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

PRESENTATION TO THE NUCLEAR WASTE TECHNICAL REVIEW BOARD

SUBJECT: **HISTORY AND EVOLUTION OF REPOSITORY CONCEPT FOR A POTENTIAL REPOSITORY AT YUCCA MOUNTAIN**

PRESENTER: DR. MICHAEL D. VOEGELE

PRESENTER'S TITLE AND ORGANIZATION: DEPUTY PROJECT MANAGER, TECHNICAL PROGRAMS
SCIENCE APPLICATIONS INTERNATIONAL CORPORATION
LAS VEGAS, NEVADA

PRESENTER'S TELEPHONE NUMBER: (702) 794-7638

OCTOBER 8 - 10, 1991

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Thermal Technical Constraints and Criteria Were Used to Develop a Conceptual Design to Support the SCP

Emph on NWTS-25

Discuss

- Logical evolution of design constraints related to repository induced impacts
- Performance measures established to ensure repository performance
- Site specific technical considerations and evaluations supporting repository design
- Repository conceptual design developed to meet performance measures and constraints

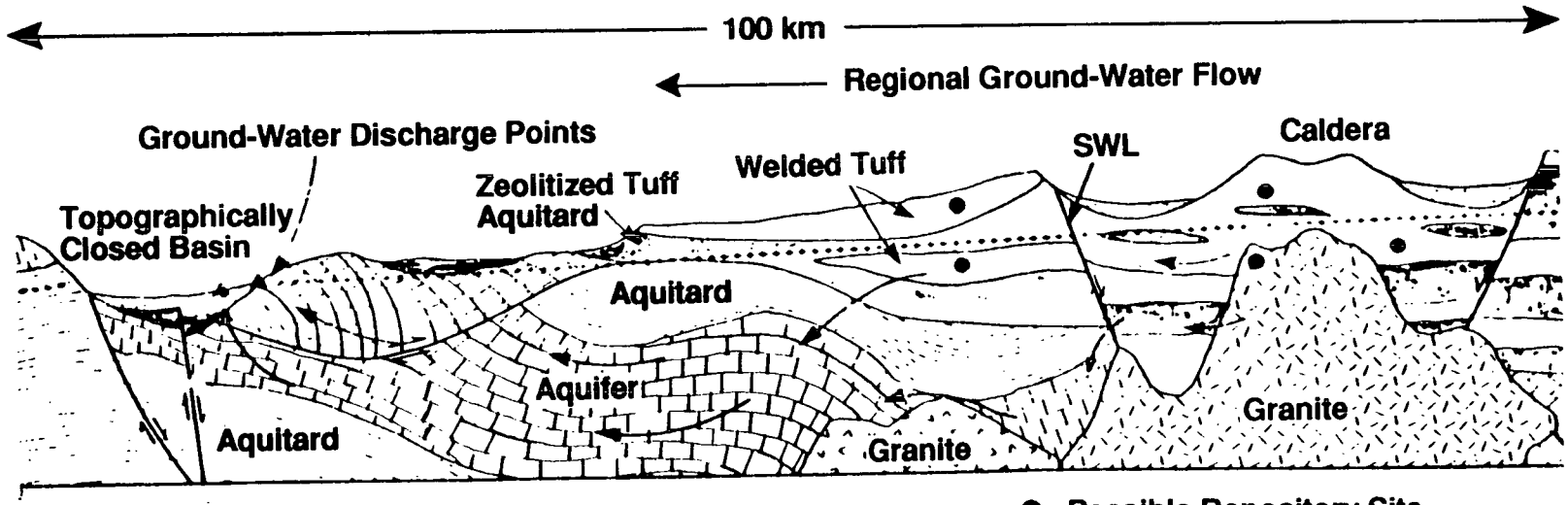
how they lead to design output incl APD

Identification of Tuff as a Candidate Material

1978 Recommendation to NAS on siting a repository in tuff

- Addressed favorable and unfavorable aspects of disposal in tuff
- Preliminary evidence suggested dominant zeolites stable for short periods to 500° C and metastable above 250° C
- Comparable to other igneous rocks in strength, thermal conductivity, heat capacity and mineability
- Repository would be relatively shallow
- Issue related to water content-zeolite stability

Multiple Natural Barrier Model of Tuff in Great Basin



SWL - Static Water Level

● Possible Repository Site

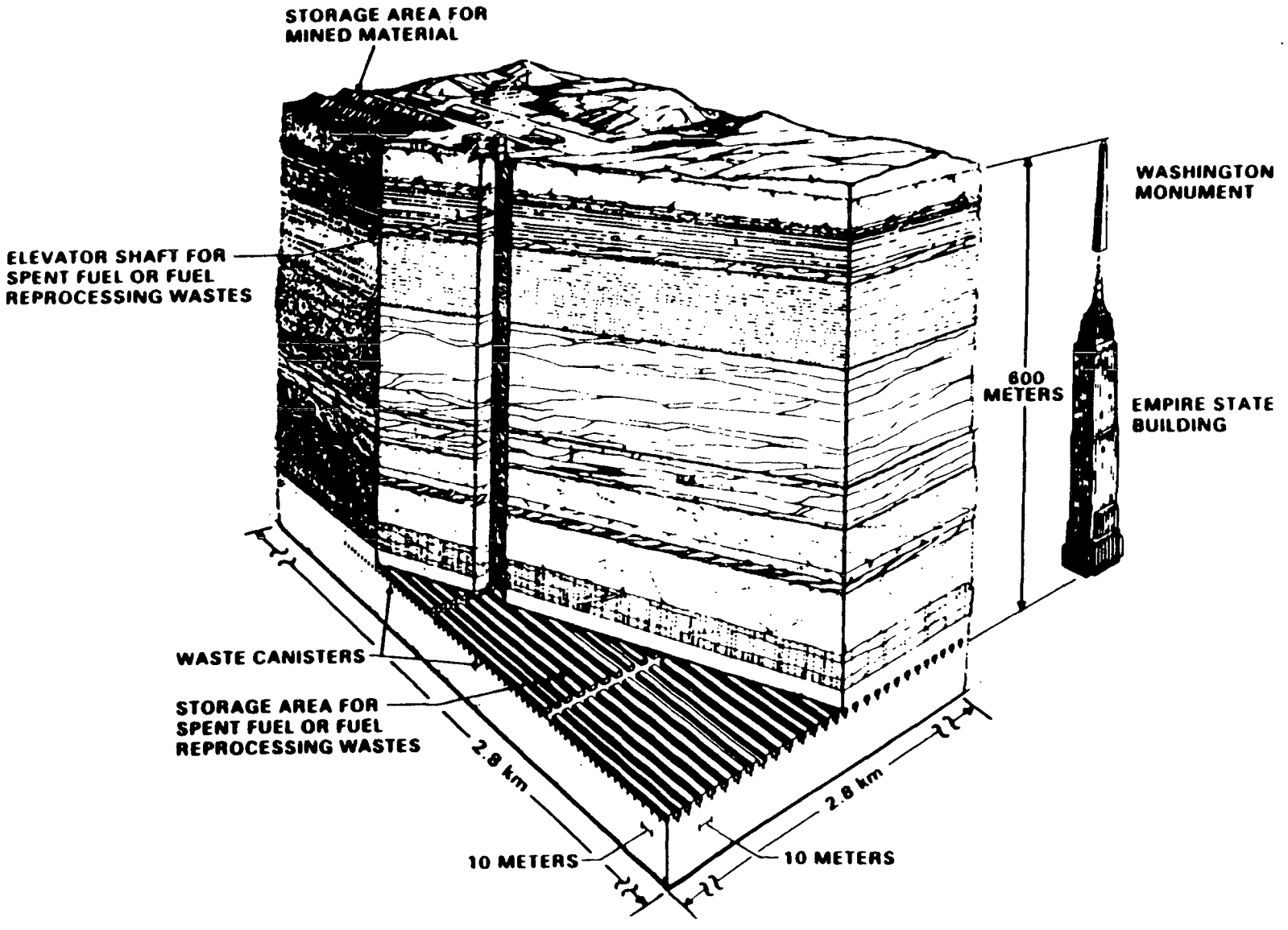
1980 FEIS Management of Commercially Generated Radioactive Wastes

Recommendation for subsurface geologic disposal accounted for thermal loading and its effects

- Repository concept - 3 sq. mi. disposal area (Approximately 65 kW/acre)
- Six generic factors relevant to geologic disposal addressed: depth, rock properties, tectonic stability, hydrologic regime, resource potential, multibarrier safety features
- Waste emplacement concepts controlled by thermal criteria
  - Addressed, with margins: uplift; surface and aquifer temperature rise; retrievability; HLW, fuel pin, canister and rock temperatures
  - Design APD {50 kW/acre (salt), 80 kW/acre (shale), 130 kW/acre (granite and basalt)}

tuff not considered at that time

FEIS - Repository Concept



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National Waste Terminal Storage (NWTS) Program Siting Documents

- **1981 (NWTS-25) Repository Performance Constraints in the Far-Field Domain:** heavy infl on current prog
  - Developed performance constraints for design and performance evaluation

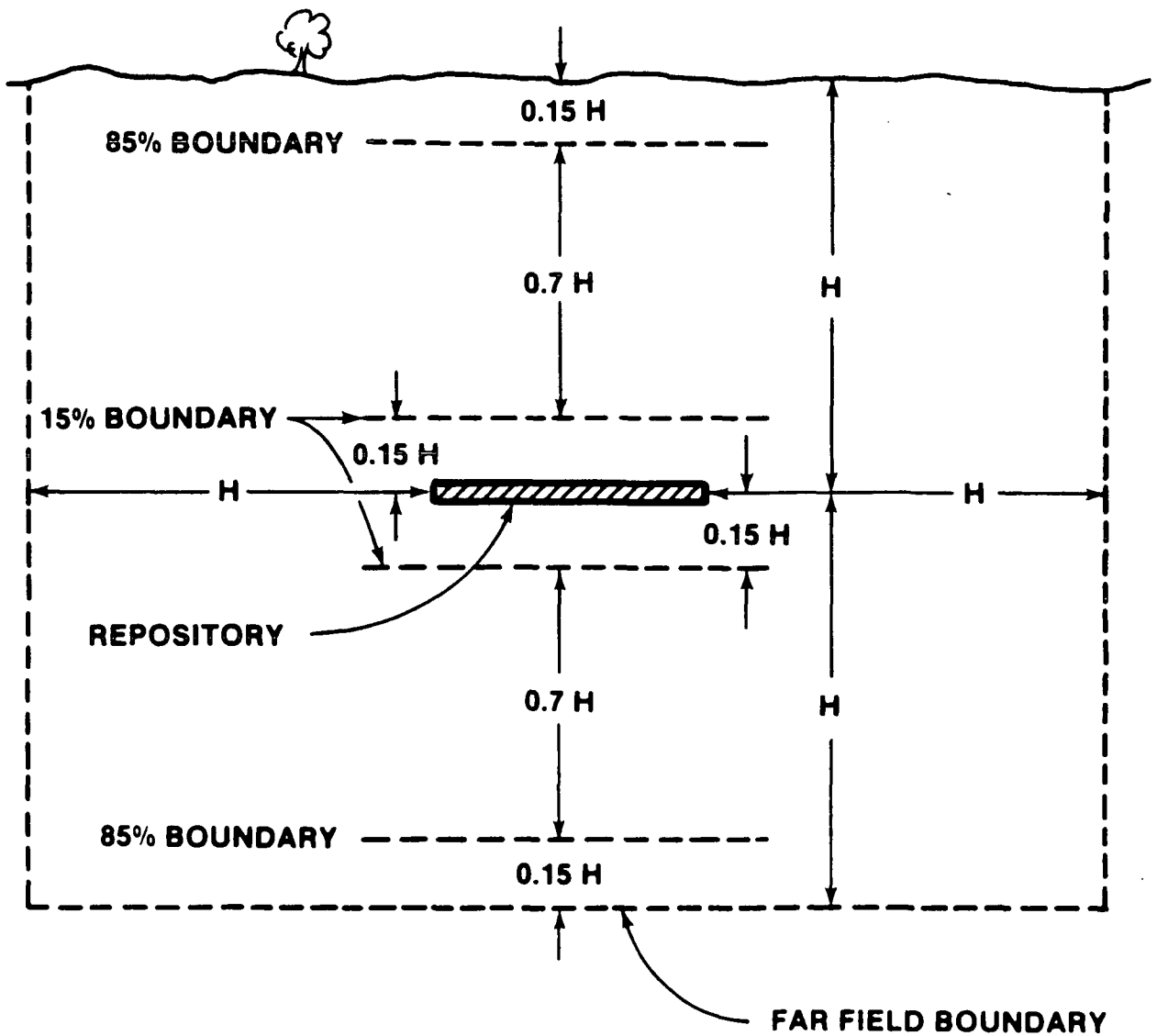
- **1982 (NWTS-33(3)) Repository Performance and Development Criteria:** precursor to 10 CFR 960
  - Functional requirement that repository contribute to the containment and isolation capability of the system

Generic Thermal Criteria Developed in NWTS Program

Repository performance constraints in the far-field domain (1981, NWTS-25)

- Developed performance constraints for design and performance evaluation
- Included irreversible thermochemical perturbations in the far-field
- Recommended that temperatures not exceed 100° C out to .15 H and not exceed 75° C outside that region

NWTS-25: Performance Constraints



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NWTS-25: Performance Constraints

(Continued)

Fracturing

- Granite & tuff - thermomechanical stresses not cause shear failure in the middle 70% of the rock between repository horizon and surface

- All rock types - vertical extent of the perturbed fissure zone not extend downward from the surface more than 15% of the repository depth

Thermally perturbed groundwater

- Basalt, granite & tuff - the time for groundwater to travel from the repository facility to the ground surface as a consequence of thermal convective forces be greater than 1,000 years

NWTS-25: Performance Constraints

(Continued)

Shaft and borehole integrity

- All rock types - during the preclosure phase, the shaft and its components undergo no fracturing due to the thermomechanical stresses and have no significant water leakage
- All rock types - deformations of the shafts and shaft liners during the preclosure phase be sufficiently small to not impede routine operations and major remedial work is not required
- Tuff - shafts be located so that they do not intersect major faults
- Granite and tuff - during the post closure phase, permeability of sealed boreholes and shafts be approximately the same as the host rock permeability for the middle 70% of their vertical length

NWTS-25: Performance Constraints

(Continued)

- Thermomechanical perturbations

  (1) Temperatures not exceed 125° C for granite and 100° C for other types in region extending from near-field outward to 15% of the repository depth, and

  (2) Temperatures not exceed 100° C for granite and 75° C for the other rock types anywhere outside of the region defined above the 15% boundary

- Heating of the ground surface and near surface

  - All rock types - maximum temperature increase within 3m of the ground surface be less than 4° C

  - Vertical surface displacements be less than variations of natural processes such as glacial rebound and erosion, say, less than approximately 3m, and smooth fashion over time

Generic Criteria Developed in NWTS Program

DOE doc.

Repository performance and development criteria (1982, NWTS-33(3))

- Functional requirement to contribute to containment and isolation capability of the system
- Limit adverse impacts of repository development and operation on site performance
- Restrict temperatures to limits within which thermal impacts can be shown to have no significant degradation on system's containment and isolation capability
- Thermal limits to be prescribed, including thermochemical interactions that accelerate the rate of transport of radionuclides

Site Specific Criteria

1980 RRC-IWG* developed reference conditions

- Developed for salt, basalt, tuff, granite, and shale
- Addressed temperature, pressure, fluid, chemical and radiation effects
- Intended to guide tests, designs, be technically conservative basis for LA, waste form development
- Developed reference repository description
  - Characteristics include: depth, room dimensions, canister thermal loads, local areal thermal loads, and average areal thermal loading
- Evaluated peak near-field temperature

* Reference Repository Conditions - Interface Working Group

Reference Repository Description

Repository Characteristics	Salt CHLW	Salt SF	Basalt CHLW	Basalt SF	Tuff CHLW	Tuff SF	Granite CHLW	Granite SF	Shale CHLW	Shale SF
Repos. depth (m)	600	600	1000		800	800	1000	1000	600	600
Room width (m)	5.5	5.5	4.3		7.5	5.0	7.5	7.5	5.5	5.5
Room height (m)	6.4	5.5	6.1		7.0	5.0	7.0	7.0	6.4	5.5
Pillar width (m)	21.3	18.3	32.3		30	20	22.5	22.5	18	18
Hole spacing (m)	1.67	3.66	3.66 (1.22)		1.19	3.50	1.83	2.67	2.34	2.85
Canister loading (kW)	0.55	2.16	1.65 (0.55)		0.55	2.16	0.55	1.0	0.55	1.0
Local areal thermal loading (W/m^2)	25	25	12.3		25	25	20	25	10	10
Average areal thermal loading (W/m^2)	15	<25	8.2		<25	<25	<20	<25	8	8

Reference Repository Description
Peak Near-Field Temperatures (°C)

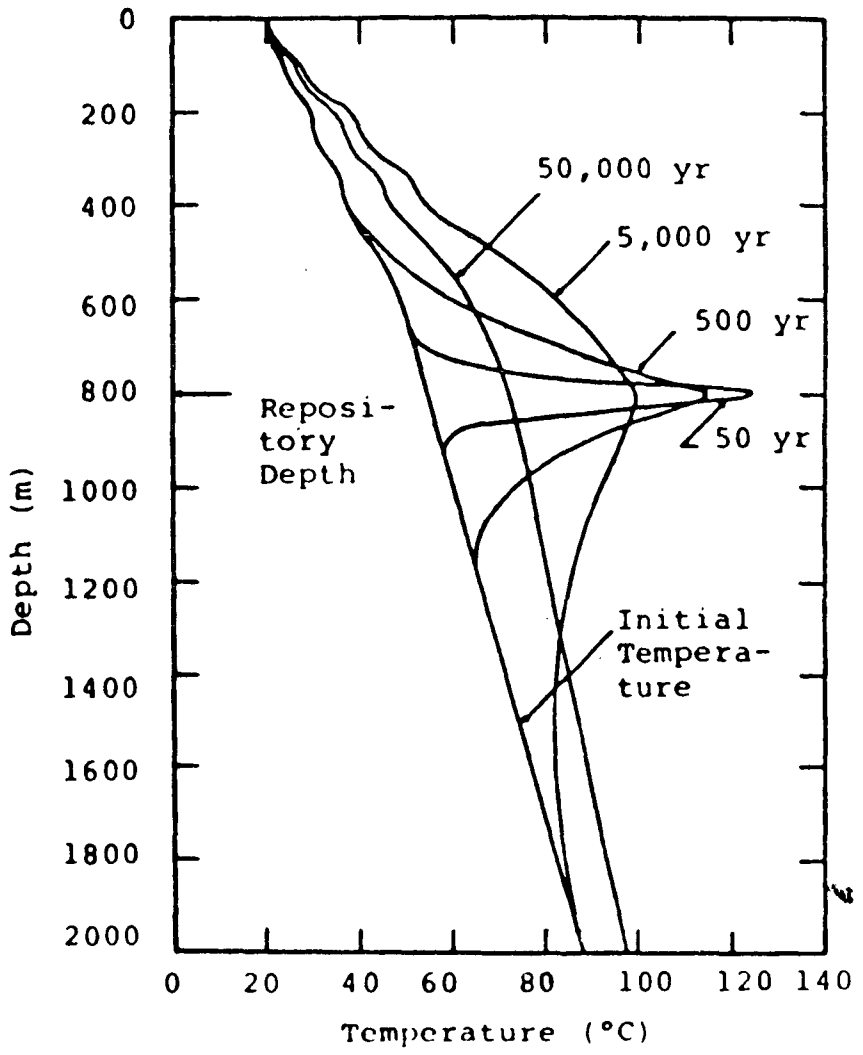
Host Rock	Location	CHLW	SF
Salt	Host Rock	140	160
T_o = 34° C	Canister Wall	145	260
	Waste	175	320
Basalt	Host Rock		145 (165)
T_o = 57° C	Canister Wall		255 (170)
	Waste		275 (185)
Tuff	Host Rock	190	215
T_o = 35° C	Canister Wall	195	235
	Waste	230	275
Granite	Host Rock	150	165
T_o = 20° C	Canister Wall	170	205
	Waste	190	225
Shale	Host Rock	125	140
T_o =38° C	Canister Wall	140	210
	Waste	165	235

Early Yucca Mountain Site Design Criteria and Concepts

1980 Thermal/mechanical modeling for a tuff repository

- Repository depth 800m - saturated zone
- Primary focus of study was fracturing of intact rock and changes in rock properties due to boiling of water
- GTL upper limit of 100 kW/ac

Far-Field Temperature Along Repository Vertical Centerline for GTL of 75 kW/acre



Early Yucca Mountain Site Design Criteria and Concepts

1980 Thermal/mechanical analysis of tuff

- Identify critical data needs, test plans, repository environment and integrate into data base for conceptual repository design
- Looked at near, room, and far scale heat effects as function of boiling temperature, gross thermal load, extraction ratio, changes in rock thermal properties
- Upper limit to GTL of 100 kW/acre at 20% extraction ratio as reference case

Early Yucca Mountain Site Design Criteria and Concepts

- 1982 Preliminary technical constraints for a repository in tuff
  - Developed quantitative limits for assessing performance
  - Summarized technical constraints, including temperature limits in very near-, near-, and far-field, that impact mineral hydration or dehydration

NNWSI Program
Preliminary Technical Constraints
Very Near-Field

Repository System Component	Operational Period $t \leq 110$ yrs	Containment Period $110 < t \leq 1000$ yrs	Isolation Period $t > 1000$ yrs
Waste Form: Spent Fuel	$t_{(CLAD)} < 425°$ C	No constraint	No constraint
CHLW	$t_{(℄)} < 500°$ C	$t_{Surface} < 100°$ C if exposed to water	$t_{Surface} < 100°$ C if exposed to water
Canister	No constraint	No constraint	No constraint
Overpack	To be determined	To be determined	No constraint
Backfill:			
Na-Montmorillonite			Function according to design
(tamped)	$t < \sim 390°$ C	$t < 100°$ C	
(compacted)	$t < 100°$ C	$t < 100°$ C	
Particulate	No constraint	No constraint	No constraint
No backfill	No constraint	No constraint	No constraint
Tuff	No constraint	No constraint	No constraint

NNWSI Program
Preliminary Technical Constraints
Near-Field

Repository System Component	Operational Period $t \leq 110$ yrs	Containment Period $110 < t \leq 1000$ yrs	Isolation Period $t > 1000$ yrs
Disposal room stability	Operational serviceability	No constraint	No constraint
Pillar stability	Factor of safety >1.5	No constraint	No constraint
Floor heave	Operational serviceability	No constraint	No constraint
Mineral dehydration/ alteration	$t < 150°$ C	No constraint	No constraint
Environment temp.	To be determined	No constraint	No constraint
Disposal rm. floor temp.	$t < 100°$ C	No constraint	No constraint
Tunnel backfill temp.	$t < 100°$ C	No constraint	No constraint
Radionuclide release rate	No release	No release	< 1 part in 10^5 per year

NNWSI Program
Preliminary Technical Constraints
Far-Field

Repository System Component	Operational Period $t \leq 110$ yrs	Containment Period $110 < t \leq 1000$ yrs	Isolation Period $t > 1000$ yrs
Shaft pillar stability	Δ Alignment < Constr. misalignment Intersect no major faults	No constraint	
Shaft & borehole seals		Effective perm. = tuff	Apply to 70% regions above & below repository
Rock mass fracturing		No new fracturing	
Mineral dehydration/alteration		t < 75° C	
Surface uplift & subsidence		< Natural analogs	
Max surface temp. increase		Δt < 6°C (comparable with natural analog)	
Thermally perturbed groundwater flow		Travel time to accessible environment >1000 yrs	

1982 NWTS Information Meeting: DOE NWTS- 30

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Early Yucca Mountain Site Design Criteria and Concepts

(Continued)

1983 NNWSI* Repository Design Approach

- Thermal loadings of 12-15 W/m^2 (48-60 kW/acre)
  - Selected to satisfy performance constraints to ensure isolation not significantly degraded
  - Repository impacts on host rock identified
- Concluded thermally induced mineral alteration not of concern in far-field

* Nevada Nuclear Waste Storage Investigations

Repository Impact on the Host Rock

Item	Near-Field	Far-Field
Mining induced stress redistribution	Yes	No
Rock temperature change	Yes	Yes
Thermal induced stress	Yes	Yes
Thermal induced uplift	N.A.	Yes
Alteration of site hydrology		
- Repository above water table	Slight	Slight
- Repository below water table	Yes	Yes
Radiation induced rock property change	No	No
Thermal induced mineral alteration	Potential	no
Rock-groundwater-waste interaction	Yes	No

Study of the Isolation System for Geologic Disposal of Radioactive Wastes

1983 - NAS Board on Radioactive Waste Management assessed status of technology for waste disposal

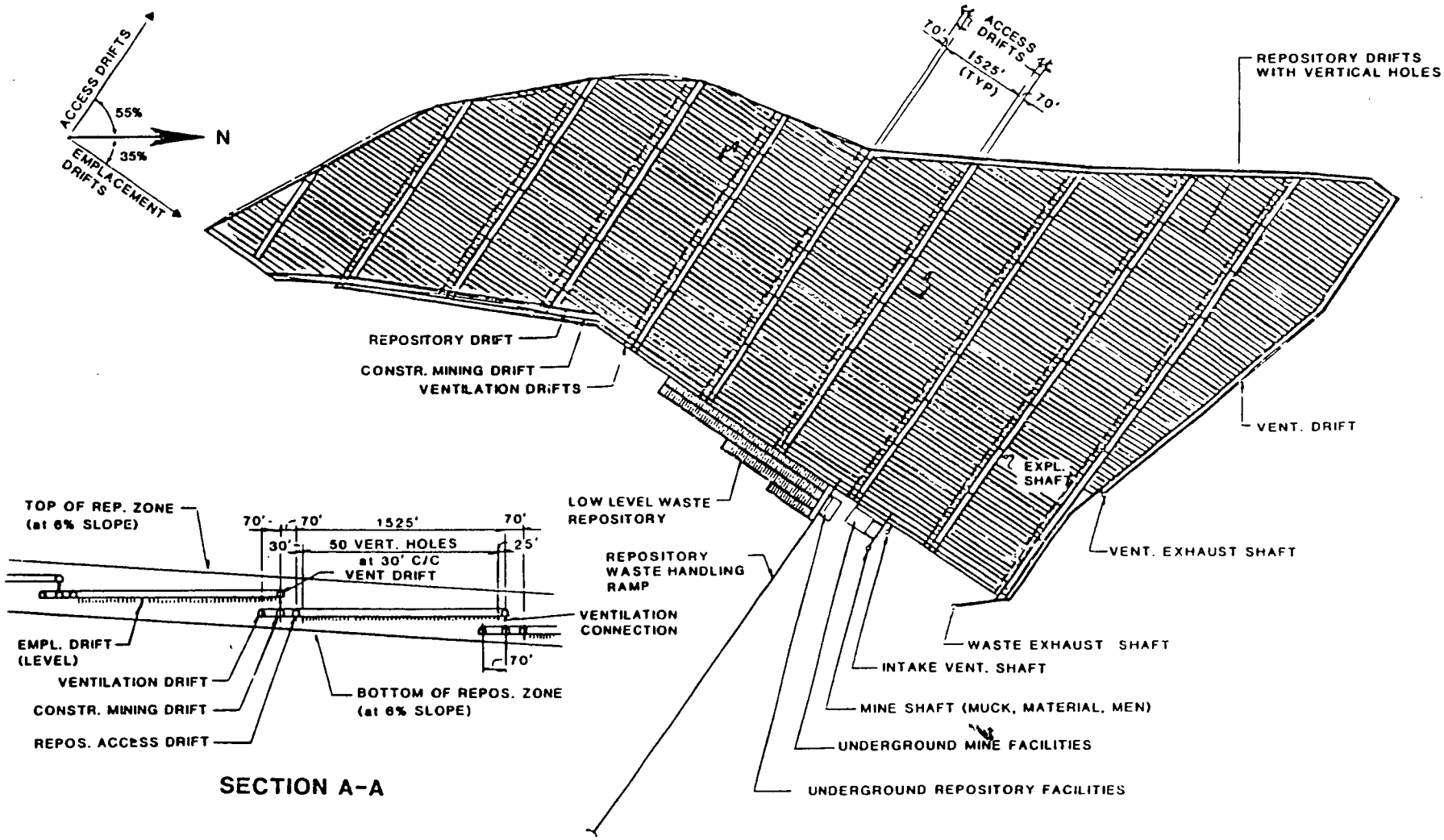
- Evaluated geologic disposal performance and release control mechanisms
- Delay of water, slow dissolution, slow release, long travel, sorption, dispersion, dilution were favorable conditions
- Tuff repository benefits seen in unsaturated zone and retardation. Uncertainties seen in hydrology and thermal effects on geochemistry

Preliminary Repository Concepts

1984 - Addressed preliminary technical constraints for 10 yrs out-of-reactor spent fuel:

- 14.1 W/m^2 (57 kW/acre) was an acceptable APD for all preliminary constraints
- Preliminary bounding calculations indicated that an APD of 22.2 W/m^2 (90 kW/acre) or more violated far-field constraints
- An APD of 18.8 W/m^2 (76 kW/acre) was acceptable for near-field concerns

NNWSI Preliminary Repository Concepts



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Preliminary Evaluations of Thermal Aspects of Site Suitability - Environmental Assessment

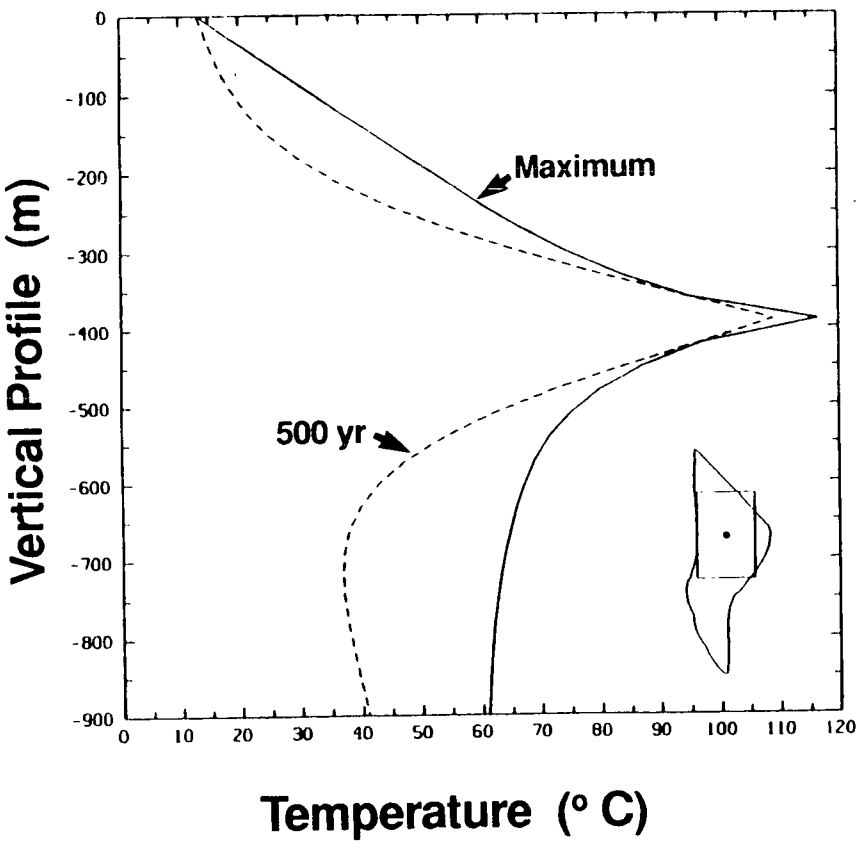
- Geochemistry guideline addressed thermal impacts on retardation
- Post Closure Rock Characteristics guideline addressed thermal impacts on isolation

Temperature Profiles Determined to Support Preliminary Findings of Environmental Assessment

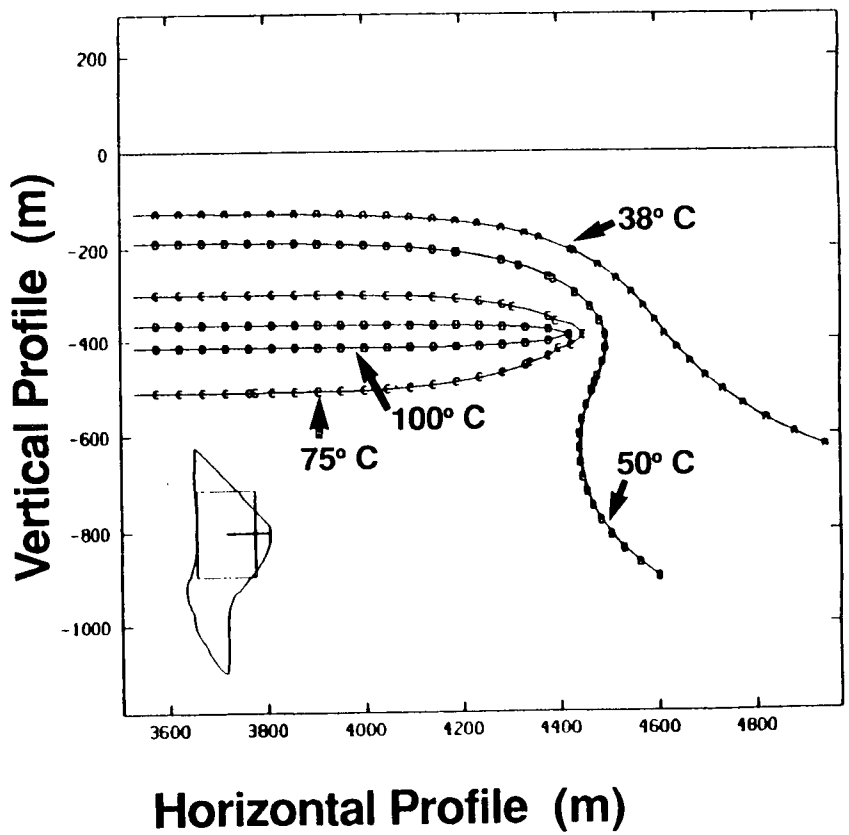
- Evaluate maximum temperature reached as function of distance from repository
- Single rectangular panel, 1260 acres at 57 kW/acre, 390m depth of repository
- Thermal properties chosen to simulate detailed thermal stratigraphy in Unit Evaluation Study

Temperature Profiles to Support EA

Vertical Temperature Profile



Maximum Temperature Contours



Final Environmental Assessment Yucca Mountain Site, 1986

- Post closure geochemistry guideline - favorable condition

  (3) Mineral assemblages subjected to expected repository conditions have equal or increased retardation capability

  - Most sorptive zeolites more than 300m below repository, where maximum induced temperature is 60° C (Δ=23° C). Unlikely that significant zeolite decomposition would take place over 100,000 yrs

Final Environmental Assessment Yucca Mountain Site, 1986

(Continued)

- Post closure rock characteristics guideline - favorable conditions

  (2) High thermal conductivity, a low coefficient of thermal expansion, or sufficient ductility to seal fractures

  - Present: low thermal expansion coefficient; calculated behavior suggests no adverse response

Final Environmental Assessment Yucca Mountain Site, 1986

(Continued)

- Post closure rock characteristics guideline - potentially adverse conditions

  (1) Rock conditions requiring engineering measures beyond reasonably available technology to ensure waste containment or isolation
  - Not present: no conditions identified requiring other than ordinary measures to ensure isolation

  (2) Thermally induced fractures, the hydration or dehydration of mineral components, brine migration, or other physical, chemical, or radiation-related phenomena that could be expected to affect waste containment or isolation
  - Not present: expected to be physically and chemically stable; calculations indicate that thermally induced fracturing would be minor

Final Environmental Assessment Yucca Mountain Site, 1986

(Continued)

- Post closure rock characteristics guideline - potentially adverse conditions

  (3) Combination of geologic structure, geochemical and thermal properties, and hydrologic conditions so heat could significantly decrease the isolation

  - Not present: properties and conditions not expected to cause a decrease

SCP/CDR Development Process: Post Closure Considerations for Performance

1984 Unit Evaluation Study at Yucca Mountain: horizon selection evaluation

- Thermal/mechanical evaluations to confirm that none of the technical constraints were violated
- Mineral hydration/dehydration limit at t<150° C
- Plots of temperature history at far-field boundary developed
- Maximum GTL = 57 kW/ac needed to meet operational constraint of drift floor temperature <100° C

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Near-Field Preliminary Technical Constraints Unit Evaluation Report

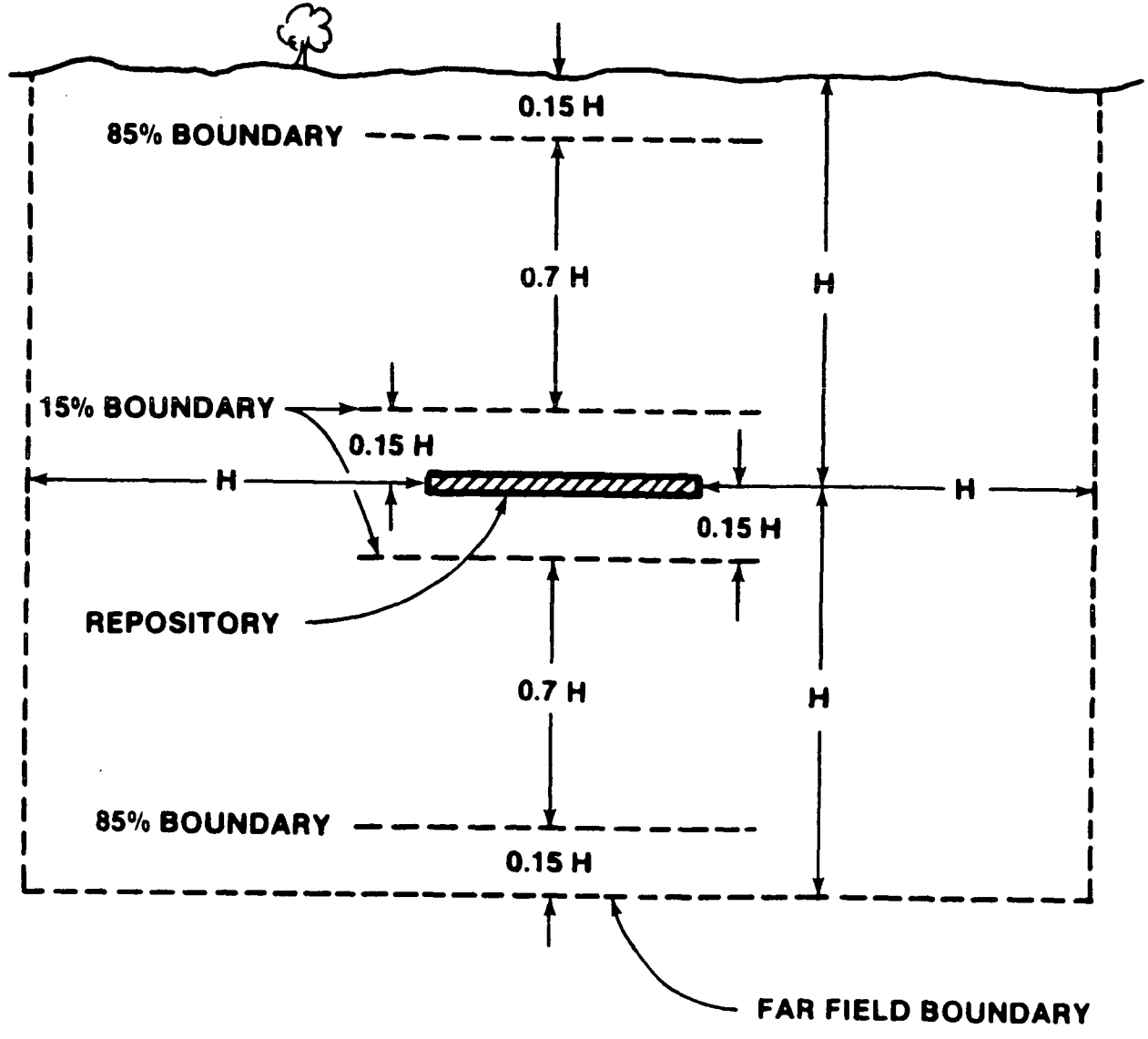
	SYSTEM COMPONENT	OPERATIONAL PERIOD	CONTAINMENT PERIOD	ISOLATION PERIOD
NEAR FIELD	ROOM:			
	ROOF, RIB, FLOOR	OPERATIONAL SERVICEABILITY	NO CONSTRAINT	NO CONSTRAINT
	ENVIRONMENT	TO BE DETERMINED	NO CONSTRAINT	NO CONSTRAINT
	FLOOR	$T < 100°C$	NO CONSTRAINT	NO CONSTRAINT
	BACKFILL	$T < 100°C$	NO CONSTRAINT	NO CONSTRAINT
	PILLAR	SAFETY FACTOR > 1.5	NO CONSTRAINT	NO CONSTRAINT
	MINERAL DEHYDRATION/ ALTERATION	$T < 150°C$	NO CONSTRAINT	NO CONSTRAINT
	ENGINEERED SYSTEM	NO RADIONUCLIDE RELEASE AT BOUNDARY	NO RADIONUCLIDE RELEASE AT BOUNDARY	$< 10^{5}$ PER NUCLIDE PER YEAR

Far-Field Preliminary Technical Constraints Unit Evaluation Report

	SYSTEM COMPONENT	OPERATIONAL PERIOD	CONTAINMENT PERIOD	ISOLATION PERIOD
FAR FIELD	SHAFT	OPERATIONAL SERVICEABILITY INTERSECT NO MAJOR FAULTS	NO CONSTRAINT	
	SEALS:			
	SHAFT AND BOREHOLE		EFFECTIVE PERMEABILILTY = TUFF*	
	ROCKMASS:			
	MECHANICAL BEHAVIOR		NO NEW FRACTURES*	
	MINERAL DEHYDRATION/ ALTERATION		T < 150°C*	
	SURFACE UPLIFT AND SUBSIDENCE		< NATURAL ANALOGS	
	SURFACE TEMPERATURE INCREASE		ΔT < 6°C (COMPARABLE TO NATURAL VARIATIONS)	
	THERMALLY PERTURBED GROUNDWATER FLOW		TRAVEL TIME TO ACCESSIBLE ENVIRONMENT > 1000 YEARS	

*THESE CONSTRAINTS APPLY TO THE "INTACT" (70% REGION) ROCKMASS

NWTS-25: Performance Constraints



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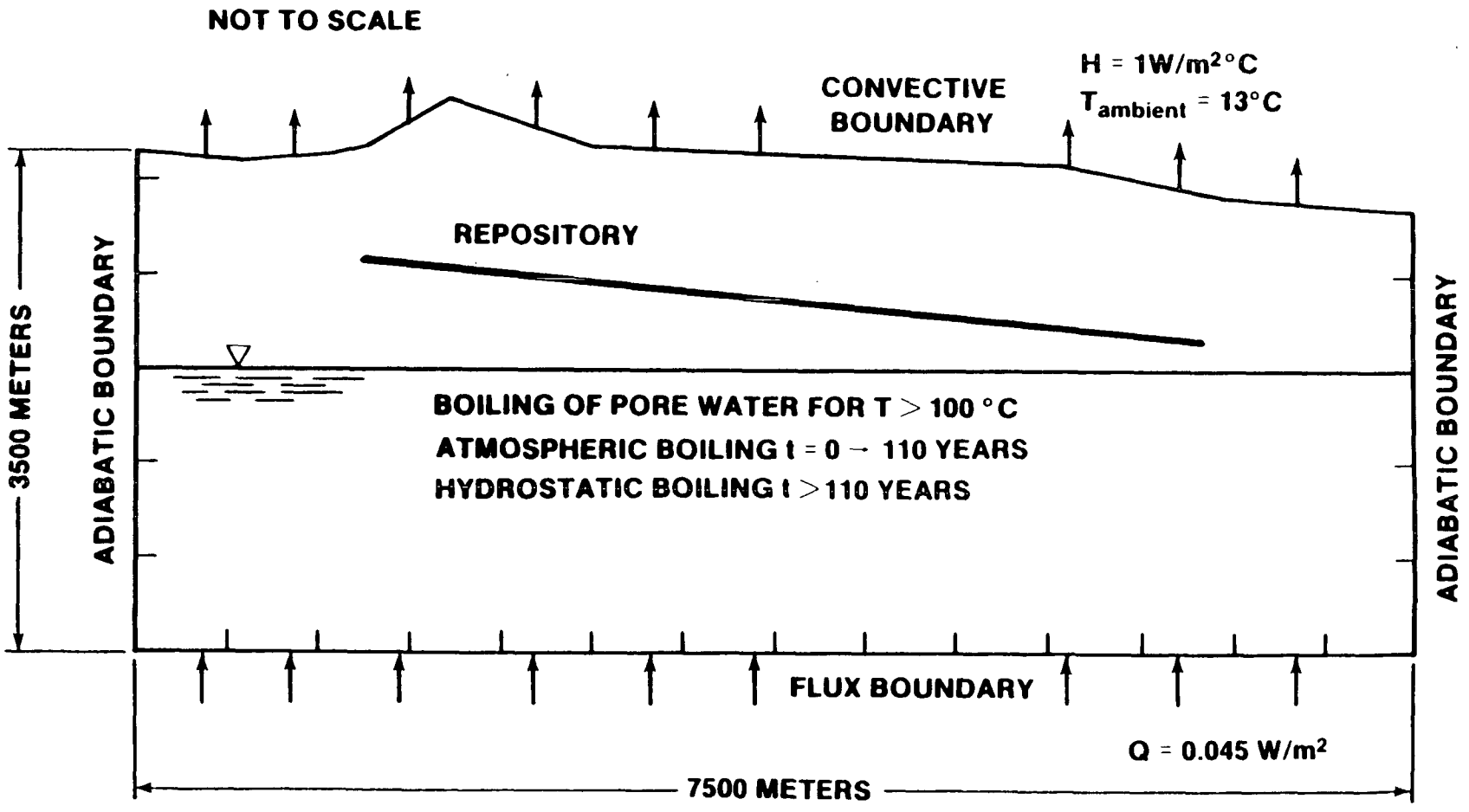
Conceptual Thermal Model



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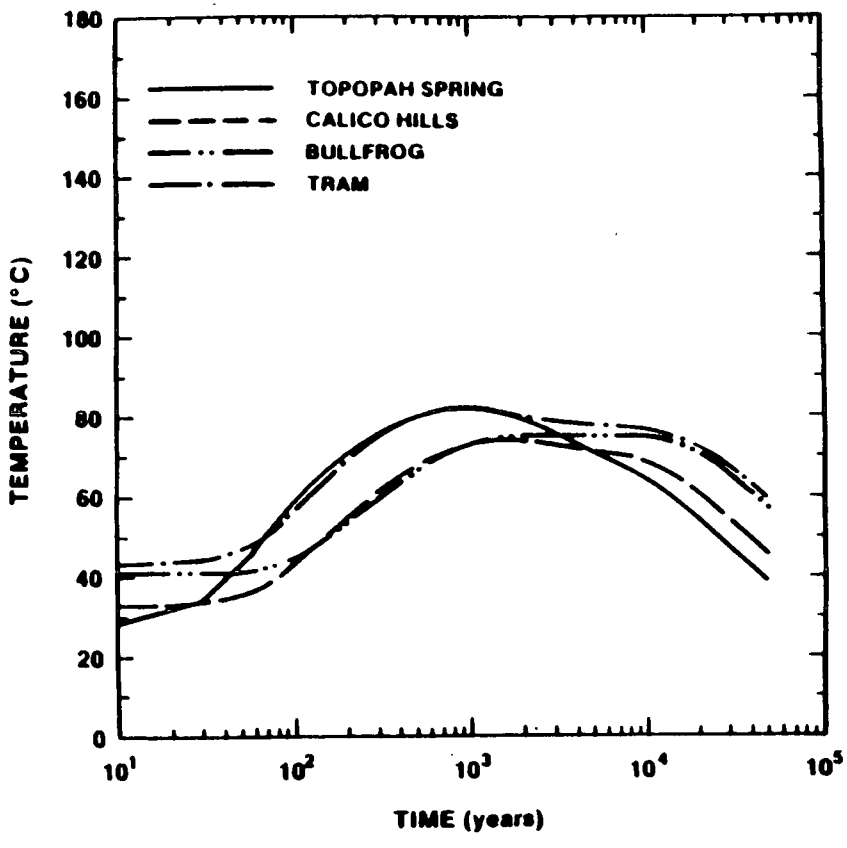
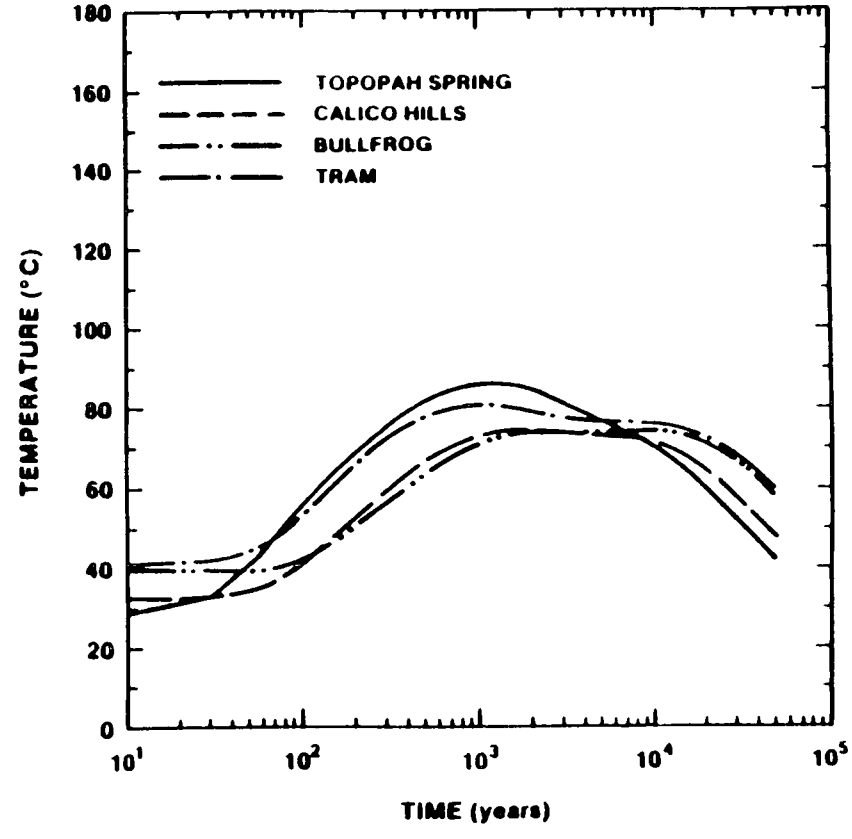
Thermal History of Selected Boundaries: Unit Evaluation Report

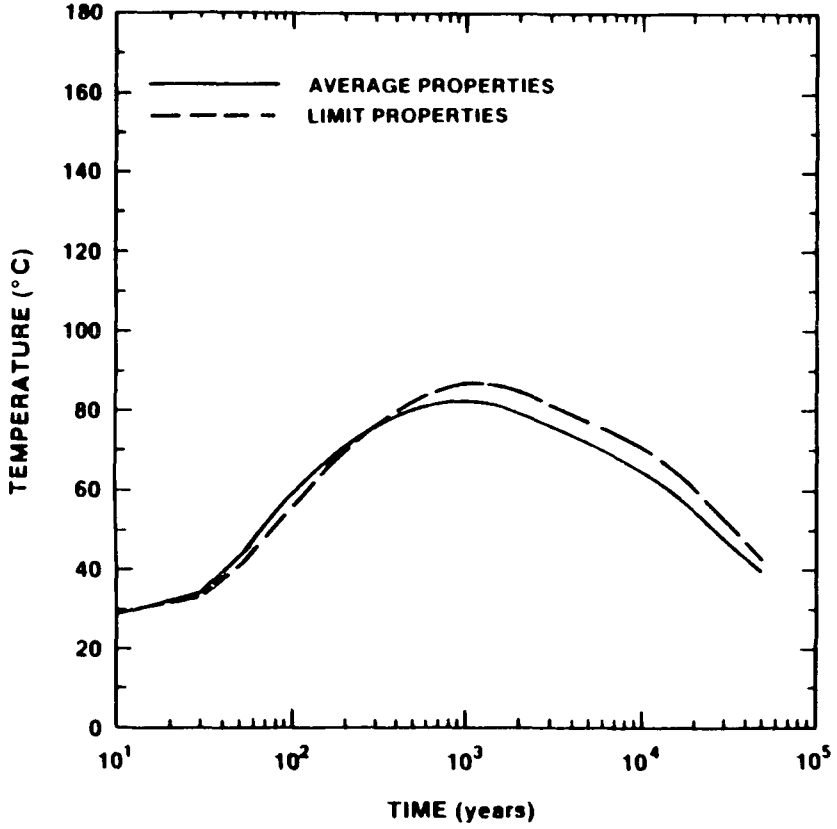


15% Boundary Below the Potential Repository Horizons (Average Properties)

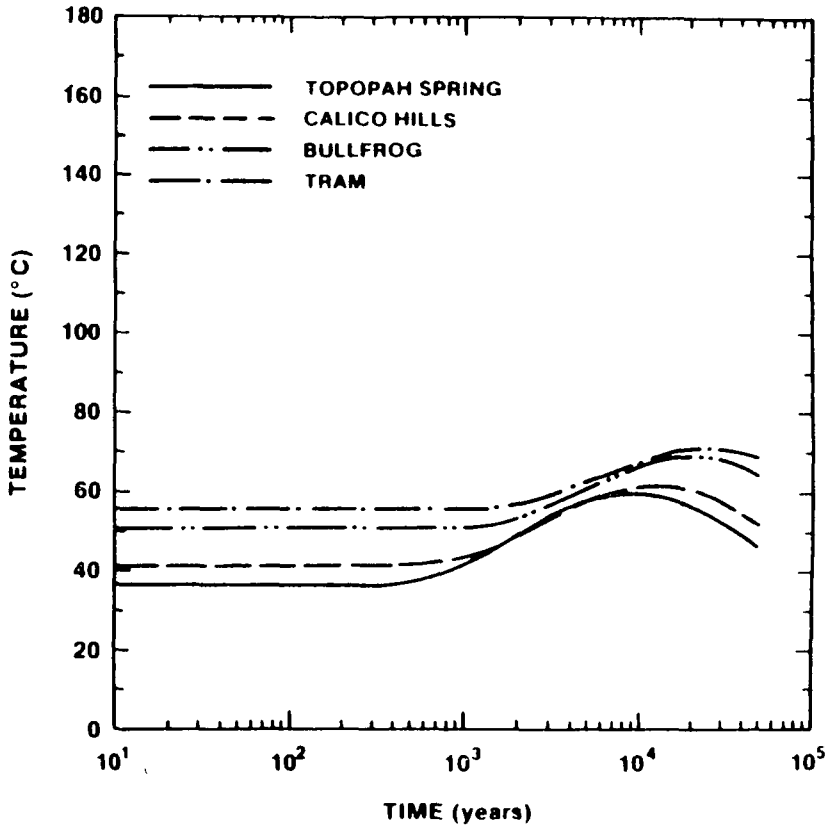


15% Boundary Below the Potential Repository Horizons (Limit Properties)

Thermal History of Selected Boundaries: Unit Evaluation Report



15% Boundary Below the Topopah Spring Horizon



85% Boundary Below the Potential Repository Horizons

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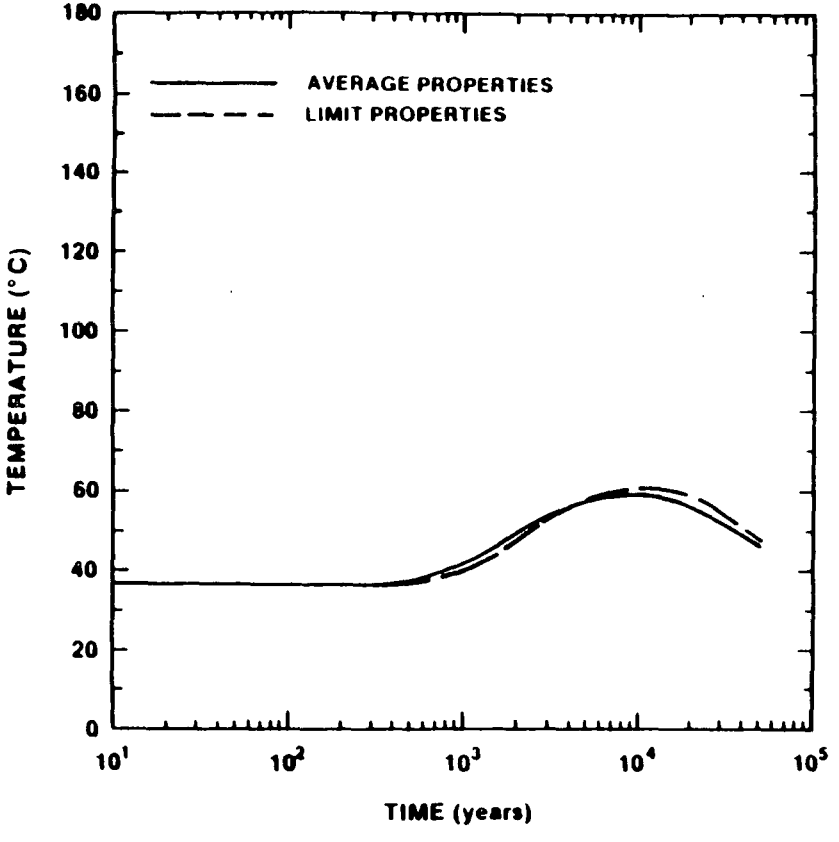
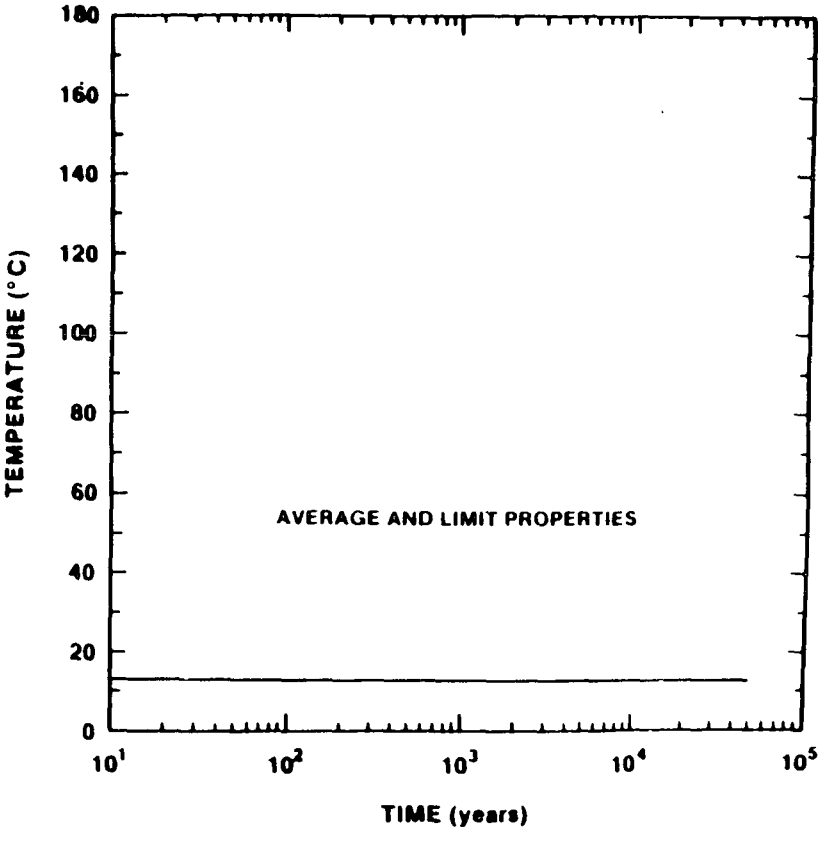
Thermal History of Selected Boundaries: Unit Evaluation Report



85% Boundary Below the Topopah Spring Horizon



3m Below Ground Surface, Repository in Topopah Spring Horizon
(Max $\Delta t = 0.6^\circ$ C at time = 3,000 yrs)

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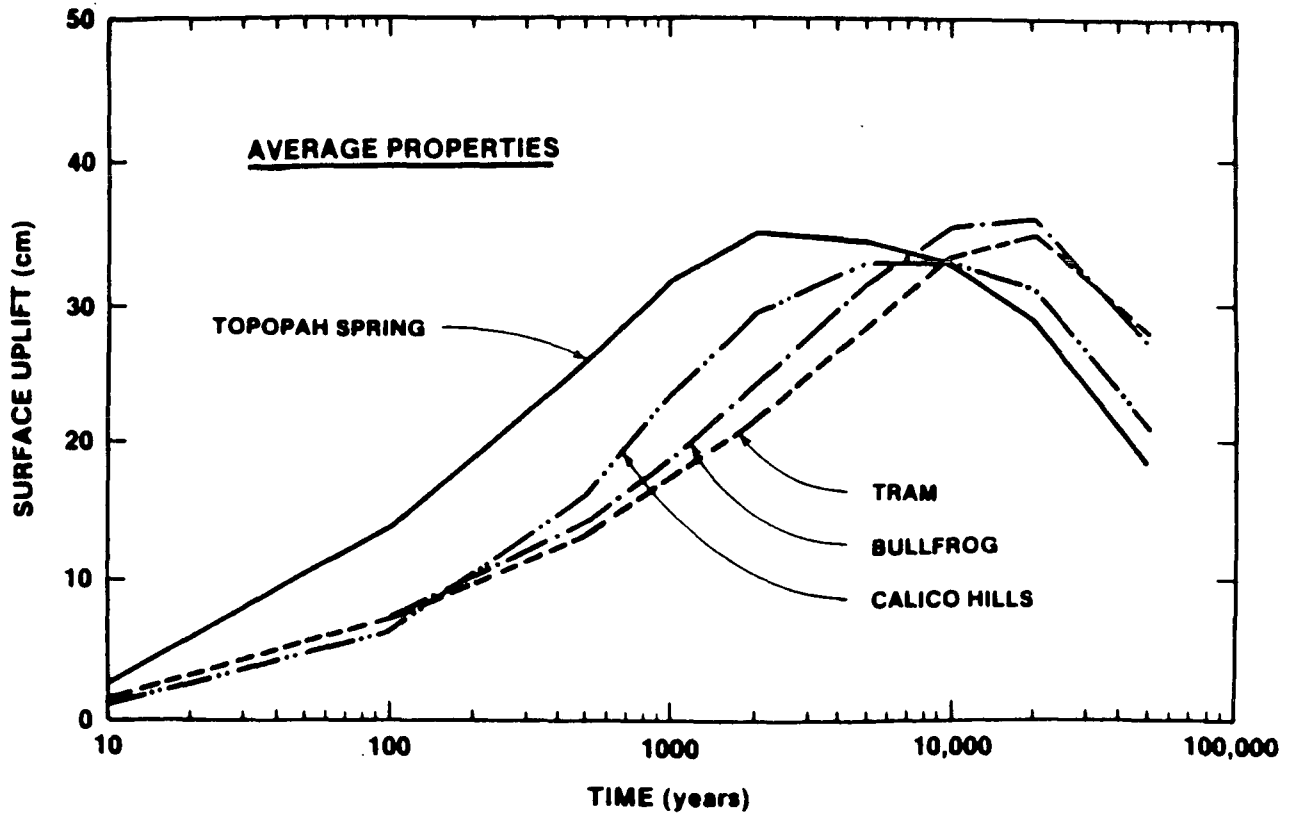
Surface Uplift Resulting From a Repository Emplaced in the Designated Units (Average Properties Throughout the Section)



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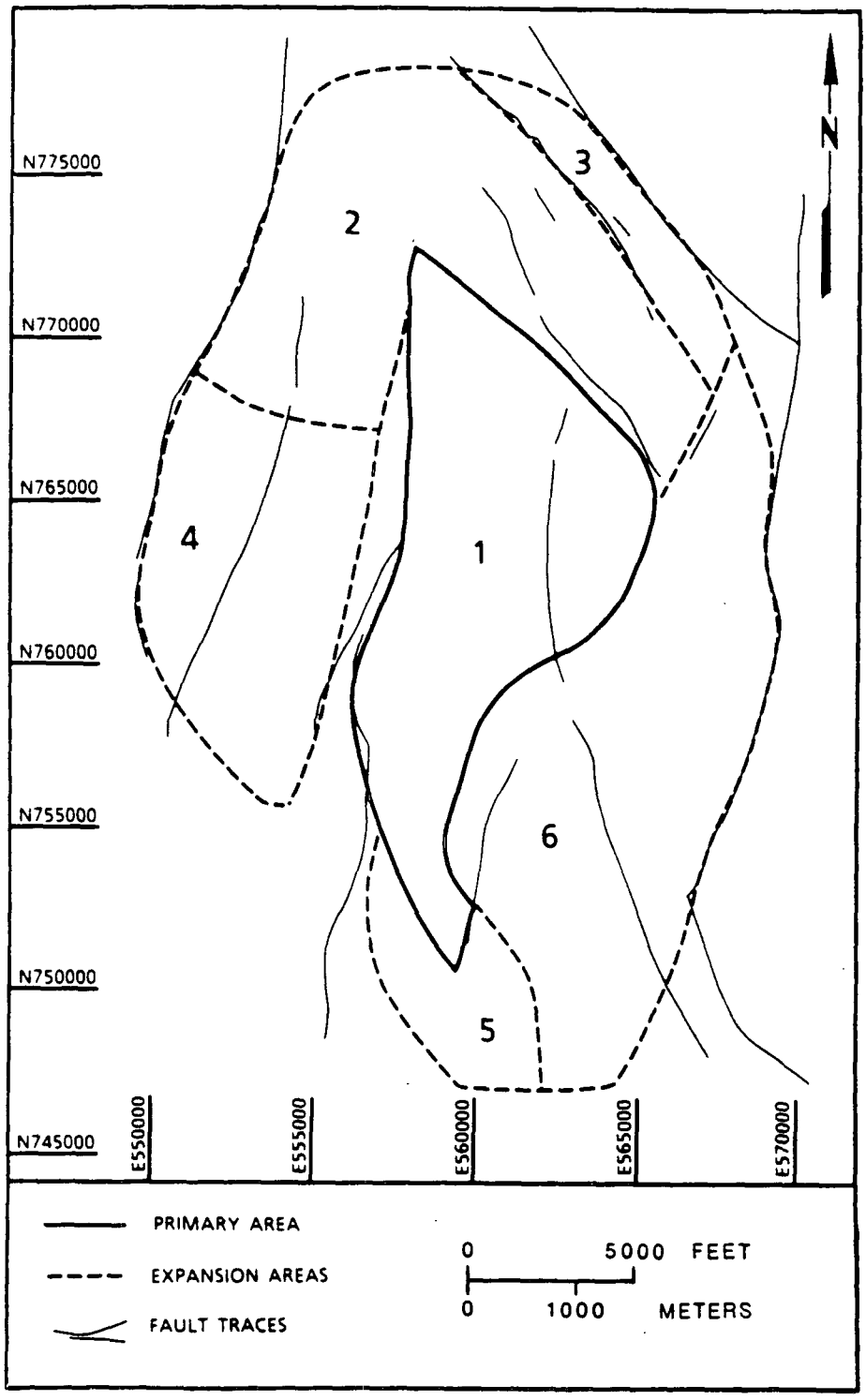
SCP/CDR Development Process: Post Closure Considerations For Performance

1984 Area available for a potential repository at Yucca Mountain

- Area requirement of 1520 acres based on 57 kW/ac APD
- Noted that value could change with other conceptual design changes
- Primary area 2200 acres, primary expansion area similar in size and properties

Primary Area (Area 1) For the Underground Repository and Potential Expansion Area (Areas 2 Through 6)



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Assessment of Repository Related Impacts - Disturbed Zone

NRC Generic Technical Position (GTP) on extent of the disturbed zone - 1986

- Four factors of concern:
  - Stress redistribution
  - Construction and excavation
  - Thermomechanical effects
  - Thermochemical effects
- Conclude
  - Five diameters reasonably conservative estimate
  - Need site specific evaluation

Assessment of Repository Related Impacts - Disturbed Zone

(Continued)

Disturbed zone boundary for a repository at Yucca Mountain - 1987

- Volume of rock with significant changes in flow of groundwater
- Site specific evaluation of the extent of the disturbed zone
  - Units with large amounts of clay and zeolites far enough away to ensure temperatures remain below values (115° to 125° C) at which changes in their hydrologic properties might occur;
  - Looked at silica dissolution and deposition
  - Looked at temperature effects on permeability
- Concluded disturbed zone extent less than 10m

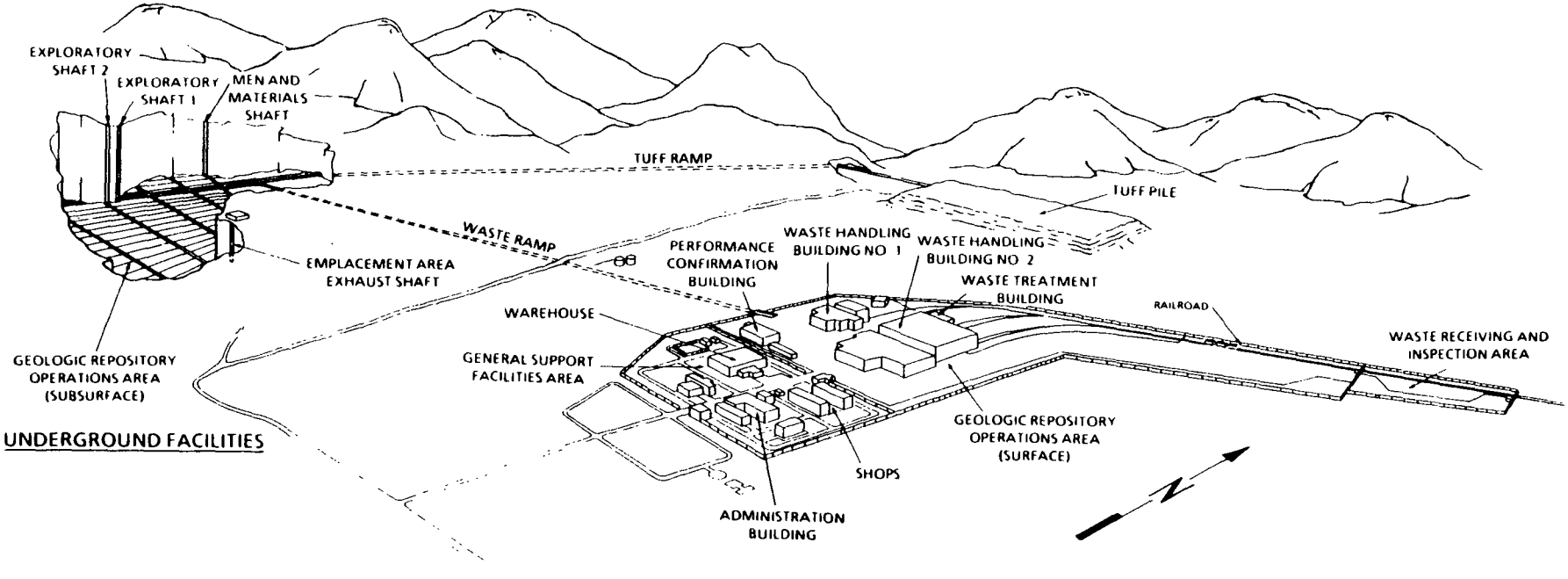
Site CharacterizationPlan
Conceptual Repository Design

- Basis is equivalent energy density through 2,000 years of 10 year old average burnup spent fuel emplaced at 57 kW/ac

- Borehole wall temperature <275° C (to ensure waste temperature less than 350° C)

- Temperatures limited in selected barriers (<200° C - 1m from borehole wall; <115° C - in Calico Hills; <115° C - in TSw3). (Rationale for the latter two limits derived from zeolite, glass, and clay alteration below the repository horizon and the potential disturbed zone boundary)

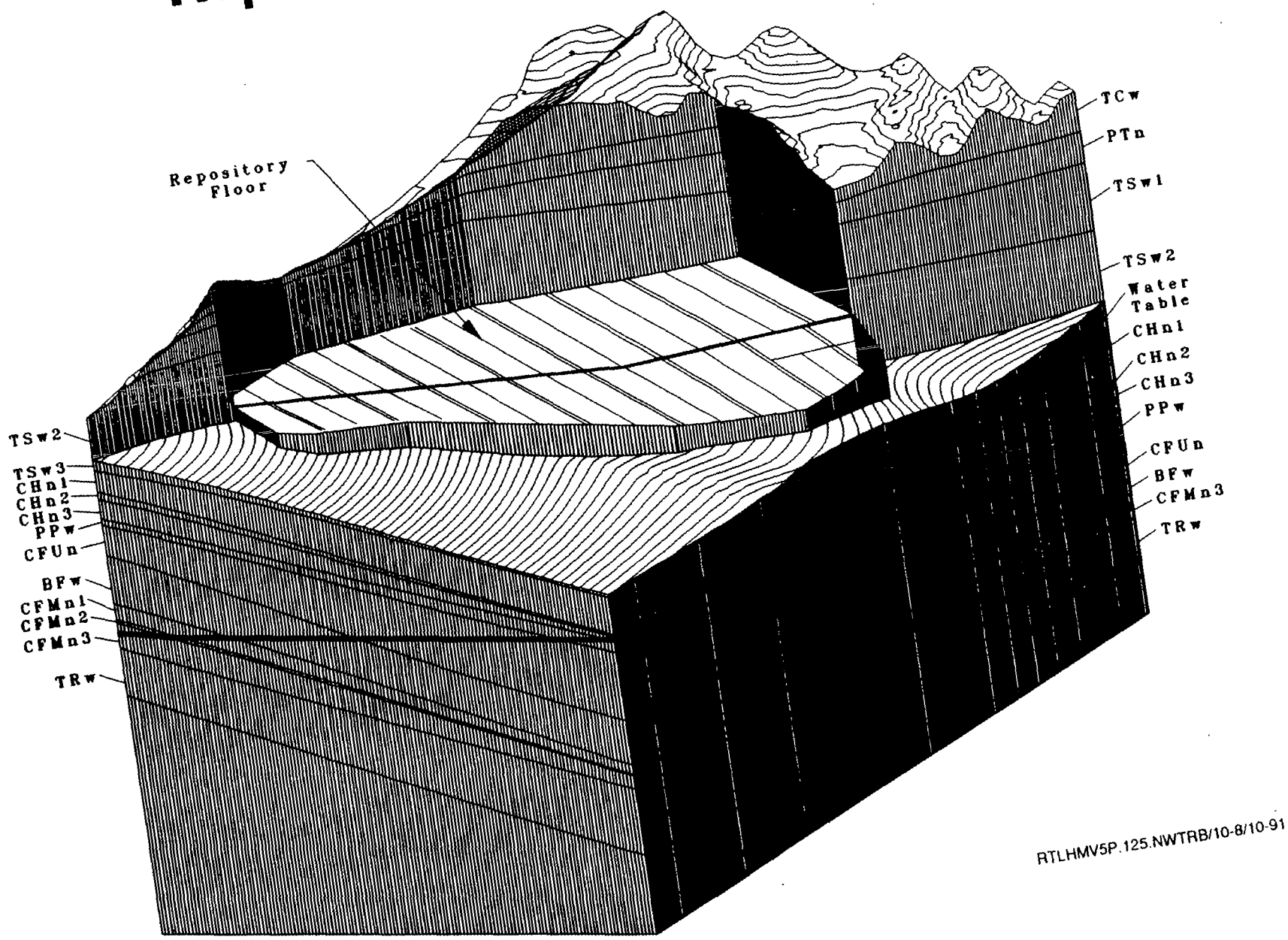
PRELIMINARY DRAWING OF PROPOSED REPOSITORY COMPLEX



UNDERGROUND FACILITIES

CENTRAL SURFACE FACILITIES

Repository Conceptual Design



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Concluding Remarks

- Thermal impacts and induced changes have been addressed in both requirements and design studies
- Yucca Mountain Conceptual Repository Design is consistent with early program concepts
- Yucca Mountain Conceptual Repository Design appears to meet constraints designed to limit impacts to system performance