ADVANCED TEST REACTOR EXPERIMENT RESEARCH PROGRAM

Frances M. Marshall, S. Blaine Grover
Idaho National Laboratory
P. O. Box 1625
Idaho Falls, ID 83415-3835 USA
208-526-8947 (phone)
208-526-1078 (fax)
Frances.Marshall@inl.gov

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 10^{15} neutrons per square centimeter per second and maximum fast [E>1.0 MeV] neutron fluxes of $5x10^{14}$ 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, and experiment programs.

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 (US). 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 is the third generation of test reactors built at this INL site location, whose mission is to study the effects of intense neutron and gamma radiation on reactor materials and fuels. 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. In 2007, DOE designated the ATR as a National Scientific User Facility (NSUF), enabling a broader user community access to perform research (irradiation testing and post irradiation examinations) in the INL facilities. This paper discusses the ATR design features, testing options, previous experiment programs, future plans for the ATR capabilities and experiments, 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 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 enabling 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.

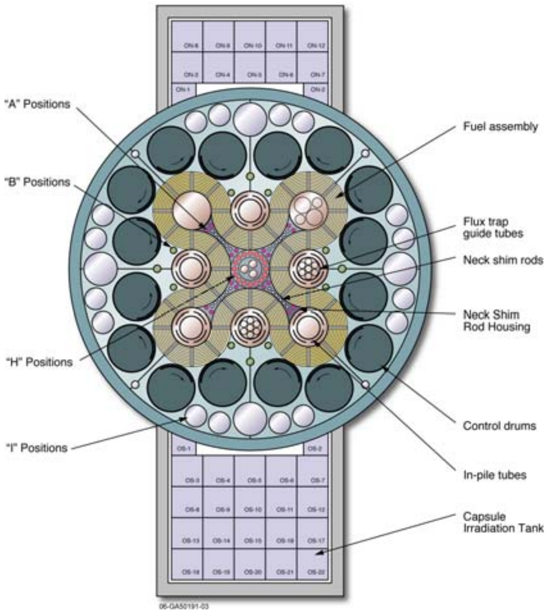

Figure 1. ATR Core Cross Section

A typical operating cycle for the ATR consists of 42 to 56 operating days and 14 outage 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. For most experiment configurations, the experiments remain in the ATR for the entire duration of the operating cycle. A hydraulic shuttle irradiation system (HSIS), recently installed into the ATR, will enable small volume, short duration irradiations to be performed in the ATR.

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), during an outage of approximately six months duration. The last CIC outage was completed in 2005 and the next one is currently scheduled to start in 2014. Additionally, the ATR reactor vessel is substantially larger than the core size resulting in 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.

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

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.

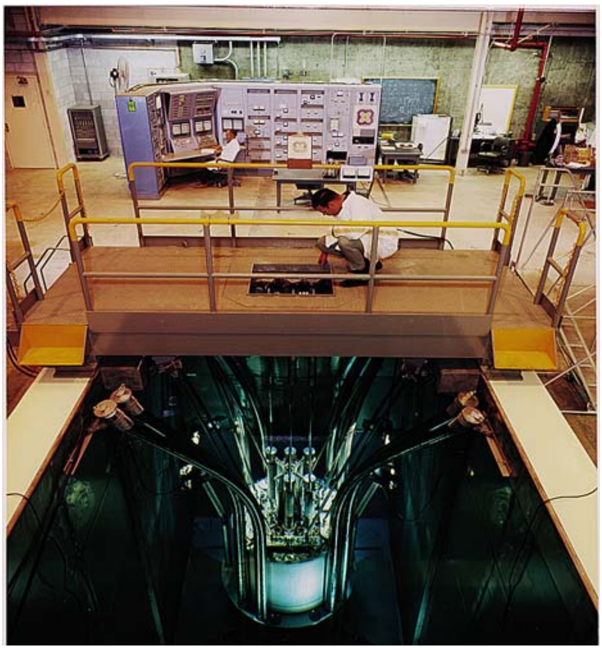

Figure 2. ATR Critical Facility

3. EXPERIMENT CAPABILITIES

There are four basic types of experiment configurations utilized in the ATR – the static capsule, the instrumented lead, the pressurized water loop experiment, and the shuttle capsules. Each is described in more detail below, with some examples of the experiments performed using each type of configuration. There are a total of 77 irradiation positions in the ATR, ranging in diameter from 1.3 – 12.7 cm, and all are 122 cm in length.

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 are 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, in which the fuel material to be tested is clad in material similar to (or compatible with) the ATR fuel element cladding.

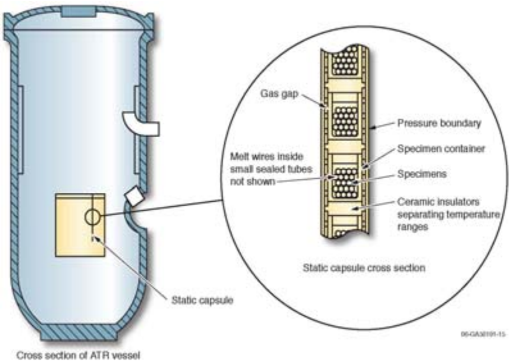

Figure 3. Static Capsule Assembly

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 in an experiment location.

Static capsule experiments are easier to insert, remove, and reposition than more complex experiment configurations. Occasionally, to meet experiment objectives, an experiment may need to be relocated to a different irradiation location within the ATR after some of the desired irradiation cycles have been completed, in order 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.

One set of experiments that has been using the static capsule configuration for fuel irradiations for several years is the Advanced Fuel Cycle Initiative (AFCI). The experiments, consist of short internal capsules, called rodlets (see Fig. 4), containing the fuel specimens. The rodlets are filled with sodium to provide optimum heat transfer and temperature equalization within the capsule and fuel. An inert cover gas plenum is also included in the top of the rodlet to provide room for swelling and collection of any fission gas releases. Several rodlets are loaded in an outer capsule with a precisely designed gas gap between the rodlets and the capsule wall. The gas gap is filled with a suitable gas mixture to control the heat transfer from the rodlets to the capsule wall and to the ATR primary coolant, which determines and controls the temperatures in the fuel rodlets. The capsules are loaded into an open top basket that positions the capsules in the proper vertical location within the selected position within the ATR irradiation position. This set of experiments requires a flux profile more like a fast reactor than the ATR typically provides, so a cadmium liner is inserted into the basket to reduce the thermal flux and adjust the fast/thermal flux ratio to more representative of a fast reactor.

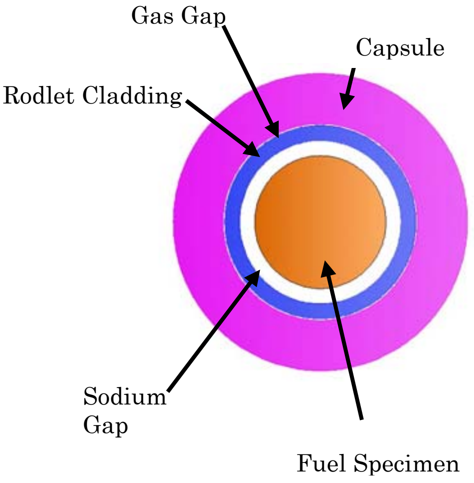

Figure 4. AFCI capsule cross section

The initial experiments sponsored by the NSUF are also static capsule type experiments. The first experiment, in collaboration with the University of Wisconsin, is comprised of 12 rodlets containing over 500 material specimens of 18 different material types to be tested. These samples are fabricated and machined in several different shapes and sizes to enable a wide variety of post irradiation tests to be performed on the materials, such as microhardness, shear punch, tensile testing, and resistivity measurements on SiC temperature monitors. As with the AFCI experiments, these rodlets and the capsule were designed to meet several different experiment parameters, such as temperature (300–700°C) and neutron exposure duration. One set of specimens will be irradiated for approximately 200 days and the other set will be irradiated for approximately 400 days.

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 an experiment's 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 5 shows a typical instrumented lead experiment configuration.

Some of the instrumented lead experiments require 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.

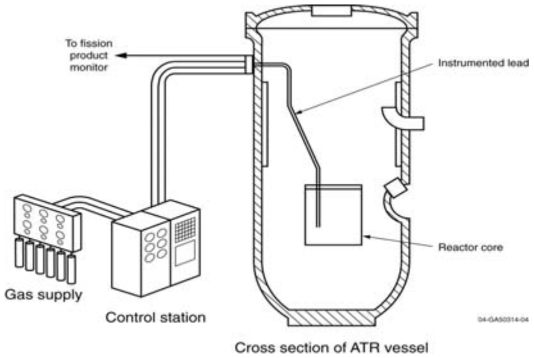

Figure 5. Example of an Instrumented Lead Experiment Configuration

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.

The Next Generation Nuclear Plant (NGNP) program is developing fuel to be used in a high temperature gas reactor environment. The first irradiation test (of eight planned tests) for this fuel development program is being irradiated in the ATR in an instrumented lead experiment. A horizontal cross-section of one of the six capsules in the experiment test train is shown in Figure 6. The test consists of six separate capsules vertically centered in the ATR core, each with its own custom blended gas supply and exhaust for independent temperature control.

Each of the six capsules is approximately 35 mm in diameter and 130 mm long, and will contain 12 prototypical fuel compacts approximately 12.5 mm in diameter and 25 mm long. The fuel compacts are made up of 780 µm diameter TRISO-coated fuel particles, graphite and a binder to hold the compacts together. The compacts are arranged in four layers in each capsule with three compacts per layer nested in a triad configuration. A nuclear grade graphite spacer surrounds and separates the three fuel compact stacks in each capsule and also provides the inner boundary for the insulating gas jacket. The graphite spacer also contains boron carbide as a consumable neutron poison to limit the initial fission rate in the fuel, providing a more consistent fission rate/power production during the planned two-year irradiation.

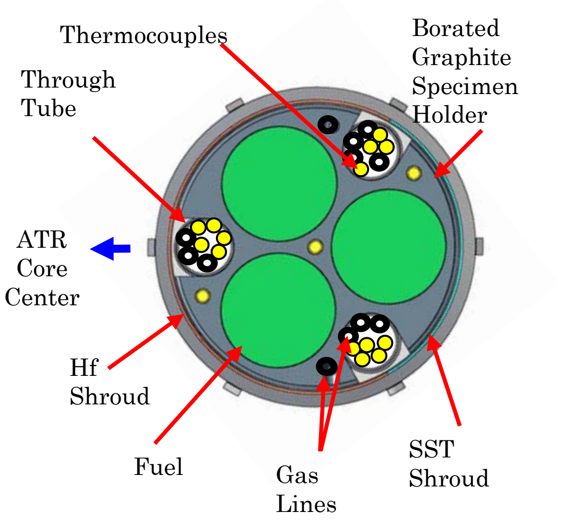

Figure 6 - AGR Capsule Cross-Section

The graphite spacer has machined features to accommodate the thermocouples for measuring temperature within the capsule and for three tubes that provide a pathway for gas lines and thermocouples to the lower experiment capsules. Flux wires were also installed in the capsules to measure both the thermal and fast neutron fluence. These experiment capsules are also monitored for gaseous fission products that would indicate a possible particle fuel coating failure.

3.3 Pressurized Water Loop Experiment

The pressurized water reactor (PWR) loop 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.

There are two Powered Axial Locator Mechanism (PALM) drive units that can be connected to specially configured tests in the pressurized water 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 two 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.

3.4 Hydraulic Shuttle Irradiation System

The Hydraulic Shuttle Irradiation System (HSIS) is a system that can be used to insert experiments into and remove experiments from ATR while the reactor is operating. When ATR was initially operated, there was a pneumatic shuttle irradiation system, however, it was removed in the 1980’s. The new system was selected to be hydraulic to enable more versatility in the material that could be encapsulated in the HSIS capsules, and it was redesigned to have shorter travel times for the shuttle capsules.

The system is designed to accommodate up to 16 shuttle capsules in one “train” that can be inserted into the ATR at one time. The capsules are milled out of titanium, which was picked due to its low activation. Figure 6 shows two of the capsules with a pencil to highlight the capsule size. Capsules could be made of different materials depending on customer requirements. The shuttle is hollow and once the sample is loaded the cap is welded on. Each capsule can hold 25 grams of material and has a volume of 7.8 cm^3. The system was prepared for operability in summer 2009, and is expected to be ready for target irradiation in October 2009. Some of the programs that have been proposed for irradiation in this system are production of medical isotopes and fuel specimens to support the INL nuclear fuel development missions.

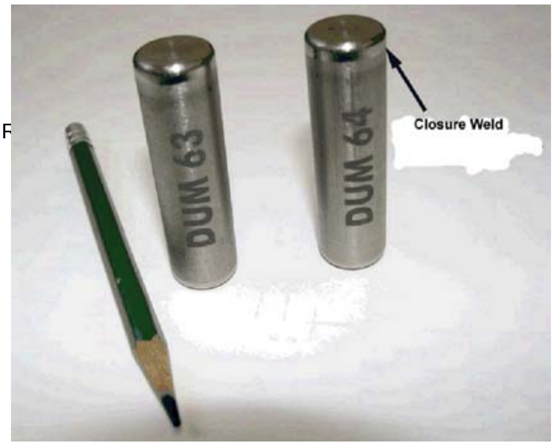

Figure 6. HSIS capsules.

4. 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 is to provide nuclear energy researchers access to world-class facilities, facilitating the advancement of nuclear science and technology within the US. Experimental irradiation testing and Post Irradiation Examination (PIE) facilities at the INL have been made available for the user community through a competitive peer review proposal process, and INL provides technical assistance in designing and analyzing reactor experiments. With this NSUF designation, DOE has committed to maintain and enhance the research capabilities necessary to further fuel and material research objectives.

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, and reactivation of a PWR loop in the ATR. A new facility for experiment assembly was completed in 2009.

5. 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. Experiments performed in the ATR have contributed to many national research missions, and continue to support fuel and material development programs. In 2007, the DOE designated the ATR as a National Scientific User Facility, enabling researcher access the INL irradiation testing research facilities, supported by DOE. The DOE has committed to ensuring that ATR has the support to continue operating for several more decades and is investing in enhancements to the ATR and other INL facilities that complement the ATR in supporting the DOE nuclear fuels and materials research missions.

ACKNOWLEDGEMENTS

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