INL/CON-12-27737
PREPRINT

Advanced Test Reactor National Scientific User Facility: Addressing Advanced Nuclear Materials Research

Enlarged Halden Program Group Meeting

J. H. Jackson
T. R. Allen
F. M. Marshall
J. I. Cole

March 2013

Advanced Test Reactor National Scientific User Facility: Addressing advanced nuclear materials research

J. H. Jackson, T. R. Allen, F. M. Marshall, J. I. Cole
Idaho National Laboratory
+1 208-526-0293, john.jackson@inl.gov

Abstract

The Advanced Test Reactor National Scientific User Facility (ATR NSUF), based at the Idaho National Laboratory in the United States, is supporting Department of Energy and industry research efforts to ensure the properties of materials in light water reactors are well understood. The ATR NSUF is providing this support through three main efforts: establishing unique infrastructure necessary to conduct research on highly radioactive materials, conducting research in conjunction with industry partners on life extension relevant topics, and providing training courses to encourage more U.S. researchers to understand and address LWR materials issues.

In 2010 and 2011, several advanced instruments with capability focused on resolving nuclear material performance issues through analysis on the micro (10^{-6} m) to atomic (10^{-10} m) scales were installed primarily at the Center for Advanced Energy Studies (CAES) in Idaho Falls, Idaho. These instruments included a local electrode atom probe (LEAP), a field-emission gun scanning transmission electron microscope (FEG-STEM), a focused ion beam (FIB) system, a Raman spectrometer, and an nanoindentor/atomic force microscope. Ongoing capability enhancements intended to support industry efforts include completion of two shielded, irradiation assisted stress corrosion cracking (IASCC) test loops, the first of which will come online in early calendar year 2013, a pressurized and controlled chemistry water loop for the ATR center flux trap, and a dedicated facility intended to house post irradiation examination equipment. In addition to capability enhancements at the main site in Idaho, the ATR NSUF also welcomed two new partner facilities in 2011 and two new partner facilities in 2012; the Oak Ridge National Laboratory, High Flux Isotope Reactor (HFIR) and associated hot cells and the University California Berkeley capabilities in irradiated materials analysis were added in 2011. In 2012, Purdue University's Interaction of Materials with Particles and Components Testing (IMPACT) facility and the Pacific Northwest Nuclear Laboratory (PNNL) Radiochemistry Processing Laboratory (RPL) and PIE facilities were added.

The ATR NSUF annually hosts a weeklong event called User's Week in which students and faculty from universities as well as other interested parties from regulatory agencies or industry convene in Idaho Falls, Idaho to see presentations from ATR NSUF staff as well as select researchers from the materials research field. User's week provides an overview of current materials research topics of interest and an opportunity for young researchers to understand the process of performing work through ATR NSUF. Additionally, to increase the number of researchers engaged in LWR materials issues, a series of workshops are in progress to introduce research staff to stress corrosion cracking, zirconium alloy degradation, and uranium dioxide degradation during in-reactor use.

1. Introduction

The Advanced Test Reactor (ATR), located at the Idaho National Laboratory (INL), which is owned by the US Department of Energy (DOE), 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 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 provides a brief introduction to the ATR design features, testing options, future plans for the ATR capabilities and experiments, an overview of the PIE capabilities at the INL and broader discussion of the ATR NSUF program. Detailed information about the facilities and the ATR NSUF program can be found on the ATR NSUF web site, http://atrnsuf.inl.gov.

2. The Advanced Test Reactor (ATR)

The ATR is a multipurpose irradiation test facility that has supported fuel and material testing for the U.S. government for over 40 years of continued operation. The ATR is operated at approximately 110 MWt (compared to a maximum power of 250 MWt), and at that power can provide thermal neutron fluxes of 4.4×10^{14} n/cm^2-s and maximum fast ($E > 1.0$ MeV) neutron fluxes of 2.2×10^{14} n/cm^2-s. The testing positions vary in diameter from approximately 1.27 cm to a maximum of approximately 12.7 cm, and all are the same length at the active core height of 1.2 m.

Four types of irradiation configurations are available to experimenters: static-sealed capsule tests with passive instrumentation, instrumented lead tests with active instrumentation for measurement and control of specific testing parameters, pressurized-water reactor (PWR) loops that are connected to in-pile tubes and flux traps, and hydraulic shuttle irradiations where the sample capsule can be inserted and removed from the core for durations shorter than an operating cycle. In the PWR loop tests there is the capability to perform transient testing using the Powered Axial Locator Mechanism (PALM), a mechanically driven device that will move experiments into and out of the reactor core within the reactor vessel. Currently, there are six PWR experiment loops operational, and one of them is available for use by the ATR NSUF user community.

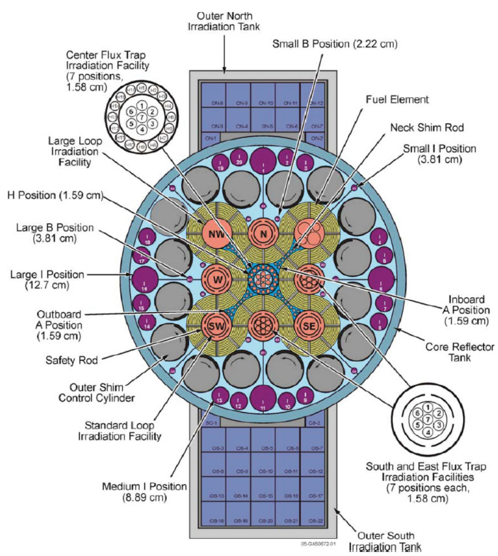

Figure 1: ATR cross section.

3. Post Irradiation Examination Capability at INL and CAES

3.1 Hot Fuel Examination Facility (HFEF)

Located at the INL Materials and Fuels Complex, HFEF is a large, heavily shielded, alpha-gamma hot cell facility designed for remote examination of highly irradiated fuel and structural materials. Its capabilities include nondestructive (dimensional measurements and neutron radiography) and destructive examination (such as mechanical testing or metallographic/ceramographic characterization). It can accept full-size light water reactor fuel assemblies.

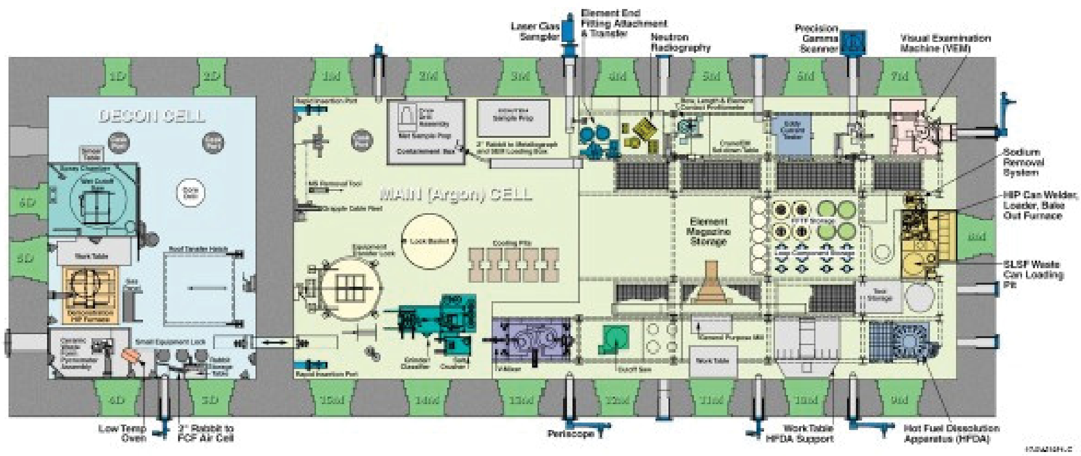

Figure 2: HFEF layout.

The HFEF is comprised of two adjacent large, shielded hot cells in a three-story building, as well as a shielded metallographic loading box, an unshielded hot repair area and a waste characterization area. The main cell (argon atmosphere) has 15 workstations, each with a viewing window and a pair of remote manipulators. A decontamination cell (air atmosphere) has six similarly equipped workstations. The cells are equipped with overhead cranes and overhead electromechanical manipulators. Cell exhaust passes through two stages of HEPA filtration. The facility is linked to analytical laboratories and other facilities by pneumatic sample transfer lines.

HFEF also has a 250 kW Training Research Isotope General Atomics (TRIGA) reactor, for neutron radiography irradiation to examine internal features of fuel elements and assemblies.

3.2 Electron Microscopy Laboratory (EML)

The Electron Microscopy Laboratory (EML) is a user facility dedicated to materials characterization using as its primary tools electron and optical microscopy. EML is a radiological materials area (RMA), permitting work to be performed with both radioactive and non-radioactive materials. A portion of the laboratory is dedicated to sample preparation, providing the researcher with facilities support, equipment, safety systems, and procedures to prepare samples of diverse materials for analysis.

The three primary instruments in EML are a JEOL 2010 scanning transmission electron microscope (TEM), a JEOL JSM-7000f scanning electron microscope (SEM), and a FEI Quanta 3D FEG Dual Beam FIB. All of these instruments are capable of accommodating radioactive fuels and materials samples for analysis and processing.

The TEM is capable of operating at 200 kV, and is capable of magnifications from 2,000 X to 1,500,000 X. It is equipped with an Oxford Instruments energy dispersive X-ray spectrometer that can be used to gather information about the elemental make-up of a sample.

The JEOL SEM is a field emission instrument capable of operating at 30 kV, and is capable of magnifications from 15 X to 100,000 X. It is equipped with Oxford Instruments energy dispersive (EDS) and wavelength dispersive X-ray spectrometers (WDS) that can be used to obtain quantitative information about the elemental composition of a sample. It is also equipped with an electron back scatter diffraction detector (EBSD).

The FEI FIB is cabable of conducting SEM analysis and analytical work with EDS, WDS and EBSD while additionally being capable of machining site specific samples on the micron and sub-micron scale for TEM and LEAP analysis.

In addition to the TEM and SEM, EML also has several optical microscopes. Some of these are used to support sample preparation, and others are used for optical characterization of samples. Capabilities for sample preparation include cutting, grinding, and polishing, as well as specialized methods such as ultramicrotomy (cutting ultrathin slices of material with a special machine using a diamond knife), chemical and ion milling to produce thin, electron-transparent samples, etching, and coating. Fume hoods (radiological and non- radiological) and a radiological glovebox are available to protect workers and the environment from hazardous materials.

3.3 Irradiated Materials Characterization Laboratory (IMCL)

The Irradiated Materials Characterization Laboratory (IMCL) is a facility that is currently under construction and is designed to provide the critical capability to house high-end analytical instrumentation in a shielded environment for use on highly irradiated fuels and materials. The IMCL will consolidate existing capability at INL and provide purpose-built space for high-end analytical instrumentation such as an Electron Probe Micro-Analyzer (EPMA), FIB, micro-X-ray Diffraction (XRD), aberration-corrected Transmission Electron Microscope (AC-TEM), laser-based thermal analysis, mechanical testing, and sample preparation. The IMCL will first function as a purpose built instrument laboratory that corrects many of the issues that currently limit equipment performance (vibration, electromagnetic fields, etc.). Another important function of IMCL is as a laboratory for developing analysis methods on irradiated materials, initially using materials that can be contact handled in a partially shielded environment. As techniques are developed and the need arises for examinations of highly active materials, the equipment will be fully shielded. Techniques for remote Raman spectroscopy will also be developed in IMCL.

3.4 Irradiation Assisted Stress Corrosion Cracking (IASCC) facilities

In late 2012, the INL completed installation of the first of two hot cells dedicated to stress corrosion cracking and fracture toughness testing of irradiated materials. The first test cell houses two autoclaves outfitted with Instron, servohydraulic actuators and capable of simulating Boiling Water Reactor (BWR) Normal and Hydrogen water chemistries as well as Pressurised Water Reactor (PWR) environments. The servohydraulic actuators and associated specimen testing hardware located inside the autoclaves are designed to handle up to a 100 KN applied force, allowing fracture toughness testing of full sized (1T-CT) compact tension specimens. Crack growth is monitored using a reversing current, DC Potential Drop (DCPD) system similar to those employed by GE Global Research Company and Studsvik AB. The cell is shielded to allow up to a 45,000 R/hr gamma (contact) source to be handled for extended periods.

The IASCC test cell has a companion utility cell with equivalent shielding. The utility cell is outfitted with a tool port for introduction of necessary hardware and serves as the transit point for irradiated specimens as it is also outfitted with a cask ring underneath the cell designed to mate with a modified GE-100 cask. It is also outfitted with a small, JEOL JCM-5000 benchtop SEM to allow fractography of tested specimens.

Figure 3: IASCC hot cell and utility cell.

3.5 Center for Advanced Energy Studies (CAES)

The Center for Advanced Energy Studies is a public/private partnership comprised of the three Idaho public universities, private industry, and INL. The NSUF staff is housed in the CAES building. CAES is an Nuclear Regulatory Commission (NRC)-licensed facility capable of handling small quantities of radiological material. CAES provides an ideal location to house high-end microstructural characterization equipment that can be made available to ATR NSUF users as part of ATR NSUF projects and to other users on an hourly basis or through a peer reviewed proposal process if experimental results are to be published in open literature. The suite of equipment, which will remain relatively constant over the next 5 years, includes:

- The Local Electrode Atom Probe (LEAP) is a cutting-edge instrument that allows for the study of structure and composition of materials at the atomic scale.
- A FEG-STEM, used for analysis of degradation mechanisms related to nanoscale changes in composition, such as radiation-induced segregation.
- A nano-indenter coupled with an Atomic Force Microscope (AFM), one of the foremost tools for measuring local mechanical properties and for imaging and measuring surfaces at the nanoscale.
- A dual-beam FIB, required for fabricating specimens for LEAP, FEG-STEM, and nano-indenter cantilever beam testing. The FIB also acts as a full-featured, high-end scanning electron microscope.
- Mechanical testing equipment designed for testing of small, low-dose rate specimens. Available techniques include high-temperature tensile testing, shear punch testing, fracture toughness testing, and microhardness testing.
- Stress corrosion cracking test rigs for use on unirradiated materials.

4. Partner facilities

Early in the ATR NSUF Program, it was recognized that the INL facilities were not sufficient to meet all user demands for all types of irradiation projects that were being proposed by the ATR NSUF user community. For example, in some cases, the ATR neutron flux is higher than needed for some irradiations. In other cases, the PIE equipment is not available for ATR NSUF projects in a timely manner. Thus, the ATR NSUF developed the Partnership Program, the objective of which is to offer a wider range of experimental facilities than is available at INL to the ATR NSUF user community, as well as to enable increased utilization of the partner facilities. The first partnership was with the Massachusetts Institute of Technology reactor (MITR) to perform a material irradiation. Experimenters may need to use more than one facility to accomplish their research objectives, and, for awarded projects, the ATR NSUF will coordinate the work at the different facilities. This is also expected to enhance cooperation opportunities between the users and the partner facility research teams. There are now ten ATR NSUF partner facilities, some of which allow access to more than one laboratory or instrument for the ATR NSUF users. Information about capabilities of all INL and partner facilities, including information on applying for becoming an ATR NSUF partner, may be found on the ATR NSUF web site.

4.1 Massachusetts Institute of Technology (MIT)

The MIT reactor is a 5 MW_{th} tank-type research reactor with three positions available for in-core fuel and materials experiments in water loops at pressurized water reactor/boiling water reactor conditions, high-temperature gas reactor environments at temperatures up to 1400°C and fuel tests at LWR temperatures have been operated and custom conditions can also be provided. Fast and thermal neutron fluxes are up to $1x10^{14}$ and $5x10^{14}$ n/cm^2–s, respectively.

4.2 North Carolina State University (NCSU)

The NCSU PULSTAR reactor is a 1 MW_{th} research reactor, fueled by uranium dioxide pellets in zircaloy cladding. The fuel provides response characteristics that are similar to commercial LWRs, which allows teaching experiments to measure moderator temperature, power reactivity coefficients, and Doppler feedback.

Nuclear Services laboratories at NCSU offer neutron activation analysis, radiography, imaging, instrumentation testing, and positron spectrometry capabilities. Additionally, the NCSU PULSTAR reactor facility offers a selection of dedicated irradiation beam port facilities with capabilities for neutron powder diffraction, neutron imaging, intense positron source and ultra-cold neutron source. An intense positron source has been developed to supply a high rate positron beam to two different positron/positronium annihilation lifetime spectrometers.

4.3 University of Michigan (UM)

The UM Irradiated Materials Complex (IMC) houses laboratories and hot cells for conducting high-temperature mechanical property, corrosion and stress corrosion cracking experiments on neutron irradiated materials in an aqueous environment and for characterizing fracture surfaces after failure.

The 1.7 MV Tandetron accelerator in the Michigan Ion Beam Laboratory at UM offers controlled temperature proton irradiation capabilities with energies up to 3.4 MeV as well as heavy ion irradiation.

4.4 Illinois Institute of Technology (IIT)

The Materials Research Collaborative Access Team (MRCAT) beamline at Argonne National Laboratory's (ANL) Advanced Photon Source (APS) offers synchrotron radiation experiment capabilities, including x-ray diffraction, x-ray absorption, x-ray fluorescence and 5 μm spot size fluorescence microscopy.

4.5 University of Nevada, Las Vegas (UNLV)

The Radiochemistry Laboratories at UNLV's Harry Reid Center for Environmental Studies offer metallographic microscopy, x-ray powder diffraction, Rietveld analysis, SEM and STEM, electron probe microanalysis, and x-ray fluorescence spectrometry.

4.6 University of Wisconsin at Madison (UW-M)

The Characterization Laboratory for Irradiated Materials at the UW-M can be used for SEM and STEM on neutron-irradiated materials. Capabilities also include sample preparation by grinding and polishing.

A 1.7 MV terminal voltage tandem ion accelerator at UW-M features dual ion sources for producing negative ions with a sputtering source or using a radio frequency plasma source. The analysis beamline is capable of elastic recoil detection and nuclear reaction analysis.

4.7 University of California at Berkeley (UCB)

At the UCB Nuclear Engineering laboratory, nanoindenter capabilities are available for testing on low radioactive samples. The nanoindenter has two load ranges, is housed in an environmental controlled enclosure, and is equipped with a high power optical microscope and an automated lends change to allow accurate positioning of indents on a sample.

4.8 Oak Ridge National Laboratory (ORNL)

The High Flux Isotope Reactor (HFIR) provides a high flux (up to $5x10^{15}$ n/cm^2-s thermal) material irradiation test capabilities are similar to those available at the ATR. In-core irradiations are performed for medical, industrial, and isotope production and research on severe neutron damage to materials.

The Low Activation Materials Development and Analysis Laboratory (LAMDA) facility at ORNL is a set of multipurpose laboratories for evaluation of materials with low radiological activities. Testing capabilities include tensile, fracture toughness, electrical diffusivity, optical microscopy, microhardness, thermal diffusivity, etc. Samples must have gamma/beta activity corresponding to a dose of less than 60 mR/hr (at one foot).

4.9 Purdue University

Purdue's Interaction of Materials with Particles and Components Testing (IMPACT) experimental facility was designed to study in-situ dynamic heterogeneous surfaces at the nano-scale exposed to varied environments that modify surface and interface properties. In-situ techniques used in the IMPACT experiment include: low-energy ion scattering spectroscopy (LEISS), direct recoil spectroscopy, X-ray photoelectron spectroscopy (XPS), Auger electron spectroscopy (AES), EUV

(13.5-nm) reflectometry (EUVR), EUV photoelectron spectroscopy (EUVPS), and mass spectrometry.

4.10 Pacific Northwest Nuclear Laboratory (PNNL)

PNNL's Material Science and Technology Laboratory includes advanced characterization and testing facilities for both non-radioactive and radioactive structural materials for nuclear power systems, both fission and fusion materials. The characterization includes all types of microscopy, including TEM, SEM, and Optical. Mechanical property testing is available for both hot and cold samples. A high-temperature furnace on a test frame is located in a large walk-in fume hood in one of the labs for testing dispersible ceramics. A high-precision density apparatus is available for irradiated materials.

The Radiochemical Processing Laboratory (RPL) at PNNL houses specialized facilities for work with microgram-to-kilogram quantities of fissionable materials and megacurie activities of other radionuclides. These provide a platform for radiochemical process development, chemical and physical separations, radiomaterial characterization, radioisotope research, reactor dosimetry and radioactive and hazardous waste management.

5. Current research projects

5.1 University project examples

Although the ATR NSUF open proposal calls (explained in detail later) are limited to universities as the lead proposing institution, industry collaborations are strongly encouraged and several of the on-going projects support research relevant to LWR related issues. Two of these projects are highlighted below.

5.1.1 A High Fluence Embrittlement Database and ATR Irradiation Facility for Light Water Reactor Vessel Life Extension.

This project is led by Professor Robert Odette at the University of Southern California Santa Barbara and seeks to generate data to support life-extension decisions for commercial reactor pressure vessels (RPV) steels beyond the 60 years of operation currently permitted. Little data exists on high fluence ductile-to-brittle transition temperature shifts during the low flux irradiation experienced by pressure vessel steels under operation. The experiment matrix consists of 172 different alloys in an instrumented experimental assembly with controlled temperatures in the range of 250 to 310°C and a target fluence of 10^{20} n/cm^2. The post-irradiation examination will concentrate on relating potential embrittlement behaviour to the formation of nanometer scale features as a function of flux and temperature as well as exploring the potential of using thermal annealing to mitigate embrittlement.

5.1.2 Multi-scale Investigation of the Influence of Grain Boundary Character on RIS and Mechanical Behavior in LWR Steels

In this project, Professor Mitra Taheri's research team from Drexel University is taking advantage of legacy stainless steel reactor hardware from the EBR-II reactor to investigate the role grain boundary character plays in radiation induced segregation (RIS) in irradiated austenitic stainless steel alloys relevant to LWRs. The study is applicable to obtaining a more fundamental understanding of factors that influence irradiation-assisted stress corrosion cracking in commercial reactor core internals and involves the use of multiple cutting-edge materials characterization techniques such as EBSD in the SEM and LEAP (tools located at the Center for Advanced Energy Studies). In addition, results are being compared to similar studies with ion-irradiated alloys to understand differing behaviour between neutron and charged particle irradiated materials.

5.2 Industry projects

There are currently four active industry research projects being conducted at the ATR NSUF. Two of these projects involve the Electric Power Research Institute, one involves the U.S. Nuclear Regulatory Commission (NRC), and a fourth project involves the Atomic Energy of Canada Limited's (AECL) Chalk River Laboratory (CRL).

5.2.1 EPRI pilot project on SCC and IASCC of alloys X-750 and XM-19

As a means of establishing a basis for development and execution of joint ATR NSUF – Industry programs, EPRI and ATR NSUF (through INL) developed a pilot program involving shared costs and responsibilities. In addition to providing data, the pilot program is designed to:

- Develop the administrative protocols for cooperative research, such as cooperative agreements and funding.
- Develop portions of the research capability and staffing required to address future research and development needs.
- Develop a protocol for validation of data with industry; particularly stress corrosion crack growth rate data.

Discussions between ATR NSUF and EPRI identified investigation of the fracture toughness and irradiation assisted stress corrosion crack (IASCC) growth rates of irradiated high-strength alloys used for Boiling Water Reactor (BWR) repair hardware as an area of interest for an initial project; very little IASCC and irradiated fracture toughness data exist for Alloy X-750 (Ni-based alloy) and XM-19 (nitrogen strengthened austenitic stainless steel) at the exposure levels of interest, up to $1x10^{21}$ n/cm^2. Therefore, the focus of this EPRI Pilot Project is on irradiation and characterization of these alloys in both unirradiated (baseline) and irradiated states and is being conducted in three phases. Phase I and Phase II of this EPRI Pilot Project have already been completed. Phase I of the EPRI Pilot Project fabricated the EPRI Specimens from materials provided by EPRI and established the baseline fracture toughness and crack growth rates of un-irradiated material. Phase II of this project designed and fabricated the specimen holders and performed a safety analysis on a test train to meet EPRI objectives for irradiation of tensile and compact tension specimens in the center flux trap of ATR utilizing Pressurised water Loop 2A. The current phase of this project, Phase III will be to perform irradiation and post irradiation examination (PIE) of the EPRI Specimens delivered by EPRI to BEA in Phase I and II.

Irradiation will be conducted in flowing pressurized water in the Loop 2A facility installed in the Center Flux Trap at ATR at a specimen temperature of nominally 288 °C. Three specimen holders were designed and fabricated by BEA during Phase II to allow withdrawal of specimens for testing at three target fluence levels; 5.0×10^{19}, 2.0×10^{20}, and 1.0×10^{21} n/cm^2 (E>1MeV) . These specimen holders will contain CT Specimens, Dogbone Tensile Specimens, and TEM Specimens during irradiation and then the specimen holders and their contents will be transported by BEA from the ATR to the HFEF to be disassembled. Following disassembly, the Dogbone Tensile Specimens will be tested at the HFEF, IASCC and fracture toughness pecimens will be tested at the newly installed IASCC facilties, and TEM Specimens will be analyzed in the Electron Microscopy Laboratory.

5.2.2 EPRI zirconium growth project

In the EPRI zirconium growth experiment, zirconium specimens are being irradiated in the ATR to study the mechanisms of irradiation-induced growth and its dependence on hydrogen content and neutron fluence. Two hundred specimens of various zirconium alloys with various hydrogen concentrations are being irradiated in an inert environment at a temperature of 285°C ±10°C and to four targeted neutron fluence levels. The hydrogen produced by corrosion and dissolved in zirconium alloys during service in light water reactors can form hydrides that may promote irradiation growth. Differential strain caused by hydrogen-assisted irradiation growth is postulated to be partly responsible for fuel channel bowing observed in operating boiling water reactors. Post-irradiation length change measurements and transmission electron microscopy will be performed to investigate the mechanisms of irradiation-induced and hydrogen-assisted growth.

5.2.3 NRC IASCC and fracture toughness of irradiated 304 SS

The NRC IASCC research program will utilize an ATR test capsule that was previously designed and will be used to irradiate similar alloys of interest for a different customer. The two alloys of interest for this NRC project, 304L stainless steel weld heat affected zone, and a sensitized 304 stainless steel, will be placed in a backup location in what is referred to as the EPRI 3 experiment holder and will be irradiated to a fluence of approximately 1×10^{21} n/cm^2 (E>1 MeV) (~1.4 dpa). In total, eight 0.4T-CT specimens will be irradiated; four of each alloy. Four of these specimens (two from each alloy) will be retained at INL for Crack Growth Rate (CGR) and fracture toughness testing, and the remaining four will be shipped to ANL for comparison.

5.2.4 AECL TEM and microhardness of X-750 CANDU reactor springs

The purpose of this joint project is to examine microstructural changes of alloy X-750 as a function of neutron irradiation and temperature. The primary objectives were to prepare Transmission Electron Microscopy (TEM) foils with an active Focused Ion Beam (FIB) facility and to characterize the hardness of the irradiated spring sections. The ATR NSUF maintains an active FIB and TEM facility at both the Center for Advanced Energy Studies (CAES) in Idaho Falls, Idaho and at the Idaho National Laboratory (INL) Materials and Fuels Complex (MFC). Additionally, a shielded microhardness tester is available at the MFC complex. TEM foils were prepared using nine spring sections at the ATR NSUF facilities; primarily at CAES and at MFC as needed from material provided by AECL.

6. Opportunities for new research

ATR NSUF offers several opportunities for researchers to submit proposals for research to be performed at the ATR NSUF facilities. In addition to the proposals that can be submitted directly to the ATR NSUF, a PI may also submit a joint proposal to both the ATR NSUF and Nuclear Energy university Programs (NEUP) research call offered by the DOE, if the PI needs both developmental research funds and access to the ATR NSUF research facilities. Proposals that are suitable may also be proposed for access to both ATR NSUF and the ANL's APS. Guidelines and information related to all proposal submittals are available on the NSUF web site. All proposals are submitted through a web-based submittal system designed to help prospective researchers develop, edit, review, and submit their proposals. Information on the two primary ATR NSUF proposal calls is provided below:

Open Calls: One proposal option is continuously open rolling call for reactor irradiation or major PIE proposals with project selections twice a year, in the fall and in the spring. Proposals for these calls focus on irradiation/post irradiation examination of materials and fuels and on post irradiation examination of previously irradiated materials or fuels from the ATR NSUF Sample Library (described previously). These calls also offer researchers the option to submit proposals for synchrotron radiation experiments through the ATR NSUF partnership with Illinois Institute of Technology. This partnership has resulted in awards of 8 synchrotron radiation experiments since the partnership was formed in FY 2010.

Rapid-Turnaround Experiments (RTEs). Another option is for RTEs that can be performed in two months or less, such as PIE of previously irradiated fuels or materials, ion beam irradiation, and neutron scattering experiments. The call for RTEs is always open, allowing proposals to be submitted at any time. RTE proposals are reviewed quarterly and awarded throughout the year based on proposal review ranking and the availability of funds.

All proposals received against open calls and RTEs are subject to a peer-review process before selection. An accredited U.S. university or college must lead research proposals for irradiation/post-irradiation experiments. Collaborations with other national laboratories, federal agencies, non-U.S. universities, and industry are encouraged. Any U.S.-based entities, including universities, national laboratories, and industry can propose research that would use the MRCAT beamline at the APS or would be conducted as an RTE.

In response to requests from a number of university faculty members, ATR NSUF developed “New-User Experiment” projects. This provides an opportunity for university researchers to experience first-hand the intricacies of designing and conducting an in-reactor test. ATR NSUF selects the materials to be irradiated and each university researcher involved in the project can work with a variety of INL staff to design a capsule that meets the needs of the experiment. The project ends when the capsule is inserted into the reactor. To participate, researchers submit a letter of interest, which can be uploaded via the calls for proposals webpage. Initiation of a project will be dependent on funding available for the project and interest from the research community.

7. Educational outreach activities

The ATR NSUF education program was established to develop a cadre of nuclear energy researchers, facilitating the advancement of nuclear science and technology through reactor-based testing. ATR NSUF uses focused internships, fellowships, and faculty/student exchanges to encourage faculty and student access to cutting-edge and one-of-a-kind tools for conducting reactor-base research in nuclear science and technology, fuels, and materials. The ATR NSUF User’s Week is held at INL and includes research forums and specialized workshops. ATR NSUF is also developing a new text on irradiation test planning and execution. The ATR NSUF sponsors a colloquium series, with speakers from the INL and university community of researchers. The emphasis of all education programs is to allow for maximum interaction and access to the nation’s experimental nuclear research infrastructure. Full details regarding ATR NSUF educational programs are on the web site and primary programs are summarized below. In addition to these opportunities, additional workshops can be requested by users as desired.

7.1 Internships and Fellowships

Internships are the direct mechanism by which undergraduate and graduate students can access the ATR NSUF and be introduced to mentors. Each year, approximately 15 interns are exposed to research and gain experience with tools in reactor-based nuclear science and technology. Typically interns spend 10 to 12 weeks in the summer on a paid internship sponsored by the ATR NSUF. Graduate students may use their intern experience to conduct thesis or dissertation research, and these internships can last for up to one year. Internships are also used to support the increased impact of the ATR NSUF on facility operations. Post-doctoral fellowships give recent doctoral graduates an opportunity for a short (up to 3 years) duration appointment in areas that align with current or future ATR NSUF research.

7.2 Visiting Scientists

The ATR NSUF education program has two programs for visiting scientists and students. The Faculty and Student Research Team (FSRT) program awards faculty-led team contracts to partner with an INL mentor and work on building capability needed in the user facility. In addition, teams gain an understanding of INL, build technical knowledge, and establish relationships with INL researchers. The ATR NSUF also uses an existing INL program called the Faculty and Staff Exchange program. Participants in this program are sent to universities or other research facilities and are encouraged to spend time at a university/INL to teach, perform research, collaborate, and be involved in campus/laboratory life.

7.3 User’s Week

Annually, the ATR NSUF hosts a User’s Week to provide a venue to inform the nuclear science and technology community of current issues and the tools and facilities available through the use of the ATR NSUF to address these issues. User’s Week is comprised of a research forum that discusses current collaborative nuclear technology research being conducted in the NSUF. Sessions are also held to familiarize participants with the ATR NSUF research facilities and capabilities. User’s Week also has extended courses on fuels and materials and how to conduct and execute irradiation experiments. Scholarships to cover travel expenses are available to some of the faculty and student participants.