THE ADVANCED TEST REACTOR IRRADIATION FACITILITES AND CAPABILITIES

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SUMMARY

The Advanced Test Reactor (ATR) is the third generation of test reactors built at the Test Reactor Area (TRA), located in the Idaho National Engineering and Environmental Laboratory (INEEL), to study the effects of intense neutron and gamma radiation on reactor materials and fuels. ATR has a maximum power of 250MW and can provide maximum thermal neutron fluxes of 1E15 neutrons per square centimeter per second. This allows considerable acceleration of accumulated neutron fluence to materials and fuels over what would be seen in a typical power reactor. Since power operation of the ATR began in 1969, numerous testing methods have been developed to take advantage of the capabilities of the ATR. The wide range of experiment facilities in the ATR and the unique ability to vary the neutron flux in different areas of the core allow numerous experiment conditions to co-exist during the same reactor operating cycle. Simple experiments may involve a non-instrumented sealed capsule containing test specimens with no real-time monitoring and control capabilities. More sophisticated testing facilities include inert gas temperature control systems and pressurized water loops that have continuous chemistry, pressure, temperature, and flow control as well as numerous test specimen monitoring capabilities. There are also apparatus that allow for the simulation of reactor transients on test specimens. The Irradiation Test Vehicle, installed in 1999, is the newest testing apparatus in the ATR that accommodates up to fifteen separate tests, each with its own temperature control and monitoring capabilities as well as neutron spectral tailoring capability. The U.S. Department of Energy intends to maintain and expand the capabilities of the ATR to ensure it remains a viable facility for the Department's materials and fuels testing programs for the foreseeable future.

I. INTRODUCTION

Present and future operations of Idaho's Advanced Test Reactor (ATR) were discussed in References 1 and 2. This paper provides an overview of the types of experiments that are typically performed in the ATR and describes how research programs interface with reactor operations.

The ATR is located in a complex known as the Test Reactor Area (TRA) at the Idaho National Engineering and Environmental Laboratory (INEEL). TRA was established in the early 1950s with the development of the Materials Testing Reactor, which operated until 1970. Two other major reactors followed; the Engineering Test Reactor operating from 1957 to 1981, and the ATR, which began operation in 1967 and is still in operation. These reactors have produced much of the world's data on materials response to reactor environments.

The ATR is considered to be among the most technologically advanced nuclear test reactors in the world. The unique capability of the ATR to provide either constant or variable neutron flux during a reactor operating cycle makes irradiations in this reactor very desirable. The reactor is used primarily by the DOE's Naval Nuclear Propulsion Program. Since the early 1990s, about one-third of ATR's test space has been made available for other research programs. The ATR is now serving other government programs, as well as commercial and international research. The capabilities ATR provides researchers include:

- Large Test Volumes
- Numerous Test Positions
- High Neutron Flux
- Variety of Fast to Thermal Flux Ratios
- Constant Axial Power Profile
- Power Tilt Capability
- Individual Experiment Control
- High Reactor Availability

- Frequent Experiment Changes
- Support Facilities
- Favorable Cost Sharing

The simplest experiment performed in the ATR is a capsule experiment. The material to be irradiated is sealed in aluminum, zircaloy, or stainless steel tubing. The sealed tube is placed in a holder that sits in a chosen test position in the ATR. Capsules typically have no instrumentation, but can include flux-monitor wires and temperature melt wires for examination following the irradiation.

The next level in complexity is a temperature-controlled capsule. During a temperature controlled capsule experiment, a conducting (helium) and an insulating (typically neon or possibly argon) gases are mixed to control the thermal conductance across a predetermined gas gap. Thermocouples measure temperature continuously and provide feedback to the gas system that adjusts the mixture to achieve the desired temperature.

The pressurized water loop experiment is the most comprehensive type of testing performed. A tube runs through the reactor core from vessel top to bottom and is attached to its own individual water system. The cooling system includes pumps, coolers, ion exchangers, heaters to control test temperature, pressure, and chemistry. Loop tests can precisely represent conditions in a commercial power reactor.

Occasionally ATR performs transient testing using a Powered Axial Locator Mechanism (PALM). ATR has two such mechanisms. The PALM tests usually last from a few hours to two days. Some other experiments are removed from the reactor when a PALM test is performed. Hence, this is perhaps the most costly type of test to perform in the ATR.

Cranes and special handling tools are available to either remove or insert customer hardware into the reactor. Underwater storage facilities and working trays (for experiment assembly/disassembly) are available in the large ATR canal adjacent to the reactor vessel. Facilities and specialized counting equipment are available at the Test Reactor Area to analyze flux wires from experiment irradiations and calculate total neutron fluence or neutron spectra data. Based on the complexity of the experimental needs of the customer, ATR operations can also provide real time monitoring and data collection equipment.

Shown below is a summary of a few of the irradiation programs successfully completed in the ATR:

- Space reactor materials and coolants (LiH SP-100)
- Mixed Oxide Fuel Irradiations (MOX)
- Modular High Temperature Gas Cooled Reactor Testing (NPR)
- Tensile, Charpy, CREEP, Zircaloy Growth materials testing
- Pu-238 production feasibility
- Fusion insulator materials
- Reduced Enrichment Research & Test Reactor fuel testing
- Numerous medical, industrial, and research radioisotopes

II. INTERFACE BETWEEN REACTOR OPERATIONS AND RESEARCHERS

Operation of the Advanced Test Reactor is based on a yearly schedule divided into multiple time intervals called "cycles". The length of a reactor cycle (specified in days) and the reactor power (Megawatts) is variable, and dependent upon the customer's experimental requirements and the design basis reactor safety documentation. In order to maintain reactor operational efficiency, equivalent reactor availability, and meet the needs of the customers, the reactor schedule is prepared a year in advance. Integrated into this schedule are planned reactor outages for routine reactor/plant maintenance and removal/insertion of customer experiments.

All experiments to be irradiated in the ATR are controlled by an NQA-1 quality assurance program with multiple reviews/approvals prior to acceptance of customer hardware for irradiation. In addition, for every ATR cycle, complex multi-group neutron diffusion and transport theory calculations are performed, reviewed, and approved for both fuel and experiments to verify that the reactor will operate within the required safety parameters to protect the public and environment. Experiment operational parameters (flow, temperature, pressure, and heat generation) and experiment failure modes are compared to the ATR design basis safety documentation to complete the necessary reviews to ensure safe operation of the experiment and the ATR.

III. STATIC CAPSULE TESTING

Static capsules (referred to as drop-in) may include special passive instrumentation (melt wires for temperature monitoring, neutron fluence monitors, etc.) during irradiation (Fig. 1). The temperature of a static capsule may also be controlled, within limits, by incorporating a small insulating gas jacket (filled with an inert gas) between the specimens and the outside capsule pressure boundary. The width of the gas jacket, the type of gas, and the gamma heating characteristics of the specimens and capsule materials are used to provide the irradiation temperature desired by the experimenter. Static capsules may vary in length (from several centimeters to about 1.2 meters) and diameter (from 1.2-cm to 12.7-cm), and are usually sealed in aluminum, zircaloy, or stainless steel tubing to provide containment. Depending upon the contents and pressure of the capsule, a secondary containment may be included to meet the ATR safety requirements. Capsules, which are usually contained in a basket, are uniquely designed for each customer's needs, and usually cost less than any of the other types of tests, but provide less flexibility and control of operating parameters.

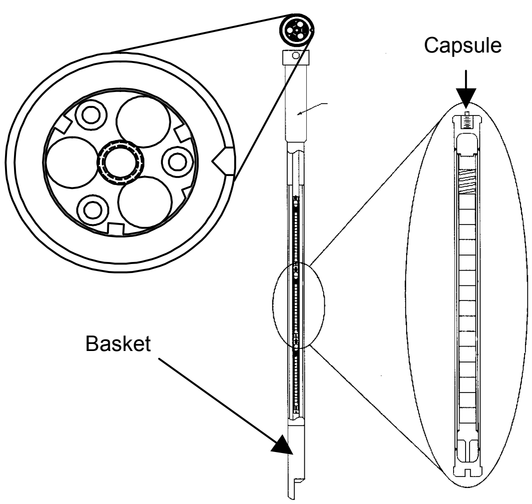

Figure 1. Drop-In Test Assembly for MOX Fuel Testing including capsule and basket

IV. LEAD EXPERIMENTS

The next level of testing in order of complexity provides continuous monitoring (and possibly control) of experiment parameters during irradiation utilizing instrumented leads in the capsules. These experiments are commonly called 'lead experiments' after the instrument leads they contain. The experiment containment is very similar to a static capsule, with the major difference being an umbilical tube attached to the top of the containment. The umbilical tube is used to carry instrument wires (thermocouples, neutron fluence, and gas lines) that lead outside the reactor vessel to data collection/monitoring equipment. Each instrumented lead experiment, which may contain several vertically stacked capsules, is uniquely designed for the irradiation position within the ATR core and the umbilical tube routing needed to connect the experiment to the collection/monitoring equipment. The most common parameter to be monitored and controlled is the specimen temperature during irradiation. Over several decades, individual programs (notably the New Production Reactor program) have designed, built, and irradiated instrumented lead experiments with temperature control. The temperature of each experiment specimen capsule is controlled by varying the thermal conductivity of a gas mixture in a very small gas jacket between the specimens and the experiment containment. This is accomplished by blending two gases with dissimilar thermal conductivities. Helium and neon have been chosen to provide the thermal conductivity variability, but other gases may be used if desired. 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. Temperature measurements are taken with at least two thermocouples per experiment specimen capsule. The thermocouples typically used 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 used in pairs to assure long term service in the high radiation environment. The thermocouple reading is used as the direct control parameter to the gas mixing functions. Additionally, the control systems provide automatic gas verification to assure that the correct gas is connected to supply ports in the system. 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. Alarm functions are provided to call attention to circumstances such as temperature excursions or valve position errors. Helium purges to individual specimen capsules are under automatic control in the unlikely event that the availability 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. Manual control capability is provided at the gas blending panels to provide helium purge in the event of a computer failure. Data archive and acquisition are also included as part of the control system function. Real 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 is archived to removable media. 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 format for at least six months.

V. IRRADIATION TEST VEHICLE

During the late 1990s, the Irradiation Test Vehicle (ITV) was installed in ATR's center flux trap. This permanent facility provides a pressure boundary, gas jacket, and temperature control gas for an experiment assembly as well as the umbilical tube needed for the instrument leads or environmental (either gas or water) system for the experiment. By using this facility, the experimenter avoids the cost of design and fabrication of the umbilical tube required to house the instrument leads and temperature control gas lines to experiment. Since this facility is located in the center flux trap (at the very center of the ATR core), the ITV provides new opportunities to perform temperature controlled material irradiations in high flux regions at reasonable cost to users (Fig. 2).

Development of the ITV called upon the broad experience gained from previously instrumented experiments including design, analytical modeling, blended gas temperature control and automated computer control systems. The ITV provides up to 650 cc of instrumented irradiation volume in 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 temperature of each specimen capsule may be controlled up to 800 °C or possibly higher depending on the internal heating and heat transfer properties of the materials used in the experiment. This facility provides a test platform that permits experimenters to subject a broad range of material specimens to varying ranges of temperatures and neutronic conditions. The ITV facility also permits changing of specimens with as little imposition on reactor operations as possible. Experiment handling takes place within the standard seven-day outage between 40-50 day operating cycles.

The ITV consists of three concentric tubes [called mini-in-pile tubes (MIPTs)] to meet pressure boundary, gas, and 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 experiment chamber. This tube has seventeen channels that terminate at elevations corresponding to the individual gas chamber positions. Five channels are for supply and ten for exhaust (the other two channels are for MIPT sweep gas supply and exhaust). Although five gas supply and ten exhaust channels are provided in each MIPT, the experimenter may select to use fewer than five capsules simply by having the experiment designed with a longer experiment specimen capsule 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 units are installed into the reactor with an aluminum filler sleeve. 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. 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 filler material is replaceable 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.

Temperature measurement and control is accomplished in the same manner as the lead experiments discussed in the previous section. 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, and can be monitored by the same systems as the standard lead experiments discussed in the previous section. A completely separate gas supply system using similar equipment has also been installed to maintain a controlled gas atmosphere within the ITV experiment capsules.

The ITV control system uses fiber optic links and an Ethernet data bus for the communication needed to access the thermocouple outputs and to manipulate the control gas system components. This assures the appropriate gas blends are sent to the corresponding experiment specimen sets. The automated Distributed Control System (DCS) is designed to monitor, control, archive data, and generate reports without the attention of operators during reactor operations. 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 provide offsite real-time data. Data archival, reporting format, and frequency can be directed by the test sponsor.

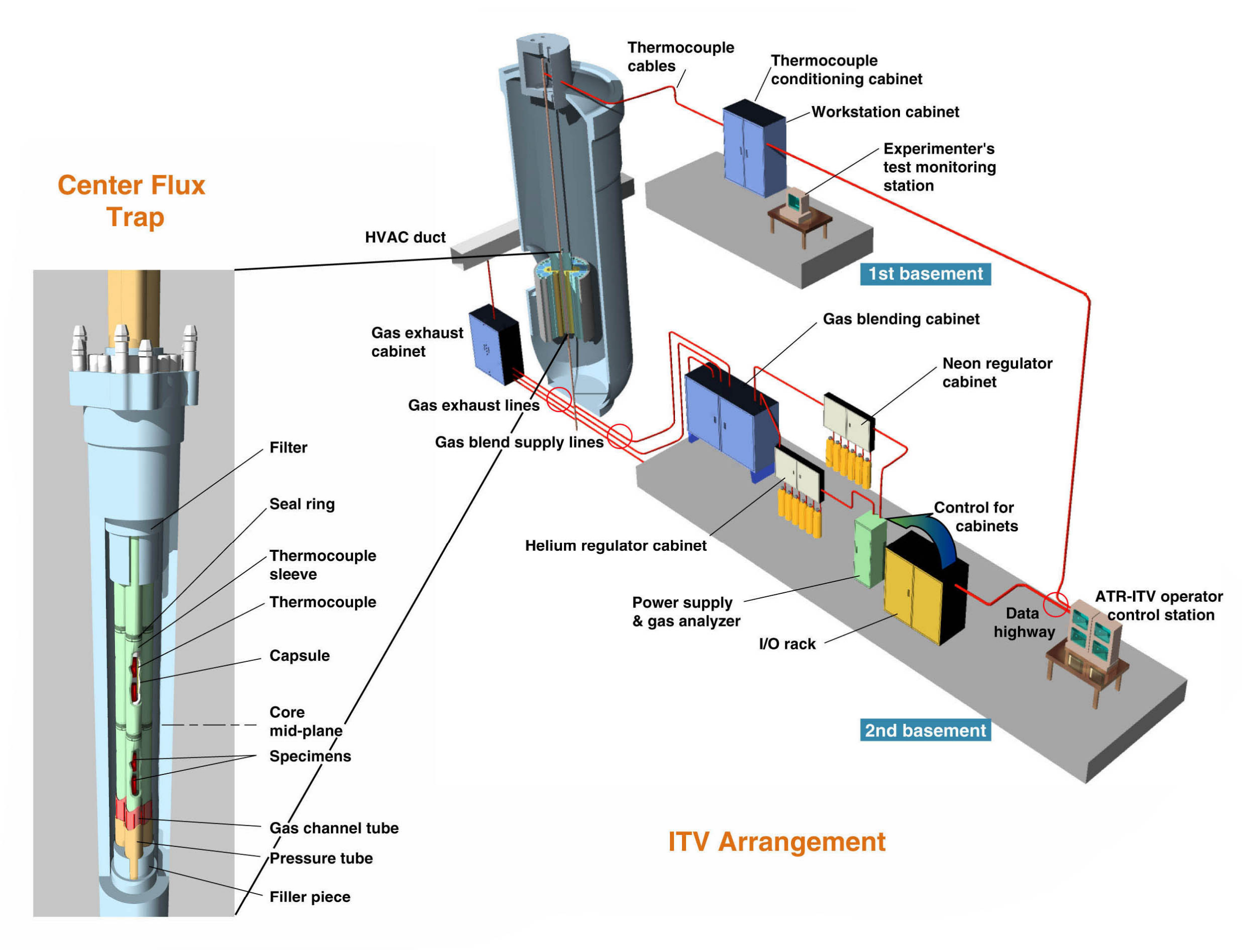

Figure 2. Irradiation Test Vehicle

The initial fabrication and installation of the ITV systems addresses the major complexities that often are the greatest threat to successful experiment programs. All ITV systems remain intact when experiment test trains are removed. New test trains simply establish control parameters, analytical determination of gas gap dimension, and are then assembled and inserted in the ITV.

VI. IN-PILE LOOP TESTS

When viewed from above, the ATR fuel in the reactor core resembles a four-leaf clover created by the serpentine fuel arrangement. The fuel arrangement creates nine primary test locations called flux traps. Five of the flux traps contain In-Pile Tubes (IPT). The other four positions contain capsule irradiation facilities and the ITV as mentioned above.

An IPT is the in-reactor component of a separate pressurized water loop and creates a unique testing facility. The IPT provides a barrier between the reactor water and the pressurized loop coolant for the test. Although isolating the experiment from the reactor water, it still subjects the test materials to the neutron and gamma environment of the reactor. The IPT extends completely through the reactor vessel with closure plugs and seals at the reactor's top and bottom heads. This allows the top seals to be opened and each experiment to be independently inserted or removed. The experiments are suspended from the top closure plugs using hanger rods. The hanger rods position the test within the neutron flux and provide channels for test instrumentation. Anything from reactor fuel rod bundles to core components to medical isotopes can be irradiated or tested.

Each IPT is connected to a separate pressurized water loop, which allows material testing at different pressures, temperatures, flow rates, and water chemistry (Fig. 3). The loops are connected to a state-of-the-art computer control system. This system controls, monitors, and provides emergency functions and alarms for each loop.

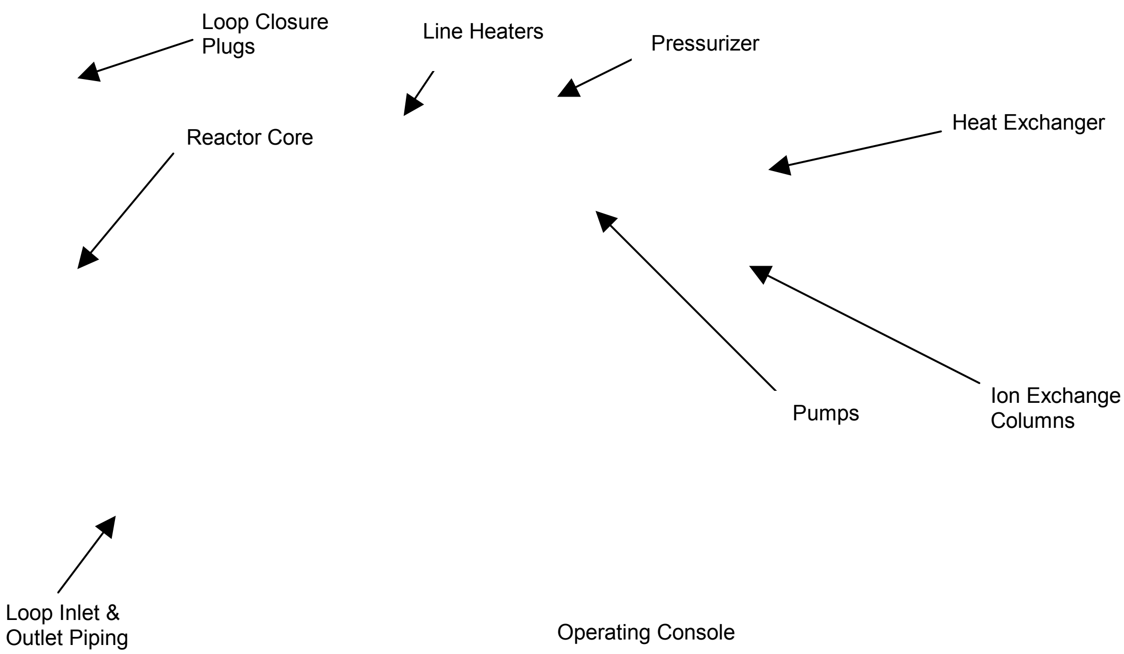

Figure 3. Pressurized Water Loop in the ATR

The experiment designers, though constrained by ATR's unique operating and safety requirements, are free to develop a test with specific operating conditions within the space and operating envelope created by the IPT and loop. A loop experiment can contain a variety of instrumentation including flow, temperature, fluence, pressure, differential pressure, fission product monitoring, and water chemistry. All of these parameters can be monitored by the Loop Operating Control System (LOCS) and controlled by the LOCS reactor control system, or by operator intervention. The LOCS is a state-of-the-art computer system designed specifically for the ATR loops. The system controls all aspects of the loop operations (flow, pressure, and temperature) for all five loops simultaneously. This information is displayed on the Loop Operating Console and interfaces with the reactor control system, which is a similar system controlling the reactor. Loop Operators are stationed at the controls to operate and monitor the systems. The test loops are operated and adjusted to meet test sponsor requirements. Typical operations include setting, monitoring and maintaining flow rates, temperatures, pressure, and chemistry.

All test specific information from reactor power levels to test temperatures is monitored and can be recorded. The data can be averaged daily, hourly or every 2 to 3 seconds. This information can be recorded and transferred to the test sponsors. The massive amount of information is typically averaged over longer periods before being permanent recorded and transferred to the sponsors. If desired, any off-normal event can be recorded on a shorter time period and the data provided.

Test parameters are measured using a variety of instrumentation. Digital outputs for all the measurement devices are routed to the LOCS. Flow is measured in-core and out-of-core using flow venturis and/or orifice plates. Differential pressure transmitters are connected to the high and low side of the flow device with the impulse lines routed through the loop cubicle and into the test. Pressure, differential pressures and level indications are measured throughout the loop system. Differential pressure transmitters are connected with impulse line to the loop at various locations, pump inlet, pump outlet, IPT inlet, test inlet, test outlet, IPT outlet, pressurizer surge line, etc. Standard pressure gauges are also installed in the secondary cubicles with impulse lines connected to the loop. Temperatures are measured with a variety of thermocouples installed either directly in the test specimens or inside loop coolant. Loop thermocouples are typically installed in thermowells welded into the loop piping. This allows thermocouple replacement without opening the loop system. Fission product inventories in the loop water are measured by gamma detectors in the loop cubicles. They are also measured by taking water samples, which are analyzed in the Chemistry Lab. Loop chemistry is monitored with on-line instrumentation. In addition, water samples are taken and analyzed in the ATR Lab. The chemistry is maintained with on-line purification systems and adjusted with a chemical addition system.

Fluence is typically calculated based on actual operating powers obtained from the reactor control system. Actual fluence can be confirmed by measuring flux wire installed in or around the test. Flux wires must be removed from the test and counted, thus they are passive devices used to confirm predicted values. On-line fluence measurements can be obtained, though not typically done, by installing a Self-Powered Neutron Detector in the test section.

Loop experiments are loaded into the IPT either from the ATR canal using the ATR Transfer Cask or directly from the shipping casks. These are 30-ton shielded casks specifically designed to interface with the ATR reactor top. The loop is depressurized and partially drained, the IPT closure seals are removed, and the cask is set over the IPT and the test lowered down into the IPT. The cask is then removed, the closure seals are reinstalled, the instrumentation lines are connected and the loop refilled.

There are two Powered Axial Locator Mechanism (PALM) drive units that can be connected to specially configured tests in the loop facilities so that complex transient testing can be performed. The PALM drive units move a small test section from above the reactor core region into the core region and back out again either very quickly, approximately 2 seconds, or slowly depending on test requirements. This process simulates multiple startup and shutdown cycles of test fuels and materials. Thousands of cycles can be simulated during a normal ATR operating cycle. The PALM drive units are also used to precisely position a test within the neutron flux of the reactor and change this position slightly as the reactor fuel burns.

VII. FUTURE TESTING

U.S. Department of Energy base programs at ATR are expected to continue well into future decades. Other federal, commercial and international programs will likely continue to utilize part of ATR as well. In anticipation of this, INEEL will continue to develop user facilities at ATR and make testing at ATR more user-friendly. The Irradiation Test Vehicle is the first such facility and provides rapid access at low cost to a temperature controlled facility in a high neutron flux. Testing is planned for the future to support researchers working on Generation IV reactors. More collaboration with universities is being encouraged and an experiment/isotope shuttle facility may be added at a future date.

VIII. SUPPORT FACILITIES AT TRA

TRA has the necessary facilities to support different testing programs at TRA. These facilities include a Hot Cell facility, modern fabrication facilities, and a new Test Train Assembly Facility (TTAF). The Hot Cell provides a method of interfacing with dry load casks for shipping experiments to test sponsors and is currently increasing its post irradiation examination capabilities. The fabrication facilities consist of dedicated weld and machine shops that contain computer-controlled lathe and vertical milling machines. The existing TTAF is currently being replaced with a new facility and updated equipment. The assembly capabilities in the new TTAF will include induction brazing, electro-plating, thermocouple potting and splicing, all types of welding including resistance spot welding (instrument leads) and autogenous welding, liquid nitrogen shrink fits, and a vacuum drying oven for removing moisture from porous materials (e.g. graphite, etc.). These facilities are staffed with personnel that experienced in the delicate operations need to fabricate test trains such as machining of very small intricate parts, conducting induction brazing multiple thermocouples into a small diameter bulkhead, and performing welding inside of inert gloveboxes on small intricate parts.

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