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

NUCLEAR WASTE TECHNICAL REVIEW BOARD
EBS PANEL MEETING

SUBJECT: LONG-TERM CRITICALITY WASTE PACKAGE DEVELOPMENT

PRESENTER: THOMAS W. DOERING

PRESENTER'S TITLE AND ORGANIZATION: MANAGER, WASTE PACKAGE DESIGN
M&O/LAS VEGAS, NEVADA

PRESENTER'S TELEPHONE NUMBER: (702) 794-1857

PLEASANTON
MARCH 10-11, 1994

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Criticality Safety Requirement

Title 10 CFR Part 60.131.(b).(7) states: "Criticality control. All systems for processing, transporting, handling, storage, retrieval, emplacement, and isolation of radioactive waste shall be designed to ensure that a nuclear criticality accident is not possible unless at least two unlikely, independent, and concurrent or sequential changes have occurred in the conditions essential to nuclear criticality safety. Each system shall be designed for criticality safety under normal and accident conditions. The calculated effective multiplication factor $k_{(eff)}$ must be sufficiently below unity to show at least a 5% margin, after allowance for a bias in the method of calculation and uncertainty in experiments used to validate the method of calculation."

Note: underline has been added

Calculational Bias and Uncertainties

$$k_c + \Delta k_u + \Delta k_m < 1.0$$

Where:

k_c = k_{eff}, calculation results

Δk_u = bias and uncertainties in benchmark critical experiments and system being calculated

Δk_m = regulatory margin of safety: 0.05 (10 CFR 60)

Criticality Analysis Method

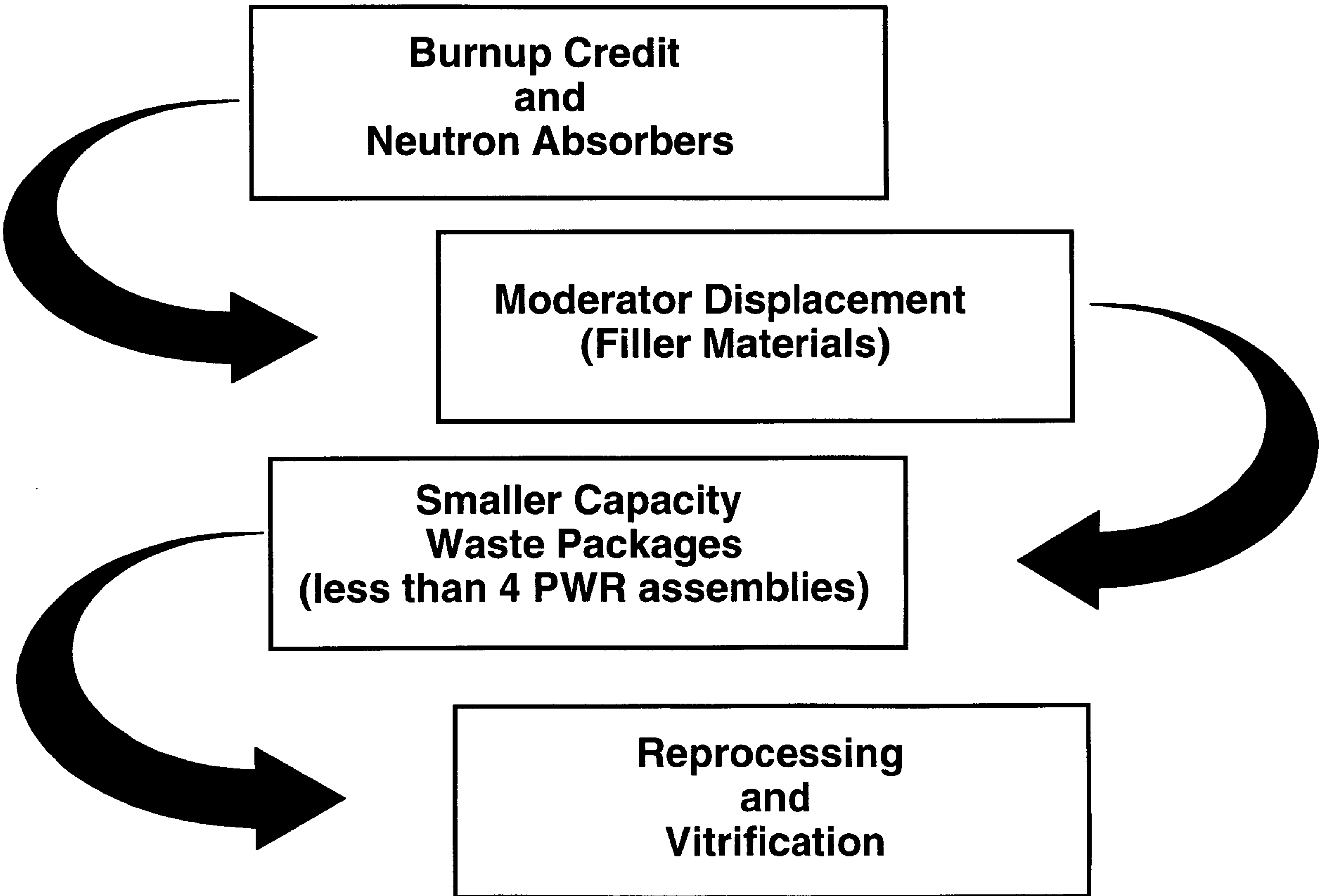
- Assume burnup credit

- Calculate k_{eff} over time
  - Geometry and configuration effects
  - No additional neutron absorbers
  - Assuming moderator

- Calculate quantity of neutron absorbers needed for $k_{eff} \leq 0.95$
  - Determine initial amount of neutron absorber
  - Calculate rate of neutron absorber leaching/depletion
  - Define long-term neutron absorber requirements

- Repeat calculation for different Spent Nuclear Fuel characteristics and design options

Waste Package Design Strategies



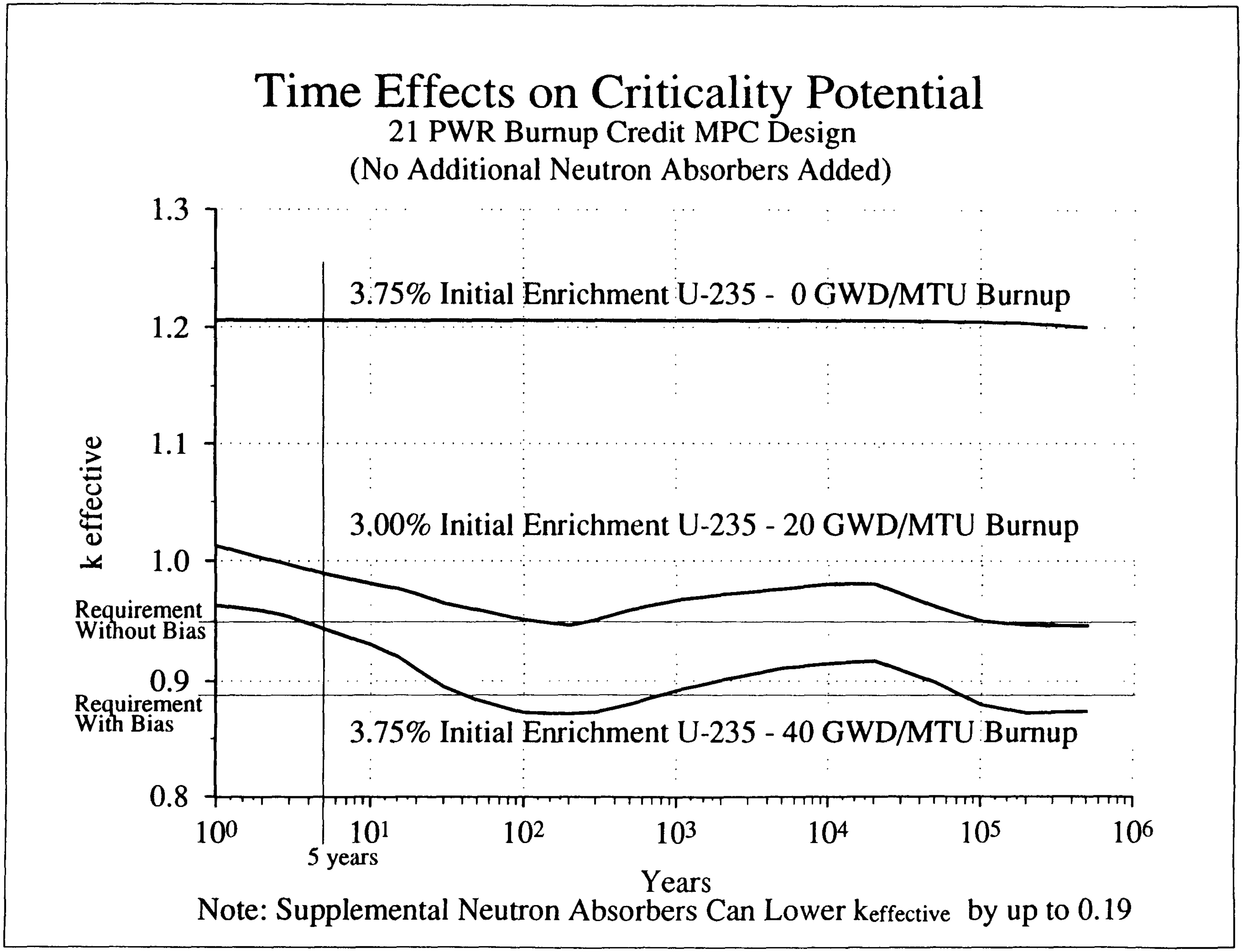
Long-Term Criticality Considerations

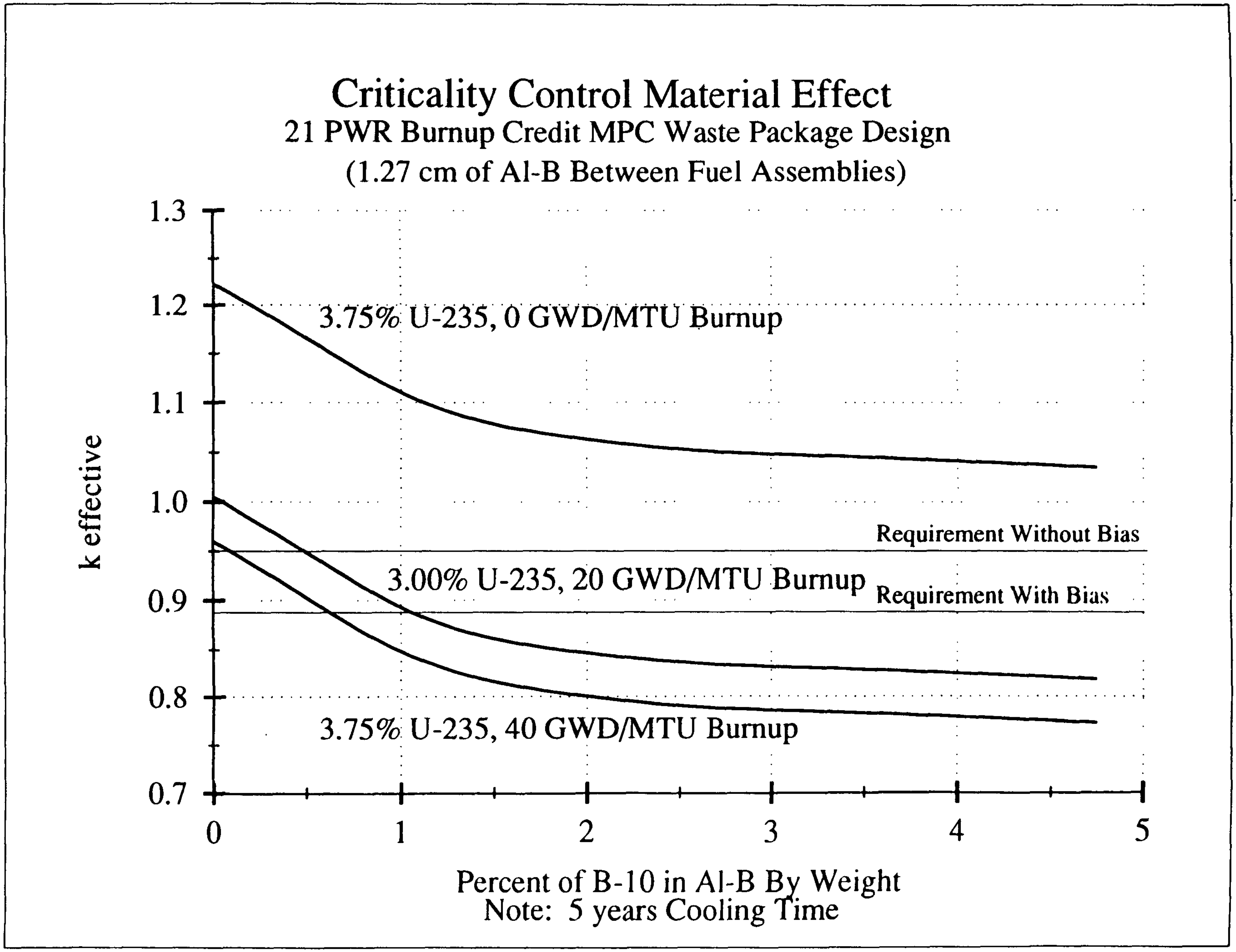
- The long-term effects
  - The criticality potential of Spent Nuclear Fuel changes
  - Neutron absorber materials removed

- Sufficient neutron absorber materials are needed to account for the removal processes over the lifetime of the waste package

Time Effect on Criticality

- Pu-241 in spent fuel decays away reducing k for the first 100 to 200 years (fissile material)
- Pu-240 and fission products decay increasing k out to ~20,000 years (neutron absorber)
- Pu-239 decays away reducing k (fissile material)


Time Effects on Criticality Potential
21 PWR Burnup Credit MPC Design
(No Additional Neutron Absorbers Added)
k effective
Years
3.75% Initial Enrichment U-235 - 0 GWD/MTU Burnup
3.00% Initial Enrichment U-235 - 20 GWD/MTU Burnup
3.75% Initial Enrichment U-235 - 40 GWD/MTU Burnup
Requirement Without Bias
Requirement With Bias
5 years
1.3
1.2
1.1
1.0
0.9
0.8
10^0
10^1
10^2
10^3
10^4
10^5
10^6
Note: Supplemental Neutron Absorbers Can Lower $k_{effective}$ by up to 0.19



Criticality Control Material Effect
21 PWR Burnup Credit MPC Waste Package Design
(1.27 cm of Al-B Between Fuel Assemblies)
k effective
1.3
1.2
1.1
1.0
0.9
0.8
0.7
3.75% U-235, 0 GWD/MTU Burnup
Requirement Without Bias
3.00% U-235, 20 GWD/MTU Burnup
Requirement With Bias
3.75% U-235, 40 GWD/MTU Burnup
0
1
2
3
4
5
Percent of B-10 in Al-B By Weight
Note: 5 years Cooling Time

Disposal Criticality Control

- Pre-closure
  - Deterministic approach
  - Similar to transportation/storage

- Post closure
  - Bounding long-term deterministic approach
  - Probabilistic approach
  - Fault tree/consequence analysis

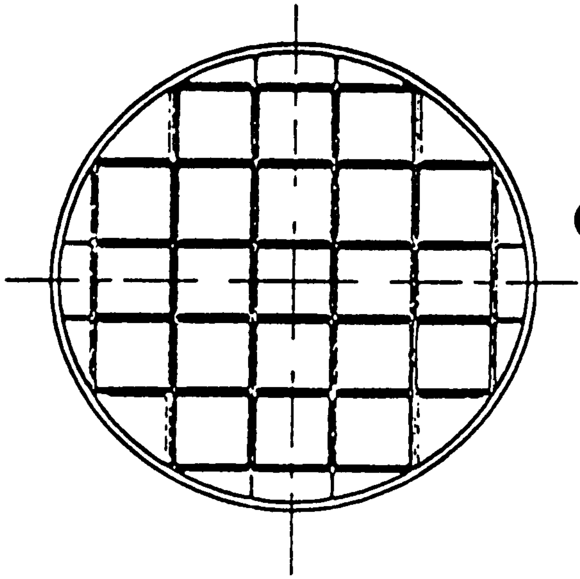
Post Closure Deterministic

- Use degradation rates of basket and spent fuel components

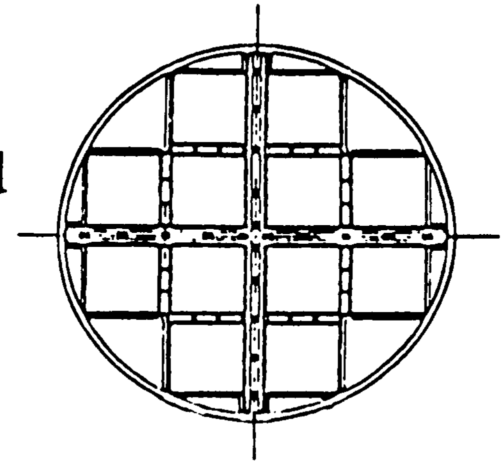
- Determine approximate times of component failures

- Perform criticality analysis at times of each component failure

Containment Period

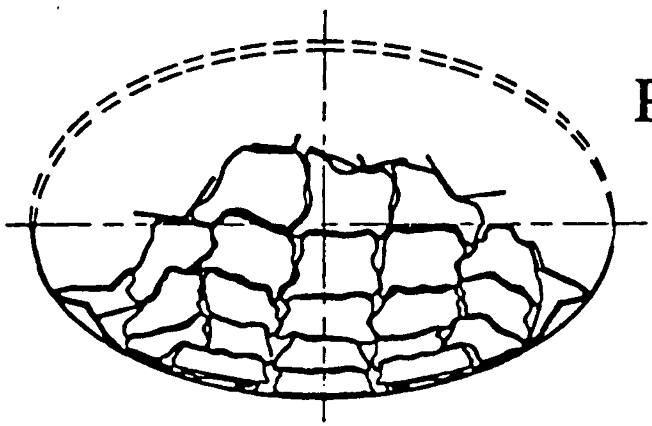


BURNUP CREDIT



FLUX TRAP

Post-Containment Period



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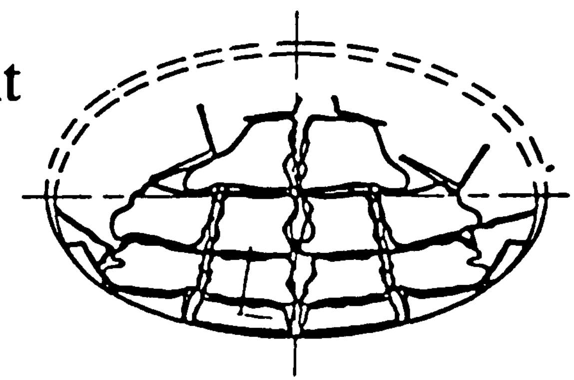

FLUX TRAP

Post Closure Probabilistic Approach

- Identify possible modes of degradation and design failures which could cause criticality events
- Work with performance assessment to assign probabilities for each failure mode
- Establish a probabilistic risk assessment of criticality events in a repository

Waste Package Criticality Fault Tree

- Water inflow to repository
- Failure of drift drainage and/or reflux diversion
- Sufficient water to cover most of the waste package
- Breach of waste package outer barrier
- Breach of waste package inner barrier
- Breach of MPC shell
- No filler material or lost filler material
- Failure/inadequacy of neutron absorber
- Potential for criticality event

Criticality Event

- Required conditions
  - Breach of waste package barriers
  - Moderator (water) present in waste package/repository in sufficient quantity
  - Requires the separation of the neutron absorber material from the assemblies
- Likely consequences (Natural Analog OKLO)
  - Slow increase in neutron flux and temperature
  - A brief neutron flux spike
  - No mass boiling of water
  - Decreasing neutron flux from absorber buildup and decreased moderation
  - Additional short lived fission products produced

Conclusions

- Approach for demonstrating criticality control
  - Bounding deterministic analysis
  - Probablistic analysis
- Burnup credit is important for waste packages with more than 4 PWRs for long-term criticality control
- Long-term performance of materials important
- Low probability of criticality events