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Fuel Cycle Technologies

Engineering Analysis
to Support Extended Storage and Transportation of Used Nuclear Fuel

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Nuclear Waste Technical Review Board
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Outline

- **Engineering Analysis for Transportation**
  - Assessment of the criticality safety impact of fuel degradation and reconfiguration
- **Burnup Credit**
  - Disposal criticality activities and update
  - Storage and transportation
- **Engineering Analysis Plans for FY12**

Introductory Remarks

- Without sufficient experimental data and experience for used nuclear fuel (UNF) systems and contents during extended storage (ES), there is uncertainty in establishing the safety basis for ES.
- Starting with the fundamental safety requirements (limit dose, control release, prevent criticality) and working back to limiting system requirements may help formulate solutions that provide flexibility relative to the data gaps and uncertainties.
- Potential corollary: Can cladding integrity be assured with the certainty needed to withstand regulatory scrutiny and provide public confidence in the ES safety basis?

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Assessment of the Safety Impact of Fuel Degradation and Reconfiguration

- **The potential for fuel/clad degradation and reconfiguration is a key issue in ES that cross-cuts virtually all safety-significant regulatory requirements**
  - Will used fuel remain in the configuration that is analyzed in current and future SARs?
  - If the as-analyzed configuration cannot be assured, what are the safety and operational implications?
- **Fuel reconfiguration could have an impact on virtually all aspects of a used fuel storage and transport systems' performance**
  - Criticality safety
  - Containment
  - Fuel handling and ability to retrieve
  - Shielding
  - Thermal
  - Structural performance (potentially)

The potential for fuel reconfiguration is perhaps the most important issue for consideration in ES

Assessment of the Safety Impact of Fuel Degradation and Reconfiguration

- **To address the issue of, or potential for, fuel reconfiguration it is necessary to understand the…**

1 ***Likelihood of fuel reconfiguration and associated dependencies***

- *Thermal history*
- *Burnup – low, med, high?*
- *Storage time, conditions*
- *Stress history and future stresses during normal transport*
- *Cladding specifics*
- *etc…*

2 ***Potential extent of fuel reconfiguration and associated dependencies***

- *Thermal history*
- *Burnup – low, med, high*
- *Storage – time, conditions*
- *Stress history and future stresses during normal transport*
- *Cladding specifics*
- *etc…*

3 ***Impact of credible fuel reconfiguration on safety***

- ***Criticality safety***
- *Containment*
- *Shielding*
- *Thermal*
- *Structural performance*
- *Fuel handling and ability to retrieve*

Experimental efforts are planned to address the likelihood and extent of fuel reconfiguration during ES; MANY inter-dependencies to consider

Engineering analysis initiated to assess impact of fuel reconfiguration on safety, with initial focus on Criticality Safety

Assessment of the Safety Impact of Fuel Degradation and Reconfiguration

- **Observations**
  - Used nuclear fuel (UNF) is currently stored in multi-assembly canisters, and will be in the foreseeable future
  - Future UNF could be canned in single assembly damaged fuel canisters (DFCs) to be inserted into larger multi-assembly canisters. This approach would ensure future retrievability of the assemblies, but at a cost.
  - There is no assurance currently that UNF (cladding and fuel) and baskets will be intact (not degraded) after ES periods.
  - This lack of assurance exists regardless of aging study R&D conducted on UNF, including high burnup UNF, in the near future (~next 10-20 years) due to uncertainties in extrapolating test results (e.g., over ES durations or to include consideration of non-experiment conditions).

Assessment of the Safety Impact of Fuel Degradation and Reconfiguration

- **IF it can be assured that UNF within multi-assembly canisters will remain subcritical (safe) under all credible conditions after ES, then:**
  - Potentially reduce monitoring needs for canisters during ES.
  - There would be no need to open the multi-assembly canisters after ES and prior to transportation.
  - Safety significance related to extrapolation of test results on UNF to predict the UNF condition after ES would be removed (or greatly reduced).
  - Shifts focus of experiments performed on aged UNF (from qualified data for safety case to technical understanding to inform safety case).
  - UNF experimental information could help determine what configurations are credible (likelihood and potential), thereby reducing and/or eliminating criticality mitigation needs related to fuel reconfiguration
- **If safety is assured and retrievability of UNF after ES is deemed of secondary importance, canning assemblies in DFCs may not be essential (and would result in significant cost savings).**
  - In an ES world – should “retrievability” be re-considered / re-defined?

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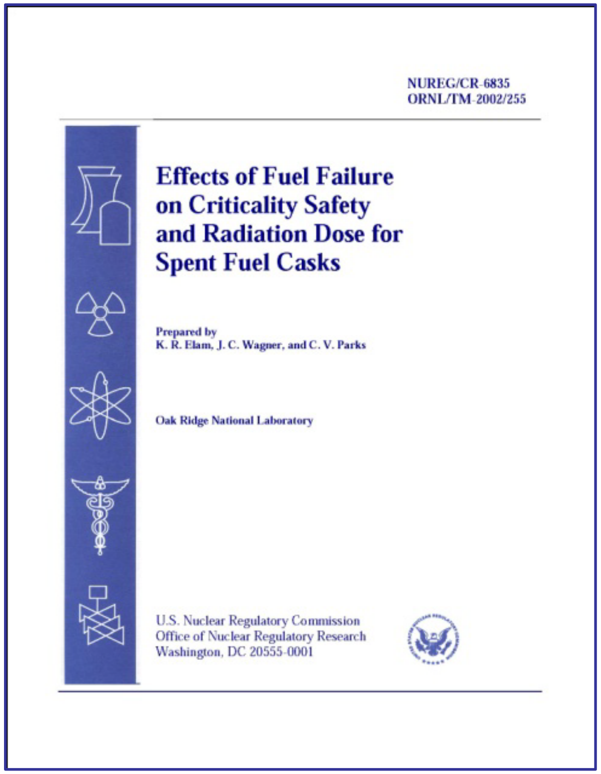
Assessment of the Criticality Safety Impact of Fuel Reconfiguration

- **Initial assessment (criticality):**
  - Using NUREG/CR-6835 as a reference basis, analyses are being performed to quantify the increase in reactivity associated with fuel reconfiguration in multi-assembly canisters.
  - The condition of the UNF for these analyses is varied to encompass a range of damaged conditions (input sought from clad materials experts).
  - Once the reactivity effects are sufficiently quantified and understood, options for mitigating the increase in reactivity due to fuel reconfiguration can be determined.


NUREG/CR-6835
ORNL/TM-2002/255

Effects of Fuel Failure on Criticality Safety and Radiation Dose for Spent Fuel Casks

Prepared by
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U.S. Nuclear Regulatory Commission
Office of Nuclear Regulatory Research
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Assessment of the Criticality Safety Impact of Fuel Reconfiguration

- **Mitigation options include:**
  - Safety analyses performed for a $k_{eff} \leq 0.95 - \Delta k_{reconfig}$
    - *where $\Delta k_{reconfig}$ = the maximum possible reactivity increase due to credible fuel reconfiguration*
  - Package design modifications (OR limit size or payload)
  - Use of rod inserts, e.g., controls rods and/or burnable poison rod assemblies, in the fuel assembly lattice
  - Crediting inherent margins (conservatisms, including expanded credit for burnup and cooling time) in the safety analyses
  - Allow higher k_{eff} limit, e.g., 0.98, for fuel reconfiguration
  - Moderator exclusion
- **Results of engineering analysis can inform and focus testing and experimental data needs relative to identifying credible fuel reconfiguration**

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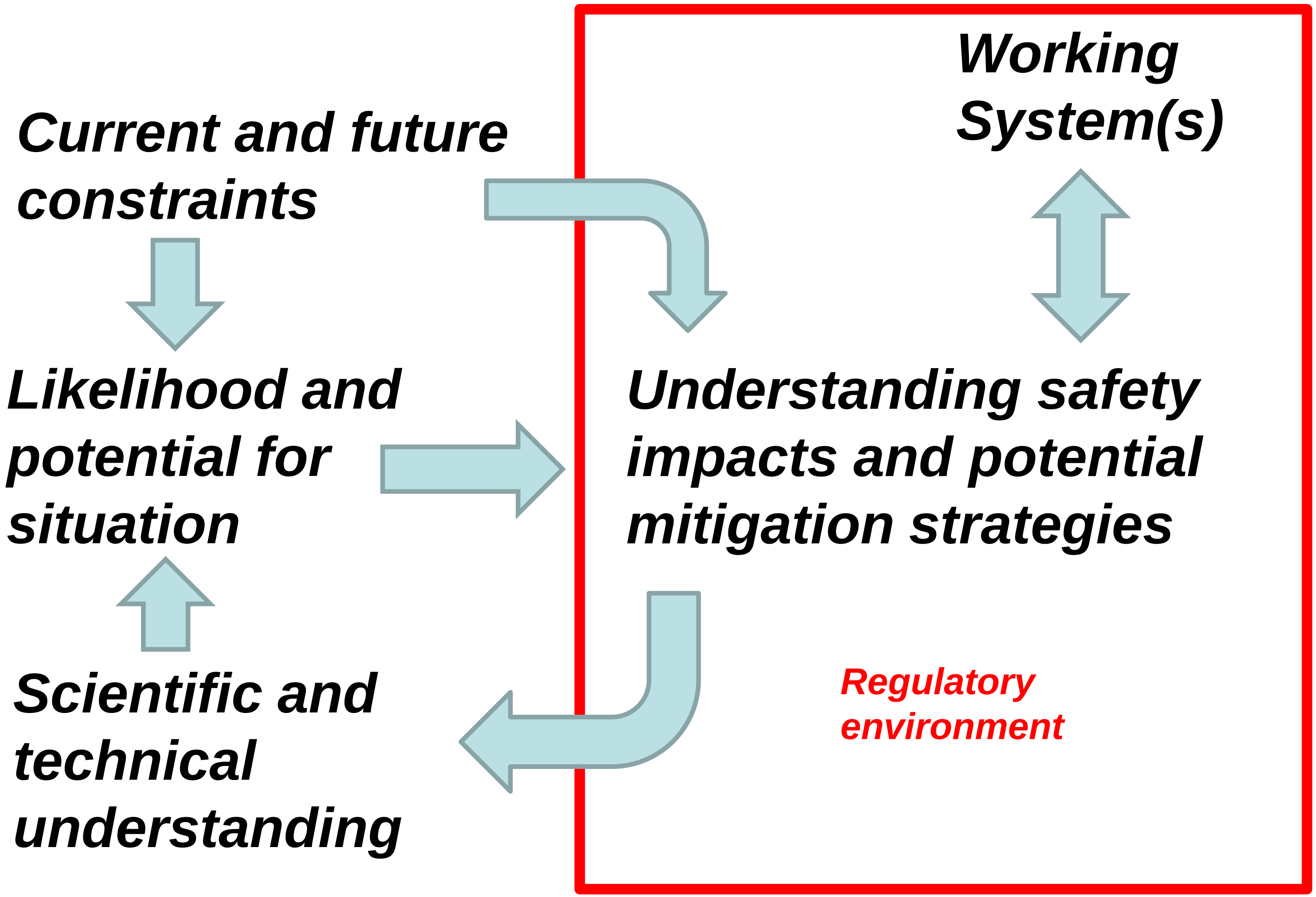
An Integrated Approach to Addressing Extended Storage



Assessment of the Criticality Safety Impact of Fuel Reconfiguration

- **Eight degradation scenarios considered**
  - Gross rod failures - Removal of single and multiple rods from assembly lattice
  - Gross cladding failure - Removal of cladding material (non-physical condition)
  - Rod bowing - Optimum rod pitch within fuel storage cell, both with and without cladding
  - Poison degradation - Missing poison segment of varying location and size as well as single missing panel
  - Degradation/failure of cask internals - Axial misalignment of fuel assemblies
  - Gross assembly failure - Both optimum pitch pellets and homogenous rubble

- **Representative fuel types in three representative cask designs over a range of enrichments, burnups, and decay times considered**
  - GE 10x10 (BWR) in Holtec MPC-68: Uniform 5 w/o fresh, 35 GWd/MTU, 70 GWd/MTU, cooling time range 5-300 years
  - W 17x17 OFA (PWR) in Holtec MPC-24: Uniform 5 w/o fresh
  - W 17x17 OFA (PWR) in GBC-32: Enrichment range ~2-5 w/o, burnup range 10-70 GWd/MTU, cooling time range 5-300 years

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Preliminary Results – Maximum Impacts on k_{eff} (% Δk)

Reconfiguration Scenario	PWR fuel (32 assembly cask)	BWR fuel (68 assembly cask)
Single rod removal	0.10	0.29
Multiple rod removal	1.86	2.42
Cladding removal	3.52	4.98
Axial displacement (20 cm)	12.49	8.52
Missing poison (5 cm segment)	1.24	2.90
Missing poison (10 cm segment)	2.63	6.36
Missing poison panel	1.08	0.71
Optimum rod pitch, clad	1.69	12.07
Optimum rod pitch, unclad	4.89	14.70

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Next Steps for Assessment of Fuel Degradation and Reconfiguration

- **For criticality safety:**
  - Complete and finalize reactivity impact analysis
  - Consult with subject matter experts to
    - *Determine which scenarios are credible, and hence must be addressed*
    - *Develop defensible justification for excluding any that are judged to be not credible*
  - Evaluate mitigation options for credible fuel reconfigurations conditions
  - Where mitigation options are judged to be inadequate or too costly, inform experimental testing program to focus their efforts toward developing data to justify exclusion of (or reduction of the impact of) the reconfiguration condition(s)
- **Proceed to evaluate other safety significant aspects:**
  - Containment
  - Fuel handling and retrievability (operational aspects)
  - Shielding
  - Thermal
  - Structural performance (potentially)
- **Assess safety impact of other potential system/component failures**

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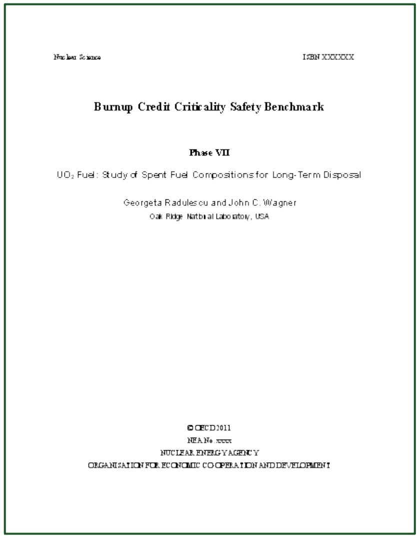
- **Engineering analysis plans for FY12**

Burnup Credit – FY11 Accomplishments

- ***Burnup Credit Criticality Safety Benchmark Phase VII, entitled UO_2 Fuel: Study of Spent Fuel Compositions for Long-Term Disposal* completed March 2011**
  - Objective: Improve understanding and confidence in our ability to predict k_{eff} and source terms for timeframes relevant to extended storage and disposal of UNF through international code comparisons



Nuclear Science ISBN XXXXXX

Burnup Credit Criticality Safety Benchmark

Phase VII

UO_2 Fuel: Study of Spent Fuel Compositions for Long-Term Disposal

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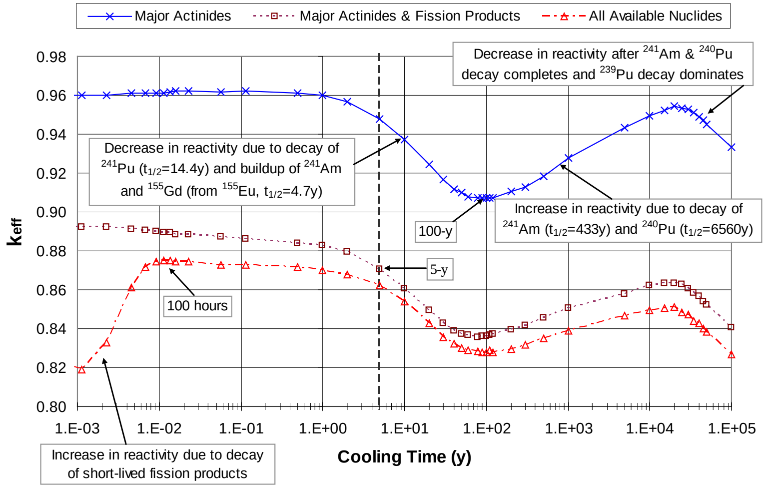
ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

- ***Review of Yucca Mountain Disposal Criticality Studies* published at International High-Level Radioactive Waste Management Conference**
  - Summarizes post-LA work conducted while preparing RAIs and closeout of YMP
  - Additional validation data identified that was not available at the time the Yucca Mountain License Application was submitted

- **Experimental validation data**
  - ORNL RCA capability demonstration and process and methods development completed from analysis of ATM-104 fuel samples
  - Weapons grade MOX RCA analysis completed under different sponsor but UFD is supporting computational evaluation work (in-process)
  - ENUSA BWR fuel sample data purchased (RCA and operating history information)
    - *Analyses being completed under a different sponsor*

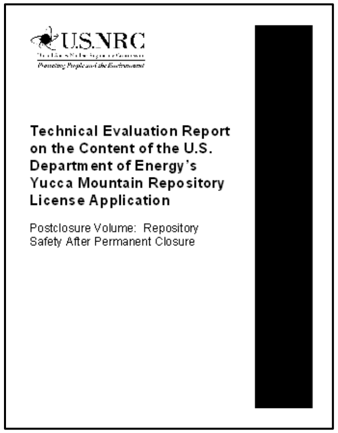
- **Burnup credit analysis in support of fuel reconfiguration assessment**

Reactivity of CSNF as a Function of Time



Burnup Credit – update on status of post-closure criticality LA review

- **NRC issued first of three Technical Evaluation Reports (TERs) regarding Yucca Mountain License Application**
  - "DOE developed an adequate technical basis for screening out the criticality event class on the basis of low probability"
  - "NRC staff found it reasonable to take burnup credit for PWR and BWR fuel"
    - *Overall acceptance of burnup credit for BWR fuels is based on analyses of waste forms not explicitly analyzed being completed prior to waste receipt (i.e. modern assembly designs)*
  - Noted exception in TER
    - *"Taking full credit for the neutron absorptive properties of Mo-95, Tc-99, Ru-101, Rh-103, and Ag-109 was technically unjustified due to insufficient and inadequate radiochemical assay data… However, … DOE showed that the isotopic bias and uncertainty incorporated into the critical limit should make up for the errors and uncertainties in the predictions of these five isotopes."*


U.S.NRC

Technical Evaluation Report on the Content of the U.S. Department of Energy's Yucca Mountain Repository License Application

Postclosure Volume: Repository Safety After Permanent Closure

- **DOE Disposal R&D Roadmap identifies criticality to be low priority at this time for evaluation of generic disposal concepts**
  - R&D determined to be not necessary relative to early decision points (site screening & selection)
  - *Note: The Disposal Roadmap does not address Storage and Transport*

Burnup Credit in FY12

- **Focus should shift to Storage and <u>Transportation</u>**
  - Burnup credit key to demonstrating compliance with criticality safety regulatory requirements for high-capacity transportation packages, as well as for demonstrating criticality safety for fuel reconfiguration scenarios

- **High-priority research areas for Storage and Transportation require irradiated fuel testing**
  - Opportunities to collect burnup credit validation data should be seized

- **ORNL is the world leader in burnup credit implementation and provides technical consultancy to NRC and foreign burnup credit programs**
  - Validation data continues to be a challenge, topic of debate nationally and internationally
    - *Similar to what has been done recently to supplement criticality validation for fission products, sensitivity/uncertainty methods provide a potential pathway to supplement depletion validation where data are sparse or not available and may provide a means to reduce conservatism in depletion validation associated with experimental measurement uncertainties.*
  - ORNL will continue to inform UFD/DOE on opportunities for validation data, as well as developments in regulatory guidance and positions and international programs

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Engineering Analysis

- **Purpose: apply and develop analysis capabilities to address technical issues and data gaps associated with ES of UNF and transport of UNF following ES.**
- **Scope: the broad technical areas and associated regulatory requirements for ensuring the safety of UNF storage and transport, including used fuel characterization, materials, structural, thermal, radiation shielding/characterization, containment/confinement and nuclear criticality safety.**
- **Efforts will be prioritized to develop an improved understanding of UNF performance characteristics and develop validated analysis capabilities that can be used to extend the technical bases for the safe storage and transport of UNF during protracted time periods.**
- **Focus on addressing immediate modeling needs with existing codes**
- **Potential linkages and leveraging opportunities: NEAMS, LWRS, NEUP, international partners**

Engineering Analysis: FY12 Plans

- **Activities:** (theory + experiment + **modeling** = science-based)
  - **Assess specific applications for modeling and analysis**
    - Assess data needs and current analysis capabilities on recently developed, flexible multi-canister concept
  - **Initiate/conduct modeling and analysis for specific applications, e.g.,**
    - Thermal analysis/profiles to characterize reality, e.g., during drying ops.
    - Criticality safety / burnup credit
    - Clad creep and annealing; hydrogen reorientation
    - Fuel/clad initial material properties
    - Canister/overpack corrosion
- **Deliverables:**
  - Contribute to FY12 Revision of the Storage R&D Gap Analysis Report
  - Report identifying specific applications for early analysis and M&S capability gaps: This report will be the result of the multi-lab team's assessment of early analysis work will be initiated to support the data gap report.
- **Team:**

ornl OAK RIDGE NATIONAL LABORATORY | INL Idaho National Laboratory | Sandia National Laboratories | Pacific Northwest NATIONAL LABORATORY | Los Alamos NATIONAL LABORATORY

Discussion / Questions?

- **Contact info:**
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