U.S. DEPARTMENT OF ENERGY | Nuclear Energy

Fuel Cycle Research and Development

Technology Readiness Levels for Advanced Nuclear Fuel and Materials

Shannon M. Bragg-Sitton, Ph.D.
Deputy National Technical Director

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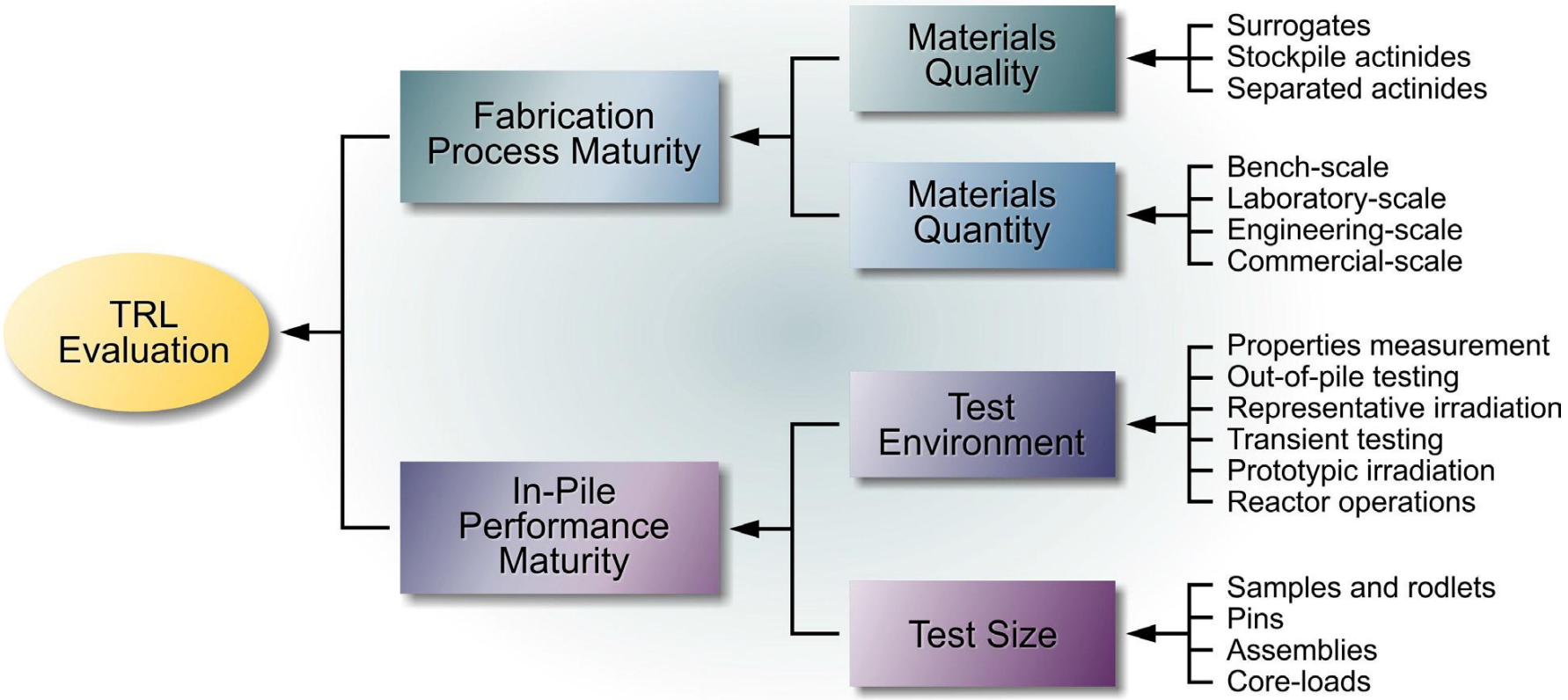
Idaho National Laboratory

Advanced Fuels Campaign

Overview


TRL Evaluation
Fabrication Process Maturity
In-Pile Performance Maturity
Materials Quality
Materials Quantity
Test Environment
Test Size
Surrogates
Stockpile actinides
Separated actinides
Bench-scale
Laboratory-scale
Engineering-scale
Commercial-scale
Properties measurement
Out-of-pile testing
Representative irradiation
Transient testing
Prototypic irradiation
Reactor operations
Samples and rodlets
Pins
Assemblies
Core-loads

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Fabrication Process Maturity

- **Measures how well the fabrication process is understood and validated**

Attributes to be considered:

- **Quality of materials used for fabrication process development and testing**
  - Surrogate materials – non-radioactive or less-radioactive materials with properties similar to the actual actinides; selection of surrogate depends on phenomena of interest
  - Representative materials from stockpile – individually separated actinide elements that must be blended together for use in fuel fabrication experiments; generally requires a non-prototypic conditioning step; isotopic vectors typically different
  - Representative materials from recycling process – optimization of fabrication process using actinides recovered from separations processes, co-precipitated through a prototypic process and conditioned for use as feedstock
- **Quantity of materials for fabrication process development and testing**
  - Bench-scale – up to 100 g batch sizes (e.g. multiple pellets/year)
  - Lab-scale – up to 1 kg quantity batch sizes, ~10 kg TRU/yr (e.g. multiple pins/year)
  - Engineering-scale – 1-10 kg batch sizes, ~100 kg TRU/yr (e.g. a few assemblies/year)
  - Commercial-scale – 1-10 kg batch sizes, throughput rate ~tons TRU/yr (e.g. a few hundred assemblies/year – core loads)

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Fuel Performance Maturity

- **Measures how well the in-pile performance of the fuel is understood and validated**

Parameters to be considered:

- **Test environment to determine performance parameters**
  - Fundamental property measurements
  - Out-of-pile testing
  - In-pile testing in representative spectrum
  - Transient testing
  - In-pile testing in prototypic spectrum
  - Reactor operations
- **Size of test campaigns to assess performance parameters**
  - Samples and rodlets
  - Pins – close to full-length, representative fuel heights and plenum volumes; prototypic cladding
  - Assemblies – prototypic design, lead fuel assemblies
  - Full-core assemblies – operations program; statistical and long-term reliability related issues quantified

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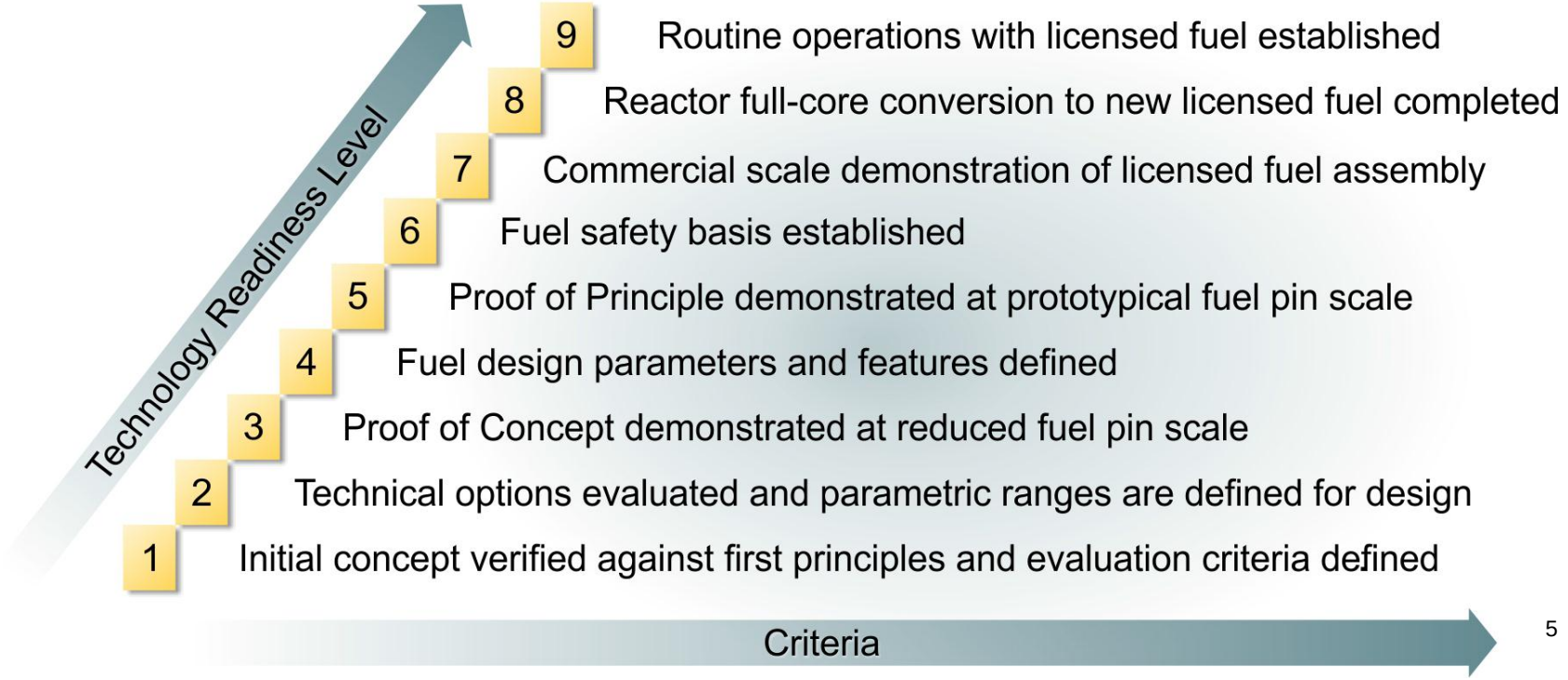
TRL Definitions

- **High level TRL completion criteria:**
  - TRL evaluation based on binning the state-of-knowledge for each attribute
  - Activities required to achieve goals identifed as a function of technical elements, attributes and bins
  - TRL Advancement requires development to the point of both fabrication and performance maturity



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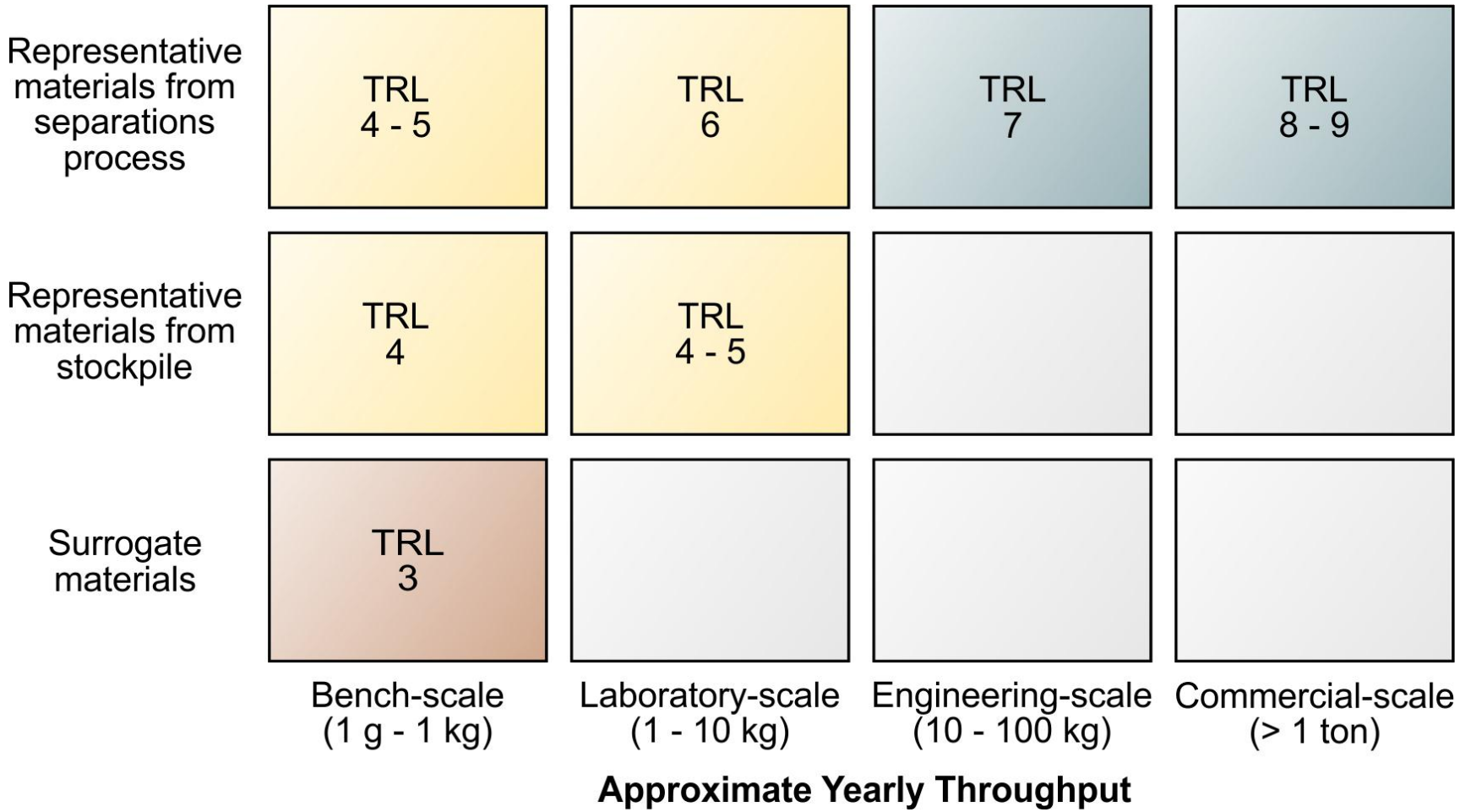
TRL Binning for Fabrication Process Maturity



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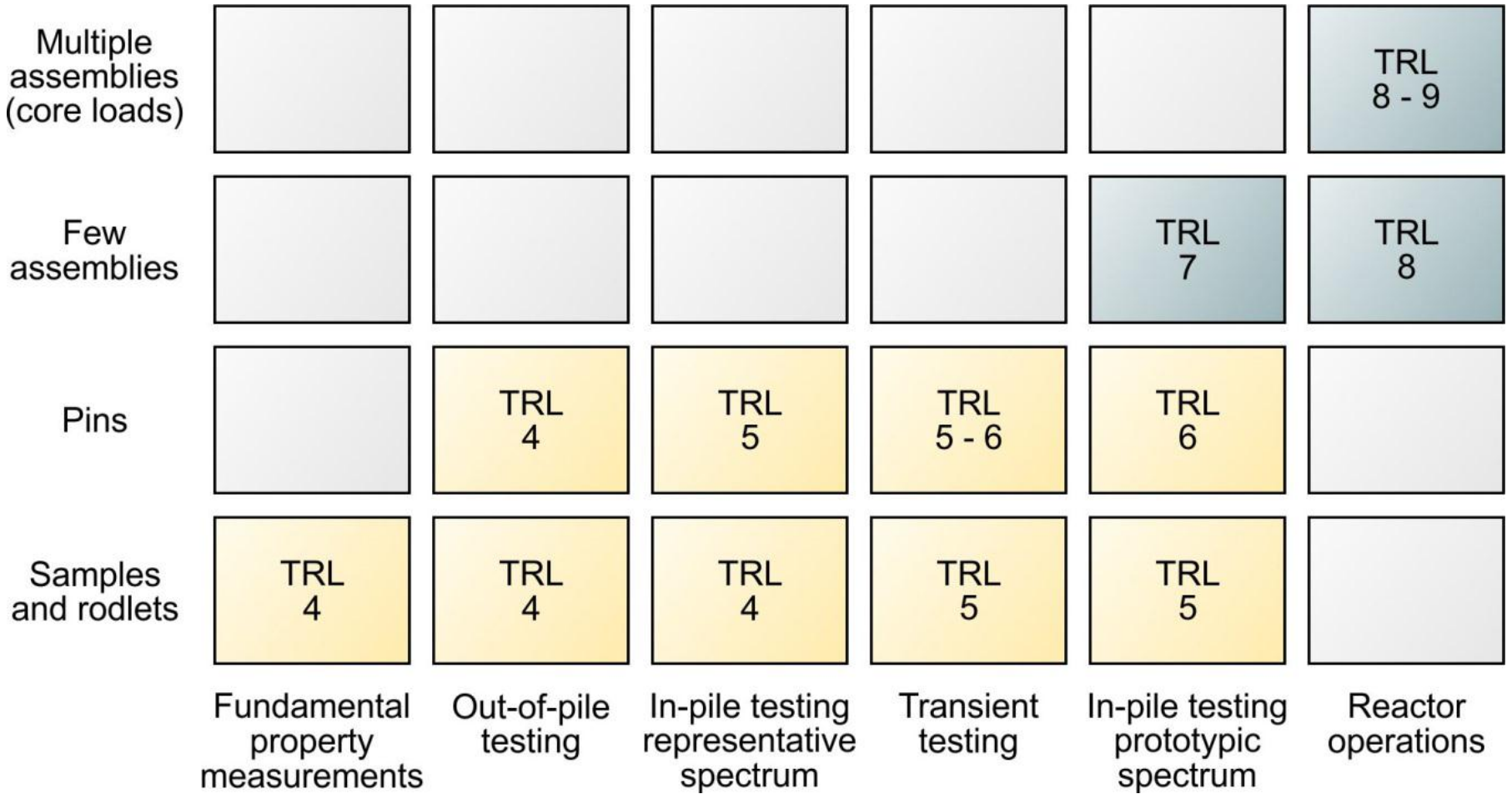
TRL Binning for Irradiation Performance Maturity



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Summary of criteria and activities for each TRL, specific to advanced fuels

TRL	Function	Definition
1	Proof-of-Concept	A new concept is proposed. Technical options for the concept are identified and relevant literature data reviewed. Criteria developed.
2		Technical options are ranked. Performance range and fabrication process parametric ranges defined based on analyses.
3		Concepts are verified through laboratory-scale experiments and characterization. Fabrication process verified using surrogates.
4	Proof-of-Prinicple	Fabrication of samples using stockpile materials at bench-scale. Irradiation testing of small-samples (rodlets) in relevant environment. Design parameters and features established. Basic properties compiled.
5		Fabrication of pins using prototypic feedstock materials at laboratory-scale. Pin-scale irradiation testing at relevant environment. Primary performance parameters with representative compositions under normal operating conditions quantified. Fuel behavior models developed for use in fuel performance code(s).
6		Fabrication of pins using prototypic feedstock materials at laboratory-scale and using prototypic fabrication processes. Pin-scale irradiation testing at relevant and prototypic environment (steady-state and transient testing). Predictive fuel performance code(s) and safety basis established.
7	Proof-of-Performance	Fabrication of test assemblies using prototypic feedstock materials at engineering-scale and using prototypic fabrication processes. Assembly-scale irradiation testing in prototypic environment. Predictive fuel performance code(s) validated. Safety basis established for full-core operations.
8		Fabrication of a few core-loads of fuel and operation of a prototype reactor with such fuel.
9		Routine commercial-scale operations. Multiple reactors operating.

LWR Accident Tolerant Fuels

Transmutation Fuel
TRU-metal, TRU-oxide
(roughly same TRL)
Metal experience: mostly U.S.
Oxide experience: mostly International (France and Japan)

Fast Reactor Metallic U-Pu-Zr
- Not formally licensed for a full core load
- Not used in industrial-scale

Fast Reactor Metallic (U-Zr), Oxide (U, Pu)
- Licensed for reactor operations
- Successful mission operations
- Operational database wider for MOX, especially considering International experience

LWR UO_2-Zr Fuels