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Advanced Test Reactor Capabilities And Future Operating Plans

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Frances M. Marshall

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Frances M. Marshall
Idaho National Laboratory

P. O. Box 1625, Idaho Falls, Idaho 83415-7101, Frances.Marshall@inl.gov

ABSTRACT

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 48" long and 5.0" diameter) provide unique testing opportunities. The current experiments in the ATR are for a variety of test sponsors – US government, foreign governments, private researchers, and commercial companies needing neutron irradiation services. There are three basic types of test configurations in the ATR. The simplest configuration is the sealed static capsule, wherein the target material is placed in a capsule, or plate form, and the capsule is in direct contact with the primary coolant. The next level of complexity of an experiment is an instrumented lead experiment, which allows for active monitoring and control of experiment conditions during the irradiation. The highest level of complexity of experiment is the pressurized water loop experiment, in which the test sample can be subjected to the exact environment of a pressurized water reactor. For future research, some ATR modifications and enhancements are currently planned. This paper provides more details on some of the ATR capabilities, key design features, experiments, and future plans.

1. INTRODUCTION

The Advanced Test Reactor (ATR) was the 45th of 52 nuclear reactors built at the National Reactor Testing Station, now the Idaho National Laboratory (INL), and is currently one of only three remaining operating reactors on the INL site. The INL is owned by the US Department of Energy (DOE), currently operated by Battelle Energy Alliance (BEA), and has been designated by the DOE as the lead laboratory for nuclear energy research. The ATR is the third generation of test reactors built at the Reactor Technology Complex (RTC), whose mission is to study the effects of intense neutron and gamma radiation on reactor materials and fuels. The current experiments in the ATR are for a variety of customers – US DOE, foreign governments and private researchers, and commercial companies that need neutron irradiation testing. The ATR has several unique features that enable the reactor to perform diverse simultaneous test for multiple test sponsors. The ATR has been operating since 1967, and is expected to continue operating for several more decades. The remainder of this paper discusses the ATR design features, testing options, previous experiment programs, and future plans for the ATR capabilities and experiments.

2. ATR TESTING CAPABILITIES

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 maximum operating power is 250 MW, however, the reactor is currently operated closer to nominal 110 MW, because of current customer requirements; the ATR is still capable of full power operations. The ATR core is comprised of 40 curved plate fuel elements arranged in a serpentine arrangement, around a 3 x 3 array of primary testing locations, called flux traps. These locations are the highest flux locations in the core. The physical configuration of the ATR, the 4-leaf clover shape, allows the reactor to be operated at different power levels in the four corner "lobes" to allow for different testing conditions for multiple simultaneous experiments. Figure 1 shows a cross section of the ATR core, with the irradiation locations identified.

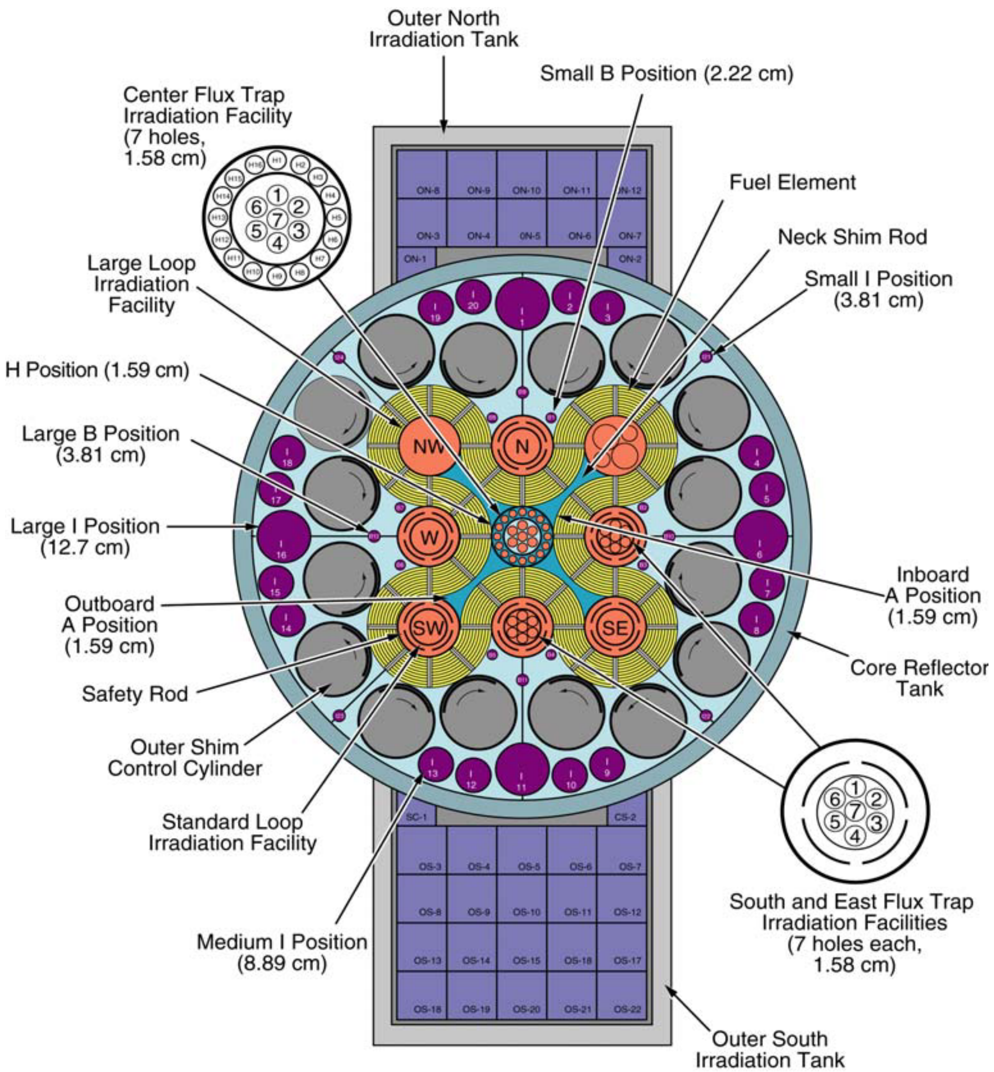

Figure 1. ATR Cross Sectional Diagram and Irradiation Locations

The key design features of the ATR are as follows:

- Large test volumes – up to 48" long and up to 5.0" diameter
- A total of 77 testing positions
- High neutron flux – up to 1E15 n/cm^2-s thermal, up to 5E14 n/cm^2-s fast
- Variety of fast/thermal flux ratios (0.1 – 1.0)

- Constant axial power profile – rotating control drums instead of vertical control rods
- Power tilt capability- different power levels for experiments in same operating cycle
- Individual experiment control
- Simultaneous experiments in different test conditions
- Frequent experiment changes
- Core internals replacement every 10 years - all core internal equipment is replaced
- Solid stainless steel reactor vessel positioned ~ 48" from the active core region to minimize vessel embrittlement
- Accelerated testing for fuel development and materials testing

The ATR is used primarily by the US DOE, but is also available to support other US government programs, commercial organizations, and international researchers. The ATR operates nominally 75% of the year, in cycles that average seven weeks in length, with outages lasting one or two weeks. As testing has progressed at the ATR since initial operations, several changes to the reactor and secondary plant have been needed. Some of the changes were implemented to offer more testing capabilities to researchers and other changes have upgraded the plant operating characteristics and increase operational reliability. Changes to the reactor to expand the testing capabilities include addition of the Powered Axial Locator Mechanism (PALM), which allows rapid movement of experiment materials axially in and out of the reactor core flux region to simulate reactor startup and other transient conditions. This allows a test sponsor to simulate thousands of reactor operating cycles in a single ATR operating cycle. The instrument and control reactor protection systems have been upgraded to more reliable digital systems, resulting in fewer unintentional RPS shutdowns; the number of unplanned scrams decreased from 11 in 1980 to 1 in 2004.

2.1 Static Capsule Experiment

There are three basic types of test configurations used in the ATR. 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 48" 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 2 shows the MOX irradiation test capsule and basket assembly. Some of the capsule experiments contain material that can be in contact with the ATR primary coolant, and may need the cooling function, and these capsules will not be sealed, but in an open configuration. Examples of this are 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.

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 inert gas is sealed into the capsule.

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.

2.2 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 defining difference between the static capsule and the instrumented lead experiment is an umbilical tube that runs from the experiment in the reactor through the reactor vessel and houses instrumentation connections. In a temperature-controlled capsule 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. Figure 3 shows a typical instrumented lead experiment.

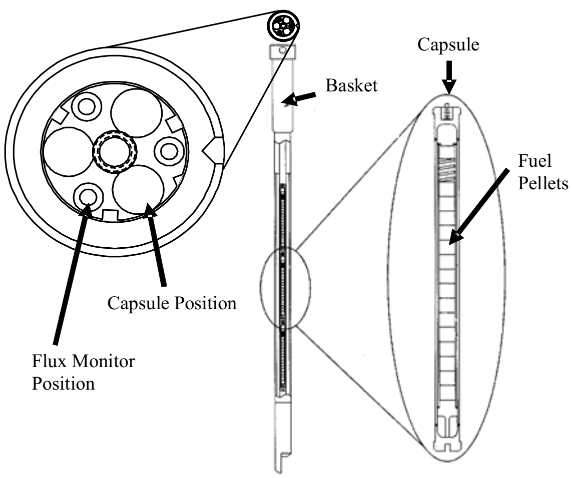

Figure 2 - Static Capsule and Basket Assembly Utilized for MOX Fuel Testing

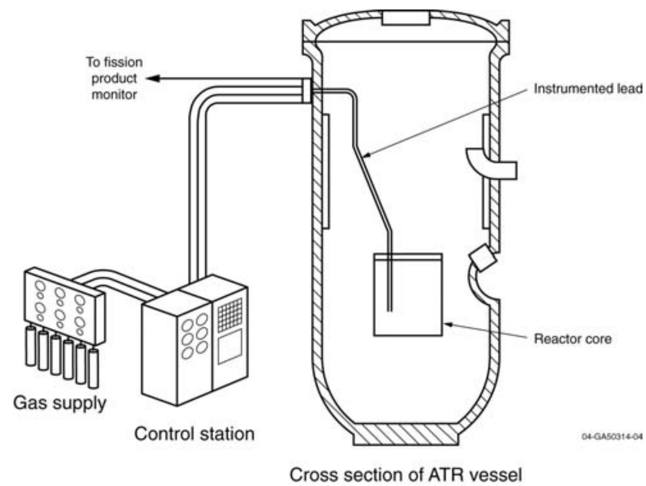

Figure 3 – Typical Instrumented Lead Experiment Configuration

Another feature of the instrumented lead experiment is the ability 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 on a circular first-in, first-out format.

The primary advantage to 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.

2.3 Pressurized Water Loop Experiment

The pressurized water 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, 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. As in the instrumented lead experiments, 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. There are operator control display stations for each loop where information is continuously displayed and monitored by the reactor operations staff. Because of the extensive amount of instrumentation in the loop experiments, 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 pressurized water loop experiments (as the instrumented lead experiments) offer more precise monitoring and control of the experiment parameters during irradiation as well as monitoring the loop water chemistry to establish specimen performance during the irradiation. The real-time feedback of experiment conditions and irradiation results can also be an asset to the experiment sponsor.

3. PREVIOUS AND CURRENT TESTS IN THE ATR

The tests performed in the ATR have been diverse in their design, objectives, and sponsors. The ATR has been used to support major nuclear reactor research initiatives for the United States and international collaborations. Some of the more notable experiments are discussed here.

As part of the nuclear non-proliferation initiatives, it was proposed that weapons grade plutonium could be mixed with commercial uranium oxide and burned in current light water reactors. As part of that initiative, however, some testing was needed on the mixed oxide fuel (“MOX”). A simple capsule was prepared to contain nine fuel samples; the samples were exposed to a variety of burnups to simulate LWR burnup profiles. The irradiations have been completed, but the analysis of the data still continues. Preliminary data suggest that MOX would be an acceptable fuel form for LWRs.

In the late 1980’s, the US was interested in designing and deploying smaller high temperature reactors – Modular High Temperature Gas Reactor (MHTGR). Several tests were performed in the ATR on particle fuels. One experiment was performed, but there was evidence of fuel failure, so the test was terminated. The project was subsequently cancelled, so these tests were also discontinued. The data obtained from this experiment, however, have been valuable in establishing fuel fabrication techniques and fuel testing program for the Advanced Gas Reactor project.

Several stainless steel samples were irradiated to simulate commercial power plant neutron damage. Some samples were welded prior to irradiations and some samples were welded after the irradiations. The experiment objectives were to determine particle migration, and to perform stress corrosion cracking studies of the irradiated samples. These experiments also simple capsule experiments, however, one of the experiments included some additional flux enhancement, so additional fuel was included as part of the experiment in the test location.

The objective of the Reduced Enrichment for Research and Test Reactors (RERTR) project is to develop low enrichment (<20%) fuels to replace the current high enriched fuels used in many research reactors. As part of this fuel development, irradiation tests are required. Thus far, there have been several tests performed in the ATR and several research reactors have converted to the low enriched fuel. Currently tests are being performed on high density uranium-molybdenum fuels. As testing progresses on these fuels, analysis will proceed to convert the ATR to low enriched fuel.

Graphite samples were irradiated to high-density losses due to radiolytic oxidation in a gas controlled, high temperature environment for Magnox, in support of life extension studies. This was a temperature controlled instrumented experiment. Some samples were irradiated in an inert environment, and others were in a CO_2 environment to assess the environmental effect on the density loss. The experiment successfully achieved the results the customer wanted, however, final analysis results are still pending.

The Advanced Fuel Cycle Initiative (AFCI) is currently performing tests in the ATR. Currently all the tests are in simple capsules, to burn various compositions of metal and nitride fuels. The overall AFCI irradiation testing objective is to determine what fuel materials could reduce the amount of minor actinides in current LWR to minimize the need for long-term storage of spent fuel waste. Subsequent tests will include actinides in the fuel.

Several tests have been performed concerning the production of Pu-238, both as a resource in the production of deep space power systems and to determine more detailed cross section data for spent fuel non-proliferation initiatives.

4. FUTURE TESTS PLANNED OR PROPOSED IN THE ATR

The AFCI tests will continue for several more years. Most of the tests are for various fuel forms.

Several organizations are interested in performing boiling water reactor (BWR) simulations in the ATR. These tests will require reactivation of a pressurized water loop, then subsequent modification of the loop to simulate the BWR conditions (i.e., voids in the core region of the coolant). These testing conditions will challenge the current safety basis and operating processes of the ATR, but have the potential to yield valuable information about BWR aging issues, and design constraints on new BWRs.

The Advanced Gas Reactor (AGR) program is currently planning several tests to be performed in the ATR for the next ten years. The initial test is to demonstrate and qualify new particle fuel for use in high temperature gas reactors.

The Next Generation Nuclear Plant (NGNP) is planning to perform graphite creep experiments. The previously used nuclear grade graphites are no longer available, however, the currently available graphites have not undergone as much testing as is necessary to use them in new reactor designs. The US DOE has started design of an experiment to collect creep data.

Several organizations have expressed interest in producing medical and industrial isotopes in the ATR. Currently, only high specific activity cobalt is being produced at the ATR, but with several reflector positions empty, the ATR is a good candidate to produce some isotopes. As research expands on shorter half-life isotopes, however, the ATR will be a less optimum candidate for medical isotopes unless a shuttle system is installed that will allow rapid insertion and removal of the targets from the reactor on hourly or daily bases.

5. FUTURE ACTIVITIES FOR THE ATR

The DOE and BEA have committed to a strong future for the ATR. The fifth core internals replacement was completed in January 2005, so that the reactor structural internals, reflector, fuel, and in-reactor testing facilities are all new. The next core internals replacement is scheduled for 2013, with a full testing schedule up until the outage. Additionally, some modifications have been proposed and work has begun on some of them, to keep the ATR available to a variety of test sponsors at least until 2025. After 2025, there has not been a test plan developed yet, but is expected that the ATR will still be fully operational, if there are testing needs. The current safety basis documents reference 2040 as the material degradation lifetime limit, however, this is under review for possible lifetime extension.

In order to support the some of the research for the advanced reactor concepts as part of the Generation IV and Advanced Fuel Cycle Initiative (AFCI), there is a need for a fast reactor conditions. The US DOE is funding a modification to the ATR to establish a lobe of the ATR that will support fast spectrum testing. In order to achieve the desired testing conditions, the reactor lobe will have to be operated at approximately double the current lobe power, and additional fuel elements ("booster fuel") will be installed in the same lobe. Currently, the booster fuel is expected to be aluminum clad uranium silicide, although there is still substantial development work to be performed as part of the project. The new testing system is expected to provide a fast flux of 10^{15} n/cm^2-s, and be operational in October, 2009.

The current contractor operating the ATR, BEA, has committed to DOE to implement several upgrades to the ATR and auxiliary capabilities. The total financial commitment for the upgrades is $20M in the next 10 years. These upgrades are:

Reactivate a pressurized water test loop and install an In-Pile-Tube. This loop would be to support commercial nuclear power plant test programs for both Pressurized Water Reactors and Boiling Water Reactors for high burnup fuel development and plant reliability research. Testing conditions could also be established to simulate supercritical water testing in support of the Generation IV research.

Determine the hot cell needs to complement the reactor capabilities. Currently there are no operational hot cells at the RTC, however, there are hot cells and radioanalytical laboratories nearby, at the Materials and Fuels Complex (MFC), formerly Argonne National Laboratory-West, that can be utilized. BEA has committed to perform a full study of the needs and determine if there is a need for operational hot cells at the RTC. Additionally, new post irradiation examination (PIE) equipment will be purchased to be available to multiple programs at both the MFC and/or the RTC hot cells.

Installation of a new transfer shuttle irradiation system (i.e., a rabbit) that can be used for short-term tests or short half-lived isotope production. An additional area of research that could be performed at the INL with the rabbit system is neutron activation analysis. The reactor position location for the rabbit system has not yet been selected, but the desired choices are the high flux regions nearest to the reactor driver fuel.

Upgrades to the fuel fabrication facility. The current production line has not had many upgrades since initial operations in the 1980's, and some of the equipment used is significantly older. In addition to the ATR fuel, this production facility also produces fuel for other research reactors, and the need to convert the research reactor fuel to low enriched uranium (LEU) will require modifications to the fuel fabrication facility. BEA has proposed to support some of the necessary modification to enable the fabrication of low enriched uranium- molybdenum (“U-moly”) research reactor fuel.

As part of the RERTR program, the ATR fuel is expected to be converted from high enriched uranium to low enriched uranium. There is still substantial analysis and fuel development needed to ensure that ATR testing capabilities are not diminished after the conversion.

6. CONCLUSION

The ATR continues Idaho’s tradition of pioneering nuclear reactor research, and will continue well into the 21st century as an important contributor to both DOE’s nuclear research objectives, and research objectives of other test sponsors. Additionally, collaborative and complementary capabilities of other research reactors will be vital to achieve the objectives of several national and international initiatives. DOE’s commitment to the INL and BEA’s commitment to invest in the ATR upgrades will ensure that the ATR is ready and available to meet diverse nuclear research needs for many years to come.

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