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J. R. Venhuizen
D. W. Nigg
G. E. Tripard

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J. R. Venhuizen[1], D. W. Nigg[1], and G. E. Tripard[2]

[1]Idaho National Engineering and Environmental Laboratory, Idaho Falls, Idaho, USA
[2]Washingston State University, Pullman, Washington, USA

SUMMARY Moderating material has been installed in the original thermal-neutron filter region of the Washington State University (WSU) TRIGA™ type reactor to produce an epithermal-neutron beam.

INTRODUCTION Attention has been focused upon the development of a convenient, local, epithermal-neutron beam facility at WSU for collaborative Idaho National Engineering and Environmental Laboratory (INEEL)/WSU boron neutron capture therapy (BNCT) preclinical research and boronated pharmaceutical screening in cell and animal models. The design of the new facility was performed in a collaborative effort[1,2] of WSU and INEEL scientists. This paper summarizes the physical assembly of this filter.

FACILITY DESCRIPTION

In this design, the original graphite has been removed from the thermal column region and replaced with an epithermal-neutron filtering, moderating, and collimating assembly, as shown in Figure 1. The spectrum is tailored in this region such that most neutrons emerge with energies in the epithermal energy range (0.5 eV – 10 keV). Downstream of the filtering and moderating region is a cadmium thermal-neutron absorber, a bismuth and lead gamma shield, and a conical neutron collimator composed of bismuth surrounded by borated polyethylene. A lead gamma shield and lithiated polyethylene thermal-neutron absorber complete the assembly. Provision is made for several different exit port aperture sizes, as shown in Figure 1. A key distinguishing feature of the WSU facility is the incorporation of a high-efficiency, neutron moderating and filtering material, FLUENTAL™, developed by the Technical Research Centre of Finland[3]. FLUENTAL is manufactured by hot isostatic pressing of a powered mixture of 69% (by weight) aluminum fluoride, 30% aluminum, and 1% lithium fluoride. A block of this material, having a thickness in the beam propagation direction of 0.64 m and transverse dimensions of approximately 0.6 m, is surrounded by aluminum oxide to produce the neutron filtering and moderating region. MCNP[4] and DORT[5] radiation transport design calculations for the coupled core and filter-collimator assembly indicate that an epithermal-neutron flux of approximately 10^9 n/cm^2-s at a reactor power of 1 MW will be produced at the exit port of the collimator (with the reactor core optimally loaded). The background neutron KERMA (a measure of the fast-neutron contamination) for the beam is calculated to be in the range of approximately 2.0 x 10^{-11} to 4.0 x 10^{-11} cGy/n-cm^2. The computational methods used for this design were previously validated against INEEL measurements performed for a similar neutron beam facility that is in operation at the FiR 1 TRIGA research reactor in Finland[6]. An additional key feature of the WSU beam facility design is the provision for adjustable filter-moderator thickness (in 4 cm steps) to systematically explore the radiobiological consequences of increasing the fast-neutron contamination above the nominal value associated with the baseline system described above.

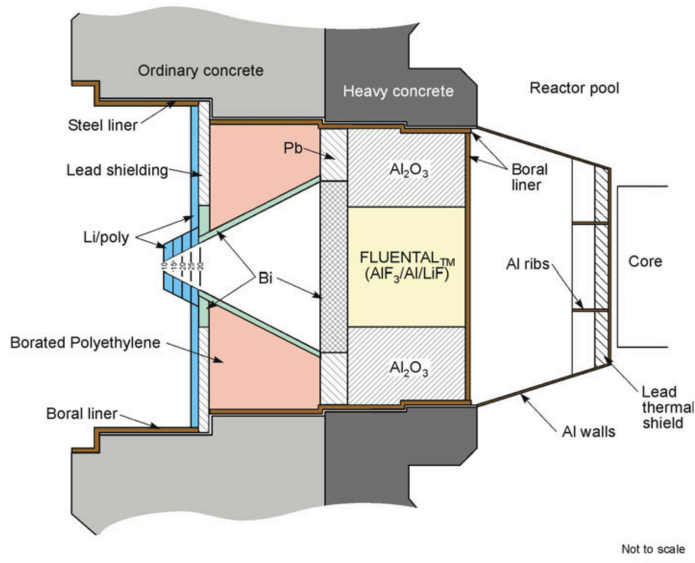

Figure 1. WSU column assembly, with epithermal-neutron filter in place.

CONSTRUCTION

Thermocouples and Nitrogen Vent Line

Prior to installation of the filter-moderator components, thermocouples were placed at selected locations on the lead primary gamma shielding at the far end of the thermal column cone housing. Five thermocouple leads were attached to the lead thermal shield; the sixth lead is attached to the center of the boral liner facing the cone. Also included with the thermocouple leads was a 0.635 cm diameter nylon tube that vents into the bottom of the cone area to supply a nitrogen-purge in the cone area.

Aluminum Oxide and FLUENTAL Assembly

The primary filter moderator-filter assembly was built up from blocks of aluminum oxide and FLUENTAL. A sheet of boral prevents the blocks from falling into the cone area. The FLUENTAL material consists of 17 blocks of nominal dimensions 63.5 x 22 x 8 cm, 8 blocks of 63.5 x 11 x 8 cm, and 6 blocks of 63.5 x 22 x 4 cm. This allows stacking the blocks in a cube arrangement of 8 rows measuring 63.5 x 64 x 66 cm when complete. The 4 cm thick blocks make it possible to shorten the filter in 4 cm increments if desired. The alumina blocks were produced in 8 x 8 x 16 cm size by Coors Ceramics (Golden, CO., USA) to mate with the FLUENTAL. The blocks were stacked with an offset in both directions to minimize streaming paths. Cadmium sheets, 30 mil thick, were 'hung' over the end of the assembly, providing a thermal neutron absorber.

Gamma Shield

The gamma shield consists of 10.16 cm of lead bricks covering the outside area of the alumina blocks, and 10.16 cm of bismuth covering the FLUENTAL region. The lead bricks are stacked on edge, with an over-lapping design to prevent streaming. The four interlocking bismuth shield blocks, designed to mate with the lead bricks, were cast at the INEEL.

Collimator Design

The design of the cone-shaped bismuth collimator was based on a tradeoff of cone height to maximize the neutron collimation versus intensity loss of the neutrons. The final design selected was a truncated right circular cone with a base opening diameter of 91.4 cm, a height of 38.1 cm, and a wall thickness of 3 cm. The angle of the cone is 45 degrees, giving an opening of 25.4 cm. The final 5 cm of the cone is fitted with a collar, designed so that various shaped apertures can be fabricated from lithiated polyethylene and inserted in a flanged opening. The bismuth cone is supported by borated polyethylene (Reactor Experiments, 5% Borated Polyethylene, Catalog Number 201) for the first 27.9 cm, and two rows (10.16 cm) of lead bricks. The last five cm of the bismuth staves are fitted with a bismuth collar designed to provide a transition from the cone-shape to mate with the lead bricks while providing shielding for the capture gammas generated from the boron in the polyethylene. The collar was formed in a mold also, in two pieces due to the final weight (~45 kg each). This bismuth collar will accommodate lithiated polyethylene final neutron beam delimiters.

Collimator Assembly

The collimator was assembled in two halves. The poly sheets have the corresponding cone shape cut in them, are bolted together with nylon bolts. With the lower half of the poly in position, the front lead bricks were assembled up to the level of the collimator collar. The lower half of the collar was placed on the lead, and the bismuth staves put into position. The bottom seven staves are pinned to the collar with aluminum rod. A carbon fiber ring was put in place at the rear of the assembly, and a lexan ring inserted at the front of the assembly, providing support for the top half of the collimator staves. With the top half of staves and poly in place, the upper bismuth collar was positioned, and lead bricks continued up to the level of the top of the collar. The top of the collar and accompanying lead bricks are used to support the final large bismuth lintel piece. With the lintel positioned, the remainder of the lead bricks were added to complete the lead wall. The lead wall was covered with lithiated polyethylene, held in place with nylon bolts.

Conclusions

A new epithermal-neutron beam is available for research in the U.S. The beam is being characterized, with a measured source plane (defined at the lexan opening) useful for treatment planning calculations. A beam monitor system remains to be developed and installed. When completed, beam measurements will be made and compared to the FiR 1 neutron source and to calculated values.

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