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Preliminary Analysis of the Maximum Disposal Capacity for CSNF in a Yucca Mountain Repository

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EPRI draft report of preliminary work in preparation

- Publicly available end of this month (May 2006)

Draft report authors

- Mick Apted, Monitor Scientific LLC (lead)
- John Kemeny, University of Arizona
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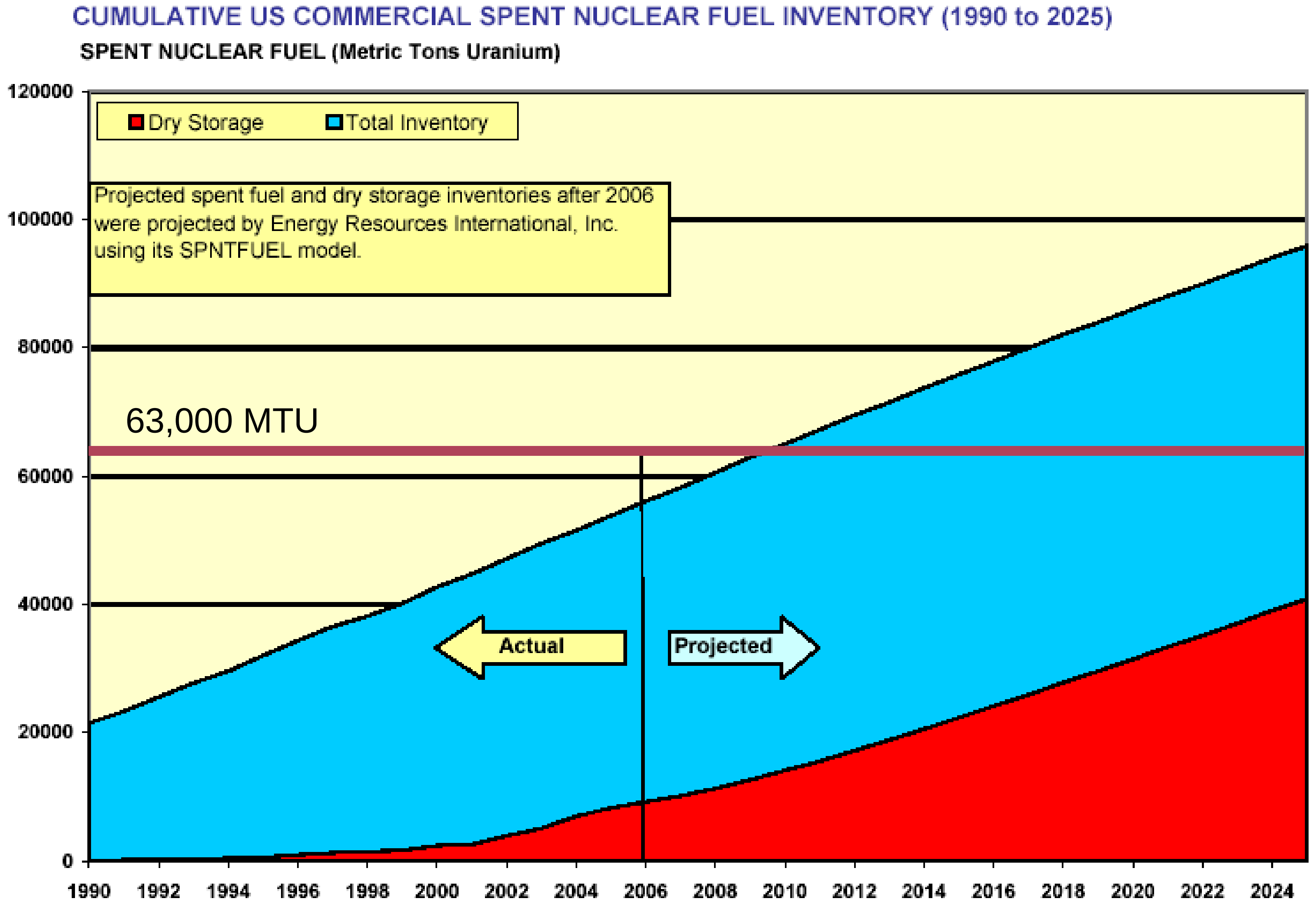
Spent Fuel Inventories are Rising Past 63,000 MTU

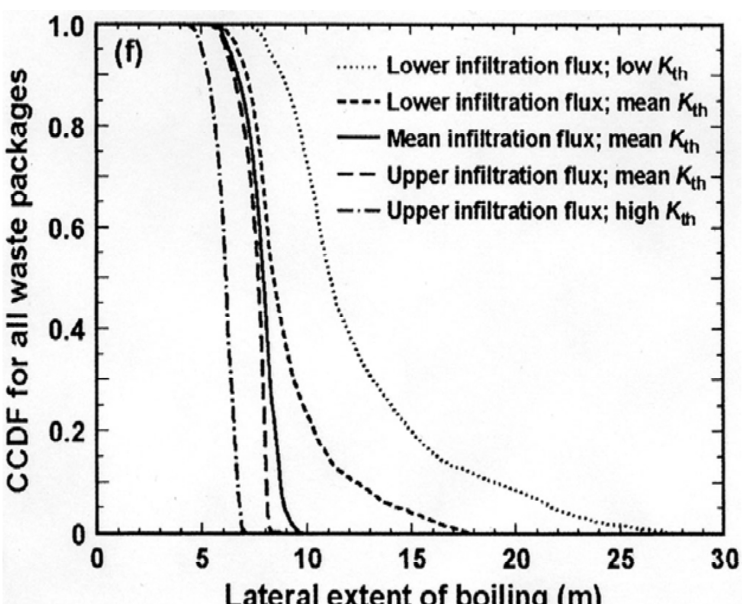


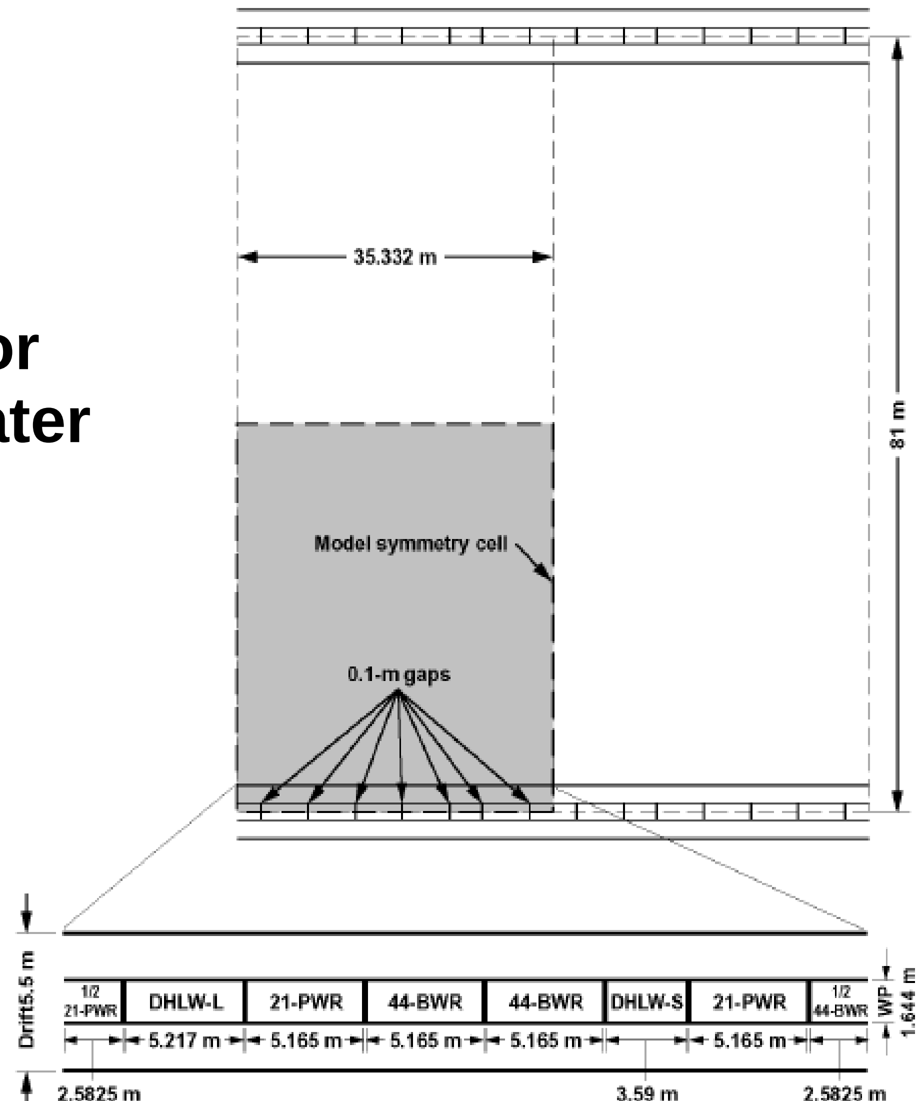
Purpose & Approach

- *Preliminary* analysis of the maximum physical capacity of a geological repository at Yucca Mountain for the disposal of commercial spent nuclear fuel (CSNF)
  - NWPA: 70,000 MTHM (63,000 MTHM CSNF)
- Assure minimal impacts on cost or schedule of DOE's current 70,000 MTHM design:
  - Consider only Yucca Mountain area currently characterized by DOE
  - Start with DOE's current 'line-load', high-temperature operating mode (HTOM) repository design
  - Apply thermal constraints on natural and engineered barriers
- Use conservative, convection-only, thermal modelling
- Identify alternatives that may further optimize CSNF disposal capacity

DOE's Line-loaded, High-Temperature Operating Mode (HTOM) Repository Design

- **Maximum waste package temperature 160-180˚C**
- **Conservative 81-m pitch between drifts to maintain sub-boiling 'pillar' of tuff for drainage of condensate water**





Temperature Limits Assumed in Preliminary EPRI Analysis

- Cladding: 350°C (optional?)
  - E.g. NRC's TPA does not take credit for cladding
- Waste package surface: up to 309°C analyzed (could easily go higher)
- Rock wall: 200°C (somewhat higher possible and still avoid SiO_2 phase change)
- Relax goal of maintaining pillars below boiling for all time after repository closure

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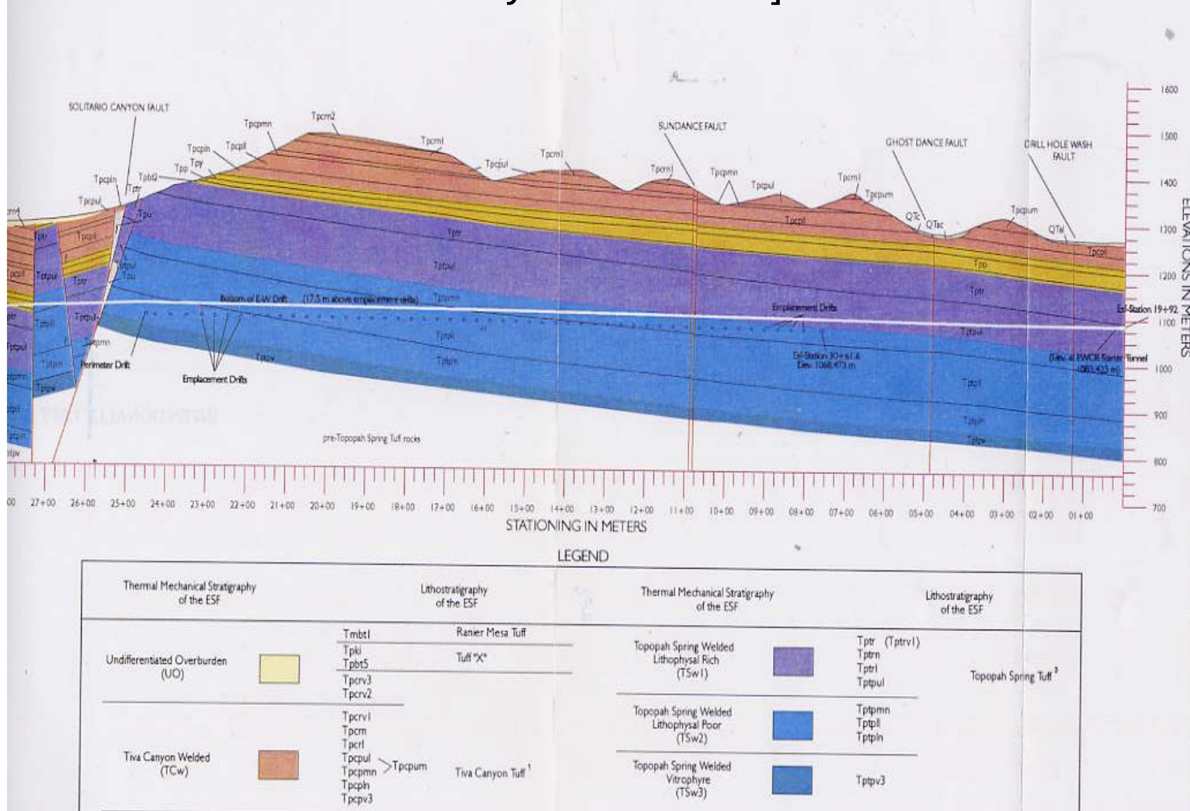
Options the EPRI Team Analyzed

- Option 1: Expanded repository ‘footprint’
- Option2: Multi-level repository
- Option 3: Grouped, single-level emplacement drifts
- Determine the range in ‘expansion factor’ attributable to each option
- Combinations of Options

Option 1: Current One-level HTOM Design but Extended Over a Larger Explored Area

- **Proposed repository is located in the lower Topopah Spring Tuff (~170-m thick)**
- **Major NW-trending faults define suitable rock blocks (although ‘respect distance’ from faults required)**
- **Maintain ~200 to 400-m of rock cover**
- **Maintain ~200 to 400-m to water table below**

[**Approximate Location of Emplacement Drifts, DOE Line-loaded HTOM Design,** taken from Yucca Mountain Viability Assessment]



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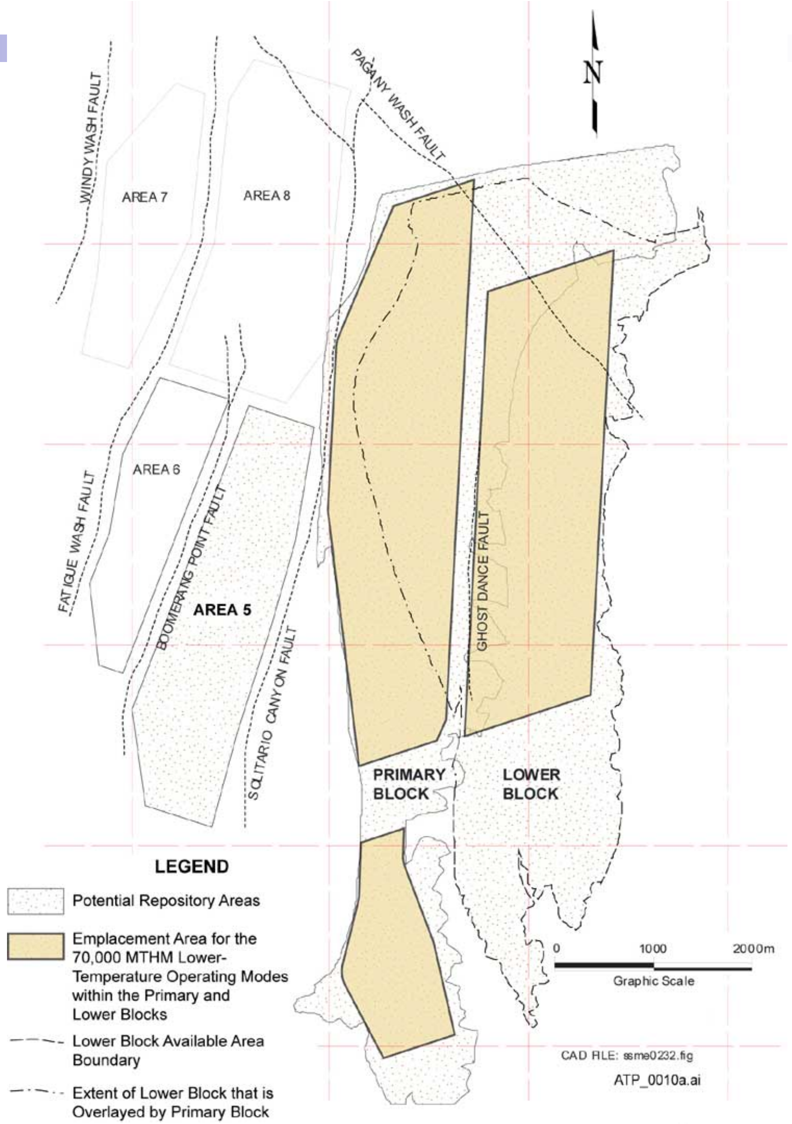
Option 1: Extended 'Footprint' (2)

- FEIS (DOE, 2002) identified additional rock blocks suitable for expansion of YM repository, based on various designs and thermal-loading strategies.



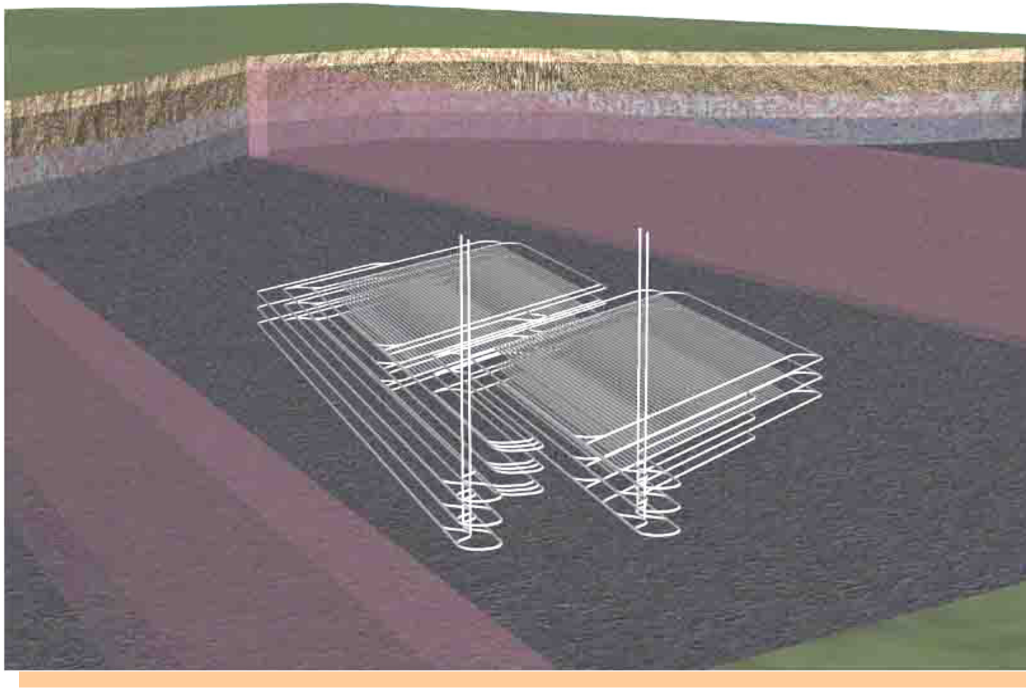
Option 1: Extended 'Footprint' (3)

Source	Extended Area (km^2)	Expansion Factor
Mansure and Ortiz (1984)	37.03	5.7
CRWMS M&O (1994)	10.90	1.7
Yucca Mountain Science and Engineering Report (USDOE, 2002b)	23	3.5
FEIS (2002a and earlier drafts, Section 2.1.2.2)	10	1.5
Peterson (2006)	17	2.6
This Study		
Confident	13	2.0
Possible	17-23	2.6-3.5

Expansion Factor = Maximum MTHM of CSNF/ 70,000 MTHM

Option 2: Multi-level Repository

- Three-level repository design
- Additional drifts 30 to 50 meters above and below current HTOM design
- Same and lower line loads considered (1.45 and 1.0 kW per meter)



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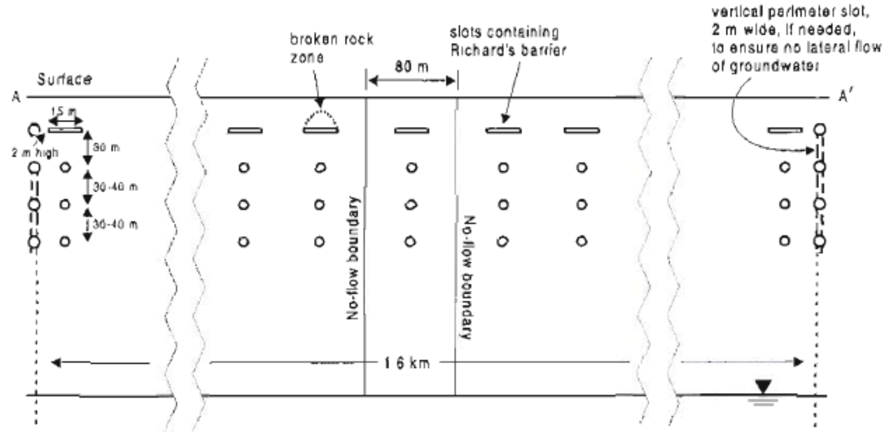
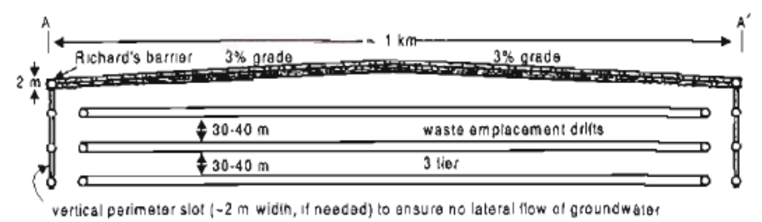
Multi-level Repository Designs are not New

- Previously considered by DOE for Yucca Mountain
- Europeans and Japanese considering it
- Charles Fairhurst 1999 report to ACNW (right)
  - Figure 2b and 2c from “Engineered Barriers at Yucca Mountain: Some Impressions and Suggestions”



b) Cross section normal to long axes of drifts
(20x 3 tier columns)



c) Section perpendicular to AA'
Note: The 60 km of drifts in the EDA II design could be accommodated as 3 layers of 20 drifts per layer, each drift 1 km long

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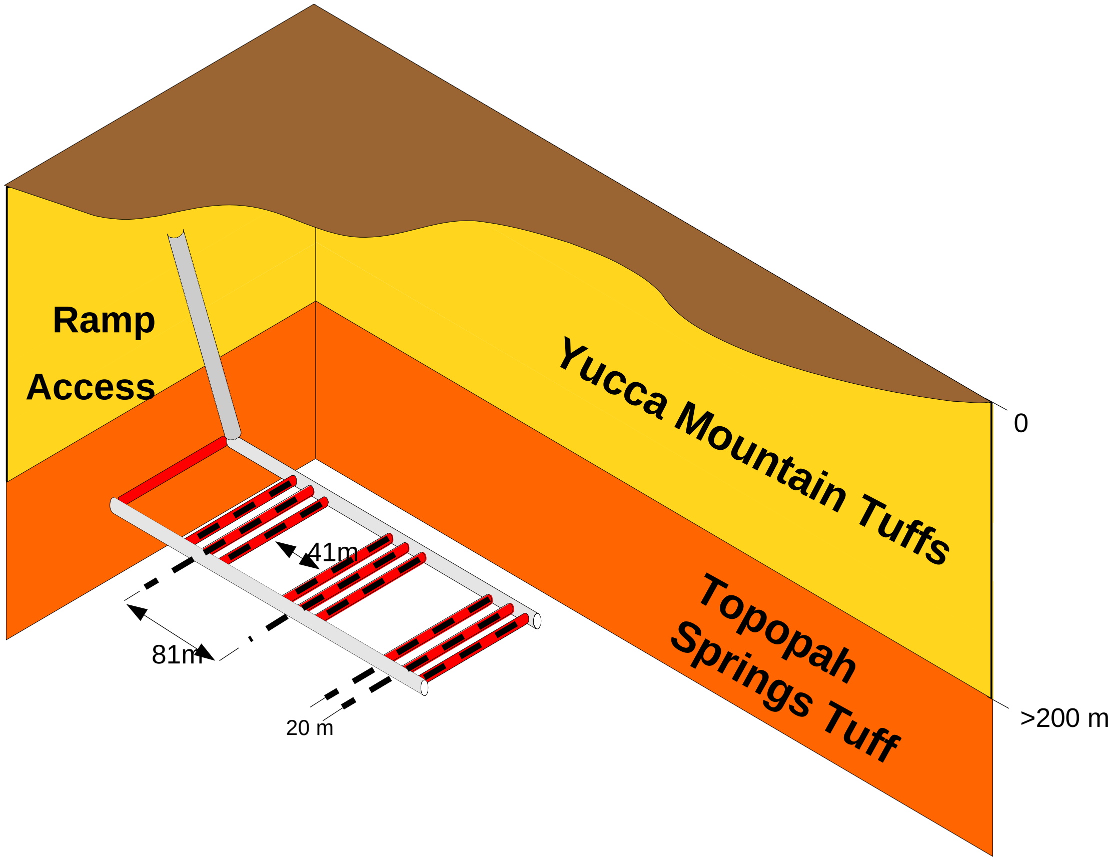
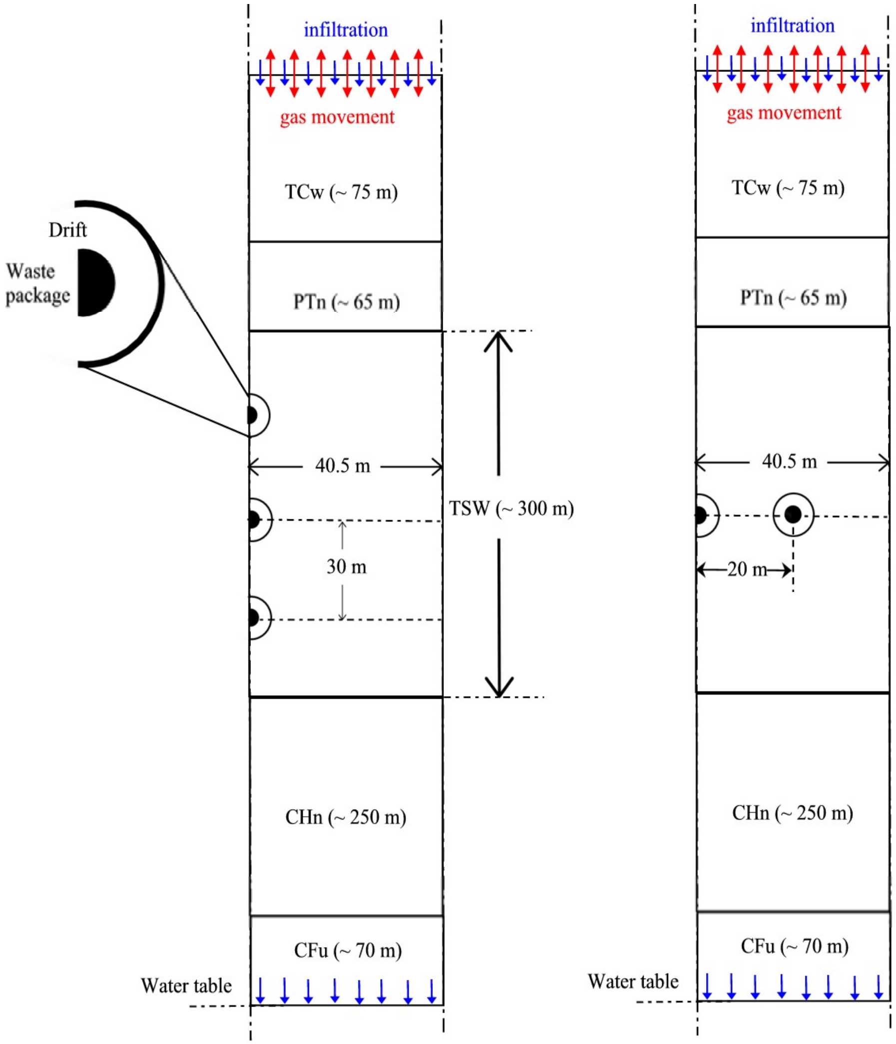
Option 3: “Grouped” Disposal Drifts

- Groups of three at the same elevation
- 20-meter spacing within the group
- Leaves 41 meters between groups (“pillar”)
- Same and lower line loads considered (1.45 and 1.0 kW per meter)



Thermal Analysis of Options 2 and 3

- Used TOUGH2 Code (same as used by DOE/YMP)
  - 2-D model initially
- Used DOE/YMP published, reference tuff properties
- Successful calibration benchmark to DOE/YMP results for reference repository design
- Option 2: 3-level repository (left)
- Option 3: 3-grouped drifts (right)



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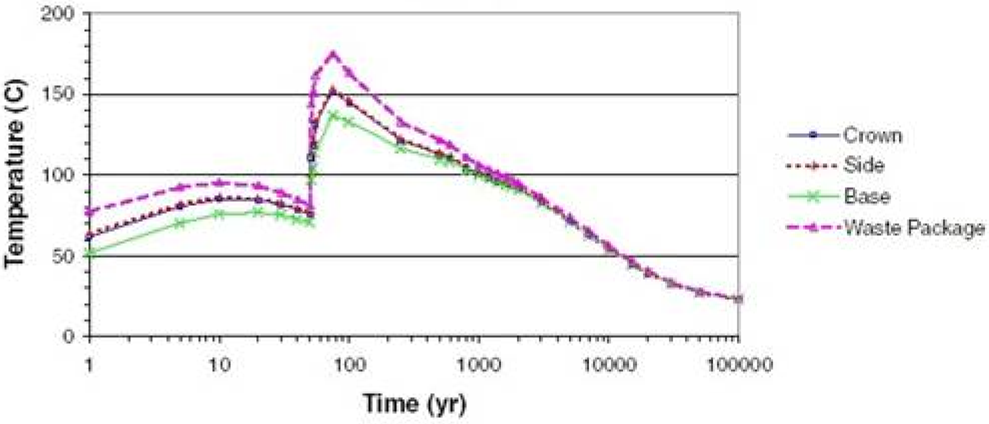
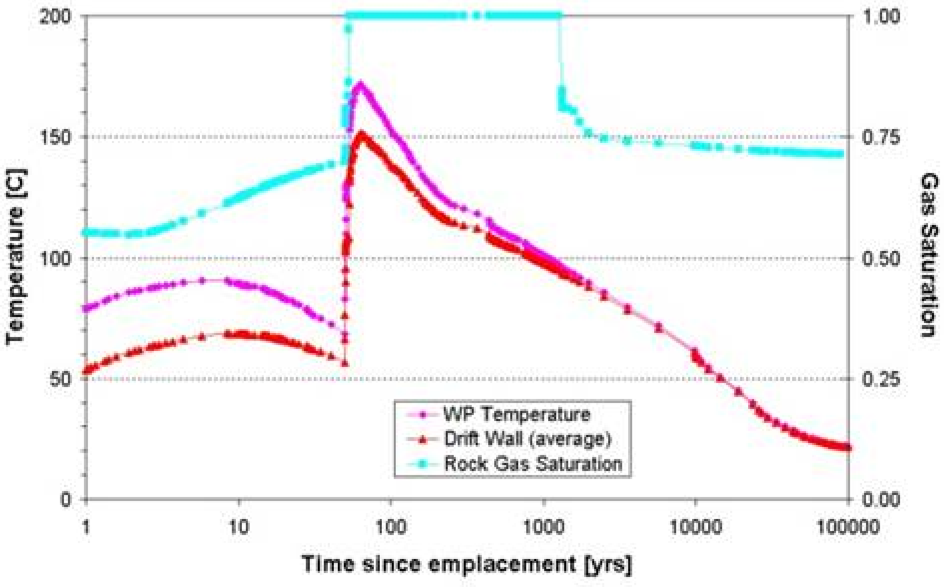
EPRI Model Calibrated Against More Detailed YMP Model



(a) Reported results [BSC 2003 Figure 6.5-7].



(b) Model calibration results.

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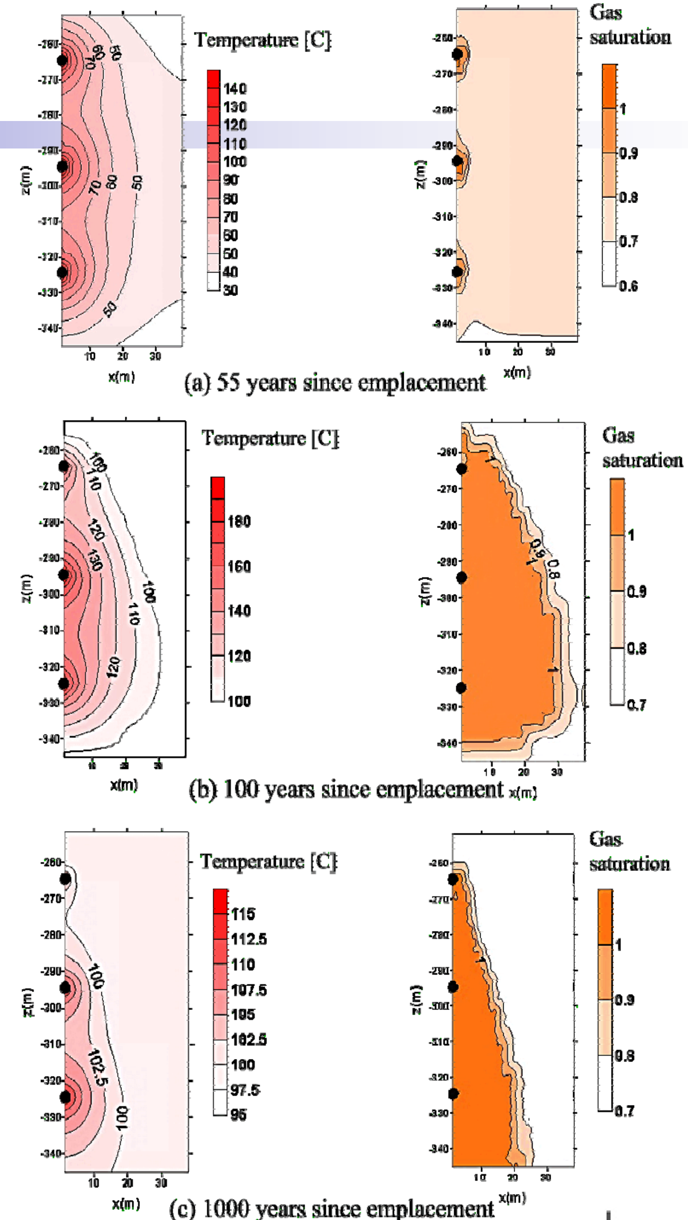
Option 2: Multi-level Repository Permutations Considered

Case	Repository Concept	Initial Loading	Expansion Factor	Ventilation Duration/Effic.
1	Three-level, 30-m vertical drift spacing	1450 W/m for all waste packages	3 times	0 – 50 yrs: 86.3%
2	Three-level, 30-m vertical drift spacing	1000 W/m for all waste packages	2 times	0 – 50 yrs: 86.3%
3	Three-level, 50-m vertical spacing	1000 W/m for all waste packages	2 times	0 – 50 yrs: 86.3%
4	Three-level, 50-m vertical spacing	1450 W/m for all waste packages	3 times	0 – 50 yrs: 86.3%
5	Three-level, 30-m vertical spacing	1450 W/m for all waste packages	3 times	0 – 50 yrs: 87.3%; 50 – 300 yrs: 93%
6	Three-level, 30-m vertical spacing	1000 W/m for all waste packages	2 times	0 – 50 yrs: 87.3%; 50 – 300 yrs: 93%

Expansion Factor = Maximum MTHM of CSNF/ 70,000 MTHM

Option 2: Multi-level Repository Example Output (Case 1)

- Upper level performs the same as the DOE 1-level HTOM design.
- Above-boiling period in lower drifts lasts several thousands of years after repository closure.
- In some cases, the 'pillar' between the lower two levels is predicted to dry out for 200-300 years before returning to sub-boiling drainage conditions.
- *Conservative analysis*: Including convection and 3-D edge-cooling/ condensation effects would lead to drainage of condensate water as well as lower, less extensive and shorter temperature excursions, (i.e., no blockage of 'pillars').



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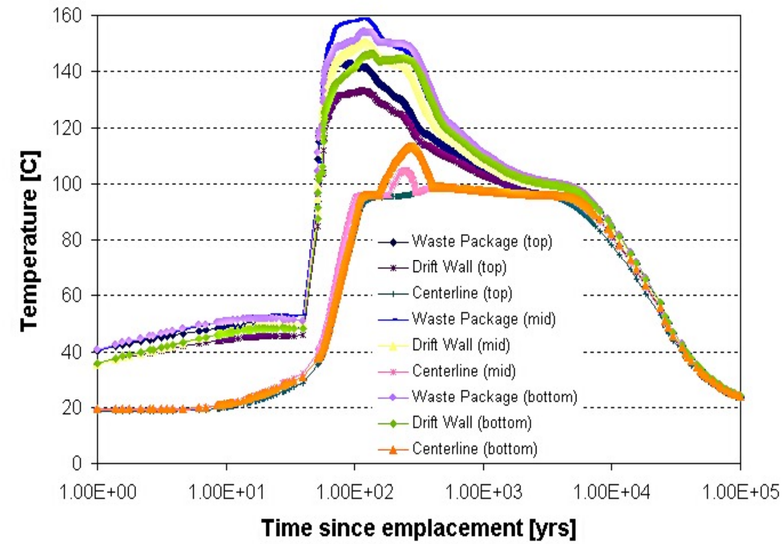
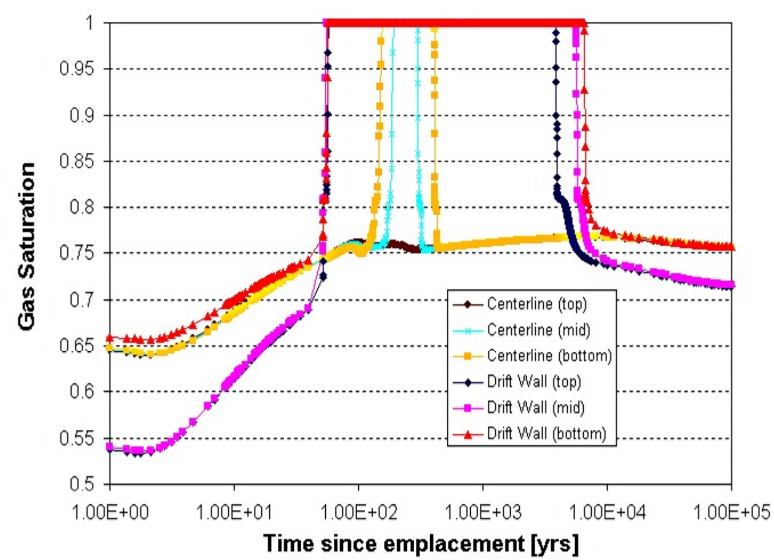
Option 2: Multi-level Repository Example Output (Case 1) (cont'd.)

- Peak temperatures do not exceed limits for waste package, cladding, or tuff
- Duration of 'pillar' blockage is short relative to 'thermal barrier' period around drifts
- Blocked condensate water unlikely to be transported via 'heat pipes' through 'thermal barrier' to emplacement drifts



(a) Temperature vs. time



(b) Gas saturation vs. time

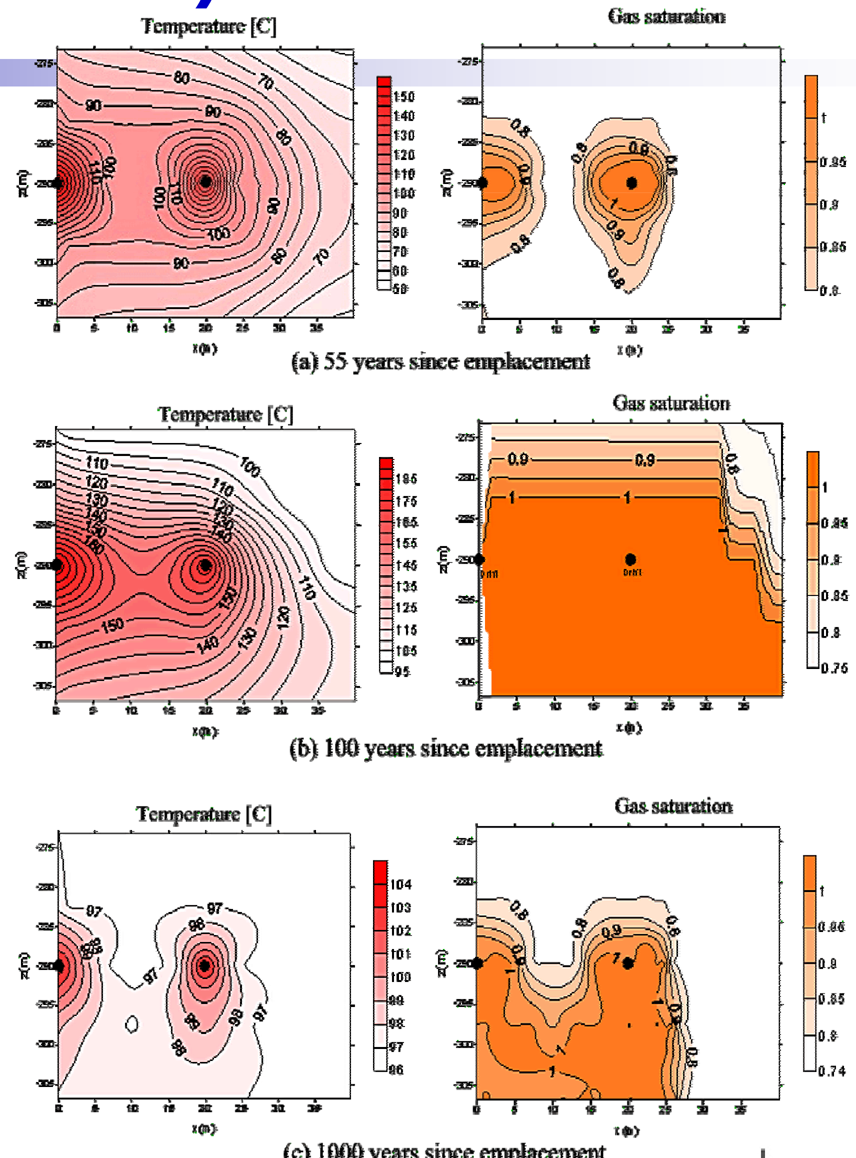
Option 3: Grouped-drift Repository Permutations Considered

Case	Repository Concept	Initial Loading	Expansion Factor	Ventilation Duration/Effic.
7	Single-level, 3-drifts 20-m apart	1450 W/m for all waste packages	3 times	0 – 50 yrs: 87.3%; 50 – 300 yrs: 93%
8	Single-level, 3-drifts 20-m apart	1450 W/m for center waste package, 725 W/m for side drifts	2 times	0 – 50 yrs: 87.3%; 50 – 300 yrs: 93%
9	Single-level, 3-drifts 20-m apart	1450 W/m for center waste package, 725 W/m for side drifts	2 times	0 – 50 yrs: 86.3%.
10	Single-level, 3-drifts 20-m apart	1450 W/m for all waste packages	3 times	0 – 50 yrs: 86.3%.
11	Single-level, 3-drifts 20-m apart	1450 W/m for all waste packages	3 times	0 – 50 yrs: 91%; 50 – 300 yrs: 96%
12	Single-level, 3-drifts 20-m apart	1450 W/m for center waste package, 725 W/m for side drifts	2 times	0 – 50 yrs: 91%; 50 – 300 yrs: 96%

Expansion Factor = Maximum MTHM of CSNF/ 70,000 MTHM

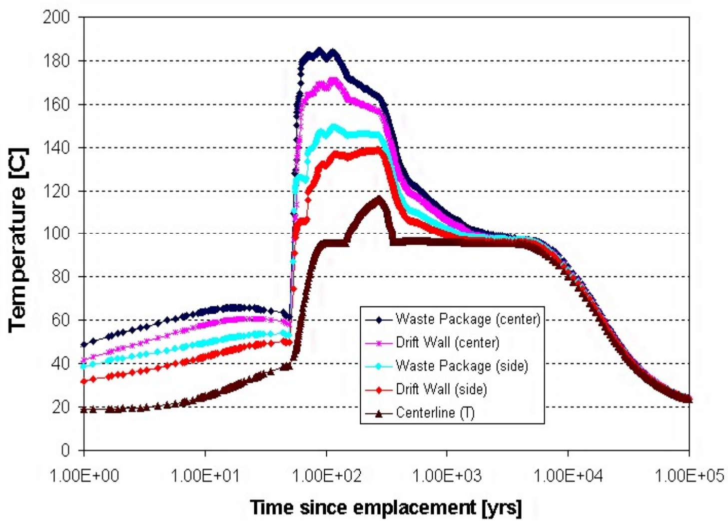
Option 3: Grouped-drift Repository Example Output (Case 10)

- Center drift attains and sustains highest temperature
- Temporary blockage of ‘pillars’ for several hundred years
- Sub-boiling ‘pillar’ eventually opens between all emplacement drifts

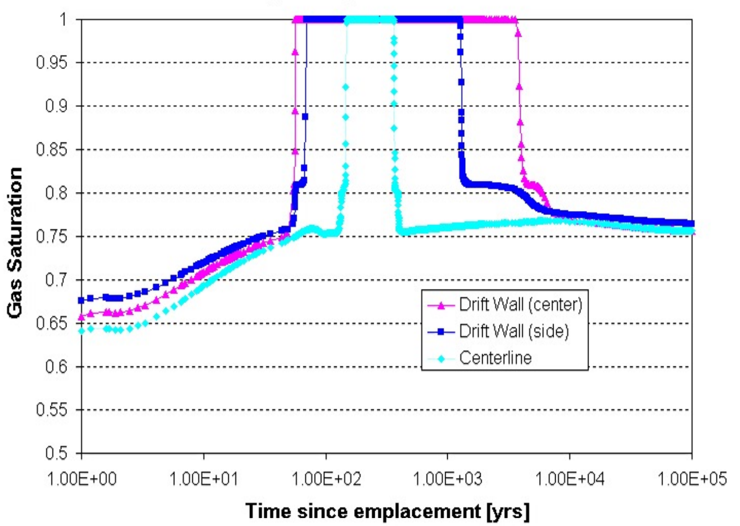


Option 3: Grouped-drift Repository Example Output (Case 10) (continued)

- Peak temperatures do not exceed limits for waste package, cladding, or tuff
- Duration of blockage (i.e., above-boiling condition) of 'pillar' much shorter than 'thermal barrier' period of drifts



(a) Temperature vs. time



(b) Gas saturation vs. time

Derived Expansion Factors

Option 1: Extended ’Footprint”:
2 to 3.5 times the current CSNF limit of 63,000 MTHM

Option 2: Multi-level Repository:
2 to 3 times the current CSNF limit

Option 3: Grouped-drift Repository:
2 to 3 times the current CSNF limit

Combining Option 1 with Option 2 or 3

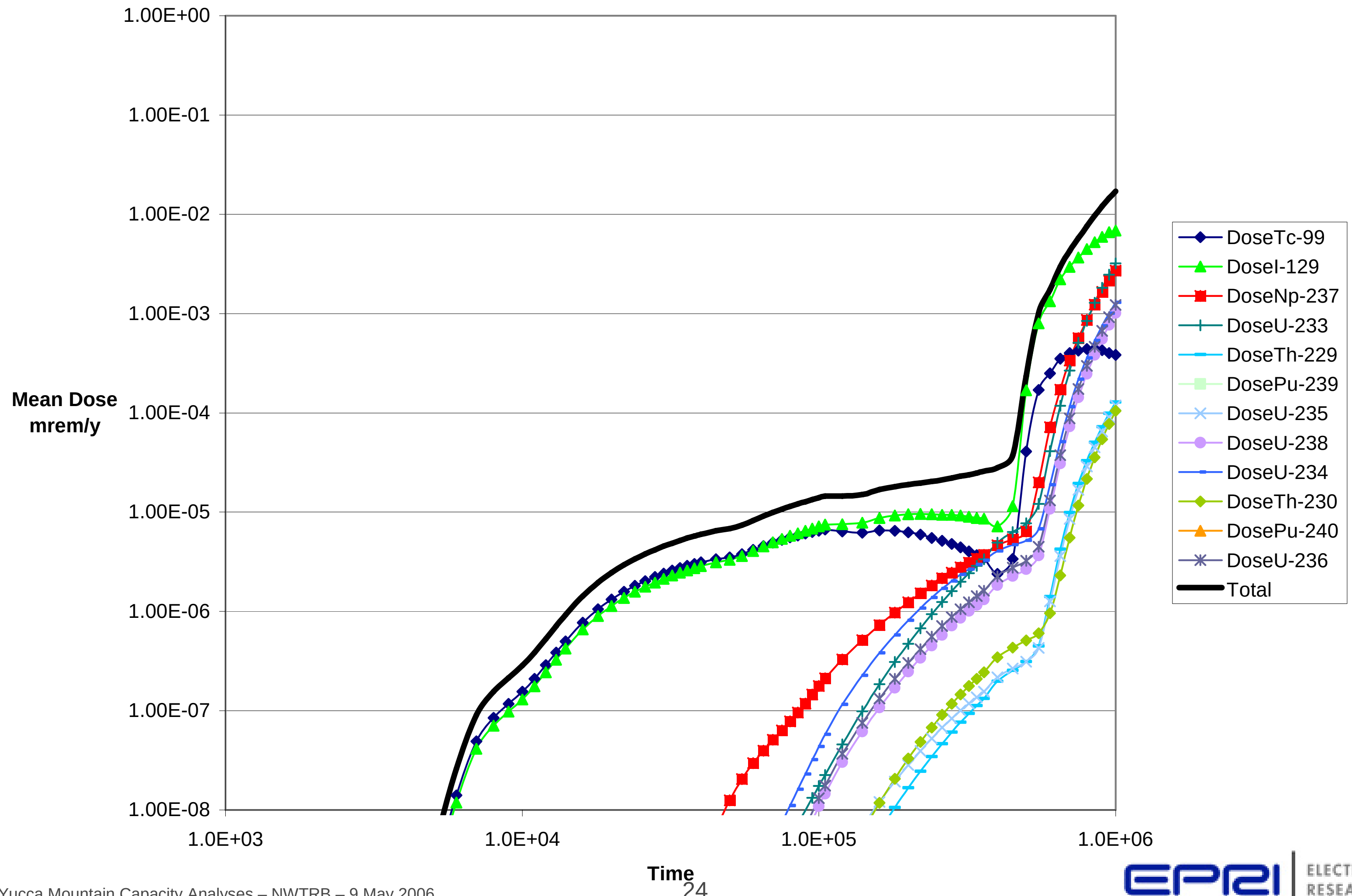
- At least four times the existing CSNF limit can be emplaced at Yucca Mountain with current or limited additional information (~260,000 MTHM)

- With additional site characterization and/or design optimization, possibly upwards of nine times the existing CSNF limit could be emplaced (~570,000 MTHM)

Significant Margin in Probability-Weighted Dose

~350 mrem/yr

~15 mrem/yr



Potential Additional 2006 EPRI Work on Yucca Mountain Technical Capacity

- More detailed hydrothermal modeling
  - 3-D to include edge effects
- Construction issues
  - No significant issues expected
  - May have to construct $2^{nd}/3^{rd}$ drifts after first is loaded
- Need for additional ventilation
- Surface aging to achieve even higher mass loadings
- Different loadings within drift “triplets”
- Description of additional site investigation and R&D needs and general schedule for completion
- Effects of higher pillar temperatures on fracture opening or closing
- Report to be completed by end of 2006

Summary

- *Preliminary* EPRI analysis of the Yucca Mountain maximum physical capacity for CSNF
  - Additional work in 2006 will explore these options in more detail
- Four to nine times the existing limit for CSNF possible
- Options EPRI considered have minimal impacts on cost or schedule of DOE's current 70,000 MTHM design:
  - Start with DOE's High-Temperature Operating Mode (HTOM), line-loaded repository design
  - Use current site characterization information
  - Additional information required to expand repository can be collected in parallel

BACKUP SLIDES

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Results Summary

Cases	Maximum WP Temperature	Maximum Drift Wall Temperature	Above-Boiling Time Duration at WP and near Drift [yrs][1]	Maximum Temperature at Centerlines of Pillars between Drifts	Location and Duration of Dry-out at Centerline of Pillars between Drifts[2]
1	214 °C at 90 yrs	197 °C at 94 yrs	53 – 12,700	142 °C at 300 yrs	Lower two drifts; 112 – 414 yrs
2	158 °C at 113 yrs	150 °C at 122 yrs	57 – 6,550	113 °C	Lower two drifts; 155 – 406 yrs
3	138 °C at 182 yrs	132 °C at 186 yrs	65 – 6,200	100 °C	Bottom drift; 245 - 344 yrs
4	184 °C at 118 yrs	172 °C at 121 yrs	54 – 12,100	129 °C	Lower two drifts; 142 – 396 yrs
5	128 °C at 576 yrs	124 °C at 608 yrs	400 – 12,100	96 °C	No
6	111 °C at 844 yrs	109 °C at 844 yrs	500 – 6,500	96 °C	No
7	147 °C at 519 yrs	139 °C at 519 yrs	340 – 3,840	111 °C	433 – 593 yrs
8	115 °C at 744 yrs	112 °C at 746 yrs	490 – 3,600	96 °C	No
9	184 °C at 88 yrs	171 °C at 115 yrs	60 – 3,600	116 °C	148 – 362 yrs
10	229 °C at 67 yrs	198 °C at 227 yrs	56 – 3,870	154 °C	107 – 382 yrs
11	146 °C at 523 yrs	138 °C at 525 yrs	330 – 3,660	110 °C	441 – 603 yrs
12	115 °C at 718 yrs	111 °C at 805 yrs	520 – 3,500	96 °C	No

[1]: The listed above-boiling time period is the longest among all the drifts.

[2]: In cases where more than one pillars experience dry-out, the listed is the longest among all the pillars

EBS Failure Distribution for Case with Peak WP Temperature of 309°C