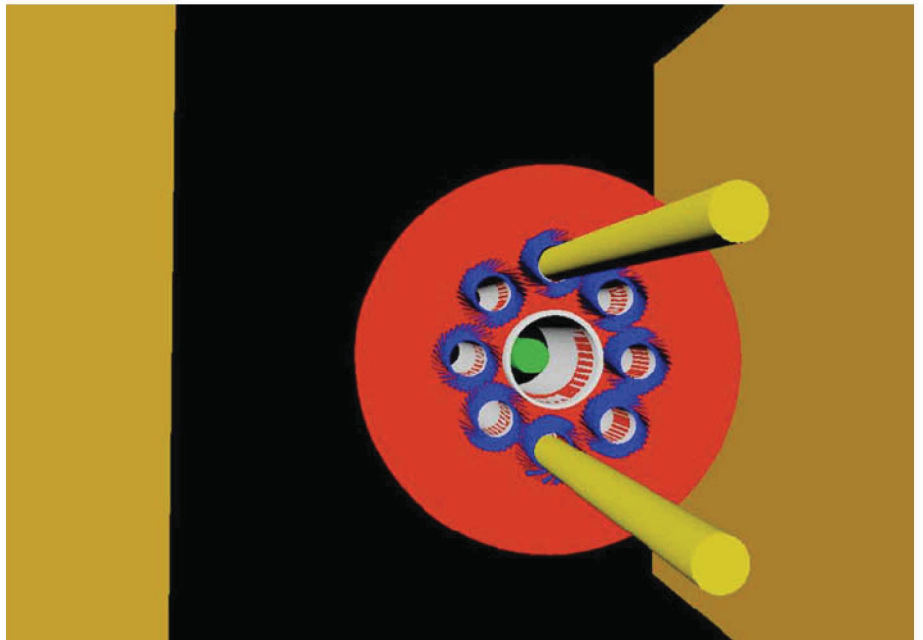


Update on INSIGHTS Development

September 2011



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Update on INSIGHTS Development

September 2011

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ABSTRACT

INSIGHTS is a transformational separate effects testing capability to perform in situ irradiation studies and characterization of the microscale behavior of nuclear fuel materials under a wide variety of in-pile conditions. Separate effects testing including growth, irradiation, and monitoring of these materials, and encompasses the full science based approach for fuels development from the nanoscale to the mesoscale behavior of the sample material and other defects driven by the modeling and simulation efforts of INL.

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ACRONYMS

ALD	Atomic Layer Deposition
ATR	Advanced Test Reactor
BOL	beginning of life
CAES	Center for Advanced Energy Studies
CRADA	Cooperative Research and Development Agreement
DOE	Department of Energy
DPA	displacements per atom
FCR&D	Fuel Cycle Research and Development
HIP	Hot Isostatically Pressed
IAC	Idaho Accelerator Center
IJRC	Idaho Joint Research Complex
INL	Idaho National Laboratory
ISU	Idaho State University
LDRD	Laboratory-Directed Research and Development
LEU	low-enriched uranium
MCNP	Monte Carlo Neutral Particle (transport code)
MOCVD	Metalorganic Chemical Vapor Deposition/
MOX	molybdenum oxide
NEUP	Nuclear Energy University Program
NS&T	National Science and Technology
NSUF	National Scientific User Facility
R&D	research and development
RD&D	research, development, and deployment
SEM	scanning electron microscope
SNICS	source of negative ions by cesium sputtering
SRPAS	Spatially Resolved Positron Annihilation Spectroscopy
TEM	transmission electron microscope
TREAT	Transient Reactors Experiment and Test Facility

Update on INSIGHTS Development

1. Developing Revolutionary Fuels

The key to developing revolutionary fuels is high-fidelity simulation containing models that are detailed enough and broad enough to encompass the largest discovery phase space possible. The development of the necessary models and theories will require novel data and innovative measurement techniques that are synergistically bound to the modeling effort. From a scientific perspective, it is clear that the right environment for these measurements is tantamount for rapid and broad development.

The beginning of life (BOL) behavior of fresh fuels is of fundamental importance to a detailed, microstructural understanding of fuel dynamics that will lead to a broad predictive modeling capability of engineering scale fuel performance. The INSIGHTS program seeks to exponentiate fuel development through a scientific understanding and description of the BOL grain structure ordering and dynamics that drive phenomena that impact the fuel performance later in the life cycle.

The variables that impact BOL fuel dynamics must be controllable, variable, measurable and as independent from one another as possible, to ensure the widest range of conditions are understood and incorporated into the models. To facilitate novel high fidelity measurements, a new paradigm is needed. This new paradigm starts at the lowest levels including novel engineered samples to well understood and controlled irradiation conditions. This proposed effort begins to develop a demonstration of some of these capabilities. This effort encompasses all the required aspects for making game-changing advances in nuclear fuels development. Among these advances are 1) Development of preliminary separate effects irradiation capabilities including separate control of temperature, pressure, neutron flux and gamma dose, 2) Development of advanced materials growth and characterization, including sample fabrication capabilities to create engineered single crystals, bulk crystals, bi- and tri-crystals, and advanced in-situ irradiation imaging and 3) Development of novel detectors and sensors for real-time, wireless, in-pile irradiation characterization.

The separate effects testing program leverages INL, ISU and DOE assets to make Idaho the leader in fuels development and testing, harnessing local assets synergistically including ATR, TREAT, CAES, IAC, IJRC while leveraging INL investments in Program Development and LDRD projects, as well as DOE funded NEUP projects. This synergy relies on a strong public private partnership in support of the DOE and industry missions. As part of NSUF, this program will increase INL's visibility, and position INL as a world leader in advanced fuels separate effects testing. In developing these capabilities, the time from irradiation to examination will be drastically shortened from months to hours to minutes, to ultimately, real time three-dimensional movies across multiple length scales. This exponentiation in research provides the greatest reach into discovery phase space.

A notional timeline is presented below. Each of the three major thrusts support the final goal of a comprehensive separate effects testing system focused on enabling science based research in support of the phenomena associated with the fuel dynamics during the beginning of life. The vision of INSIGHTS is going to rely heavily on expertise and infrastructure at the Idaho Accelerator Center and the Idaho Joint Research Center. A key component to success is the involvement of research faculty, their graduate students and postdocs in an open and academic environment. There are three primary R&D areas that directly support the separate effects testing capability: 1) INSIGHTS development, 2) Materials Growth and Characterization, and 3) Novel Detector and Sensor Development. The INSIGHTS development effort consists of an early RD&D effort, construction and finally operation of the completed system. Measurements supporting program needs can begin early in the RD&D stages with full spectroscopic measurements being performed after commissioning. Key to the success of this program is high quality, well understood research-sized samples prepared specifically to meet modeling and simulation goals. This effort is focused not only on the preparation of samples but also on the characterization advancements needed to provide the high-fidelity datasets during in-situ irradiations. Early samples

prepared under this effort can be used in support of meeting mission needs for topics such as thermal transport and diffusivity, atomistic migration, and development of in-situ irradiation and heating imaging systems such as specially designed SEMs. The third component focuses on novel detector and sensor development designed to directly measure and quantify the separate effects parameters to a high precision in real time. These technologies being created in the early stages of this component can be immediately used in support of the nuclear data program needs, as well as improved in-pile instrumentation.

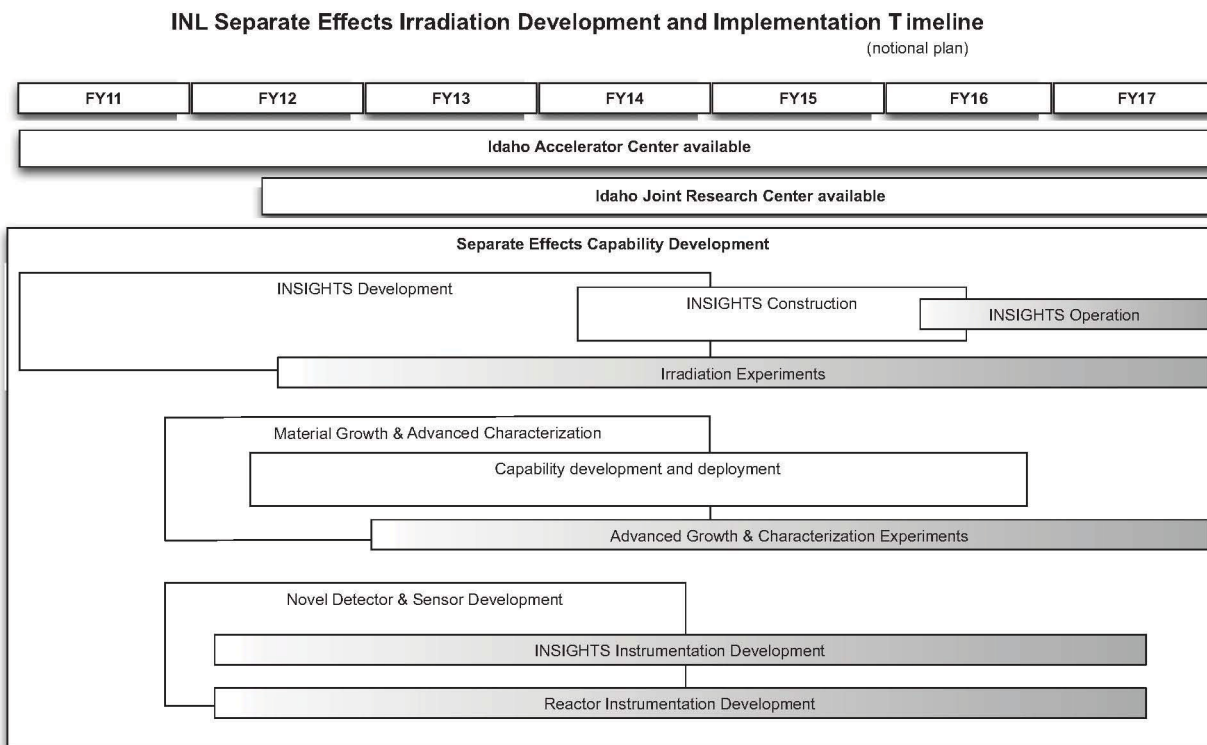


Figure 1. INSIGHTS irradiation development and implementation notional timeline.

2. Separate Effects Irradiation Development

Advancing the fuel cycle requires advancements in our basic understanding of fuel behavior under irradiation. Investments are being made in advanced modeling and simulation to predict in-pile behavior and as the tool for innovative fuel design. These new models will require novel data to not only benchmark key calculations but to actually guide their development. The required data will need to be of unprecedented precision and granularity. To further complicate the delivery of these data, some of the most interesting measurements will need to be made in-pile during the first few hours of irradiation. These sensitive new measurements may require novel wireless systems to package and send data from in-pile sensors to remote data acquisition systems, which must be maintained well outside the neutron radiation field. Delivering this high precision, in-pile data is a daunting task and we propose to take the first necessary steps in developing a viable research and development effort to meet these challenges.

The goal of the Fuels Modeling and Simulation effort is to develop predictive models for evaluating a broad set of advanced fuel designs and concepts. These advanced tools must potentially incorporate all of the relevant physics and chemistry, spanning phenomena from the meso-scale to the micro-structural level and over a large range of environmental variables, such as heat, pressure and radiation. Though they are potentially powerful vehicles of innovation and discovery, these new tools have little value to the community without a dedicated accompanying validation effort. The endeavors of science-based simulation and high-fidelity, separate effects experiments are intrinsically tied together – developing the

detection and measurement systems envisioned will require the direct support of simulation, and the development of the simulation will require the delivery of detailed data from advanced detection systems from well designed experiments. This allows one then to focus not so much on the end goal but on the developmental synergy between experiment and simulation. In a science-based approach to this problem, experimentalists will work closely with modelers to develop small-scale, separate-effects experiments that provide foundational physical information about the early dynamics of fuel in an environment that can be very similar but much less complicated to model than a reactor core.

An intense neutron separate-effects facility with independent gamma delivery, hydraulic application and temperature control will provide an experimental environment with unprecedented flexibility, control and access for detailed measurements on small fuel samples and configurations. The proposed facility will provide a number of direct line-of-sight experimental channels capable of delivering tailored neutron spectra with fast fluxes that approach 10^{15} cm⁻²s⁻¹, with prompt gamma radiation highly suppressed by the lead scattering media. An adjustable electron linear accelerator will be used as an external gamma source, controlled independently of the neutron flux, to provide specific doses to any of the experimental channels. The inclusion of small-scale ovens and hydraulic presses in experimental volumes will provide the other independently controlled forces known to impact early fuel dynamics. The system will be designed with simplicity and flexibility in mind, to insure many unforeseen measurements can be accommodated and simulated. Advanced measurement techniques will be developed to deliver the specific and detailed data required to benchmark and advance the fuels modeling and simulation effort. Pre- and post-irradiation measurement capabilities will be developed, as well as in-situ measurements, given the unique access and controllability of the facility.

2.1 INSIGHTS Development

INSIGHTS development relies on early infrastructure investments to provide the tools for the necessary RD&D on the INSIGHTS design, neutron target source development, material irradiation experiments, and advanced detector and sensor designs. This infrastructure primarily consists of a tandem pelletron, high dose neutron irradiation cave, charged particle end stations, and broader accelerator support.

2.1.1 Current Status

2.1.1.1 Pelletron Installation

A 4.5 MV tandem Pelletron charged particle accelerator has been successfully installed and commissioned at the Idaho Accelerator Center (IAC). The ion source included with the pelletron can generate 200 microamps of positively charged protons and accelerate them to 9 MeV. Calculation results show a yield of 1012 neutrons/second achievable from a water-cooled Be target with this arrangement. Key follow-on efforts are the completion of the necessary shielding to run the accelerator at full current and the construction of the charged particle beam optics and necessary shielding to allow neutron production for development of the prototype system. National Electrostatics Corporation, in collaboration with accelerator scientists at the IAC, has provided a design and cost quote for installation of the beam optics required to complete the irradiation end stations.

2.1.1.2 Modeling, Simulation and Preliminary Design

Irradiation Chamber and Neutron Source

The proposed facility will provide a number of direct line-of-sight experimental channels capable of delivering tailored neutron spectra with fast fluxes that approach 10^{15} /cm²s, with a high neutron to gamma ray flux ratio, with the gamma ray field suppressed by the lead down-scattering structure. A preliminary design, shown in Figure 2, was determined by optimizing the total neutron flux and relative neutron energy spectrum with a series of MCNP calculations that considered various compositions and configurations of booster fuel. The experimental volumes are being designed to provide separate control

of temperature (from 77 K to 3000 K), pressure (up to 100 atmospheres) and will provide the other independently controlled forces known to impact early fuel dynamics. All of these parameters can be controlled independently while providing unprecedented access to the samples during irradiation, something current reactor irradiation facilities cannot deliver. Figure 3 shows a boosted design with LEU fuel pins surrounding the experimental channels.

Initial MCNP simulations of the INSIGHTS experimental chambers have been completed. Numerous neutron sources and boosted fuel forms were considered to optimize the total neutron production and energy spectrum characteristics within the experimental chambers. Future effort will focus on the necessary design details and on narrowing the options for cost-effectiveness and availability of booster fuel.

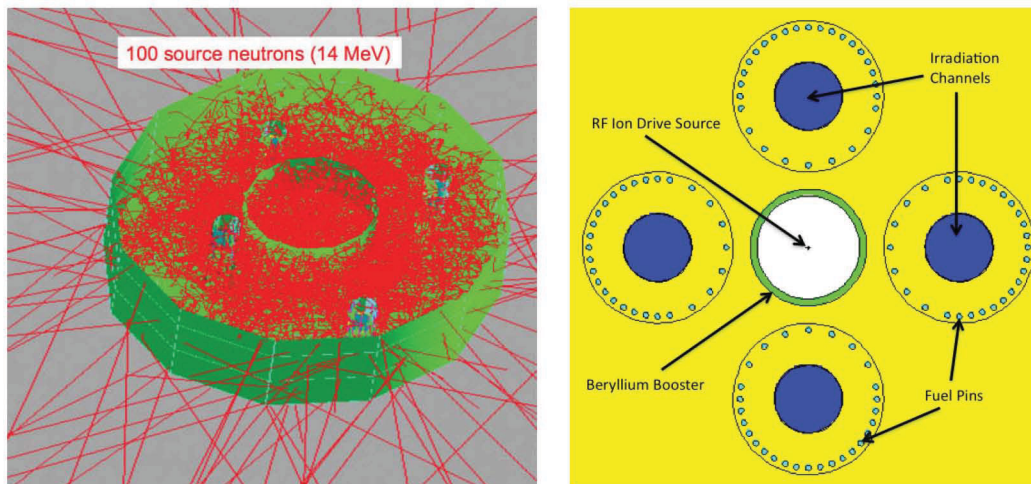


Figure 2 (on the left). A mid-plane slice of source neutrons in an MCNP simulation of a simplified fast flux irradiation chamber. The neutrons are down-scattered several times before exiting the lead volume, increasing the flux well above the nominal geometric fall-off that goes as $1/r^2$

Figure 3 (on the right). Shown here is part of the cross section of the baseline irradiation chamber, as modeled in MCNP, near the mid-line. The chamber is primarily composed of lead, shown in yellow. The simulation includes the accelerator-driven neutron source (center) surrounded by a thin-shell beryllium multiplier. The four primitive bores run from one end to the other parallel to the cylindrical axis. Along the central axis of the bores are experimental channels, providing direct line of sight viewing of irradiated samples. The channels are surrounded by lead, providing gamma shielding from the LEU boosters that surround the channels. In this configuration, a useable fast flux of 1×10^{14} is achieved. The shape and intensity of the fluxes can be tailored by changing the configuration surrounding the experimental channel.

2.1.1.3 Charged Particle Irradiations

Positive ion irradiations were performed on organic binder materials used in MOX fuel fabrication as part of the early harvest strategy for INSIGHTS development. These samples will be characterized for cross-linking defects and displaced lattice sites using positron annihilation spectroscopy at the INL. The proton and lithium beam irradiations were performed with the Florida State University tandem accelerator while the INL Pelletron awaits beam optics and adequate shielding. Future work will be performed on-site with the Pelletron charged particle beam lines.

2.1.2 Next Steps

A prioritized investment list is provided in the following table. The table outlines the major necessary progression to be taken in the next three years to meet the INSIGHTS Development goals.

The very next step is to complete the pelletron end stations (neutron and charged particles). To achieve this goal, the accelerator shielding needs finished to allow the pelletron to be run at full current. The beam optics system that directs beams to both the neutron high dose cave and charged particle end station needs to be installed. In parallel with that effort, continued modeling and simulation support needs to be provided. This funding is to optimize the neutron production target, neutron economy in the INSIGHTS system, and developing the validation experiments. To increase the capabilities of the system and meet the needs of INL researchers, the purchase and installation of a SNICS source for the pelletron system is needed. This will add the ability to implant ions and perform high damage irradiations using heavy isotopes. During the course of completion of the previous three tasks, first measurements using the available system will be conducted during the follow on years. These measurements will be in direct support of DOE and INL missions. Included in this effort is the providing measurements and fields for the advanced detector and sensor development efforts.

The specific design efforts planned for FY13 and 14 will be guided by the experimental results obtained in the RD&D of FY12. The engineering design goals starting in FY13 are geared for determining the pertinent design parameters needed to facilitate the beginning of construction of INSIGHTS in FY14.

Table 1. INSIGHTS Development

Priority	Capability	Description of Capability	Currently Funded	Anticipated Start Date	Anticipated Completion Date	Estimated Cost
1	Pelletron End Station Completion	Positive Ion Irradiation, Ion Implantation, High DPA Irradiation	No	FY12	12 Mo.	\$1.3 M
2	Modeling and Simulation Support	Support the calculation and development of the INSIGHTS system	No	FY12	12 Mo.	\$500 k
3	SNICS Source for Positive Ion Accelerator	Additional isotope irradiation capability up to U	No	FY13	12 Mo.	\$750 k
4	Measurement support for INSIGHTS	Early measurements to support Fuel Cycle R&D efforts	No	FY13-15	36 Mo.	\$1.3 M
5	Engineering and Design Support	Provide Engineering design needed for construction of INSIGHTS	No	FY13-14	~24 Mo.	TBD
6	INSIGHTS Construction	Construction	No	FY14-16	~24 Mo.	TBD
7	INSIGHTS Operation	Full scale	No	FY16-	TBD	TBD

2.2 Materials Growth and Characterization

The separate effects testing RD&D program relies on materials growth and characterization infrastructure to provide the tools for the necessary science based samples needed for high fidelity measurements in INSIGHTS. This infrastructure primarily consists the completion of the MOCVD growth tool at the IJRC, the completion of the gas handling system that supports the MOCVD growth tool, the completion of the in-situ SEM microscope, the purchase and installation of the in-situ TEM microscope,

2.2.1 Current Status

2.2.1.1 Materials Growth

This effort is highly synergized with the DOE-NEUP projects. Several key base components have been purchased by INL. These include the purchase of a hybridized MOCVD/ALD tool radioactive materials hoods and in-situ positron annihilation spatially resolved spectroscopy system for inclusion in an ISU owned SEM. These items have been situated in the new IJRC materials growth and characterization laboratories. Synergistic equipment provided by Idaho State University include a high power single crystal growth furnace that is being commissioned to grow actinide metals, oxides and various ceramic materials as large single crystals, bi- and tri-crystals. The first UO₂ single crystal has been grown with this new system. An in-situ SEM has been purchased by ISU and has been commissioned at the IJRC. Modifications are being designed to incorporate a multi-axis stress and strain capability to the imaged samples, as well as a temperature control capability. Further modification is under way to integrate a positron annihilation scanning detection system with the SEM imaging chamber.



Figure 4, on the left the newly commissioned in-situ SEM at the IJRC. On the right the newly commissioned fuel testing furnace capable of 1500 C.

Also shown in Figure 4 is the newly commissioned fuel testing furnace. This large diameter furnace is capable of 1500 C and provides line of sight access capabilities to the separate effects testing program. Recently, ISU has purchased an intense DD neutron source to use in concert with the furnace described above.

2.2.1.2 Materials Characterization

Positron Annihilation Spectroscopy

Spatially Resolved Positron Annihilation Spectroscopy (SRPAS) is a recently developed measurement technology developed at the INL that provides a capability to characterize distributed changes in fuel plate strain and defect characteristics nondestructively. SRPAS research has primarily focused on unirradiated U-Mo fuel plates with both induced strain and high concentrations of defects, although the technique can be developed for use on irradiated fuel. Figure 5 shows a Hot Isostatically Pressed (HIP) fuel plate and the SRPAS response from this fuel plate. The SRPAS data indicates significant strain effects and defect concentrations in the outer area of the plate with low concentrations of defects in the surrogate fuel portion of the plate. (The center of the plate produces a SRPAS response similar to virgin aluminum alloy.) The SRPAS data suggest that fuel failures during irradiation may have likely resulted from differential strain effects from the outer portion of the plate to the surrogate fuel portion and occurred at the interface between the high and low strain regions of the plate. It is expected that the SRPAS technology can be used on irradiated specimens to assess the effects of incremental irradiation on the structure of the fuel material, which may occur within a few hours of the start of fuel irradiation.

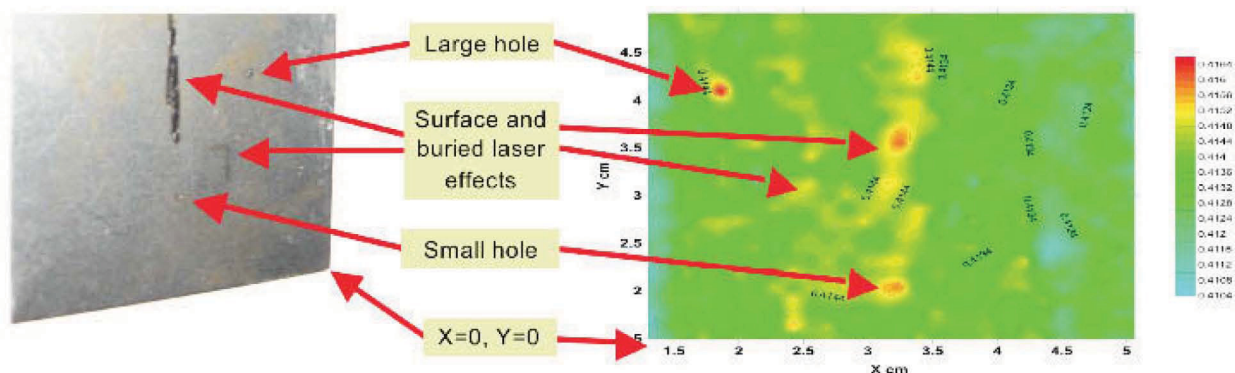


Figure 5 Resolution measurements performed with SRPAS.

Through a CRADA with General Electric and an INL LDRD, progress continues on adapting the SRPAS technique for other fuel forms and general fuel characterization.

In-situ SEM

Simple SEM imaging of fuel materials is of sufficient spatial resolution to resolve grain size and distribution of the fuel meat and interfaces, as well as defect structure and bubble composition. This information is used to validate and inform numerous models that simulate fuel defect formation and dynamics. SEM imaging has been used primarily as a standard pre-irradiation and post-irradiation examination technique.

An existing SEM machine is being leveraged to develop an in-situ SEM capability that will allow real time SEM imaging of materials under charged particle irradiation, with independent temperature and stress/strain application. The SEM machine has been installed at the IJRC and is operational. As charged particle beam lines are developed for the Pelletron accelerator, an effort will be made to direct a charged particle beam into the SEM imaging chamber for in-situ irradiation imaging capability.

In-situ TEM

To provide a more detailed atomistic level imaging capability, an In-situ TEM is anticipated to work in concert with the pelletron and other irradiation capabilities described above. The In-situ TEM has specially designed hot and cold stages providing a dynamic temperature range for samples during imaging from 77 K up to 1500 K. In addition, the samples can be put under stress, strain or torsion using a modified sample stage. This TEM is intended to couple to the pelletron, positive ion irradiation capability to provide a high DPA in-situ irradiation capability. This concert of capabilities fills a void in the science based approach to multi-scale, multi-physics data sets needed for the advanced modeling and simulation effort. A TEM has been selected for this portion of the project and can be seen in Figure 6 and Figure 7.

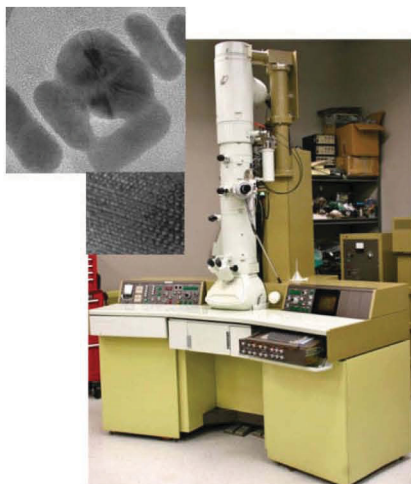


Figure 6 (on the left). Proposed in-situ TEM microscope. Not shown is the digital image capture portion of the microscope. Inset in the figure are atom level and nanoparticle level images of gold particles.



Figure 7 (on the right). In-situ sample holders. In the foreground, the heated and cooled sample holder, in the background, the stress/strain/torsion sample holder.

A TEM has been selected, a design for beam line optics has been created and the space has been identified for this capability. A NEUP scientific infrastructure grant has been submitted to develop this capability. As of the date of writing, no word has been given on the status of this funding.

2.2.2 Next Steps

A prioritized investment list is provided in the following table. The table outlines the major necessary progression to be taken in the next three years to meet the INSIGHTS Development goals.

Central to the whole Separate Effects testing program is the ability to grow novel engineered samples. The next step is to complete the installation of both the MOCVD tool and the gas-handling infrastructure. Without these components, no engineered actinide fuel samples can be fabricated. Once the MOCVD tool is commissioned and operating with a complete gas handling system, then science based experiments can be developed. Several additional capabilities will be needed to develop in-situ characterization of the engineered samples. This will provide grain level to atomistic level real time movies of high DPA irradiations and thermal treatments in support of the NS&T mission. These capabilities will require an upgrade to the in-situ SEM, and the purchase and installation of the in-situ TEM. In parallel, the engineering design and support for advanced in-situ characterization equipment needs to move forward to support the broader separate effects based testing program and INSIGHTS. This will provide engineering support to create the needed pressure vessels, control mechanisms, data management and integration systems, and improved accelerator based imaging systems.

Table 2. Materials Growth and Characterization

Priority	Capability	Description of Capability	Currently Funded	Anticipated Start Date	Anticipated Completion	Estimated Cost
1	Completion of MOCVD Installation	ability to grow and characterize engineered crystals in support of FCR&D	No	FY12	12 Mo.	\$1.3 M
2	Completion of Gas Handling System	Maintain environmental and health safety during operation of the MOCVD tool	No	FY12	12 Mo.	\$750 k
3	In-situ SEM Upgrade	Provides heated sample for real time movies of fuel samples heated through melting	No	FY12	12 Mo.	\$150 k
4	Engineering Design Support for In-situ characterization	Provide engineering support for accelerator based imaging, in-situ measurement	No	FY13-16	36 Mo.	TBD
5	In-situ TEM System	Provides atomistic level real time movies with heated/cooled samples during irradiation	No	FY13	12 Mo.	\$350 k

2.3 Detector and Sensor Development

The third main development area is advanced detector and sensor development for measuring and monitoring an in-pile environment in real-time. This effort is synergistic with the advanced reactor instrumentation development for the ATR and TREAT reactors. Uncertainties in the irradiation conditions also propagate into uncertainties in the final results of experiments. Understanding and minimizing these uncertainties is the focus of this portion of the science-based fuels program. The combination of high-fidelity characterizations and well-parameterized irradiation conditions is key for the advanced simulations efforts.

2.3.1 Current Status

This is currently a highly leveraged activity that involves several NEUP contracts and is just getting underway.

2.3.1.1 Nanovision and Photonic Crystal Detectors

It may be possible to measure fuel sample deformations with a novel monitoring system that utilizes an embedded photonic crystal structure. This novel technique that we refer to as “NanoVision”, utilizes the photonic crystal structure in a completely new fashion in order to yield information on real time fuel changes on the scale of nanometers as opposed to millimeters. It becomes possible to measure nearly atomistic changes in real-time during irradiation. NanoVision provides a unique monitoring capability which can be applied to fuel materials, cladding materials, any material in which more precise information over grain swelling, grain compression, temperature, crack formation and propagation is desired in two or three dimensions. This system provides unprecedented accuracy (nm scale deformations) and can do it in a repeatable fashion using nanotechnology. The photonic crystals have

been successfully fabricated, but further development is required to adapt them to the particular needs of in-situ fuel monitoring.

The proposed research is designed to monitor several key parameters in fuel performance. The parameters of concern which NanoVision is optimally designed for is pellet swelling, pellet compression, grain reformation, crystal reorientation and restructuring, temperature and crystal separation. This is an initial list of parameters that can be monitored in three dimensions with NanoVision. These parameters can be created from three distinct versions of NanoVision which all center on the photonic crystal structure.

Shown in **Error! Reference source not found.** and Figure 8 are examples of the NanoVision photonic crystal structures. These structures demonstrate the change in wavelength as the sample is perturbed.

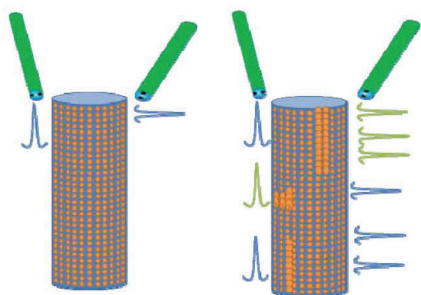


Figure 8. A fuel pellet covered in one template. As the fuel pin is deformed, the structure on the right is deformed producing a change in the wavelength of re-emission as a function of position detecting single grain relocations on the nanometer scale.

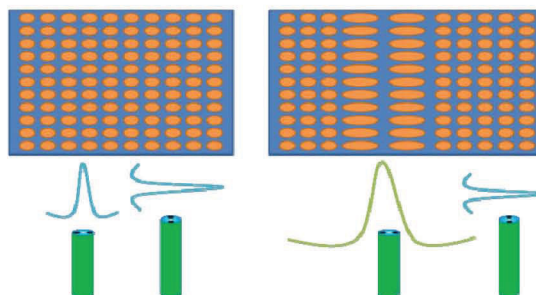


Figure 9. Demonstration of the photonic crystal structure. Polarization maintaining fibers bring white light incident on the structure. When the structure is unmodified, it will focus and re-emit only blue light. As the array becomes perturbed as shown on the right, only the perturbed dimension changes, and re-emits in a longer wavelength, green.

2.3.1.2 *Plasmonically Cloaked Nanoparticle Scintillator*

The focus of this research is advanced measurement techniques utilizing cutting edge Plasmonic cloaked and metamaterial neutron scintillators. The goal of the project is to measure the fission neutron spectrum, fission neutron yield, and time dependence of the neutron yield as a function of incident fission neutron energy. These innovative ideas bring game changing technology to the table, which is applicable to nuclear data, national security and the DOE. The project is centered around cutting edge advances in plasmonic cloaking, metamaterials and custom growth techniques to produce neutron scintillators that are intrinsically gamma blind. This work will address many of the pitfalls of other scintillator systems that had been proposed previously. This project has been funded through the DOE-NEUP program.

2.3.2 **Next Steps**

A prioritized investment list is provided in the following table. The table outlines the major necessary progression to be taken in the next three years to meet the INSIGHTS Development goals.

The next step of this program is to begin the work on the NanoVision project. This currently funded NEUP contract is slated to start FY12. In parallel, the Plasmonically Cloaked nanoparticle scintillator is currently funded under an NEUP contract and will also start in FY12. The Photonic Crystal Fiber In-Core monitoring development should be started early in FY12 as it supports NanoVision program and leverages the gains of the program on in-situ monitoring work, providing unprecedented fidelity and precision in-core data. Lastly, a new project utilizing semiconductor uranium oxide to produce in core self powered devices that can transmit environmental, structural, and reactor health data wirelessly should

be initiated. The potential of this project could be the holy grail of in core instrumentation. These advances are only possible through the synergy with the materials growth and characterization efforts and the irradiation capability development described above. This would position INL to be the world leaders on a very promising technology.

Table 3. Advanced Detector and Sensor Development

Priority	Capability	Description of Capability	Currently Funded	Anticipated Start Date	Anticipated Completion Date	Estimated Cost
1	Completion of NanoVision	nanometer resolution measurement system of samples during irradiation	Yes	FY12-14	36 Mo.	\$1.2 M
2	Photonic Crystal Fiber In-Core Monitoring	Ability to measure stress, strain, compression, neutron spectra, and general in-core monitoring during the standard fuel cycle	No	~FY12-14	36 Mo.	\$1.3 M
3	Plasmonically Cloaked Nanoparticle Scintillator	Create large volume scintillators from nanoparticles	Yes	FY12-14	36 Mo.	\$800 k
4	Self Powered In-Core UO ₂ semiconductor based multi-parameter measurement system	In fuel, on pellet, integrated semiconductor based measurement system and wireless data transmission	No	FY13-17	48 Mo.	TBD

3. Supporting Facilities and Infrastructure

The right scientific environment is essential for a successful separate effects testing program. Overlapping disciplines of nuclear reactor technology, materials science, nanotechnology, computer simulation and modeling, and nuclear physics must be integrated in a single working environment to produce the transformational advances required for fuels development. Similar to the efforts by the NSUF and CAES, the rapid dissemination and availability of new scientific data indicates the need for an open access environment fostering close collaboration between the INL, other national laboratories, universities, and private industries across these varied disciplines.

3.1.1 Idaho Accelerator Center

The Idaho Accelerator Center (IAC) is a unique research facility operated by Idaho State University located in southeast Idaho. The Center has three laboratories: on the university campus, in the Universities' Business and Research Park and at the Pocatello Airport. It provides opportunities for scientists and engineers from the University, the private sector and the national laboratories to utilize specialized nuclear facilities. It serves as a principal investigating conduit for R&D in nuclear physics applications in materials science, biology, homeland and national security.

3.1.2 Idaho Joint Research Center

ISU has acquired a 216,000 square foot laboratory formerly known as the Ballard Building near the IAC and main ISU campus in Pocatello, Idaho. The facility has ample electric power supply, gas

handling, and other building infrastructure to accommodate current and future INSIGHTS development needs, as well as fuel fabrication, detector development, and full scale separate effects testing campaign needs. The facility is equipped with nearly 100,000 sq. ft. of class 100 clean room space suited for radioactive materials handling and use. Nuclear material handling falls under the active ISU NRC license. All of the INSIGHTS advanced detector development and engineered fuel sample fabrication operations have moved into the new facility. It is envisioned that this facility could become the home of a new collaborative effort between ISU and the INL. At this time, however, the facility is solely an ISU owned and operated location.

This facility provides a much-needed pipeline for training and educating the next round of scientists, engineers, and technicians in the field of nuclear science and engineering. INL's involvement would provide guidance in the shaping and direction of this new facility, in addition to opening a doorway for attracting the best students to INL.