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INTRODUCTION

The Idaho National Laboratory (INL), the University of Washington (UW) Neutron Therapy Center, the University of Essen (Germany) Neutron Therapy Clinic, and the Northern Illinois University(NIU) Institute for Neutron Therapy at Fermilab have been collaborating in the development of fast-neutron therapy (FNT) with concurrent neutron capture (NCT) augmentation [1,2]. As part of this effort, we have conducted measurements to produce suitable benchmark data as an aid in validation of advanced three-dimensional treatment planning methodologies required for successful administration of FNT/NCT.

Free-beam spectral measurements as well as phantom measurements with Lucite™ cylinders using thermal, resonance, and threshold activation foil techniques have now been completed at all three clinical accelerator facilities. The same protocol was used for all measurements to facilitate intercomparison of data. The results will be useful for further detailed characterization of the neutron beams of interest as well as for validation of various charged particle and neutron transport codes and methodologies for FNT/NCT computational dosimetry, such as MCNP [3], LAHET [4], and MINERVA [5].

METHODS AND MATERIALS

Figure 1 shows the three treatment facilities, each with the same Lucite phantom in position for irradiation, with the isocenter of the beam located at the center of the top phantom surface in each case. The phantom has a diameter of 15.2 cm and a height of 21.6 cm. The field size at the isocenter was set as closely as possible to 8.0 cm x 8.0 cm for all irradiations. The UW treatment

Figure 1. Neutron therapy treatment facilites - UW (Top), Essen (Center), and Fermilab (Bottom).

facility has a 10.5 mm thick beryllium neutron production target mounted in the gantry – this is the standard target used for therapy at UW. A proton beam is incident on the target at a current of approximately 67 microamperes effective DC, with a nominal proton energy of 50.5 MeV. The Essen neutron source [6], also gantry mounted, is produced by a 14 MeV, 75 mA deuteron beam incident on a 5 mm thick beryllium target. The Fermilab facility features a fixed (non-gantry) beam, with a somewhat harder neutron energy spectrum produced by 66 MeV protons impinging at a current of approximately 25 microamperes on a 22.1 mm thick beryllium target in these experiments. Patient positioning at Fermilab is accomplished by a chair that has the capability of precise rotation and translation to produce essentially any beam-patient orientation desired. The target-to-isocenter distances are 1.5 m, 1.9 m and 1.25 m for the UW, Fermilab and Essen facilities, respectively.

Several different types of foil packages containing gold, manganese, aluminum, copper, and indium foils of various thicknesses, with and without cadmium covers, were placed at various depths along the central axis of the phantom. After the completion of each irradiation, the induced activities produced by the various interactions of interest in the foils were measured by gamma-ray spectrometry, and the results were converted to saturation activities.

RESULTS AND DISCUSSION

Figure 2 shows some typical results for the activation of bare and cadmium-covered 0.0254 mm (1 mil) thick gold foils via the interaction $^{197}Au(n,\gamma)^{198}Au$ as a function of depth along the phantom centerline for the three beams, normalized to the charged particle current incident on target in each case. Uncertainties are comparable to the size of the data points shown. With cadmium covers on the foil packages, the activation of gold by neutron capture is largely due to resonance neutron absorption at the primary resonance energy (5 eV) and above. Measurements using uncovered foils also include activation by thermal neutrons, of particular interest for NCT applications. The relative magnitudes of the activation rates produced by the three beams are consistent with the different target-isocenter distances and the incident charged particle beam energies for each case. Measurements were also made with heavier 0.254 mm (10 mil) foils in order to obtain useful data for several ^{197}Au (n,xn) threshold reactions in gold as well, where x is as high as 6. These interactions are sensitive to neutrons of higher and higher energies as x increases, providing additional spectral information as a function of depth in each case.

This information, along with information [7] from the numerous other thermal, resonance, and threshold interactions in the other foils in the phantom described here, as well as in a smaller phantom that has a different spectral sensitivity, allows the development of a self-consistent picture of the space and energy dependent behavior of the neutron flux in a representative application. Free-beam spectral measurements have also been completed using various foil packages placed at the beam isocenter. Taken as a whole, this will provide benchmark data for validation of computations required for beam characterization and treatment planning. Intercomparison of the performance of the neutron beams at the three facilities on a common basis will also be facilitated.

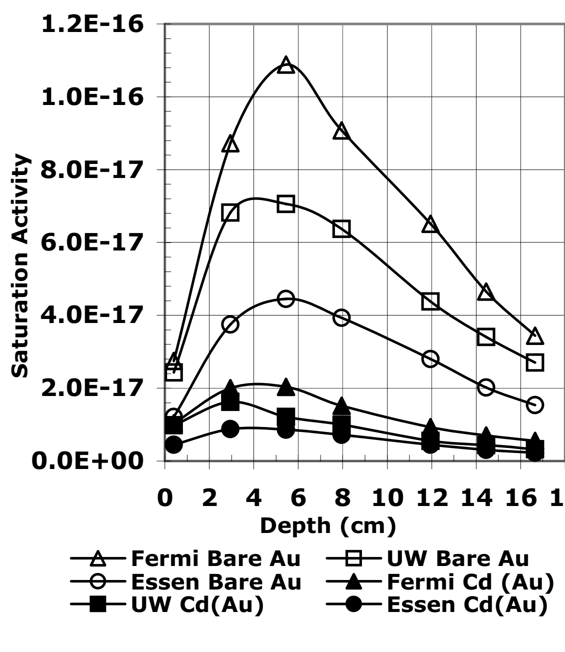

Figure 2. Saturation activity of ^{198}Au in 0.0254 mm thick gold foils as a function of depth along the phantom centerline for the three beams. Units are activations per second per atom per microampere of incident charged particle current on target.

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