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Advanced Test Reactor – Testing Capabilities and Plans

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The Advanced Test Reactor (ATR), at the Idaho National Laboratory (INL), is one of the world's premier test reactors for providing the capability for studying the effects of intense neutron and gamma radiation on reactor materials and fuels. The physical configuration of the ATR, a 4-leaf clover shape, allows the reactor to be operated at different power levels in the corner "lobes" to allow for different testing conditions for multiple simultaneous experiments. The combination of high flux (maximum thermal neutron fluxes of 1E15 neutrons per square centimeter per second and maximum fast [E>1.0 MeV] neutron fluxes of 5E14 neutrons per square centimeter per second) and large test volumes (up to 122 cm long and 12.7 cm diameter) provide unique testing opportunities. For future research, some ATR modifications and enhancements are currently planned. In 2007 the US Department of Energy designated the ATR as a National Scientific User Facility (NSUF) to facilitate greater access to the ATR for material testing research by a broader user community. This paper provides more details on some of the ATR capabilities, key design features, experiments, and plans for the NSUF.

Keywords: Advanced Test Reactor, Idaho National Laboratory, test reactor, research reactor, irradiation testing, neutron flux, National Scientific User Facility

1. INTRODUCTION

The Advanced Test Reactor (ATR), located at the Idaho National Laboratory (INL), is one of the most versatile operating research reactors in the United States. The ATR has a long history of supporting reactor fuel and material research for the US government and other test sponsors. The INL is owned by the US Department of Energy (DOE) and currently operated by Battelle Energy Alliance (BEA). The current experiments in the ATR are for a variety of customers – US DOE, foreign governments, and private researchers, and commercial companies that need neutrons. The ATR has several unique features that enable the reactor to perform diverse simultaneous tests for multiple test sponsors. The ATR has been operating since 1967, and is expected to continue operating for several more decades. Also at the INL are several facilities used for experiment preparation and post irradiation examination (PIE). In 2007, DOE designated the ATR as a National Scientific User Facility (NSUF), enabling a broader user community the ability to perform research (irradiation testing and PIE) in the INL facilities. This paper discusses the ATR design features, testing options, previous experiment programs, future plans for the ATR capabilities and experiments, a brief overview of the PIE capabilities at the INL and some discussion of the NSUF plans.

2. ATR DESCRIPTION

The ATR is a pressurized, light-water moderated and cooled, beryllium-reflected highly-enriched uranium fueled, nuclear research reactor with a maximum operating power of 250 MWth. The INL is owned by the US Department of Energy (DOE). The ATR is one of the most versatile operating research reactors in the United States. The ATR core cross section, shown in Figure 1, consists of 40 curved aluminum plate fuel elements configured in a serpentine arrangement around a 3 by 3 array of large irradiation locations in the core termed "flux traps." The flux traps have the highest flux in the reactor due to the close proximity of the fuel. This core configuration creates five main reactor power lobes (regions) that can be operated at different powers during the same operating cycle. In addition to these nine flux traps there are 68 additional irradiation positions in the reactor core reflector tank. There are also 34 low-flux irradiation positions in the irradiation tanks outside the core reflector tank.

General design information and operating characteristics for the ATR are presented in Table 1. The ATR has several unique features that enable the reactor to perform diverse simultaneous tests for multiple test sponsors. The unique design of ATR control devices permits large power variations among its nine flux traps using a combination of control cylinders (drums) and neck shim rods. The beryllium control cylinders contain hafnium plates that can be rotated toward and away from the core, and hafnium shim rods, which withdraw vertically, can be individually inserted or withdrawn for minor power adjustments. Within bounds, the power level in each corner lobe of the reactor can be controlled independently to allow for different power and flux levels in the four corner lobes during the same operating cycle.

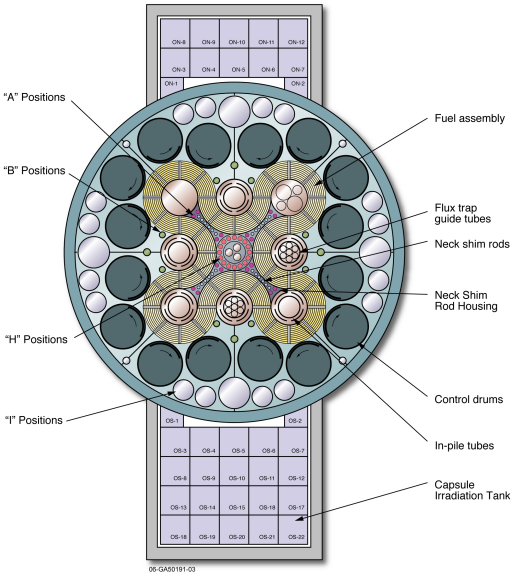

Figure 1. ATR Core Cross Section

Table 1. ATR Design and Operating Information

Reactor	
Thermal Power (Maximum Design Power)	250 MW_{th}
Power Density	1.0 MW/liter
Maximum Thermal Neutron Flux	1.0 $x10^{15}$ n/cm^2-sec
Maximum Fast Flux	5.0 $x10^{14}$ n/cm^2-sec
Number of Flux Traps	9
# Experiment Positions	68
Core	
Number of fuel assemblies	40
Active length of Assemblies	1.2 m (4 ft)
Number of fuel plates per assembly	19
Reactivity Control Drums/Rods	Hafnium
Primary Coolant System	
Design Pressure	2.7 MPa (390 psig)
Design Temperature	115°C (240°F)
Reactor coolant	Light water
Maximum Coolant Flow Rate	3.09 m^3/sec (49,000 gpm)
Coolant Temperature (Operating)	< 52°C (125°F) inlet, < 71°C (160°F) outlet

A typical operating cycle for the ATR consists of 42 to 56 operating days and 14 outages days, during which operators refuel the reactor and insert, remove, or reposition experiments. There are usually 6 operating cycles each year, for an average total of 250 operating days each year. Experiments remain in the ATR for the entire duration of the operating cycle. A hydraulic shuttle irradiation system (HSIS) is being installed into the ATR, and will be operational in October 2008. This will enable small volume, short duration irradiations to be performed in the ATR. This system will enable up to 16 small shuttle capsules will to be inserted into the shuttle system for a single shuttle operation.

Most experiments are handled, using long handled tools, through ports in the reactor vessel head, so that the vessel head does not need to be removed during every outage; some experiments need to be handled with a crane and are lifted directly out of the top of the vessel into a specially designed container.. All other experiments are moved into the adjacent ATR canal area for some cooling time prior to packaging for shipment to other facilities for post irradiation examination.

A unique feature of the ATR is that the core internal components are removed and replaced every 8-10 years, during a core internals changeout (CIC) , an outage of approximately six months duration. Additionally, the ATR reactor vessel is substantially larger than the core size allowing for reduced neutron flux embrittlement of the reactor vessel. Unlike commercial LWRs in the US, the ATR has no established lifetime or shutdown date. Analyses and surveillances are routinely performed to monitor the material condition of the key structural components.

The ATR also contains a separate facility, the Advanced Test Reactor Critical (ATRC) facility (Figure 2), which is a full-size replica of the ATR operated at low power (5 kW maximum) and used to evaluate the potential impact on the ATR core of experiment test trains and assemblies. Mock-ups of experiments can be inserted in the ATRC, and such parameters as control rod worths, reactivities, thermal and fast neutron distributions, gamma heat generation rates, ATR fuel loading requirements, and void/temperature reactivity coefficients can be determined prior to insertion into the ATR.

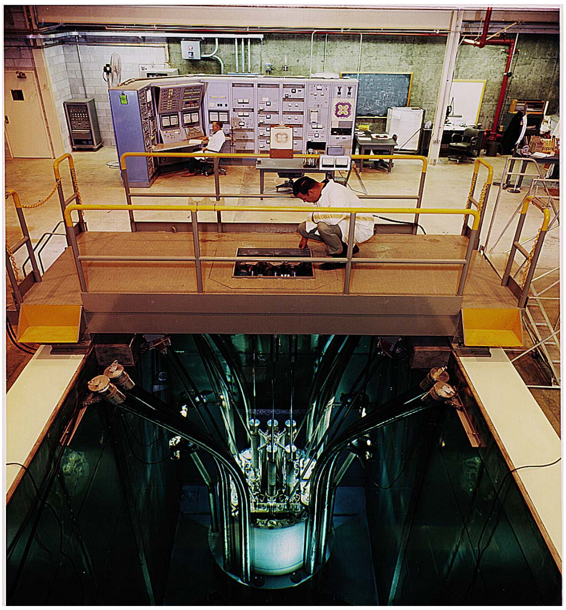

Figure 2. ATR Critical Facility

3. EXPERIMENT CAPABILITIES

There are three basic types of experiment configurations utilized in the ATR – the static capsule, the instrumented lead, and the pressurized water loop experiment. Each is described in more detail below, with some examples of the experiments performed using each type of configuration.

3.1 Static Capsule Experiment

The simplest experiment performed in the ATR is a static 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. A single capsule can be the full 1.2 m core height, or may be shorter, such that a series of stacked capsules may comprise a single test. Capsules are usually placed in an irradiation basket to facilitate the handling of the experiment in the reactor. Figure 3 shows a simplified drawing of a static test capsule and basket assembly. Some capsule experiments contain material that can be in contact with the ATR primary coolant; these capsules will not be sealed, but in an open configuration, such that the capsule is exposed to and cooled by the ATR primary coolant system. Examples of this are Reduced Enrichment for Research and Test Reactors (RERTR) fuel plate testing, such that the fuel to be tested is in a cladding material similar to (or compatible with) the ATR fuel element cladding.

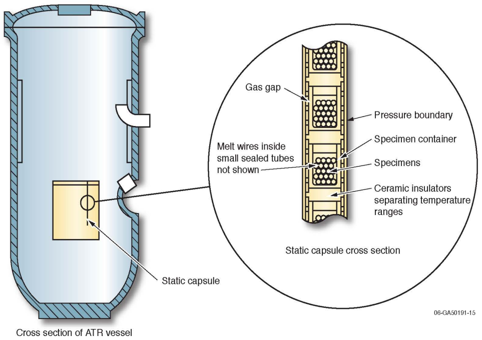

Figure 3. Static Capsule Assembly

Static capsules typically have no instrumentation, but can include flux-monitor wires and temperature melt wires for examination following the irradiation. Limited temperature control can be designed into the capsule through the use of an insulating gas gap between the test specimen and the outside capsule wall. The size of the gap is determined through analysis for the experiment temperature requirements, and an appropriate insulating or conducting gas is sealed into the capsule. An additional adjustment that has been used in static capsule experiments is flux tailoring in a single position – a filtering material can be used to change the fast:thermal ratio and fuel can be added to increase the overall flux.

Static capsule experiments are easier to insert, remove, and reposition than more complex experiment configurations. Relocations to a different irradiation location within the ATR are occasionally desired to compensate for fuel burn-up in a fuel experiment. A static capsule experiment is typically less costly than an instrumented one and requires less time for design and analysis prior to insertion into the ATR.

3.2 Instrumented Lead Experiment

The next level in complexity of ATR experiments is an instrumented lead experiment, which provides active monitoring and control of experiments parameters during the irradiation period. The primary difference between the static capsule and the instrumented lead experiment is an umbilical tube that runs from the experiment in the reactor core region through a penetration in the reactor vessel and houses instrumentation connections that lead to a monitoring/control station elsewhere in the reactor building. In a temperature-controlled experiment, thermocouples continuously monitor the temperature in the experiment and provide feedback to a gas control system to provide the necessary gas cooling mixture to the experiments to achieve the desired experiment conditions. The thermocouple leads and the gas tubing are in the umbilical tube. A conducting (helium) gas and an insulating (typically neon or possibly argon) gas are mixed to control the thermal conductance across a predetermined gas gap. The computer-controlled gas blending system allows for the gas mixture to be up to 98% of one gas and as low as 2% of the other gas to allow for a wide range of experiment temperature ranges. Temperature measurements are typically taken with at least two thermocouples per capsule to provide assurance against an errant thermocouple and to also provide redundancy in the event of a thermocouple failure. The INL has developed (and continues further research on) thermocouples capable of performing at ever higher temperatures – the current tests are operating at 1200°C and the next experiments will be operating closer to 1500°C Figure 4 shows a typical instrumented lead experiment.

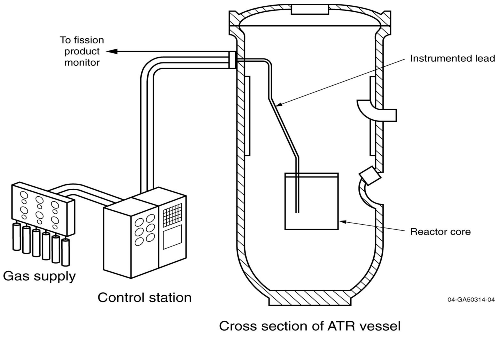

Figure 4. Example of an Instrumented Lead Experiment Configuration

Some of the instrumented lead experiments need specialized environments, such as an oxidized cover gas. The instrumented lead experiment allows for precise environmental conditions to be established and monitored, ensuring that the experiment data objectives can be met satisfactorily. Use of the instrumented lead experiment configuration enables researchers to monitor the gas around the test specimen for changes to the experiment conditions. In a fueled experiment, for example, there is sometimes a desire to test for fission gases, which could indicate a failure of the experiment specimen. Gas chromatography can also be used to monitor oxidation of an experiment specimen. The instrument leads allow for a real time display of the experiment parameters on an operator control panel. The instrumented leads can also be used to provide an alarm to the operators and experimenters if any of the experiment parameters exceed test limits. For any monitored experiment parameter, a data acquisition and archive capability can be provided; typically the data are saved for six months.

The primary advantage of the instrumented lead experiment is the active control of the experiment parameters that is not possible in a static capsule experiment. Additionally, the experiment sponsor does not have to wait until the full irradiation has been completed for all experiment results; the instrumentation provides preliminary results of the experiment and specimen condition.

3.3 Pressurized Water Loop Experiment

The pressurized water loop (PWL) experiment is the most complex and comprehensive type of testing performed in the ATR. Five of the ATR flux traps contain in-pile tubes (IPTs), connected to pressurized water loops, that provide a barrier between the reactor primary coolant system and a secondary pressurized water loop coolant system. The experiments are isolated from the ATR reactor coolant system since the IPT extends through the entire reactor vessel. There are closure plugs at the top and bottom of the vessel to allow the experiments to be independently inserted and removed.

The secondary cooling system includes pumps, coolers, ion exchangers, heaters to control experiment temperature, and chemistry control systems. All of the secondary loop parameters are continuously monitored, and computer controlled to ensure precise testing conditions. Loop tests can precisely represent conditions in a commercial pressurized water reactor. Operator control display stations for each loop continuously display information that is monitored by the ATR staff. Test sponsors receive preliminary irradiation data before the irradiations are completed, so there are opportunities to modify testing conditions if needed. The data from the experiment instruments are collected and archived similar to the data in the instrumented lead experiments. The real-time feedback of experiment conditions and irradiation results can also be an asset to the experiment sponsor..

4. POST IRRADIATION EXAMINATIONS

The Hot Fuels Examination Facility (HFEF) [1] (Fig. 5) located within the Materials and Fuels

Complex (MFC) at Idaho National Laboratory is a large alpha-gamma multi-program hot cell facility which is designed to remotely characterize highly irradiated fuel and structural materials. Some of the most commonly performed tests are described below. In addition to the hot cell work, the INL operates several radiochemistry laboratories that are also available for PIE work. The wide range of fuel handling and measurement capabilities at HFEF, coupled with the INL's experience in testing and analyzing fuel behavior make HFEF an ideal facility in which to perform post-irradiation and spent nuclear fuel characterization activities.

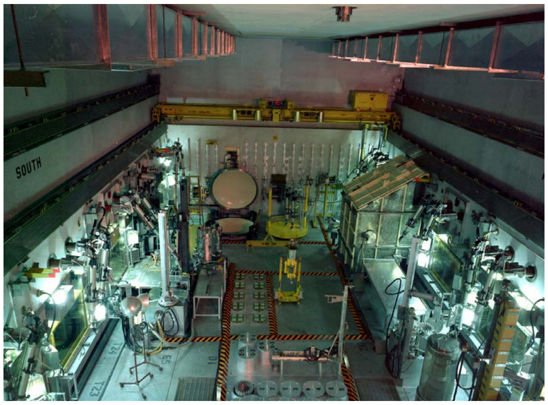

Figure 5. HFEF Main Cell (West View)

4.1 Visual Examination

An experiment capsule can be visually examined to determine its mechanical integrity and surface appearance, and the mass of the capsule can be measured. Deviations from as-built conditions will be examined by close-up photography prior to performing subsequent PIE tasks. Of note are capsule tube and end cap failures, cracks, deformations, blisters, areas of discoloration, corrosion, and loss of material by wear.

4.2 Neutron Radiography

Neutron radiography can be used to examine the internal condition of the capsule assembly prior to disassembly. This non-destructive technique is able to detect the presence of water or bonding material within the capsule cavity indicating a leak or containment failure. Data can be obtained on the general condition of the specimens, including axial position, radial position and gap, distortion or bow, and the fuel column length within the capsule.

Neutron radiography is performed at the MFC Neutron Radiography Facility which interfaces through the floor of the HFEF Main Cell. The neutron beam is generated by a 250 kW Training Research Isotope General Atomics (TRIGA) reactor located below the Main Cell.

4.3 Internal Gas Pressure and Void Volume Analyses

The Gas Assay, Sample, and Recharge system can be used to puncture the capsule assembly, to measure the free volume and internal gas pressure and to collect samples for gas composition and isotopic analyses and total elemental composition.. This system provides internal void volume and gas pressure data to an accuracy within ± 5% in a pressure – volume range of 0.03 to 60 liter-atmosphere.

4.4 Assembly Dimensional Inspections

The diameter profile of a specimen can be measured using the Element Contact Profilometer (ECP), a remotely operated, continuous-contact profilometry gauge for measuring axial and spiral diameter profiles of cylindrical elements and capsules. This is capable of measurements to an accuracy of ±0.0003 in. (7.6 μm) and can measure percentage swelling over a range of 0.13 – 8.7%. The length of the rodlet can be measured with an accuracy of ±0.010 inches and the bow of the fuel rodlet can be measured to an accuracy of ±0.020 inches.

4.5 Gamma Scan

Experimental components can be gamma scanned over their entire accessible length to measure total activity and isotopic activity of select fission products and activation products in structural materials. Gamma spectra can be used to determine fuel pellet or fuel pin separations in the fuel column, fuel redistribution, fission product migration, and the relative axial burnup profile.

4.6 Optical and Electron Microscopy and Radiochemical Analyses

Optical and electron microscopy are used to analyze microscopic features such as fuel restructuring, pore density and size distribution, fuel-cladding chemical interaction, grain size and structure in the fuel and cladding, precipitates, and cladding integrity. The fuel burnup of a representative number of fuel samples can be determined by radiochemical analyses on samples supplied to the Analytical Laboratory.

Sample preparation is performed in an inert, argon atmosphere sub-cell of the HFEF Main Cell equipped with an independent atmosphere control system. The sample preparation sub-cell has facilities for sectioning, mounting, grinding, polishing and etching. The optical microscopy, scanning electron microscopy and radiochemistry samples are transferred by a pneumatic transfer system.

5. ATR NATIONAL SCIENTIFIC USER FACILITY

In 2007, the DOE designated the ATR as a National Scientific User Facility (NSUF). The mission of the ATR NSUF, to provide nuclear energy researchers access to world-class facilities, thereby facilitating the advancement of nuclear science and technology within the U.S, is accomplished by providing experimental irradiation testing and PIE facilities for the user community and technical assistance in designing and analyzing reactor experiments. With this designation, DOE has committed to maintain and enhance the research capabilities necessary to further fuel and material research objectives. Access to the ATR NSUF also includes access to the INL PIE facilities and science and engineering support for experiments. The user facility will:

- Support both basic and applied research and development
- Increase the effectiveness and decrease the uncertainty associated with development of new fuels and materials for existing and advanced reactor concepts
- Facilitate the development and validation of new analytical models to improve nuclear energy systems
- Encourage research collaboration on high-quality scientific experiments using the ATR and assure that unique research capabilities are made available to a broader scientific community
- Provide access to the ATR for production of medical, research, and industrial isotopes
- Provide a platform for educating and training nuclear scientists, radiochemists, engineers, and trades critical to the nuclear industry
- Support new nuclear programs at universities that do not have a dedicated research reactor, and augment those programs that do have research reactors.

The reactor and associated PIE facilities can be accessed for non-proprietary work by university-led teams, at no cost, through award of proposals selected on a competitive basis. The first proposal solicitation was offered in 2008 and four proposals were selected. It is anticipated that in the future, up to 15 experiments may be offered in a single year, depending on the complexity of the experiments proposed and available funding.

There are several projects underway and planned to enhance the research value of the INL facilities. These include addition of PIE equipment to the HFEF and Analytical Labs, reactivation of a PWR loop in the ATR, addition of the shuttle irradiation system, and building a new facility for test train assembly.

6. CONCLUSION

The ATR is a versatile research reactor, with several unique design features and offering several testing configurations that enable the reactor to support multiple diverse experimental programs. In 2007, the DOE designated the ATR as a National Scientific User Facility (NSUF), enabling the INL to support non-proprietary research at no cost to the user. Associated INL facilities, such as experiment assembly, use of experimental instrumentation, and PIE, can also be accessed through the NSUF proposal competition process. The ATR is expected to continue operations for many years into the 21st century.

ACKNOWLEDGEMENTS

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