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INSTALLATION OF THE IRRADIATION TEST VEHICLE IN THE ADVANCED TEST REACTOR

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ABSTRACT

The Irradiation Test Vehicle (ITV) was installed in the Department of Energy's Advanced Test Reactor (ATR) during May 1999. 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 permanently installed in-pile tubes running the length of the reactor vessel. The bores of these in-pile tubes 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 - 800C, achieving neutron damage rates as high as 10 displacements per atom per year in Vanadium. The experiment specimen temperature control is fully automated using a Distributed Control System (DCS) to control up to 15 separate blended gas channels for the ITV. The system remains in place as a permanent ATR Experiment support system and has excess capacity to accommodate experiment program growth. The ITV was initially installed with instrumented dummy tests to allow for testing and characterization of the control system.

I. INTRODUCTION

The development of the ITV was originally initiated to support fusion reactor material irradiation for the US DOE Office of Fusion Energy. However, the test vehicle design is flexible enough that it can accommodate the objectives of many other test programs. The three in-pile tube design allows for tests of different durations to be conducted simultaneously and independently. Because the test trains within the in-pile tubes consist of up to five independent capsules, opportunities for further cost sharing are possible.

II. DESCRIPTION

A. Design Objectives

The primary design criteria for the facility were as follows:

(1) Accurate temperature measurement and control for multiple specimen sets simultaneously and independently.
(2) The ability to conduct experiments involving liquid metals and other reactive materials.
(3) The ability to perform neutron spectral tailoring over a long period of time and high dpa

The design team set out to accomplish these objectives while still minimizing costs to customers. It was recognized that costs could be reduced if the design also incorporated the following attributes.

(1) No reactor vessel pressure boundary penetration required to replace tests.
(2) Utilize the equipment and methods previously developed for handling Naval Reactor experiments to install and discharge the ITV tests.
(3) Leave as much of the irradiation facility in place between tests as possible.
(4) Automated control and data acquisition to reduce operational staff requirements.

B. In-Tank Hardware Design

ATR flux trap positions offer the highest fluxes in the reactor. Four of these positions have been made available to non-Naval Reactors programs. The irradiation position selected for the ITV was the center flux trap that is the second largest of the four available.

The design configuration chosen for the ITV is based on three "mini" in-pile tubes (MIPTs) passing through the entire length of the reactor. These three

MIPTs are a permanent part of the reactor and are not changed out as new tests are installed. The MIPTs pass through closure plugs in the bottom and top heads of the reactor vessel and provide a complete separation between tests placed in the dry bores of the MIPTs and the reactor coolant. The MIPTs are classified as ASME Section 3, Class 1 pressure boundaries and provide the reliability needed to allow the use of reactive materials in experiments.

Through the core region the MIPTs are surrounded by an aluminum filler piece to minimize neutron moderation. This aluminum filler piece is surrounded by a replaceable neutron filter. The filter configuration is a hinged clamshell arrangement and is easily replaced during reactor outages. The standard filter design utilizes borated aluminum. Other filter materials which are compatible with the ATR primary coolant and the clam shell design are possible.

Test trains are loaded into the bores of the MIPTs through the top of the reactor. No reactor pressure boundary penetration is required to perform this operation.

A cross section of the ITV through the core region is shown in Figure 1. The inside bores of the MIPTs are 2.54 cm. Allowing for capsule wall thickness the maximum specimen diameter is about 2.2 cm. A total instrumented volume of 650 ccs is available in the 15 capsule positions of the ITV.

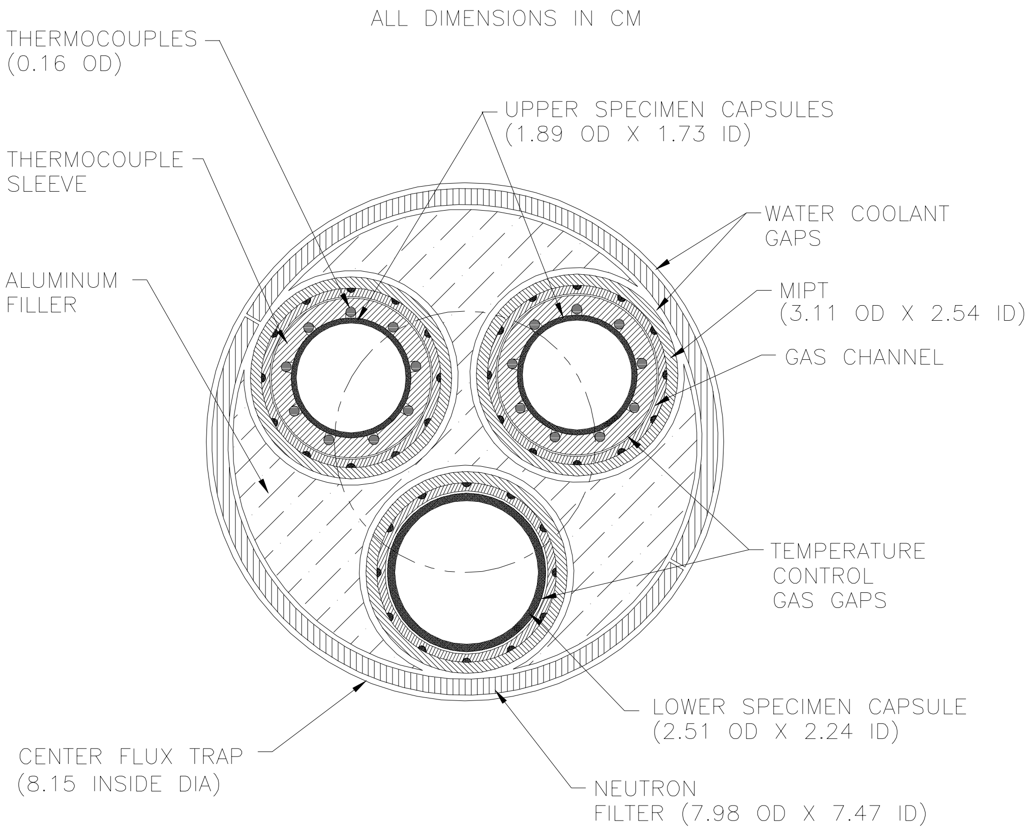

Figure 1. ITV Core Region Cross Section (specimens not shown)

C. ITV TEMPERATURE CONTROL SYSTEM

Temperature control within the ITV is accomplished by coupling a distributed control system with a gas blending system to automatically control the gas blend within the temperature control gas gaps. Figure 2 illustrates the temperature control system arrangement in the ATR.

The automated DCS is designed to monitor, control, archive data and generate reports.. The system provides normal onsite experiment monitoring and can be configured to provide offsite real-time data transmittal.

The ITV Temperature Control System uses fiber optic links and an Ethernet data bus for the communications needed to access the thermocouple outputs and to manipulate the gas blending 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 are used as direct control parameters that automatically control and vary the thermal conductivity of the gas mixture in the gap between the specimen capsule and the experiment pressure vessel. Helium and neon provide the thermal conductivity variability for the experiment specimen content. The gas blending capability permits a blend range of 98% of one gas to 2% of the other, thereby allowing a very broad range of temperature control for each specimen capsule.

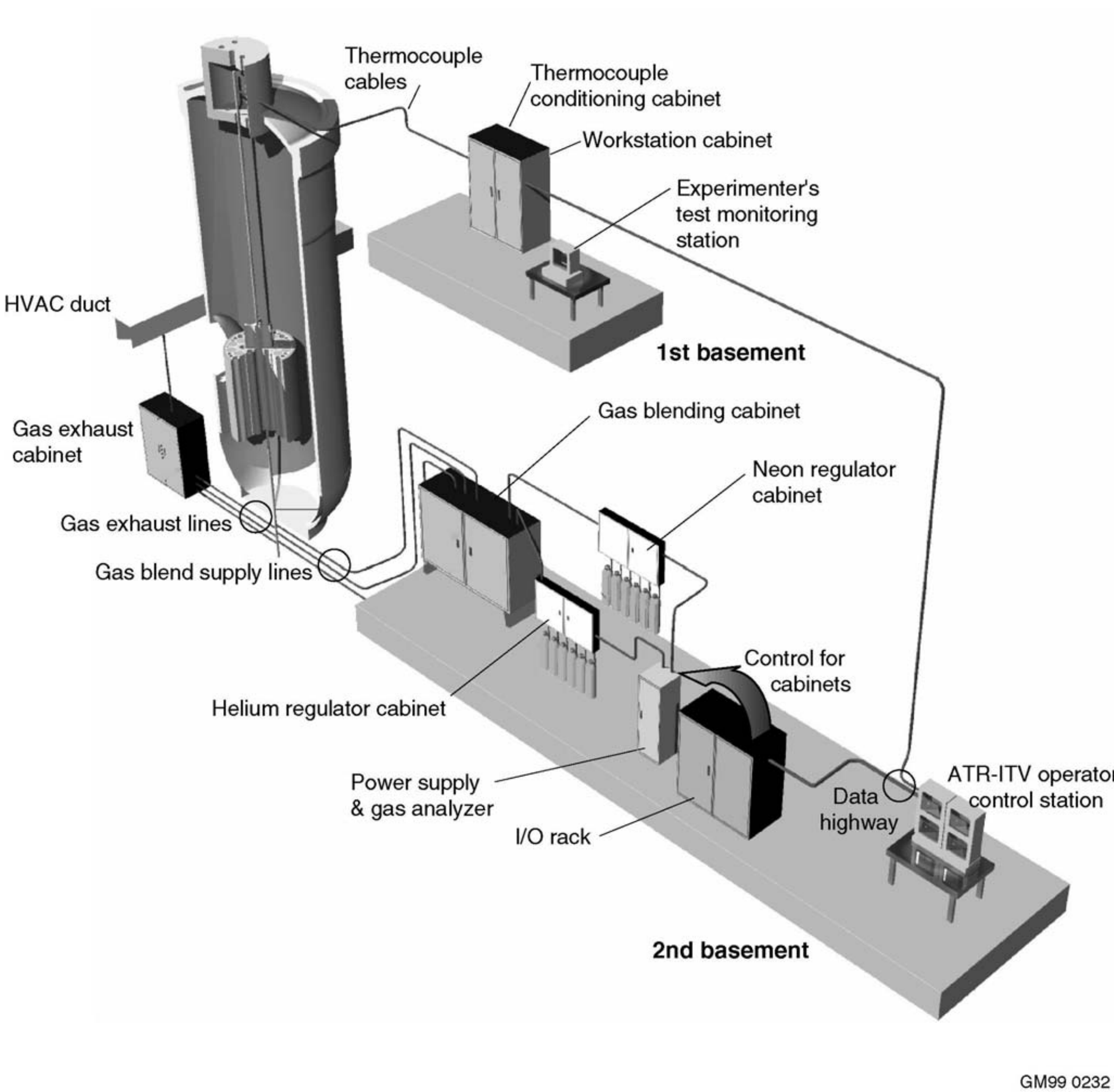

Figure 2. ITV Control System Arrangement

The gas gaps between the outside diameter of the test train capsules and the bores of the MIPTs are supplied gas blends via small gas lines to the bottom of the MIPTs and then are distributed to five different capsule elevations in each MIPT. After the gases reach the core region, they are fed into small channels machined into the MIPTs. At the appropriate elevations, holes are drilled through into the bores of the MIPTs allowing the gases to flow into the gaps between the outside surface of the capsules and the inside bores of the MIPTs. The gases then exhaust through holes drilled on the opposite sides of the MIPTs and exhaust out the bottom of the MIPTs. The gas blend for each capsule elevation is kept separate from the others by means of metallic piston rings installed in spacers between the capsules. The exhausts from all the capsule elevations are combined before they exit the MIPTs. Figure 3 shows the gas distribution within MIPTs.

Automatic gas verification assures that the correct gas is connected to supply ports in the system. Each time a new bottle is put on the system, it is automatically verified via the gas analyzer.

In the event that the ability to control the temperature is lost, helium purges to individual specimen capsules are under automatic control. Manual purge control is provided in the event of a DCS power failure.

Alarm functions are provided to call attention to circumstances such as temperature excursion, valve position errors, low bottle pressure, and other abnormal operations. Data acquisition and archival are also included as part of the control system functions. Real time displays of temperatures, gas blends, and alarm conditions are provided in the operator control station and at the experimenter's monitor located in the reactor building. Data is archived, date stamped, and can be recorded at rates from once per second to once per hour as directed by the customer.

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

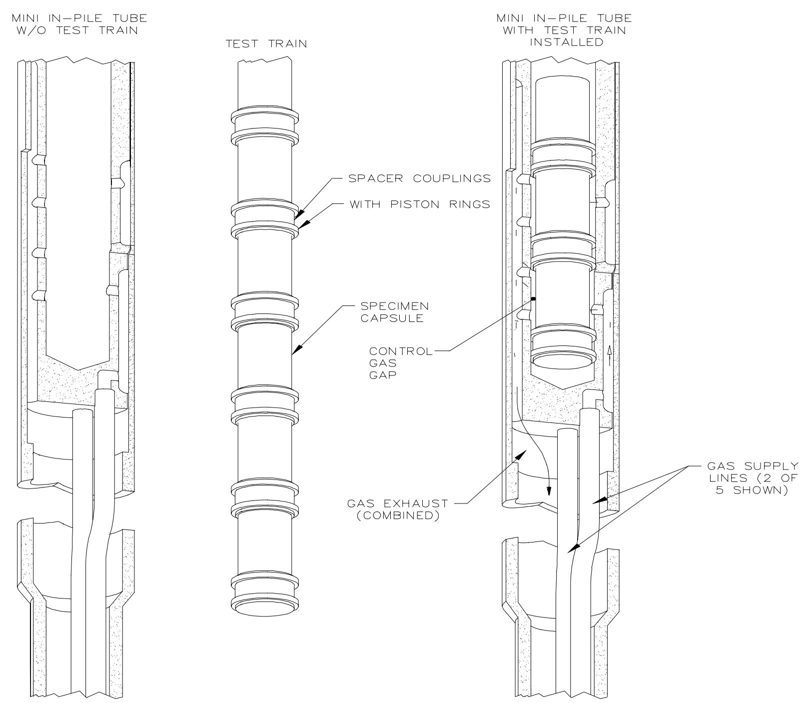

Figure 3. Distribution of Control Gases to the Different Capsule Elevations

D. PERFORMANCE

1. Neutron Spectrum

The ITV was originally designed to primarily serve the fusion materials testing community. Two basic design objectives for this community were to be able to achieve 10 DPA per year in vanadium while limiting the V-51 transmutation to less than 0.5% for a 30 DPA experiment. Physics evaluations performed for the ITV have shown that these objectives can be met with the current design.

Figure 4 illustrates the neutron spectrum with a borated aluminum filter versus an unborated dummy filter.

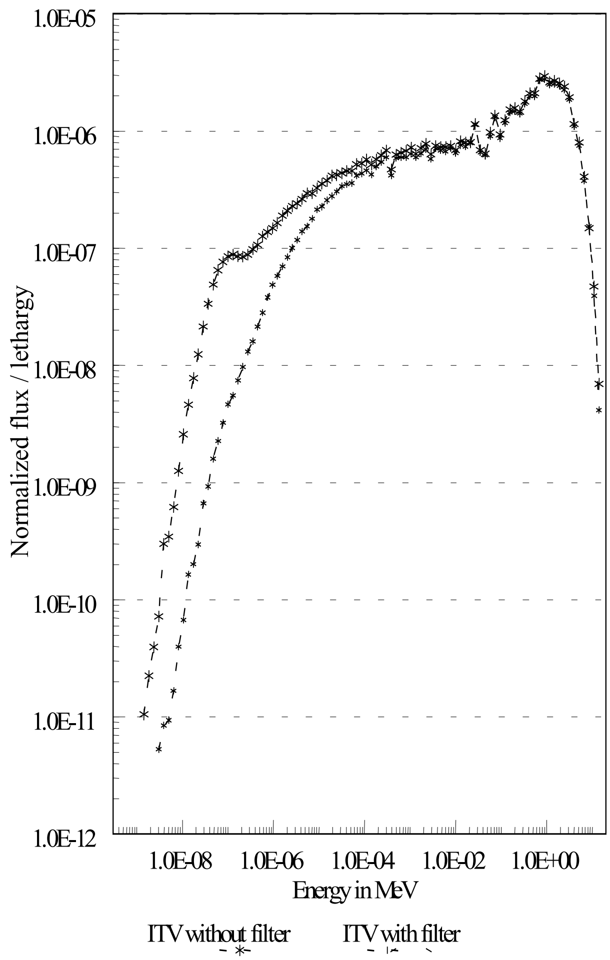

Figure 4. Neutron Spectrum for ITV with and without Borated Filter

2. Thermal Characteristics

The ITV is designed to provide a broad range of temperature capabilities. In the high flux position, the high end of the temperature range is usually limited by test train capsule materials and instrumentation rather than limitations of the permanently installed facility. The low end of the temperature range is set by the reactor coolant temperature and the nuclear heating rate. The nuclear heating rates for various components in the ITV, with and without a borated neutron filter, are shown below in Table 1. Representative operating temperatures for a capsule set loaded with 50% V and 50% Li by volume are presented in Table 2.

Table 1. Total heat rate distributions in the ITV test assembly

Location		Total Heat Rate (w/g) [a, b]
With Dummy Aluminum Filter	SST Dummy Test	5.06
	SST MIPT	5.42
	Water	11.0
With Borated Aluminum Filter	SST Dummy Test	3.75
	SST MIPT	4.16
	Water	9.65

a. Total heat rates were averaged over the 48" core height. The peak to average ratio is 1.42.

b. Calculated heat tallies were normalized for a center lobe power of 25 MW (typical of recent reactor operation).

Table 2. Calculated capsule temperatures assuming a 50-50 V-Li loading and a 50-50 He-Ne control gas blend (except where noted otherwise).

Capsule No.	Gas Gap Size – Gaps filled with 50-50 He-Ne Blend			
	0.15 mm	**0.30 mm**	**0.64 mm**	**1.12 mm**
5				450C
4			475C	650C
3		575C		
2	325C			
1	220C (100% He)	470C		

These preliminary calculations indicate that operating temperatures as low as 250C are achievable in the ITV facility. Temperatures in excess of 700C are also easily achievable, however, design attention to capsule materials and instrumentation will be required.

E. Program Expansion Capabilities

The thermocouples required for temperature measurement are part of the removable experiment specific test trains. ITV flexibility permits other types of instrumentation, (e.g. pressure, electrical conductivity, etc.) to be incorporated into test trains.

The capsules provide a sealed boundary between the temperature control gases and the specimens being irradiated. Test programs may include on-line measurement of gases produced during irradiation. The same can be achieved by measurement means of small gas lines routed through the tops of the capsules in the same fashion as the TC cables enter.

III. USING THE ITV

The initial fabrication and installation of the ITV systems addressed the major complexities that often are the greatest threat to successful experiment programs. With the ITV installed in the ATR, all systems except the thermocouples in the test trains 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.

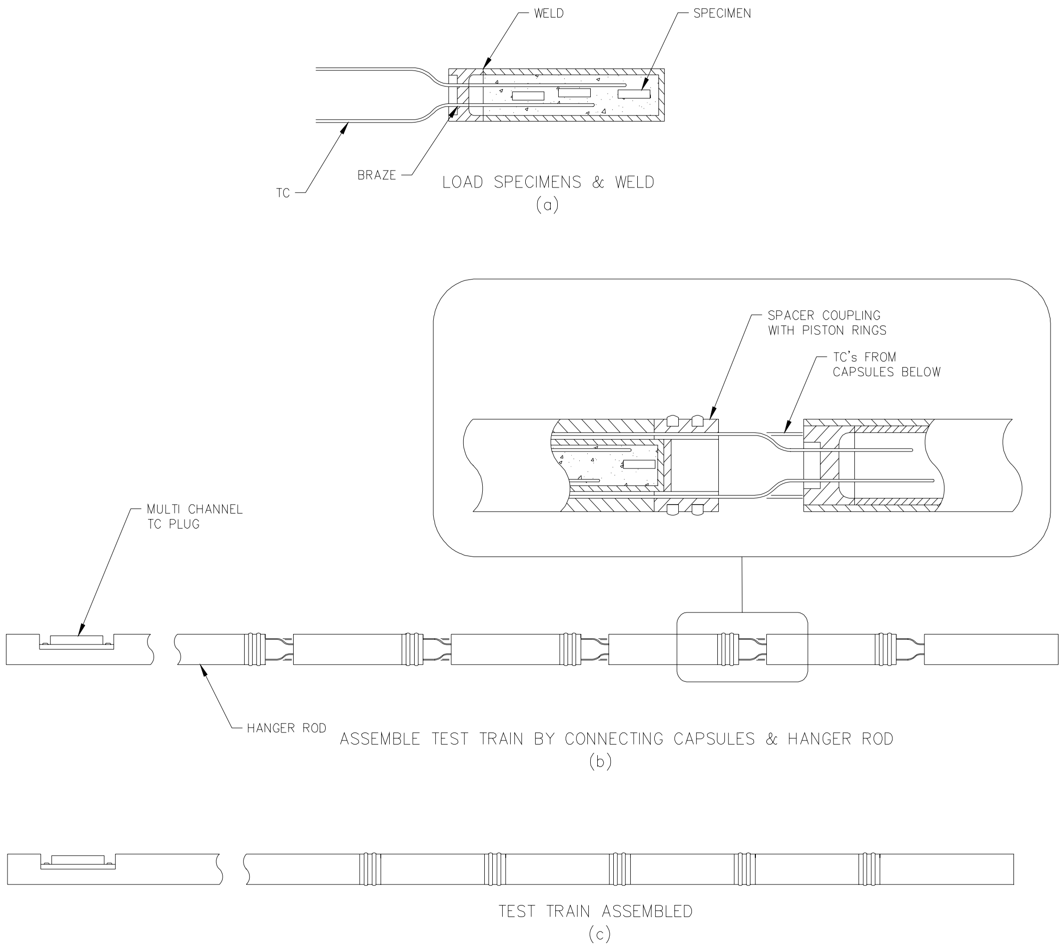

Figure 6. Assembly of Capsules and Test Train

A standard test train design has been developed and is available as a starting point for experimenters. Designs radically different from the standard are also possible. The following is a description of how the standard design would be constructed, installed, irradiated, and discharged.

A. Fabricate and Load Capsules

The capsule bodies and top heads are machined from 300 series stainless steel and thermocouple cables are brazed into the top heads. Specimens are then loaded into the capsules and the heads welded to the bodies (see Figure 6a).

B. Assemble Test Train

The capsules are linked together with coupling spacers that also incorporate metal seal rings to separate the gas control levels. The linked capsules are then connected to a hangar rod (actually a tube) which allows thermocouples to pass through its center. This completes the test train assembly (see Figures 6b and 6c).

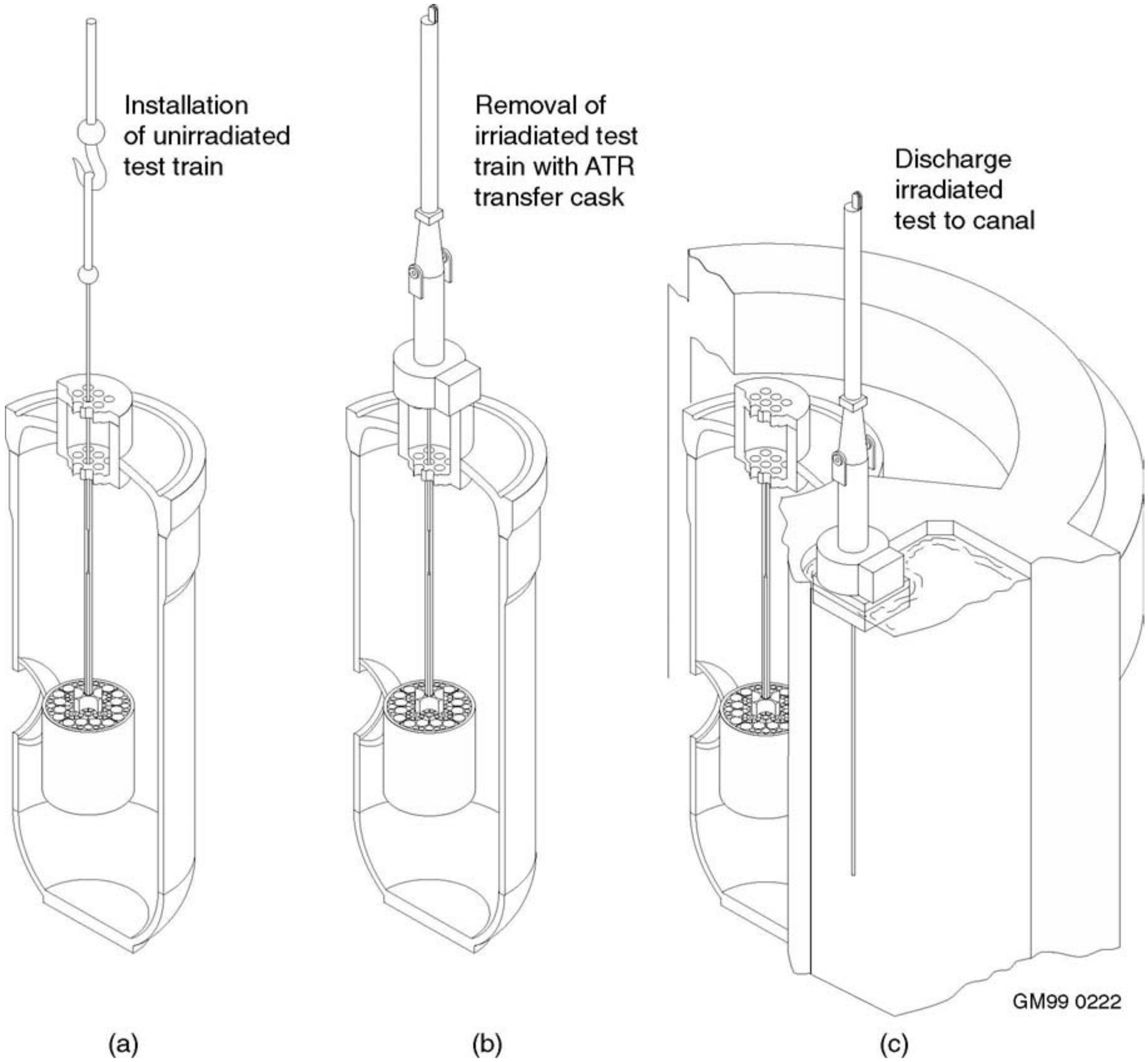

Figure 7. Insertion and Discharge of an ITV Test Train

C. Install Test Train in Reactor

The test train is lifted over the reactor top and lowered into the bore of the selected MIPT by means of a small crane (see Figure 7a). This is a straightforward and relatively simple operation. As shown in the figure, no cask is required for this operation, however, a cask is required to remove the existing irradiated dummy test that previously occupied the position. After the test is lowered into position and secured, a single multi-conductor thermocouple cable is connected and the test is ready to operate.

D. Irradiate

Prior to reactor startup, all experiment control functions identified by the experiment program will be programmed into the DCS. The automated DCS will monitor, control, archive data and generate reports in accordance with the programmed requirements throughout reactor operations. The experimenter may monitor test performance at the monitoring station in the first basement of the ATR during the irradiations.

Based on experiment requirements, the neutron filter may be changed during the irradiation period. The spent filter is manually discharged through the ATR drop chute and the new filter lowered in place during planned outages.

E. Discharge into Canal and Prepare for Shipping

The irradiated test train is removed through the reactor top and discharged to the canal using the ATR transfer cask (see Figures 7b and 7c). In the canal, the capsules are separated by cutting through the coupling spacers. Once separated, the capsules can be shipped in a small cask such as the GE-100. Alternatively, the hangar rod can be removed from the test train and the capsules transported to the TRA hot cells using an on-site shipping cask for further disassembly.

IV. CURRENT STATUS

The ITV has been installed with instrumented stainless steel dummy test trains. Initial indications are that the facility is functioning as designed. Over the next few months, system performance data will be collected. As of May 1999, all three MIPTs are available for new customers.

V. CONCLUSIONS

A new irradiation facility has been installed in the ATR and is ready to receive experimenter test trains. This facility offers high neutron fluxes, accurate temperature control for multiple capsule positions, and the ability to tailor the flux by means of a replaceable neutron filter. The facility has been designed to reduce costs and risks to experimenters by minimizing the amount of hardware that must be fabricated and installed for each new test insertion, including an automated temperature control and data acquisition system in place to support each new test.

ACKNOWLEDGEMENTS

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