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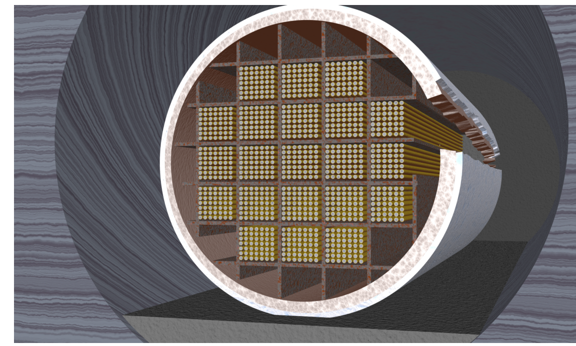

NSUF Ion Beam Investment Options Workshop: Used Fuel Disposition Program Data Needs

INL Meeting Center
Idaho Falls, ID
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Outline

Used Fuel Disposition (UFD) campaign overview:

- Mission and objectives: Storage / Transportation / Disposal
- UFD R&D in the context of ion beam irradiation capabilities

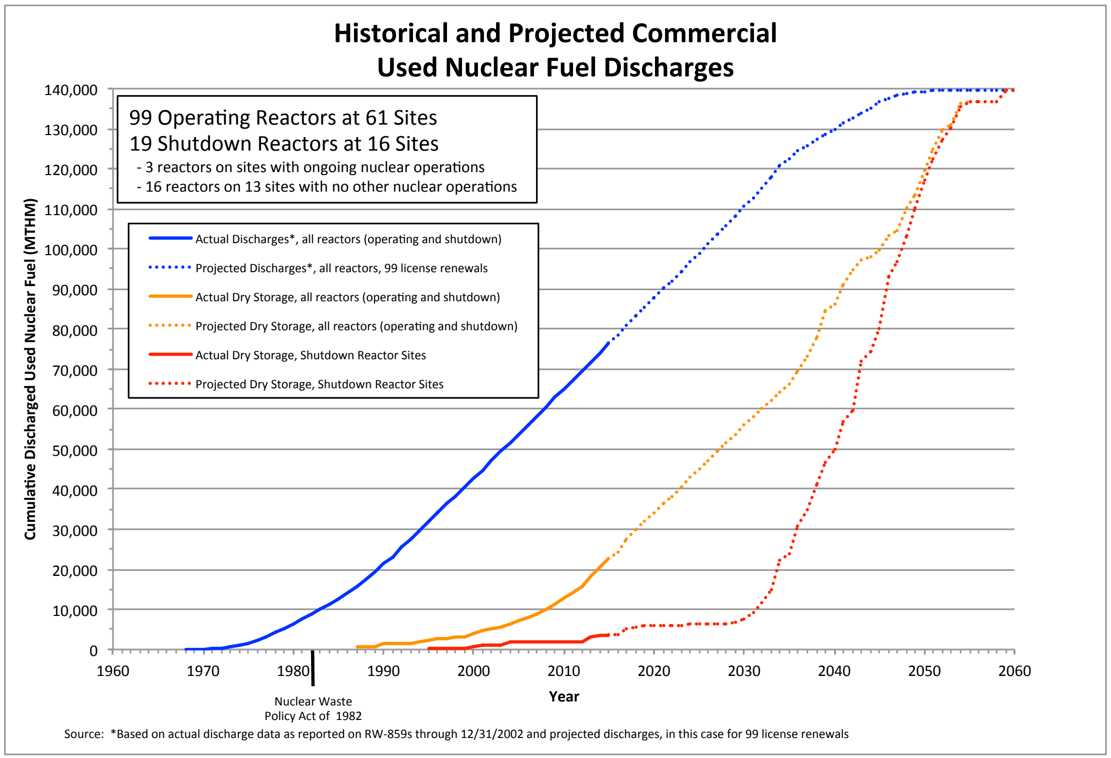
Storage and transportation:

- Cladding: High-burnup cladding performance
- Cladding: Pellet/clad delamination
- Cladding: Radiation annealing
- Bolted cask: Embrittlement of elastomer seals

Review of criteria

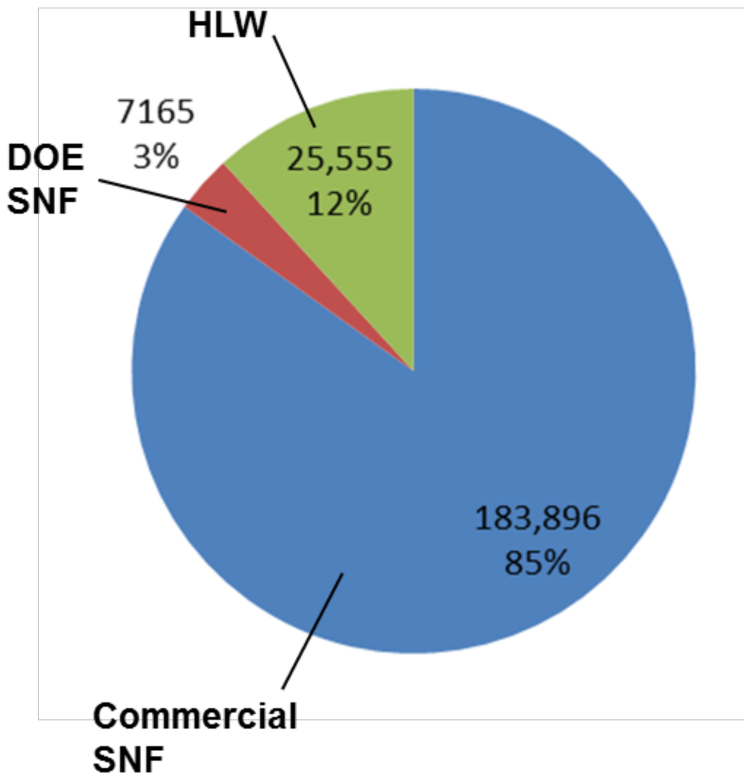
Historical and projected spent nuclear fuel (SNF) and high-level radioactive waste (HLW) in the U.S.

Historical and projected commercial SNF discharges



Currently over 1500 casks loaded in the U.S. located at 50+ interim storage sites.

Projected volumes of SNF/HLW in 2048



Volumes in m^3 (assuming constant rate of nuclear power generation and packaging of future commercial SNF).

Used Fuel Disposition Campaign mission

Identify alternatives and conduct scientific research and technology development to enable storage, transportation and disposal of used nuclear fuel and wastes generated by existing and future nuclear fuel cycles

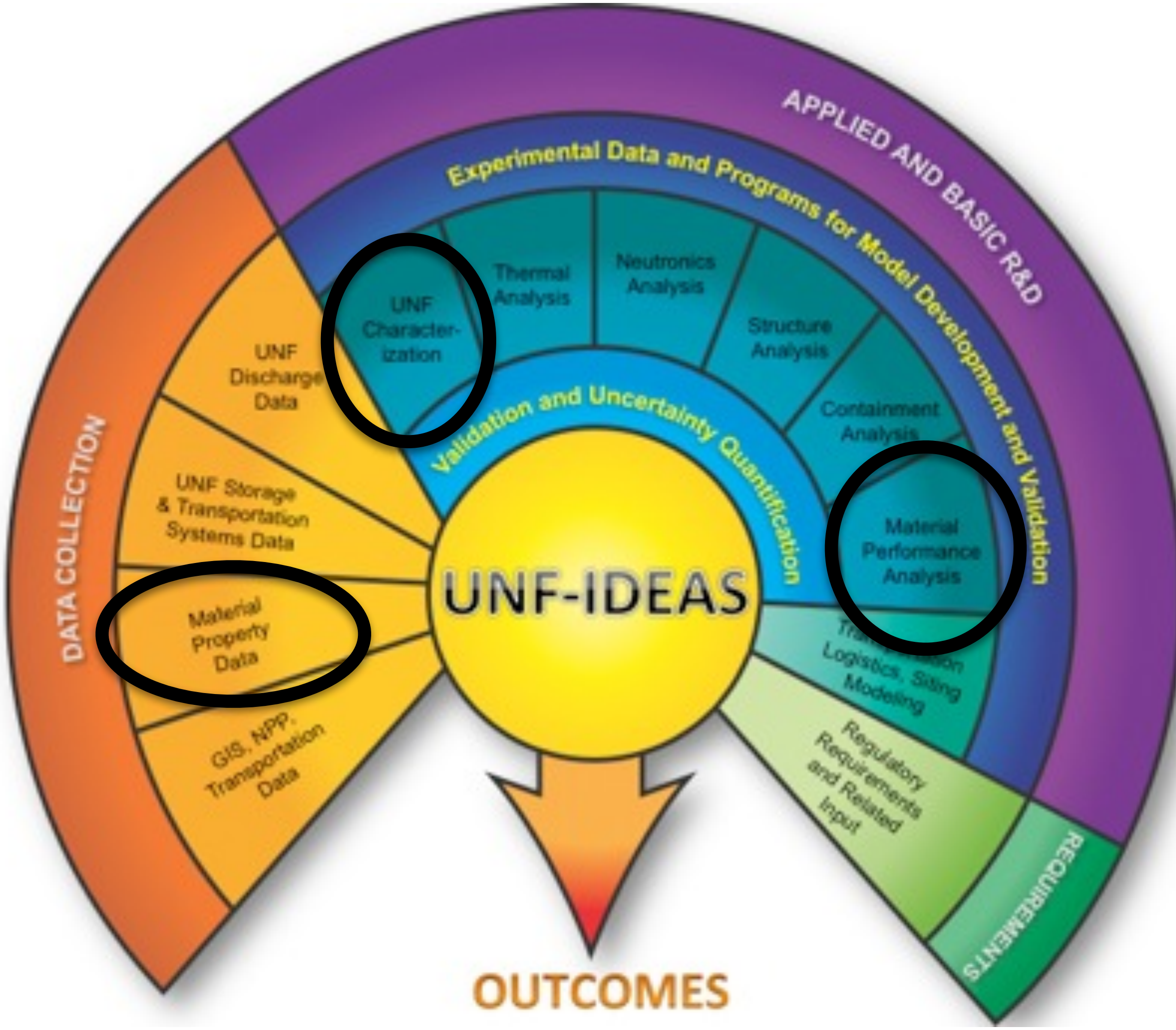
Storage and transportation R&D focus:

- Extended storage of UNF
- Fuel retrievability and transportation after extended storage
- Transportation of high-burnup UNF (>45 GWd/MTU)

Disposal R&D focus:

- Sound technical basis for multiple viable disposal option in the U.S.
- Increase confidence in robustness of generic disposal concepts
- Develop the science and engineering tools needed to support disposal concept implementation

UFD R&D data needs in the context of ion beam irradiation capabilities



[Courtesy of J. Scaglione, ORNL]

UFD data need drivers

What data already exists and relevance to UFD mission

- Data collected within UFD campaign.
- Proprietary data (e.g. ZIRLO™, M5®).
- How do we interpolate gaps between existing data points?

Relevance of data w.r.t. regulatory performance criteria for storage and transportation?

- Metrics extracted from 10CFR71, 10CFR72.
  - "…spent fuel cladding must be protected during storage against degradation that leads to gross ruptures…"
  - "…degradation of the fuel during storage will not pose operational safety problems w.r.t. its removal from storage."
- Recommendations from SFST-ISG-11.3 and NUREG-1567.

Where are the data gaps and why?

- Access to high burn-up data difficult to obtain? What about newer alloys?
- Compliance: DOE Order 435.1 "Radioactive Waste Management".
- Separate effects testing.
- NRC and industry data needs?
- When do we stop collecting data relevant to UFD needs?

Gaps for storage and transportation

Degradation mechanisms	Storage importance
Annealing of radiation damage	H
H_2 effects: embrittlement and reorientation	H
H_2 effects: delayed hydride cracking	H
Oxidation	M
Creep	M
Corrosion and SCC	M
Thermal aging effects	M
Corrosion: blistering	M
Corrosion atmospheric	H
Corrosion: aqueous (pitting, crevice)	H
Thermo-mechanical fatigue of seals and bolts	M
Freeze-thaw	M
Corrosion of embedded steel	M

[Gap Analysis to Support Extended Storage of UNF, FCRD, 2011]

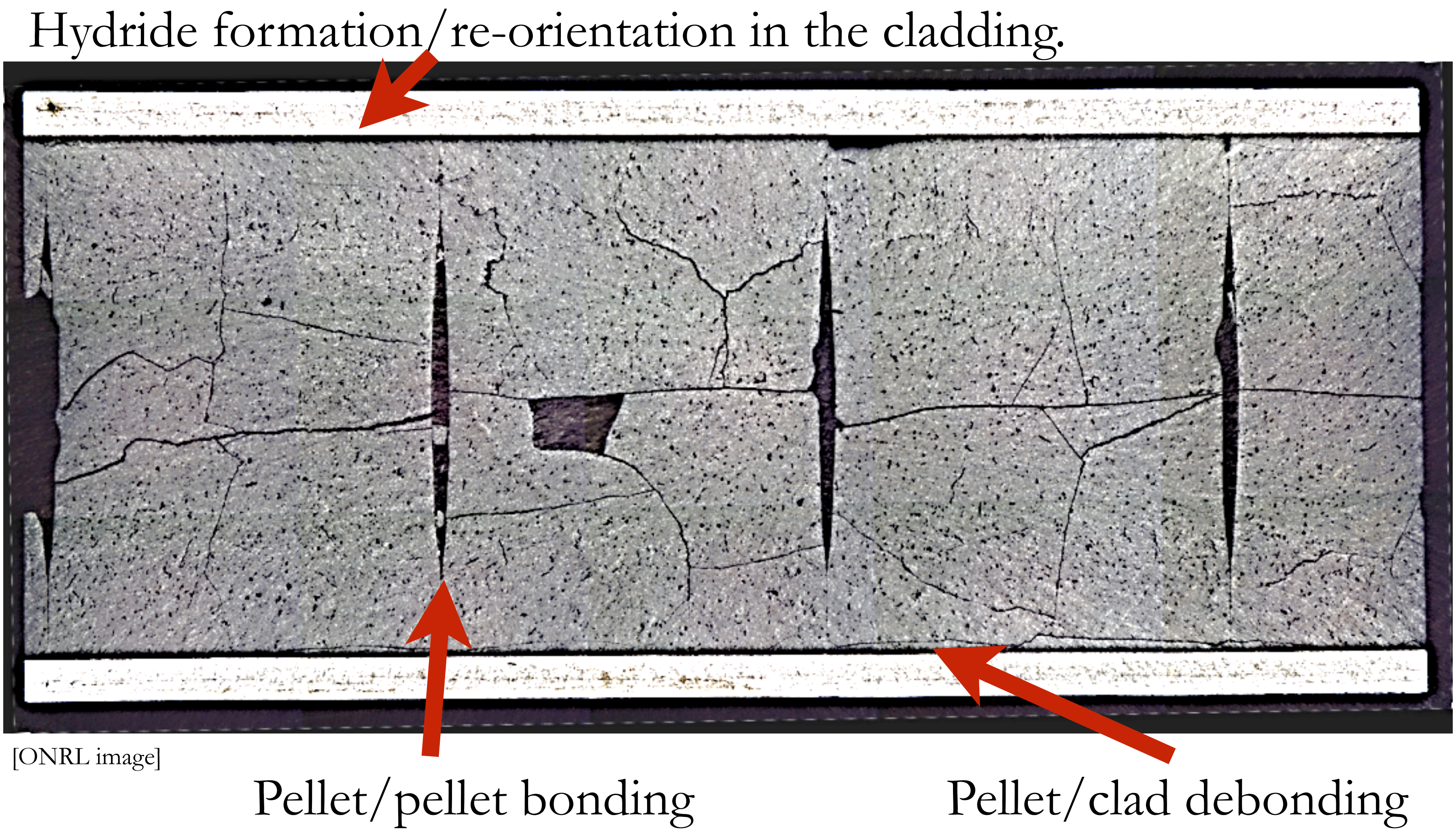
Ion beam irradiation capabilities that could help closing data gaps

- **Emulate Initial storage materials conditions (materials damage).**
- **Emulate alpha irradiation during storage.**
- **Handle irradiated materials.**
- **Have the ability to perform accelerated aging.**
- **Collect microstructural characterization in coupled environments.**

Storage and transportation R&D:

- Extended storage of UNF
  - Cladding: Annealing of radiation damage.
  - Bolted cask: Embrittlement of elastomer seals.
- Fuel retrievability and transportation after extended storage
  - Cladding: High-burnup cladding performance.
  - Cladding: Hydride reorientation and embrittlement.
- Transportation of high-burnup UNF
  - Cladding: Pellet/clad delamination.
  - Fuel: Pellet/pellet bonding.

Most of the data needs are related to the performance of high burn-up fuel pins



[ONRL image]

- **Integrity of spent-fuel (retrievability and transpostation) is highly dependent on cladding and fuel pin performance.**
- **Lack of data for actual high burn-up fuel due to operational limitations.**

Hydride reorientation and embrittlement (M/H)

- **Influencing parameters**
  - Temperature, H concentration, crystallography, defect density, stress level, solubility limit.
- **Data already available**
  - Terminal Solid Solubility (TSS), optical microscopy quantification of precipitation morphology (Arborelius, Motta, Billone, Chung), in-situ XRD.
- **Data needs:**
  - Radial-hydride formation below licensing limits (400°C) on irradiated cladding materials.
  - Effect of peak cladding temperature and pressure on hydride formation mechanisms in irradiated materials: Ductile-to-Brittle Transition Temperature (DBTT).
  - Collect microstructural information on interaction between hydride and deformation mechanisms of (irradiated) cladding matrix.
  - Data on fracture toughness for various burn-up level is scarce at best.
    - No data on radial hydrides cladding.
  - Data on ZIRLO™, M5®.

Pellet/clad delamination (M/H)

- **Influencing parameters**
  - Temperature, loading mode, burn-up, composition, interface roughness, interface chemistry (intermixing).
- **Data already available**
  - Data associated with in-reactor behavior (fission product swelling, reactivity induced accident).
- **Data needs:**
  - Characterization of interfacial features (roughness, void structure, etc.) and environmental factors (thermal/irradiation) on delamination process.
  - Interfacial fracture toughness data for pellet/clad interfaces (not to mention high burn-up) does not exist to date.
  - Interfacial fracture toughness data for pellet/pellet interface. Emulation of irradiated fuel?

Radiation annealing (M)

- **Influencing parameters**
  - Temperature, loading mode, burn-up, composition.
- **Data already available**
  - Hardness tests vs. annealing temperature (Ito, 2004).
- **Data needs:**
  - Low-temperature annealing studies applicable to extended storage (over long period of time).
  - Hardness recovery of irradiated cladding materials (especially for newer alloys ZIRLO™, M5® [high burn-up]) as a function of time during long term annealing.

Embrittlement of elastomer seals/polymeric neutron shields (L)

- **Influencing parameters**
  - Temperature, composition, alpha irradiation.
- **Data already available**
  - Rubber-glass transition temperature for unirradiated samples (BAM, Germany).
- **Data needs:**
  - Study of coupled alpha irradiation and temperature on cross-linking of polymer?
  - Failure of elastomer seals.

Review of criteria

Criterion	Priority
Ability of the facility to produce results of high scientific merit and the potential to meet needs of DOE-NE and industry.	HIGH*
Ability of the facility to provide a variety of ion irradiations (ion types, energies, multiple beams, etc.).	MEDIUM
Ability of the facility to provide a variety of irradiation environments and conditions.	MEDIUM
Ability of the facility to collect microstructural characterization data onsite and in-situ.	HIGH
NE support and activities (performed and anticipated) at the facility including the volume of experiments that can be handled.	LOW
Unique capabilities of the facility including new technology.	LOW
Ability of the facility to handle radioactive materials in the beams and elsewhere onsite.	HIGH
Ability of the facility to produce high quality data that can support verification and validation for modeling and simulation.	HIGH