ANALYSIS OF NEUTRON PRODUCTION IN THE HIGH-POWER RACE TARGET

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The High-Power RACE Target is a component of the Reactor-Accelerator Coupling Experiments (RACE) Project conducted at the Idaho State University Idaho Accelerator Center (ISU-IAC). The target was designed to be coupled to a high-power electron linear accelerator and will produce photoneutrons through brehmstrahlung emissions. The target consists of an aluminum body with a cavity machined in the front face for copper-tungsten disks. The disks are separated by aluminum spacers, which create channels for cooling water. The body of the target has another cavity to allow the insertion of a natural uranium rod for increased neutron production.

The target was tested at ISU-IAC with an electron linear accelerator in April and August 2006 to determine neutron generating performance. MCNPX, a Monte Carlo radiation transport code, was used to simulate neutron production in this target. A 23 MeV electron beam was modeled on the face of the target and all gold foils were modeled in their precise locations. A comparison of experimental to calculated values will be presented.

I. INTRODUCTION

The High-Power Race Target is a component of the Reactor-Accelerator Coupling Experiments (RACE) Project[1] that were conducted at the Idaho State University Idaho Accelerator Center (ISU-IAC). The target was designed to be coupled to a high-power electron linear accelerator (linac) and will produce photoneutrons through brehmstrahlung emissions.

The target consists of an aluminum body with a cavity machined in the front face for copper-tungsten disks. The disks are separated by aluminum spacers, which create channels for the flow of cooling water. The body of the target has another cavity which will allow the insertion of a natural uranium rod for increased neutron production through photo-fission in addition to photo-neutron production in heavy metals.

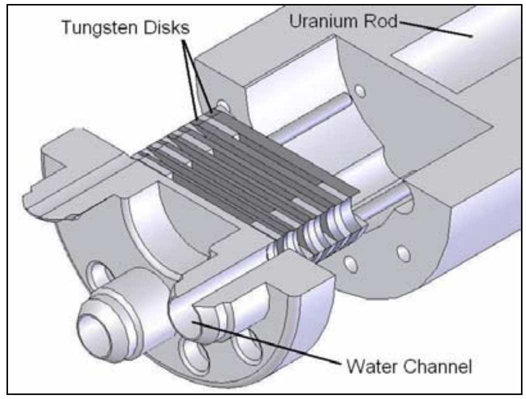

Figure 1. Cross Section View of the Front of the High-Power Race Target.

For a more detailed description of the target design, see Ref. 2 in these proceedings.

II. TESTING

The target was transported to the ISU-IAC for testing with an electron linear accelerator in April 2006 and again in August 2006. The natural uranium rod was not available during testing, so the middle section was filled with lead pellets.

Gold foils were placed at various locations along the target to record activation levels (Fig 2). Several foils were placed along the side of the target to provide data about the difference in flux between the sides and top of the target. Table I shows the locations of the gold foils for the August test only.

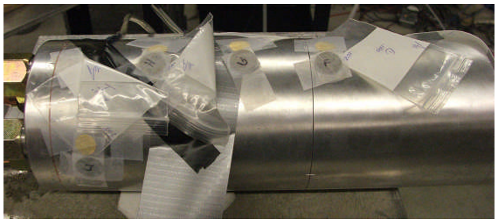

Figure 2. Gold Foils (gray foils are cadmium covered from the April 2006 test).

Table I. Gold Foil Axial Positions (measured from the face of the target).

Foil	Position **(in)**
A	0.25
B	1.125
C	2.125
D	3.125
E	4.125
F	5.125
G	6.125
H	7.125
I	8.125
J	9.125

The target was tested with a currently available lower-power electron beam to determine its thermal and neutron generating performance. The beam was turned on for 1847 seconds with a frequency of 90±1 Hz, current of 8±0.5 mA, and pulse width of 4±0.5 µs. The linac was characterized immediately following the August test and was found to produce 23±1 MeV electrons.

The April tests have not been studied at length due to changes that were made in the testing process to provide for lower thermal losses. For results of thermal testing of the target, see Ref. 3 in these proceedings.

III. *MCNPX* SIMULATION

MCNPX,[4] a Monte Carlo radiation transport code, was used to model electron-photon-neutron transport in this target. A monoenergetic 23 MeV electron beam was modeled on the face of the target with a directional bias toward the target face. The radial beam intensity was modeled as a linear distribution. The steel table and polyurethane blocks that were used to align the target with the beam port were modeled to accurately represent the experimental setup (Figures 3 and 4).

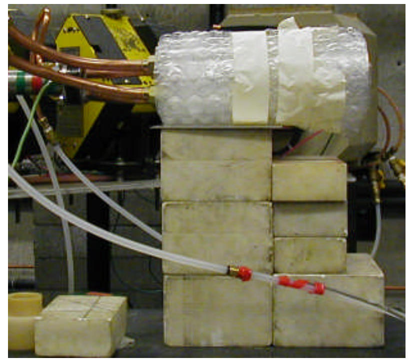

Figure 3. Target in Front of the Beam Window of the ISU Electron Linac (The target is shown wrapped in "bubble wrap" to reduce heat loss through the walls for a simultaneous thermal experiment[3]).

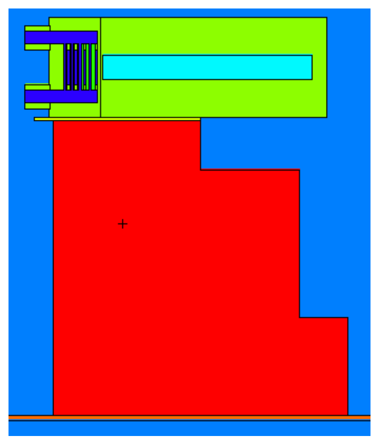

Figure 4. Side View of *MCNPX* Model (The target is shown in green, lead in light blue, water in dark blue and polyethylene in red).

All gold foils were modeled in their precise locations on the body of the target. Cell detectors (F4 tallies) were used to predict activation levels in the gold foils. Variance reduction techniques were used to decrease relative errors in accordance with the *MCNPX* manual.[3] A tally multiplier card was used to account for the power inputs and was calculated by multiplying the energy, amperage, frequency, and pulsewidth of the electron beam used in the experiments.

IV. TEST RESULTS

The first model was created with borated polyethylene and full density lead in the cavity. Table I shows gold foil activation levels at different points on the target for the 23 MeV electron beam. The beam power for this particular test was 648 W. The activity decreased in the foils from the front of the target to the rear of the target, as expected, both experimentally and in the model.

Table I. Measured Gold Activation in the HP RACE Target (23 MeV electron beam)

Location (in)	Aug Test dps	err %	MCNPX dps	err %
0.25	2306	2%	1072	3%
1.125	2839	2%	1532	2%
2.125	2115	2%	1486	2%
3.125	1489	3%	1140	4%
4.125	1023	3%	719	4%
5.125	699	4%	414	6%
6.125	517	4%	217	7%
7.125	364	5%	136	10%
8.125	256	6%	52	10%
9.125	190	7%	49	18%

The differences between activation in the experimental and theoretical tests prompted a series of parametric studies to determine possible causes. The lead pellets in the cavity did not fill 100% of the cavity due to their spherical shape. The maximum spherical packing density has been shown to be ~78%[5]. The amount of boron present in the polyurethane and the accuracy of the beam characterization were other issues that needed to be tested.

New models were generated to determine the response of the system to different combinations of lead density and amount of boron in the polyurethane. A 25 MeV, full density lead, borated polyurethane model was also run to compare to the experiment and the 23 MeV model.

As can be seen in Figures 5 and 6, the model was not sensitive to changes in polyurethane or lead. The most significant change in activation in the *MCNPX* models occurred with an increase in electron beam energy. Relative errors in the August test values were all less than 7%. The relative errors in *MCNPX* were less than 6% in the first 4 inches of all models and increased to as much as 27% at the back of the target. These errors primarily occur because the electron beam is modeled on the face of the target and photo-neutrons must be transported to the back of the target. Running enough particles to produce very good statistics at the back of the target is prohibitive from a time perspective.

V. CONCLUSIONS

HP RACE models created prior to the ISU experiments suggested neutron production higher than that of the previous RACE targets with a U rod inserted in the cavity. The August 2006 tests show that the actual neutron production of this target is higher than the models show, even with lead pellets in the cavity.

There was little success, however, in creating models that produced results close to those of the experimental setups. Previous RACE tests have produced similar trends, wherein the shape function of the models closely matches the experimental results, but the flux magnitude does not[6].

The errors could be due to choices made in the specification of the MCNP input deck, such as densities, material compositions or the source energy distribution. They could also occur from the propagation of errors from the experiment to the final model.

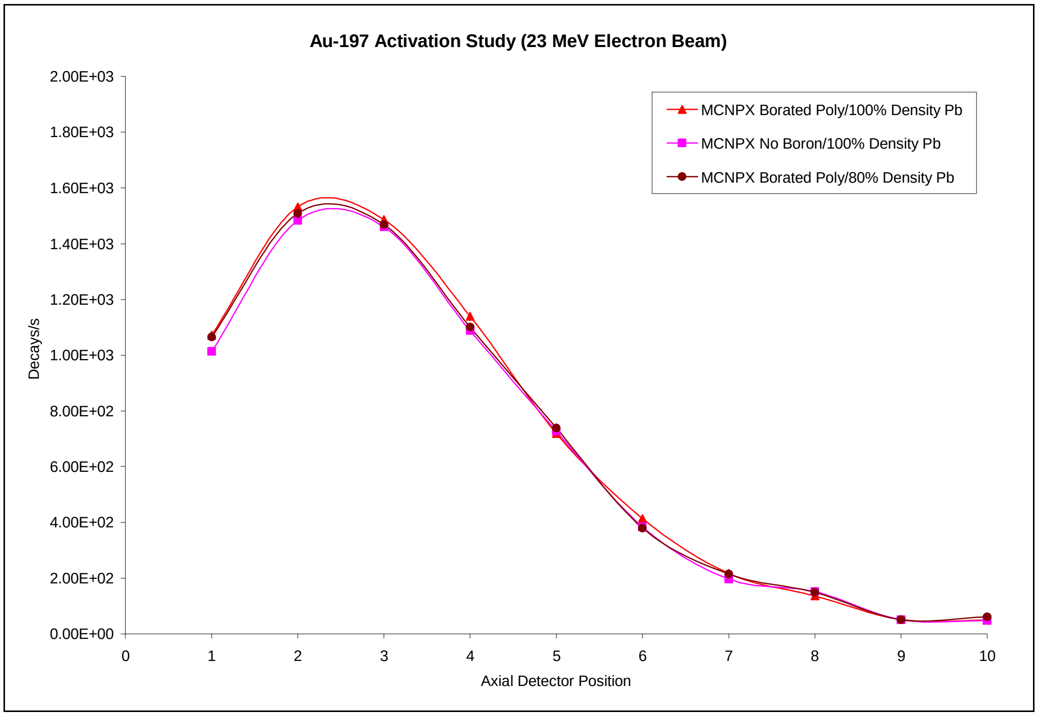

Figure 5. *MCNPX* Results for Different Combinations of Boron and Lead Amounts in the HP RACE Target

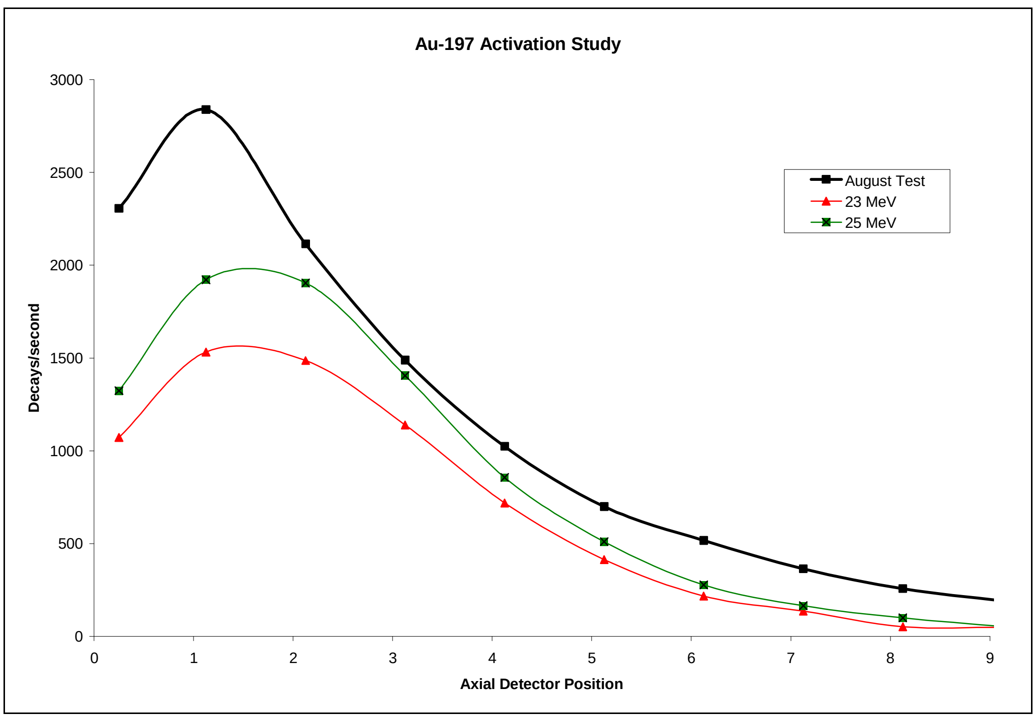

Figure 6. *MCNPX* Results for Different Electron Beam Energies Compared to Experimental Tests Completed in August 2006.

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