Medical Isotope Production Using A 60 MeV Linear Electron Accelerator

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INTRODUCTION

Medical isotopes can be produced by reactors and accelerators [1]. For certain isotopes there could be an advantage to a certain production method. For example; in some cases production via the (γ,n) or (γ,p) reaction has advantages that include high production yield [2] and production in a matrix that simplifies chemical separation of the desired isotope. To maximize isotope production, a high photon flux at the energy corresponding to the peak of the giant dipole resonance is required. This peak is typically between 10-20 MeV [3]. To efficiently produce a high photon flux at this energy range, electron accelerators with energy greater than 40 MeV are used. In order to estimate the production yield and design efficient production geometry, transport codes such as MCNP [4] can be used in conjunction with the proper nuclear photon reaction cross section.

In this work we report experiments and calculations for production of ^{67}Cu [6] produced by the reaction ^{68}Zn(γ,p)^{67}Cu. Two geometries were considered; direct electron irradiation of Zn plates and irradiation with bremsstrahlung from a water cooled tantalum target. The purpose of this experiment was to test which of the two geometries is more effective and also to provide data for verification of MCNP calculations.

EXPERIMENTAL SETUP

The experiments were done at the Gaerttner LINAC Laboratory at Rensselaer Polytechnic Institute [5]. Several square Zn plates with side dimension of 5.08 cm and thickness of 0.16 cm where stacked and irradiated. In the first experiment, 22 plates where irradiated with a 55 MeV electron beam with an average current of 4 μA. In the second experiment, 36 plates were irradiated with bremsstrahlung produced by a 49 MeV electron beam with average current of 100 μA interacting with a bremsstrahlung production target. This target consisted of two 0.16 cm Ta plates and two 0.32 Ta plates separated by 0.16 of water channels and encapsulated with 0.16 cm of Al. The target was cooled by water flow through the channels. After the irradiation, the 184.6 keV gamma ray from ^{67}Cu was measured with a high resolution, efficiency calibrated, HPGe gamma detector. The activity of ^{67}Cu at the end of irradiation was determined by correction for decay and detection efficiency. The typical electron energy spread of the RPI LINAC is a Gaussian with a 10% FWHM. The overall accuracy in determining the activity in each plate was estimated to be about 10%.

CALCULATIONS

To calculate the ^{67}Cu production, first the average photon flux in each plate was calculated using MCNP5 [4]. The flux was then convoluted with the ^{68}Zn(n,p)^{67}Cu reaction cross section obtained from the evaluated photo-neutron library [3]. To obtain the actual activity, the results were scaled by the number of electrons that struck the target (determined from the measured electron current and irradiation time). Experimentally the electron current was measured by monitoring the current on the Zn stack or the Ta conversion target, which resulted in electron leakage and a lower measurement of the actual electron beam current. A leakage correction factor was obtained from the MCNP calculations and was found to be about 15%.

RESULTS AND CONCLUSIONS

For direct electron irradiation of the Zn plates, the experiment resulted in a total of 291 μCi of ^{67}Cu produced while the calculations yielded 270 μCi. The profiles of the activity spread in the plates were in reasonable agreement as shown in Fig. 1. Considering the accuracy of the measurement, this is good agreement and indicates that both the gamma flux calculated by MCNP, and the ^{68}Zn(γ,p)^{67}Cu cross section data are accurate.

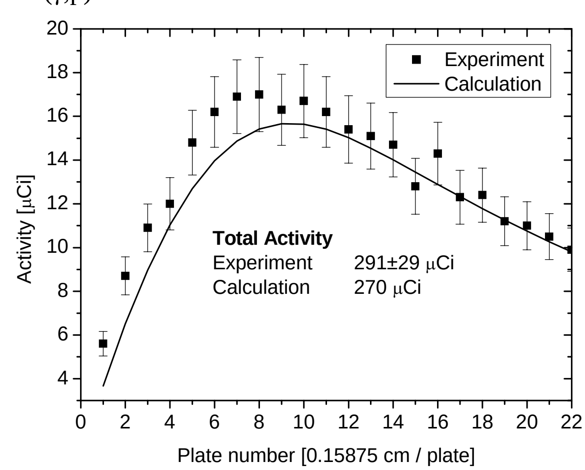

Fig. 1 - Measured and calculated ^{67}Cu activity in 22 irradiated Zn plates. Electron beam energy was 55 MeV and average current of 4 μA.

The bremsstrahlung irradiation experiment results in production of 2431 μCi of ^{67}Cu, and the calculations yielded 3714 μCi. It is not clear why there is such disagreement (factor of ~1.5) between the two. Normalization of the activity vs. depth of Zn plate calculation to the experiment show that the shapes were in excellent agreement. This might indicates a possible problem with the electron beam energy measurement during the experiment. Calculation with a beam energy of 40 MeV yields good agreement in both the activity distribution and the total activity (2436 μCi).

Neglecting the small difference in electron beam energy between the two experiments, and normalizing the experimental production per average electron beam power on target we get 1.98 μCi/(W·hour) for direct electron irradiation and 0.75 μCi/(W·hour) for the irradiation with bremsstrahlung. The calculations show the same trend but with a smaller difference 1.83 μCi/(W·hour) (1.71 μCi/(W·hour) when calculated with beam energy of 49 MeV) for direct electron irradiation, and 1.14 μCi/(W·hour) for irradiation with a bremsstrahlung converter. Thus for a bremsstrahlung converter target configuration, a better optimization of a converter-Zn stack configuration is required in order to further increase the yield. Scaling the direct electron irradiation experiment for a current of 200 μA and running the production experiment for one ^{67}Cu half life (2.58 days) will result in an activity of 1.1 Ci (41 GBq). According to reference [6] this will be sufficient for about 10 cancer treatment doses. Another factor of 5 in ^{67}Cu activity can be achieved by using a Zn target that is enriched in ^{68}Zn.

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