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Published in:
AIP Conference Proceedings - American Institute of Physics

Link to article, DOI:
10.1063/1.4773933

Publication date:
2012

Document Version
Publisher's PDF, also known as Version of record

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Citation: AIP Conf. Proc. **1509**, 25 (2012); doi: 10.1063/1.4773933
View online: http://dx.doi.org/10.1063/1.4773933
View Table of Contents: http://proceedings.aip.org/dbt/dbt.jsp?KEY=APCPCS&Volume=1509&Issue=1
Published by the AIP Publishing LLC.

Flexible, Durable Proton Energy Degraders for the GE PETtrace

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Abstract. In order to limit the formation of radioisotopic impurities during proton bombardments of solid targets, two methods of introducing degrader foils into the beam upstream of the target were tested. The first design uses a 445 μm thick fixed degrader machined from a single piece of aluminum. The second design permits introduction of foils made of any material and was tested with foils as thick as 635 μm (also aluminium). In both cases, the foils are cooled with by water flowing through an annular channel outside the radius of the beam. Both designs proved durable and tolerated proton beam currents in excess of 80 μA.

Keywords: Cyclotron; degrader; proton energy; solid target
PACS: 29.20.dg; 87.57.un; 87.57.uk

INTRODUCTION

Accelerator production of nonstandard radioisotopes for PET necessitates control of particle energy to limit formation of radioisotopic impurities. The General Electric (GE) PETtrace's 16.1 MeV beam in stock configuration offers no control of incident proton energy, inconveniencing users hoping to match irradiation energies to solid target production demands. We report a convenient method of energy degradation using foils of variable thickness. The design is tolerant of production beam currents and offers the possibility for parasitic production of useful isotopes in the degrader foil.

MATERIALS AND METHODS

Approximations of the temperature of a thin foil cooled at its boundary can be made with the use of the heat equation:

$$\frac{\partial}{\partial x_i}\left(k_i \frac{\partial T}{\partial x_i}\right) + q = \rho c \frac{\partial T}{\partial \tau} \qquad (1)$$

14th International Workshop on Targetry and Target Chemistry
AIP Conf. Proc. 1509, 25-29 (2012); doi: 10.1063/1.4773933

where T = absolute temperature
q = net rate of heat generation per unit volume
k_i = thermal conductivity in the i^{th} direction
ρ = density
τ = time
c = heat capacity
x_i = spatial coordinates.

For a uniform beam in all radial values r < a, where a is the boundary of the beam, and fixed at T_0 the temperature at the boundary of the disc, R, if the only heat transfer mechanism assumed is conduction, the equation in cylindrical coordinates becomes:

$$T = \frac{q}{2k}\left(\frac{-r^2}{2} - a^2 \ln\frac{a}{R} + \frac{a^2}{2}\right) + T_0 - H(r-a)\left\{\frac{q}{2k}\left(a^2 \ln\frac{r}{R} - \frac{r^2}{2} - a^2 \ln\frac{a}{R} + \frac{a^2}{2}\right)\right\} \quad (2)$$

where H is the Heaviside step function. The solution achieved by matching boundary conditions described above is shown and plotted in Figures 3-5 for aluminum and molybdenum foils used in experiments described below [1]. On the basis of these predictions, two degraders were designed and built for routine production of ^{64}Cu, $^{66/68}$Ga, ^{44}Sc, ^{89}Zr, ^{45}Ti and other radionuclides using homemade solid targets (see Figure 1).

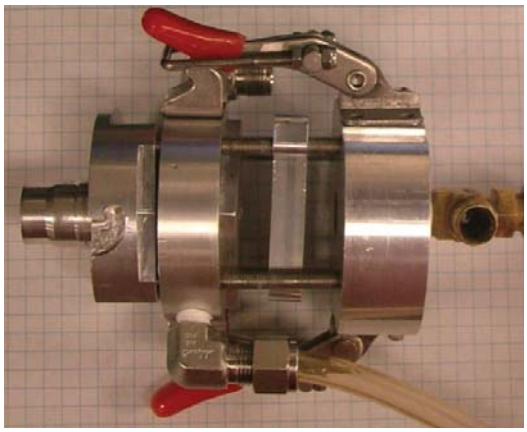

FIGURE 1. Assembled degrader and solid target. Beam moves from left to right through PETtrace snout, degrader, solid target, and water cooling flange.

The first degrader incorporates a fixed thickness (445 μm) window machined from a single piece of Al. The second degrader is similar in design but accepts foils of variable thickness. The windows in both cases are cooled by direct contact with an annular channel of 2 L/min water (Figure 2). Using the variable thickness degrader, aluminum and molybdenum foils of 635 μm (Al) and 127 μm (Mo) thickness were tested in beam. Beam energies absent degraders and after the fixed degrader (445 μm thickness) were measured using a stacked foil technique that has been reported previously [2]. Proton energies of 13.01 ± 0.01 MeV (mean ± sd, n=2) were measured for the degraded beam, and an energy of 15.97 ± 0.06 MeV (n=3) was measured for

the undegraded beam, which agree closely (within 5%) with predictions used for the calculation of energy deposited in the foils.

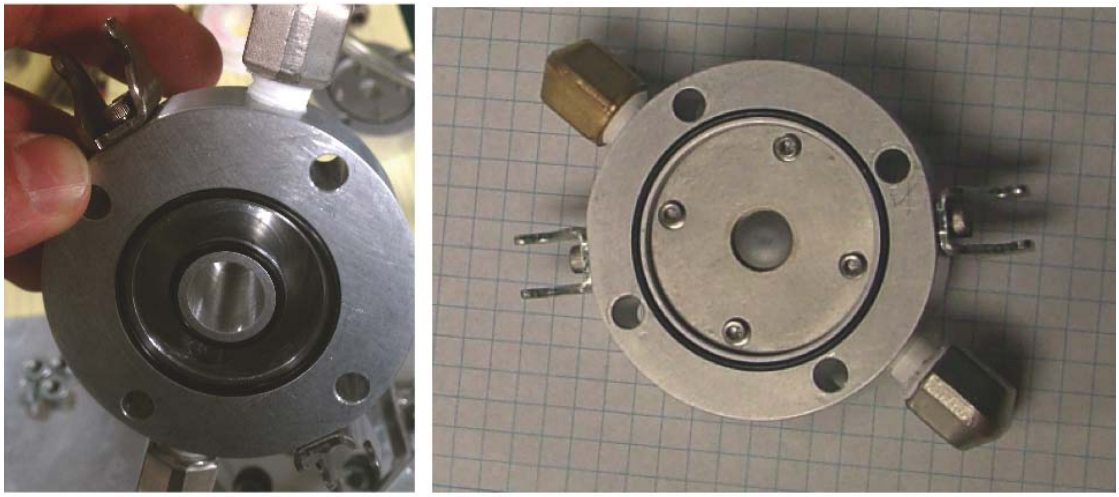

FIGURE 2. Annular water channels and sealing o-rings (Left); Front (beam side) of variable thickness degrader with Mo foil in place (Right).

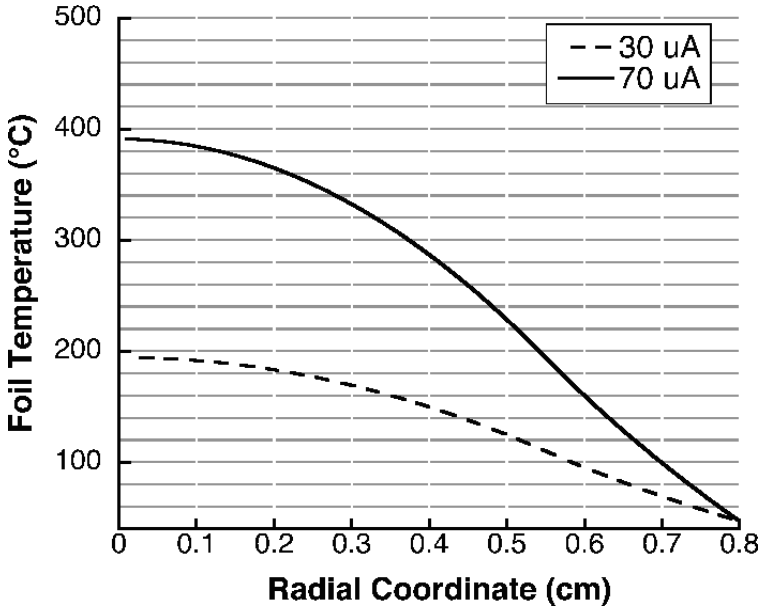

FIGURE 3. Predicted foil temperature vs. radial distance from the center of beam for 445 μm Al foil.

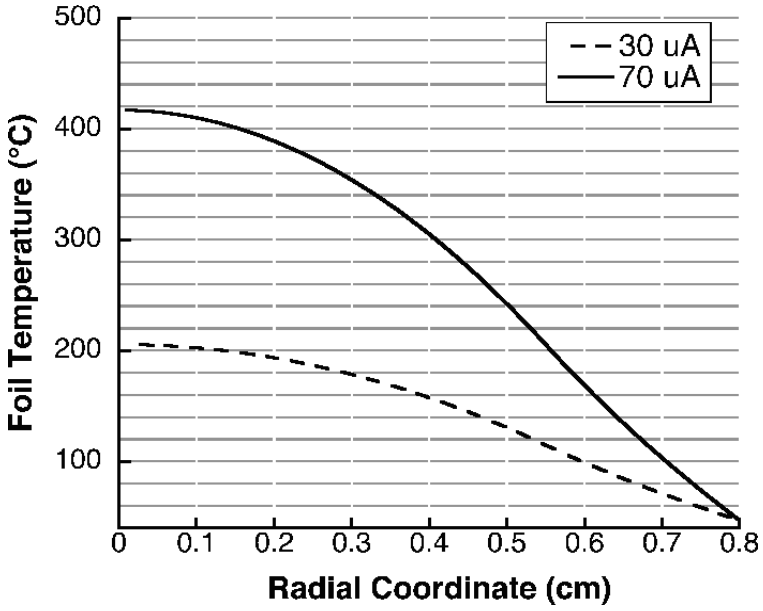

FIGURE 4. Predicted foil temperature vs. radial distance from the center of beam for 635 μm Al foil.

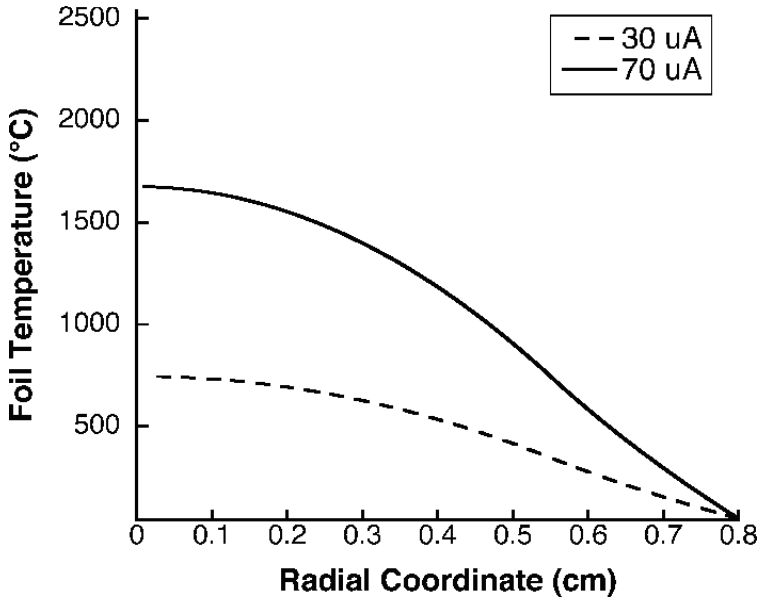

FIGURE 5. Predicted foil temperature vs. radial distance from the center of beam for 127 μm Mo foil.

RESULTS AND DISCUSSION

The 635 μm Al foil in the variable degrader housing withstands 75 μA irradiation currents with only minor discoloration and no failures in beam. These values are more than double the proton flux currently used to irradiate solid targets at the UW. The 127 μm Mo foil has been similarly durable, tolerating beam currents up to 85 μA with the added benefit of parasitic ^{95m}Tc production for customers seeking long-lived analogues of the nuclear medicine isotope ^{99m}Tc for developmental chemistry. The

445 μm Al fixed degrader proved to be a reliable radionuclide production aid, tolerating 30 μA for routine production of several radionuclides and logging almost 3000 uAhrs before developing a small crack in beam (see photograph, Figure 6). The degraders' principle disadvantage is their inability to support irradiations with the target material in inert atmosphere (either cooling gas like He or under cyclotron tank vacuum). Exposing often expensive solid target materials to beam in ambient air beckons the added risks of accelerated oxide or nitride formation, increased target degradation and vaporization, and decreased adhesion to thermally conductive backing materials.

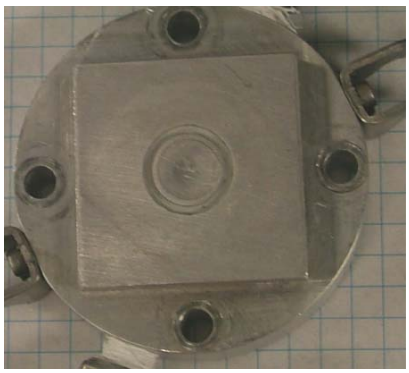

FIGURE 6. Front (beam side) of the fixed degrader after failure, showing barely visible crack in center of the window.

CONCLUSION

The benefits of limiting proton beams' interaction with target material to only the most energetically productive values have been reported [3]. In the absence of variable extraction capabilities, these simple designs offer cyclotron operators access to cross section peaks and minimized target mass while decreasing the likelihood of competing nuclear reactions.

ACKNOWLEDGMENTS

The authors gratefully acknowledge the support of NIH Radiological Sciences Training Grant T32 CA009206.

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