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Section 3. Irradiation facility and technology. 1. Irradiation facility

Temperature controlled material irradiation in the advanced test reactor

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Abstract

The United States Department of Energy (US DOE) has initiated the development of an Irradiation Test Vehicle (ITV) for fusion materials irradiation at the Advanced Test Reactor (ATR) in Idaho Falls, Idaho, USA. The ITV is capable of providing neutron spectral tailoring and individual temperature control for up to 15 experiment capsules simultaneously. The test vehicle consists of three In-Pile Tubes (IPTs) running the length of the reactor vessel. These IPTs are kept dry and test trains with integral instrumentation are inserted and removed through a transfer shield plate above the reactor vessel head. The test vehicle is designed to irradiate specimens as large as 2.2 cm in diameter, at temperatures of 250–800°C, achieving neutron damage rates as high as 10 displacements per atom per year. The high fast to thermal neutron flux ratio required for fusion materials testing is accomplished by using an aluminum filler to displace as much water as possible from the flux trap and surrounding the filler piece with a ring of replaceable neutron absorbing material. The gas blend temperature control system remains in place from test to test, thus hardware costs for new tests are limited to the experiment capsule train and integral instrumentation.

1. Introduction

Development of the Irradiation Test Vehicle (ITV) at the Advanced Test Reactor (ATR) was initiated to support fusion reactor material irradiation testing for the United States Department of Energy (US DOE) Office of Fusion Energy. The ATR was chosen to perform this testing because of space available in the reactor and the extensive experience of the ATR program in successfully completing many types of material testing programs. Also, the ATR schedule for continued operation in the future enables the reactor to meet the long term objectives of the US DOE fusion testing program.

The ATR is light water cooled and moderated with a rated thermal power of 250 MW. The ATR has been in operation since 1967, primarily in support of the US Naval Nuclear Propulsion Program, and is expected to continue operation well into the next century. Significant features of the ATR that make this reactor attractive for fusion reactor materials testing include high fast flux, the ability to tailor the fast-to-thermal flux ratios, and the ability to operate at varying power levels in different regions of the core. Table 1 contains calculated neutron spectral data for the ITV assuming an ATR center lobe power of 26 MW. The "filtered" values are based on using a 0.25 cm thick aluminum–boron alloy filter with a 4.3 wt% B-10 loading.

The multiple "in-pile tube" arrangement of the ITV in a prime flux trap position in the ATR allows different test programs to be conducted simultaneously and allows for cost sharing opportunities. The combination of the ATR nuclear testing experience base, the ATR facility unique control features, the ITV flexibility, and the opportunity for cost sharing are significant advantages for future nuclear materials testing programs.

The in-tank design of the ITV, which began in 1995, is virtually complete, and the gas control system has been fabricated and is currently undergoing operational testing. Current plans are to complete installation and begin operation of the ITV in 1998.

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Table 1
Neutron fluxes for ATR ITV mid-plane specimen capsules

Flux component		Fluxes @ 26 MW center lobe power	
		Unfiltered (n/cm^2 s)	Filtered (n/cm^2 s)
Thermal	<1.0 eV	1.13×10^{14}	1.76×10^{13}
Fast	>0.1 MeV	4.55×10^{14}	4.54×10^{14}
Total		1.02×10^{15}	8.63×10^{14}

2. ITV description

The primary objective of the ITV development process is to provide a test platform that will permit the experimenter to subject a broad range of material specimens to a wide range of temperature and neutronic conditions. The ITV facility must also permit the changing of specimens with as little imposition on reactor operations as possible. Preferably, experiment handling should take place within the standard seven day outage between 40 and 50 day operating cycles.

The ATR ITV development has called upon decades of experience at the Idaho National Engineering and Environmental Laboratory's (INEEL) Test Reactor Area (TRA). The reactor design, analytical modeling, blended gas temperature control and automated computer control systems are all products of this experience. Once installed, the ITV provides up to 650 cm of instrumented irradiation volume in a maximum of 15 capsule positions, each capable of being controlled at ± 5°C of its selected temperature. The largest specimen that can be irradiated in the ITV is approximately 2.2 cm diameter. Depending on position in the core, the control temperature of each specimen capsule may be selected from a range of 250–800°C.

The ITV reactor internals portion consists of three In-Pile Tubes (IPTs) that serve as the experiment test assembly separation boundary with the ATR primary coolant. Each IPT is independent of the others with respect to installation and removal of experiment assemblies. The IPT arrangement permits the use of proven reactor tank boundary sealing mechanisms. The separation provided by the IPTs establishes a natural accommodation within the ITV for different customers. Further separation of each IPT for up to five individual specimen capsules allows even greater flexibility.

The initial fabrication and installation of the ITV systems addresses the major complexities that often are the greatest threat to successful experiment programs. Once the ITV is installed in the ATR, all systems remain intact thereafter, even when experiment test trains are removed. For new test trains all that remains is establishment of control parameters, analytical determination of gas gap dimensions, followed by assembly and insertion.

The automated digital control systems is designed to monitor, control, archive data and generate reports without the attention of operators during reactor operations. The cost of added staff often creates a prohibitive burden on long-term experiment programs, so the ITV control system eliminates the need for additional operators by performing startup, normal preset operations, and shutdown with minimal operator intervention. Abnormal conditions are alarmed and procedures identify the appropriate operator response. Monitoring and archiving of specimen temperature, control gas mixture, and alarm status is provided. The system provides normal onsite experiment monitoring and can be set up to provide offsite real-time data transmittal. Data archival, reporting format, and frequency can be directed by the customer (with some limitations based on the number of customers and their requests).

The temperature of each experiment specimen capsule is controlled by varying the thermal conductivity of the gas mixture in the gap between the specimen capsule and the experiment pressure vessel. This will be accomplished by blending two gases with dissimilar thermal conductivities. Helium and neon have been chosen to provide the thermal conductivity variability for the projected experiment specimen content at this point in the development. (As circumstances dictate, other gas combinations could be implemented at a later date.) Normal operations call for the gases to be blended automatically to control the specimen capsule temperature. The gas blending capability permits a blend range of 98% of one gas to 2% of the other allowing a very broad range of control.

Helium purges to individual specimen capsules are under automatic control in the unlikely event that the ability to measure or control the temperature is lost. In order to assure the time response is minimized, the gas system provides a continuous flow to the specimen capsules. Manual control capability is provided at the gas blending panel to provide helium purge in the event of a computer failure.

3. Design concept

The design configuration chosen for the ITV development is referred to as the "mini in-pile tube" (MIPT) concept. The IPT configuration in the ATR refers to the provision of an ASME Section III, Class 1 pressure boundary that passes through the reactor core via one of the flux trap locations. The IPT is an extension of the reactor tank boundary to the ATR primary coolant and provides separation from the reactor environment but passes directly through the core. The region of the IPT located within the flux trap provides high neutron flux and is virtually surrounded by the fuel elements. There are nine flux trap positions in the ATR. They are designated as N, NE, NW, C, E, W, S, SE, and SE as shown in Fig. 1. The ITV will occupy the C position and will have three 3.11 cm outside diameter pressure tubes (MIPTs) within the flux trap baffle. Fig. 2. is a core region cross-section of the C flux trap occupied by the three ITV MIPTs and the associated components.

The MIPT concept uses concentric tubes to meet pressure boundary, gas, thermocouple distribution and experiment location requirements. The ITV in-core arrangement without the experiment assembly consists of the pressure tube (MIPT) and the gas channel tube. The pressure tube provides the pressure boundary between the reactor coolant and the specimen holders. The gas channel tube is machined to incorporate axial channels in the external surface to route gas to each gas chamber. This tube has 12 channels which terminate at elevations corresponding to the individual gas chamber positions. Five channels are for supply and five for exhaust (the other two channels are for MIPT sweep gas supply and exhaust). Although five gas supply and exhaust channels are provided in each MIPT, the experimenter may elect to use fewer than five spaces simply by designing the experiment assembly with longer experiment specimen capsules and locating the seal ring spacers at different elevations.

The gas channel tube is installed into the pressure tube with an interference shrink fit to assure a seal between each gas channel. The pressure tube and the gas channel tubes are assembled as a unit and all three are installed into the reactor with the aluminum filler sleeve. Fig. 1 illustrates the ITV assembly installation. The total assembly length is 10.97 m. The MIPT assembly is sealed at the top and bottom heads of the reactor using modified seal designs that have been used successfully since the ATR was put into service in 1967.

Spectral tailoring is accomplished by using materials, such as boron, that will affect the flux to which the experiment specimen is exposed. Thermal neutron filtering materials can be included as part of the experiment assembly or can be located in a channel outside of the aluminum filler especially provided for this purpose. The outside filter material is renewable during reactor outages. By using this approach, filtering capability can be retained for long durations by replacing filters as their neutron poison depletes. The use of neutron filtering material must be carefully analyzed to limit its impact on reactor operating cycle length and power level.

A basic test train design has been generated for the initial fusion materials test in the ITV. For this test two capsule sizes will be used as shown in Fig. 2. The larger

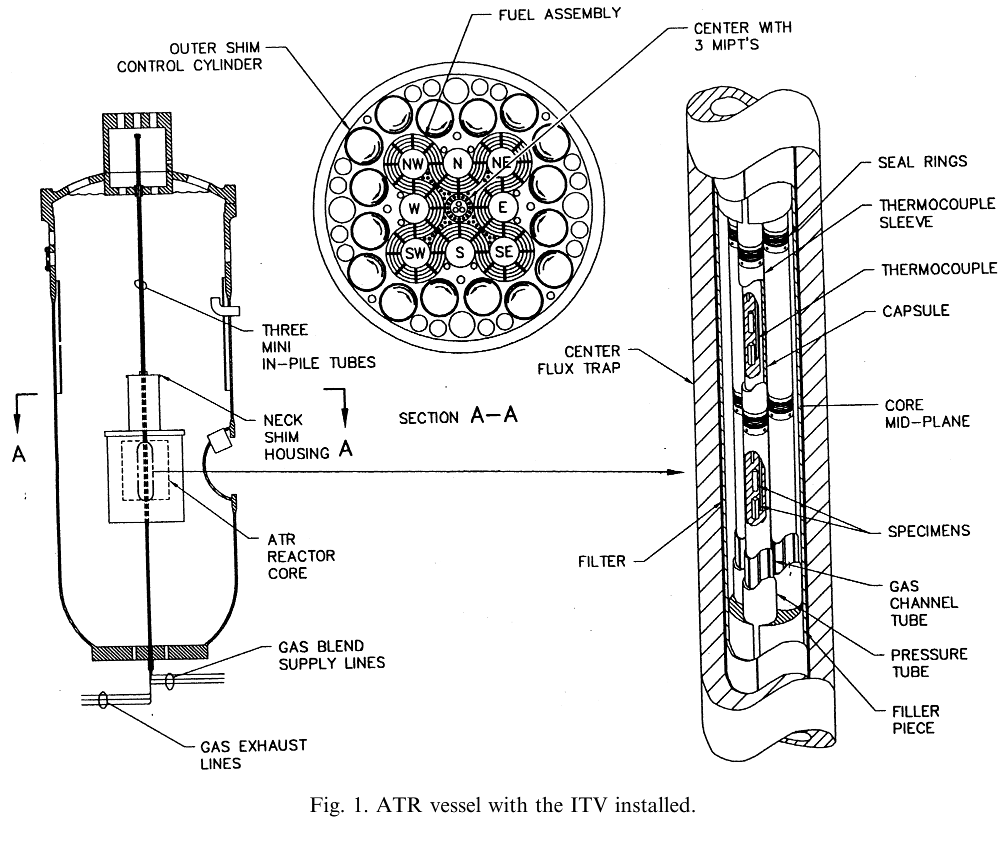

Fig. 1. ATR vessel with the ITV installed.

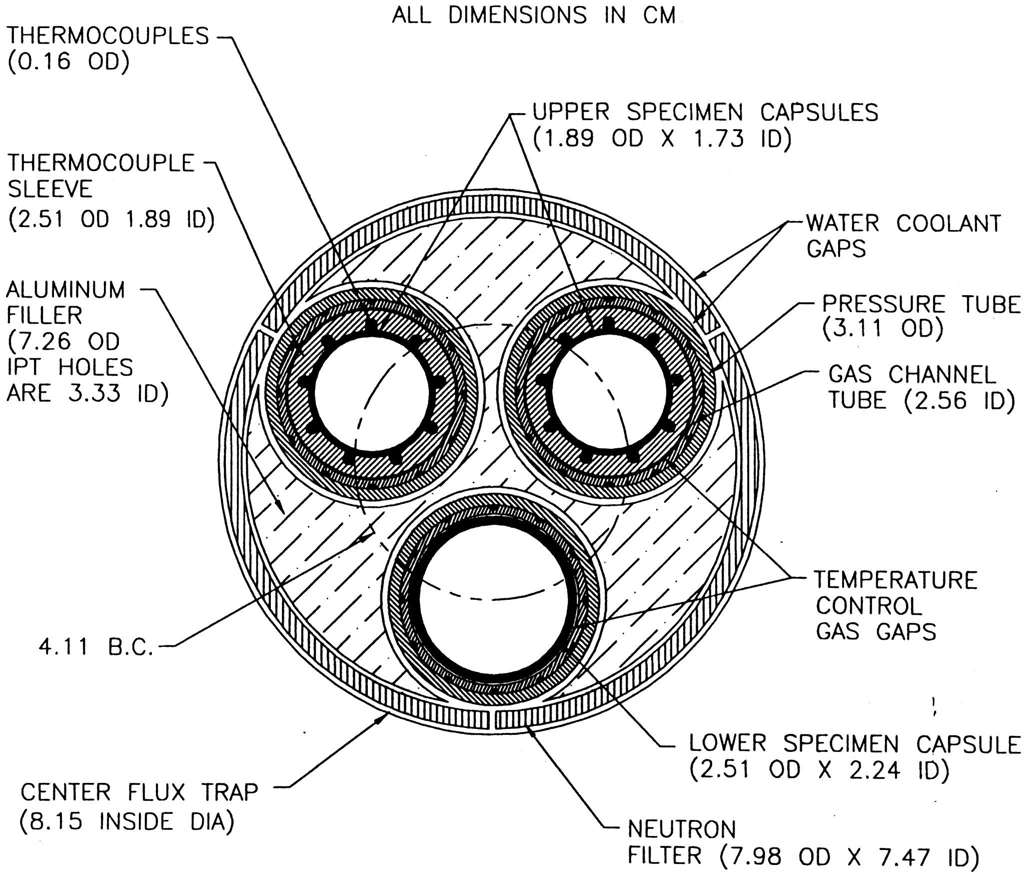

Fig. 2. Core region ITV cross section without specimens.

capsule size (2.24 cm ID) is possible because no instrumentation passes below the bottom instrumented capsule in a test train. For the first fusion materials test it has been decided that this larger capsule should be extended beyond normal length and placed immediately below core mid-plane (see Fig. 1, isometeric view.).

The control gas system provides individual supply lines to the supply channels of the gas channel tube from the gas blending panel. The blended gas flows through the individual experiment chambers and out the exhaust channels to the exhaust gas manifold located in a room directly below the reactor tank. All gas connections to the ITV are made through the reactor bottom head. The exhaust gas is discharged to the main reactor building ventilation exhaust. Monitoring of the exhaust gases is possible and there are several systems available for consideration that have been employed on previous temperature controlled experiments conducted in the ATR.

The ITV Control System (Fig. 3) uses fiber optic links and an ethernet data bus for the communications needed to access the thermocouple outputs and to manipulate the control gas system components. This assures that proper gas blends are sent to the corresponding experiment specimen sets.

Temperature measurements are taken with at least two thermocouples per experiment specimen capsule. The thermocouples selected for the first test train are type K (special grade, ± 0.4%) 0.16 cm sheath diameter and high purity magnesia insulation. Other arrangements are possible including, multi-junction thermocouples within a single sheath. The type K calibration was selected and is provided in pairs to assure long-term service in the high radiation environment. The thermocouple reading is used as the direct control parameter to drive the gas mixing function. Additionally, the control system provides automatic gas verification to assure that the correct gas is connected to supply ports in the system. Alarm functions are provided to call attention to circumstances such as temperature excursions, or valve position errors. Data acquisition and archival are also included as part of the control system functions. Real-

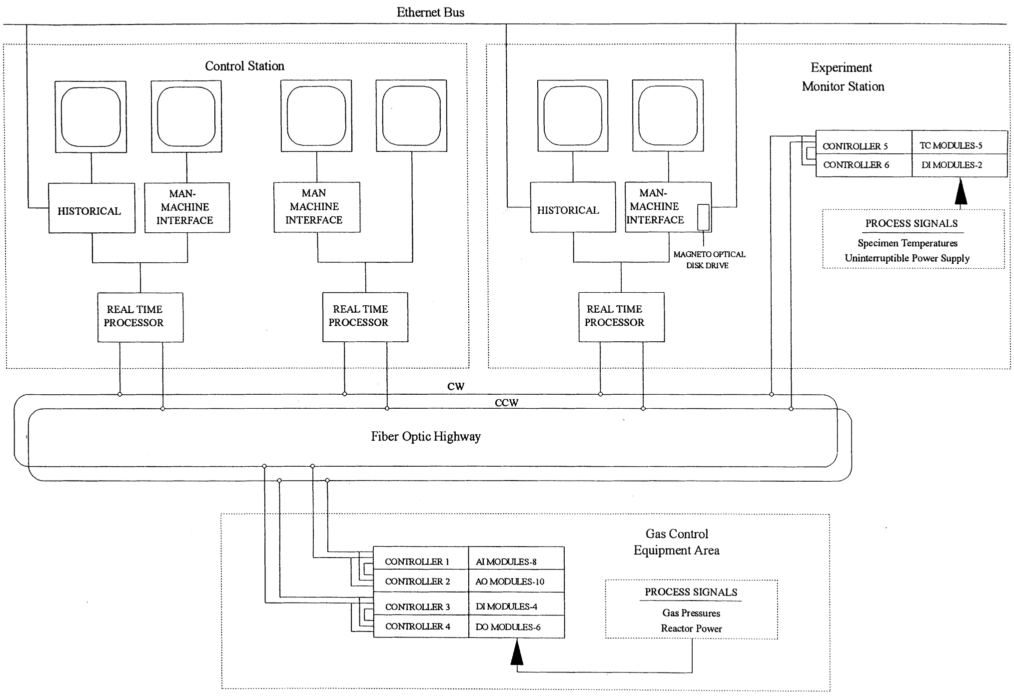

Fig. 3. ITV control system.

time displays of all temperatures, all gas mixtures, and all alarm conditions are provided in the operator control station and at the experimenter's monitor located in the reactor building. All data are archived to removable media. The data is time stamped and recorded once every 10 min or more frequently by exception not to exceed a rate of once every 10 s. The control processor will record these values in a circular first-in, first-out file format for at least six months.

All components having critical bearing on continued experiment operation at the specified conditions are redundant or have designed backup features capable of operating under full design conditions with the same service life as the primary components. These redundant and/or backup components include auxiliary and uninterruptible power supplies, operator-controlled station monitors, data processors and man–machine interface, gas blending valves and thermocouples. The ability to monitor and operate using these redundant features is automatic. This combination of redundant hardware, software and automation creates an experimenter's facility of exceptional reliability that provides maximum assurance that an experiment program will be completed as planned.

4. Support facilities and services

A wide array of technical services are available at TRA to support irradiation programs in the ATR. Facilities and personnel are available to assist in all aspects of material testing programs; from test design to post-irradiation examination of test specimens. Support facilities include full-service hot cells, radiological measurements laboratories, machining and fabrication shops, test assembly facilities, and waste management. The "User's Guide for the Advanced Test Reactor", available upon request, provides detailed information on capabilities of the ATR, TRA, and other facilities at the INEEL.

5. Conclusion

The ITV, scheduled for completion in 1998, will provide new opportunities for performing materials irradiations in high flux regions of the ATR at reasonable costs to its users. The ability to monitor and control temperatures of up to 15 separate test capsules in three separate IPTs gives the ITV the flexibility to meet the needs of a wide variety of materials testing programs.