STATUS OF THE IRRADIATION TEST VEHICLE FOR TESTING FUSION MATERIALS IN THE ADVANCED TEST REACTOR - H. Tsai, I. C. Gomes, and D. L. Smith (Argonne National Laboratory), A. J. Palmer, and F. W. Ingram (Lockheed Martin Idaho Technologies Company), F. W. Wiffen (U.S. Department of Energy)

SUMMARY

The design of the irradiation test vehicle (ITV) for the Advanced Test Reactor (ATR) has been completed. The main application for the ITV is irradiation testing of candidate fusion structural materials, including vanadium-base alloys, silicon carbide composites, and low-activation steels. Construction of the vehicle is underway at the Lockheed Martin Idaho Technology Company (LMITCO). Dummy test trains are being built for system checkout and fine-tuning. Reactor insertion of the ITV with the dummy test trains is scheduled for fall 1998. Barring unexpected difficulties, the ITV will be available for experiments in early 1999.

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 in using a mixed-spectrum reactor for testing fusion materials lies mainly in curtailing the undesirable side effects of thermal neutrons, e.g., atypical transmutations. The ATR-ITV project is an effort to create an instrumented, versatile test vehicle that would be suitable for a wide range of neutron damage studies on various candidate fusion materials.

ITV FUNCTIONAL REQUIREMENTS

The following functional requirements were specified by the fusion materials community and used by the LMITCO for the vehicle design.

1. Thermal Neutron Filtering

   The neutron flux in the test volume shall be hardened to limit the thermally dominant $V(n,\gamma)Cr$ transmutation in vanadium-base alloys to <0.5 wt.% Cr during the irradiation. In addition, the filtered neutron spectrum shall permit the conduct of dynamic helium charging experiments (DHCEs)[1] for vanadium alloys. The thermal neutron filter shall be external and replaceable in order to maintain a high-quality neutron environment throughout the irradiation.

2. Multiple Test Temperatures and Active Temperature Control

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

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[1]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 a DHCE, 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 DHCE in a mixed-spectrum reactor lies in preventing the back conversion of ^3He into ^3H through the (n,p) reactions, which have a high reaction cross section for thermal neutrons.

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

5. Accommodation of Liquid Metal Specimen Bond

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

FINAL ITV DESIGN

Through close interactions between the LMITCO designers and the fusion materials community, a design of the ITV that meets all of the above functional requirements has been achieved [1]. This finalized design is described below.

The ITV will occupy the ATR's central flux trap, which has a diameter of 81.5 mm and a length of 1219 mm (i.e., the core height). The vehicle will have three side-by-side, 31-mm-OD stainless steel in-pile tubes within the flux trap baffle. Up to nine thermocouples and 12 gas lines (for temperature control or purging) are feasible in each in-pile tube. Figure 1 is a core-region cross section of the central flux trap when it is occupied by the three ITV in-pile tubes and associated components. The instrumentation and control for each in-pile tube will be independent, i.e., each can be inserted and removed without affecting the other two. Each tube will form its own pressure boundary.

Each in-pile tube can accommodate up to five axially stacked specimen capsules. A thermocouple sleeve and a gas channel tube will separate the specimen capsules from the in-pile tube. Holes in this sleeve will accommodate the thermocouples extending from the top of the vehicle to each capsule. The thermocouples will be 1.6-mm-diameter sheathed Type K (chromel-alumel) with either single or multiple hot junctions in the sheath. The outside wall of the thermocouple sleeve and the inside wall of the gas channel tube form a gas gap. Through active regulation of the blending of the gas mixture in this gap, the temperature of each specimen capsule can be individually controlled. Helium and neon are the two blending gases chosen; other gases may also be used. The gas blending capability permits a blend range of 98% of one gas to 2% of the other to allow a broad range of control. In the unlikely event that the ability to measure or control the temperature is lost, the gas gap of the affected capsule will be automatically purged with helium to prevent overtemperature.

The ITV will have an automated digital control system. The purpose of the control system will be to monitor, control, archive data, and generate reports without the attention of operators during reactor operations. The system will provide normal onsite experiment monitoring as well as offsite real-time data transmittal via fiber-optic links and an Ethernet data bus.

A single, replaceable thermal neutron filter will encompass all three in-pile tubes. The filter will be a 2.5-mm-thick sleeve made of an Al-B alloy with 4.3 wt.% of ^{10}B. An aluminum filler block, to minimize water inside the filtered volume, will occupy the interstitial space between the three in-pile tubes. The calculated neutron fluxes in the in-pile tubes at the core midplane are shown in Table 1. With an estimated fast flux of ≈4.5 x 10^{14} n/cm²/s (E>0.1 MeV), the target dose rate of ≈10 dpa/y (vanadium) will be attainable at the anticipated central lobe power of 26 MW. If the sleeve is replaced every ≈5-10 dpa, the V-to-Cr transmutation would be insignificant and a DHCE would be feasible, based on the results of preliminary physics analyses [2].

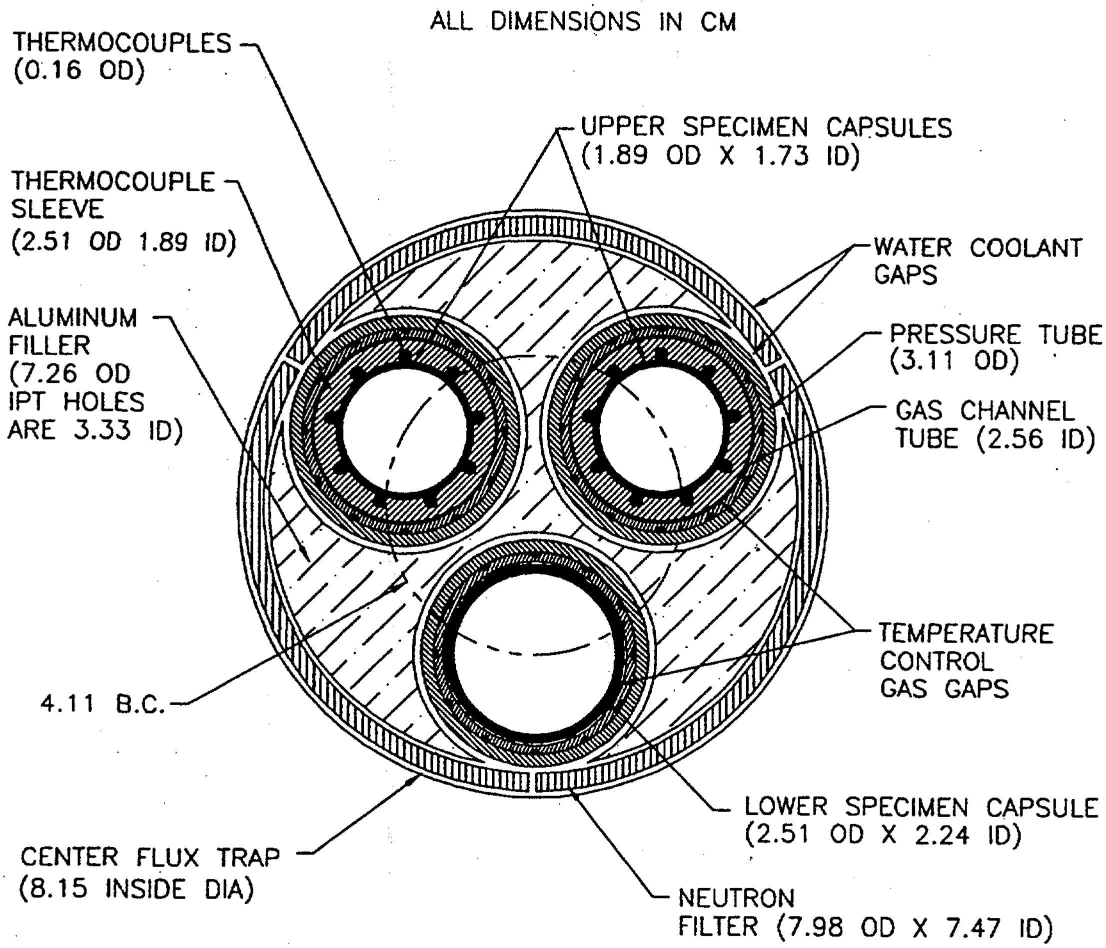

Fig. 1. Core region ITV cross section without specimens

Table 1. Calculated neutron fluxes in in-pile tubes at the core midplane at 26 MW center lobe power

	Neutron Flux (n/cm²/s)	
	Unfiltered	Filtered
Thermal (E < 1.0eV)	1.13 x 10^{14}	1.76 x 10^{13}
Fast (E > 0.1MeV)	4.55 x 10^{14}	4.54 x 10^{14}
Total	1.02 x 10^{15}	8.63 x 10^{14}

A conceptual test train design has been generated for the initial fusion materials test in the ITV. To maximize the utilization of the high-value space near the core midplane, the in-pile tube would have five capsules of two diameters, as shown schematically in Fig. 2. The thermocouple sleeve would terminate at the top of capsule No. 2, just below the core midplane, thereby giving capsule No. 2 the largest possible diameter or volume. A trade-off of this configuration is that capsule No. 1, at the bottom, would have no instrumentation. The available test volume and instrumentation in each capsule with this conceptual test train design is shown in Table 2.

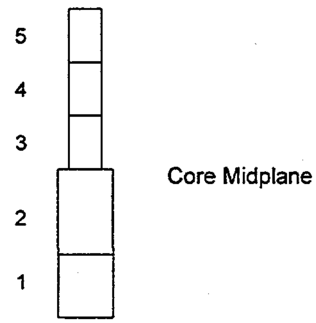

Fig. 2. Schematic diagram of five-capsule configuration for initial fusion materials experiment in ITV.

Table 2 Conceptual test train design for initial fusion materials test in ITV (see Fig. 2)

Capsule No.	Inside Ht. (mm)	Inside Dia. (mm)	Volume (cm^3)	No. of TCs[a]	No. of TC Junctions[a]	Normalized Neutron Flux[b]
5	178	16.5	38	2	4	0.42
4	178	16.5	38	2	4	0.78
3	178	16.5	38	2	2	0.97
2	320	21.3	114	3	5	0.91
1	206	21.3	73	0	0	0.44

[a]TCs: thermocouples. One each of the thermocouples in capsules 5, 4, and 2 would be a multi-junction design with three hot junctions.
[b]At axial midplane of each capsule.

STATUS OF ITV FABRICATION

The upper and lower reactor enclosures have been completed. The in-pile tubes are ≈33% complete and the dummy test trains are ≈75% complete. Essentially all ex-reactor auxiliary handling equipment is complete. Overall, about 60% of the ITV hardware has been fabricated.

FUTURE ACTIVITIES

The remaining ≈40% of the hardware is expected to be completed before mid-September 1998. During the next 49-day reactor outage, scheduled to begin on September 15, 1998, the ITV with the dummy test trains will be installed in the reactor. After the reactor start-up, the system will be checked out for one or two reactor cycles (2-3 months). Barring unexpected difficulties, the ITV would then be available for experiments in early 1999.

Discussion is ongoing between the U.S. DOE and the Japanese Monbusho in regard to using the ITV for the post-Jupiter phase of the U.S.-Japan (Monbusho) collaboration.

REFERENCES

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2. I. C. Gomes, H. Tsai, and D. L. Smith, "Neutronic Analysis of the DHCE Experiment in ATR-ITV," Fusion Materials Semiannual Progress Report for period ending June 30, 1997, DOE/ER-0313/22, pp. 232-237.