U.S. DEPARTMENT OF ENERGY
OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT

# NUCLEAR WASTE TECHNICAL REVIEW BOARD
# FULL BOARD MEETING

# SUBJECT: DISPOSAL CRITICALITY CONTROL


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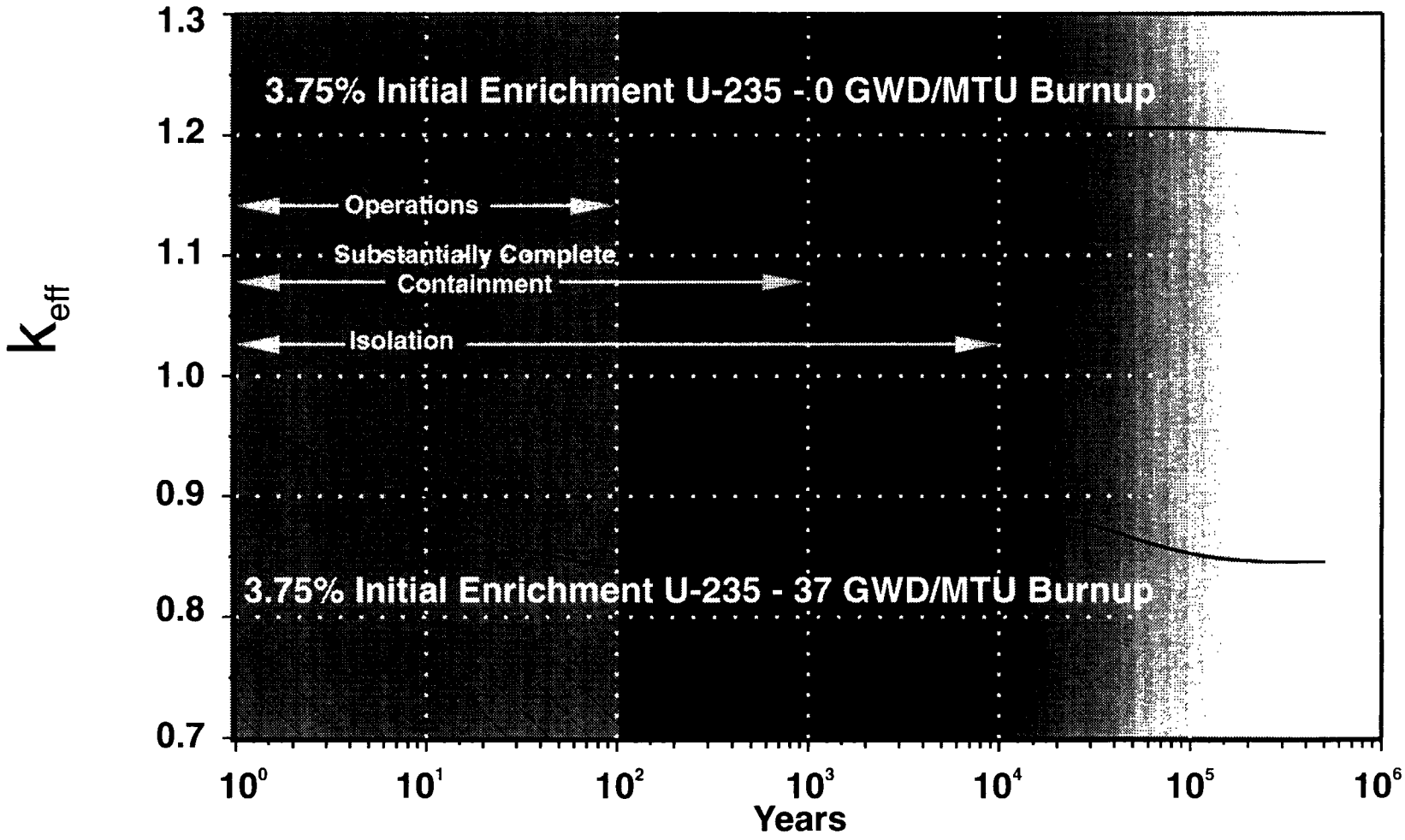
# Criticality Potential of Commercial Spent Nuclear Fuel

- Majority of spent nuclear fuel does not have the potential for a nuclear chain reaction
- Preliminary calculations have indicated more than 90% of the spent fuel in waste packages would not have the potential to go critical; remainder can be controlled with supplemental neutron absorbers
  - Assuming intact conditions
  - Accounting for reduced reactivity due to fuel burnup
  - With moderator present

# Time Effects on Criticality Potential

## 21 PWR MPC Conceptual Design

### (No Additional Neutron Absorbers Added)

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# Technical Approach for Disposal Criticality Control

- Design waste package for criticality control through substantially complete containment phase and early isolation phase
  - Multiple containment barriers
  - Long-term performance materials
- Use repository engineered barrier and natural barrier features to limit potential for criticality after substantially complete containment period
  - Dry unsaturated site
  - Low water movement

# Technical Approach for Disposal Criticality Control Analysis

- Divide the time period of disposal into three phases
- Evaluate each phase with appropriate method
  - Deterministic for Operations Phase
  - Deterministic and probabilistic for Substantially Complete Containment Phase
  - Probabilistic for Isolation Phase
- Perform bounding deterministic evaluations for time period of disposal and trending evaluations beyond

# Mined Geologic Disposal System Waste Package Approach

- Examine disposal criticality control regulations
- Examine long-term conditions
- Evaluate available criticality control method(s) for long-term performance
- Develop disposal criticality control strategies
- Apply above to Three Phase Approach, for disposal criticality control/evaluations

# Mined Geologic Disposal System Waste Package Approach
(Continued)

- Develop "Disposal Criticality Analysis Technical Report" and the supporting technical information

- Submit "Disposal Criticality Analysis Topical Report" to NRC

# Regulations

- **Title 10 CFR Part 60.131.(b)(7)**
  - **Control criticality for all repository systems, including isolation**
  - **Criticality not allowed unless two unlikely, independent, and concurrent or sequential changes occur**
  - **Criticality safety required under normal and accident conditions**
  - **$k_{eff}$ must be $\leq$0.95 (a 5% margin below unity), accounting for**
    - » **bias in the calculational method**
    - » **uncertainty in experiments validating the calculational method**

# Long-Term Conditions

- Changing spent fuel conditions
  - Isotopic concentration
  - Waste form degradation
- Changing waste package conditions
  - Material degradation
  - Changing geometry
- Changing repository conditions
  - Temperature/humidity (effects degradation)
  - Water movement (moderator and transport mechanism)

# Available Criticality Control Methods

- **Three general methods for criticality control in commercial light water reactor fuel**
  - **Limit fissile material**
    - » **Reduced fissile content from fuel burnup**
    - » **Limited package capacity**
    - » **Loading limits**
  - **Limit neutrons**
    - » **Neutron absorbers present in fuel from burnup**
    - » **Supplemental neutron absorbing materials**
    - » **Isolate neutrons from assemblies by the geometry**
  - **Limit moderator**
    - » **Moderator displacement (filler material)**
    - » **Moderator exclusion (sealed barriers)**
    - » **Rod consolidation**

# Design Methods for Disposal Criticality Control

- **Burnup Credit**
  - Using "Principal Burnup Credit Isotopes"
    - » Net depletion of fissile material (U-233, U-235, Pu-239, Pu-241)
    - » Build in of neutron absorbers (actinide and fission product absorbers)
  - Long-term changes in criticality potential
- **Supplemental Neutron Absorbers**
  - Control panels (in basket between assemblies)
  - Control rods (in most PWR assemblies)
  - Accounting for long-term removal of neutron absorber
- **Moderator Displacement**
  - Filler load into waste package at repository
  - Long-term performance of filler considered

# Time-Phased Approach for Criticality Analysis

- **Repository Preclosure, Operations Phase**
  - Personnel safety issues paramount
  - Covers first ~100 years
  - Deterministic analysis used

- **Post-closure, Substantially Complete Containment Phase**
  - Waste package provides substantially complete containment and exclusion of moderator (water)
  - Period covers first ~1000 years
  - Deterministic analysis in early years, and probabilistic analysis of situations that increase $k_{eff}$ in later years
  - External events considered

# Time-Phased Approach for Criticality Analysis
(Continued)

- **Post-containment, Isolation Phase**
  - Period after Substantially Complete Containment Phase
  - Controlled release from engineered barrier
  - Covers through time of isolation
    - » Regulations: 10,000 years (subject to EPA rule)
    - » Analysis: examine beyond 10,000 years for trends
  - Probabilistic approach with bounding deterministic calculations
  - External events considered

# Deterministic and Probabilistic Analysis Methods

- **Deterministic**
  - **Conditions (essential system parameters) are known/can be controlled**
  - **Accident conditions evaluated deterministically**
  - **Design basis accident(s) determined probabilistically**
    - » **Accidents considered**
    - » **Credible accidents determined**
    - » **Most credible becomes design basis accident(s)**

# Deterministic and Probabilistic Analysis Methods

(Continued)

- **Deterministic and Probabilistic**
  - Most conditions are known/can be controlled
  - Uncertainities exist in some conditions
- **Probabilistic**
  - Conditions cannot be known exactly
  - Probabilities of possible conditions can be estimated

# Criticality Probabilistic Risk Analysis Methodology

- Identify initiating events, i.e.
  - Water intrusion into the repository from perched water, increased precipitation, rise in water table, etc.
- Identify subsequent events, i.e.
  - Breach of containment barriers
  - Loss of neutron absorber materials
  - Sufficient moderator (water) in waste package
- Combine events into fault/event trees

# Criticality Probabilistic Risk Analysis Methodology

(Continued)

- Determine probabilities for events
- Compute expected frequency and types of criticality events, based upon fault tree scenarios
- Perform consequence analysis for credible criticality events
- Combine the probabilities and consequences of various scenarios for risk assessment

# A Criticality Event in the Repository

## Required conditions

- Criticality event internal to the waste package
  - Breach of waste package barriers
  - Moderator (water) present in waste package/repository in sufficient quantity
  - Requires the separation of the neutron absorbers (in the fuel and supplemental) material from the fuel assemblies

# A Criticality Event in the Repository
(Continued)

- Criticality event external to the waste package
  - Waste package barriers significantly degraded
  - Sufficient water to separate absorbers and fissile material
  - Mechanism to accumulate fissile material in a critical configuration

# Disposal Criticality Schedule

- Major Activities
- "Disposal Criticality Analysis Technical Report" to NRC in FY96
- Key data gathering/testing completed by end of FY97
- "Disposal Criticality Analysis Topical Report" to NRC in FY98
- Technical Site Suitability in FY98
- Long-term material performance test information available in the year 2000
- Mined Geologic Disposal System License Application in the year 2001

# Conclusions

- Disposal criticality control technical approach developed
  - Internal waste package criticality
  - External waste package criticality
- Disposal criticality control analysis approach identified
  - Three-phase approach
  - Deterministic and probabilistic methods

# Conclusions
(Continued)

- Mined Geologic Disposal System Waste Package Approach
  - Regulations
  - Long-term control methods
  - Apply three-phase approach
- Schedule developed