INL/EXT-11-23107

National Postirradiation Examination Workshop Needs Assessment

Porter J. Hill

September 2011

INL/EXT-11-23107

National Postirradiation Examination Workshop Needs Assessment

Porter J. Hill

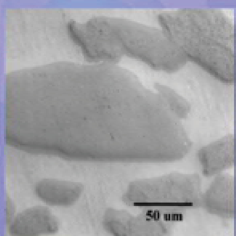
September 2011

Idaho National Laboratory
Idaho Falls, Idaho 83415

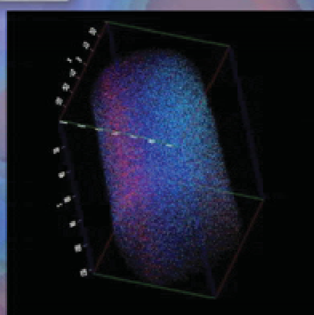
http://www.inl.gov

Prepared for the
U.S. Department of Energy
Office of Nuclear Energy
Under DOE Idaho Operations Office
Contract DE-AC07-05ID14517

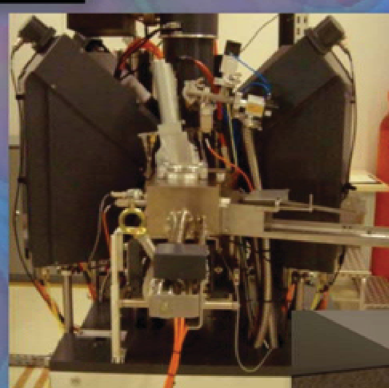
NATIONAL Postirradiation Examination WORKSHOP



March 29-30, 2011
Gaithersburg, MD



NEEDS ASSESSMENT
September 30, 2011



U.S. DEPARTMENT OF ENERGY

Idaho National Laboratory INL

ABSTRACT

The development of advanced nuclear fuels and materials requires a clear understanding of irradiation effects on the materials performance. Development of this understanding at present relies on irradiation experiments ranging from tests aimed at targeted phenomenology to integral effects under both prototypic and off-normal conditions. Within the Department of Energy's (DOE) science-based approach toward fundamental understanding of fuel performance and behavior, more specialized experiments and measurements are needed.

To support the development of advanced nuclear fuels and materials, the nation needs a consolidated, state-of-the-art, postirradiation examination (PIE) capability that can reliably extract the needed data from the experimental programs. In some cases, new capabilities beyond the current state-of-the art need to be developed and implemented to perform measurements that were not needed in the more empirically based approaches used in earlier fuel development and qualification programs. A national PIE workshop was held in March 2011to bring experts together from around the U.S. nuclear complex to develop the PIE needs that are necessary to support both DOE and U.S. commercial industry goals for nuclear energy. During the workshop, it was recognized that significant capability already exists across the DOE complex, in industry, and in universities. These capabilities must be maintained, upgraded, and developed to the extent possible while bringing new capabilities online to support research on highly irradiated fuels and materials. Further, the needs identified in this document show a need to reduce the sample size and examination time in order to couple the measurements with a robust modeling capability within an infrastructure that can meet the needs of higher demand and a variety of customers.

A consolidated capability where a comprehensive set of measurements can be simultaneously performed on highly irradiated nuclear fuels and materials is essential for efficiently implementing fuel and materials development programs in a cost effective manner. This document is an initial attempt to captures national PIE needs necessary to support current and future nuclear research, and where possible, identify where those capabilities are allocated. It is based on the input gathered during the workshop and does not reflect an in-depth national effort to gather and validate PIE capabilities. The purpose of the Needs and Allocation Document was to analyze the data provided by the attendees to determine, at a high level, if there were major gaps or needs that were not being addressed at a national level. For questions related to the National PIE Workshop or this assessment, please contact Lori Braase, lori.braase@inl.gov, Porter Hill, porter.hill@inl.gov, or Jason Schulthess, jason.schulthess@inl.gov.

This page intentionally left blank.

CONTENTS

ACRONYMS

ATR	Advanced Test Reactor
CD	Critical Decision
DOE	Department of Energy
DOE-NE	Department of Energy Office of Nuclear Energy
NDE	Non Destructive Examinations
NRC	Nuclear Regulatory Commission
NSUF	National Scientific User Facility
PIE	postirradiation examination

NATIONAL PIE WORKSHOP NEEDS ASSESSMENT

1. INTRODUCTION

On January 31, 2011, Peter B. Lyons, Acting Assistant Secretary for Nuclear Energy, approved Critical Decision (CD)-0, Approve Mission Need, for the Advanced Postirradiation Capability Project. As stated in the Mission Need, "*A better understanding of nuclear fuels and material performance in the nuclear environment, at the nanoscale and lower, is critical to the development of innovative fuels and materials required for tomorrow's nuclear energy systems.*" 0

Establishing a world-class postirradiation examination (PIE) capability is paramount to meeting our national PIE needs. The complex behavior of fuels and materials in a nuclear-reactor (i.e., irradiation) environment must be clearly understood if our nation ever hopes to fully exploit the potential of nuclear fission as an energy source. Understanding the complex nature of irradiation-driven phenomena in materials and fuels can only be understood through a scientific program that includes experimental irradiation testing and advanced PIE coupled with a robust material behavior modeling program.

1.1 National PIE Strategy

The U.S. Department of Energy (DOE) issued a DOE Strategic Plan in March 2011 [2]. This strategy includes goals for transformation of the nation's energy system, leadership in clean energy technologies, maintain a vibrant effort in science and engineering as a cornerstone for leadership in strategic scientific areas, and enhancing nuclear security through defense, nonproliferation, and environmental efforts. More specifically, DOE Office of Nuclear Energy (DOE-NE) has published supporting goals, in the DOE-NE Roadmap in April 2010 [3], for nuclear energy that relate to existing reactors, new reactors, nuclear fuel cycles, and minimizing nuclear proliferation and terrorism. Postirradiation examination capabilities are crucial to achieving these goals as the behavior of fuels and materials in a nuclear reactor environment is extremely complex and represents the limiting factor in plant safety, longevity, efficiency, and economics.

1.2 National PIE Workshop

A National PIE Workshop was held March 29-30, 2011, in Gaithersburg, MD, to identify the nation's needs for PIE to support advanced fuels and nuclear material development [4]. It is part of broader goal to address the DOE missions in nuclear plant efficiency, economics, and safety, improved use of nuclear fuels, and fuel resources safe and publically acceptable solution to used fuel long-term storage and disposal, and reduced environmental impact of nuclear energy production and use.

During the workshop, the National PIE needs were identified from various perspectives, including universities, industry, vendors, Nuclear Regulatory Commission (NRC), Advanced Test Reactor (ATR) National Scientific User Facility (NSUF), and DOE-NE national laboratories. Achieving the state-of-the art capabilities that can support a complete transition to science-based approach requires progressive set of actions:

The first step, after multiple decades of neglect, is to update and refurbish the existing capabilities and replace the older capabilities with newer, more accurate, and more reliable set of instruments.

The second step is to introduce advanced instruments and scientific techniques, commonly used in other applications with nonradioactive materials, into PIE applications. The objective is to start characterizing radioactive samples at nano-scale to micro-scale length resolutions. Some of these instruments, when applied to radioactive materials characterization, require special facilities with very strict environmental control.

The third step is to design and develop instruments that currently do not exist but are required to measure properties at various length and time scales in order to support a complete fundamental understanding of radioactive materials behavior. Such instruments would be valuable to understand separate effect phenomenology and to support the multi-physics, multi-scale, predictive fuel performance modeling efforts. These capabilities are also likely to require new facilities with very specialized environmental control and integration among multiple techniques.

During the workshop, breakout sessions were organized around the following topic areas:

- Fuel Cycle Research and Development/Fast Reactor Fuels
- Light Water Reactor Fuels
- Gas Cooled Reactor/Particle Fuels
- Modeling and Simulation/Scientific Measurements
- Nuclear Materials.

At the conclusion of the workshop, four high-level needs were identified as common themes from the five breakout teams. Those needs are summarized below:

1. Understanding material changes in the extreme nuclear environment at the nanoscale, especially for highly activated fuels and materials. Nanoscale studies have significant importance due to the mechanisms that cause materials to degrade, which occur at the nanoscale.
2. Enabling additional proficiency in experimentation and analysis through robust modeling and simulation coupled with advanced characterization.
3. Advancing the infrastructure and accessibility of physical and administrative systems to meet the needs of participating organizations. The inability to accommodate different time cycles and constraints make working and collaborating within the national laboratories challenging. This also includes the development of talent and the retention of expertise to support the research needs of the future.
4. Pursuing in-situ instrumentation and measurements to better examine dynamic changes to materials' microstructure, deformation, and surface effects as they occur in real time rather than the static, end-state data obtained by most current PIE methods. Also the ability to interpret the PIE data accurately requires a detailed understanding of the irradiation history and associated initial and boundary conditions.

The National PIE Workshop was also a response to the research challenges for advanced PIE needs for nuclear fuels and materials development outlined by Energy Secretary Chu and the DOE-NE *Nuclear Energy Research and Development Roadmap*, which was delivered to Congress in April 2010 [3]. PIE technial needs for nuclear fuels and materials development were identified for short-term (less than 10 years) and long-term (greater than 10 years) research. Gaps in existing PIE capabilities were discussed along with potential future solutions. These gaps and potential solutions were organized into the tables in this document in an initial attempt to identify any critical missing technical capabilities.

2. PIE NEEDS ASSESSMENT

The needs identified during the National PIE Workshop will inform the identification and evaluation of alternatives in support of the CD-1 activities for state-of-the art PIE capabilities. It will also be used to support PIE strategic planning, define future capability needs, and support the conceptual designs for advanced PIE facility(ies) and associated instrumentation.

The National PIE Workshop provided a forum for participants to identify short- term and long-term PIE needs. Short-term was defined as a capability that was needed in the next ten years, while long-term, greater than 10 years, was focused on future capability development for examinations under irradiation at the nano- and micro-scale as well as in-situ instrumentation. These needs are addressed in separate sections of this document as follows:

- Section 2, Base assumptions for Needs
- Section 3, Short Term Needs with the following subsections
  - Non Destructive Examinations (NDE)
  - Microstructure, Phase, and Property Analysis
  - Chemical, Isotope, and Radiological Analysis
  - Thermal Property Examination
  - Mechanical Properties
  - Sample Preparation and Physical Properties Capabilities
  - In-Situ
  - Modeling
  - Infrastructure
  - Misc
- Section 4, Long Term Needs with the following subsections
  - NDE
  - Microstructure, Phase, and Property Analysis
  - Chemical, Isotope, and Radiological Analysis
  - Thermal Property Examination
  - Mechanical Properties
  - Sample Preparation and Physical Properties Capabilities
  - In-Situ
  - Modeling
  - Infrastructure
  - Misc

Each subsection identifies the PIE capability needed, the justification, and possibilities of how to fulfill the need, otherwise referred to as "allocation."

The needs presented in this document generally are not allocated as a one-to-one relationship to a capability. Nuclear fuel and material research is a multivariate effort that takes a variety of capabilities to examine the phenomena that occur to materials under irradiation conditions. Therefore, the allocation attempts to identify the suite of capabilities available to fulfill the need. This allocation is not meant to be an exhaustive or in-depth assessment.

The needs contained in Section 2 have been developed from input from the National PIE workshop, and allocated to current PIE capabilities, where known. The allocation is based on available input primarily from the expertise and best practices of researchers and experts participating at the National PIE workshop. Additional relevant allocations may exist across the national materials research community, but those identified in this document are specific to the handling, research, and development of irradiated nuclear fuels and materials.

2.1 Short Term Needs

This section captures the short term capabilities needed to provide national PIE services for current and future customers. The objective is to support highly irradiated nuclear fuels and materials research for projects and programs with near-term needs. These needs are short term and can be implemented in the next ten years.

2.1.1 Non-Destructive Examination

Need-ID	Technical Need: (What)	Basis: (Why)	Solution: (How, Who, Where)	Processes	Allocation			
					Current Capability	Location	Future Capability	Location
N063	Perform non-destructive imaging radiography of fuel pin	Need to see image of fuel in fuel pin before sizing to determine where to section/cut. Non-destructive imaging provides early data before waiting for extensive PIE. Also provides intact view of fuel pin before sectioning.	Neutron radiography (NRAD)	-Neutron Radiography	X	INL-HFEF		
N070	Perform neutron radiography digital imaging	Current non-destructive capability is limited with "film" technologies	NRAD reactor at INL (uses film)	-Neutron Radiography -Micro-Scale Analysis	X	INL-HFEF		
N072	Improved ability for operators to see and capture images in hot cells	Damage has occurred to experiments when personnel have limited field of vision. Improved data collection from strategically placed recording capability.	Several manufacturers of high rad tolerant cameras	-Visual Examination	Partial	INL-HFEF	X	?
N160	Measure irradiated fuel Pellet, grain and pore size			-Surface Examination	X	INL-HFEF INL-EML	X	INL-APEX

2.1.2 Sample Preparation and Physical Properties Capabilities

Need-ID	Technical Need: (What)	Basis: (Why)	Solution: (How, Who, Where)	Processes	Allocation			
					Current Capability	Location	Future Capability	Location
N051	Ability to perform sample preparation	To support test	Within INL (APEX)	-Sample Preparation	X	INL-EML INL-HFEF INL-AL	X	INL-APEX INL-IMCL
N147	Capability to fabricate mechanical properties test specimens			-Sample Preparation	X	LANL-CMR	X	INL-HFEF
N152	Measure irradiated fuel using Metallography			-Metallurgical Analysis	X	INL-HFEF ORNL-??		
N153	Measure irradiated fuel using Microhardness			-Hardness Testing	X	INL-HFEF		
N167	Ability to machine various types of mechanical test samples from irradiated material.	Mechanical property data base is needed during development of a new material	Remotely computer controlled milling machine / EDM equipment.	-Shielded Preparation Cell -Sample Preparation -Containment Box Sample Preparation -Cell 3-M, 6-M, 10-M and 11-M disassembly -Sample Prep EDM	Partial	INL-HFEF LANL-CMR	X	INL-APEX

Need-ID	Technical Need: (What)	Basis: (Why)	Solution: (How, Who, Where)	Processes	Allocation			
					Current Capability	Location	Future Capability	Location
N181	Ability to perform non destructive examination on a few rods using gamma scan and segment rod, metallography, ceramography, H2 content	Defuel long rod segments, measure stresses on rod ring compression capsules, and welding	Micro & nano hardness	-Gamma Scanning -Hardness Testing -Metallurgical Analysis -Impurity Analysis -Gamma Spectroscopy -Micro-Gamma Spectroscopy -Sample Preparation	X	INL-HFEF INL-AL		

2.1.3 Microstructure, Phase and Property Analysis

Need-ID	Technical Need: (What)	Basis: (Why)	Solution: (How, Who, Where)	Processes	Allocation			
					Current Capability	Location	Future Capability	Location
N017	Characterize distinct phases of microstructure, both phase & chemistry at the micro scale	Different phases have different properties		-Crystal Structure Analysis -Electronic microscopy	Partial	INL-AL INL-EML	X	INL-APEX INL-IMCL
N033	Measure microstructure microchemistry of fuels and materials pre and post irradiation in 2-D	Understand irradiation effects on microstructure and microchemistry Use to validate models	TEM varieties, Atom probe (INL) EPMA (INL) Light sources (ANL, BNL)	-Atomic Scale Tomography -Light Sources -Electronic microscopy	Partial	INL-EML INL-AL INL-CAES ANL-APS BNL-NSLS	Partial	INL-APEX

Need-ID	Technical Need: (What)	Basis: (Why)	Solution: (How, Who, Where)	Processes	Allocation			
					Current Capability	Location	Future Capability	Location
N034	Measure thermophysical and mechanical properties of pre and post irradiated material and fuel in 2-D	Understand changes in mechanical & thermophysical properties as function of irradiation Use to validate models	STDM new techniques? That can employ use of modified existing technology	-Thermal Properties Analysis -Thermal Diffusivity Analysis	Partial	INL-HFEF INL-AL	X	INL-APEX
N044	Determine composition of damage and microstructures of fuel materials		Only very few researchers claimed (with ambiguity) that oxygen can be effectively characterized.	-High Sensitivity, Nano Scale, Nano Microscopy and Chemical Analysis -High Resolution Chemical and Electronic Microscopy and Chemical Analysis -Quantitative Micro Scale Elemental Analysis and Chemical Maps -Electronic microscopy	Partial	INL-EML INL-CAES	X	INL-APEX INL-IMCL
N053	Measure elemental changes of hydrides intermetallic behavior and structure defects	Traditional method - etching - direct observation Intermetallic phase change / RIS	EBSD / back scatter CBED - image filtered		Partial	INL-EML INL_CAES	X	INL-APEX INL-IMCL

Need-ID	Technical Need: (What)	Basis: (Why)	Solution: (How, Who, Where)	Processes	Allocation			
					Current Capability	Location	Future Capability	Location
N065	Perform micro-phase and chemistry analysis	Phase analysis can be inferred from chemistry analysis, but with increased uncertainty. Want to know what phases & compounds form across fuel cross-section - which elements bind together & may prevent migration vs. which elements more on their own.		-Quantitative Micro Scale Elemental Analysis and Chemical Maps -Electronic microscopy	Partial	INL-AL	X	INL-APEX INL-IMCL
N079	Spatial resolution on a sub millimeter scale of gross distributions of fuel clearly distinguished from cladding and structural materials, within TREAT test loops in pretest geometry and post test disrupted geometry in 3-D.	To determine reactivity effects of fuel redistributions effects of fuel penetration into/through structure						
N080	Measure FCMI pressures w/o affecting the post irradiation conditions at the F/C interface, best if measured at same axial position as measurements of fuel and cladding mechanical properties	Validate analyses of cladding stresses and cladding failure						

Need-ID	Technical Need: (What)	Basis: (Why)	Solution: (How, Who, Where)	Processes	Allocation			
					Current Capability	Location	Future Capability	Location
N095	Using a TEM and atom Probe measure void formation, swelling, distortion of specimens>40dpa, to 60dpa	Licensing >60 year	TEM, FEG-STEM? ANL, INL	-Micro-Scale Analysis -Nano Scale Microscopy	Partial	INL-EML INL-CAES	X	INL-APEX INL-IMCL
N097	Measure microstructure of irradiated materials before, after and in between radiation	To establish structure-property relationships and, in turn, physically-based embrittlement models.	National labs have the capability	-Microstructure	Partial	INL-HFEF INL-AL INL-EML INL-CAES	X	INL-APEX INL-IMCL
N098	Measure IASCC CGR of LWR core internal materials under LWR environment at a high dose	This is important for reactor re-licensing efforts (some are coming due soon)	Some capability exists (Studsvik, JAEA, GE-Hitachi) very limited U.S. capability. INL is starting to develop	-Irradiation Assisted Stress Corrosion Cracking Analysis	Partial	INL-FASB	X	APEX
N099	Measure environmentally assisted fatigue in LWR materials at	Most data that is used is based on un-irradiated materials	Specific shielded Equipment that can be dedicated to these sometimes lengthy (~1/2 R+) tests.	-Irradiation Assisted Stress Corrosion Cracking Analysis	Partial	INL-FASB	X	INL-IMCL
N102	Measure microstructural characterization and progression under irradiation	Input and feedback from the M&S effort to develop models for physical & mechanical properties	Synchrotron? In-site ion bombardment In-site properties in neutron bombardment.	-				

Need-ID	Technical Need: (What)	Basis: (Why)	Solution: (How, Who, Where)	Processes	Allocation			
					Current Capability	Location	Future Capability	Location
N104	Determine damage mapping grain by grain	Xray micro tomography	0	-Crystal Structure Analysis -Micro-Scale Crystal Structure Analysis	Partial	INL-AL INL-EML	X	INL-APEX INL-IMCL
N105	Determine high contrast methods for picking out subtle radiation effects			-				
N109	Measure fuel microstructure at micro meter and smaller, at a rate of a sample per week to start	Understand evolution of fuel structure and influence on properties	TEM, STEM, FIB, High Temp XRD	-Crystal Structure Analysis -Micro-Scale Analysis -Micro-Sampling -Nano Scale Microscopy	Partial	INL-EML INL-AL INL-CAES	X	INL-APEX INL-IMCL
N124	Measure microstructural changes that govern and accompany degradation of vessel material properties	Understanding material degradation at longest life	Advanced microstructural characterization (APFIM, FIB, AEM, SIMS, etc.) complete to irradiation capable "met lab"	-Micro-Sampling -Metallurgical Analysis -High Resolution Chemical and Electronic Microscopy and Chemical Analysis	Partial	INL-AL INL-CAES INL-EML	X	INL-APEX INL-IMCL

Need-ID	Technical Need: (What)	Basis: (Why)	Solution: (How, Who, Where)	Processes	Allocation			
					Current Capability	Location	Future Capability	Location
N129	Measure microstructural and mechanical characteristics of corrosion films as well as underlying metal	Understanding of corrosion mechanism and predictability and for modeling	Full characterization of films and metal. Some (most) capabilities exist but technique development may need to be undertaken to improve quality of data		Partial	INL-AL INL-EML INL-CAES	X	INL-IMCL INL-APEX
N133	Measure retrospective neutron dosimetry and helium using Optical			-Metallurgical Analysis				
N134	Measure retrospective neutron dosimetry and helium using FTIR			-High Sensitivity, Nano Scale, Nano Microscopy and Chemical Analysis				
N135	Measure retrospective neutron dosimetry and helium using Auger			-High Sensitivity, Nano Scale, Nano Microscopy and Chemical Analysis			X	INL-APEX
N149	Measure irradiated FGR fuel	Needed to support design bases, validate models?						
N151	Measure irradiated fuel using Profilometry			-Element Contact Profilometry System	X	INL-HFEF		

Need-ID	Technical Need: (What)	Basis: (Why)	Solution: (How, Who, Where)	Processes	Allocation			
					Current Capability	Location	Future Capability	Location
N154	Provide microstructure Analysis using SEM / SPP			-Surface Examination	Partial	INL-EML	X	INL-APEX INL-IMCL
N159	Measure irradiated fuel using Gamma scan			-Gamma Scanning -Gamma Spectroscopy	X	INL-HFEF INL-AL ORNL		
N162	Measure irradiated fuel using LOCA testing							
N165	Detect and identify particles at nano-scale.	It is important for noble metal applications.	Field emission SEM with at least 100,000 X magnification.	-Surface Examination	Partial	INL-EML	X	INL-APEX INL-IMCL
N168	Perform composition analysis of irradiated fuel pellet	Fission product distribution. Retention by the additive.	Laser ablation equipment and ICP-MS	-Mass Spectrometry	X	INL-AL		
N169	Perform microanalysis of RIM structure on high burnup fuels	Fission gas release mechanisms (normal + transient conditions)	High res. SEM with WDS/EDS and TEM/STEM with PEELS/EDS capable of examining irradiated fuels Synchrotron	-Micro-Scale Analysis -Surface Examination -Nano Scale Microscopy	Partial	INL-EML INL-CAES	X	INL-APEX

Need-ID	Technical Need: (What)	Basis: (Why)	Solution: (How, Who, Where)	Processes	Allocation			
					Current Capability	Location	Future Capability	Location
N170	Measure Chemical composition, microstructure, and mechanical properties for Position-specific analysis of cladding (hydride formation, CRUD deposition, oxidation, etc)	Provides understanding of variable end-point behavior of cladding à can be used to identify mechanisms responsible for variable behavior	Need accurate sectioning capabilities (Saw/EDM +FIB) and a suite of characterization equipment (chemical, structural, mechanical) e.g. nano-SIMS, TEM, nanoindenter	-Micro-Sampling -Nano Indenter -High Sensitivity, Nano Scale, Nano Microscopy and Chemical Analysis -Shielded Preparation Cell -Sample Preparation -Sample Prep EDM	Partial	INL-HFEF INL-EML INL-AL INL-CAES	X	INL-APEX INL-IMCL
N176	Ability to perform non destructive examination of gap between end plate and top of rod on pre-storage assembly			-Neutron Radiography	X	INL-HFEF		
N179	Ability to perform non destructive examination a few rods using Profilometry			-Element Contact Profilometry System	X	INL-HFEF		

2.1.4 Chemical, Isotope, and Radiological Analysis

Need-ID	Technical Need: (What)	Basis: (Why)	Solution: (How, Who, Where)	Processes	Allocation			
					Current Capability	Location	Future Capability	Location
N017	Characterize distinct phases of microstructure, both phase & chemistry at the microscale	Different phases have different properties		-Crystal Structure Analysis -Electronic microscopy	Partial	INL-AL INL-EML	X	INL-APEX INL-IMCL
N033	Measure microstructure microchemistry of fuels and materials pre and post irradiation in 2-D	Understand irradiation effects on microstructure and microchemistry Use to validate models	TEM varieties, Atom probe (INL) EPMA (INL) Light sources (ANL, BNL)	-Atomic Scale Tomography -Light Sources -Electronic microscopy	Partial	INL-EML INL-AL INL-CAES ANL-APS BNL-NSLS	Partial	INL-APEX
N034	Measure thermophysical and mechanical properties of pre and post irradiated material and fuel in 2-D	Understand changes in mechanical & thermophysical properties as function of irradiation Use to validate models	STDM new techniques? That can employ use of modified existing technology	-Thermal Properties Analysis -Thermal Diffusivity Analysis	Partial	INL-HFEF INL-AL	X	INL-APEX

Need-ID	Technical Need: (What)	Basis: (Why)	Solution: (How, Who, Where)	Processes	Allocation			
					Current Capability	Location	Future Capability	Location
N044	Determine composition of damage and microstructures of fuel materials		Only very few researchers claimed (with ambiguity) that oxygen can be effectively characterized.	-High Sensitivity, Nano Scale, Nano Microscopy and Chemical Analysis -High Resolution Chemical and Electronic Microscopy and Chemical Analysis -Quantitative Micro Scale Elemental Analysis and Chemical Maps -Electronic microscopy	Partial	INL-EML INL-CAES	X	INL-APEX INL-IMCL
N053	Measure elemental changes of hydrides intermetallic behavior and structure defects	Traditional method is etching and direct observation. Intermetallic phase change / RIS	EBSD / back scatter CBED - image filtered		Partial	INL-EML INL-CAES	X	INL-APEX INL-IMCL

Need-ID	Technical Need: (What)	Basis: (Why)	Solution: (How, Who, Where)	Processes	Allocation			
					Current Capability	Location	Future Capability	Location
N065	Perform micro-phase and chemistry analysis	Phase analysis can be inferred from chemistry analysis, but with increased uncertainty. Want to know what phases & compounds form across fuel cross-section - which elements bind together & may prevent migration vs. which elements more on their own.		-Quantitative Micro Scale Elemental Analysis and Chemical Maps -Electronic microscopy	Partial	INL-AL	X	INL-APEX INL-IMCL
N079	Spatial resolution on a sub millimeter scale of gross distributions of fuel clearly distinguished from cladding and structural materials, within TREAT test loops in pretest geometry and post test disrupted geometry in 3-D.	To determine reactivity effects of fuel redistributions effects of fuel penetration into/through structure						

Need-ID	Technical Need: (What)	Basis: (Why)	Solution: (How, Who, Where)	Processes	Allocation			
					Current Capability	Location	Future Capability	Location
N080	Measure FCMI pressures w/o affecting the post irradiation conditions at the F/C interface, best if measured at same axial position as measurements of fuel and cladding mechanical properties	Validate analyses of cladding stresses and cladding failure						
N095	Using a TEM and atom Probe measure void formation, swelling, distortion of specimens>40dpa, to 60dpa	Licensing >60 year	TEM, FEG-STEM? ANL, INL	-Micro-Scale Analysis -Nano Scale Microscopy	Partial	INL-EML INL-CAES	X	INL-APEX INL-IMCL
N097	Measure microstructure of irradiated materials before, after and in between radiation	To establish structure-property relationships and, in turn, physically-based embrittlement models.	National labs have the capability	-Microstructure	Partial	INL-HFEF INL-AL INL-EML INL-CAES	X	INL-APEX INL-IMCL
N098	Measure IASCC CGR of LWR core internal materials under LWR environment at a high dose	This is important for reactor re-licensing efforts (some are coming due soon)	Some capability exists (Studsvik, JAEA, GE-Hitachi) very limited U.S. capability. INL is starting to develop	-Irradiation Assisted Stress Corrosion Cracking Analysis	Partial	INL-FASB	X	APEX
N099	Measure environmentally assisted fatigue in LWR materials at	Most data that is used is based on unirradiated materials	Specific shielded Equipment that can be dedicated to these sometimes lengthy (~1/2 R+) tests.	-Irradiation Assisted Stress Corrosion Cracking Analysis	Partial	INL-FASB	X	INL-IMCL

Need-ID	Technical Need: (What)	Basis: (Why)	Solution: (How, Who, Where)	Processes	Allocation			
					Current Capability	Location	Future Capability	Location
N102	Measure microstructural characterization and progression under irradiation	Input and feedback from the M&S effort to develop models for physical & mechanical properties	Synchrotron? In-site ion bombardment In-site properties in neutron bombardment.	-				
N104	Determine damage mapping grain by grain	Xray micro tomography	0	-Crystal Structure Analysis -Micro-Scale Crystal Structure Analysis	Partial	INL-AL INL-EML	X	INL-APEX INL-IMCL
N105	Determine high contrast methods for picking out subtle radiation effects			-				
N109	Measure fuel microstructure at micro meter and smaller, at a rate of a sample per week to start	Understand evolution of fuel structure and influence on properties	TEM, STEM, FIB, High Temp XRD	-Crystal Structure Analysis -Micro-Scale Analysis -Micro-Sampling -Nano Scale Microscopy	Partial	INL-EML INL-AL INL-CAES	X	INL-APEX INL-IMCL

Need-ID	Technical Need: (What)	Basis: (Why)	Solution: (How, Who, Where)	Processes	Allocation			
					Current Capability	Location	Future Capability	Location
N124	Measure microstructural changes that govern and accompany degradation of vessel material properties	Understanding material degradation at longest life	Advanced microstructural characterization (APFIM, FIB, AEM, SIMS, etc.) complete to irradiation capable "met lab"	-Micro-Sampling -Metallurgical Analysis -High Resolution Chemical and Electronic Microscopy and Chemical Analysis	Partial	INL-AL INL-CAES INL-EML	X	INL-APEX INL-IMCL
N129	Measure microstructural and mechanical characteristics of corrosion films as well as underlying metal	Understanding of corrosion mechanism and predictability and for modeling	Full characterization of films and metal. Some (most) capabilities exist but technique development may need to be undertaken to improve quality of data		Partial	INL-AL INL-EML INL-CAES	X	INL-IMCL INL-APEX
N133	Measure retrospective neutron dosimetry and helium using Optical			-Metallurgical Analysis				
N134	Measure retrospective neutron dosimetry and helium using FTIR			-High Sensitivity, Nano Scale, Nano Microscopy and Chemical Analysis				

Need-ID	Technical Need: (What)	Basis: (Why)	Solution: (How, Who, Where)	Processes	Allocation			
					Current Capability	Location	Future Capability	Location
N135	Measure retrospective neutron dosimetry and helium using Auger			-High Sensitivity, Nano Scale, Nano Microscopy and Chemical Analysis			X	INL-APEX
N149	Measure irradiated FGR fuel	Needed to support design bases, validate models?						
N151	Measure irradiated fuel using Profilometry			-Element Contact Profilometry System	X	INL-HFEF		
N154	Provide microstructure Analysis using SEM / SPP			-Surface Examination	Partial	INL-EML	X	INL-APEX INL-IMCL
N159	Measure irradiated fuel using Gamma scan			-Gamma Scanning -Gamma Spectroscopy	X	INL-HFEF INL-AL ORNL		
N162	Measure irradiated fuel using LOCA testing							
N165	Detect and identify particles at nano-scale.	It is important for noble metal applications.	Field emission SEM with at least 100,000 X magnification.	-Surface Examination	Partial	INL-EML	X	INL-APEX INL-IMCL
N168	Perform composition analysis of irradiated fuel pellet	Fission product distribution. Retention by the additive.	Laser ablation equipment and ICP-MS	-Mass Spectrometry	X	INL-AL		

Need-ID	Technical Need: (What)	Basis: (Why)	Solution: (How, Who, Where)	Processes	Allocation			
					Current Capability	Location	Future Capability	Location
N169	Perform microanalysis of RIM structure on high burnup fuels	Fission gas release mechanisms (normal + transient conditions)	High res. SEM with WDS/EDS and TEM/STEM with PEELS/EDS capable of examining irradiated fuels Synchrotron	-Micro-Scale Analysis -Surface Examination -Nano Scale Microscopy	Partial	INL-EML INL-CAES	X	INL-APEX
N170	Measure Chemical composition, microstructure, and mechanical properties for Position-specific analysis of cladding (hydride formation, CRUD deposition, oxidation, etc)	Provides understanding of variable end-point behavior of cladding à can be used to identify mechanisms responsible for variable behavior	Need accurate sectioning capabilities (Saw/EDM +FIB) and a suite of characterization equipment (chemical, structural, mechanical) e.g. nano-SIMS, TEM, nanoindenter	-Micro-Sampling -Nano Indenter -High Sensitivity, Nano Scale, Nano Microscopy and Chemical Analysis -Shielded Preparation Cell -Sample Preparation -Sample Prep EDM	Partial	INL-HFEF INL-EML INL-AL INL-CAES	X	INL-APEX INL-IMCL
N176	Ability to perform non destructive examination of gap between end plate and top of rod on pre-storage assembly			-Neutron Radiography	X	INL-HFEF		

Need-ID	Technical Need: (What)	Basis: (Why)	Solution: (How, Who, Where)	Processes	Allocation			
					Current Capability	Location	Future Capability	Location
N179	Ability to perform non destructive examination a few rods using Profilometry			-Element Contact Profilometry System	X	INL-HFEF		

2.1.5 Thermal Property Examination

Need-ID	Technical Need: (What)	Basis: (Why)	Solution: (How, Who, Where)	Processes	Allocation			
					Current Capability	Location	Future Capability	Location
N007	Measure thermal shock of SiC matrix TRISO						X	INL-APEX
N010	Measure high temperature fuel performance in air and/or steam environment	Important for defining fuel performance limits; data will be used in sector licensing (defining radionuclide release limits during off-normal events)	Need furnace facility that can heat fuel specimens to ~1600 C in air/steam/He mixtures and measure solid (Cs, As, Si, Eu, I????) and gaseous (Kr, Xe) fission product releases.	-High Temperature Furnaces			X	APEX
N011	Measure thermal conductivity and thermal expansion of bulk fuel samples	Need to know the changes in thermal properties with neutron flux in order to refine thermal models of test irradiation capsule, and the HTGR reactor core.	Shielded instruments for measures (1) thermal conductivity on bulk samples (whole compacts) (2) thermal expansion dilatometer installed in hot cell	-Thermal Properties Analysis	Partial	INL-FASB INL-AL	X	APEX

Need-ID	Technical Need: (What)	Basis: (Why)	Solution: (How, Who, Where)	Processes	Allocation			
					Current Capability	Location	Future Capability	Location
N015	Measure thermal conductivity on every fuel specimen, as a function of temperature in an inert environment on micrometer scale	Critical to calculating fuel temperature, which affects many irradiation performance parameters	Something like an STDM, but better temperature range	-Thermal Properties Analysis -Thermal Diffusivity Analysis	Partial	INL-AL	X	INL-APEX
N030	Provide thermodynamics Data (solutions)	Link to mesoscale models	Knudsen cell (shields)	-Thermo-Dynamic Analysis			X	INL-APEX
N037	Measure thermal diffusivity in oxide fuel and mass transport as a function of composition	e.g. thermal diffusivity & fission gas retention/release are important components of fuel performance An opportunity exists	- thermo = calorimetry, gravimeter, etc. - structure = XRD, neutrons, light sources & - instruct = SEM/EBSD, HR-TEM, etc.	-Crystal Structure Analysis -Micro-Scale Analysis -Surface Examination -Nano Scale Microscopy -Thermal Properties Analysis -Thermal Transport Properties -Thermal Diffusivity Analysis	Partial	INL-EML INL-AL INL-CAES	X	INL-APEX

Need-ID	Technical Need: (What)	Basis: (Why)	Solution: (How, Who, Where)	Processes	Allocation			
					Current Capability	Location	Future Capability	Location
N038	Measure thermal diffusivity, mass transport, and mechanical properties as a function of microstructure	(1) Improve current fuel performance models such as fission gas release (2) Extend in a "science based" fashion to innovative fuel designs.	- Composition = SEM, etc. - Thermal diffusivity = laser flash etc. - Mass transport = radiotracers, SIMS, fuel cell approaches, etc.	-Surface Examination -High Sensitivity, Nano Scale, Nano Microscopy and Chemical Analysis -Thermal Properties Analysis -Thermal Transport Properties -Thermal Diffusivity Analysis	Partial	INL-EML INL-AL	X	INL-APEX
N039	Perform comprehensive thermodynamic and structural characterization before K & D	Current microstructural & atomistic models require both data for validation, & data for guidance.	Theme = any tech. that resolves multidimensional defect interaction/behavior (which would take steps toward long term - radiation effects)	-Structure and Properties Analysis -Thermo-Dynamic Analysis			X	INL-APEX

Need-ID	Technical Need: (What)	Basis: (Why)	Solution: (How, Who, Where)	Processes	Allocation			
					Current Capability	Location	Future Capability	Location
N067	Measure fuel thermal properties: diffusivity, emissivity, conductivity, expansion, as a function of radius, phase and composition	Thermal properties tell us how fuel expands & how fuel constituents migrate radially within fuel (M&S)	Laser flash STDM	-Thermal Properties Analysis -Thermal Diffusivity Analysis	Partial	INL-AL INL-FASB	X	INL-APEX
N078	Measure thermal properties of bulk and selected sub-structures down to the 100's of microns scale	In house detailed thermal analysis & validate analytical predictions (or assumptions) of those thermal properties as used in computations of temperatures & local temperature gradients within fuels		-Thermal Properties Analysis	Partial	INL-AL INL-FASB	X	INL-APEX
N081	Measure melt point on bulk and spatially resolved samples, must have the ability to control the atmosphere to image the target areas of interest Tm±≤10°C	Safety/operational limits Performance codes Phase diagrams	Bulk: thermal arrest Spatial: laser melting Neither fully implemented currently in US JAEA has thermal arrest ITU has laser based Tm	-Thermal Properties Analysis -Thermal Properties Analysis -Thermo-Dynamic Analysis				

Need-ID	Technical Need: (What)	Basis: (Why)	Solution: (How, Who, Where)	Processes	Allocation			
					Current Capability	Location	Future Capability	Location
N082	Measure thermal conductivity bulk and spatially resolved to high temp (<2500°C) under controlled atmosphere spatial <10µm	Thermal transport model development & validation	Laser flash for bulk. Laser-based surface technique (not implemented for ceramics & may not be viable) seems viable for metals L> localized - long term New technique using neutrons?	-Thermal Diffusivity Analysis	Partial	INL-AL	X	INL-APEX
N087	Measure thermodynamic properties	Safety Link atomistic models to thermochemical models Phase diagrams	- DSC, solution calorimeter - Knudson cell	-Thermo-Dynamic Analysis -Thermal Diffusivity Analysis			X	INL-APEX
N089	Develop TED thermal expansion difference monitor	Temp important independent variable. SiC may not be the best	Restore capability from the past	-Thermal Properties Analysis				
N113	Measure fuel thermal conductivity	Governs heat X-port, affect thermo chemistry, reaction energies, diffusion, etc	Available at INL only	-Thermal Properties Analysis	Partial	INL-AL	X	INL-APEX
N114	Measure thermodynamic measurement of Cp	Thermo chemistry affects X-port, thermal & mechanical properties	STA-high temp – in process at ORNL		Partial	ORNL	X	INL-APEX
N115			Knudson Cell				X	INL-APEX

Need-ID	Technical Need: (What)	Basis: (Why)	Solution: (How, Who, Where)	Processes	Allocation			
					Current Capability	Location	Future Capability	Location
N128	Measure thermal conductivity of irradiated corrosion films on cladding and fuel as a function of exposure (thickness)	To predict cladding corrosion, hydrogen absorption and temperature of fuel	Good, reliable methods of thermal conductivity of films need to be developed and vetted. Techniques need to be developed	-Thermal Properties Analysis				
N171	Measure thermal conductivity of irradiated fuels with sub-mm spatial precision	Fuel temperature controls actinide + fission product migration and release	Limited capability exists at INL & ORNL	-Thermal Properties Analysis	Partial	INL-AL ORNL	X	INL-APEX

2.1.6 Mechanical Properties

Need-ID	Technical Need: (What)	Basis: (Why)	Solution: (How, Who, Where)	Processes	Allocation			
					Current Capability	Location	Future Capability	Location
N001	Perform probabilistic strength analysis on irradiated TRISO	Need to understand mechanisms	Still in need of development	-Mechanical Properties Testing				
N002	Determine Stress evolution in SiC TRISO shell under irradiation	Failure of TRISO is fundamental and still poorly understood	Not sure					
N003	Measure the tomography of highly irradiated fuel	Internal evolution of kernel and outer buffer to support modeling is critical	Tomography of some fuel at ORNL. Capability should be expanded and exploited.	-Atomic Scale Tomography	Partial	ORNL		
N005	Measure residual stress of compact for SiC matrix application	As irradiated, stress will evolve in compact leading to stress, let's look at stress	A group should be formed to look for a way to map residual stress in compacts	-SiC Residual Stress				

Need-ID	Technical Need: (What)	Basis: (Why)	Solution: (How, Who, Where)	Processes	Allocation			
					Current Capability	Location	Future Capability	Location
N013	Measure pyrocarbon properties evolution such as anisotropy and density	Shielded equipment to determine effect of irradiation on properties	Shielded PIE equipment	-Density / Weight values				
N024	Measure the micro structure, mechanical properties, Impurities and their distribution in 3-D	Starting point for the simulations	Record keeping from the birth to irradiation. characterization BD x-ray tomography and microstructure reconstruction	-High Resolution Chemical and Electronic Microscopy and Chemical Analysis -Mechanical Properties Testing				
N031	Measure atomic potential	Link to mesoscale models	Nano-indenter. AFM	-Surface Morphology -Nano Indenter				
N041	Measure large sections of irradiated clad fuels tomography in micrometers	For stochastic DIBN of failures the interesting science occurs at a limited # of locations	High energy x-ray tomography on clad fuel is possible but needs SXR Not sure how much potential there is for neutron tomography	-Neutron Radiography -Crystal Structure Analysis				
N059	Measure fuel pin dimensions	Dimensional swelling or contraction is important phenomena. Non destructive, whole pin information is important to collect early in PIE.	Existing dimensional measurement for miniature rockets (full size?) at HFEF	-Element Contact Profilometry System	X	INL-HFEF		

Need-ID	Technical Need: (What)	Basis: (Why)	Solution: (How, Who, Where)	Processes	Allocation			
					Current Capability	Location	Future Capability	Location
N060	Measure fuel pin surface features	Need to examine surface of fuel pin to look for evidence of interaction with reactor coolant or severe interaction with fuel (on inside)	Photographic capabilities exist at HFEF	-Visual Examination	X	INL-HFEF		
N066	Measure fuel density	Want to compare fuel density before & after irradiation as a measure of fuel swelling. May also tell us about phase changes (M&S)	Immersion density	-Density / Weight values	X	INL-HFEF INL-AL		
N077	Determine mechanical properties of regions of microstructure (hardness), cladding (strength, ductility) and of coatings (scratch resistances)	Validate FCMI analysis, effectiveness of liners & coatings, behavior of fuel at ultra high flux with its inventory of solid (et.al.) FPs		-Mechanical Properties of Microstructure				
N090	Determine the irradiation effected properties at high DPA (note: Several of the SMRs designs exceed the DPA of best cladding HT-9, and most capabilities are in place except for irradiation enhanced creep).	Creep data are necessary to model fuel pin diameter change to understand failure mechanisms	The capability to measure and reconstitute experiment to measure creep as a function of time, or in the long-term measure creep in reactors	-Mechanical Properties Testing	Partial	INL-HFEF ORNL ANL LANL	X	IMCL

Need-ID	Technical Need: (What)	Basis: (Why)	Solution: (How, Who, Where)	Processes	Allocation			
					Current Capability	Location	Future Capability	Location
N100	Determine the mechanical characterization of grain boundaries as a function of dose	Fundamental understanding of mechanical characteristics and maybe new alloy development	Starting down this path at INL w/nano-indenter, AFM. Need highly trained staff	-Surface Morphology -Nano Indenter	Partial	INL-CAES	X	INL-APEX
N101	Determine the full mechanical and physical properties of irradiated materials	Provides data to the licensing process	Various capabilities in DOE complex and universities	-Mechanical Properties Testing	Partial	INL-HFEF INL-AL	Partial	INL-IMCL INL-APEX
N116	Provide In-cell mechanical properties testing on materials	Clad properties	In process at ORNL	-Mechanical Properties Testing	X	INL-HFEF ANL ORNL	X	INL-IMCL
N117	Measure fuel mechanical properties by testing nano-indentation, flex, and vibration on used fuel.	Future fuel properties for advanced fuel / fission products		-Nano Indenter -Mechanical Properties Testing -Flex and vibration			Partial	INL-APEX
N136	Measure weight and Dissolution			-Density / Weight values	X	INL-AL	X	INL-APEX

2.1.7 In-Situ

Need-ID	Technical Need: (What)	Basis: (Why)	Solution: (How, Who, Where)	Processes	Allocation			
					Current Capability	Location	Future Capability	Location
N021	Ability to reconstitute fueled or material tests with in-situ measurement capabilities	Allows for re-irradiation after initial examination		-Sample Preparation			Partial	INL-HFEF

Need-ID	Technical Need: (What)	Basis: (Why)	Solution: (How, Who, Where)	Processes	Allocation			
					Current Capability	Location	Future Capability	Location
N035	In-situ analysis on irradiated specific set (e.g., F.G. release mechanisms and pathways)	Validate models	In-situ TEM (irradiate while observing effects & mechanisms) @ ANL		Partial	ANL		
N040	In-situ micro strain measurements of irradiated materials under various temperature conditions	Micro structural Informal models of mechanical behavior rely on crystallization of strain to elucidate creep/mechanical strength	Loading MMLs are possible at SXR, neutron and using conventional x-ray diffusion. Use SXR, neutron preference because of bulk penetration		Partial	SXR		
N042	In-situ on defect density types in a wide range of materials including simple elemental system	Volume averaged defects are a good filter for essential radiation tolerance and potentially more cost effective to study than TEM - breadth of material including simple model system crucial for insight	Diffraction Line broadening studies can be insightful - needs high resolution					

Need-ID	Technical Need: (What)	Basis: (Why)	Solution: (How, Who, Where)	Processes	Allocation			
					Current Capability	Location	Future Capability	Location
N046	In-situ characterization of mechanisms such as gas bubble dissolution in the bulk and on grain boundaries and mechanisms of gas bubble coalescence in the bulk and on grain boundaries (etc.)	In-situ techniques (ion beam substituting in-reactor irradiations) have limitations. However, in-situ ion irradiations can be very informative on interpretation of Mechanisms that can hardly be understood well only by PIE complementary experiments. This will be strong if it is conducted on reactor irradiated materials.						
N076	Measure microstructure with high resolution of grain boundaries, micro cracks, porosity, size distribution, and composition information	Micro/macro scale fuel changes during irradiation and during transients to model development/valid Leading to modeling of FCMI						
N177	Identify the location of failed rod	Establish clad / fuel initial condition of fuel going in.						

2.1.8 Modeling and Simulation

Need-ID	Technical Need: (What)	Basis: (Why)	Solution: (How, Who, Where)	Processes	Allocation			
					Current Capability	Location	Future Capability	Location
N025	Develop time and spatial evolution under gradient fields	Provide correct boundary conditions for modeling and simulation effort	Correct analysis of irradiation conditions: temp, time, stress strain, dose etc.					
N026	Develop and correlate collective and cooperative behaviors	Bulk properties after irradiation	Bulk characterization or the same material					
N032	Measure defect characteristics of irradiated materials	Link to atomic and mesoscale models	Position annihilation	-Voids and Defects Analysis			Partial	INL-APEX
N130	Address data generation, storage, dissemination, control, management, data and knowledge transfer.	Without proper management and dissemination of data to the right people its value will be lost.	Manage data and plan early to do so.					

2.1.9 Infrastructure

Need-ID	Technical Need: (What)	Basis: (Why)	Solution: (How, Who, Where)	Processes	Allocation			
					Current Capability	Location	Future Capability	Location
N022	Ability to accept a wide variety of specimen sizes and containers/casks	Allows for as much flexibility as possible		-Small Cask Receiving -Large Cask Receiving	Partial	INL-HFEF ORNL		
N023	Segment capabilities as much as practical	Avoid simple point failures for facility/capability access						
N036	Ability to store samples in inert conditions				X	INL-HFEF	X	INL-APEX

Need-ID	Technical Need: (What)	Basis: (Why)	Solution: (How, Who, Where)	Processes	Allocation			
					Current Capability	Location	Future Capability	Location
N047	Ability to collect and archive data	Use throughout R.D community to future	Establish a national archive				X	INL-User Facility
N048	Ability to transmit data	Near term testing analysis	Open web based				X	INL-User Facility
N049	Ability to store and archive samples	Repeat future measurement/modeling	On site sample storage		X	INL-HFEF	X	INL-APEX
N050	Ability to verify data	Independent analysis	Use independent process					
N069	Improve in cell thermal capabilities that allow bringing higher decay heat samples into the hot cell w/o challenging the integrity of the sample	Could examine fuel removed from a reactor quicker		-Micro-Scale Analysis				
N071	Develop low maintenance, high capability manipulators for remote handling or robotics	Current models are very high maintenance. Hard to change out. Newer models, with less maintenance, are less capable then older technology.	Work with manufacturers to collaborate on new designs.					
N088	New hot cells should have an inert (Argon) atmosphere	Any perceived experiment on metal fuel requires an inert atmosphere, with HFEF being the only inert cell	Inert newly proposed hot cells		X	INL-HFEF	X	INL-APEX
N092	A system and procedures need to be in place to assume the accuracy of both unirradiated and irradiated materials	For both understanding and eventual licensing archiving is necessary	Exam creep in existing system and improve upon it.					

Need-ID	Technical Need: (What)	Basis: (Why)	Solution: (How, Who, Where)	Processes	Allocation			
					Current Capability	Location	Future Capability	Location
N093	Measure IASCC susceptibility and crack growth rate on materials >20dpa to determine synergistic effect of irradiation at a rate of 2-3 tests/yr	Licensing >60 year Disposition of in-service cracks	Autoclaves in load frames to test SCC properties ANL, INL GE methodology Studsvik, JAEA	-Irradiation Assisted Stress Corrosion Cracking Analysis	Partial	ANL	Partial	INL-FASB
N106	New hot cell:	Perform various NDA exams on rods / assemblies	INLs HFEF can handle full length rods and intact assemblies					
N107	A hot cell capability to handle full length rods / assemblies	Enable fuel exams and provide disposal path because vendors / utilities can't take material back	INL can receive, store and dispose of limited quantities of commercial fuel	-Cell 3-M, 6-M, 10-M and 11-M disassembly -Large Cask Receiving	X	INL-HFEF		
N108	Develop the ability to manage, store and dispose of exam materials and fuel remnants				Partial	INL-HFEF		
N112	Capability to automate analysis of images	Data reduction	Like available but not used on fuels					
N118	Provide analysis of rapid response to failure	-Required per CFR						
N119	Perform analysis to better understand late blooming material degradation	-Failure phenomena that we currently don't understand						

Need-ID	Technical Need: (What)	Basis: (Why)	Solution: (How, Who, Where)	Processes	Allocation			
					Current Capability	Location	Future Capability	Location
N120	Ability to handle large scale fuel samples (14 - 16 ft)	-Fuel size is large		-Cell 3-M, 6-M, 10-M and 11-M disassembly -Large Cask Receiving	Partial	INL-HFEF		
N121	Develop a process of working between labs and industry	-Time and cost are big factors			Partial	INL-NSUF	X	INL-NSUF
N122	Develop a data library	-Much data already exists just need access to it						
N123	Generate a library samples	-Both irradiated and unirradiated to support reanalysis and follow up studies			Partial	NSUF		
N125	Through put to greater than or equal to 5 sets a material per year	"Late blooming phases"	[to 0.1 dpa]					
N138	Recover Fuel Assemblies from cask			-Small Cask Receiving -Large Cask Receiving	X	INL-HFEF		
N139	Provide removal of fuel rods			-Large Cask Receiving	X	INL-HFEF		
N140	Reduce the size of the PIE hardware			-Cell 3-M, 6-M, 10-M and 11-M disassembly	X	INL-HFEF		
N141	Ability to perform decontamination on cells							

Need-ID	Technical Need: (What)	Basis: (Why)	Solution: (How, Who, Where)	Processes	Allocation			
					Current Capability	Location	Future Capability	Location
N142	Reduce the disposal size and packaging of waste			-Waste Treatment Packing and Disposal				
N144	Ability to manage materials							
N145	Provide IR Tags							
N146	Ability to handle Cask			-Small Cask Receiving -Large Cask Receiving	X	INL-HFEF ORNL		
N163	Capability to handle full length fuel rods		PIE site would ideally own a cask that can be licensed for fuel shipments from utility to a DOE PIE lab. DOE would coordinate shipment as well as PIE (like Studsvik does)	-Cell 3-M, 6-M, 10-M and 11-M disassembly -Large Cask Receiving	X	INL-HFEF		
N164	Ability to perform PIE on assembly or skeleton				Partial	INL-HFEF		
N174	Ability to perform non destructive examination pre-storage assembly	Remote O2, Dr-85	Measure assembly and rod bowing		X	INL-HFEF		

2.1.10 Other / Miscellaneous

Need-ID	Technical Need: (What)	Basis: (Why)	Solution: (How, Who, Where)	Processes	Allocation			
					Current Capability	Location	Future Capability	Location
N008	Measure LOCA for application relating to Light Water Reactors (LWR)						Partial	ORNL
N009	Determine internal TRISO gas pressure and gas species as well as high temperature iodine release						Partial	INL-APEX
N014	Measure gamma tomography of fission products in graphite			-Atomic Scale Tomography				
N126		Apply to vessel integrity at life beyond 60						
N127	Measure degradation of reactor vessel internal properties and the changes that accompany them at a rate at least one set of materials per year	Property database. Understand key material & exposure inputs (quantitative effects statistically valid)and variables separable	Coordinate test programs consistent test methods good "prior to test" materials characterization					
N166		Distribution of noble metal particles.						
N175	Identify if failed fuel rods contain water and how much	Temp sensors						

Need-ID	Technical Need: (What)	Basis: (Why)	Solution: (How, Who, Where)	Processes	Allocation			
					Current Capability	Location	Future Capability	Location
N178	Ability to perform non destructive examination a few rods using Profilometry, Fission gas – puncture, Oxide thickness, Gamma scan, Segment rod, metallography, ceramography, H2 content, SEM microscopy, ion probe	Capability of receiving an entire assembly	Creep analysis		X	INL-HFEF INL-AL INL-EML INL-CAES ORNL	X	INL-HFEF INL-APEX INL-IMCL
N183			Particulate 3 mm to 0.1 micro meter					

2.2 Long-Term Needs

This section captures the long-term capabilities needed to provide national PIE services for current and future customers beyond ten years. The objective is to support highly irradiated nuclear fuels and materials research for projects and programs with extended future requirements for PIE capabilities, including nano-and micro-scale techniques and sophisticated instrumentation under irradiation conditions.

2.2.1 Non-Destructive Examination

Need-ID	Technical Need: (What)	Basis: (Why)	Solution: (How, Who, Where)	Allocation			
				Current Capability	Location	Future Capability	Location
LTN26	Perform bow and length measure on full assemblies to support new reactors as well existing LWRs	Reactivity and fuel handling forces are imported by assembly distortion	None exist. In the past we had the VAD, partial assembly & disassembly machine	X	INL-HFEF		
LTN27	Measure bundle interactions in a full assembly that can be reviewed with neutron radiography tomography	Bundle interactions may be life limiting for the fuel prior To individual cladding breach	Capability may exist	Partial	INL-HFEF		

2.2.2 Microstructure, Phase and Property Analysis

Need-ID	Technical Need: (What)?	Basis: (Why)	Solution: (How, Who, Where)	Allocation			
				Current Capability	Location	Future Capability	Location
LTN18	Measure microstructure and microchemistry of fuel and materials pre and postirradiation in 3-D as function of irradiation condition	- Understand irradiation effects on microstructure & microchemistry - Use to validate models	- Atom probe (INL,?) - Light sources (ANL, BNL) - Neutron sources (LANL) - PAS	Partial	INL-CAES ANL BNL LANL	Partial	ANL BNL
LTN29	Measure void swelling					Partial	INL-APEX
LTN36	Measure property development using short term instruments	validation					
LTN45	Measure hydride embrittlement					X	INL-APEX
LTN46	Perform analysis on low Internal components baffles, shrouds, bolts, CDRM nozzles, instrumentation tubes	Life beyond 60 – License extension considerations – safety *materials degradation beyond current 40 year expectancy. SCC, void formation, volumetric changes	- FIB - sample prep - SIMS - micro chemistry - Auger Microscope - Electron Backscatter			X	INL-APEX
LTN47	Measure LWR pressure boundary components	Degradation mechanisms need to be understood to enable mitigation processes and effective inspection processes	- Analytical TEM - Atom Probe Tomography Fatigue data – Vibration correlations to aging / dpa and weld performance			X	INL-APEX
LTN50	Measure grains and grain boundaries in 3-D as well as other microstructural features	Allows direct comparison to computations at nano and mesoscale engineering	Improve tomography (maybe light sources)				

2.2.3 Chemical, Isotope, and Radiological Analysis

Need-ID	Technical Need: (What)	Basis: (Why)	Solution: (How, Who, Where)	Allocation			
				Current Capability	Location	Future Capability	Location
LTN01	Measure oxidation and steam reactions, under irradiated conditions, for graphite and SiC matrix TRISO fuels		Both hot cell, bench-top, and in-reactor facilities				
LTN02	Measure corrosion effects specific to advanced coolant applications such as fluoride salt						
LTN03	Measure coalescence of fission gas bubble	To validate fission gas release model	X-ray (or other) tomographic microscopy of irradiated fuels to higher resolution			Partial	INL-APEX
LTN05	Measure pressure in fission gas bubbles	Needed for FGR model	X-ray small angle scattering. Ex. X-ray absorption spectroscopy				
LTN06	Analyze chemical and structural evolution of CRUD in LWR cladding	Validate understanding & drive development of physically-based models	Requires detailed characterization of highly radioactive materials	Partial	INL-AL INL-EML	X	INL-APEX
LTN08	Perform trace gas analysis in pole with a microscope		Mass spec attached to microscope				
LTN21	Measure compositional analysis across few nano meters subsurface	Link to atomistic & mesoscale model	Rutherford back - scatter spectroscopy				
LTN38	Measure real time gas and fission product XYA mapping						

2.2.4 Thermal Property Examination

Need-ID	Technical Need: (What)	Basis: (Why)	Solution: (How, Who, Where)	Allocation			
				Current Capability	Location	Future Capability	Location
LTN04	Measure diffusivity vs. burnup	Needed for FGR model				X	INL-APEX
LTN13	Measure 3-d distribution of temperature and strain in neutron irradiation environment for prototype	Direct engineering scale validation of new fuel type geometries can accelerate certification	Does LTD CAP in SITU now for temp				
LTN15	Measure thermal properties of an engineering prototype in 3-D using non destructive tests	This is where the rubber hits the road	Needs segmented R&D				

2.2.5 Mechanical Properties

Need-ID	Technical Need: (What)	Basis: (Why)	Solution: (How, Who, Where)	Allocation			
				Current Capability	Location	Future Capability	Location
LTN19	Measure thermophysical and mechanical properties of pre and postirradiated materials and fuels in 3-D	- Understand changes in mechanical & thermophysical properties as function of irradiation conditions - Use to validate models	- Light sources?			Partial	INL-APEX
LTN34	Perform environmental strain measurements	Material constitutive properties are needed for modeling	Most likely optimum solution			Partial	INL-IMCL
LTN35	measure mechanical properties of high dose (200+ dpa) materials in fast reactors with shielded characterization equipment	Validation of predictions Provide any growth for months (no data extent)		Partial	INL-HFEF ANL LANL	X	INL-IMCL

Need-ID	Technical Need: (What)	Basis: (Why)	Solution: (How, Who, Where)	Allocation			
				Current Capability	Location	Future Capability	Location
LTN43	Measure corrosion and mechanical behavior of fuel rod welds.	For storage	Capabilities exist	Partial	INL-HFEF ANL LANL	Partial	INL-IMCL
LTN48	Develop other containment structures that could include reinforced concrete, fuel pool liners, racks, components and dry storage casks and seals	Life-expectancy considerations For safety and containment.					

2.2.6 In-Situ

Need-ID	Technical Need: (What)	Basis: (Why)	Solution: (How, Who, Where)	Allocation			
				Current Capability	Location	Future Capability	Location
LTN07	Capabilities to probe defect and chemical evolution at micro meter scale during irradiation	Validate understanding & drive model development	New capabilities possibly required - chemical mapping beyond scope of IVEM?				
LTN14	Ability to observe of nucleation of bubbles under heating over volumes involving many grains in 3-D	Kinetics of Bubble Nucleation	Potential opportunities using coherent X-ray diffractive imagery ~~Might provide a movie - but sources necessary in its infancy~~				
LTN23	Perform mechanical, microstructure and damage evolution experiments under irradiation condition	For time and spatial correlation and validation of modeling					
LTN30	Measure IASCC in-reactor tests CGR synergistic effects of environment and irradiation	Validation	Halden, JAEA,				

Need-ID	Technical Need: (What)	Basis: (Why)	Solution: (How, Who, Where)	Allocation			
				Current Capability	Location	Future Capability	Location
LTN31	Measure and monitoring material properties in reactor						
LTN32	Atomic level displacements while under irradiation chemistry effects on material properties						
LTN33	Perform in-reactor CGR testing in test reactor	Real time measurement of crack growth in actual environment (neutron & chemical)	Can be built at test reactor. JAEA and Halden may already do this				
LTN37	Perform in-situ testing to complete image of rad damage grain by grain		Microtomography				
LTN51	Perform direct imaging of radiation cascades	Provide ability to understand initiating event for rad damage	FEL based systems				
LTN52	Perform direct imaging of corrosion reactions including under rad or on rad materials	Basic understanding of environmental effects	New facility maybe on a neutron scattering or light source				
LTN54	Ability to extract fuel rods periodically						

2.2.7 Modeling and Simulation

Need-ID	Technical Need: (What)	Basis: (Why)	Solution: (How, Who, Where),	Allocation			
				Current Capability	Location	Future Capability	Location
LTN09	Measure real-time modeling simulation of fuel performance	Shorten timeline for Fuel Performance Certification	INL/other scientists			X	DOE Labs
LTN10	Perform real-time testing to validate models	Shorten timeline for Fuel Performance Certification	INL/other scientists			X	INL Labs
LTN41	Develop statistically valid distribution of features					X	INL-APEX

2.2.8 Infrastructure

Need-ID	Technical Need: (What)	Basis: (Why)	Solution: (How, Who, Where)	Allocation			
				Current Capability	Location	Future Capability	Location
LTN24	Develop remote handling systems that are better able to simulate human hand movements and translate in a remote capability (computer enhanced similar to current Wii technology)	Would require less training to allow individuals from any background/skill to manipulate in-cell exams, etc.	Don't know what the industry's current capabilities are				
LTN25	Increase thru-put and reduce in-cell down-time of m/s manipulators by employing PIE measuring exam devices that can be operated "fly-by-wire" from outside the cell (although this may result in a more - complex in-cell system)						
LTN39	Develop Long term disposal, storage and ownership of the samples	- Supports sample transfer		Partial	INL	Partial	INL
LTN40	Measure material composition & processing parameters that govern irradiation induced changes in highly irradiated materials including large sample material handling, tolerance on compositions, and Material sectioning	Control & selection of materials for new plants Sorting of materials (as classes) for life prediction of old plants	Advanced microstructural & micro dimensional characterization capabilities [to ~ 100 dpa] Remote / robotics sample prep.			Partial	INL-APEX
LTN42	Determine the long term effect of hydrogen in cladding during storage, and the predictability of hydride orientation	For the integrity of fuel rod during storage especially dry storage	Existing capabilities may suffice but multiple exams necessary	Partial	INL ORNL ANL	X	INL-APEX

Need-ID	Technical Need: (What)	Basis: (Why)	Solution: (How, Who, Where)	Allocation			
				Current Capability	Location	Future Capability	Location
LTN44	Provide long-term storage behavior of irradiated Fuel as a function of hydride reorientation					Partial	INL-APEX

2.2.9 Other / Miscellaneous

Need-ID	Technical Need: (What)	Basis: (Why)	Solution: (How, Who, Where)	Allocation			
				Current Capability	Location	Future Capability	Location
LTN11	Obtain a full suite of fuel characterization equipment	Future	National archives			X	INL-APEX INL-IMCL INL-HFEF
LTN12	Make all Data commercial available	Validation	Restrictive/National Lab				
LTN16	All of the short-term needs, but w/ radiation effects including a path dependence of material properties WRT	Model validation fuel design etc.	No current in-situ facilities Rabbits at HFIR	Partial	ORNL-HFIR	Partial	INL-ATR
LTN17	Measure the micro structure and composition as a function of irradiation compared to "cold" composition and microstructure		Shuttle at ATR				
LTN20	Specific sets						
LTN22	Measure material parameters by estimating by back simulation not forward	link to various exp data (quantified)	Superfast computers			Partial	DOE labs (NEAMS)
LTN28	RIS						
LTN49	Analyze the characterization of very high burnup fuel and cladding	Very high burnup data does not exist. Data will be used for fuel improvement.	All equipment used in short-term projects will be needed.	Partial	INL ORNL	X	INL-APEX INL-IMCL
LTN53	Same as short term						

3. VERIFICATION

Needs verification confirms that all elements of the PIE capabilities perform their intended functions and meet the performance requirements allocated to them. The goal is to verify the national PIE capability to meet all requirements prior to production and operation. The national PIE development effort will consider the needs defined in Section 2 and determine the extent of implementation as a result of new and upgraded PIE facilities, equipment, and expertise. Acceptable verification methods include:

- *Review*. Used in the context of a technical design review, a group of technically competent individuals examines system designs critically to verify that all activities correspond to project requirements at the appropriate stage of the system life cycle.
- *Test*. Test denotes the determination, by technical means, of the properties or elements of items, including functional operation, and involves the application of established scientific principles and procedures. The item is subjected to a systems series of planned stimulations, often using special test equipment.
- *Analysis*. Analysis uses established technical or mathematical models or simulations, algorithms, charts, graphs, circuit diagrams, or other scientific principles and procedures to provide evidence that stated requirements were met.
- *Demonstration*. Demonstration is an element of verification or inspection that generally denotes the actual operation, adjustment, or reconfiguration of items to provide evidence the designed functions were accomplished under specific scenarios.
- *Examination*. Examination is generally nondestructive and includes the use of sight, hearing, smell, touch, and simple physical manipulation; mechanical and electrical gauging and measurement; and other forms of investigation. Examination may also include review of descriptive documentation and comparison of item features and characteristics with predetermined standards to determine conformance to requirements without the use of special laboratory equipment of procedures.
- *Similarity*. One way to avoid a new qualification process for an item is to claim that the requirements have been verified by similarity between the current requirements and those of a prior system.
- *Simulation*. More and more often, requirements are proven satisfied in a design by simulation. This is a valid approach when it is very difficult to set up the conditions in the real world and the simulation adequately reflects real-world conditions.

4. IMPLEMENTATION

The next step in the assessment process is to perform alternative analysis to identify options to meet the needs. The center point for the alternatives analysis is driven by the CD-0 Mission Analysis document issued in January 2011. These needs will be used to inform the alternatives analysis of the future projects that will be designed to meet the national needs for PIE.

5. REFERENCES

1. DOE-NE, *Mission Need Statement for Advanced Postirradiation Examination Capability: A Non-Major System Acquisition Project,* U.S. Department of Energy Office of Nuclear Energy, Washington, D.C., January 2011.
2. DOE, *Strategic Plan*, DOE/CF-0067, U.S. Department of Energy, Washington, D.C, May 2011.
3. DOE-NE, *Nuclear Energy Research and Development Roadmap, Report to Congress.* U.S. Department of Energy Office of Nuclear Energy, Washington, D.C., April 2010.
4. Idaho National Laboratory, *National Postirradiation Examination Workshop Report*, June 1, 2011, INL/EXT-11-21922