaction of interest, there has been some success seen with these models when compared to experimental data [3]. However like all experimentally based model the results are tied closely to the data set being used and problems have often occurred when there is a wide range of data in the libraries which do not show good agreement. There is also the problem that occurs when there is a lack of data in the libraries which means that the simulation is unable to compute the results as these are directly related to the data and cannot, with these models, be extrapolated or estimated.

Below are some of the benchmarking results obtained comparing QGSP_BIC_AllHP to experimental data, Figures 1 and 2 [4–8].

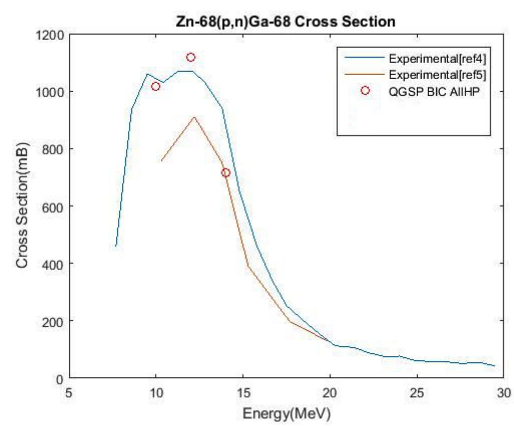

Figure 1: Experimental and simulated cross section results for the production of Ga-68 [5, 6].

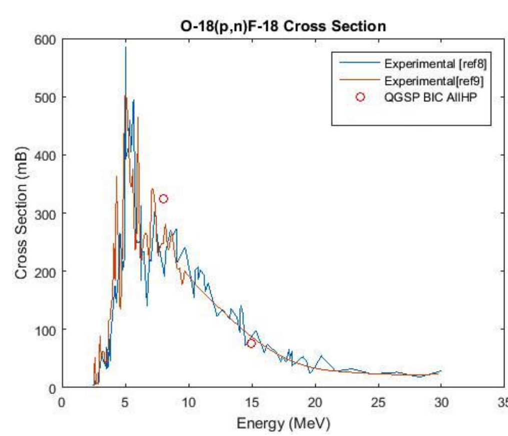

Figure 2: Experimental and simulated cross section results for the production of F-18 [7, 8].

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ACTIVITY

Each simulation in this work has been carried out using a mono-energetic pencil beam impinging on a single isotopic thick target. The range for each beam through each target has been calculated to ensure that the yield obtained is not dependant on target thickness. The results are scaled up to be comparative to a 1 mA beam current under a 30 min irradiation time. The decay after irradiation is also shown for various times dependant on the half life of the isotope of interest.

The isotope Ga68 is primarily used for PET diagnostics, but there is some option for its use as a therapy isotope. The reaction Zn68(p,n)Ga68 [4] has been used here to directly produce the isotope of interest. This reaction has been benchmarked with the PHP model and activity calculated for a 30 min irradiation time at 10 MeV [1]. The results from this work are reproduced below in Figure 3. In comparison the results obtained using the AllHP model are shown in Figure 4. The values have been calculated using a 30 min irradiation time of a 14 MeV beam. These results show that a more than reasonable amount of the product is produced over this time, a high activity generator production would elute 150 mCi from the target every 30–40 minsIAEA.

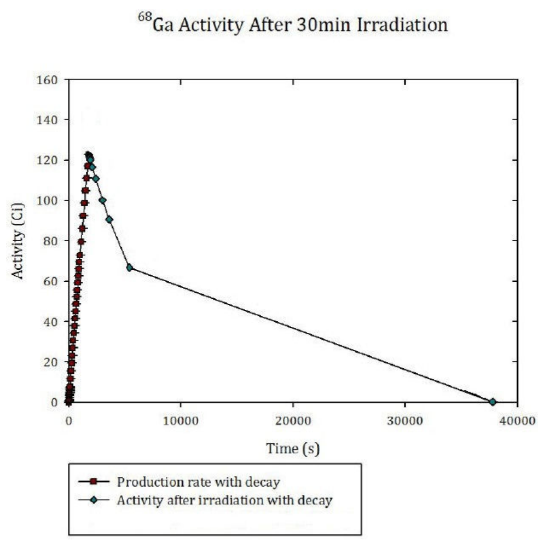

Figure 3: Activity of Ga-68 obtainable using QGSP_BIC_PHP

The isotope Cu62 is primarily used for PET diagnostics, but there is some option for its use as a therapy isotope. The reaction Ni62(p,n)Cu62 [4]has been used here to directly produce the isotope of interest. The results obtained using the AllHP model, were benchmarked against [9], for a 15 MeV proton beam are show in Figure 5.

The isotope F18 is primarily used for PET diagnostics, but there is some option for its use as a therapy isotope. The reaction O18(p,n)F18 [4] has been used here to directly produce the isotope of interest. The results obtained using the AllHP model, which have been benchmarked against [7, 8], for a 15 MeV proton beam are show in Figure 6. F18 decays

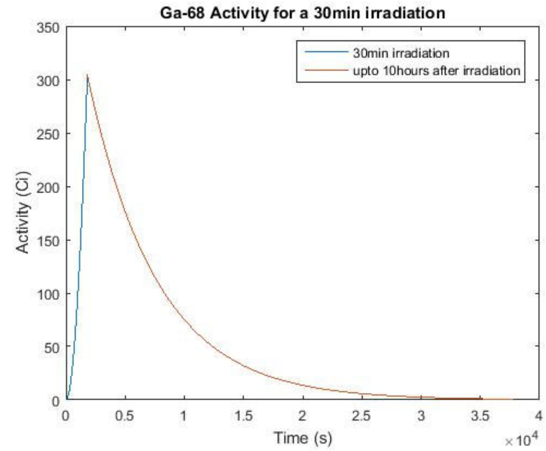

Figure 4: Activity of Ga-68 obtainable using QGSP_BIC_AllHP

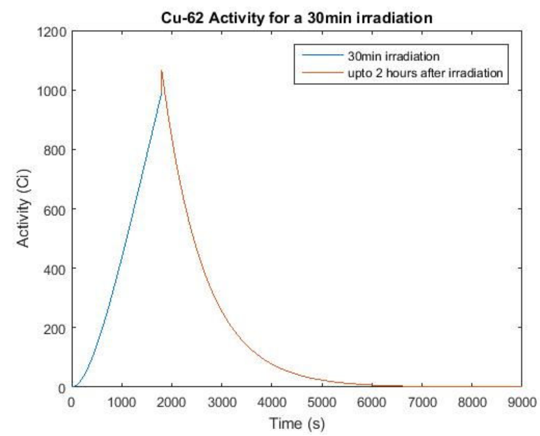

Figure 5: Activity of Cu-62 obtainable using a) QGSP_BIC_PHP and b) QGSP_BIC_AllHP

via beta+ with a half-life of 109 mins [4]. An irradiation time of 30 mins has been considered in the production mechanism of this isotope. While the half-life is more than 3 times the irradiation time it is not feasible for the irradiation time to be any longer when considering on-demand local production of the isotope. However it can be seen that the activity produced from this irradiation time is of a reasonable value and should be sufficient as a viable production method.

The isotope Sc44 is primarily used for PET diagnostics. The reaction Ca44(p,n)Sc44 [4] has been used here to directly produce the isotope of interest. The results obtained using the AllHP model, which were benchmarked against [10], for a 15 MeV proton beam are show in Figure 7. Sc44 decays via beta+ with a half-life of approximately 4 hours [4]. An irradiation time of 30 mins had been considered. While the half-life is significantly larger than the irradiation time it is not feasible for the irradiation time to be any longer when considering on-demand local production of the isotope. However it can be seen that the activity produced from this irradiation time is of a reasonable value and should be sufficient as a viable production method.

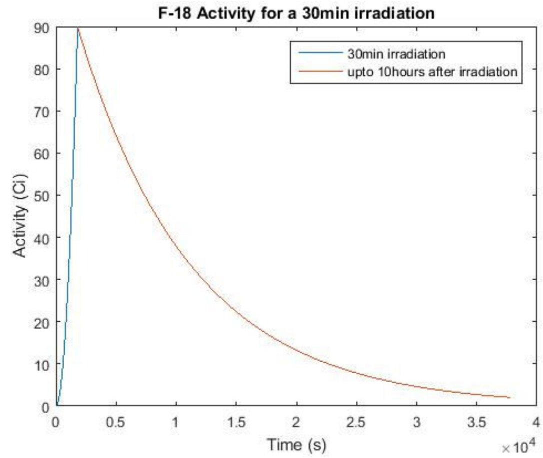

Figure 6: Activity of F-18obtainable using QGSP_BIC_AllHP.

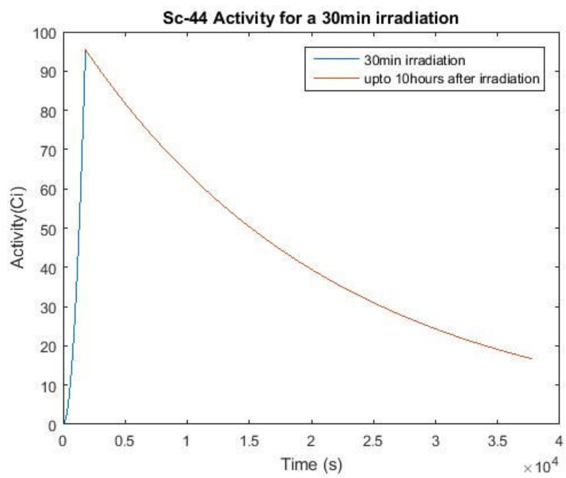

Figure 7: Activity of Sc-44 obtainable using QGSP_BIC_AllHP

CONCLUSIONS

After much work has been carried out to develop a data driven high precision transport model for low energy protons, a good first attempt, QGSP_BIC_AllHP, has been included in the standard GEANT4 release. This model is starting to be used and validated by those studying low energy accelerator based production of radioisotopes. While limited the results presented here, and in other work show some promise of an accurate model when compared to experimental results. Using this model it has been possible to predict activity yields for several significant radioisotopes and to develop new production methods with the aim to make vital, life-saving treatments more widely available. The results presented here show a low energy proton irradiation of the right target yields a significant activity of the desired radioisotope and proving the viability of this production route.

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