GEN IV International Forum℠

PERFORMANCE ASSESSMENTS FOR FUELS AND MATERIALS FOR ADVANCED NUCLEAR REACTORS

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28 May 2020

Meet the Presenter

Dr. Daniel LaBrier is an Assistant Professor of Nuclear Engineering at Idaho State University. He earned his doctorate in nuclear science and engineering from ISU in 2013, with an emphasis in irradiated materials characterization. His research focuses on characterizing nuclear-grade materials that are exposed to extreme environments and nuclear reactor safety projects, including investigation of corrosion and erosion of structural materials relevant to LWR and advanced (SFR, MSR, HTR) systems. His research interests include development and qualification of fuels and materials for advanced reactor concepts, investigating thermal hydraulic effects on material performance, and used fuel recycling techniques.

In the recent past, Dr. LaBrier has contributed to projects related to chemical effects testing for Generic Safety Issue (GSI)-191, materials testing capability development for the TREAT reactor restart, and design of advanced reactor testing systems. After serving as a post-doctoral fellow at the University of New Mexico and as a research professor at Oregon State University, Dr. LaBrier returned to ISU in March 2019 and maintains residence as a researcher at the Center for Advanced Energy Studies (CAES) in Idaho Falls, ID.

Idaho State University

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Disclaimer

- Views presented here are solely my own, and:
  - Do not support a particular reactor technology or pathway to deployment,
  - Do not necessarily support a specific entity, whether my home institution (Idaho State University), my funding partners, or any associated affiliates,
  - And are not supported financially by any entity.

Introduction

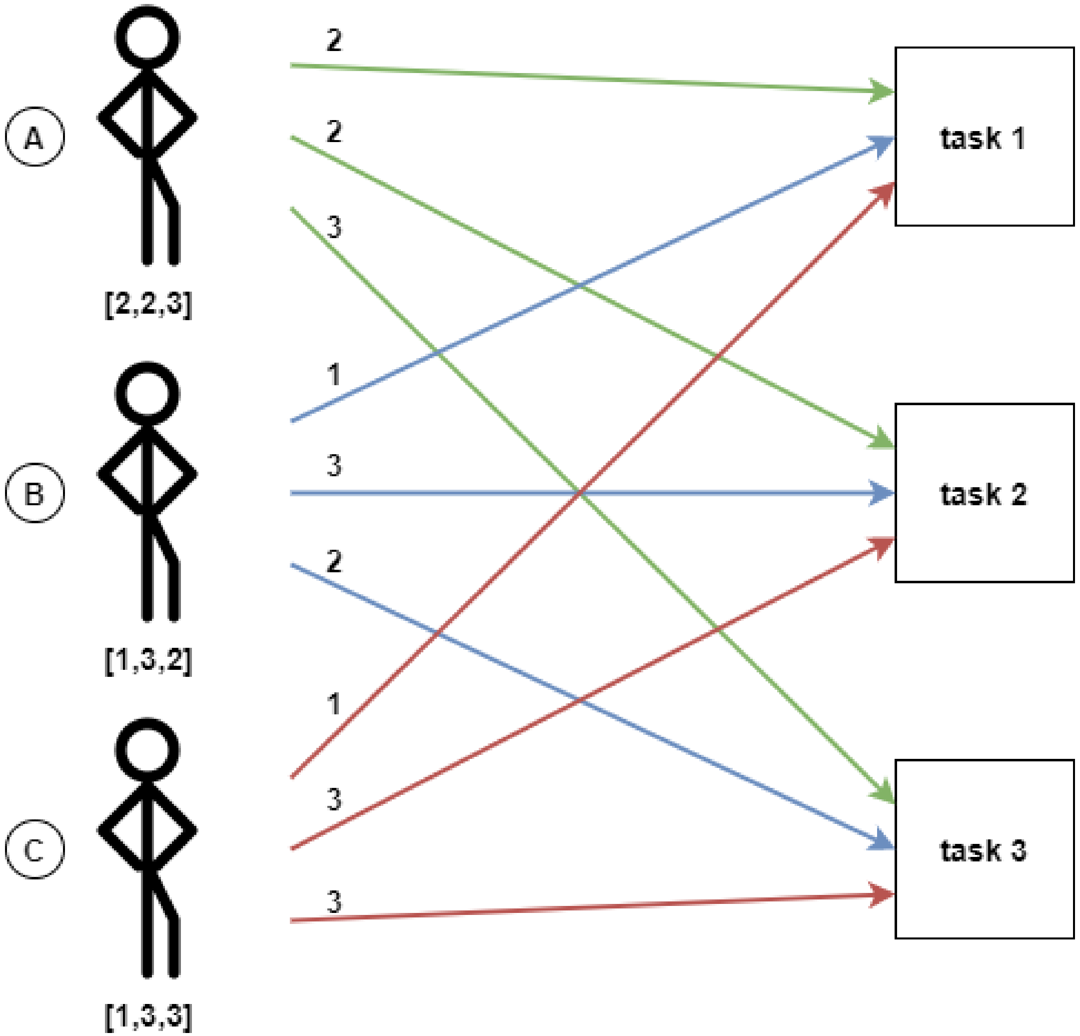
- A host of novel fuel and material concepts are being investigated as part of the GenIV reactor development initiative.
- While many of these candidates are rooted in historical programs from previous reactor development campaigns, most of these concepts were never fully evaluated for long-term performance in non-LWR facilities.

Introduction (cont.)

- Performance data that is needed for material downselection, feasibility studies, and eventual qualification is, currently, very costly in terms of monetary cost and human capital.
- The use of an '***all of the above***' strategy for performance assessment is needed to reduce the cost of ushering materials through the qualification process.
- In this presentation, we will discuss the efforts that are currently underway, and those planned for the near future, to advance many of these candidates from concept to deployment

Impetus

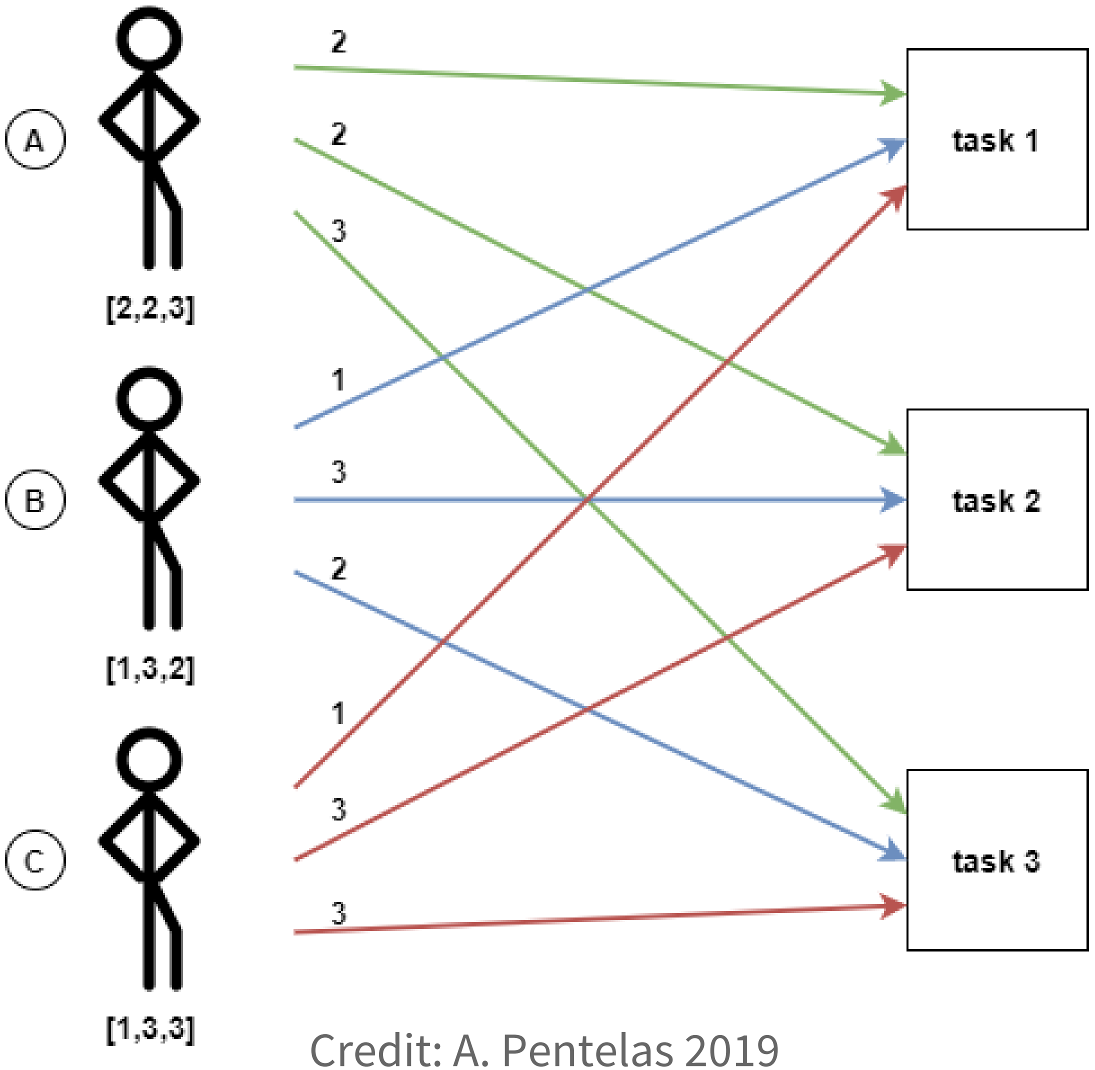
- A variety of technological paths exist for:
  - Core design
  - Core materials
  - Heat exchange system
  - Heat removal system
  - Working fluid(s)



Credit: A. Pentelas 2019

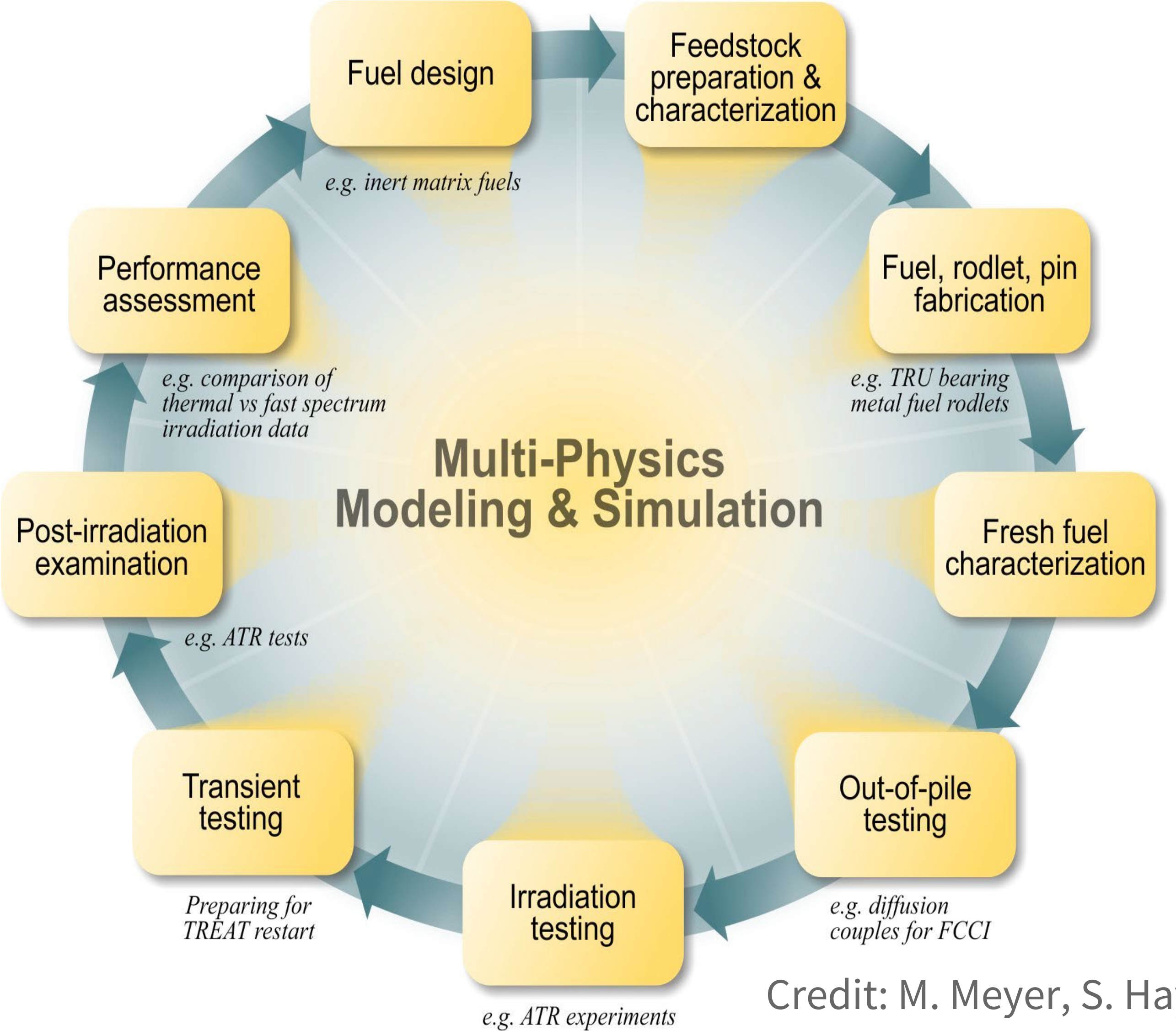
Impetus (cont.)

- When all is said and done, every entity will need to scrutinize their systems through the process of qualification
  - Regardless of technology
  - Regardless of design
  - Regardless of
- All entities are in the same boat…



Credit: A. Pentelas 2019

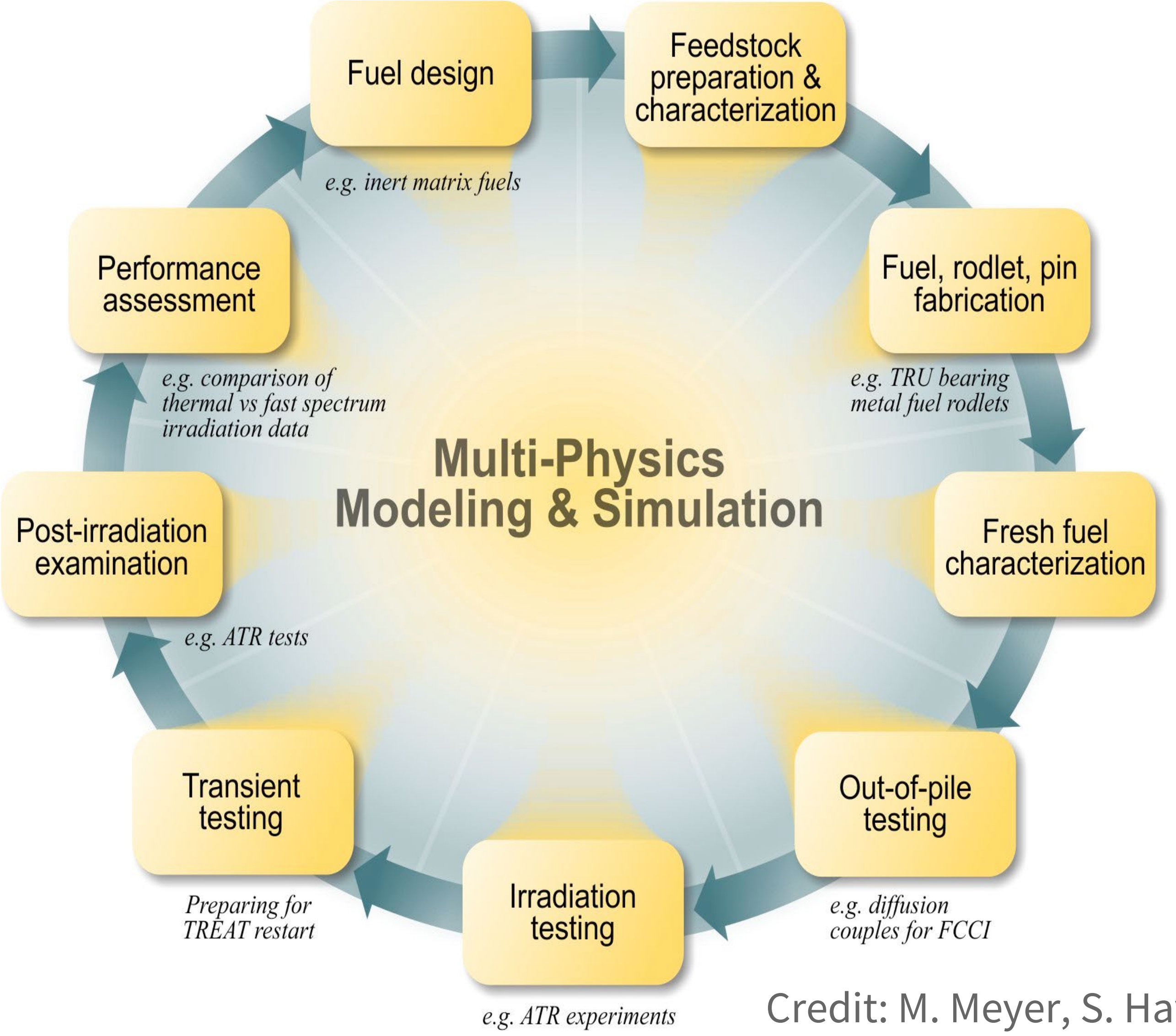
Qualification



Credit: M. Meyer, S. Hayes (INL)

- Consider one aspect of reactor development: ***materials***
- Involves every aspect:
  - Fuel and Core
  - Structural
  - Primary and secondary cooling
  - Heat removal and exchange
  - Safety systems

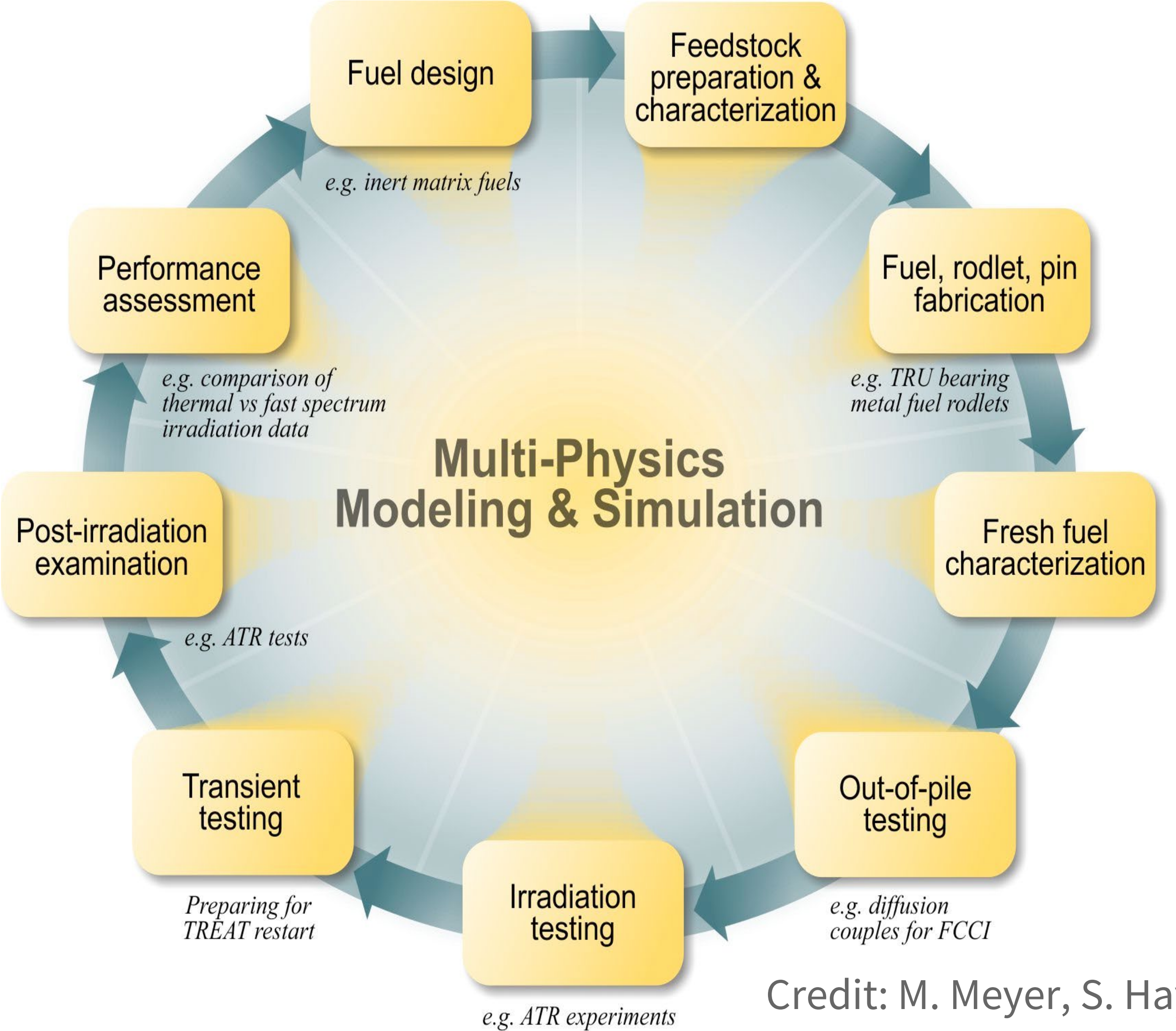
Qualification (cont.)



- Modeling and simulation can only go so far…
- Well-vetted experimental data is crucial to successful qualification process

Credit: M. Meyer, S. Hayes (INL)

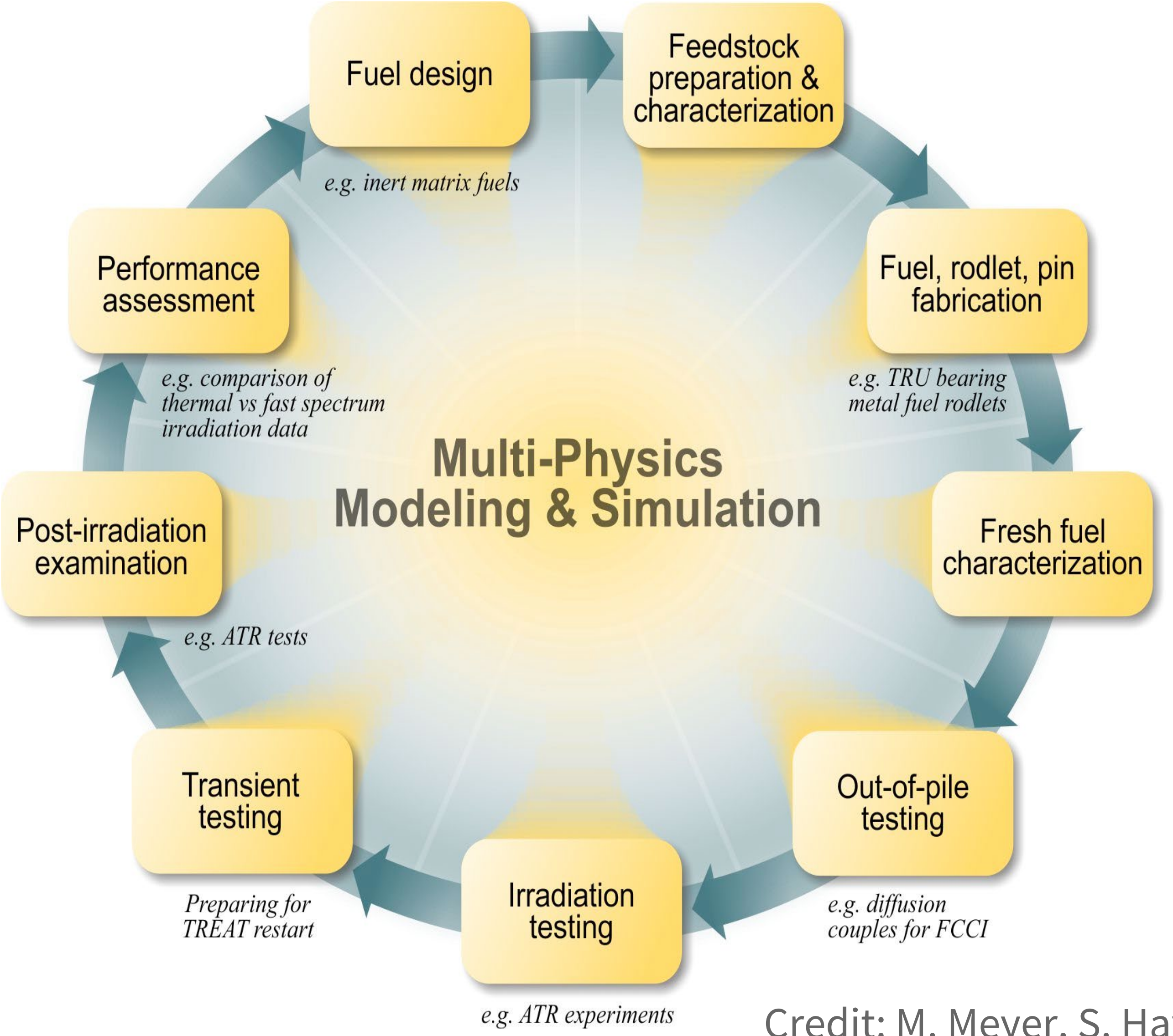
Qualification (cont.)



Credit: M. Meyer, S. Hayes (INL)

- Resources for advanced testing are currently stretched thin, especially:
  - Irradiation
  - Safety
  - Transient
- Pathways for qualification also include the need for quality assured work
  - Limits individual vendor testing

Qualification (cont.)



- Not very often does the first trial succeed, for ANY technology
- Material testing is an ***iterative*** process
- = EXPENSIVE! In terms of money, time, resources

Credit: M. Meyer, S. Hayes (INL)

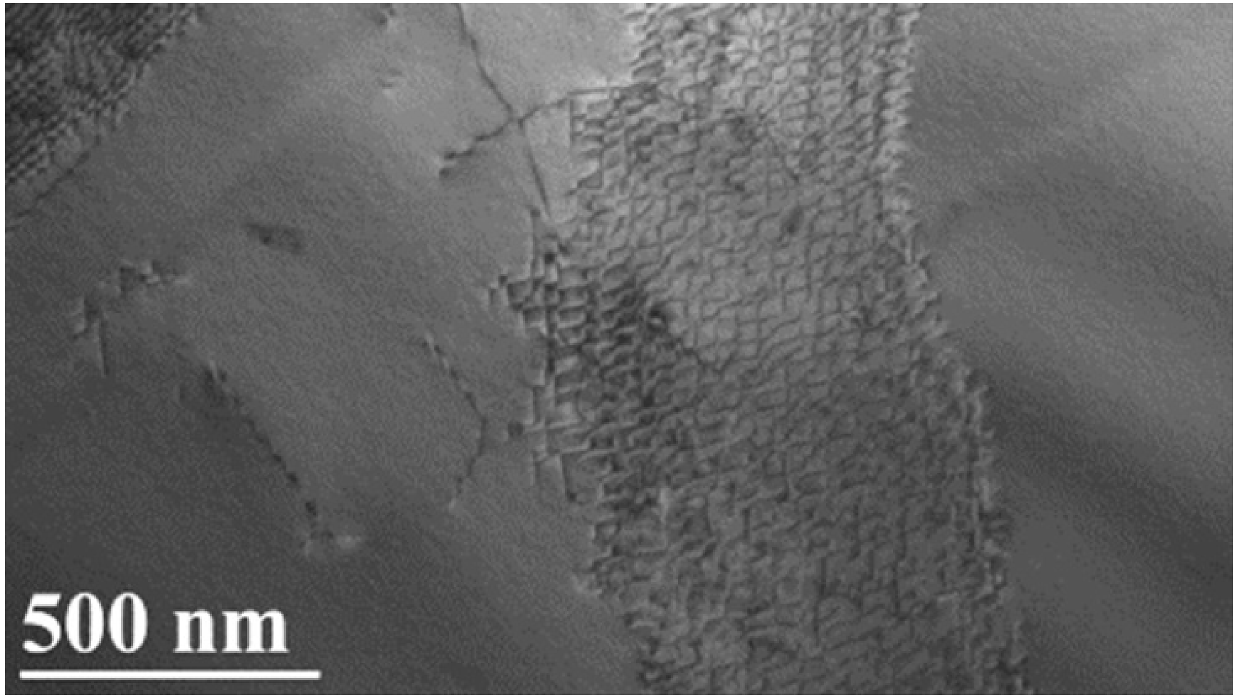
Historical

- Process of Fuel and Material Development:
  - Selection of Potential Candidates
  - Lab Scale Development
  - Scale-Up
  - Qualification
  - Demonstration
- Typical schedule for complete development and licensing for new fuel & materials: 20-25 years.

Credit: D.C. Crawford, et al. JNM 2007

Historical (cont.)

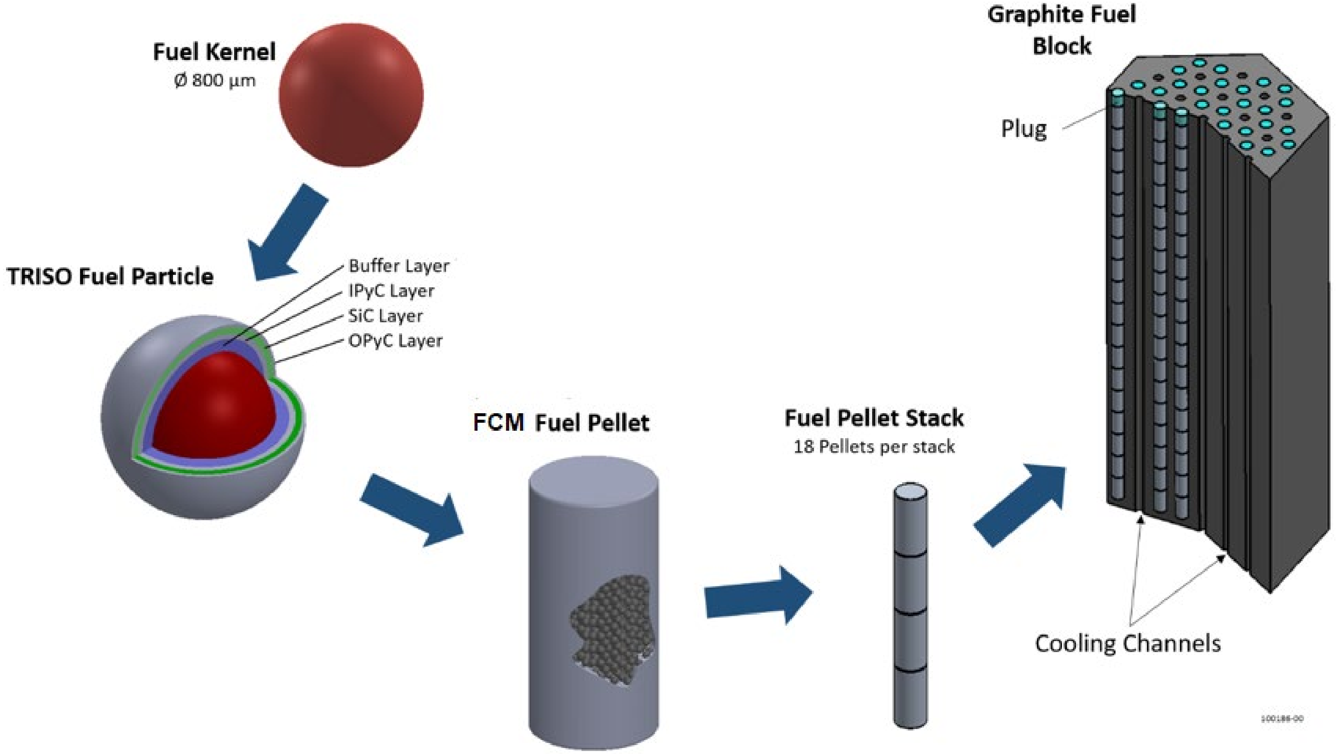
- Recent example: Alloy 617
- Added to ASME Boiler & Vessel Code in May 2020
- Qualification took 12 years, $15M investment from US DOE
- First addition to B&PV Code in 30 years



Alloy 617, 500 nm. Credit: INL

Looking to the Future…

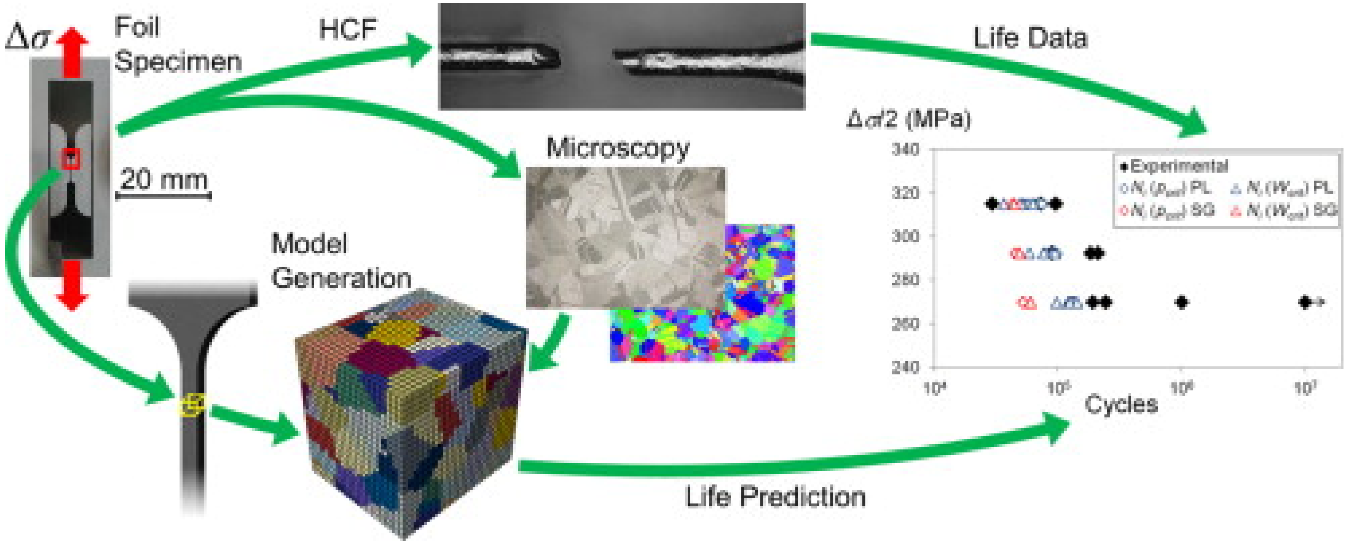
- Editorial: if as an industry, we want to deploy advance nuclear reactors, we require:
  - changes in paradigm,
  - thought process,
  - reimaging &/or optimizing all possible uses for data
- “***All of the above***” strategy is a great sound byte…but what exactly does that mean?



Credit: USNC, 2020

All of the above Strategy

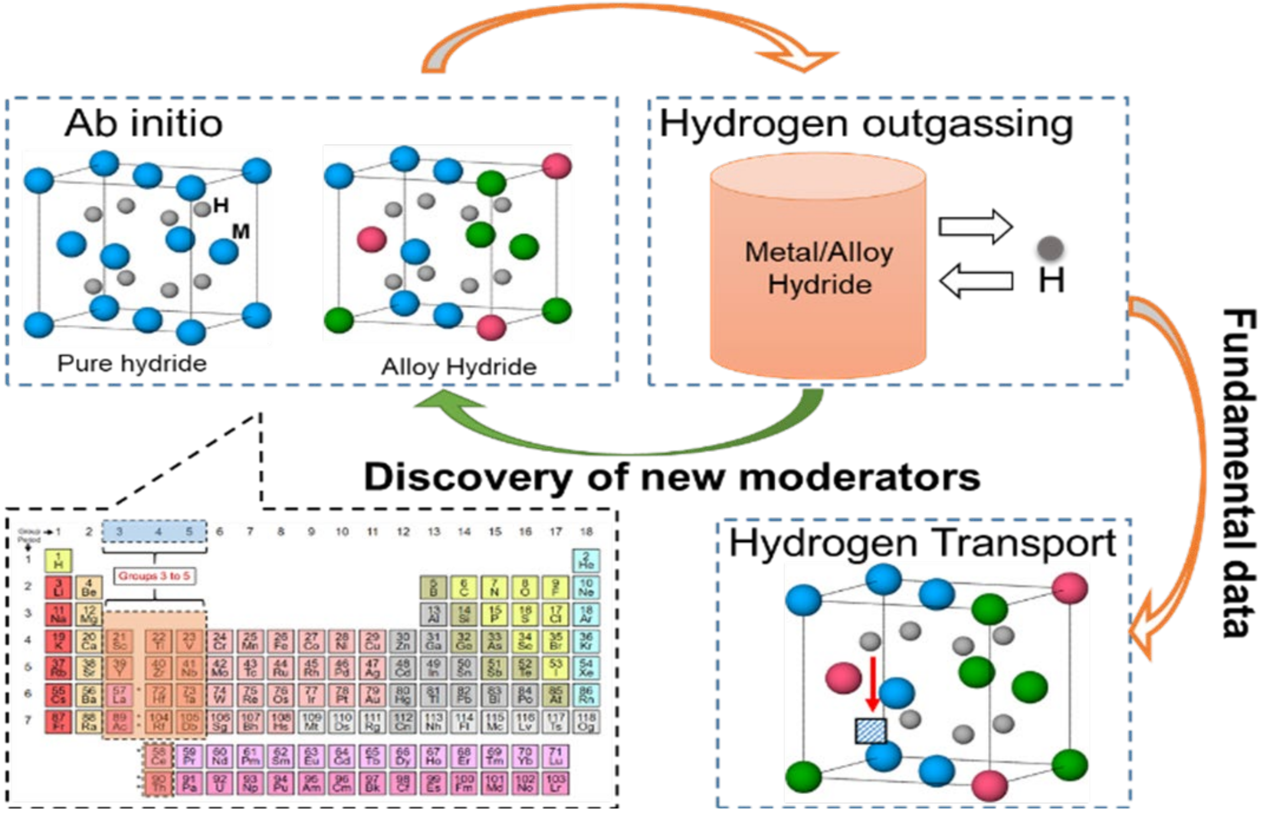
- How to best approach these challenges?
  - Reduce dose/irradiation hazards
  - Reduce footprint
  - Process automation
  - Develop correlations and models to better predict scale-up processes



Credit: C.A. Sweeney, 2015

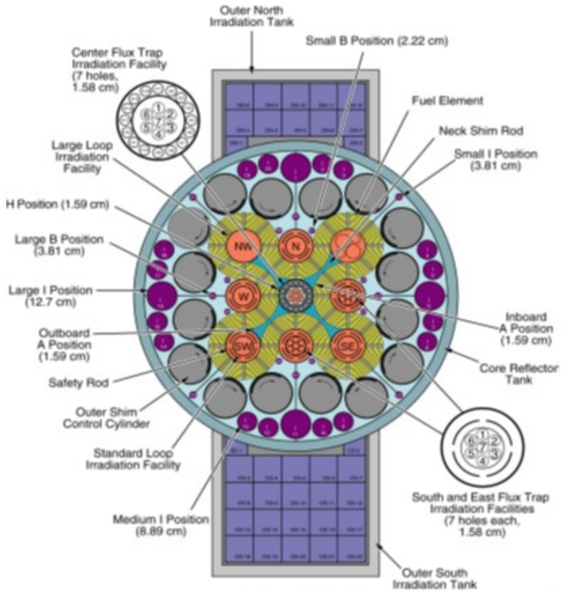
All of the above Strategy

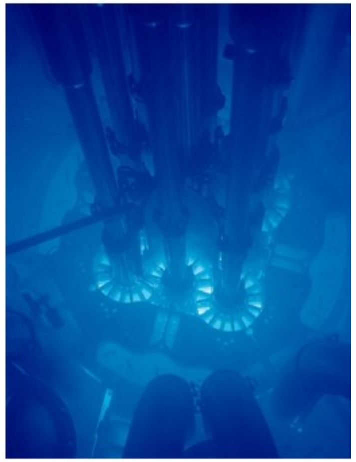
- Design
  - Specific figures of merit
- Development
  - new methods for sussing out novel materials
- Performance
  - More flexible testing methods
  - More testing facilities
- Post-performance assessment
  - More flexible analysis methods
  - More facilities



Testing, testing, testing…

- Operations
  - Physical, mechanical
- Irradiation
  - Flux density, neutron spectrum
- Safety
  - DBA or BDBA conditions

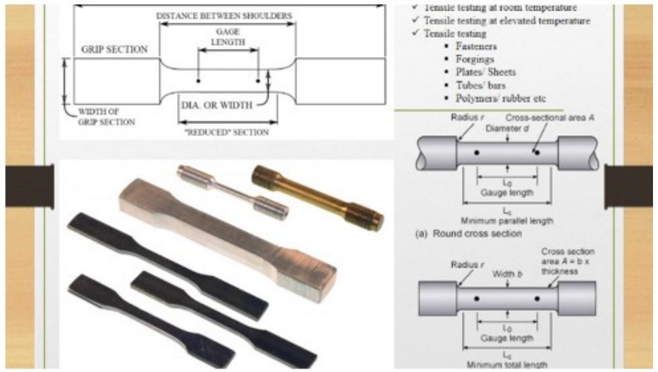




Credit: INL, ORNL

Testing, testing, testing…

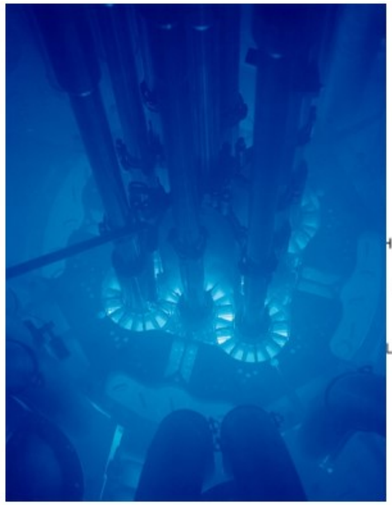
- Operations
  - Physical, mechanical, chemical
  - High temperatures, gradients
  - Corrosion, erosion
  - Oxidation
  - Fatigue, creep, stress/strain
  - Multiple facilities can be used
  - Timelines may be shortened
  - However, testing still needs to be sufficient for regulatory concerns

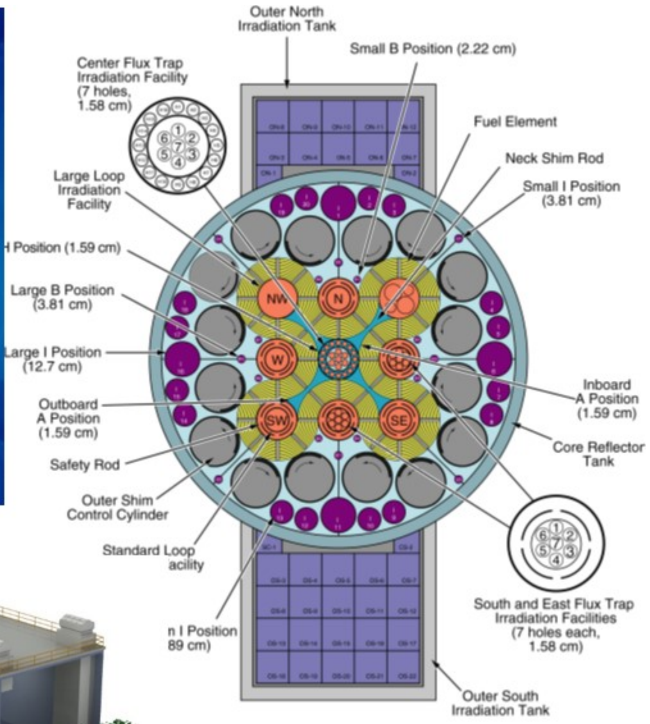


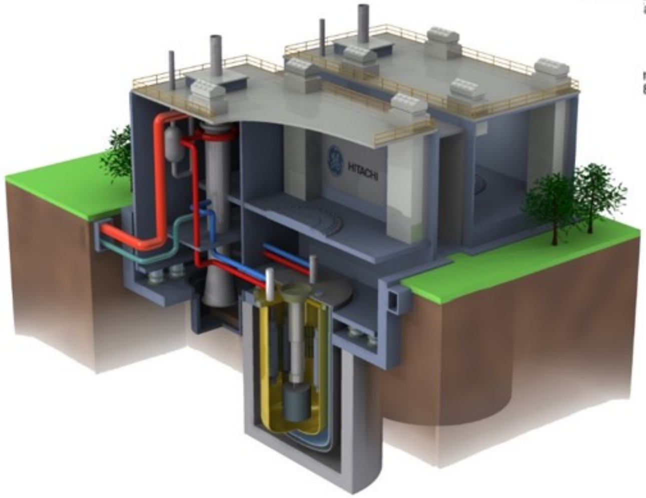
Credit: INL

Testing, testing, testing…

- Irradiation
  - Flux density
  - Neutron spectrum
  - Fluence
  - Limited number of facilities that can satisfy normal ops conditions, and are in high demand
  - Even more concern for satisfying regulatory concerns



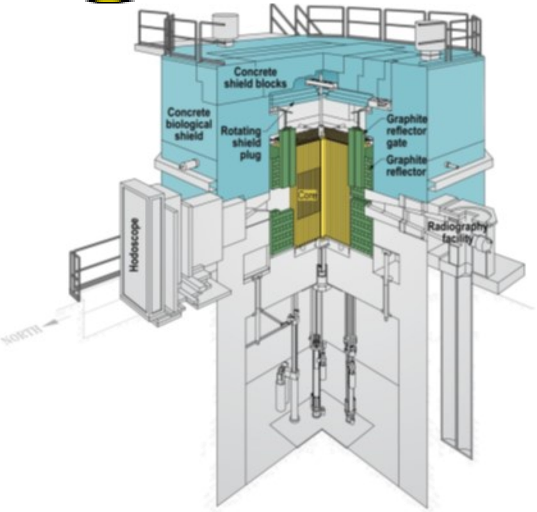


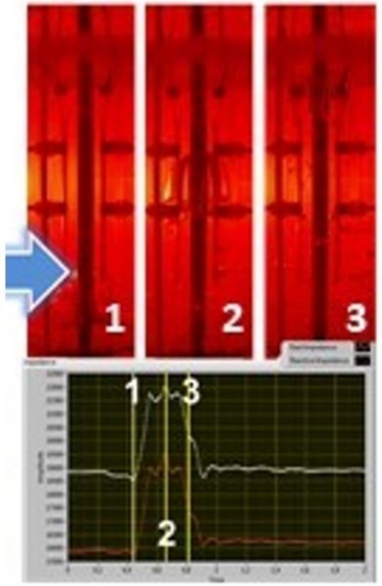


Credit: INL; GE

Testing, testing, testing…

- Safety
  - DBA or BDBA conditions
  - Can be in-pile or out-of-pile (depending on goal of test)
  - Extremely limited facilities, extremely high demand
  - One limiting factor: amount of damage (dpa) that can be imparted on a sample vs. time

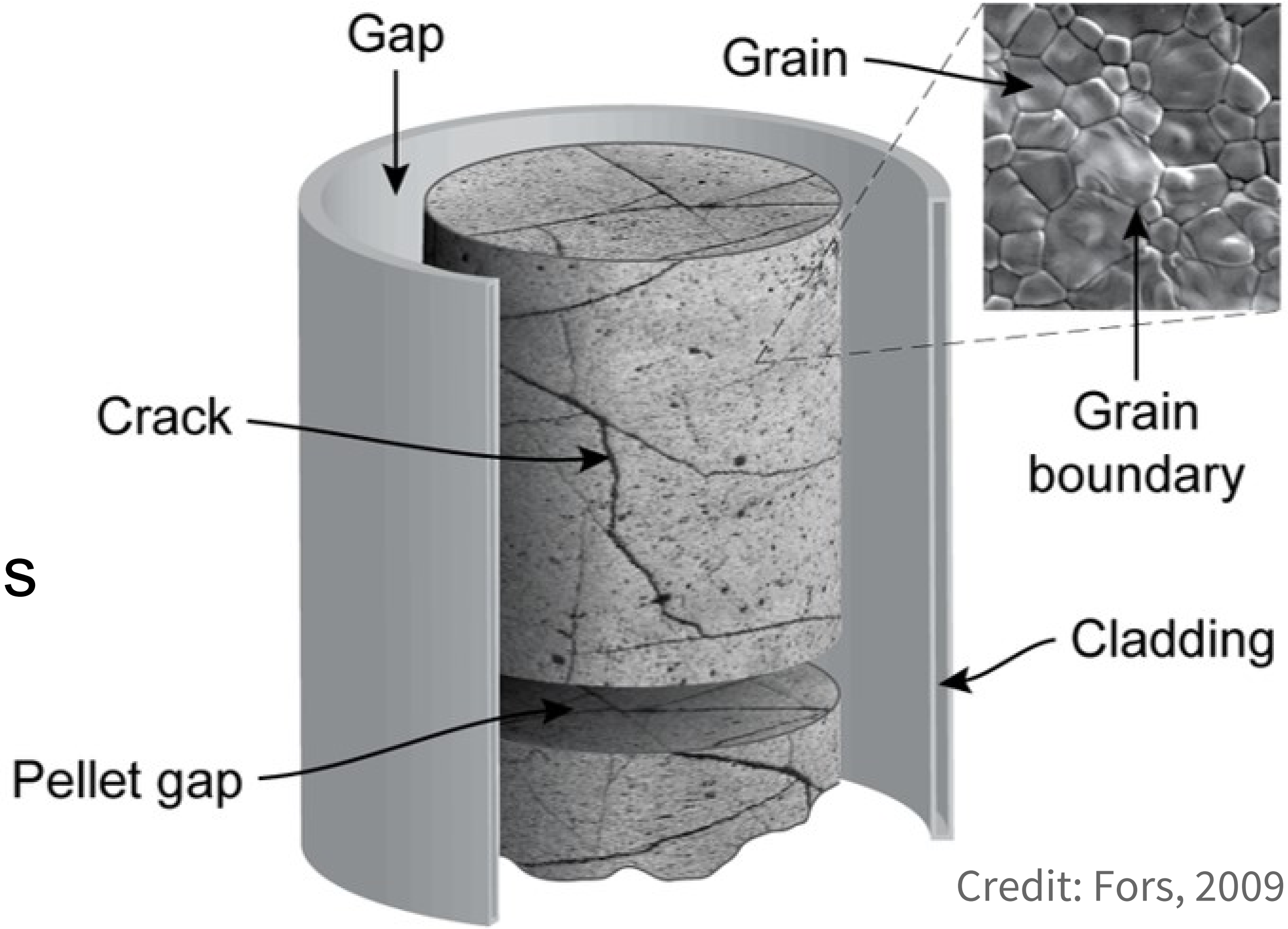




Credit: INL, ORNL

Importance of Scale

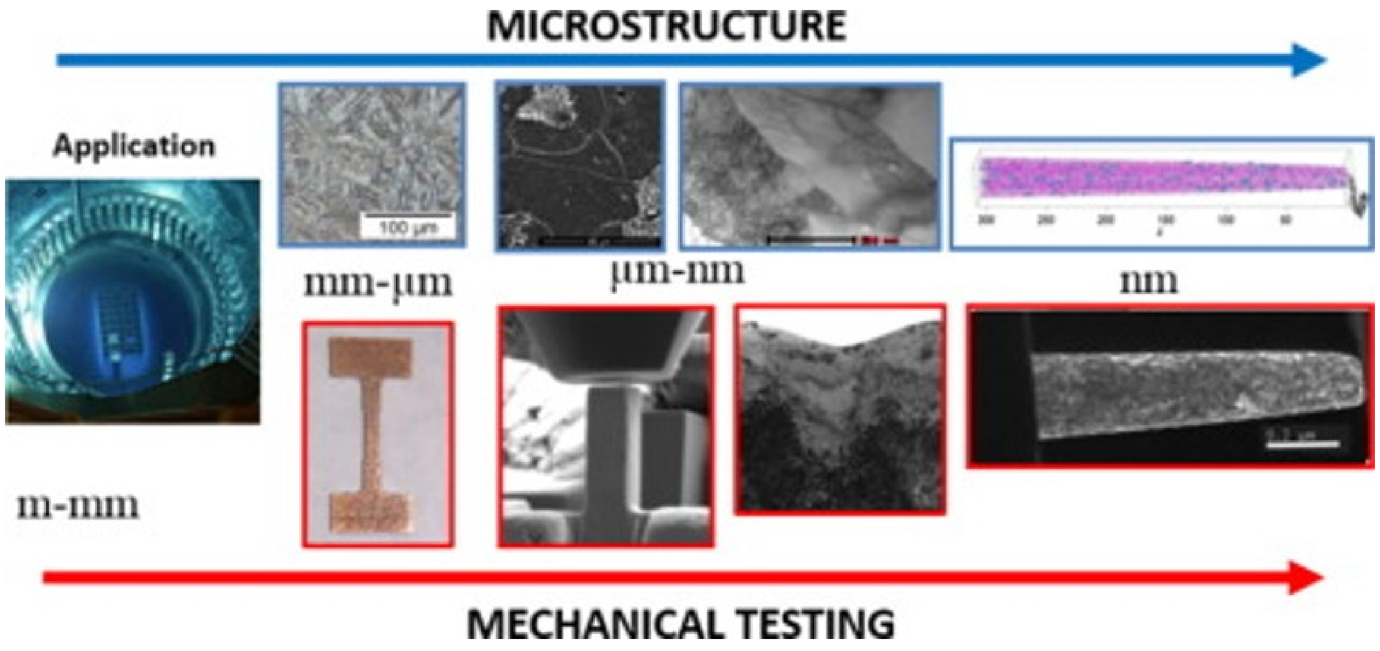
- Reimagine how data can be collected and applied to material qualification
- Traditional use of bulk properties to assess failure mechanisms in materials
- Harder to accomplish with radioactive/irradiated materials



Credit: Fors, 2009

Importance of Scale

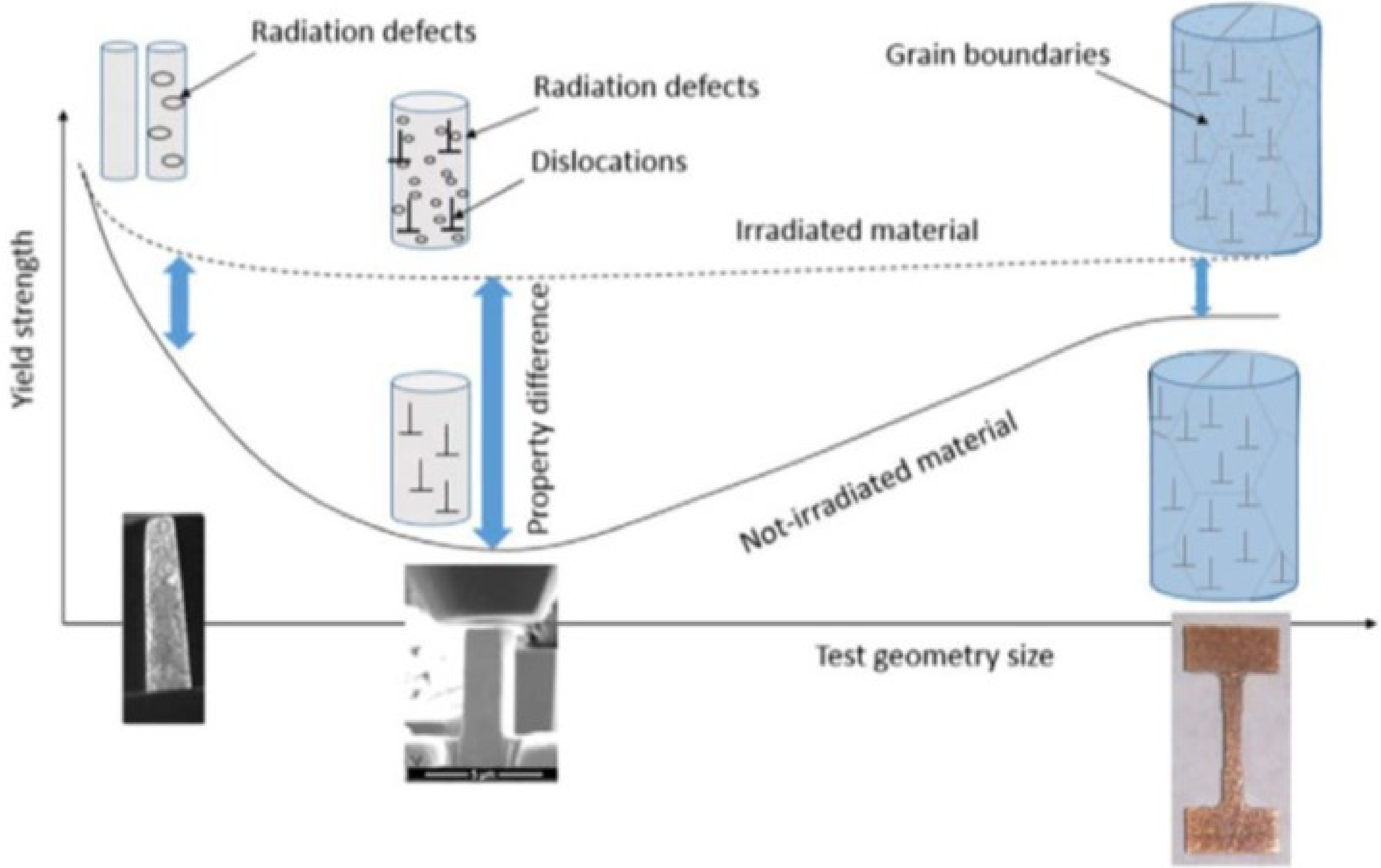
- Better understand connection between microscale and macroscale correlations
- Develop concepts for automated testing systems
- Demonstrate advantages to automated mechanical testing and data management using reduced scale samples



Credit: Hosemann, 2017

Importance of Scale

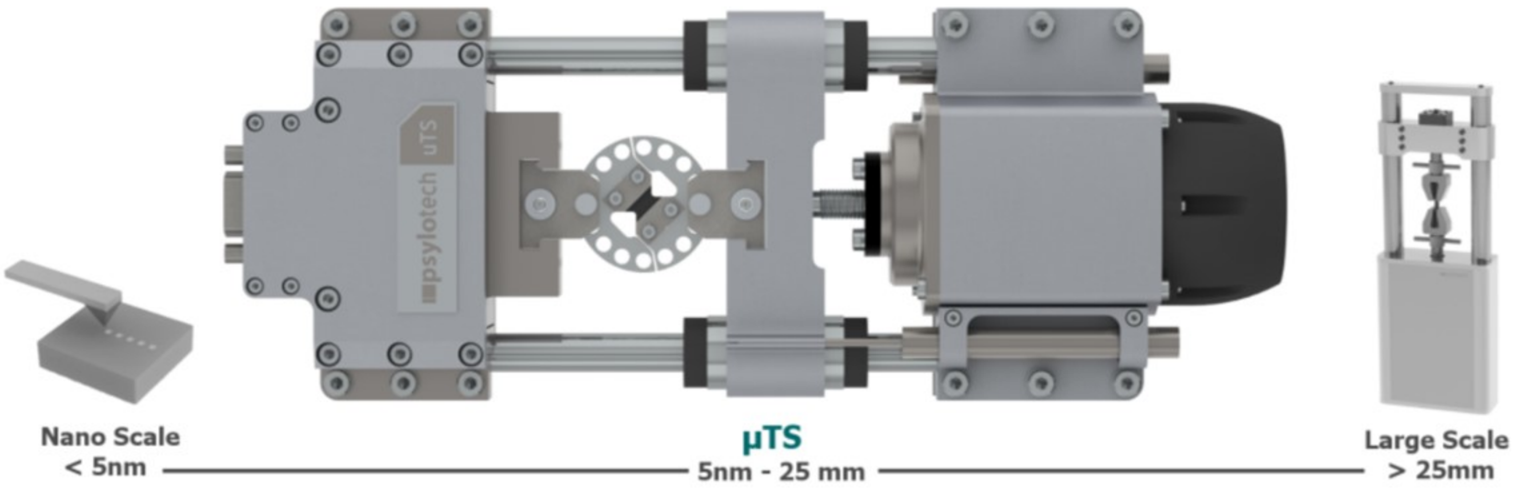
- Micromechanical testing capabilities have improved drastically over the past decade
- The ability to represent bulk property information from microscale sample analysis is a key development!



Credit: Hosemann, 2018

Importance of Scale

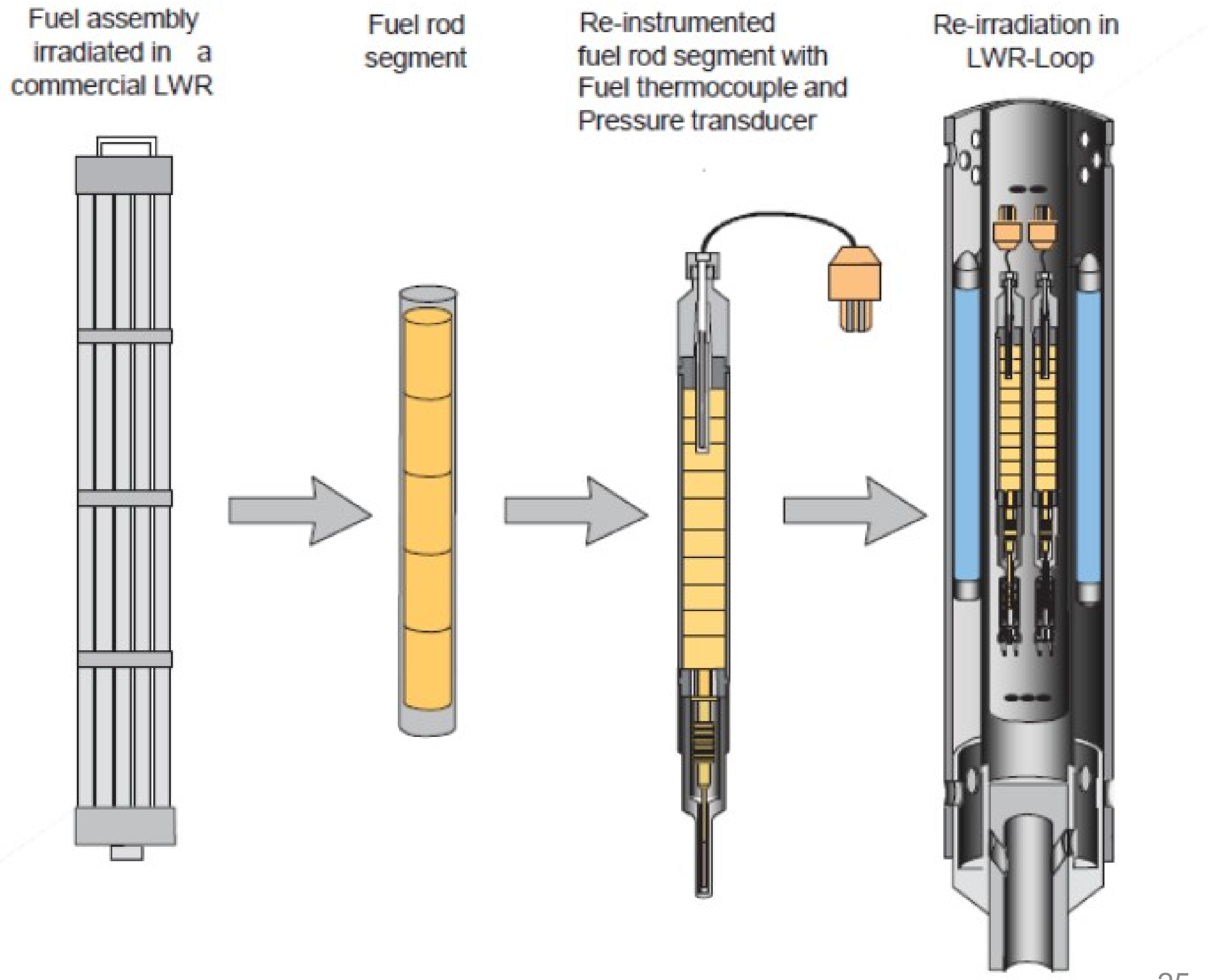
- Achievable using three key principles:
  - Repeatable methods
  - Correlation development
  - Large quantity testing
- Allows for more testing and better testing – relief in the data pipeline



Credit: Psylotech

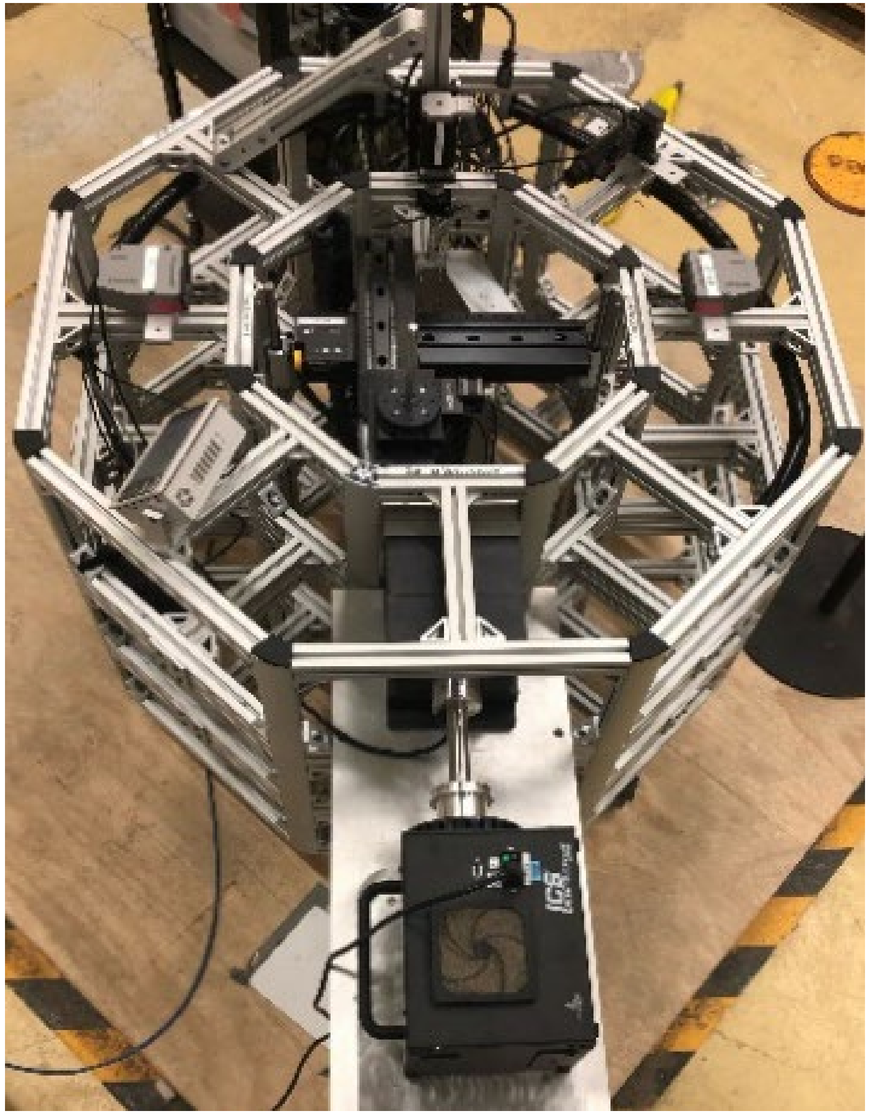
Techniques: Reimagined

- Refitting fuel samples for multiple test campaigns
- Performed at Halden facility (Norway) for decades
- Present need for similar testing capabilities



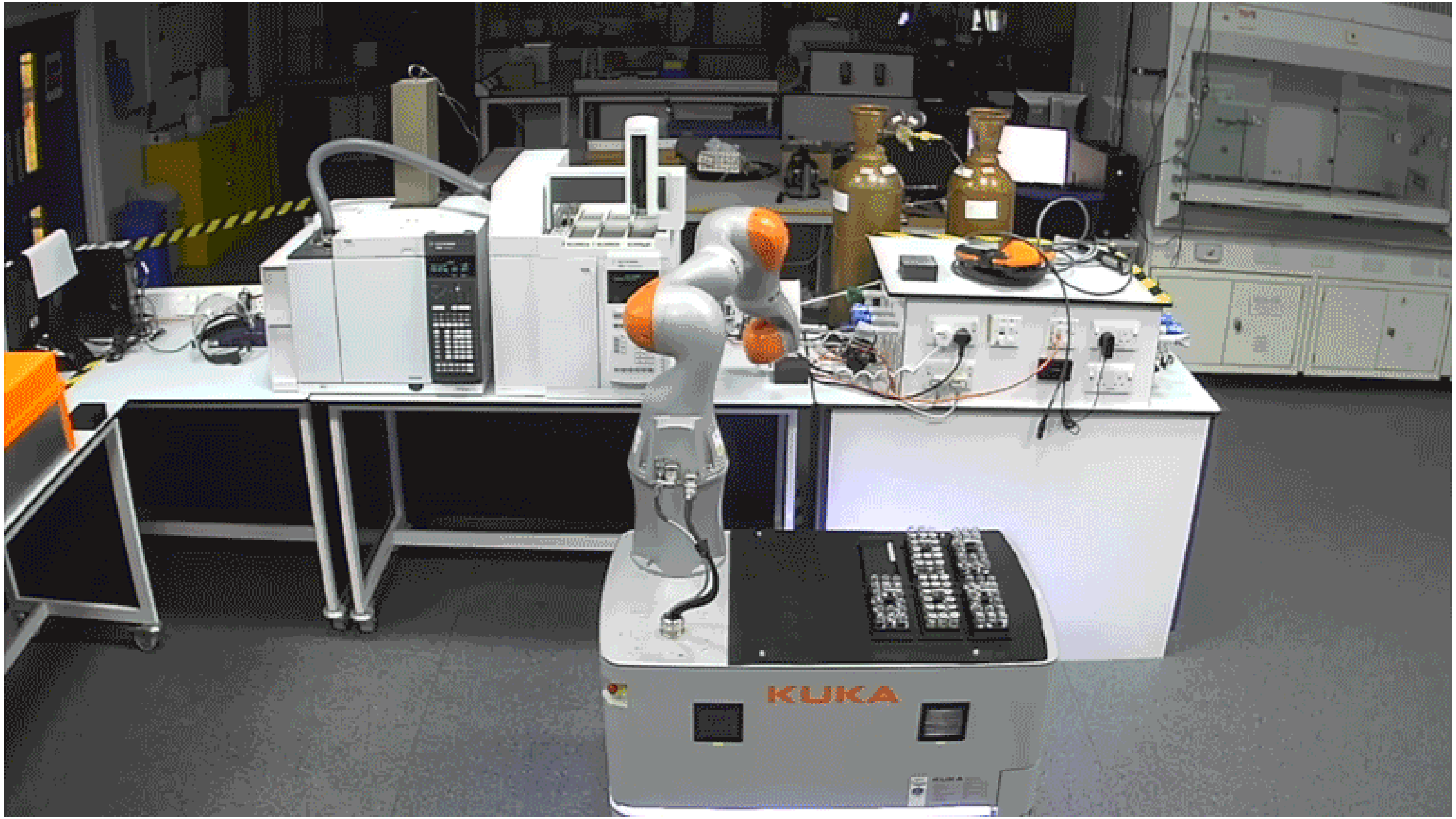
Techniques: Reimagined

- Multiple PIE techniques fitted to a single device



Techniques: Reimagined

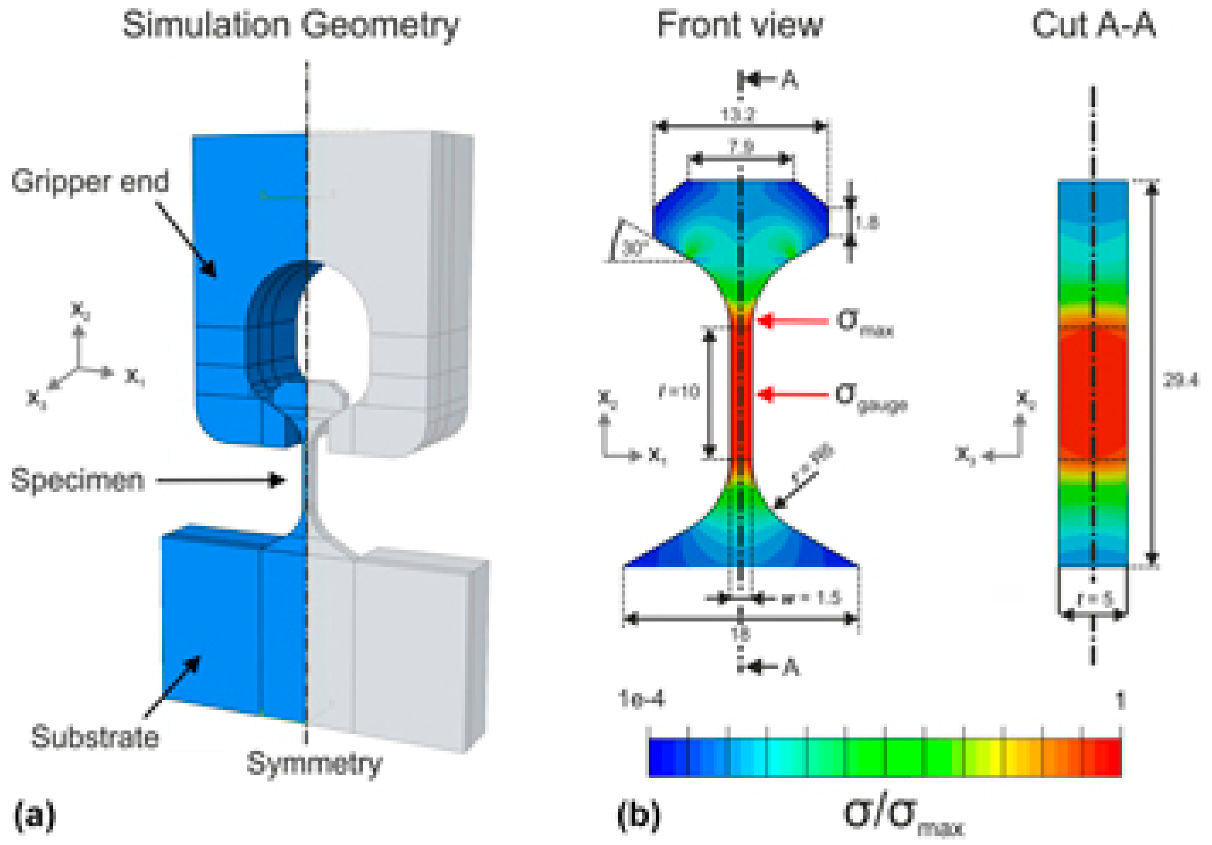
- Use of robotics to improve efficiency
- Suited for areas to minimize dose



Credit: Univ. Liverpool

Techniques: Reimagined

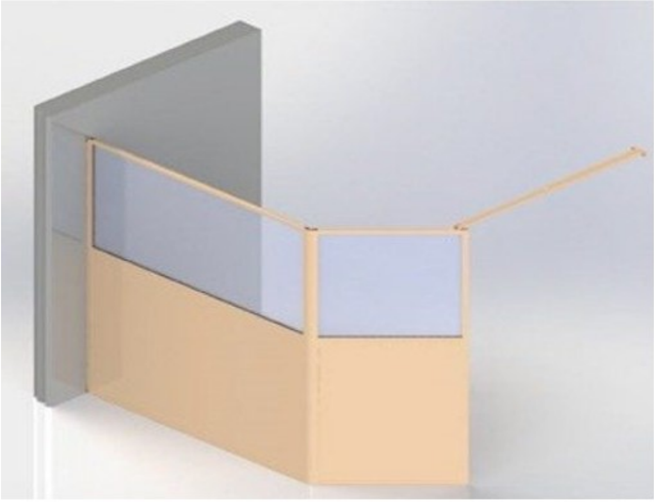
- Use of FIB technology to create more samples (or sample production rate)
- Automation Initiative – use of robotics to perform tasks
  - Widely incorporated in the automotive and medical industries
- Reduces timeline on both the front- and back-end of testing



Credit: D. Casari, et al. (2019)

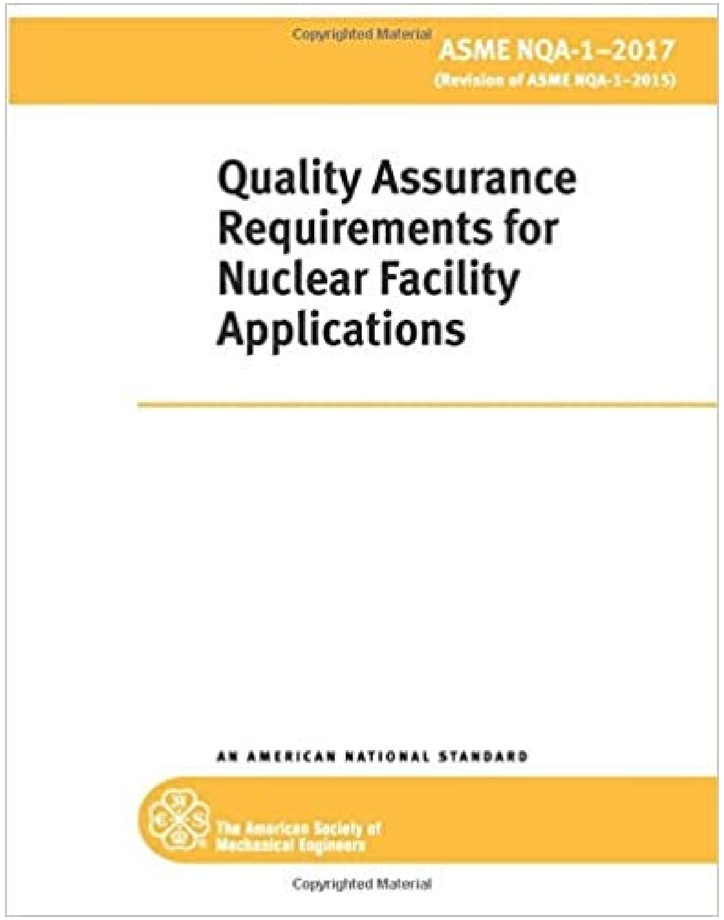
Methods: Reimagined

- Reduced size of samples for testing results in lesser dose
- Tasks that often require monolithic hot cells might be accomplished in a laboratory setting
- Use of modular shielding to reduce dose locally



Role of Quality Assurance

- Editorial: if any entity were considering the development and implementation of an NQA-1 compliant research program, this would be a ***great*** time to start!



Credit: ASME 2017

Mechanisms

- Getting access to more facilities is paramount to success – so who can be called upon?
- NSUF – Nuclear Science User Facilities
- GAIN – Gateway for Accelerated Innovation in Nuclear
- University Collaborators
- Industrial Collaborators

Summary

- Variety of novel reactor types under development is a blessing for the nuclear community…but
- Strains the available resources for assessment, irradiation and safety testing, qualification development
- Drives innovative thinking on how to assess materials for new reactor types

Thank you!

GEN IV International Forum[SM]

Upcoming Webinars

24 June 2020	Comparison of 16 Reactors Neutronic Performance in Closed Th-U and U-Pu Cycles	Dr. Jiri Krepel, PSI, Switzerland
29 July 2020	Overview of Small Modular Reactor Technology Development	Dr. Frederik Reitsma, IAEA
26 August 2020	Overview and Status Update on Molten Salt Reactor Technology Development in the US	Dr. David Holcomb, ORNL, USA