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National Scientific User Facility Purpose and Capabilities

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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. This designation allows the ATR to become more accessible to U.S. universities, the commercial power industry, other national laboratories, and international organizations to conduct nuclear energy R&D. The mission of the ATR NSUF is to provide nuclear energy researchers access to world-class facilities in order to facilitate the advancement of nuclear science and technology. In support of the mission, the INL has opened its Post Irradiation Examination (PIE) capabilities to NSUF users, formed partnerships with six other facilities, begun the installation of new state of the art equipment and initiated the design of a new shielded laboratory. This facility will be relatively easy to reconfigure to provide laboratory scale hot cave space for housing current and future nuclear material scientific research instruments.

I. INTRODUCTION[1]

The Advanced Test Reactor (ATR), located at the Idaho National Laboratory (INL), is a pressurized light water-moderated, beryllium-reflected reactor. The ATR has been in continuous operation for over 40 years and in April 2007 the U.S. Department of Energy (DOE) designated the ATR, along with the associated Post-Irradiation Examination (PIE) facilities at the INL, as a National Scientific User Facility (NSUF).

Creation of a user facility allows new communities of users access to the unique capabilities of the ATR. This includes the light water reactor industry, other national laboratories, regulators, and foreign organizations in collaboration with the university research community. Recognizing that many university users have not had a significant history in performing reactor-based testing, the ATR NSUF has instituted several educational programs to increase understanding of testing capability, design, and the conduct of experiments. The ATR NSUF has also instituted a Partnership Program, through which university and other national laboratory reactors and PIE equipment can become an integral part of the NSUF. These partnerships will ensure the maximum opportunity for NSUF customers to meet their experimental objectives.

University faculty, students, and other researchers have access to the broad variety of PIE capabilities of the INL, which include non-destructive examinations; chemical, isotopic, and radiological property examinations; and mechanical, thermal, and microstructural property examinations. In the future, the PIE capabilities available to users will be greatly expanded with the installation of state-of-the-art nanoscale and atomic-level characterization equipment in the Center for Advanced Energy Studies (CAES) as well as the building and the construction of a reconfigurable shielded facility built to house state-of-the-art analysis equipment; the Irradiated Materials Characterization Laboratory (IMCL).

II. EXPERIMENTS[1,2]

1. University Experiments

University experiments account for many of the experiments performed by NSUF. Experiments proposed by universities are subjected to a review process that screens for feasibility, technical merit on the basis of peer review, and relevance to U.S. DOE programs. The ATR NSUF proposal call is continually open, and reviews and selects proposals twice a year.

For those universities selected, the cost of the experiment is entirely borne by the NSUF. These university-led projects are non-proprietary and are expected to publish their results in the open literature.

NSUF university experiments must be proposed and lead by a US university or college, although collaborations with other parties, such as industry or foreign institutions, are encouraged.

There are six basic types of experiments available through ATR NSUF proposals:

i) static capsule irradiation experiments, experiments in which the temperature and irradiation conditions are set by design and verified after irradiation using passive monitors

ii) instrumented lead irradiation experiments which use on-line monitoring and real-time control of irradiation conditions

iii) post-irradiation examination only experiments that use previously irradiated specimens provided by the ATR NSUF irradiated sample library

iv) ATR-critical facility experiments which run at low power and are useful for testing of in-core instrumentation and cross-section measurements

v) Experiments that may be irradiated with neutrons or ions or examined at one of the six NSUF partner facilities.

As of June 2010, seventeen reactor experiments and eight PIE experiments have been awarded. Out of these, sixteen have been performed at INL facilities and nine at ATR NSUF partner facilities.

2. Rapid Turnaround Experiments

The ATR NSUF now offers rapid turnaround experiments. This type of experiment can be performed quickly (~2 months or less after award) at relatively low cost. These projects can be performed at either the INL or one of the ATR NSUF partner facilities. These experiments may include, for example, ion beam experiments, or limited microstructural examinations of previously irradiated materials from the ATR NSUF sample library, or analysis of specimens at the Advanced Photon Source.

The call for rapid turnaround experiments is open throughout the year, and award is made based on a technical ranking of each proposal. Proposals submitted should directly support Department of Energy Nuclear Energy research and development programs. It is anticipated that up to six awards will be made each year depending on availability of funding.

Rapid Turnaround Experiments are intended for non-proprietary research only, and results are expected to be published openly.

Proposals for Rapid Turnaround Experiments are accepted from accredited U.S. universities and colleges, DOE national laboratories, or industry researchers. Others interested in proposing must be collaborators on a university-led team.

3. Access for Proprietary Experiments

All research projects funded by the ATR NSUF are non-proprietary. Experiment teams must be led by U.S. universities, with the exception of Rapid Turnaround Experiments. Proprietary research may also be conducted if the user chooses to fund the work on a cost-recovery basis.

III. EDUCATION[1,2]

In recognition of the challenges facing university faculty, students and researchers who do not have experience designing a reactor experiment, the NSUF conducts a number of educational programs to familiarize and inform users with the process.

1. NSUF Users Week

The first component of the educational program is the ATR NSUF Users Week, intended for researchers from industry, national laboratories, students, faculty, and post-docs. ATR NSUF User's Week includes an introduction to ATR NSUF capabilities, a research forum where participants learn about current research projects being conducted at the ATR NSUF, and several courses offered on nuclear fuels and materials, and irradiation experimentation. The forum also includes a facilitated discussion on potential university collaborations and potential university/national laboratory/industry collaborations. Participants have a chance to tour many of the ATR NSUF research facilities, including the Advanced Test Reactor, post-irradiation examination facilities, and materials testing laboratories. User's Week activities are provided at no charge to participants.

2. New User Team Experiments

The New User Experiments are designed to help university scientists, inexperienced in reactor-based testing, learn the intricacies of designing and conducting an in-reactor test. Approximately three to five teams are selected to share in the design and irradiation of a capsule experiment. The material to be irradiated in the capsule is chosen by NSUF staff. Each team selected for participating in the project works through the experiment design process.

3. Faculty Student Research Team

The ATR NSUF has also instituted a faculty student research team 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. Faculty and students from these teams spend up to 12 weeks at the INL. Proposals are accepted for scientific projects and projects that result in increased research capability for the ATR NSUF.

4. Internships

The ATR NSUF sponsors summer interns, working both in support of scientific testing programs and ATR nuclear operations. The ATR Operator Intern program offers a scholarship and employment after graduation to a select group of interns. Graduate students may also use an internship to conduct thesis or dissertation research.

IV. INL CAPABILITIES

The INL hosts a large variety of PIE capabilities and is upgrading and adding more. Feedback from potential university users is continually solicited by the NSUF to ensure any new capability optimizes for customer needs.

1. NSUF Partner Program[2]

The ATR NSUF recognizes that ATR irradiation space may become limited and that certain desired post-irradiation examination equipment may not be available in a timely fashion, or may become oversubscribed. The ATR NSUF Partnerships Program was developed to address these challenges. The Partnerships Program allows universities to self-nominate facilities that are synergistic with the goals of both DOE and the user facility. This is done through a proposal process which is open year round. If a review panel determines that the proposed partner facility adds value to the ATR NSUF, it is added to the solicitation site, and future awarded research may be performed at that facility. Facilities of interest include, but are not limited to, research reactors, hot cells or laboratories, and accelerator facilities. The six current partner facilities and their capabilities are listed below.

Institution	Facilities
Argonne National Laboratory/Illinois Institute of Technology	Advanced Photon Source
Massachusetts Institute of Technology	Massachusetts Institute of Technology Reactor
North Carolina State University	PULSTAR Reactor
University of Michigan	Michigan Ion Beam Laboratory/Irradiated Materials Complex
University of Nevada, Las Vegas	Microstructural characterization laboratory
University of Wisconsin	Tandem Accelerator Ion Beam/Characterization Laboratory

2. Current PIE Capabilities[3]

Post-irradiation examination capabilities available to ATR NSUF users are included in four main facilities: the Hot Fuel Examination Facility (HFEF), a large hot cell facility; the Analytical Laboratory (AL), focused on analysis of irradiated and radioactive materials; the Electron Microscopy Laboratory (EML), a radiological facility containing optical, scanning, and electron microscopes; and the Fuels and Applied Science Building (FASB), used for fuel development, materials characterization and irradiated materials testing.

i. Non-Destructive Examinations

Capability	Description
Neutron Radiography	250 kW TRIGA reactor, two beam tubes and two separate radiography stations.
Precision Gamma Scanning	Measures fission and activation-product activity distribution.
Dimensional Inspection	Continuous contact profilometer. Measures diameter profiles.
Element/Capsule Bow	Measures fuel element

and Length examination	distortion and length.
Visual Exam	Dedicated workstation, and in-cell exam stage.
Eddy current examination	Measures material defects
High precision specific gravity measurements	Pycnometer and immersion scales

ii. Sample Preparation

Preparation Type	Preparation
Solid Metallography	Sectioned and cut
	Mounted into metallographic bases
	Ground and polished
Gas Sampling	Laser puncture and gas collection

iii. Chemical, Isotopic, & Radiological Analysis Capabilities

The AL offers National Institute of Standards and Technology (NIST) traceable chemical, isotopic, and radiological analysis of irradiated fuel and material via the techniques listed below.

Elemental / Chemical Mass Concentration and Isotopic Analyses
Inductively Coupled Plasma Mass Spectrometry(ICP-MS) with Dynamic Reaction Cell (DRC)
Inductively Coupled Plasma Atomic Emission Spectroscopy(ICP-AES)
Carbon, Oxygen, and Nitrogen Analysis
Atomic Absorption Analysis
Thermal Ionization Mass Spectrometry (TIMS)
Gas Mass Analysis
Isotope Mass Separator
Gross and Isotopic Radiological Analysis
Gross Alpha/Beta Analysis
Gamma Spectroscopy Analysis
Alpha Spectroscopy Analysis
Micro-Gamma Analysis
Beta Spectroscopy Analysis

iv. Mechanical Property Examination

Capability	Equipment
Metallography	Leitz metallograph or Olympus IX70 optical microscope (up to 1500X) at EML
Microhardness testing	3 LECO AMH43 testers
Tensile testing	FASB or HFEF Instron tensile tester w/ furnace (1600 C)
Shear punch testing	FASB or HFEF Instron tensile tester w/ furnace (1600 C)

v. Thermal Property Examinations

Capability
Thermal diffusivity (Laser Flash method and Scanning diffusivity analysis)
Differential Scanning Calorimetry (DSC)

vi. Microstructure Property Analysis

Capability	Equipment
Scanning Transmission Electron Microscope (STEM)	JEOL 2010, 200 kV, 2,000 X to 1,500,000 X, equipped with energy dispersive X-ray spectrometer
Scanning Electron Microscope (SEM) with energy dispersive (EDS) and wavelength dispersive X-ray spectrometers (WDS) and electron back scatter diffraction detector (EBSD)	JEOL JSM 7000F FEG SEM, up to 30 kV and 600,000 X.
	Zeiss DSM 960a SEM, up to 30 kV
	LEO 1455 VP SEM, up to 30 kV, operates at higher pressures
Dual Beam Focused Ion Beam (FIB)	FEI Quanta 3D FEG, up to 1,280,000X, ion source enables site specific sectioning of materials for 3D analysis or high resolution TEM

	characterization
Shielded Electron Microprobe	Capable of analyzing elements from Be through Cm with full matrix correction, including fission gases on samples
X-ray diffractometer	Micro diffractometer performs micro-scale phase identification, small-sample powder diffraction and texture determination

3. Future PIE Capabilities[4]

Reinvigoration of nuclear fuels and materials research will require the exploitation of research tools now commonly used in other areas of science. These new tools, and the research materials examined with them, require unique, reconfigurable, accessible, modularized support facilities that are not presently available.

Focused primarily on low activity samples, the CAES (Center for Advanced Energy Studies) Imaging Laboratory houses many of these new instruments that focus on nanoscale and atomic-level characterization, where examinations can be completed using micrograms or nanograms of irradiated materials.

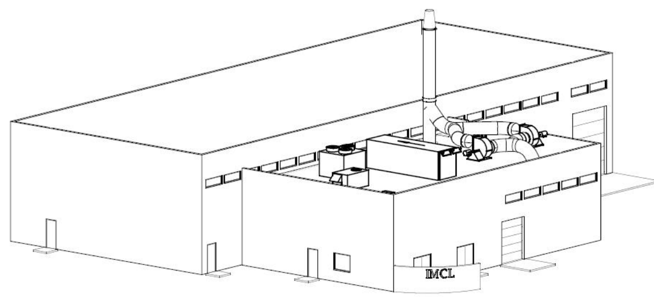
The rapid evolution of analytical electron microscopes and the advent of high-performance computer interfaces with instruments were not envisioned when most of the existing hot cell facilities worldwide were constructed. The IMCL is a new facility designed specifically to house advanced analysis tools in a remote operating environment.

i. C AES[5]

Located at the Research and Education Campus in Idaho Falls, the CAES building supports partnerships between the INL and universities. CAES supports a broad variety of research initiatives, including nuclear science and engineering, carbon management, advanced materials, bioenergy, energy policy, and modeling and simulation. Installation of advanced instruments needed to carry out research under these initiatives will be completed by the end of September 2010 and will be commissioned to handle radioactive specimens by January 2011.

By design, the CAES research facility operates in the same manner as universities do; in the case of low risk radiological research, this approach provides a cost-effective, innovative, and productive environment for exploring fundamental science questions and executing basic research complementary to research at INL Site facilities. These factors make the CAES an ideal location for state-of-the-art research equipment for use on low activity specimens.

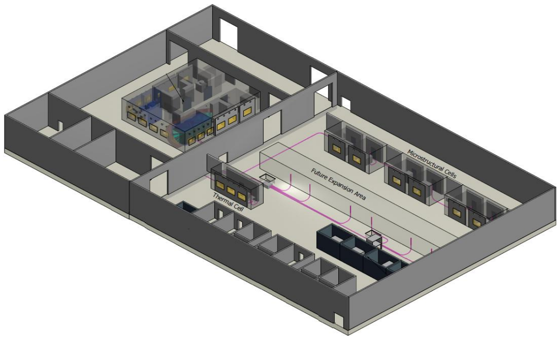
ii. IMCL[4]



The IMCL will be the first facility of its type in the U.S. designed specifically for advanced instrumentation and equipment. The IMCL will contain space for installation of instruments and equipment within shielding structures that can be redesigned and refitted when necessary. The IMCL will have mechanical systems that tightly control temperature, electrical and magnetic noise, and vibration to the standards required for advanced analytical equipment.

The IMCL will be used to routinely handle and perform micro- and nano-scale characterization of material specimens and irradiated fuel samples in the mass range of tens of grams down to micrograms. The facility will be designed to allow easy routine maintenance of the instruments. Although the IMCL represents a significant advancement over current U.S. nuclear energy research and development capability, the transition to a full-spectrum nuclear research capability will require further expansion into a new facility to keep pace with the rapidly evolving array of scientific tools available to materials researchers.

iii. Future PIE Facilities



Although the IMCL represents a significant advancement over current U.S. nuclear energy research and development capability, the transition to a full-spectrum nuclear research capability will require further expansion of capabilities. In anticipation of these PIE needs, INL has developed a design concept for a facility that houses a combination of flexible, reconfigurable cells and stationary examination lines.

iv. Capabilities

The state-of-the-art equipment installed or planned for installation in INL facilities is listed below.

- Nanoindenter/Atomic Force Microscope
- Electron Probe Microanalzyer (EPMA)
- Focused Ion Beam (FIB) - 2
- Secondary Ion Mass Spectrometer (SIMS)
- Micro X-ray Diffraction (MXRD)
- Local Electron Atom Probe (LEAP)
- Laser Flash Thermal Diffusivity (LFTD)
- Differential Scanning Calorimeter (DSC)
- Scanning Thermal Diffusivity Microscope (STDM)

v. Irradiation-Assisted Stress Corrosion Cracking (IASCC) Test Cells

Understanding the degradation of light water reactor materials exposed to radiation in a reactor environment is critical to ensuring the continued safe and reliable operation of the existing light water reactor fleet and making improvements in core materials for advanced reactor systems. Only a few IASCC systems have been built in the U.S. to conduct research on this subject. The INL is in the process of installing several IASCC test rigs in order to provide crack growth rate data on irradiated material specimens in a prototypic water reactor environment.

V. Conclusions

The NSUF offers universities and industry the chance to irradiate experiments in the ATR and make use of extensive and constantly expanding PIE capabilities. Experiments can be proposed by any U.S. university or DOE national labs. Industry researchers and foreign institutions may collaborate with a university to participate. Rapid turnaround proposals are also open to U.S. national laboratories and industry. NSUF also supports users by providing numerous education opportunities to help build understanding of the design process of an experiment. The NSUF allows parties interested in the advancement of scientific knowledge access to the powerful and versatile irradiation capabilities of the ATR, it gives them the educational tools to learn how to make the most of their experiment and it provides them with the diverse equipment and methods needed to analyze their experiment after irradiation.

VI. References

1. The Advanced Test Reactor National Scientific User Facility Advancing Nuclear Technology, T. R. Allen, et. Al., May 2009
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