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Thermal Performance of a Fast Neutron Test Concept for the Advanced Test Reactor

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THERMAL PERFORMANCE OF A FAST NEUTRON TEST CONCEPT FOR THE ADVANCED TEST REACTOR

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INTRODUCTION

Since 1967, the Advanced Test Reactor (ATR) located at Idaho National Laboratory (INL) has provided state-of-the-art experimental irradiation testing capability. A unique design is investigated herein for the purpose of providing a fast neutron flux test capability in the ATR. This new test capability could be brought on line in approximately 5 or 6 years, much sooner than a new test reactor could be built, to provide an interim fast-flux test capability in the timeframe before a fast-flux research reactor could be built [1]. The proposed cost for this system is approximately $63M [2, 3], much less than the cost of a new fast-flux test reactor.

A concept has been developed to filter out a large portion of the thermal flux component by using a thermally conductive neutron absorber block. The objective of this study is to determine the feasibility of this experiment cooling concept.

DESIGN REQUIREMENTS

Neutronics performance goals for this system are a fast (E > 0.1 MeV) flux of at least 1 x 10^{15} n/cm^2-s with a fast-to-thermal flux ratio in the vicinity of 40[4]. The addition of booster fuel is necessary to achieve these flux levels. It was assumed that typical experiments will consist of fuel specimens (~1 cm diameter) with axial heating rates up to 2.3 kW/cm (70 kW/ft) and a total heat load from all specimens as high as 200 kW. The cooling system must be capable of maintaining test article surface temperatures at or below 500°C, but the cooling system should be compatible with 1100°C as a possible test article surface temperature. Heat transfer from the experiment capsule to the neutron absorber material would be accomplished by thermal bonding using molten metal, such as Na or Li.

THERMAL HYDRAULIC ANALYSIS

A thermal hydraulic model of the proposed configuration was constructed and evaluated to determine whether the proposed configuration is capable of cooling a set of experiments located in the Northwest Lobe of the ATR. A 3D model comprised of 115, 592 elements was created using ABAQUS version 6.6-3 [5] to determine component temperatures. Figure 1 illustrates the conductive cooling system consisting of an absorber block, coolant channels, envelope tube, pressure tube, helium gas gap, and three experiment locations.

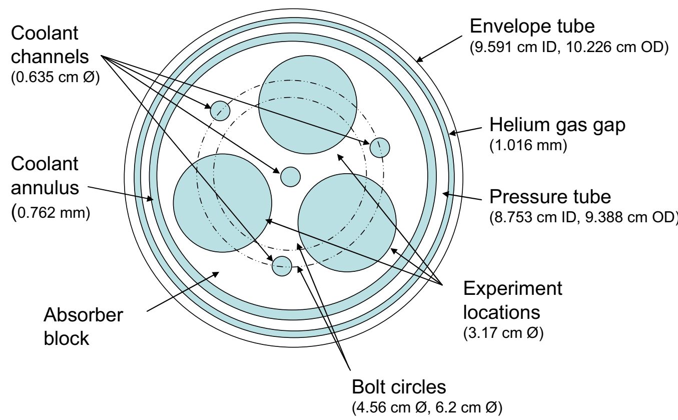

Figure 1. Proposed Configuration.

An absorber block fabricated from a Al-7 wt% Hf alloy serves a dual role as a neutron filter and a medium to conduct heat away from the experiments. Convective cooling is provided by an annular ring of coolant water between the absorber and the pressure boundary and four cylindrical coolant channels through the length of the absorber block. Oxide layers (12.7 µm, 0.0005 inch thick) are assumed to be present on the surfaces of the absorber block exposed to the water coolant. A helium gas gap in between the Inconel-600 envelope and pressure tubes exists for the purpose of leak detection monitoring. All components in the model have a length of 1.219 m (48 inches) representing the four-foot active core length.

Coolant water to the annulus and cylindrical water channels is supplied by the 2A pressurized water loop at 12.4 MPa (1800 psia). The inlet water temperature and component initial temperature are assumed to be 110°C (230 °F). Coolant flows through the annulus at a flow rate of 90 L/min (23.8 gpm) and through the water holes at 116.9 L/min (30.9 gpm). The annulus and water channel mass flow rates are specified as 0.687 kg/s-cm^2 (9.76 lbm/s-in^2) and 1.464 kg/s-cm^2 (20.81 lbm/s-in^2), respectively. The total volume of water is 4.076 x 10^{-4} m^3 (24.87 in^3), with 0.2532 L (15.45 in^3) in the annulus and 0.1544 L (9.422 in^3) in the four cylindrical water channels. The total coolant flow rate requirement is 207 L/min (54.7 gpm).

Results from RELAP5-3D [6] analyses were used to specify the convection boundary condition at the outside of the envelope tube. The external surface of the envelope tube is cooled by ATR primary coolant flowing at a velocity of 13.59 m/s (44.6 ft/s) with an average coolant temperature of 82.2°C (180 °F).

RESULTS

The design presented here is capable of maintaining all system components below their maximum temperature limits. The maximum temperature of this conduction cooling system, 224.2°C (435.6 °F) occurs in a small, localized region in the heat sink structure near the core mid-plane (see Figure 2). The temperature is well below the melting temperature of aluminum (660°C). The calculated flow instability ratio (FIR) and departure from nucleate boiling ratio (DNBR) for this configuration under nominal conditions are 6.5 and 8.0, respectively, above the required minimum values of 2 [7].

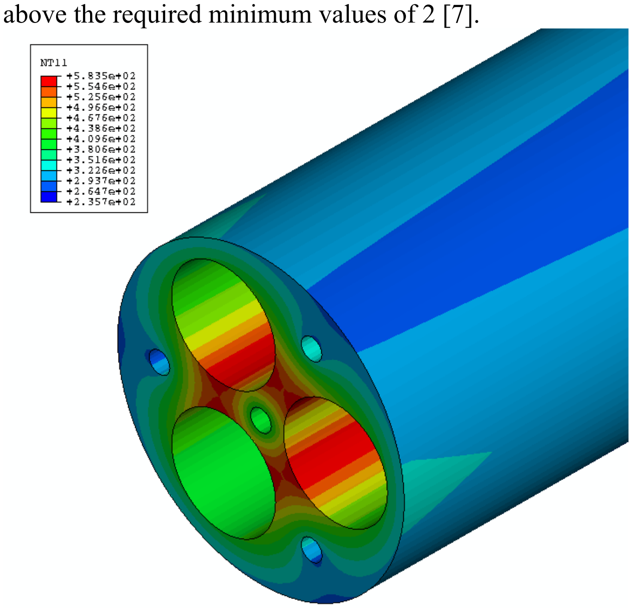

Figure 2. Radial temperature distribution (°F) in the absorber block.

FUTURE WORK

The proposed configuration is an exploratory concept to investigate the neutronic and thermal performance of the absorber block. This design can be further optimized to increase the fast neutron flux and the fast/thermal flux ratio. Water is considered to be the most viable fluid for convective cooling of the experiment. However, the total volume of water should be minimized due to its tendency to thermalize fast neutrons. The FIR and DNBR estimates are derived from scoping calculations to show design feasibility under nominal conditions. Once the design is finalized, the FIR and DNBR must be evaluated under postulated accident conditions.

Future work should include irradiation experiments to investigate:

- The rim heating effect in the fuel periphery caused by the residual thermal neutrons. PIE will be necessary to assess the impact of potentially higher fission product concentrations that may induce corrosion or cracking at the fuel-cladding interface and any fuel restructuring due to the nature of the temperature profile [3].
- Absorption capability, burnup and overall performance of the absorber block.

The selection of Hf as a thermal neutron absorber was made on the basis of familiarity of ATR operations with Hf, with the purpose of exploring the cooling options, rather than optimizing physics. Hafnium is a very attractive thermal neutron filter because of the many sequential absorption reactions it undergoes. However, a different material, such as Eu, Cd, or ^{3}He could have been selected instead.

ACKNOWLEDGMENTS

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