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TEMPERATURE CONTROLLED MATERIAL IRRADIATION IN THE ADVANCED TEST REACTOR

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ABSTRACT

The Advanced Test Reactor (ATR) is located at the Idaho National Engineering Laboratory (INEL) near Idaho Falls, Idaho, USA and is owned and regulated by the U.S. Department of Energy (US DOE). The ATR is operated for the US DOE by Lockheed Martin Idaho Technologies. In recent years, prime irradiation space in the ATR has been made available for use by customers having irradiation service needs in addition to the reactor's principal user, the U.S. Naval Nuclear Propulsion Program. To enhance the reactor's capabilities, the US DOE has initiated the development of an Irradiation Test Vehicle (ITV) capable of providing neutron spectral tailoring and temperature control for up to 28 experiments. The ATR-ITV will have the flexibility to simultaneously support a variety of experiments requiring fast, thermal or mixed spectrum neutron environments. Temperature control is accomplished by varying the thermal conductivity across a gas gap established between the experiment specimen capsule wall and the experiment "in-pile tube (IPT)" inside diameter. Thermal conductivity is adjusted by alternating the control gas mixture ratio of two gases with different thermal conductivities.

1. Introduction

Development of the ITV at the ATR was initiated to support fusion reactor material irradiation testing for the 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 250MW. 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 the northeast lobe power of the ATR at 30 MW. The "filtered" values are based on using borated aluminum filters in six of the 28 specimen capsule positions.

Table 1. Neutron Fluxes for ATR ITV Mid-plane Specimen Capsules

Flux Component	Energy	Fluxes @ 30 MW Northeast Lobe Power	
		Unfiltered (n/cm^2-sec)	Filtered (n/cm^2-sec)
Thermal	<0.5 eV	9.30×10^{13}	6.64×10^{12}
Fast	>1.0 MeV	2.13×10^{14}	1.86×10^{14}
Total		1.09×10^{15}	8.35×10^{14}

Although the ITV was initiated to support the fusion materials testing program, the design has incorporated many features (discussed in Section 2) that allow considerable flexibility to accommodate other test programs. The ITV has more irradiation space available than can be used by the fusion materials testing program, and feedback from potential customers of the ATR have indicated a need for a facility, such as the ITV, that can be shared by multiple users. The multiple "in-pile tube" arrangement of the ITV in a prime flux trap position in the ATR allows vastly different test programs to be conducted simultaneously and allows for cost sharing opportunities. This arrangement will allow economical use of the ITV for potential new customers. 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 design of the ITV, which began in 1995, is almost complete, and many of the materials and control system have already been procured. Current plans are to complete installation and begin operation of the ITV in 1998. Acceleration of this date by one year could be achieved if it becomes a higher priority for the fusion program or another user.

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 40-50 day operating cycles.

The ATR ITV development has called upon decades of experience at the INEL's 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 28 positions, each capable of being controlled at ± 5°C of its selected temperature. The ITV control temperature may be selected from the 200-800°C range.

The ITV reactor internals portion consists of four 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. The further separation of each IPT to up to seven individual specimen holder regions allows even greater flexibility.

The initial fabrication and installation of the ITV systems treats 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 the experiment assemblies are removed. All that remains is for the experimenter to establish control parameters, analytically determine gas gap dimensions, then assemble and insert the test train.

The automated digital control system 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 without operator intervention. Abnormal conditions are alarmed and procedures identify the appropriate operator response. Monitoring and archiving of specimen temperature, control gas mixture, reactor power and alarm status is provided to real time and fixed media. The system provides normal onsite experiment monitoring and can be setup to provide offsite real-time data transmittal. Data archival and reporting format and frequency can be directed by the customer. There are some limitations based on the number of customers and their requests.

The temperature of each experiment specimen capsule will be 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 highly 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. 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 capsule(s) 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 capsule(s). Manual control capability is provided at the gas blending panel to provide helium purge in the event of a flow controller or 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 thermal and fast 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 Figure 1. The ITV will occupy the NE position and will have four 4.35 cm outside diameter pressure tubes (MIPTs) within the flux trap baffle. Figure 2 is a core region cross section of the NE flux trap occupied by the four ITV MIPTs and the associated components without the experiment assembly installed.

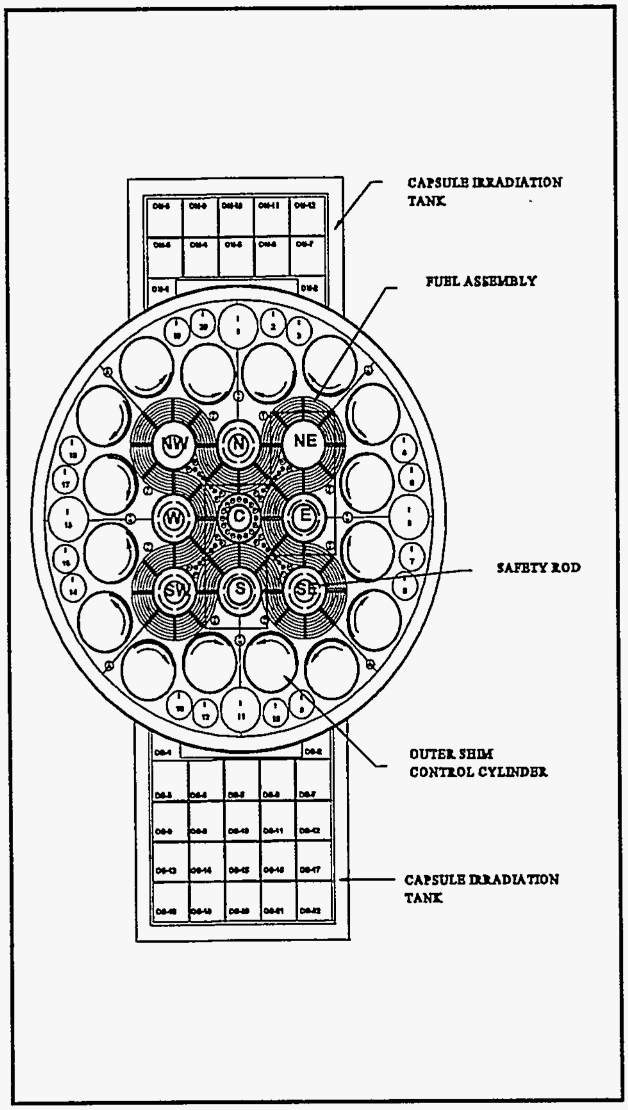

Figure 1. ATR Core Cross Sectional Diagram

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. Additionally the pressure tube provides structural stability to the component

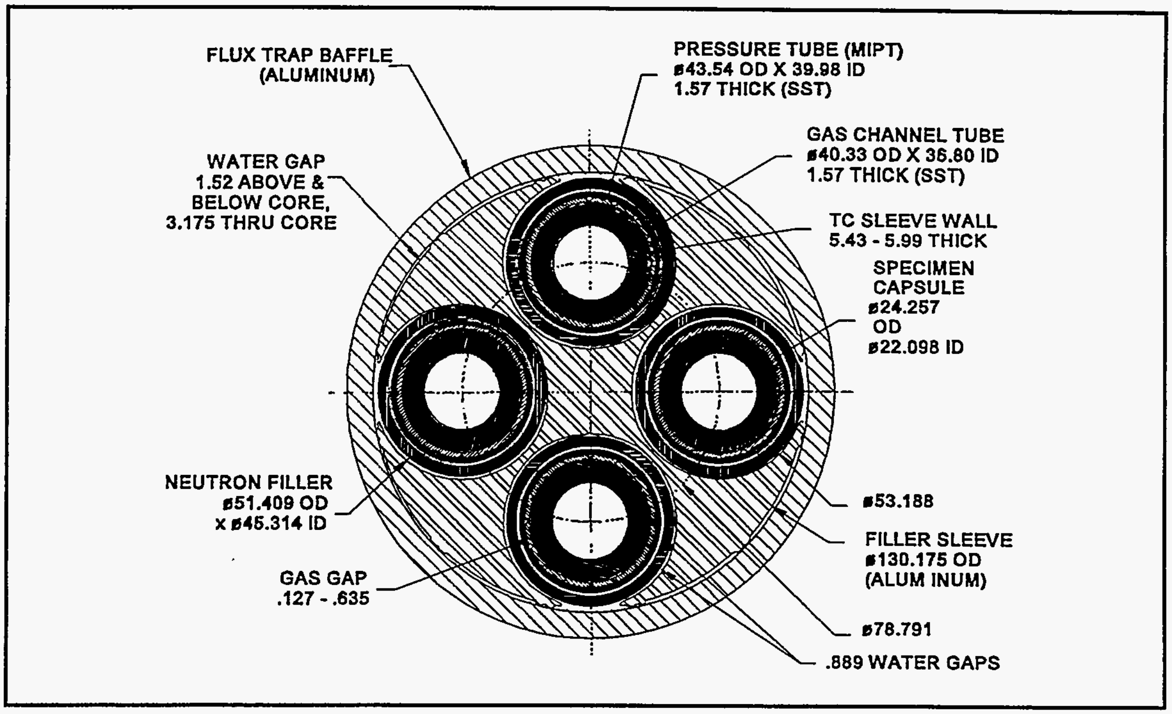

Figure 2. Core Region Cross Section, 4 MIPTs Without Specimens Installed

stack up. The gas channel tube is machined to incorporate axial channels in the external surface to route gas to each gas chamber. This tube has fourteen channels which terminate at elevations corresponding to the individual gas chamber positions. Seven channels are for supply and seven for exhaust. Although seven gas supply and exhaust channels are provided in each MIPT, the experimenter may elect to use fewer than seven spaces simply by designing the experiment assembly with longer experiment specimen capsules, that locate the seal ring spacers at different elevations.

The gas channel tube is installed into the pressure tube with an interference fit to assure a seal between each gas channel. The interference fit is accomplished by matching close tolerance dimensions on the pressure tube inside diameter and gas channel tube outside diameter then heating the outer tube, cooling the inner, then fitting together and allowing their temperature to equalize. The pressure tube and the gas channel tubes are assembled as a unit and all four are installed into the reactor with the aluminum filler sleeve. Figure 3 illustrates the ITV assembly installation. The total assembly length is 10.97 meters. 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. Neutronic filtering materials can be included as a permanent part of the experiment assembly or can be located in a channel outside of the MIPT 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.

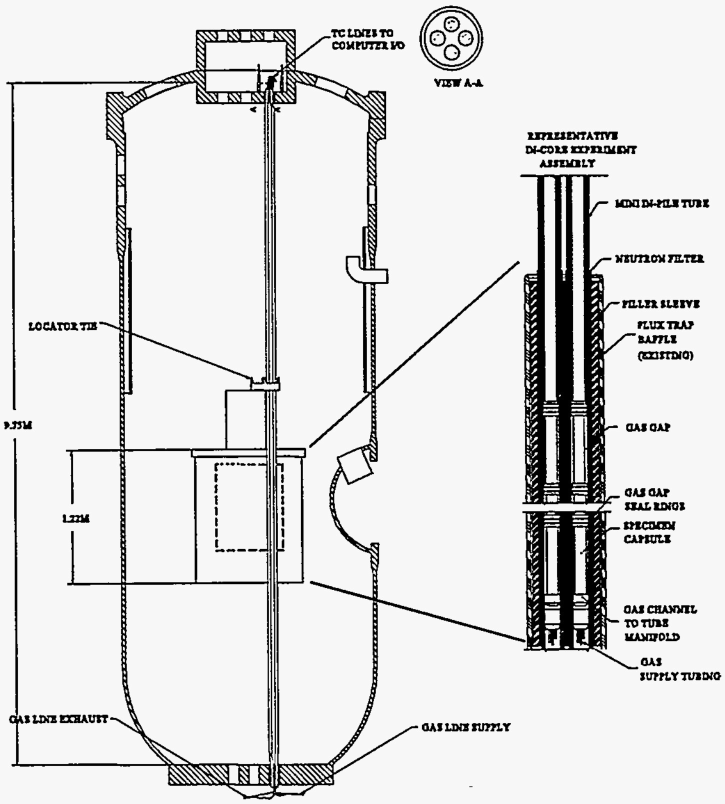

Figure 3. ATR Vessel Cross Section With MIPTs

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.

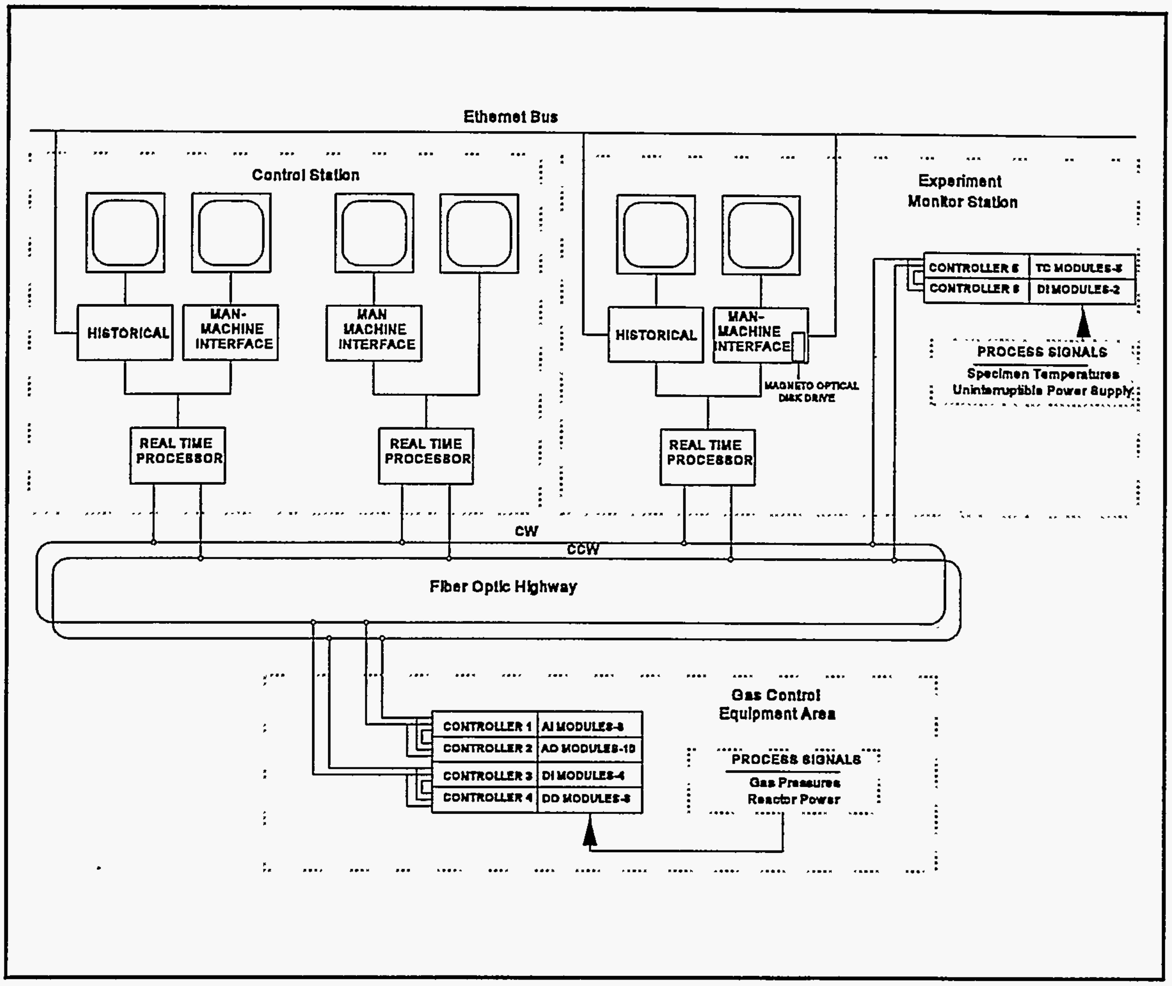

Figure 4. ITV Control System

The ITV Control System (Figure 4) 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 two thermocouples per experiment specimen capsule. The thermocouples are type K (special grade, +/-0.4%), 0.0508 cm diameter with 0.3175 cm sheath diameter and high purity magnesia insulation. The type K was selected and 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 time displays of all temperatures, all gas mixtures, reactor power and all alarm conditions are provided in the operator control station and at the experimenter's monitor located in the reactor building. All data is archived to a one gigabyte removable media optical drive. The data is time stamped and recorded once every ten minutes or more frequently by exception not to exceed a rate of once every ten seconds. 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 INEL.

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 28 separate test holders in four separate inpile tubes give the ITV the flexibility to meet the needs of a wide variety of materials testing programs.