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Summary

An irradiation test vehicle (ITV) for the Advanced Test Reactor (ATR) is being jointly developed by the Lockheed Martin Idaho Technologies Company (LMIT) and the U.S. Fusion Program. The vehicle is intended for neutron irradiation testing of candidate structural materials, including vanadium-based alloys, silicon carbide composites, and low-activation steels. It could possibly be used for U.S./Japanese collaboration in the Jupiter Program. The first test train is scheduled to be completed by September 1998. In this report, we present the functional requirements for the vehicle and a preliminary design that satisfies these requirements.

Objective

With the demise of fast reactors in the U.S., water-cooled mixed-spectrum reactors, such as the High Flux Isotope Reactor and the ATR, are increasingly being relied upon for irradiation testing of fusion structural materials. Because thermal neutrons are largely absent in the first-wall and blanket regions of a fusion reactor, the challenge of using a mixed-spectrum reactor for testing fusion materials lies mainly in curtailing the undesirable side effects of thermal neutrons (e.g., atypical transmutation). The ATR-ITV project is an effort to create a versatile test vehicle in the ATR that would be suitable for a wide range of neutron damage studies of various candidate fusion materials.

ITV Functional Requirements

The following functional requirements were identified by the fusion program and provided to LMIT to guide the vehicle design effort.

1. Thermal Neutron Filtering

   The neutron flux in the test volume shall be hardened to limit the thermally-dominant V(n,γ)Cr transmutation in vanadium-based alloys to <0.5wt.% Cr during the irradiation. In addition, the filtered neutron spectrum shall permit the conduct of dynamic helium charging experiments (DHCE)† with vanadium alloys. The thermal neutron filter shall be external and replaceable to maintain a high-quality neutron environment throughout the irradiation.

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* Work Supported by Office of Fusion Energy, U.S. Department of Energy, under Contract W-31-109-Eng-38.

† The purpose of the DHCE is to study the concurrent effects of neutron damage and helium generation, as they would occur in a fusion reactor. In the experiments, tritium would be precharged in the lithium bond of the specimen capsules. During the irradiation, the tritium would diffuse from the lithium into the specimens and some would decay in-situ into ^3He. The challenge for the DHCE in a mixed-spectrum reactor is to prevent the back conversion of ^3He into ^3H through the (n,p) reactions, which have a high cross-section for thermal neutrons.

2. Multiple Test Temperatures and Active Temperature Control

   The vehicle shall contain multiple specimen capsules each capable of operating at different temperatures. The range of test temperatures will be ≈250-750°C, depending on test material requirements. The temperature of each capsule shall be monitored on a real-time basis; it should be controllable by the blending of two gases (of differing thermal conductivities) in a radial gap that governs the dissipation of heat from the capsule.

3. High Neutron Damage Rate

   The ITV shall be located in a high fast-flux region of the ATR so that a high damage rate, ≈10 dpa in vanadium per calendar year, can be attained.

4. Irradiation Duration

   Except for possible interruption for replacement of the thermal neutron filter, the ITV shall be capable of continuous operation to up to ≈30 dpa. (The fluence requirement for the first test train may be only ≈10 dpa.)

5. Accommodation of Liquid Metal Specimen Bonds

   Capsules that contain vanadium alloy specimens may require lithium or sodium bonding for reasons of heat transfer, impurity control, and the DHCE. Capsules that contain other types of test materials may require helium bonding.

Description of the Preliminary ITV Design

Although the detailed design for the ITV has not yet been finalized, communications between the LMIT designers and the fusion program participants thus far have produced the following generally-agreed-upon design guidelines. These guidelines are consistent with the above functional requirements, based on the results of preliminary calculations.

The vehicle would occupy the ATR's central flux trap, which has a diameter of 81.5 mm and a height of 1219 mm. Three 31-mm-diam. stainless-steel in-pile tubes that contain axially stacked specimen capsules would be located side by side in the flux trap. The tubes would have independent instrumentation and each could be inserted and removed without affecting the other two. Each tube would form its own pressure boundary.

A single, replaceable thermal neutron filter would encompass all three in-pile tubes. An aluminum filler block, to minimize the amount of water inside the filtered volume, would occupy the interstitial space between the three in-pile tubes. With an estimated fast flux of $\approx 1.6 \times 10^{14}$ n/cm^2/s (E > 1.0 MeV) in the central flux trap, the goal fluence rate of 10 dpa/y (vanadium) appears attainable.

The thermal neutron filter would be a cylindrical sleeve made of Al - 4.3% ^{10}B alloy. Because the filter would be on the outside of the in-pile tubes, replacement of the filter sleeve would be possible. Based on results of preliminary analyses [1], and assuming that the sleeve is replaced every ≈5 dpa, the vanadium-to-chromium transmutation would be insignificant and a viable DHCE would be feasible.

Each in-pile tube would contain approximately five stacked specimen capsules. A thermocouple sleeve, extending from the top to the bottom, would separate the specimen capsules from the in-pile tube. Holes in this sleeve would accommodate the thermocouples that extend from the top of the vehicle to each capsule. The sleeve would also form one side of the radial gas gap to control capsule temperature. Channels machined in the in-pile tubes would allow the flow of gap-gas along the length of the capsule. Piston rings would be used to separate the gas flow in individual capsules. The gap gas would be a blend of helium and neon, continuously adjusted on the basis of real-time temperature data, to maintain a constant temperature in the capsule.

Each capsule would have two Type-K (chromel-alumel) thermocouples entering through the top end cap. The capsules would have a stainless steel construction, except those for the DHCE. To minimize tritium permeation loss through the capsule wall, the DHCE capsules would be made of a molybdenum-based alloy, TZM. Alternatively, the DHCE capsules could be made of stainless steel and contain liquid-metal-bonded subcapsules made of TZM.

The usable test volume per in-pile tube depends strongly on the size of the thermocouples that are used. (The size of the thermocouple affects the thickness of the thermocouple sleeve inside the in-pile tube.) Assuming that the diameter of the thermocouples is 2.38 mm, the useable volume per in-pile tube would be ≈200 ml.

Future Activities

Detailed design of the ITV will be finalized. Procurement and construction of the vehicle hardware will begin. Testing of ex-reactor components, such as the temperature control modules and gas analyzers, will continue. A proposal for collaboration will be presented to the Jupiter Program participants.

References

1. I. C. Gomes, H. Tsai, and D. L. Smith, "Neutronic Analysis of the DHCE Experiment in ATR-ITV," this report.