ADVANCED TEST REACTOR TESTING EXPERIENCE – PAST, PRESENT AND FUTURE

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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. 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, which places the capsule in direct contact with the primary coolant. The next level of experiment complexity is an instrumented lead experiment, which allows for active control of experiment conditions during the irradiation. The most complex experiment is the pressurized water loop, 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.

KEYWORDS : Advanced Test Reactor, Research Reactor, Department of Energy, Idaho National Laboratory

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 Untied 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 ATR is the third generation of test reactors built at the Test Reactor Area, now named 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 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. The remainder of this paper discusses the ATR design features, testing options, previous experiment programs, future plans for the ATR capabilities and experiments, and some introduction to the INL and DOE's expectations for nuclear research in the future.

2. ATR TESTING CAPABILITIES

The ATR is considered to be among the most technologically advanced and versatile 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 110 MW, due to customer requirements; the ATR is still capable of full power operations. Currently, operating cycles are 6-8 weeks in duration, with a 1 or 2 week outage, and annual availability is approximately 70%. The physical configuration of the ATR, shown in Figure 1, 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. A full core loading is 40 fuel element assemblies; there are 19 curved aluminum-clad uranium plates in each assembly. The US DOE is the primary user of the ATR, but there is increasing use by other US government programs, commercial organizations, and international researchers. The ATR was designed to accommodate a wide variety of testing requirements. The key design features are as follows:

- Large test volumes – 1.2 m long (at all testing locations) and up to 13 cm diameter
- A total of 77 testing positions
- High neutron flux – up to 10^{15} n/cm^2-s
- Variety of fast/thermal flux ratios (0.1 – 1.0)
- Constant axial power profile
- Power tilt capability
- Individual experiment control
- Simultaneous experiments in different test conditions
- Frequent experiment changes
- Core internals replacement every 10 years
- Accelerated testing for fuel

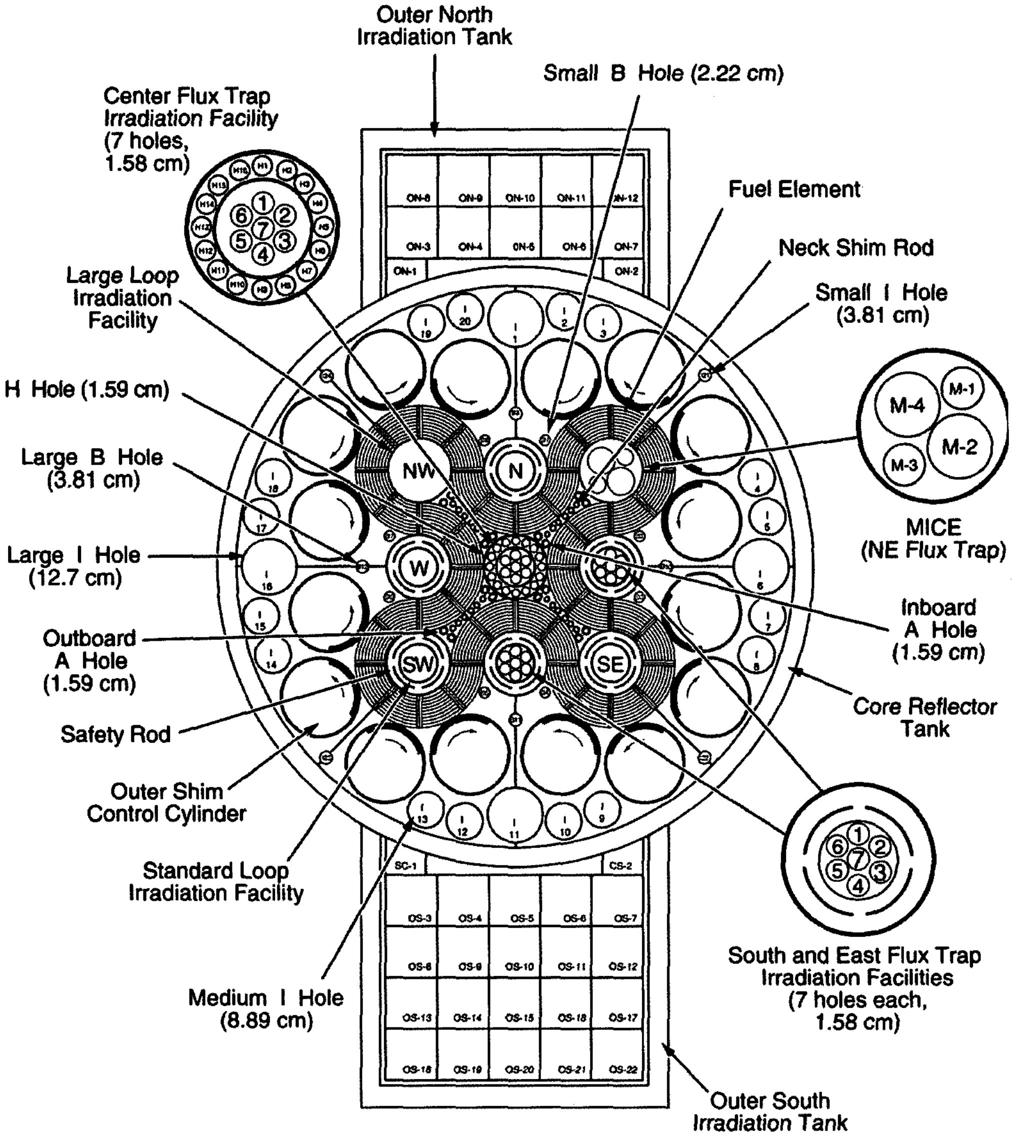

Fig. 1. Core Map of the ATR

As testing has progressed at the ATR since initial operations, several changes to the reactor and 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 experiments to be moved axially in and out of the reactor core flux region to simulate reactor startup and other transient conditions. 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.

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. Capsules typically have no instrumentation, but can include flux-monitor wires and temperature melt wires for analysis following the irradiation. For most of these experiments temperature control is achieved by design of the gap size between the test specimen and the outer capsule; the gap is filled with an inert insulating gas jacket. For some experiments the capsules are not sealed and the test specimens are exposed to the ATR primary coolant system.

One advantage of the static capsule test configuration is the relative ease of placement and removal into and out of the reactor. This allows for repositioning of capsules within a basket for different operating cycles.

The next level in complexity is an instrumented lead experiment. A common application is the 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. This type of configuration can also incorporate a fission gas monitor.

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.

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 (LWR). 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. A simplified sketch of the MOX experiment assembly is shown in Figure 2. 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.

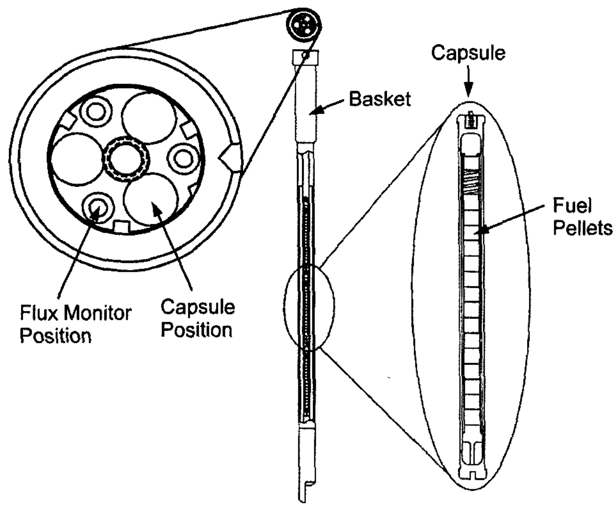

Fig. 2. Static Capsule Assembly for the MOX Experiment

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 for particle fuels were planned in the ATR. One experiment was performed, but there was evidence of fuel failure, so the test was terminated early. Subsequently the project was 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 as part of the Very High Temperature Reactor development.

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. One of the experiments required some additional flux enhancement, so additional fuel was included as part of the experiment in the test location to ensure that the flux received by the experiment was appropriate for the test data needs.

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 to determine the suitability of ATR for 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. The cross section data project is currently ongoing, and will be completed in 2008.

As part of the Global Threat Reduction Initiative, high-enriched uranium fuel is discouraged in all research and test reactors. The Reduced Enrichment for Research and Test Reactors (RERTR) program was initiated to develop and qualify new fuels. ATR has been used as the primary testing location for the new fuel types and will continue to be used until all reactor fuel development is completed and new fuels are fabricated. These tests will be static capsule configurations in reflector and flux trap positions.

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. Figure 3 shows an example of the instrumented lead experiment configuration, similar to the Magnox 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.

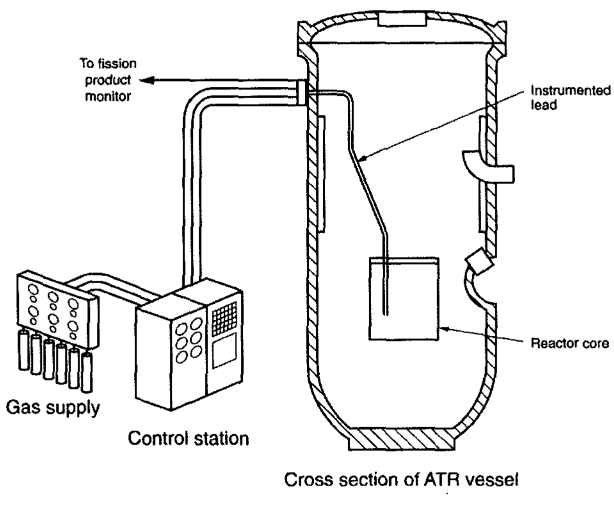

Fig. 3. Example of an Instrumented Lead Experiment Configuration

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 require modifications to 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. Preliminary analysis indicates that this testing configuration can be within the ATR safety basis and achieve the necessary testing conditions for various tests.

The Advanced Gas Reactor (AGR) program is currently planning several tests to be performed on particle fuels in the ATR for the next ten years. These tests will be instrumented lead experiments, and will utilize active temperature control.

The Next Generation Nuclear Plant (NGNP) is planning to perform graphite creep experiments. The nuclear grade graphites used in currently operating reactors 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, the only radioisotope produced at ATR is high specific activity cobalt, but with several reflector positions empty, the ATR is a good candidate to produce other needed 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.

The US government is interested in long duration, deep space missions that will require nuclear reactors for propulsion. ATR is currently the selected reactor for some of the fuel tests, and could also be used for PU-238 production for space power systems.

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, fuel, and in-reactor testing facilities are all new. The next core internals replacement is tentatively 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 customers for several more decades, if there are testing needs.

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 an ATR modification to establish a lobe of the ATR that will allow for fast spectrum testing. In order to achieve the desired testing conditions, the reactor lobe will have to operate close to double the current lobe power, and additional fuel elements ("booster fuel") will be installed in the same lobe. There is still substantial booster fuel 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.

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

Remanufacture and reinstall the Irradiation Test Vehicle (ITV), which is a multi-capsule (up to 15 simultaneous tests) testing system, previously installed in the center flux trap. Each test can have an independent control system. It was removed during the 2004 core internals replacement outage. The ITV is designed to perform high temperature experiments, and was originally intended for fusion materials research.

Reactivate a pressurized water test loop and install an In-Pile-Tube. This loop would 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. Additionally, new post irradiation examination equipment will be purchased to be available to multiple programs at both the MFC and/or the RTC hot cells.

BEA will install 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. Neither the schedule for this installation nor the reactor position location has been decided.

BEA will upgrade some of the ATR fuel fabrication equipment. The current production line has had few upgrades since initial operations in the 1980's. In addition to the ATR fuel, this production facility also produces fuel for other research reactors, and conversion of 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. THE NEW IDAHO NATIONAL LABORATORY

In February 2005 the Idaho National Laboratory was established, by combining the previous Idaho National Engineering and Environmental Laboratory with Argonne National Laboratory – West. One element of the current contract between BEA and DOE is the partnership between research organizations and commercial nuclear industry organizations. These partnerships will tie some of the INL nuclear research to the commercial nuclear power industry research, in support of both current power plant life extension and new reactor designs. The DOE's vision for the future of the INL is to

- Become the preeminent nuclear R&D laboratory in 10 years
- Be a major center for national security technology development and demonstration
- Be a multi-program national laboratory
- Foster academic, industry, government, and international collaborations to produce the investment, programs and expertise to assure the vision.

The ATR has been recognized by DOE and BEA as the cornerstone of the nuclear research to be performed at the INL over the next decade. Additionally, DOE's statement of this vision solidifies the need for a research reactor at the INL, and emphasizes that DOE is committed to the research performed at the ATR.

7. CONCLUSIONS

The ATR continues Idaho's tradition of pioneering nuclear reactor research, and will continue well into the 21st century as an important contributor to DOE's nuclear research objectives. 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 nuclear research needs for many diverse experiment sponsors for many years to come.

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