DESIGN OF THE HIGH-POWER RACE TARGET

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The High-Power Reactor Accelerator Coupling Experiments (RACE) target is a continuation of target designs originally tested under RACE at powers up to 1.6 kW. The goal of the HP RACE project was to couple a target with an electron linear accelerator at powers up to 20 kW to produce an increased number of bremsstrahlung photo-neutrons. Previous testing suggested there was a need for a new, innovative design that incorporated a cooling system into the target.

The new target is an aluminum cylinder with cavities machined for water lines, a heavy metal target, and a metallic-uranium photoneutron generator. The target is ~29 cm long and ~10 cm in diameter. The front of the target consists of a cavity that holds a stack of tungsten disks with aluminum spacers that allow cooling water to flow between the disks. Two water lines enter the face of the target and two lines exit the face of target, creating cross-flow between the disks. The rear of the target contains a cavity for a uranium rod. The tungsten disk thicknesses were optimized for both heat transfer and neutron production. The complete design process is explained herein.

I. INTRODUCTION

The High-Power RACE (HP RACE) Project is a component of the Reactor-Accelerator Coupling Experiments (RACE)[1] conducted at the Idaho State University Idaho Accelerator Center (ISU-IAC) and at the University of Texas (UT). The RACE Project specifically focuses on accelerator driven subcritical systems that include an electron linear accelerator coupled with a target that is designed to emit a large number of neutrons per unit time.

The ISU RACE target in Figure 1 was designed to be placed in the center of the graphite-reflected fuel assembly shown in Figure 2 (without fuel plates in the pictured fuel trays). The target and subcritical assembly were submerged in approximately 70 gallons of room temperature water. An electron linear accelerator (linac) with a maximum beam power of ~1 kW was used to produce photo-neutrons. Due to the low beam power and natural convection, the ISU-IAC target did not need additional cooling. The UT RACE target depicted in the drawing in Figure 3, however, was designed to be placed in a 6 in. diameter steel pipe with cooling provided by forced convection with chilled water. The UT target operated with up to 1.6 kW of beam power.[2,3]

Figure 1. ISU RACE Target (the top piece is the conflate flange used to attach the target to the vacuum tube).

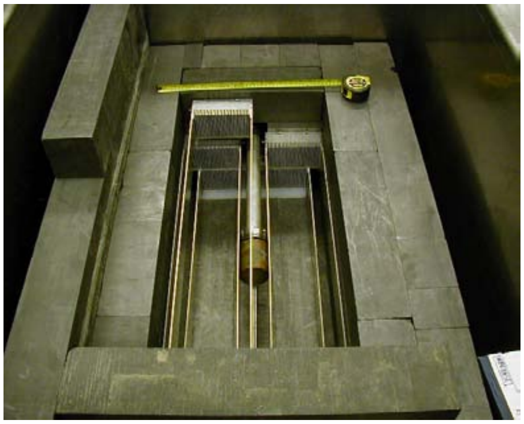

Figure 2. ISU RACE ***Assembly***[1] (empty fuel trays, graphite reflectors, linac vacuum tube and target are shown without water moderator).

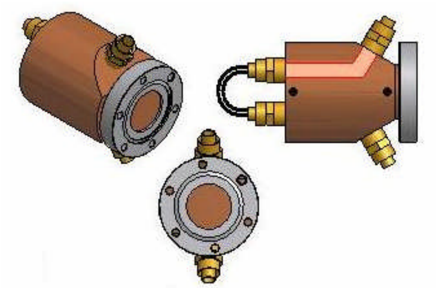

Figure 3. UT RACE Target with Chilled Water Lines[2,3] (Courtesy of Kevin Folkman, ISU-IAC).

To produce more neutrons per second, a higher power beam must be used. If the beam can place more electrons per second on the face of the target, the result will be more photo-neutrons per second. The parameters of the beam that was intended to be used with the HP RACE are:

- Power: 25 MeV
- Current: 100 mA
- Pulsewidth: 23 µs
- Frequency: 360 Hz

A beam power of 20 kW required a completely different target design than had been used previously. Neither the submerged ISU RACE target nor the Texas RACE target were believed to be capable of the cooling needed for this level of power.

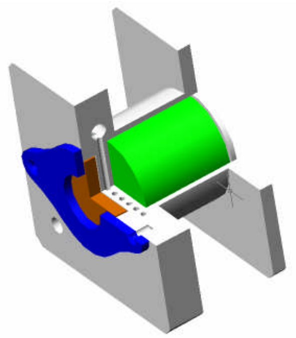

Figure 4. Isometric View of the Preliminary Design

A preliminary design was created that consisted of an aluminum (Al) body with water channels machined into the Al to allow removal of heat.[3] Analysis of the target shown in Figure 4 suggested that the water in the lines would reach boiling temperature, which could cause cavitation and instability in the cooling system. The flow rate required to remove 20 kW from this target and to prevent the coolant from boiling was calculated to be ~65 gpm. Due to the unrealistic flow requirements of this design, a completely new design was needed. The design and fabrication of the final HP RACE target will be covered in this paper.

II. FINAL DESIGN

The photo-neutron generating component of the new design is a tungsten (W) disk stack consisting of seven W disks and eight sets of aluminum (Al) spacers as seen in Figure 5. The channels created by the Al spacers allow cooling water to flow between the disks.

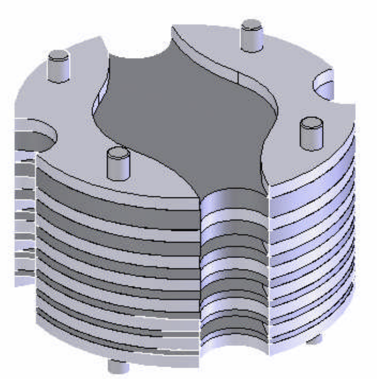

Figure 5. W Disk Stack.

Spacers made of 0.25 cm thick Al create flow channels between each W disk. The water channels alternate flow direction. The first channel flows from the top left to the bottom right and the next channel flows from the top right to the bottom left. This was done to prevent the vortices that might be created by flowing water into a single water channel from opposing directions. It was also designed this way to prevent stagnant zones in the flow that may occur in designs that appear similar to the HP RACE target.

There are four water lines (½ in. diameter), two for inlet and two for outlet. The line size was chosen for the ease of acquiring pipe and fittings. The water connections were machined into the front cover and AN fittings (Air Force-Navy Aeronautical Standard) were used to connect the water lines. Based on the use of ½ in. inlet and outlet pipes, the thickness and width of the Al spacers was determined based on the requirement that the surface area of the W disk exposed to coolant had to be large enough to keep the disk surface below the boiling temperature of water.

To evenly distribute electron energy deposition across all seven W disks, which simplifies the cooling design, the disk thicknesses increase from the front to the rear of the stack. The disks thicknesses shown in Table 1 were calculated based on the exponential decrease in particle intensity with distance in a medium. Each disk should absorb ~3 kW of power.

Table I. W Disk Thicknesses.

Position from Front to back	Thickness (cm)
1	0.12
2	0.13
3	0.15
4	0.18
5	0.22
6	0.29
7	0.41

Figure 6. Complete Target (W disk stack not shown).

The body of the target is composed of two main sections. There is a cavity machined in the body for an Al-clad U rod. It was initially designed to have a shallow back plate that would bolt to the rear of the target, allowing the removal of different rods from the hole. Due to machining constraints, the body was split into two pieces and the holes for the bolts were drilled much deeper to allow us to bolt the rear section to the front. There is also a copper gasket between the front body section and the front cover to prevent water leakage. All components of the target were designed using tolerances that would allow for thermal expansion.

The circular area located at the center of the cavity created by each set of Al spacers is 3 cm in diameter. The electron beam can essentially be “painted” back and forth across the target to effectively increase the size of the beam spot. A larger beam spot allows the coolant flowing along the face of the W disks to more effectively remove heat because there is less energy deposition per unit area of disk.

Based on an inlet channel width of 1.27 cm (½ in. inlet lines) and channel depth of 0.25 cm, the cross-sectional area of the cooling channel and the wetted perimeter were calculated. To allow for fully turbulent flow, a Reynold’s number of 15,000 was assumed. The velocity required at the center of the disk to maintain that Reynold’s number was then calculated to be 2.5 m/s. The velocity required at the entrance of the disk was calculated to be 5.9 m/s. The velocity in the square channels was then converted into a cylindrical supply-line flow rate, given ½ in. lines, of 12 gpm. Using the equation $Q=mC_p\Delta T$ and assuming that the coolant must remove all of the energy deposited in the disk to prevent heating of the target results in a change in temperature of ~1 °C from inlet to outlet. This suggests that the HP RACE design should be capable of meeting the goals of the project.

The HP RACE target was taken to the ISU-IAC in April and August 2006 and tested with an electron linear accelerator to determine thermal and neutron generation performance. Experiments and computational analysis of neutron production of the HP-RACE Target are presented in Ref. 4, and thermal hydraulics experiments are compared to computational fluid dynamics modeling in Ref. 6.

III. CONCLUSIONS

Previous RACE targets that were built and tested at the Idaho State University Idaho Accelerator Center (ISU-IAC) and at the University of Texas only used beam powers less than 2 kW. The purpose of these targets was to produce as many neutrons per unit time as possible. A simple way to do this is to increase the power, which increases the flux across the face of the target. To use beam powers as high as 20 kW, the High-Power RACE target was designed. It was built to withstand the heat associated with placing 20 kW of 25 MeV electrons on the face of the target. This target should fulfill the requirements set forth in the HP RACE Project with no further modifications or design changes.

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