

The Advanced Test Reactor National Scientific User Facility

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The U.S. Department of Energy (DOE) designated the Advanced Test Reactor (ATR) as a National Scientific User Facility (NSUF) in April 2007. The mission of the ATR NSUF is to provide researchers access to world-class facilities for the conduct of nuclear energy research. The ATR NSUF promotes collaboration among researchers conducting cutting-edge nuclear research and development by offering access to reactor test space, post-irradiation examination capability and technical assistance at no cost to U.S. university-led research teams. In turn, ATR users effectively execute nuclear energy research programs that advance the development of nuclear energy technology. Publication of results is a condition of use under this program. In addition to no-cost access, users may choose to fund proprietary research experiments.

Experiments underway in 2009 include seven capsule experiments in high and intermediate flux positions in ATR, an instrumented lead experiment in ATR, water loop and low fluence experiment in the MIT reactor and post-irradiation examination of previously irradiated advanced ceramic materials. The number and types of experiments offered will expand as the User Facility matures and as demand evolves in response to experimenter requests. Programs to enhance education and understanding of nuclear fuels and materials research are also an important element of the ATR NSUF.

I. INTRODUCTION

Cooperative development of nuclear energy science and technology by three major sectors—academia, the commercial nuclear power industry, and the federal government—is key to meeting challenges in the further development of nuclear energy technology. All three share a common need for experimental capabilities, whether for basic science investigations, applied research in nuclear fuels and materials or validation of data. In order to help meet this need, the U.S. Department of Energy (DOE) designated the Advanced Test Reactor (ATR) as a National Scientific User Facility (NSUF) in April 2007.

The ATR is a pressurized, light-water moderated and cooled, beryllium-reflected nuclear research reactor with a maximum operating power of 250 MWth. Options for testing include instrumented or instrumented (static) test trains that can be either cooled by the ATR primary coolant or installed in independently controlled test loops. Postirradiation examination of NSUF experiments is available to ATR NSUF participants at the Hot Fuel Examination Facility (HFEF), the hot Analytical Laboratory (AL),

and the Electron Microscopy Laboratory (EML) located at the INL Materials and Fuels Complex (MFC). Additional irradiation and post-irradiation capabilities are available at ATR NSUF partner facilities.

II. UNIVERSITY RESEARCH EXPERIMENTS

Access to ATR NSUF capabilities is through a competitive proposal process. Non-proprietary proposals are selected for no-cost irradiation testing and post-irradiation examination (PIE) based on technical merit. All proposals are subject to peer review and evaluation by a proposal review committee. The ATR NSUF publishes broad research request guidelines, generally corresponding to goals of DOE NE programs (Generation IV, Advanced Fuel Cycle Initiative, Light Water Reactor Sustainability). Proposals can be submitted throughout the year, and are reviewed biannually. The cost of the irradiation and post-irradiation examination is waived for experiments selected through this process, on the condition that research results are widely published in the open literature.

In the time span from the ATR NSUF opening in

2007 to the time of this conference, eleven (11) experiments have been selected that cover a broad range of topics. Of the eleven experiments selected, nine are materials irradiation experiments, one uses the ATR Critical facility (ATR-C) to test in-reactor instrumentation, and one is a post-irradiation examination only experiment. Seven of the experiments are under irradiation or will be irradiated in the ATR and two experiments are under irradiation in the MITR (Massachusetts Institute of Technology Reactor) under the ATR NSUF partnership program (explained below). An additional pathway for university research was created in 2009. Researchers are now offered access to a library of irradiated samples that is being collected by the NSUF, most from previous DOE-funded material and fuel development programs. University experimenters can propose analysis of these samples in a "PIE-only" experiment. This ensures that value is obtained from samples previously irradiated but never analyzed. One PIE only experiment has been awarded to date.

The experiments, each led by a principal investigator from a university, are described briefly below.

- University of Florida, Prof. Juan Nino, Irradiation Behavior of Oxide Ceramics for Inert Matrices—This project investigates the combined irradiation and thermal stability of perovskite structured ceramics. These materials are investigated as potential inert matrices for plutonium and minor actinide fuels that allow more rapid destruction of these elements in a fission reactor
- North Carolina State University, Prof. K. L. Murty, Influence of Fast Neutron Irradiation on the Mechanical Properties and Microstructure of Nanostructured Metals/Alloys—This research studies neutron irradiation effects on nanostructured metals and alloys. The irradiation stability of both nanograined and oxide-dispersion strengthened alloys are investigated.
- University of Illinois, Prof. James Stubbins, Irradiation Performance of Fe-Cr Base Alloys—This research seeks to provide significant new insight into the irradiation behavior of ferritic alloys. The main objective is to investigate alloy behavior under a range of irradiation conditions that serve as the basis for development of materials models.
- University of California Santa Barbara, Prof. Robert Odette, Characterization of the Microstructures and Mechanical Properties of Advanced Structural Alloys—This research project produces a library of irradiated structural materials at temperatures of 300° to 800 °C and doses of 3 – 4 dpa. The resulting sample library consists of ferritic steels, advanced nanostructured ferritic alloys and model alloys. The irradiated materials will be used to address scientific questions ranging from microstructural evolution and phase stability to radiation hardening and high-temperature radiation softening, and non-hardening embrittlement.
- Colorado School of Mines, Prof. David Olson, Advanced Nondestructive Assessment Technology to Determine the Aging of Silicon-Containing Materials for Generation IV Nuclear Reactors— This research investigates the use of silicon carbide ceramics for use as in situ, real-time radiation damage sensors to assess accumulated damage in nuclear structural materials. Irradiations are conducted in the MIT reactor.
- University of California, Santa Barbara, Prof. Robert Odette, High fluence embrittlement database and ATR irradiation facility for LWR vessel life extension—This experiment irradiates reactor pressure vessel steels and model alloys in order to determine embrittlement mechanisms as a function of temperature, compositional and processing variables.
- Massachusetts Institute of Technology, Prof. Mujid Kazimi, Irradiation behavior of triplex SiC/SiC tubing under PWR conditions. (MITR) —This experiment investigates the long-term radiation stability and corrosion resistance of silicon carbide cladding tubes for use in light water cooled reactors.
- University of Wisconsin, Dr. Yong Yang, Radiation stability of ceramics for advanced fuel applications (PIE only) —This experiment draws on the ATR NSUF library of previously irradiated material to investigate the irradiation behavior of advanced ceramic materials such as ZrC, ZrN, TiC and TiN irradiated at 800°C.
- Utah State University, Prof. Heng Ban, Irradiation effect on thermophysical properties of Hf₃Al-Al composite: A concept for Fast Neutron Testing at ATR— This experiment investigates the radiation stability and corrosion resistance of composite thermal neutron absorber

materials.

- Idaho State University, Prof. George Imel, Real-time ATRC Flux Sensors—This project compares the accuracy, response time, and long-duration performance of various types of real-time flux sensors.
- Drexel University, Prof. Michael Barsoum, Advanced Damage Tolerant Ceramics: Candidates for Nuclear Structural Applications—This experiment investigates the radiation stability of novel layered carbide structures in the family $M_{n+1}AX_n$, where M is a transition metal, A is typically Al or silicon, and X is carbon or nitrogen.

III. RESEARCH CAPABILITY

The ATR NSUF is unique in its purpose as a User Facility for studying the effects of intense neutron irradiation on materials and nuclear fuels. Current irradiation testing capabilities available to users includes static capsule and instrumented and controlled tests under a range of fast to thermal flux ratios. Post-irradiation examination capability includes a full suite of non-destructive and destructive examinations, mechanical testing, and microstructural/microchemical analysis using optical, scanning, and transmission microscopy.

Development of new experimental capability is based on user needs. Current capability development projects include improving in-reactor experiment instrumentation, adding additional post-irradiation analytical capability, improved irradiation test rigs and the capability for post-irradiation mechanical testing in simulated reactor environments.

In-reactor instrumentation development is focused on providing real-time data on material response to radiation, such as swelling, thermal conductivity and corrosion.

State-of-the-art post-irradiation analysis capabilities being installed include a shielded Electron Probe Micro Analyzer, a dual beam Focused Ion Beam, x-ray micro-diffraction, and scanning laser thermal diffusivity.

Research focused on developing a scientific understanding of material degradation phenomenon in LWRs (Light Water Reactors) is an important part of the ATR NSUF mission. A complete R&D capability to support this mission does not currently exist in the U.S. Near-term upgrades to the ATR NSUF to support this research are a pressurized water loop installed in the high flux center flux trap region of the core and environmental crack growth rate and fracture toughness testing facilities for both irradiated and non-irradiated materials. The reactor test loop allows

independent temperature, pressure, and chemistry control of experiments. This loop and support facilities are scheduled for commissioning in 2010 - 2011. Crack growth rate and environmental fracture toughness equipment for baseline testing of unirradiated materials is currently operational. The first of four environmental crack growth rate system for testing irradiated material will be functional in 2010 with additional systems made operational in subsequent years.

IV. EDUCATIONAL PROGRAMS

The ATR NSUF has developed an educational program to inform potential users of current and emerging nuclear science and technology issues and the tools available to address these issues. The first week-long ATR NSUF User Week held in June 2009 hosted more than 120 participants, consisting of undergraduate students, graduate students, post-doctoral fellows, faculty, and industrial staff attended. The program featured guest lecturers from universities, nuclear industry and DOE national laboratories.

The ATR NSUF sponsors summer interns in three primary areas: support of irradiation experiments, development of ATR NSUF capability, and nuclear facility operations. Interns focused on nuclear facility operations may be selected for tuition scholarships and provided and offered employment at the INL following university graduation.

The ATR NSUF has also instituted a faculty student research team (FSRT) program. The purpose of these teams is to engage students and faculty in a collaborative research effort with INL researchers. These teams are led by a faculty member from an accredited U.S. university and must include at least two students. Students and faculty from these teams spend up to 12 weeks at the INL.

V. PARTNERSHIP PROGRAM

The ATR NSUF seeks to promote collaboration among academia, industry, and national laboratories to advance the development of nuclear technology as a safe, sustainable source of energy. To increase overall research capability, ATR NSUF seeks to form strategic partnerships with facilities that offer significant nuclear research capability, and are accessible to all ATR NSUF users. Current partner facilities include the MIT Reactor, the University of Michigan Irradiated Materials Testing Laboratory, the University of Wisconsin Characterization Laboratory, the Pulsar reactor at North Carolina State University, and the University of Nevada, Las Vegas Transmission Electron Microscope User Facility. These facilities are accessible to research teams that

have been awarded an ATR NSUF research project.

The NSUF also seeks to establish relationships with other national user facilities to make routine the analysis of reactor-irradiated materials in the high-end analytical equipment established at these user facilities. The first of these facilities is the Advanced Photon Source at Argonne National Laboratory. This combination of national assets will optimize the scientific value from each experiment conducted.

VI. CONCLUSIONS

The ATR NSUF was created to expand opportunities for reactor-based testing to a broader spectrum of the nuclear technology research community. The NSUF provides a mechanism for university-led experiments teams to conduct irradiation science, and sponsors an educational program to improve the capabilities of researchers to conduct reactor-based experiments. Operation of the ATR NSUF includes development of research capability to conduct irradiation materials science, including establishing capabilities in support of water-cooled reactors. The NSUF will continue to improve the capability in response to customer needs.

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