8.0 OUTSIDE USERS

8.1 Targetry for RFQ production of radionuclides from ^{3}He irradiation of ^{16}O, ^{14}N, ^{12}C, ^{10}B and ^{9}Be*

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The positron emission tomography (PET) radiochemistry group at UW, Fermi National Accelerator Lab, Science Applications International (San Diego), and the Biomedical Research Foundation (Shreveport) are jointly developing a radionuclide production system using a radiofrequency quadrupole (RFQ) accelerator. When compared to cyclotrons this system has advantages which include smaller size and weight, simpler operation and maintenance, and minimal shielding. An initial RFQ project for an 8 MeV ^{3}He beam (1992 NPL Progress Report) was never completed. The new design for the RFQ being built at Fermilab calls for a high current (7.5mA particle, peak), pulsed (167 μsec, 120Hz) beam of higher energy (10.5 MeV) ^{3}He^{++}. The collaborative responsibility of the investigators at UW is to design targetry and chemical systems capable of producing ^{11}C, ^{13}N, ^{18}F, and ^{15}O in sufficient amounts for PET and compatible with the beam characteristics of the RFQ.

Data previously collected at NPL on radioisotope yields, neutron yields and windows, when critically evaluated, led to this increase in design energy. We knew from cross section measurements that to achieve useful yields of PET radionuclides from 8 MeV ^{3}He^{++} would require ~300 μA_e with at most 1.0 MeV loss in the entrance window. For the target window to tolerate this power (150 watts), the beam must be spread over 30 cm^{2} of window (Havar). We have not had an opportunity to test a window under the power load presented to the proposed targets, and the manufacturer could not guarantee this window thickness and area free of pinholes. Assembling targets with such thin material without tearing or wrinkling is also difficult. Thermal calculations suggested it would be difficult to achieve sufficient cooling in gas targets (or solid targets with gas cooling) to maintain target window integrity during high current irradiations.

Specification of the appropriate energy for the RFQ involves trade-offs between energy, current and cost to produce clinically useful radioisotope yields with robust machine and targetry performance. To help determine the optimal targetry conditions, further cross section and yield experiments were performed at NPL this past year. The results are shown in Figs. 8.1-1 and 8.1-2. These results as well as those from NPL experiments done in previous years were used to develop Table 8.1-1 below which gives the minimum mCi required for clinical PET and the current required to deliver this yield for the different nuclear reactions. One of the problems of the 8 MeV RFQ was that many of the nuclear reactions were (^{3}He, alpha) where the product nuclide is an isotope of the target element, thus yielding low specific activity radionuclides of limited usefulness in radiopharmaceutical production. By increasing the energy of the ^{3}He beam, we can lower the current on target and gain access to new reactions producing high specific activity radionuclides (on ^{14}N to produce ^{15}O and on either ^{10}B or ^{9}Be to produce ^{11}C). From these tables we conclude that sufficient ^{18}F, ^{13}N, ^{11}C and ^{15}O can be made with 9 MeV (200 μA_e) reaching the target material. For the ^{11}C, ^{13}N and ^{15}O targets at the higher energy, the current on target can be reduced and the robustness of the target windows will improve. A ^{3}He beam at 10 to 10.5 MeV on a 0.3 mil Havar window provides a good compromise. It is likely that this window can be operated at an energy deposition in the window of about 1.5 MeV and a current of < 200 μA_e in most cases, thus not increasing the power deposited in the window but doubling its strength.

Neutron measurements on these targets showed that the neutron flux was reasonably low for the higher energies, with the exception of ^{3}He on ^{9}Be which had a neutron flux approximately ten times the flux from the other nuclear reactions. The angular dependence of the neutron flux from these reactions was measured and is presented in Fig. 8.1-3. As expected, neutrons from irradiation of N and O were isotropic, those from C and Be were forward scattered. At lower energy the relative amount of forward scattering increased.

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Table 8.1-1. mCi Requirements for PET and ^{3}He Current Required from the PET RFQ

Radionuclide	mCi EOB* in tgt (Required for PET)	μA_e at 8 MeV	μA_e at 9.5 MeV	μA_e at 10 MeV
$^{16}O(^{3}He,p)\ ^{18}F$	600	360	215	180
$^{12}C(^{3}He,alpha)^{11}C$ (low SA)	1000	180	120	100
$^{10}B(^{3}He,pn)^{11}C$ (high SA)	440	140	90	80
$^{9}Be(^{3}He,n)^{11}C$ (high SA)	440	110	90	80
$^{12}C(^{3}He,pn)\ ^{13}N$	100	310	120	90
$^{16}O(^{3}He,alpha)\ ^{15}O$ (low SA)	800	340	220	190
$^{14}N(^{3}He,pn)\ ^{15}O$ (high SA)	200	170	90	70

Assumes a 1.0 MeV window at 8 MeV machine beam and 1.5 MeV windows at the higher energies and irradiation times of 1 hr for ^{18}F and ^{11}C, 20min for ^{13}N and 10 min for ^{15}O. (*EOB = End of Bombardment)

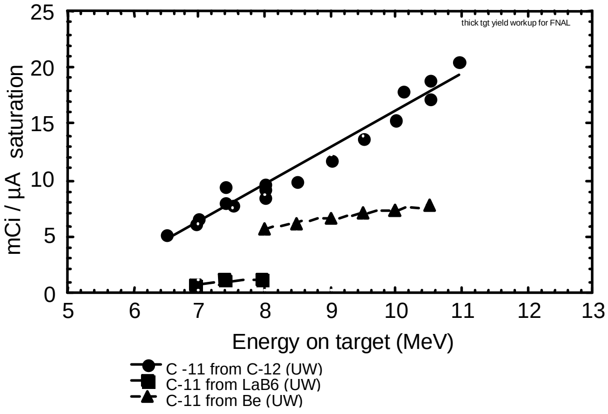

Fig. 8.1-1. ^{11}C yields from different nuclear reactions.

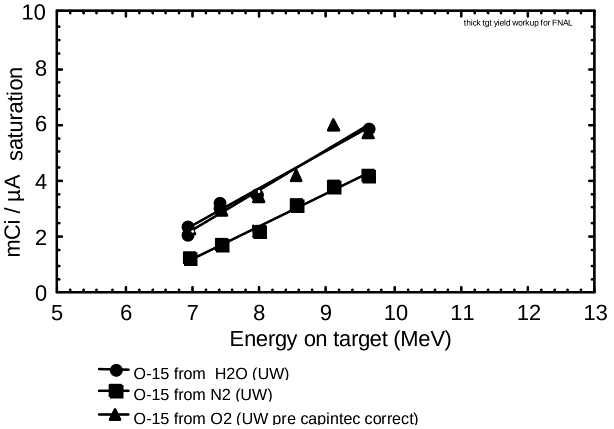

Fig. 8.1-2. ^{15}O yields from different nuclear reactions.

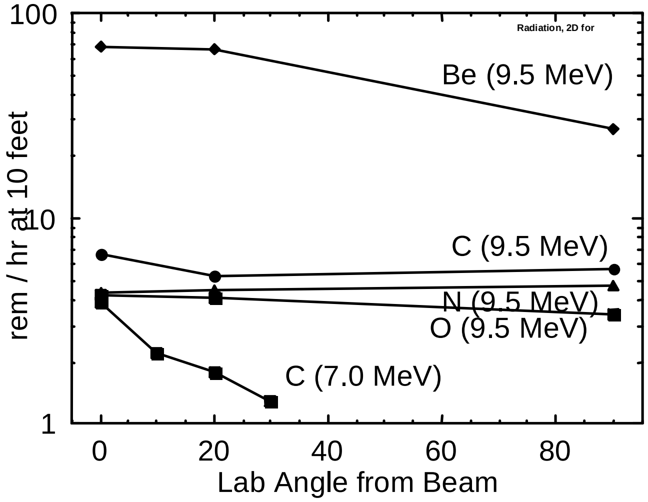

Fig. 8.1-3. Angular dependence of neutrons from ^{3}He irradiation of target materials.

8.2 Proton induced solar cell degradation

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The University of Washington Nuclear Physics Laboratory tandem Van de Graaff was used to produce a uniform proton beam over a 6-inch diameter for the purpose of irradiating solar cells and determining the proton induced degradation. This information is used in calculating the lifetime of solar cells in earth orbit. Using ~5 and 10† MeV protons and tantalum scattering foils, we were able to verify multiple scattering calculations.

Tantalum scattering foils were placed in the beam line 10 feet upstream from a 6 inch diameter exposure chamber. The final proton energies at the sample plane were 3 and 8 MeV with a beam flux of 3×10^9 cm^2-s. A small Faraday cup was scanned across the scattered beam to measure beam uniformity. The beam uniformity and intensity were as predicted with uniformity better than 10% over the 6 inch diameter.

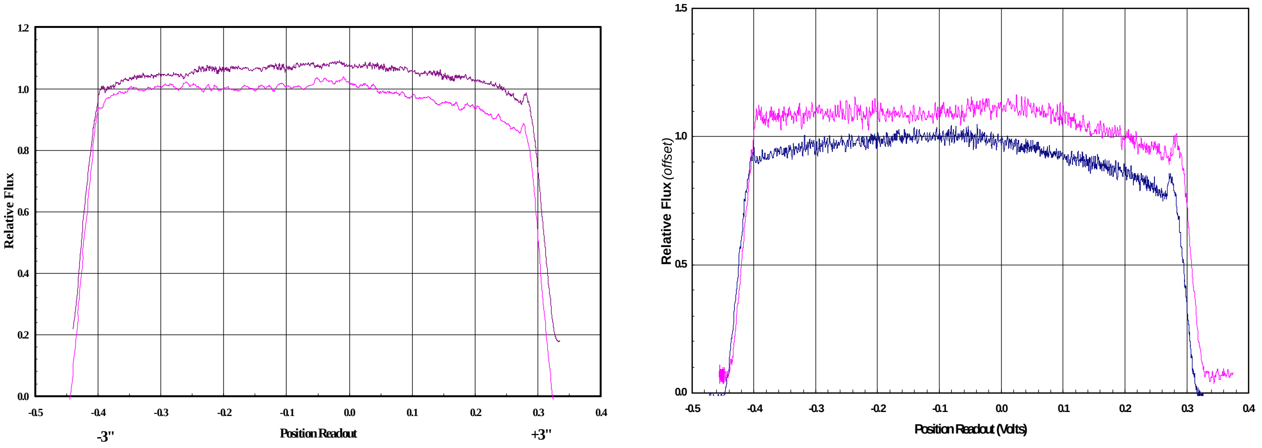

Fig. 8.2-1 and Fig. 8.2-2. Beam profiles used in the solar cell tests are shown for 8 MeV protons (left) and 3 MeV protons (right). In both cases higher energy protons (9.8 and 4.5 MeV) were incident on 1 and 2 mil tantalum scattering foils.

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8.3 Tests of radiation hardness of charge-coupled devices under exposure to protons

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A test program was performed to characterize the radiation hardness of the Scientific Imaging Technologies, Inc. (SITe) SI003A Charge-Coupled Device (CCD) for possible use in the Advanced X-ray Astrophysics Facility - Imaging (AXAF-I) Aspect Camera (AC). Intended to be a replacement for the SITe TK1024 CCD, the SI003A incorporates a 3 micron mini-channel in the parallel and serial registers and a Multi-Phase Pinned (MPP) implant in the transfer gate, improvements which should enhance the radiation hardness of the CCD.

The objectives of the test program were: 1) to obtain a data set that will be used to compare the radiation hardness of the SI003A and TK1024 imagers; 2) to expose the SI003A to a radiation environment which simulates as closely as possible the expected on-orbit environment; and 3) to characterize the pre- and post-radiation performance of the SI003A CCDs under flight-like operating conditions.

Radiation Test Program Methodogy

Two of the SI003A CCDs were exposed to the same shaped proton energy spectrum that the TK1024 CCDs were exposed to during a previous AXAF-I ACA radiation program. The objective of this method is to allow for a direct comparison of the radiation tolerance of the SI003A CCD to the TK1024 CCD radiation tolerance.

Radiation Sources

The cyclotron at the University of California Davis and the Tandem Van de Graaff generator at the University of Washington were used to cover the spectrum of proton energies needed.

At the UW a broad distribution of protons was produced by scattering through gold foils located a few meters upstream of the 60" scattering chamber. The proton flux was checked using a silicon detector with a pin-hole aperture, and was found to be uniform within a few percent over the area defined by the shadow of the collimator holder. This was sufficiently larger than the CCD's. Exposures were made to protons in the range of about 1 to 5 MeV.

This work was performed for Ball Aerospace by Spectrum Industries, Inc. of Santa Clara, California.

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