Simple SE Methods Deployed in Revitalizing the Nuclear Post- Irradiation Examination Capability for the Idaho National Laboratory

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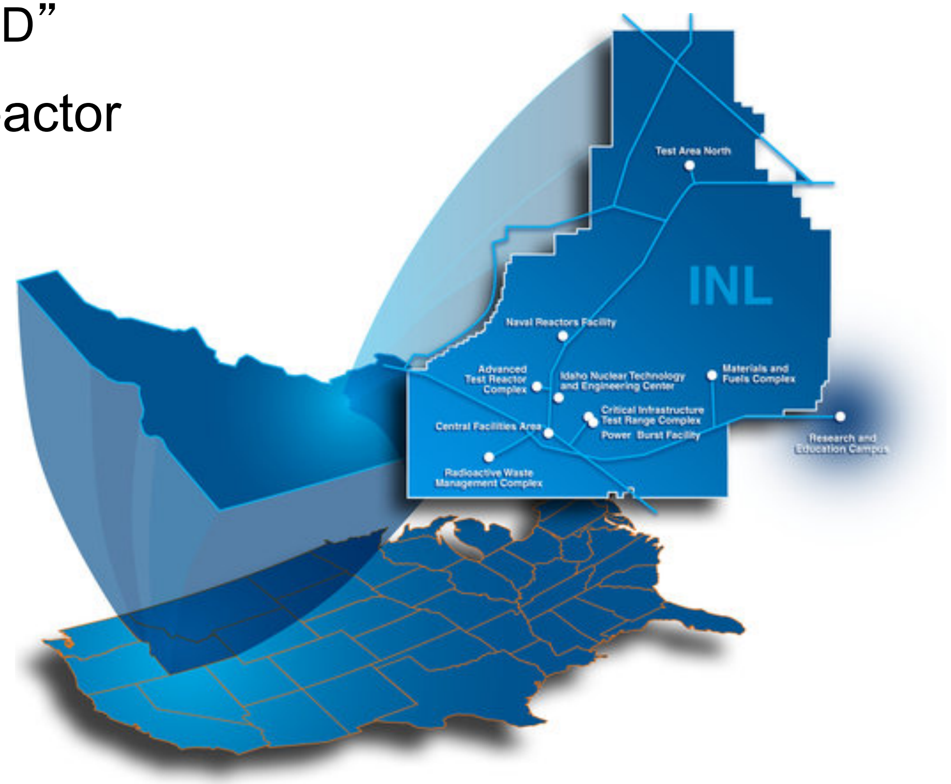
Idaho National Laboratory

Introduction

- SE is still immature and misunderstood in many industries and fields of study
- Team of systems engineers at the Idaho National Laboratory (INL) **adapted simple SE tools and techniques** for a customer unfamiliar with the power, effectiveness, or culture of SE to achieve project success

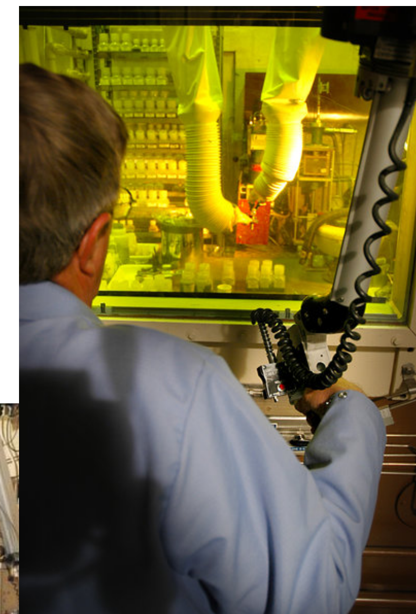
Idaho National Laboratory

- Nation's only DOE facility with …
  - Core mission of supporting the development of nuclear energy
  - Primary strategic objective of "excellence in nuclear fuels R&D"
- Operates the Advanced Test Reactor (ATR) to research and validate reactor fuel concepts
- INL Post Irradiation Examination (PIE) facilities and research staff have been the **"crown jewels" of nuclear energy research** for 40 years



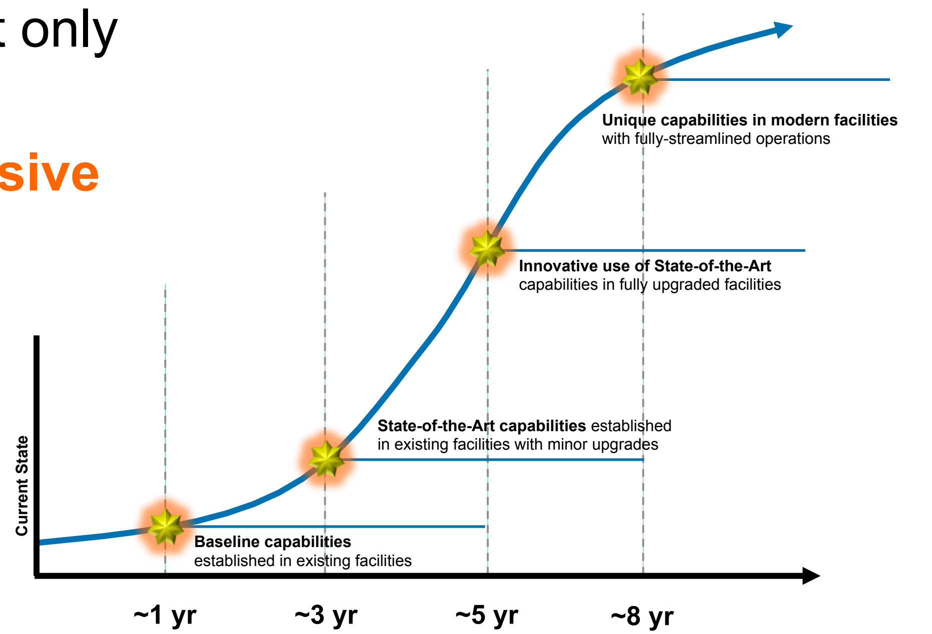
Post-Irradiation Examination

- "Post-mortem" examination of nuclear fuel elements or rods after they have been in an operating reactor
- PIE determines:
  - "Burn-up" and structural integrity of used fuel elements
  - Effectiveness of new fuels and alloys in generating nuclear energy
- PIE is **critical to nuclear reactor fuels research**
- Nuclear renaissance forces need for immediate enhancements to current PIE capabilities



PIE Four-Step Strategy

- Multi-step approach:
  - **Refurbish the baseline** PIE capabilities to provide ***basic services***
  - **Upgrade facilities** and procure new equipment to move into a ***state-of-the-art PIE capability*** that leads the nation
  - **Develop expertise and innovative use of equipment** available at only a few locations in the world
  - **Develop unique, comprehensive capabilities** that do not exist elsewhere



PIE Dilemma

- Existing facilities and equipment are in a **state of disrepair**
- Long-term **reduced funding** adversely affects readiness and effectiveness of existing facilities and equipment
- Aging **infrastructure not capable of supporting growing demands**
- PIE research scientists **want "top-of-the-line"** diagnostic equipment

BUT …

- Capabilities, equipment, requirements, or staffing **needs not defined**
- Formal engineering or budget-based needs statements not established
- Adequate/justifiable funding requests not submitted

Applying SE Tools and Methods

- Team of SEs deployed to investigate and remediate the dilemma
- SE team adapted four basic SE tools or methods
  - **Mission analysis and scoping** of existing PIE systems and capabilities
  - **Functional flow block diagram** showing flow of PIE functions
  - **Technical and functional requirements** (T&FRs) for PIE capabilities at each phase of the strategy
  - **Allocation of functions and requirements** to PIE equipment, facilities, staffing, and future equipment needs

Understanding the Problem

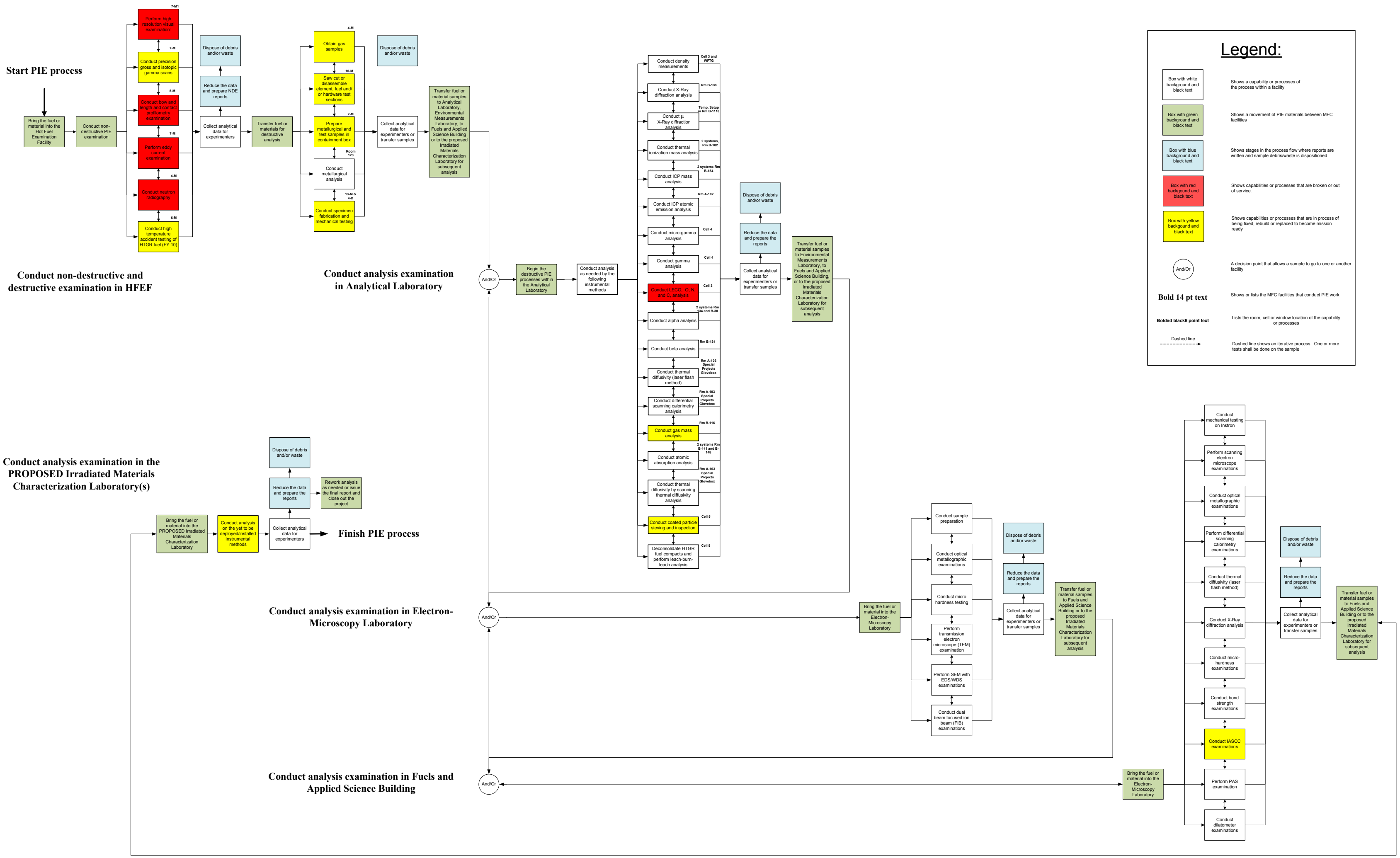
Initial Assessment of Systems and Capabilities

- Matrix of initial systems and capabilities
- **One-on-one interviews** to capture information and needs
- Difficulty getting SMEs to **focus on "needs" rather than "solutions"**

Functions		Requirements							Equipment		Status				POC
Capability	Description	Technique	Quality of Data	Throughput	Precision/Accuracy	Human Skills and Expertise	Fuel Type	Notes	Instrument (s)	Location	Status (working or not)	Current Reliability	Current Operability	Needs	Point of Contact
Characterize surface appearance of cladding	Provide a surface condition characterization of cladding and assemblies via visual examinations and photographs.	high resolution visual examination and photography with periscope.	Magnification <25X	5 elements/day	Photos with > / = 6 MP	Trained technicians	Fuel elements or plates	Cladding examination is typically performed at wind 7-1M, but photographs can be conducted through any	through-wall periscope and attached camera Visual Examination Machine	HFEF, between Windows 7M&8M	Not working	Poor	Not functional	Most periscopes in HFEF in need of critical maintenance. Clean the periscope (mirrors, general service); new	Doug Pace
	Provide a surface condition characterization of cladding and assemblies via visual	high magnification direct photography through window	Magnification depends on need	5 elements/day	Photos with > / = 6 MP	Trained technicians	Fuel elements or plates	Can be done at any window.	direct photography with hand held camera	HFEF, any window	Depends on camera	Depends on camera	Depends on camera		Doug Pace
	Provide a surface condition characterization of cladding and assemblies via		Magnification depends on need	5 elements/day	Photos with > / = 6 MP	Trained technicians	Fuel elements or plates	Can be done through any periscope.	through-wall digital camera	HFEF, any window	TBD	TBD	TBD	Cameras are available. NGNP program intends to purchase a dedicated camera	Doug Pace
Measure relative burn up profile	Provide a gross gamma value	axial gamma spectroscopy	gross and isotopic gamma scans of whole irradiation test train: 2D scans of capsule	1 test train/year	Test and isotope dependent	Trained technicians	Fuel elements or plates		Precision gamma scanner	HFEF, Windows 6M&7M	Working	Poor	Difficult	Needs renovation or replacement. Simply fixing the existing PGS will not meet	Bruce Hilton
Measure relative isotopic profile distribution	Shows axial migration, e.g. Cs	axial gamma spectroscopy	2D scans of capsule components;	1 test train/year	Test and isotope dependent.	Trained technicians	Fuel elements or plates		Precision gamma scanner	HFEF, Windows 6M&7M	Working	Poor	Difficult	Needs renovation or replacement. Simply fixing the existing PGS will not meet	Bruce Hilton
	Shows radial migration, e.g. Cs	radial gamma spectroscopy	2D scans of capsule components	Test and isotope dependent	Test and isotope dependent	Trained technicians	Fuel elements or plates	Radial system is not yet developed	Precision gamma scanner with modifications	HFEF, Windows 6M&7M	Working	Poor	Difficult	The radial system needs to be developed.	Bruce Hilton
Measure qualitative isotopic measurements	Quantitative gamma spectroscopy	Quantitative scans of fuel compacts and capsule components (graphite bodies,	2D scans of capsule components	640 graphic holder/year 36 compacts/years	0.001 repeatability and accuracy of +/- 1KEV	Trained technicians	Coated particle fuel compacts, and irradiated capsule components	Fission products of interest include gamma emissions in the range of 0.04 to 1.5 MeV,	Precision gamma scanner with modifications	HFEF, Windows 6M&7M	Working	Poor	Difficult	Scheduled for 2009 work.	Paul Demkowicz

← ***Capabilities and Measures*** | ***Equipment and Status*** →

Showing the Big Picture



Establishing Requirements

- **Baseline T&FRs** to support fuel and material development
- Decomposed according to **strategic phase** and the **type of PIE**
- **Education of customers** was a constant focus:
  - SMEs kept asking where the equipment was listed
  - Had to be reminded that T&FRs are about identifying **what must be done** and **how well**
  - **Solutions come later**.

3.1 Non-Destructive Examination

3.1.1 Characterize surface appearance of irradiated materials – Provide a surface condition macro-characterization of nuclear cladding, assemblies, and hardware via visual examinations and photographs.

3.1.1.1 Visual examination capability shall accommodate fuel elements, plates, and/or hardware items and other irradiated materials.

Justification: Photographs are required as part of the PIE record for visual examination of elements, fuel, or hardware items.

3.1.1.2 Macro images shall be at a magnification of ≤ 25X.

Justification: Higher magnifications (microscopic) shall be performed after the hardware items have been sectioned.

3.1.1.3 System shall be capable of recording digital images at a resolution of ≥ 6MP.

Justification: This resolution is adequate for enlarging the image without losing quality. With higher megapixels, more computer memory is required and transmission of photographs via email becomes problematic.

3.1.1.4 Visual examination shall be capable of imaging five (5) metal fuel or plate fuel elements per day.

Justification: The actual number of items or elements that can be imaged in a single day is a function of the size of those items or elements. Smaller, plate-type fuel elements (e.g., RERTR plates) can be examined quickly at high resolution.

Allocating Requirements

- Map T&FRs to existing PIE processes and equipment systems
- Ensure nothing was missed or overlooked
  - Multiple omissions became evident
- **Big picture graphic modified multiple times** to include omitted processes or equipment systems
- **T&FR text continuously expanded** to include corresponding functions and requirements that were likewise missed
- Data used to develop **mission needs documents** that will become the initial funding documents within the DOE business process

Project Success

- Efforts of the SE team with PIE scientists and engineers achieved unprecedented success:
  - Generated a **complete list of all PIE systems and equipment**
  - Compiled a **(wish) list of "realistic" replacement equipment** with associated schedules and cost estimates
  - Developed a **one-page FFBD of complete INL PIE processes** within five facilities and with an operational readiness color code
  - Defined nearly **$86 million in needed facility and infrastructure upgrades**, much of which was previously unknown or unidentified
  - Established **clear understanding of the size and complexity** of anticipated PIE renovations and the extent of work required
  - SE department **tasked with additional work**

Conclusion

- Did not force project to “start over”
- Did not get bogged by insisting the project to do things “our way”
- Used **simple techniques** to achieve defensible results
- Relied on **existing knowledge and background data**
- Became **part of the solution and path forward** rather than a hindrance or roadblock to progress

The ***key to long-term success*** in systems engineering is the ability to step into a project and provide quick, value-added, cost-effective assistance without hindering progress.