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

NUCLEAR WASTE TECHNICAL REVIEW BOARD

SUBJECT: SITE RESPONSE TO THERMAL LOADING

INFORMATION EXPECTED FROM LARGE BLOCK TEST

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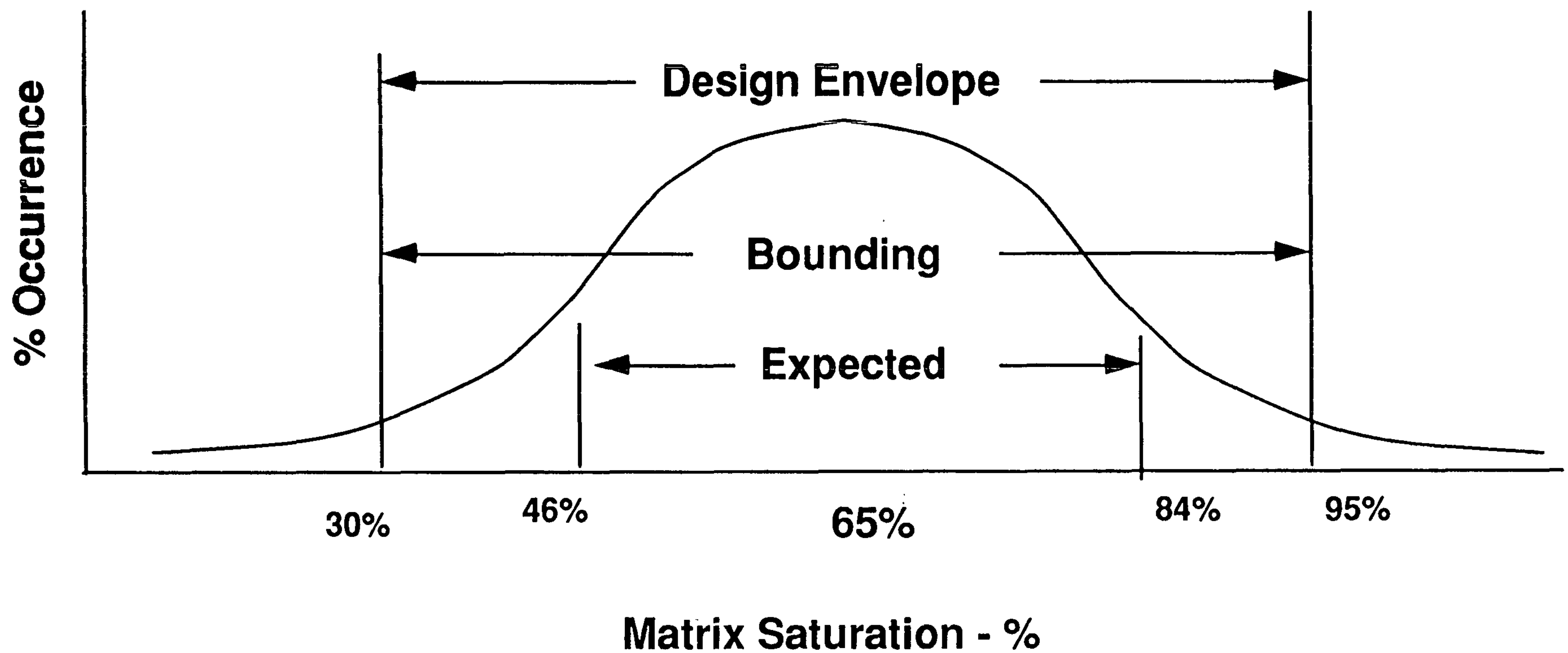
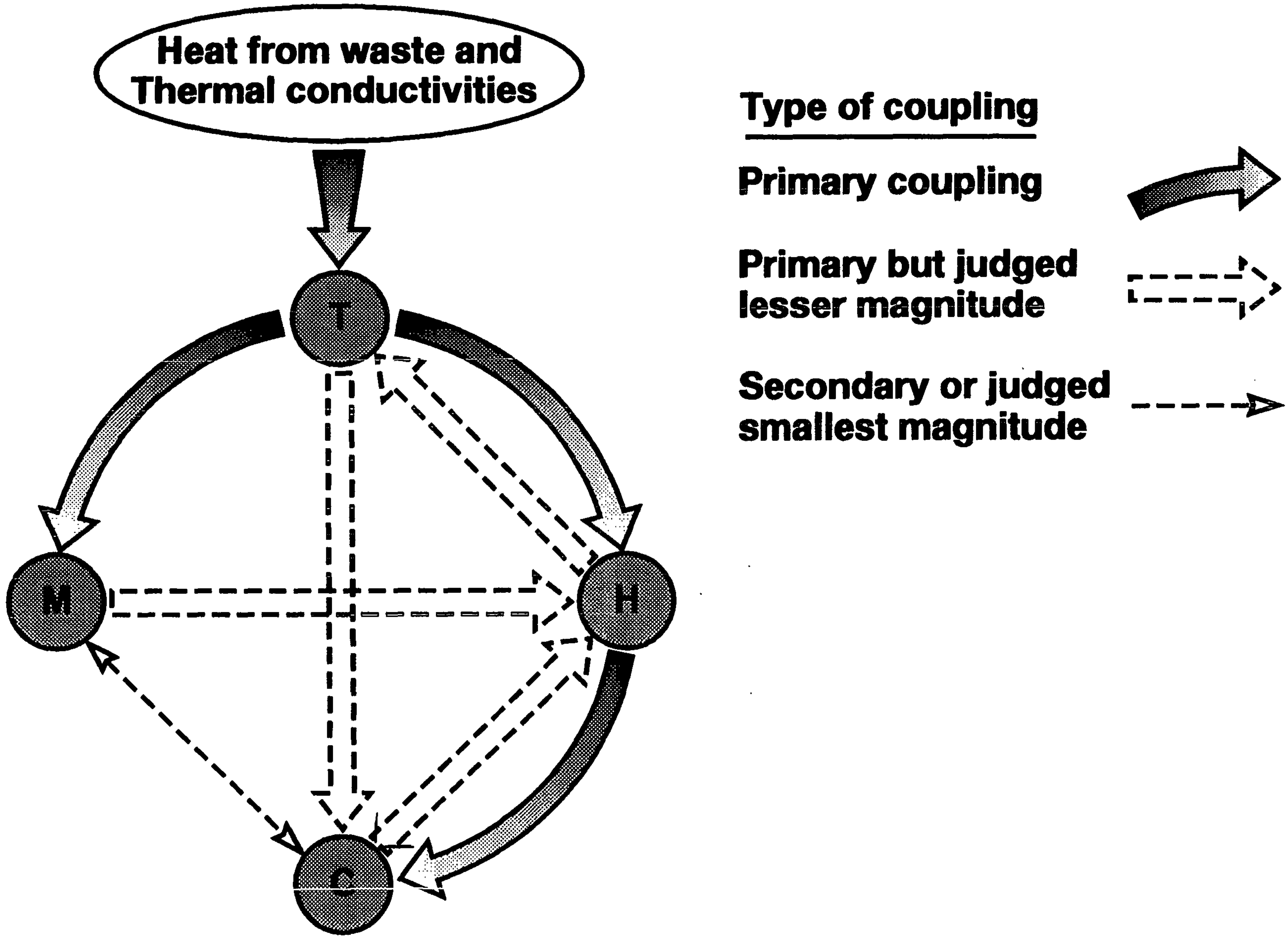
WASHINGTON, D.C.
NOVEMBER 17-18, 1994

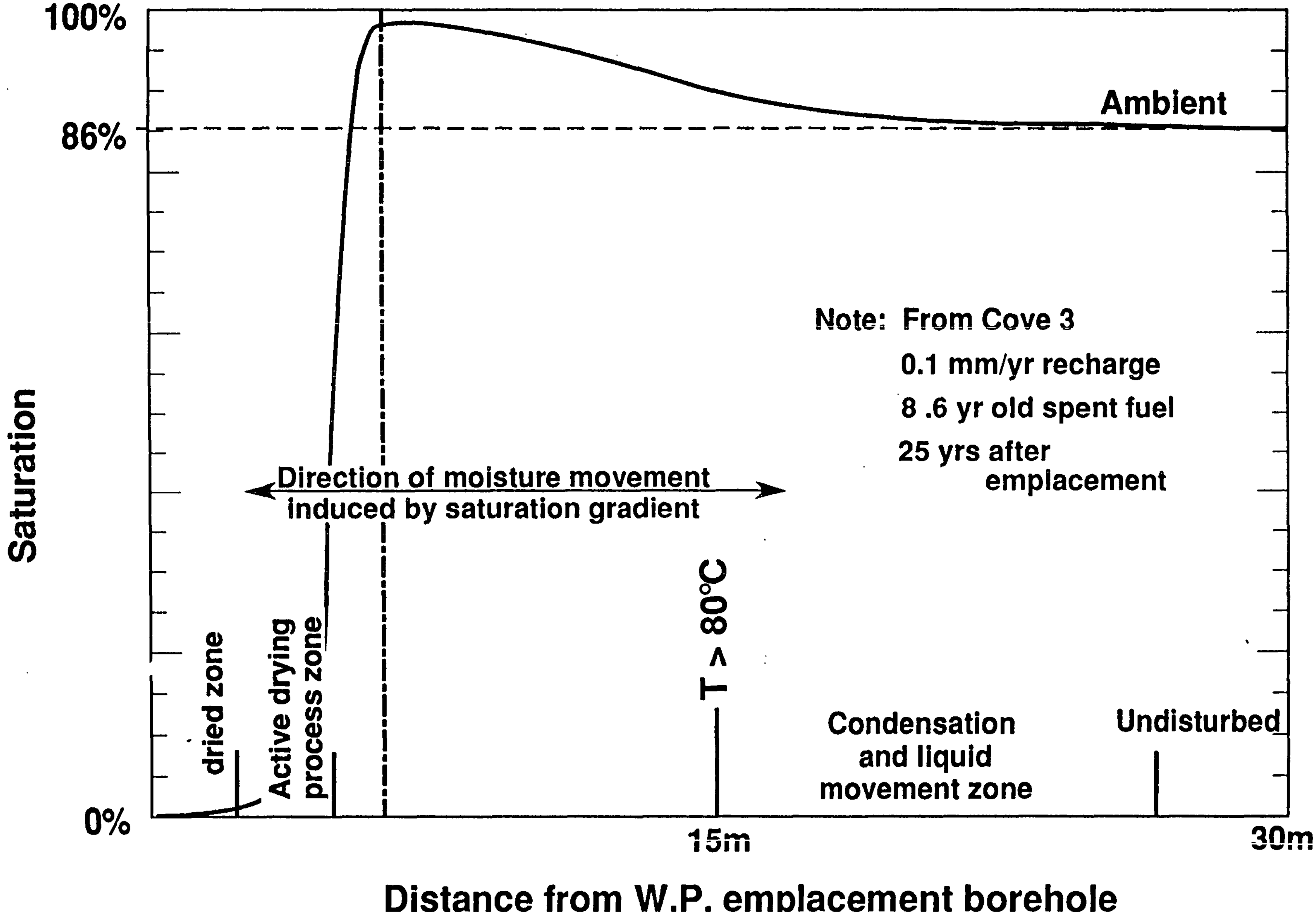
Yucca Mountain Matrix Saturation conditions as Currently Understood





ES11/2/94DW#11-01

Post-emplacement Saturation Conditions around borehole of typical Spent Fuel Canister



ES-01/02/90-DW-24

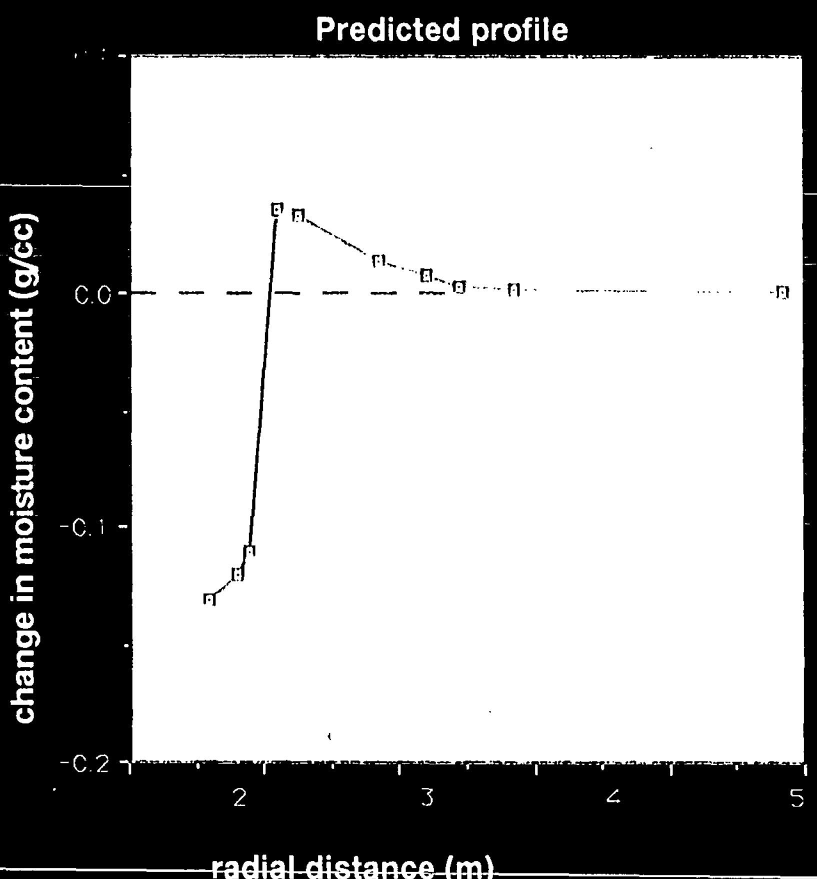
U. S. DEPARTMENT OF ENERGY

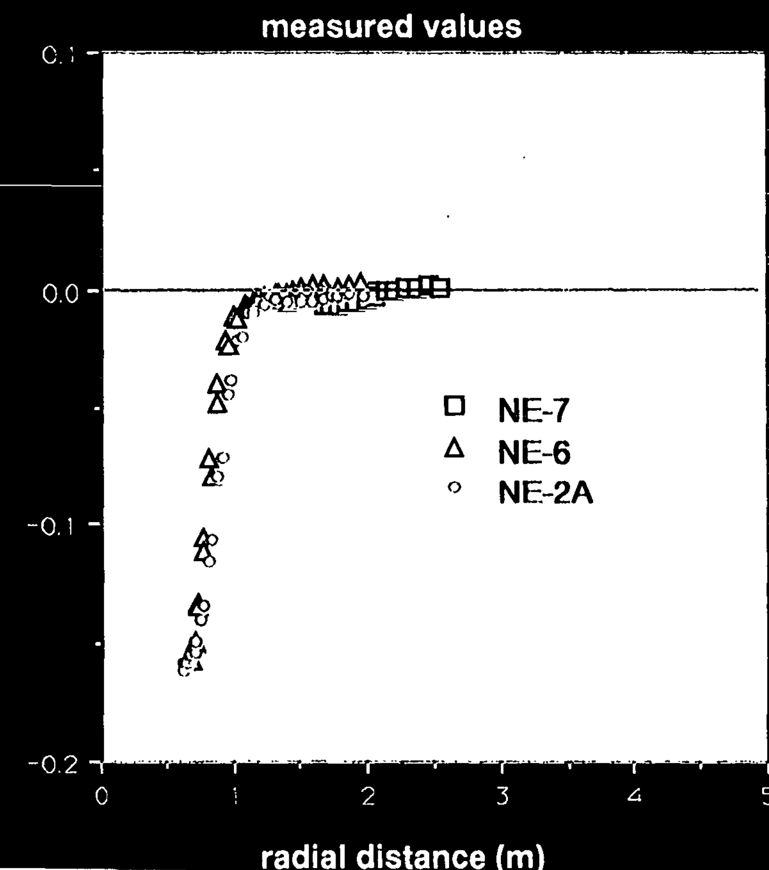
OCRWM

YUCCA MOUNTAIN

YUCCA MOUNTAIN PROJECT

Predicted and measured radial profiles are different





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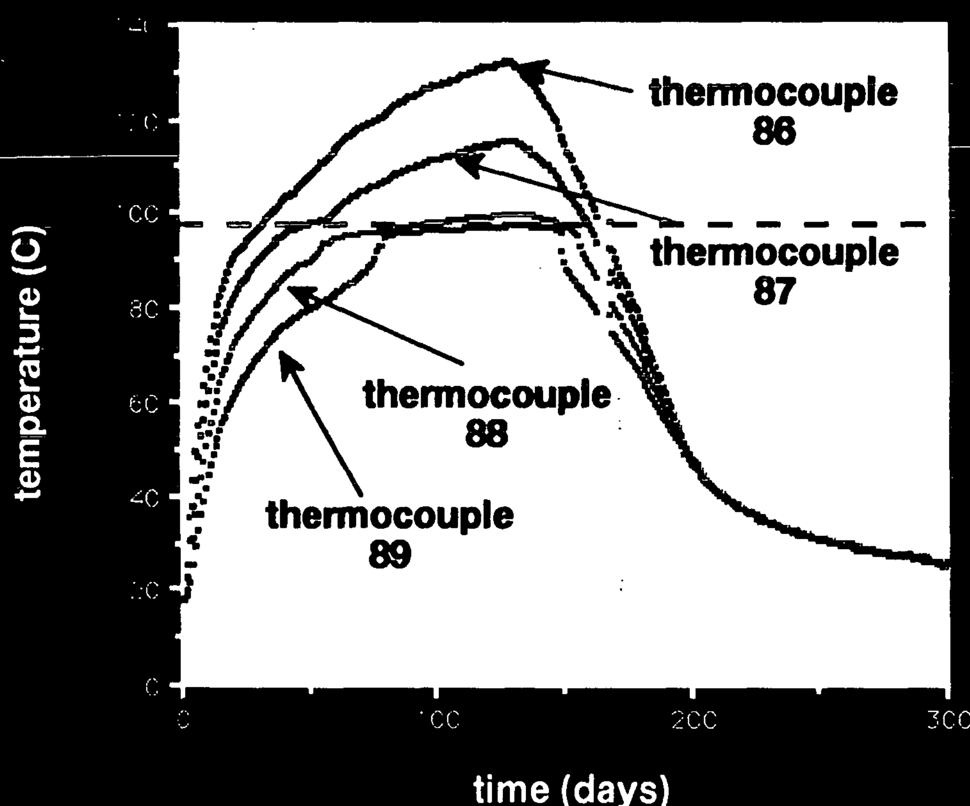
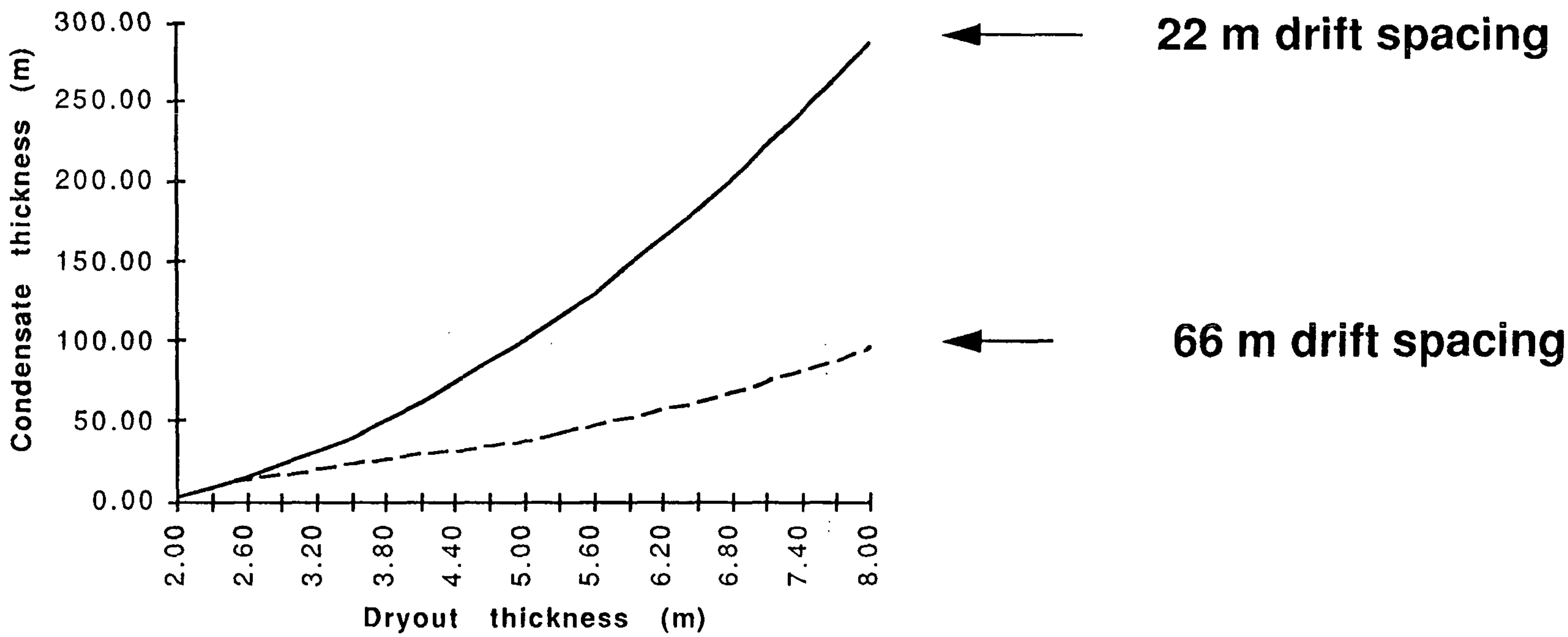
YUCCA MOUNTAIN PROJECT

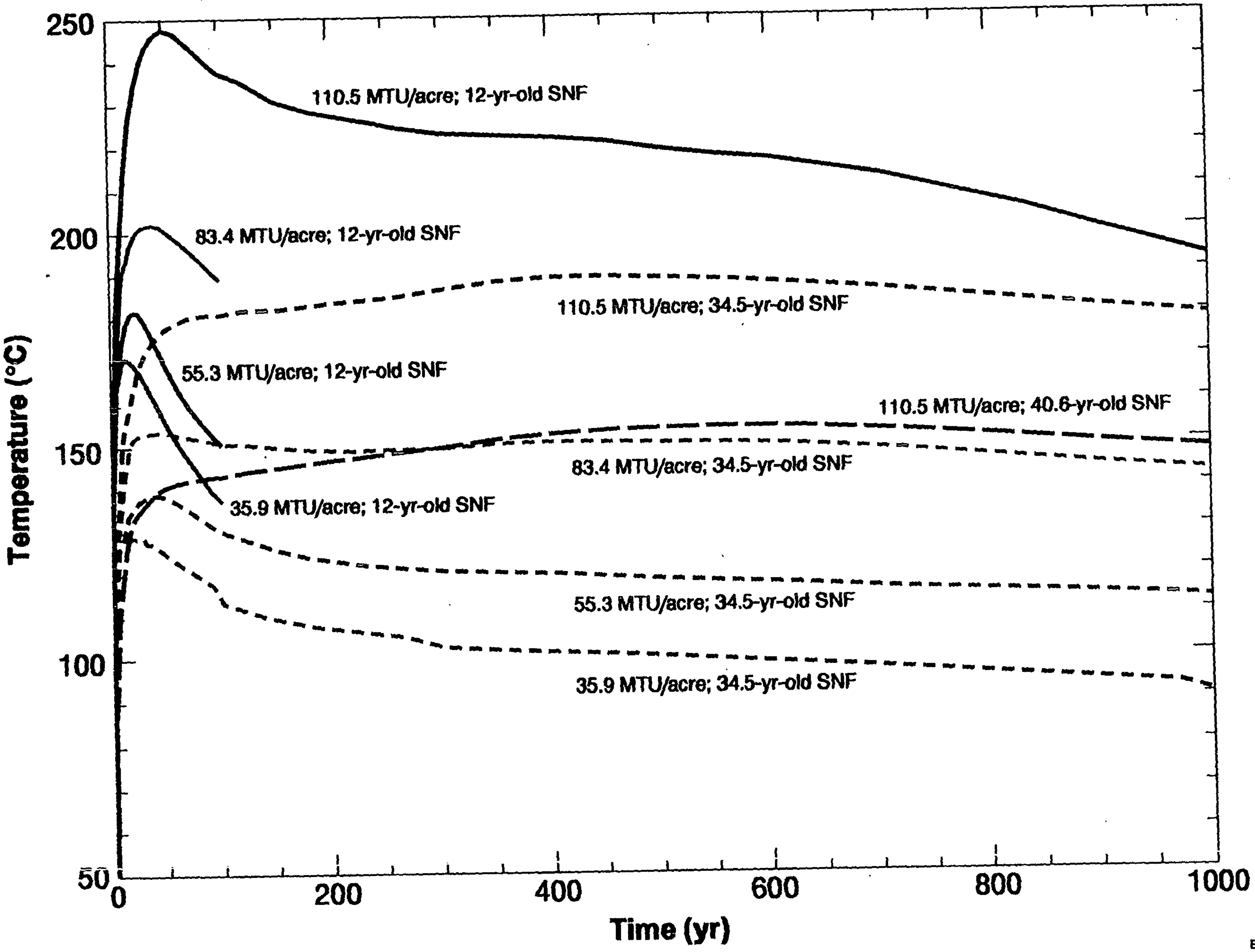
Some locations remained at boiling temperature



Where can water go?



Waste package surface temperature at repository center

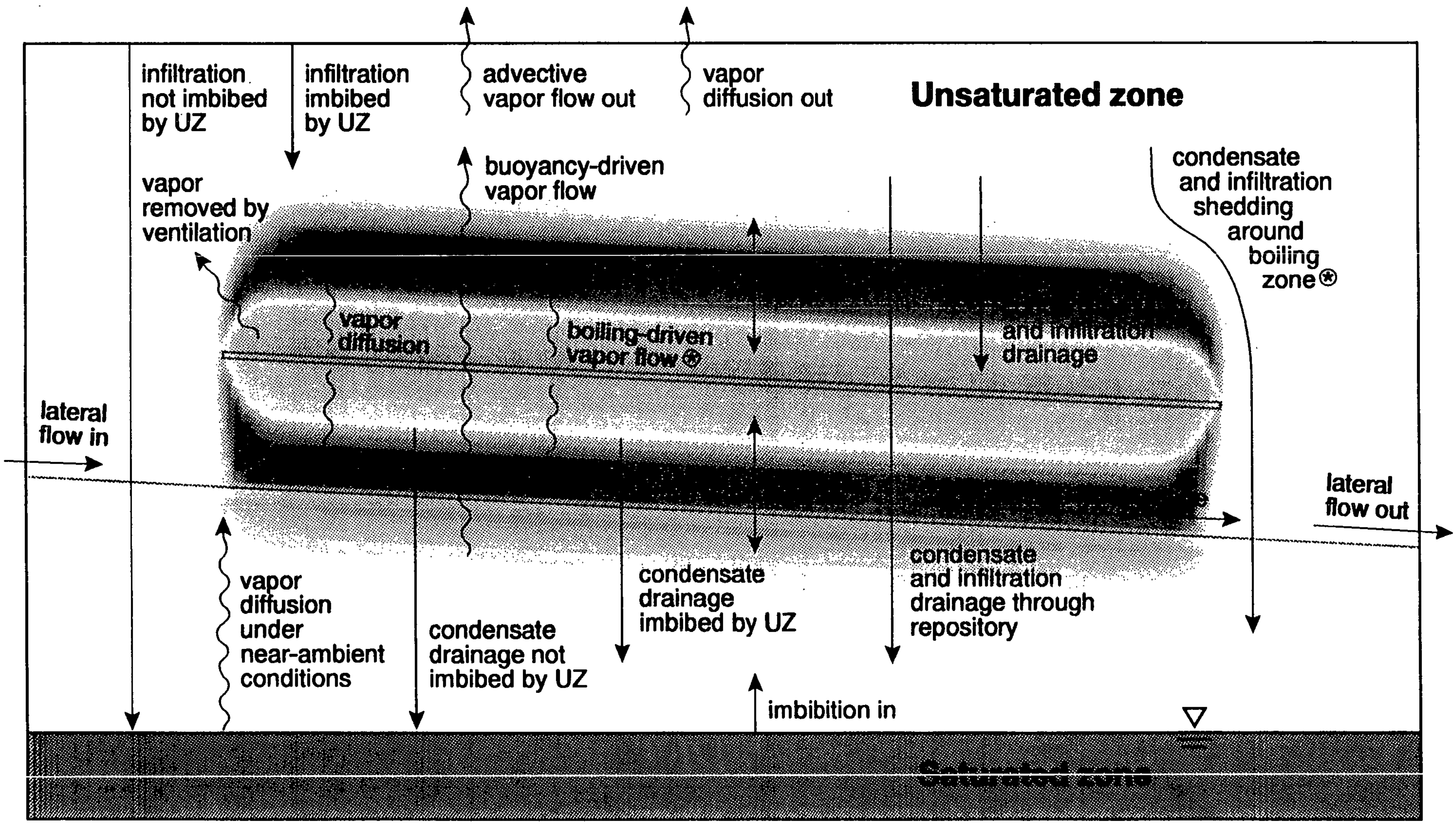


ES-TB-1 (5-19-94) IL

Thermal Responses
Spatial and Temporal Regimes

Spatial	Temporal	Low AML	High AML
Waste Package/ Drift	Years 1-20	Hot (50-80°C)/ Humid (70%) with possible liquid water. MMM and biological coupling. Locally Hot (130°C)	Hot (approaching 100° C) both average and locally. Lowered RH. Minimal liquid water.
	Years 20-100	Hot (60-90°C)/ Humid with possible liquid water. MMM and biological coupling. Locally Hot (130°C)	Hot (>100°C) Low Relative Humidity. No liquid water. No MMM and biological coupling.
	Years 100-2000	Warm (50-80°C)/Humid, possible liquid water. Locally 100-120°C. MMM and biological coupling	Hot (~150°C), low RH. No liquid water. No MMM and biological coupling.
	Years 2000-10000	Warm (40-60°C), Humid. Liquid water. MMM & biological.	Hot (~150°C), low RH. No liquid water. No MMM and biological coupling.
	Years 10000	Cool humid	Warm to cool and dry

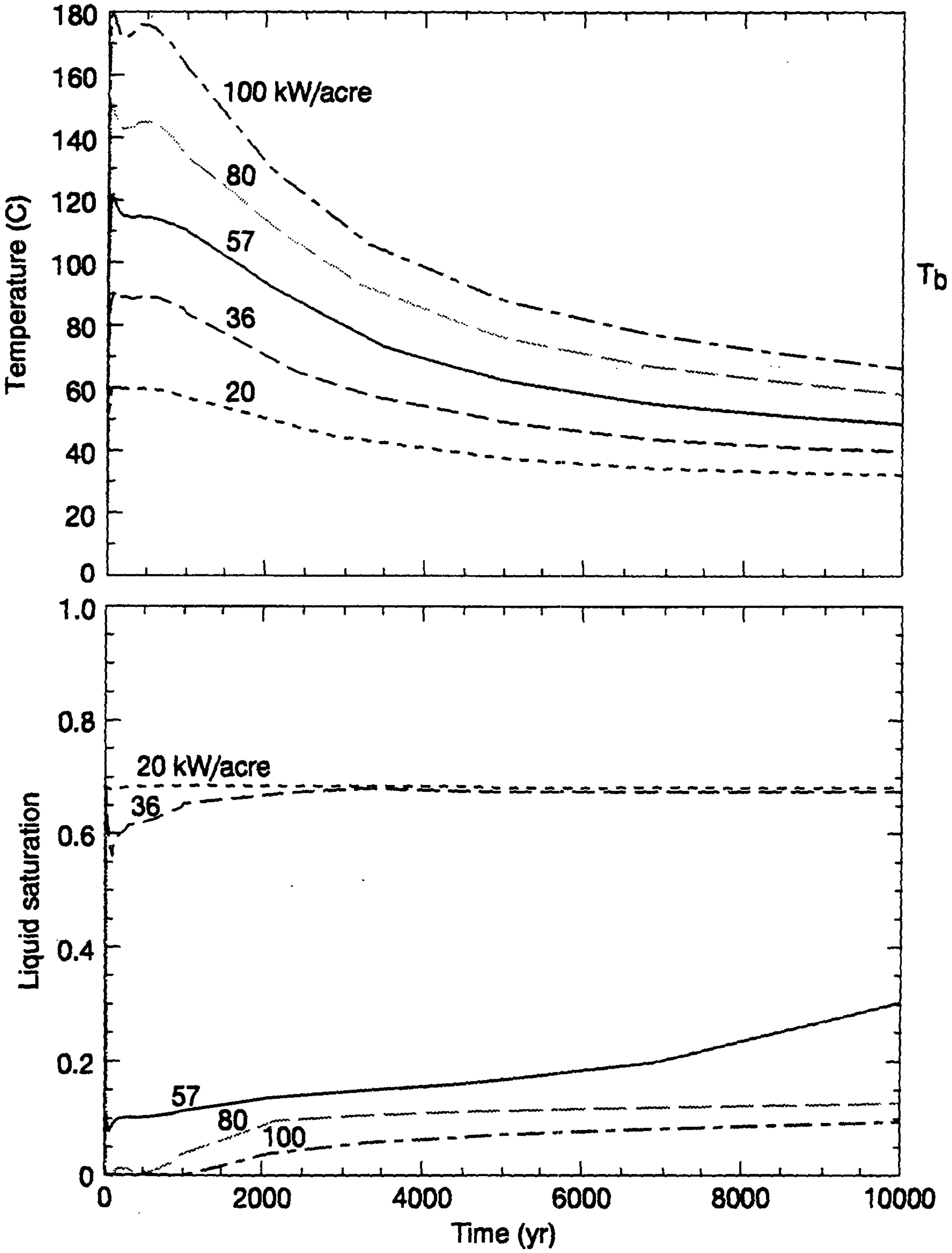
The moisture balance in the unsaturated zone (and above the repository) is affected by both ambient and repository-heat-driven processes



⊛ processes applicable to above-boiling conditions

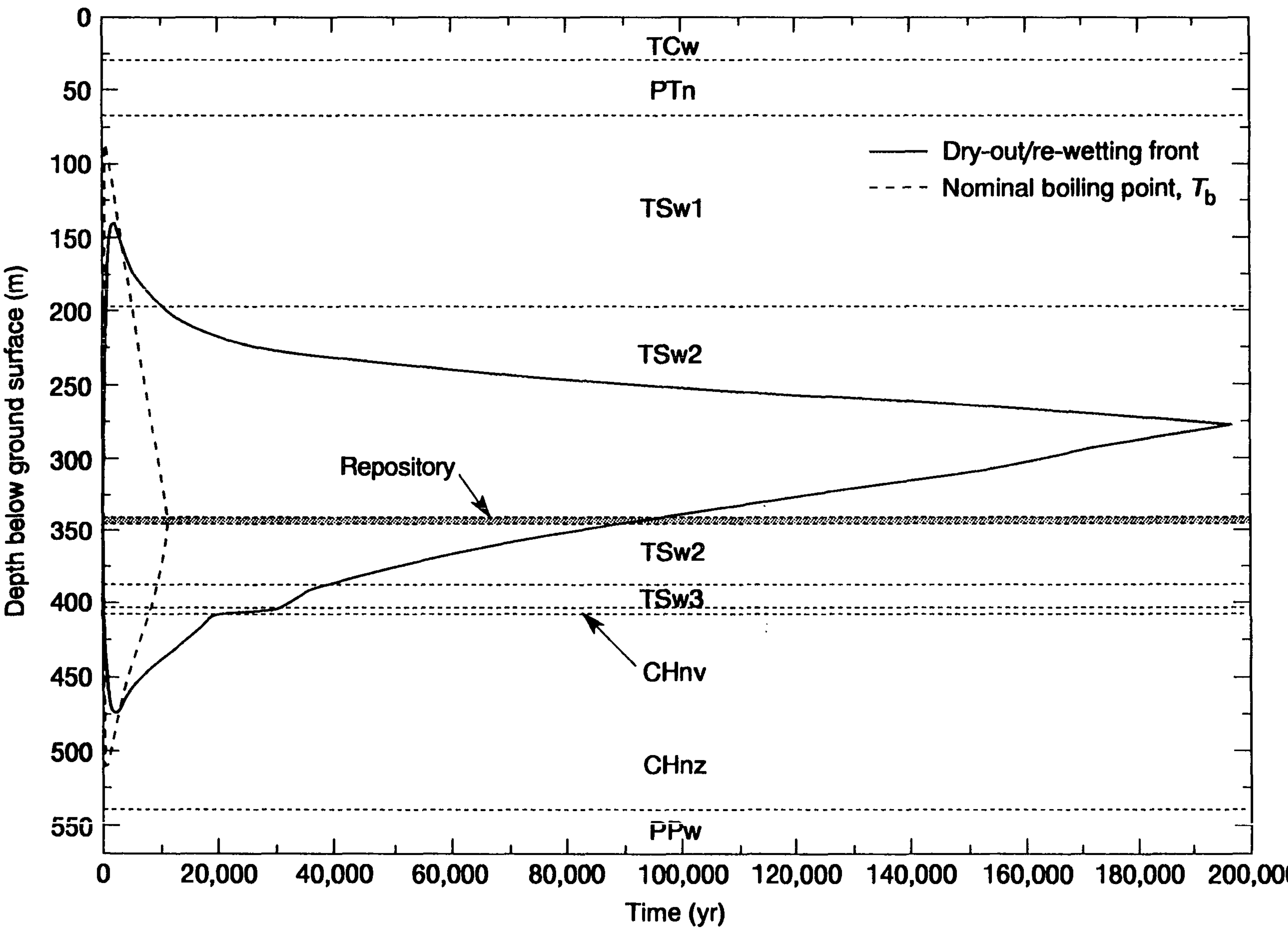
Dry steam boiling conditions persist at waste package environment for thousands of years for high APDs; For 30-yr-old fuel, the threshold APD for significant dry-out by boiling lies between 36 and 57 kW/acre

Temperature and liquid saturation history at drift wall at repository center for 30-yr-old fuel and a recharge flux of 0.0 mm/yr



The dry-out front closely follows the nominal boiling point, (T_b = 96°C), while the re-wetting front lags considerably behind T_b

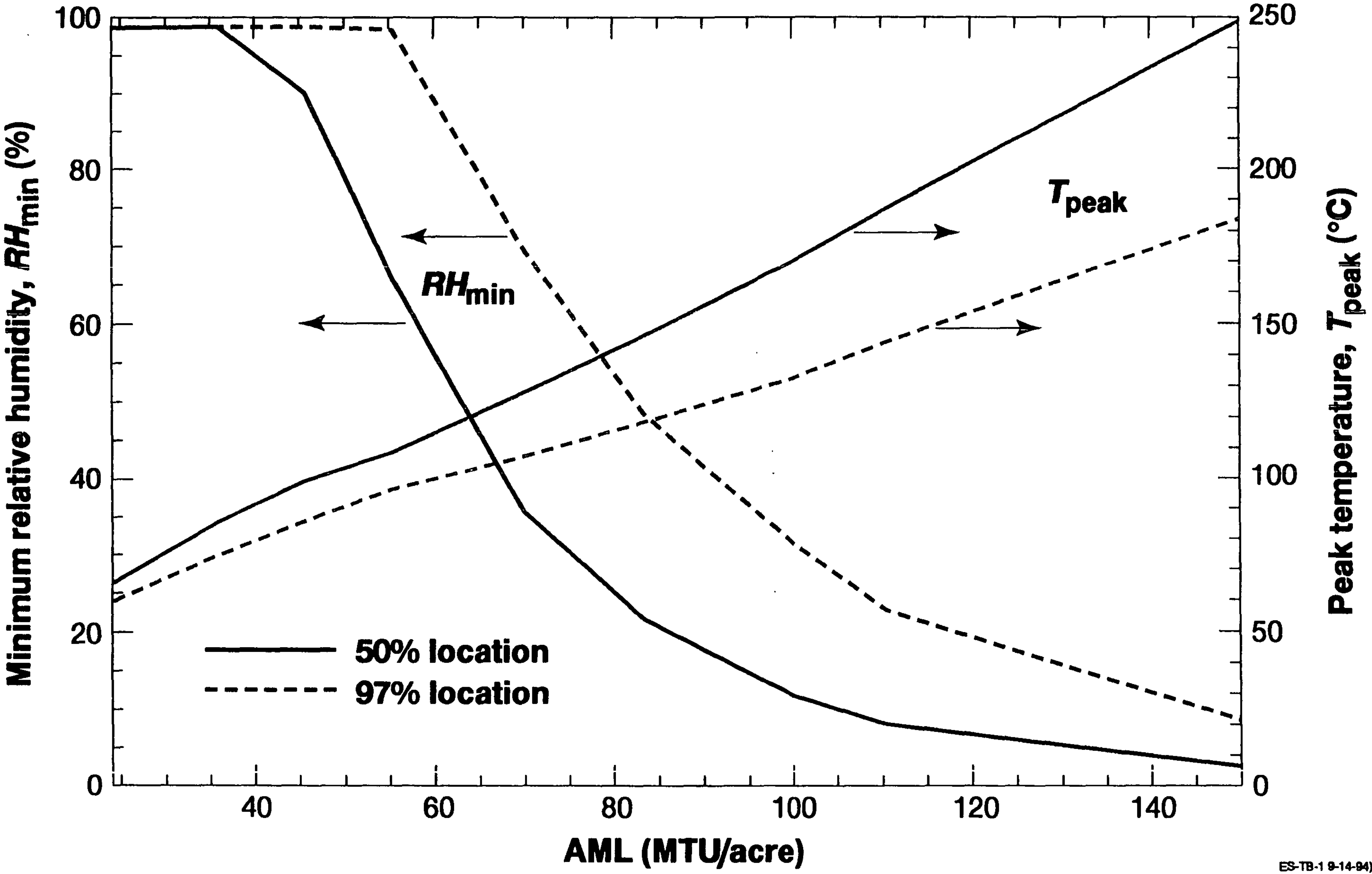
Time history of the vertical location of T_b and the dry-out/re-wetting front for 60-yr-old fuel, an APD of 114 kW/acre, and a recharge flux of 0.0 mm/yr



ES-TB-6 (6-1-92) IL

Minimum relative humidity and peak temperature depend on the location in the repository and Areal Mass Loading (AML)

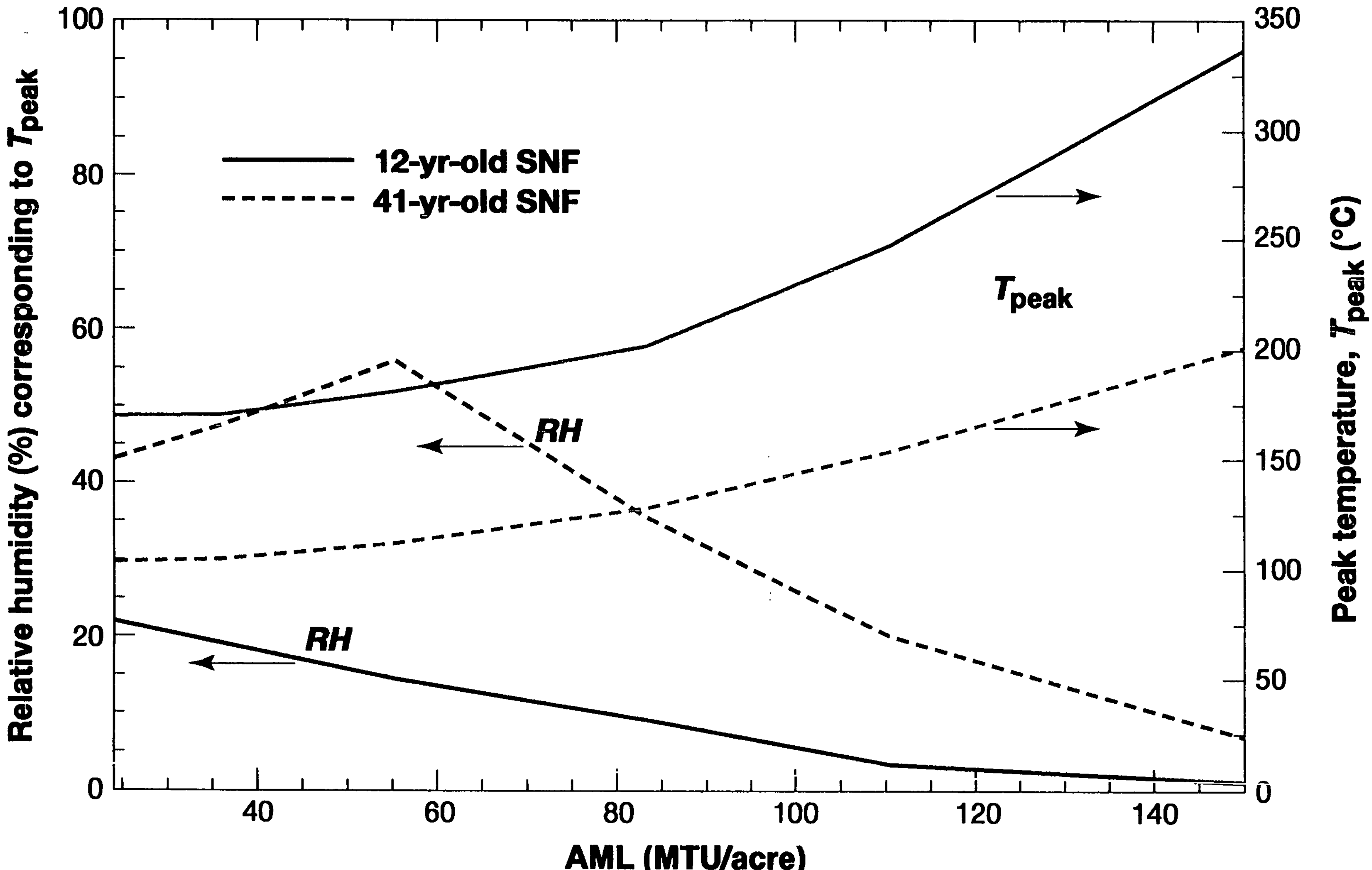
note that these curves are representative of average conditions
at the respective repository locations



ES-TB-1 9-14-94) VG

Peak temperature and corresponding relative humidity on the waste package depend on AML and the age of spent nuclear fuel (SNF)

note that the time to reach peak temperature varies significantly



ES-TB-2 9-17-94) VG

Above a threshold bulk permeability, the cooling effect of mountain-scale, buoyant, gas-phase convection begins to substantially reduce the duration of boiling conditions in the repository

area-weighted duration of the boiling period as a function of bulk permeability for AMLs of 49.2 and 154.7 MTU/acre. Note the time scales differ by a factor of 10

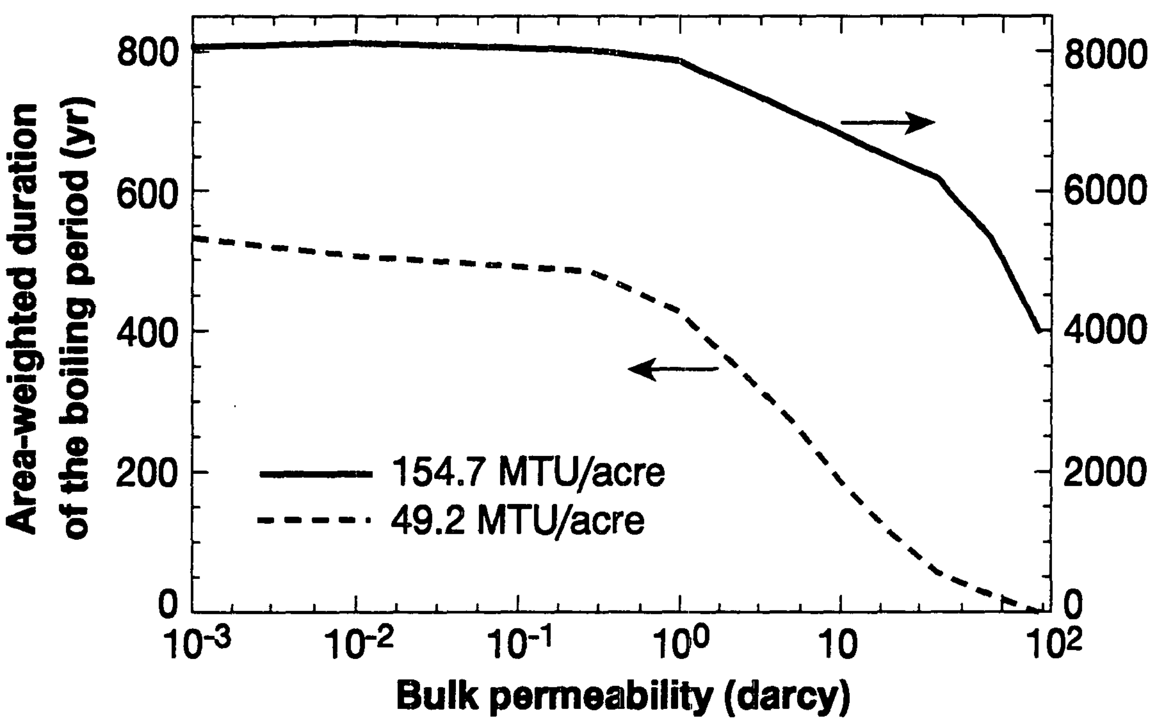


Table 3. Time to rewet to indicated relative humidity *RH* on WP, and WP temperature when that *RH* is attained for different AMLs and a binary gas-phase diffusion tortuosity factor τ_{eff} = 2.0, based on the drift-scale model. The heat generation is for a composite of 21-PWR WPs and 40-BWR WPs with 12-m WP spacing. Also, applicable to 12-PWR and 21-BWR WPs with 6.86-m WP spacing.

Table 3a AML = 24.2 MTU/acre; 99.0-m drift spacing.

SNF age (yr)	Time to rewet to indicated relative humidity (yr)				Temperature when indicated relative humidity is attained (°C)			
	60%	70%	80%	90%	60%	70%	80%	90%
41	210	440	760	2250	77.6	71.7	65.4	52.3
12	580	970	1710	3290	86.8	78.4	68.0	53.3

Table 3b AML = 35.9 MTU/acre; 66.8-m drift spacing.

SNF age (yr)	Time to rewet to indicated relative humidity (yr)				Temperature when indicated relative humidity is attained (°C)			
	60%	70%	80%	90%	60%	70%	80%	90%
41	230	490	990	1890	87.8	83.1	76.7	65.2
12	710	1160	2280	6720	105.0	94.5	75.7	48.4

Table 3c AML = 55.3 MTU/acre; 43.4-m drift spacing.

SNF age (yr)	Time to rewet to indicated relative humidity (yr)				Temperature when indicated relative humidity is attained (°C)			
	60%	70%	80%	90%	60%	70%	80%	90%
41	300	800	1550	5920	106.5	102.9	90.5	54.2
12	1900	6360	17,260	38,600	103.0	57.2	39.8	28.5

Table 3d AML = 110.5 MTU/acre; 21.7-m drift spacing.

SNF age (yr)	Time to rewet to indicated relative humidity (yr)				Temperature when indicated relative humidity is attained (°C)			
	60%	70%	80%	90%	60%	70%	80%	90%
41	7360	14,250	24,860	42,120	69.8	56.2	45.1	35.8
12	15,120	21,570	29,500	38,420	62.0	52.5	44.9	36.9

Table 2. Time to rewet to indicated relative humidity *RH* on WP, and WP temperature when that *RH* is attained for different AMLs and a binary gas-phase diffusion tortuosity factor τ_{eff} = 0.2, based on the drift-scale model. The heat generation is for a composite of 21-PWR WPs with 12-m WP spacing. Also, applicable to 12-PWR and 21-BWR WPs with 6.86-m WP spacing.

Table 2a AML = 24.2 MTU/acre; 99.0-m drift spacing.

SNF age (yr)	Time to rewet to indicated relative humidity (yr)				Temperature when indicated relative humidity is attained (°C)			
	60%	70%	80%	90%	60%	70%	80%	90%
41	90	220	640	2110	87.5	77.0	70.0	54.1
12	220	300	600	2320	116.8	108.7	101.7	94.8

Table 2b AML = 35.9 MTU/acre; 66.8-m drift spacing.

SNF age (yr)	Time to rewet to indicated relative humidity (yr)				Temperature when indicated relative humidity is attained (°C)			
	60%	70%	80%	90%	60%	70%	80%	90%
41	70	150	420	1440	98.6	91.2	85.8	72.7
12	590	880	1180	1740	110.5	103.7	95.4	84.7

Table 2c AML = 55.3 MTU/acre; 43.4-m drift spacing.

SNF age (yr)	Time to rewet to indicated relative humidity (yr)				Temperature when indicated relative humidity is attained (°C)			
	60%	70%	80%	90%	60%	70%	80%	90%
41	90	580	1010	1550	110.6	106.5	101.1	92.3
12	1710	8890	16,770	27,640	112.3	62.5	45.9	36.3

Table 2d AML = 110.5 MTU/acre; 21.7-m drift spacing.

SNF age (yr)	Time to rewet to indicated relative humidity (yr)				Temperature when indicated relative humidity is attained (°C)			
	60%	70%	80%	90%	60%	70%	80%	90%
41	17,180	23,190	28,720	34,260	52.3	46.2	42.2	38.2
12	20,120	23,110	26,100	29,100	53.4	50.5	47.6	44.7

Table 1. Peak temperature and corresponding relative humidity on the WP during the indicated time period for different AMLs and a binary gas-phase diffusion tortuosiy factor $\tau_{eff} = 0.2$, based on the drift-scale model. The heat generation is for a composite of 21-PWR WPs and 40-BWR WPs with 12-m WP spacing. Also, applicable to 12-PWR and 21-BWR WPs with 6.86-m WP spacing.

Table 1a. AML = 24.2 MTU/acre; 99.0-m drift spacing.

SNF age	Peak temperature during indicated time period (°C)			Relative humidity corresponding to peak temperature (%)		
(yr)	0-30 yr	30-100 yr	100-1000 yr	0-30 yr	30-100 yr	100-1000 yr
41	103.8	100.4	85.0	43.3	49.5	61.8
12	170.5	160.4	123.9	8.9	14.4	36.2

Table 1b. AML = 35.9 MTU/acre; 66.8-m drift spacing.

SNF age	Peak temperature during indicated time period (°C)			Relative humidity corresponding to peak temperature (%)		
(yr)	0-30 yr	30-100 yr	100-1000 yr	0-30 yr	30-100 yr	100-1000 yr
41	104.9	103.4	94.5	43.7	50.8	65.1
12	170.7	165.7	137.1	11.2	12.6	26.9

Table 1c. AML = 55.3 MTU/acre; 43.4-m drift spacing.

SNF age	Peak temperature during indicated time period (°C)			Relative humidity corresponding to peak temperature (%)		
(yr)	0-30 yr	30-100 yr	100-1000 yr	0-30 yr	30-100 yr	100-1000 yr
41	111.5	112.0	109.0	54.8	55.9	62.8
12	181.6	179.6	150.3	8.8	9.5	20.1

Table 1d. AML = 110.5 MTU/acre; 21.7-m drift spacing.

SNF age	Peak temperature during indicated time period (°C)			Relative humidity corresponding to peak temperature (%)		
(yr)	0-30 yr	30-100 yr	100-1000 yr	0-30 yr	30-100 yr	100-1000 yr
41	136.3	143.1	153.8	29.2	25.1	18.9
12	240.1	247.5	237.6	3.5	3.2	3.7

Table 1. Time required to rewet to indicated relative humidity at various repository locations, and temperature when that value of relative humidity is attained for 22.5-yr-old SNF. Locations are identified as the percentage of the repository area enclosed, with 0% corresponding to the repository center, and 100% corresponding to the edge.

Table 1a. AML = 55.3 MTU/acre.

Repository area enclosed (%)	Time to rewet to indicated relative humidity (yr)				Temperature when indicated relative humidity is attained (°C)			
	70%	80%	90%	95%	70%	80%	90%	95%
50	670	1660	3330	4630	106.7	97.2	79.9	72.2
75	410	940	1610	2280	106.7	99.4	88.8	80.5
90	NA[a]	200	380	490	NA[a]	102.5	97.3	94.8
97	NA[a]	NA[a]	NA[a]	NA[a]	NA[a]	NA[a]	NA[a]	NA[a]

Table 1b. AML = 110.5 MTU/acre.

Repository area enclosed (%)	Time to rewet to indicated relative humidity (yr)				Temperature when indicated relative humidity is attained (°C)			
	70%	80%	90%	95%	70%	80%	90%	95%
50	15,960	27,910	40,990	49,980	67.7	54.2	45.3	41.7
75	9540	15,520	24,950	32.590	75.5	63.5	53.3	47.7
90	3190	4890	7460	9890	93.1	82.0	73.4	67.9
97	1410	1810	2360	2890	106.4	100.7	93.3	87.7

Table 1c. AML = 150.0 MTU/acre.

Repository area enclosed (%)	Time to rewet to indicated relative humidity (yr)				Temperature when indicated relative humidity is attained (°C)			
	70%	80%	90%	95%	70%	80%	90%	95%
50	20,630	34,850	50,920	64,150	67.8	52.3	44.5	40.8
75	16,400	24,520	32,700	43,360	70.1	59.1	50.9	46.1
90	8660	12,090	16,520	19,780	80.9	72.0	64.1	59.1
97	4330	6020	8180	10,060	92.7	84.3	76.8	72.2

Table 1d. nonuniform, optimized AML = 128.4 MTU/acre.

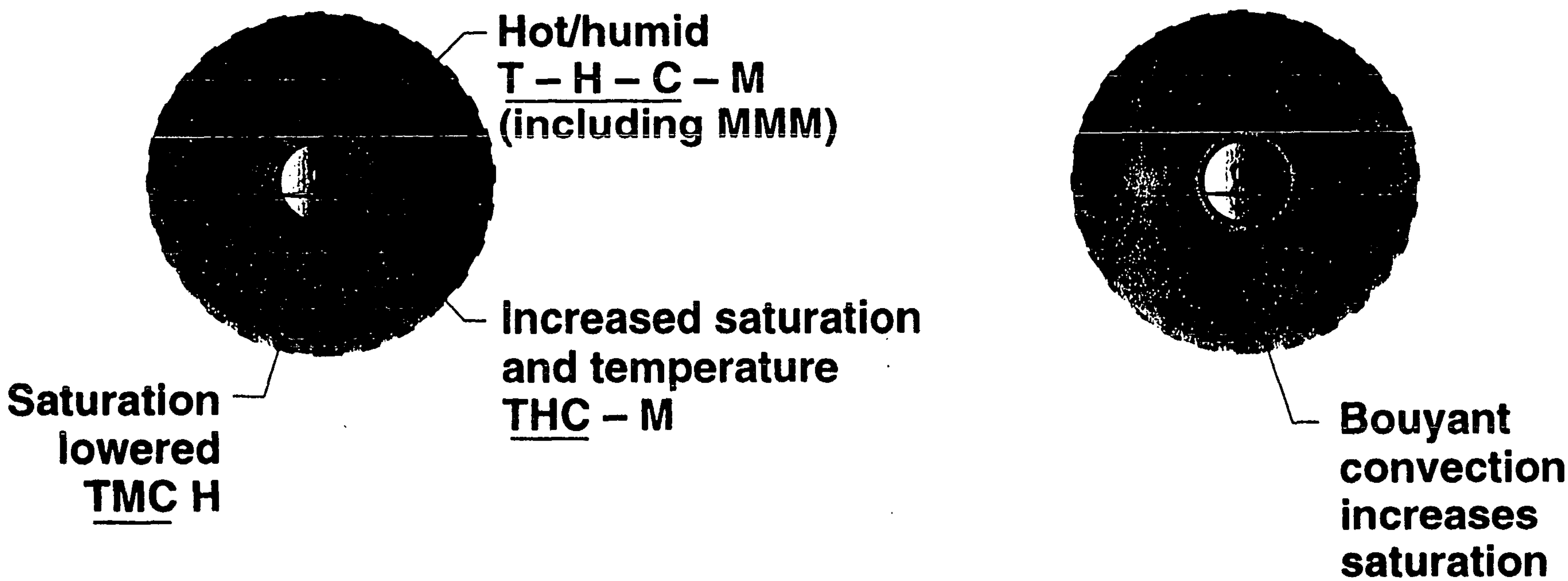
Repository area enclosed (%)	Time to rewet to indicated relative humidity (yr)				Temperature when indicated relative humidity is attained (°C)			
	70%	80%	90%	95%	70%	80%	90%	95%
50	17,860	32,330	49,080	61,000	66.9	50.7	49.2	38.7
75	14,820	25,470	37,760	44,290	69.2	55.2	46.8	43.8
90	10,470	15,280	21,040	28,070	75.5	65.8	57.7	51.2
97	6330	8830	11,710	14,380	84.6	76.6	69.7	64.9

[a] Not Applicable; relative humidity always greater than indicated value.

Ambient conditions dominate:

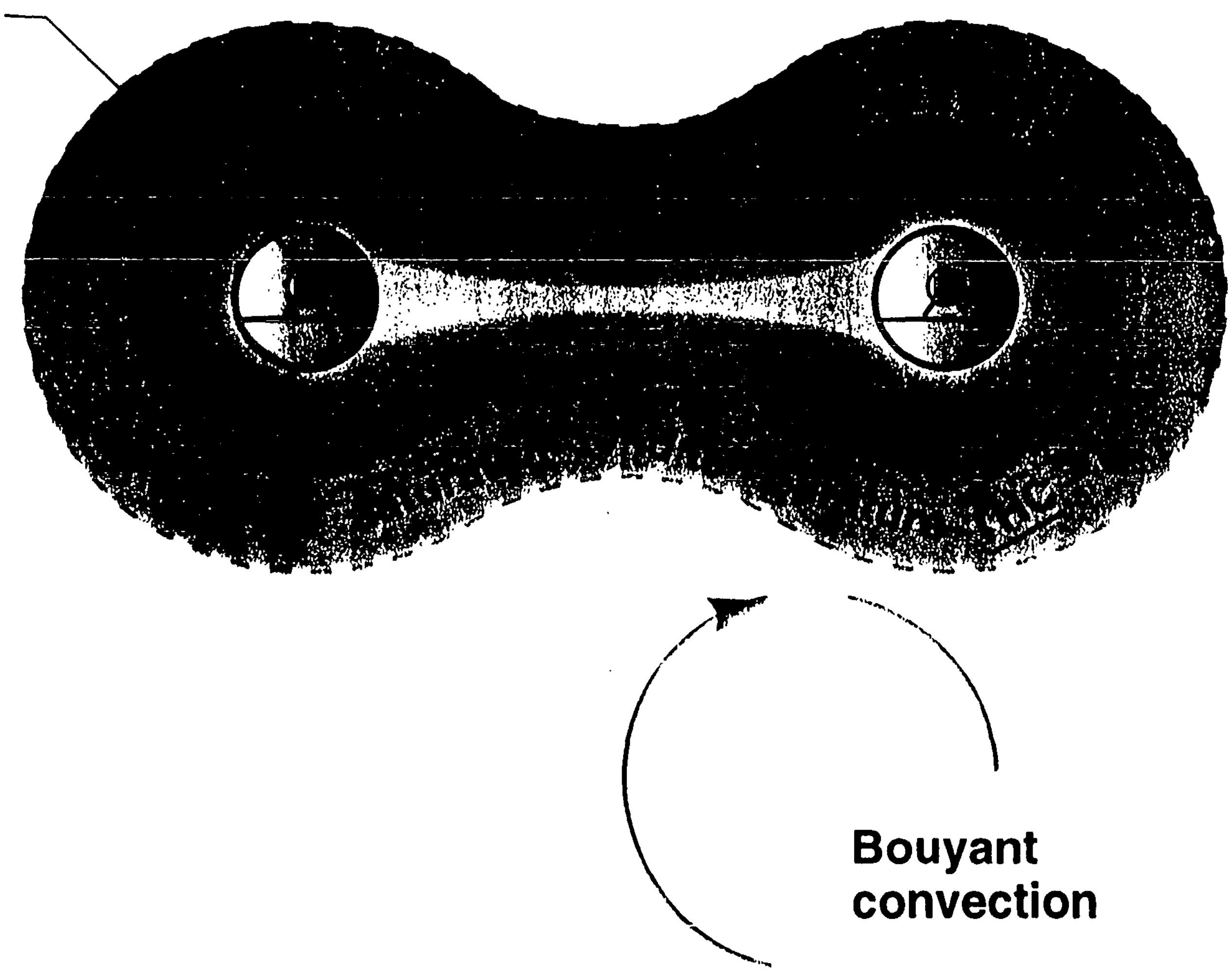
Typical of early (1-2 yrs) for high AML's or both early and longer term for low AML's

Ambient conditions

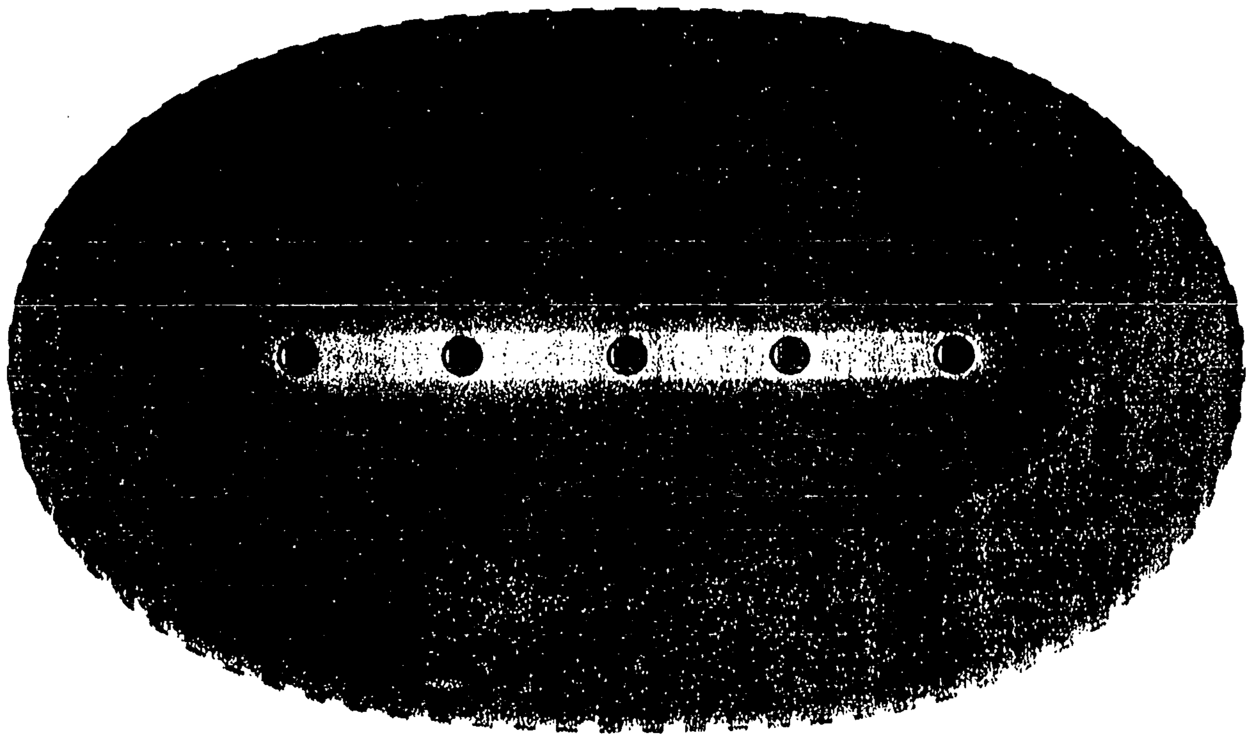


Intermediate conditions (20-100 yrs high AMLs)

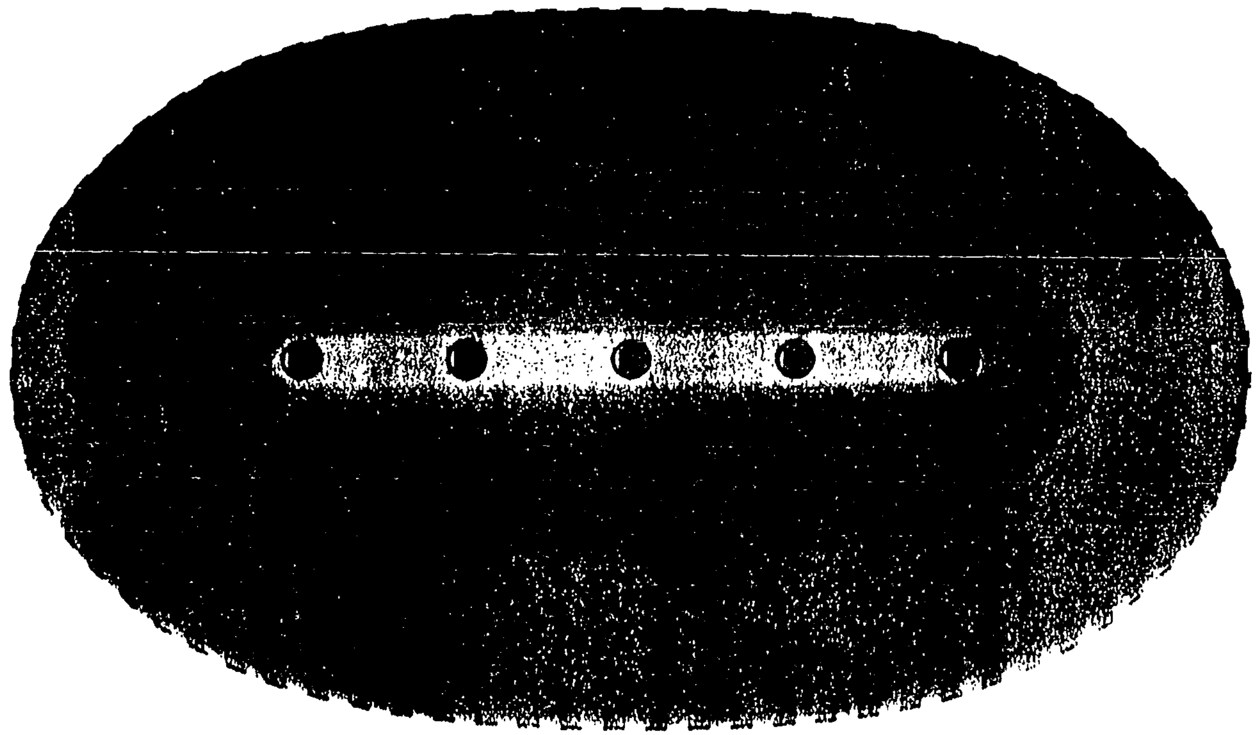
Hot/ambient saturations THC – M



Long term – higher AMLs (100's to 1000's years)

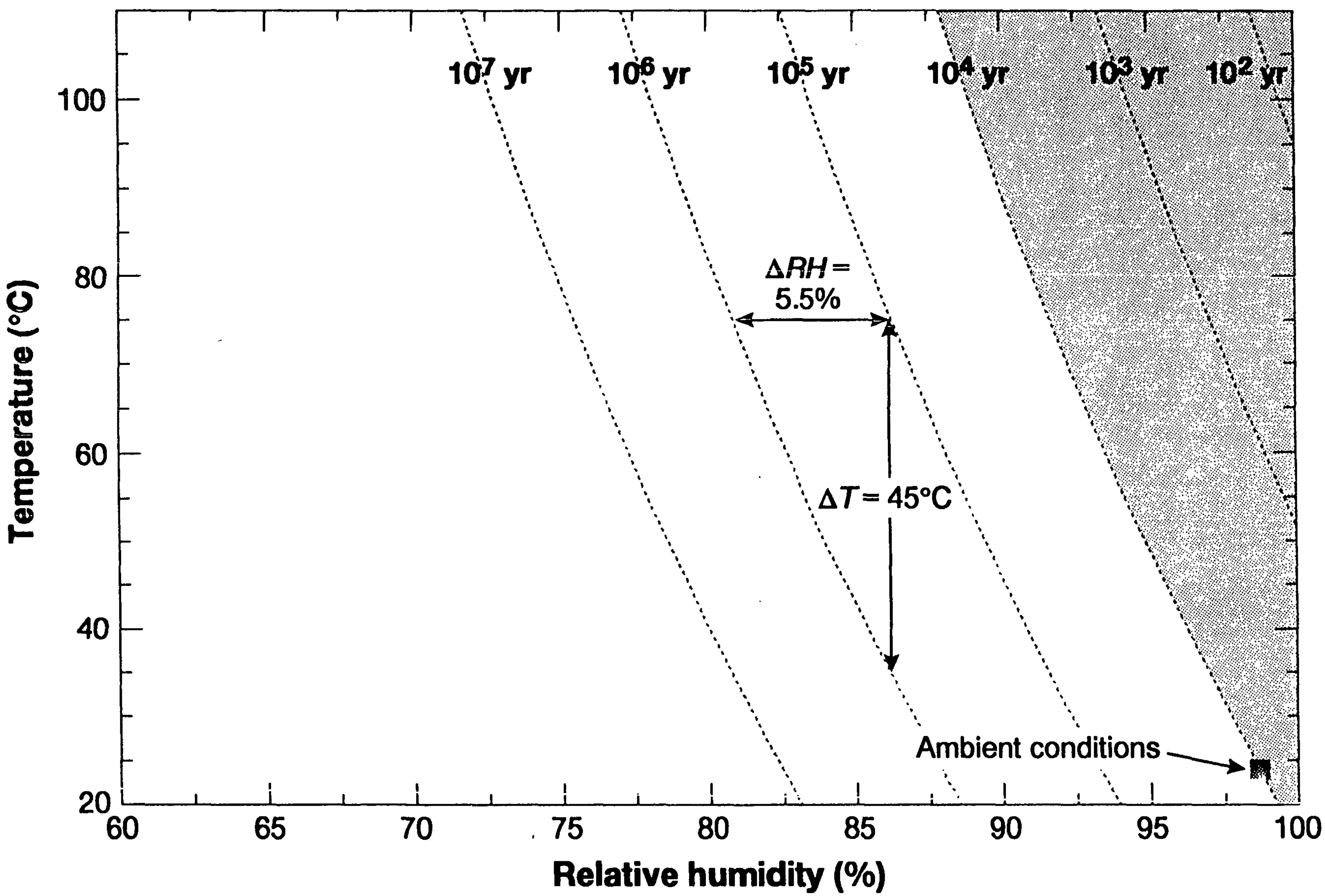


Very long term (1000's to 100,000's years) higher AMLs



WP corrosion depends strongly on *T* and *RH*

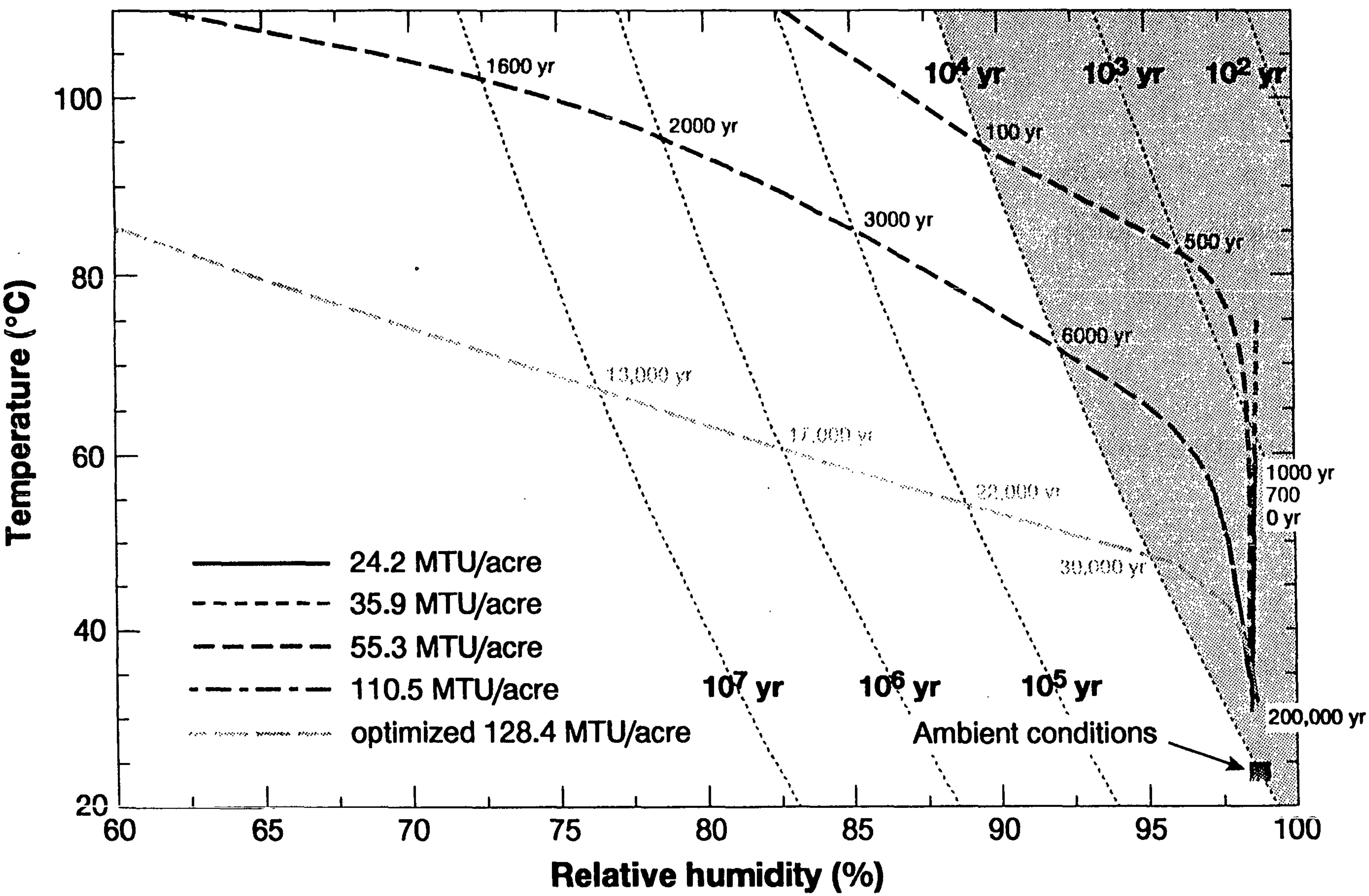
Time required to penetrate 1 cm of the WP, based on corrosion model of Stahl et al. (1994)



ES-TB-8 (10-13-94) mccoy.plt

At the repository edge, WP corrosion rate decreases with increasing AML (with an optimized-high-AML distribution yielding the greatest reduction)

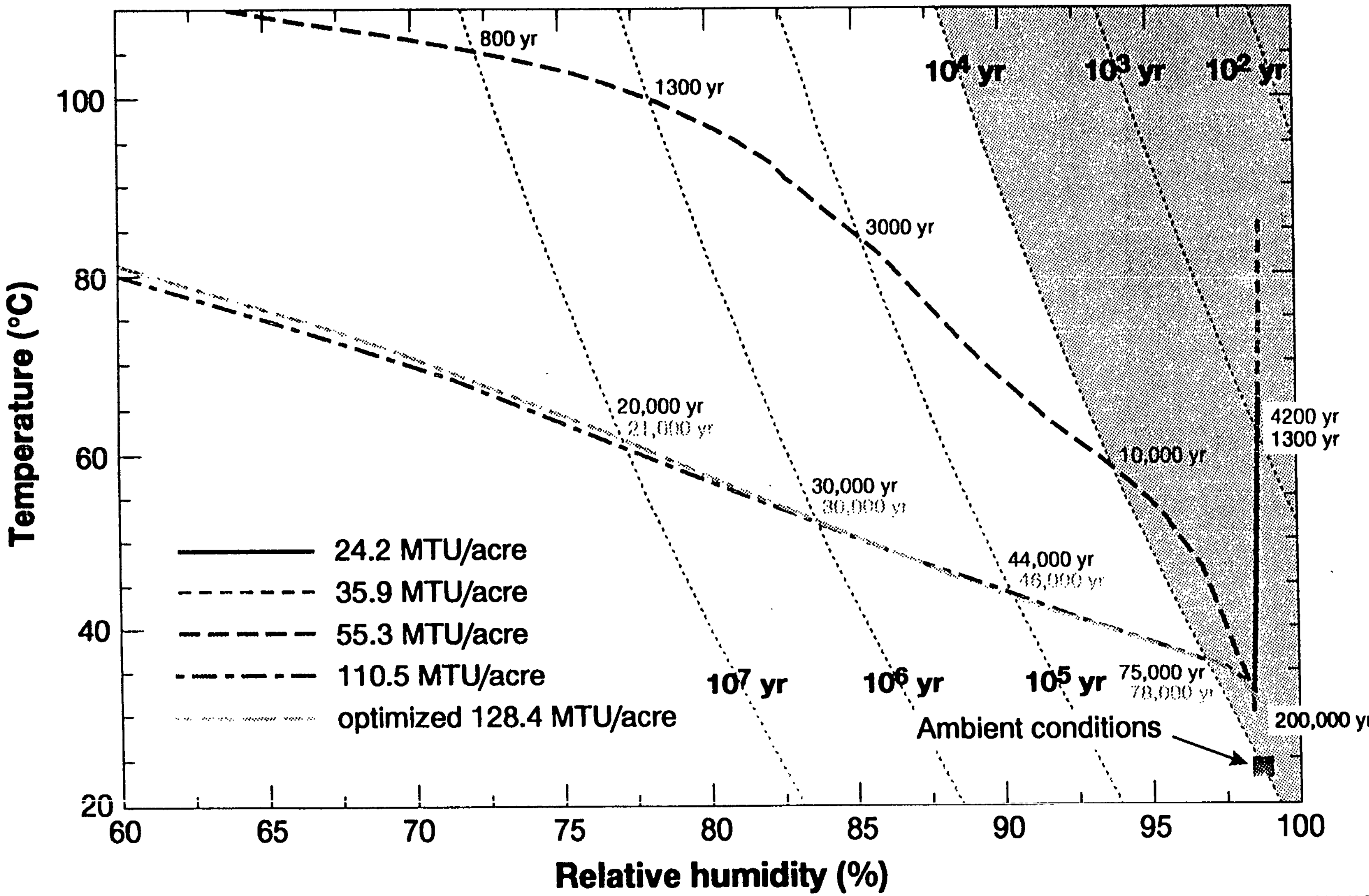
T and *RH* near the repository edge (97% location) for various AML distributions



ES-TB-7 (10-13-94) trhcmp.97

WP corrosion rate decreases with increasing AML; this trend levels off at 110 MTU/acre for the interior of the repository

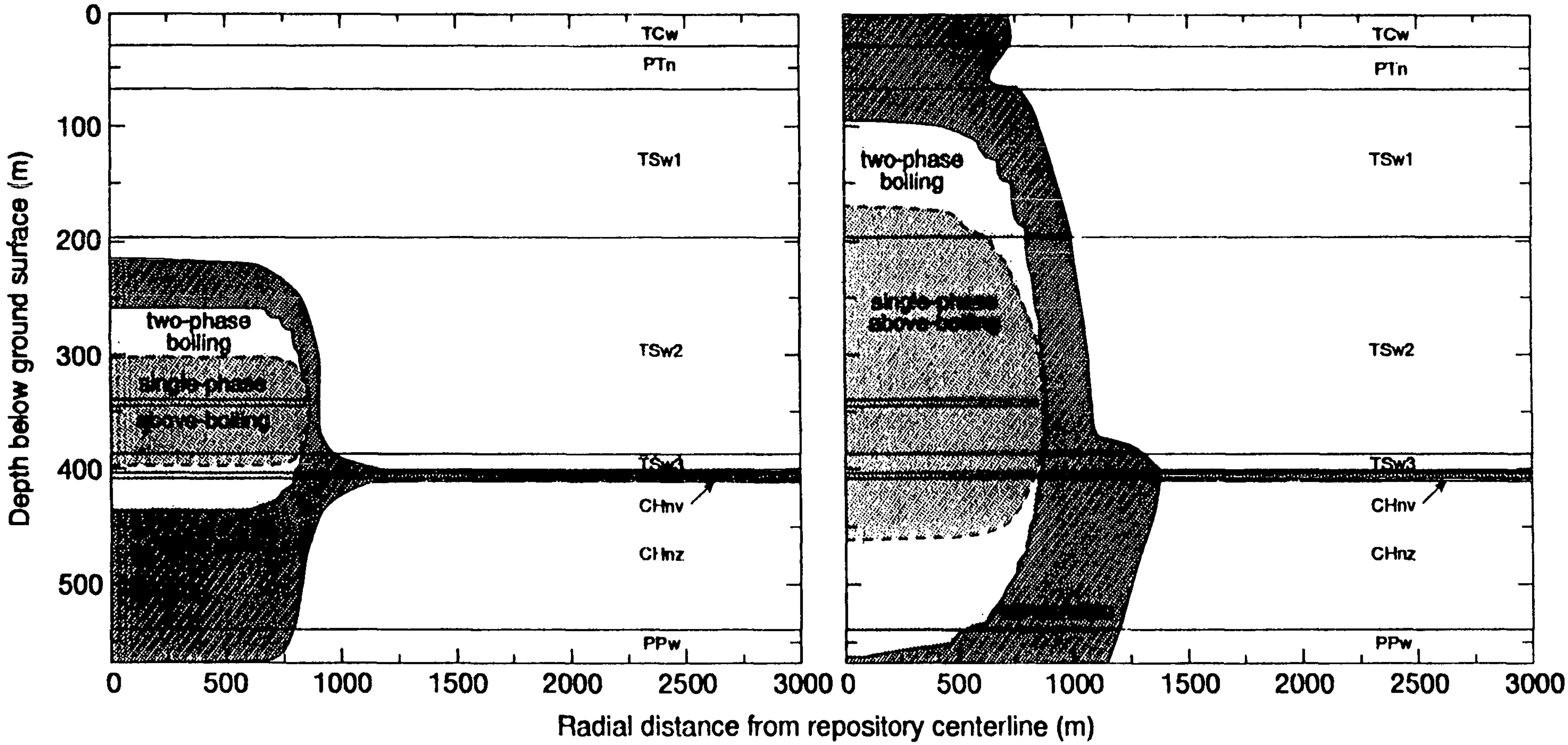
T and *RH* in the inner half of the repository (50% location) for various AML distributions



ES-TB-6 (10-13-94) trhomp.50

Repository heating can result in a single-phase above-boiling zone, a two-phase boiling zone, and a condensate zone

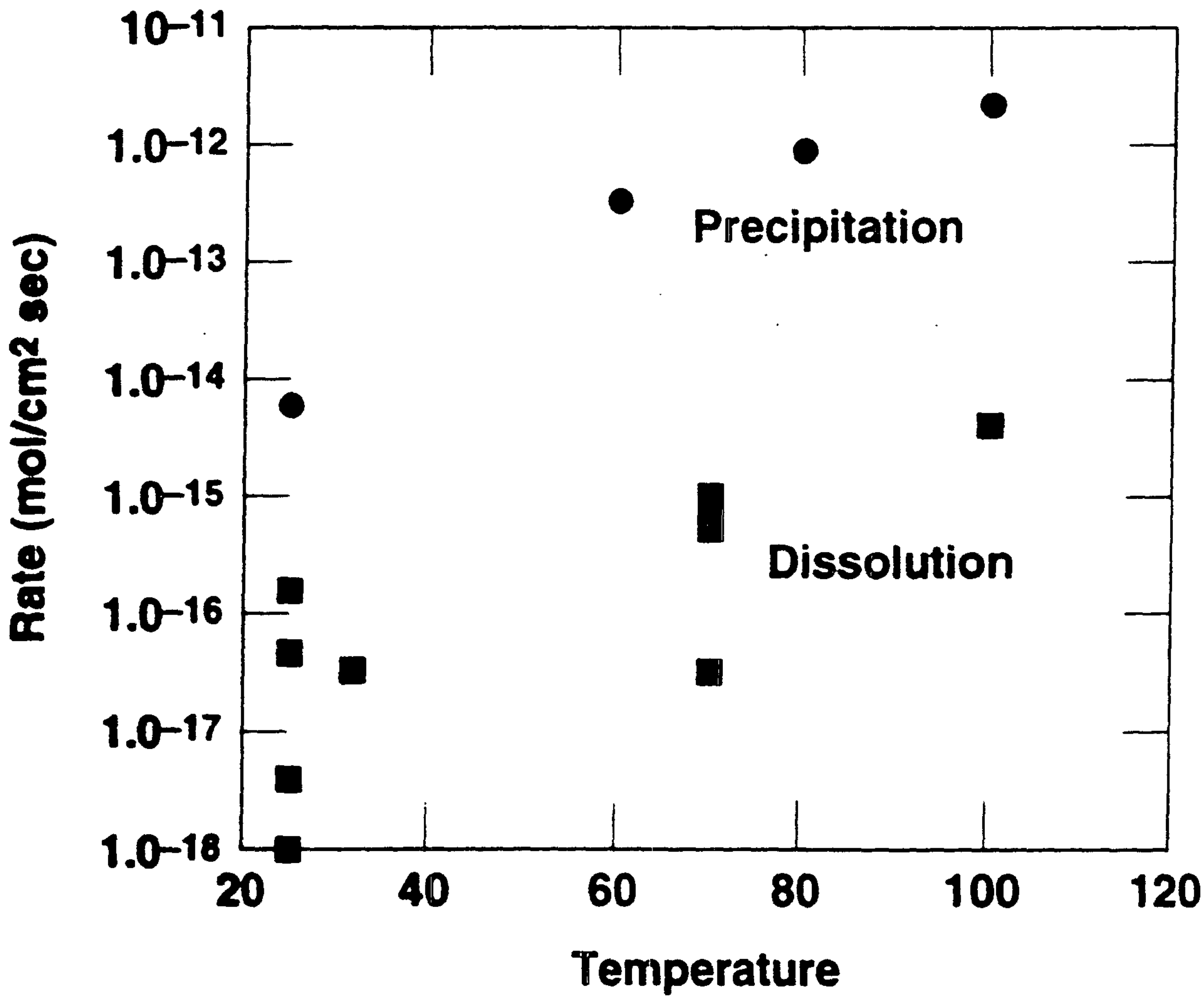
dimensionless liquid saturation contours for 30-yr-old SNF, an APD of 114 kW/acre, and a AML of 154.7 MTU/acre



t = 100 yr **t = 1000 yr**

ES-TB-5ab (6-22-93) fL

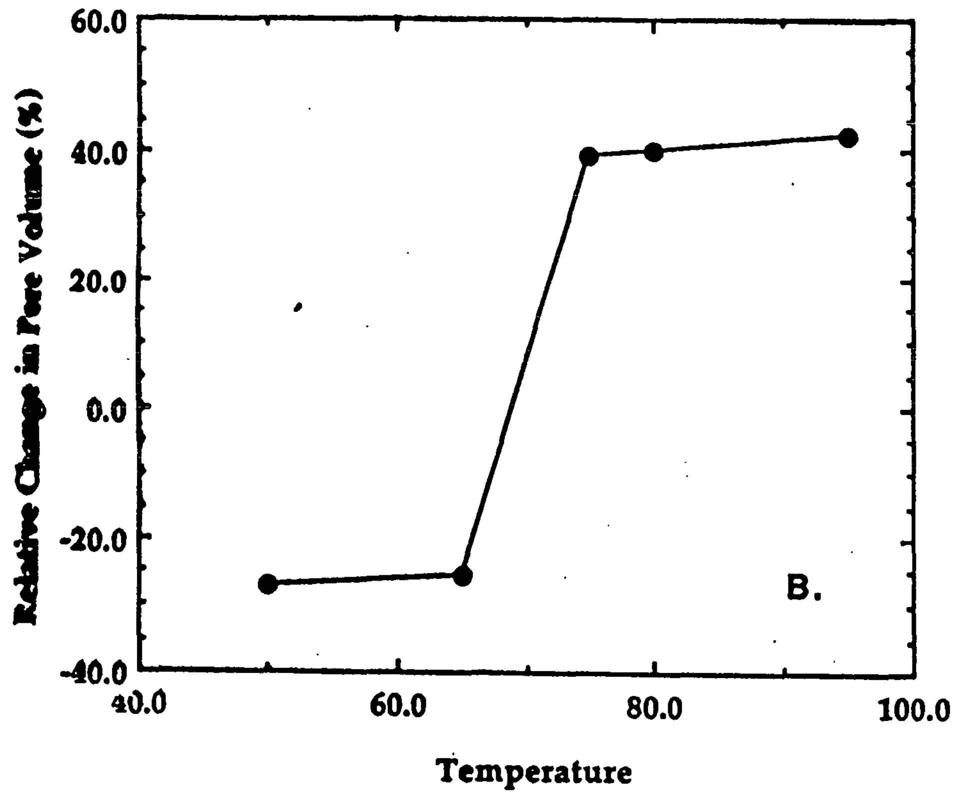
Comparison of measured rates of dissolution and precipitation

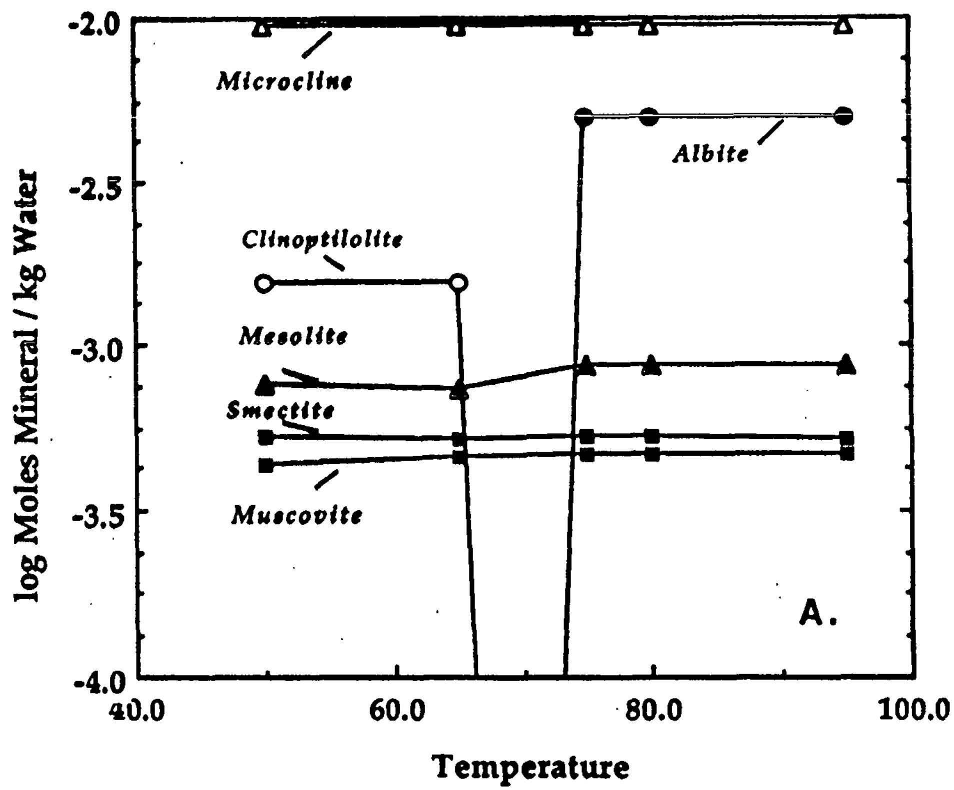


IMPACT ON HYDROLOGY OF EQUILIBRIUM

- **Model porosity change through changes in mineral volumes.**

  - J-13 water, Tpt mineralogy (using approach of Delany, 1985)





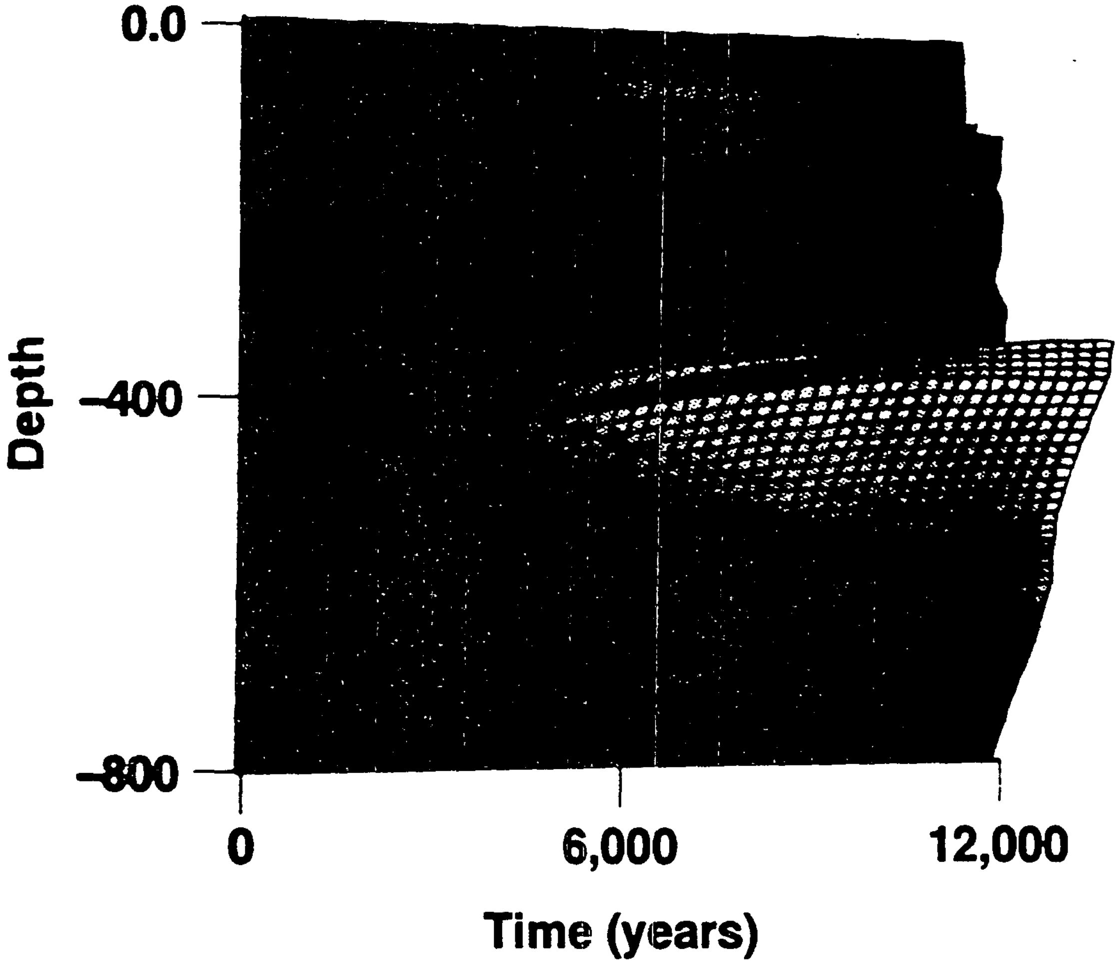
EQUILIBRIUM AND KINETICS IN THE ALTERED ZONE

- Evolution is slower than in near-field.
- Consider cumulative time at temperature, vs. time required to achieve equilibrium (example using Rimstidt and Barnes, 1980 rate):

$$R_I = t / [\, 5 / (\, 10^{(-0.707 - 2598.0 / T)}\,) / (\, SA / M)]$$

- Values of R_I greater than 1.0 indicate where available time exceeds by the computed factor the amount of time necessary to achieve equilibrium.

Is time sufficient to achieve equilibrium for SiO_2 precipitation?



Duration of 60°–100°C period, compared to time required to achieve equilibrium for SiO_2 precipitation (114 Kw/acre APD).

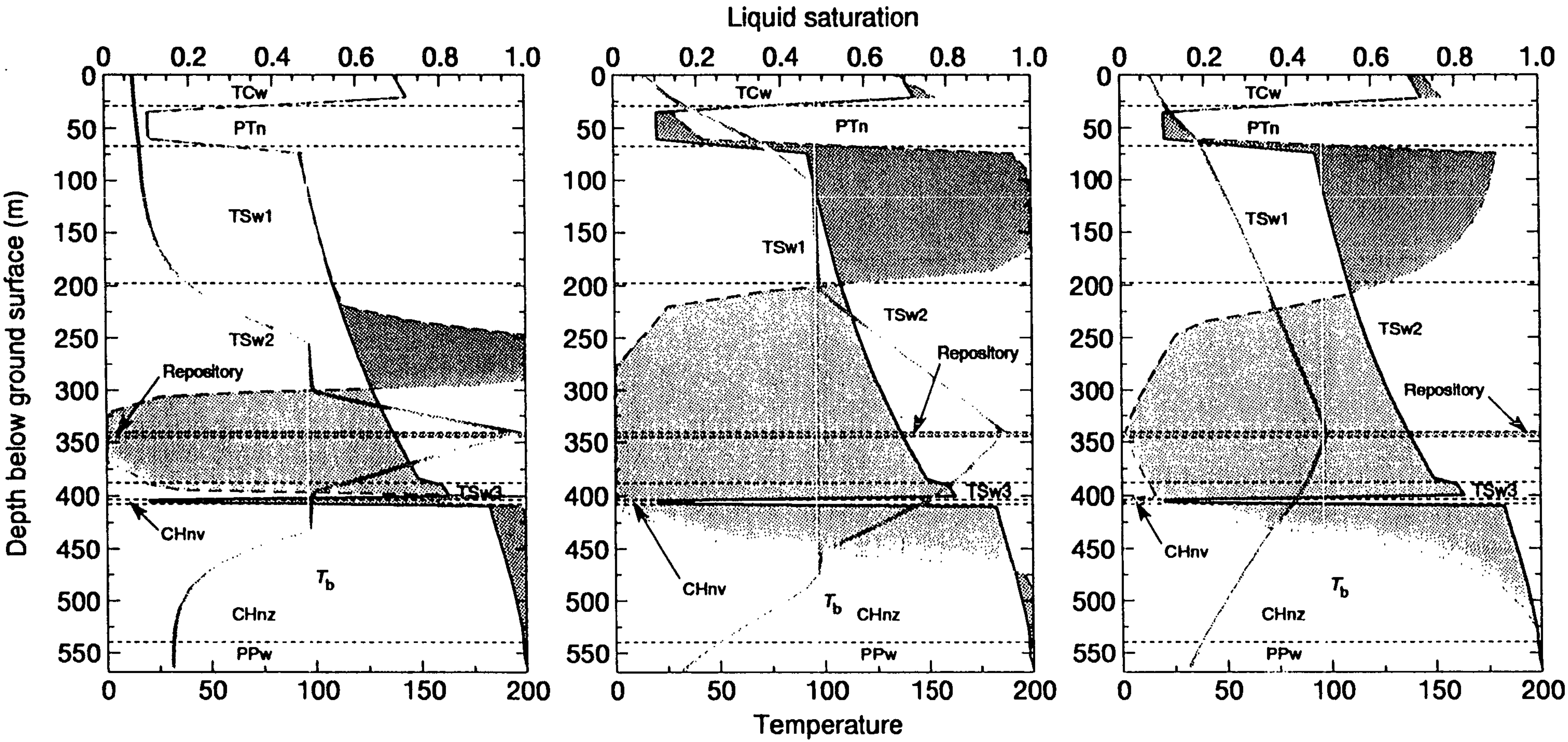
CONCLUSIONS REGARDING COUPLED PROCESSES IN THE ALTERED ZONE

- With the exception of regions near waste packages where fluid velocities are high, preliminary results suggest chemical and mineralogical equilibrium will probably be achieved in most areas

- In regions where equilibrium may be achieved, changes in porosity may be on the order of several tens of percent, but are sensitive to temperature , initial mineralogy, and water chemistry.

The dry-out front closely corresponds to the nominal boiling point; the condensate zone results in re-fluxing above the dry-out zone

Vertical liquid saturation and temperature profiles at the repository center for 30-yr-old fuel, an APD of 114 kW/acre, and a recharge flux of 0.0 mm/yr

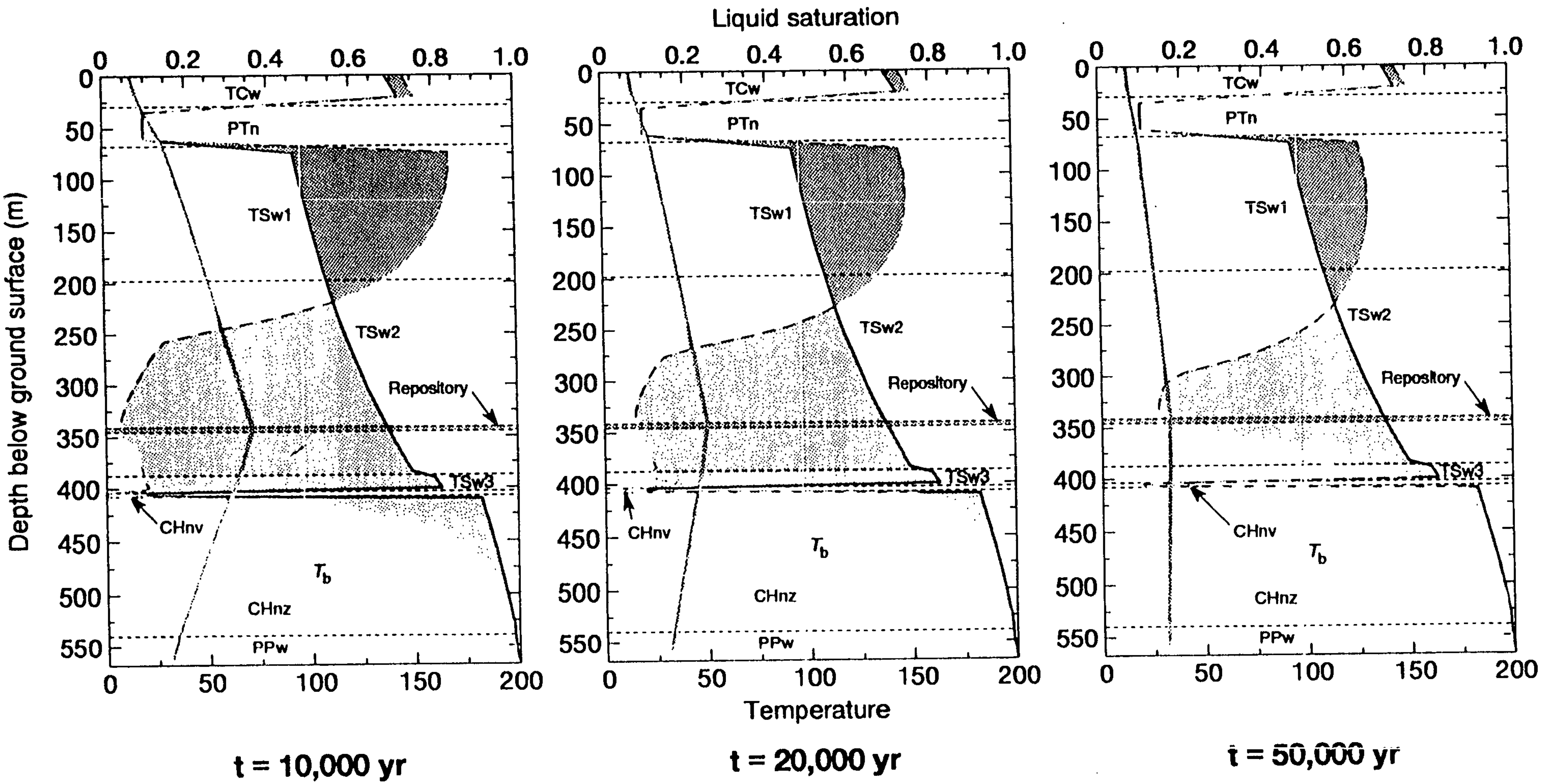


t = 100 yr **t = 1000 yr** **t = 5000 yr**

ES-TB-12abc (6-6-92) IL

The re-wetting front lags considerably behind the nominal boiling point; the dry-out zone persists long after boiling ceases

Vertical liquid saturation and temperature profiles at the repository center for 30-yr-old fuel, an APD of 114 kW/acre, and a recharge flux of 0.0 mm/yr



ES-TB-14abc (6-6-92) IL

There are two fundamental (temporal and spatial) regimes for repository-heat-altered flow and transport processes

Heat-driven flow regime: the regime for which repository heat significantly drives gas- and liquid-phase flow

Heat-altered property regime: the regime for which the intrinsic flow and transport properties have been significantly altered by repository heat

The *heat-altered property regime* continues after the *heat-driven flow regime* ceases

The temporal and spatial extent of the *heat-altered property regime* in the SZ depend on site properties and thermal design

For both the MD and ED repository concepts, the primary factors include:

- the spatial extent of the heat-driven flow regime
- the repository depth below ground surface
- the standoff between the repository and the water table
- the total emplaced inventory of SNF

The temporal and spatial extent of this regime is less sensitive to the Areal Mass Loading (AML), SNF aging, and drift ventilation

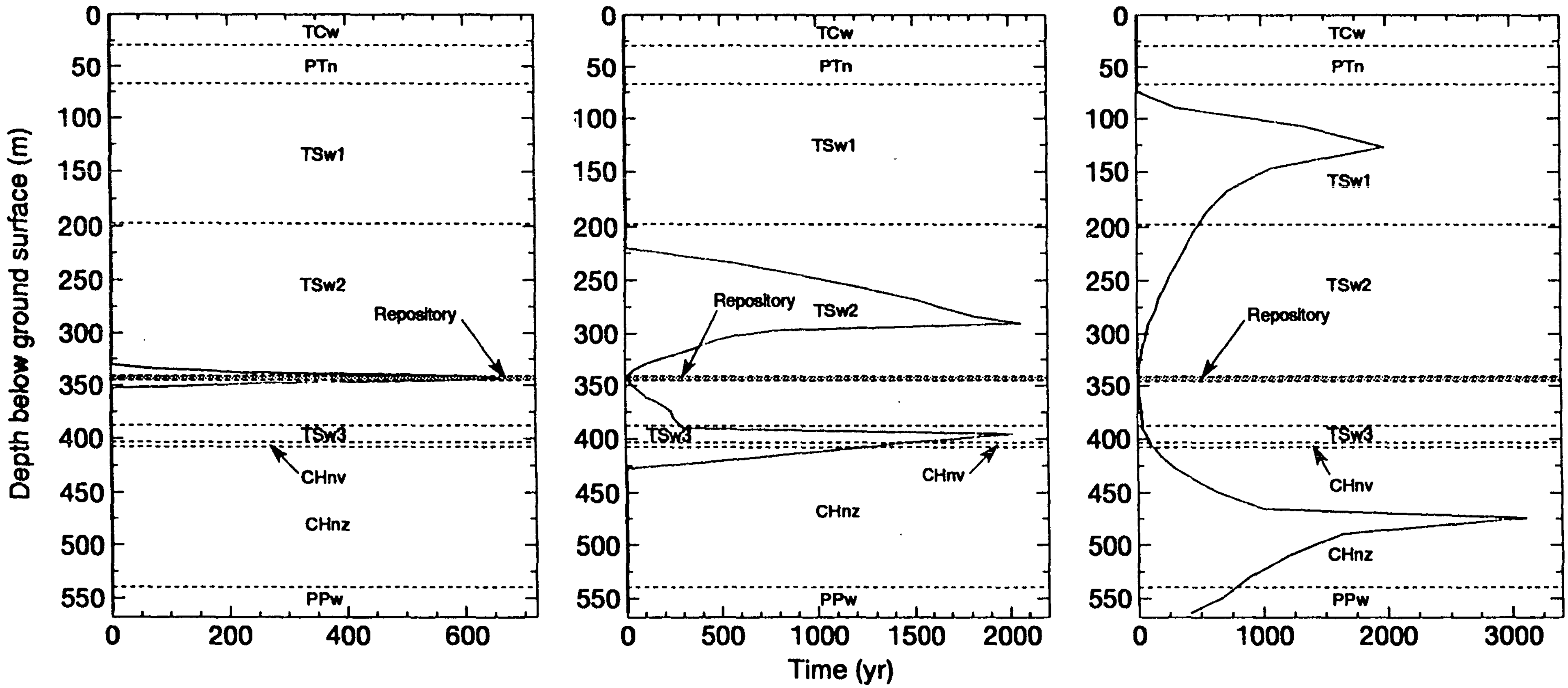
The temporal and spatial extent of the *heat-driven flow regime* in the SZ depend on site properties and thermal design

For both the MD and ED repository concepts, the primary factors include:

- the repository depth below ground surface
- the standoff between the repository and the water table
- the total emplaced inventory of SNF

The temporal and spatial extent of this regime is less sensitive to the Areal Mass Loading (AML), SNF aging, and drift ventilation

The duration of time between 95.9° and 100.4°C along the repository centerline for AMLs of 49.2, 77.4, and 154.7 MTU/acre, a k_b of 280 millidarcy, a net recharge flux of 0 mm/yr, RIB Version 4 K_{th} data, including hydrothermal flow in the saturated zone



49.2 MTU/acre
10-yr-old SNF; 57 kW/acre

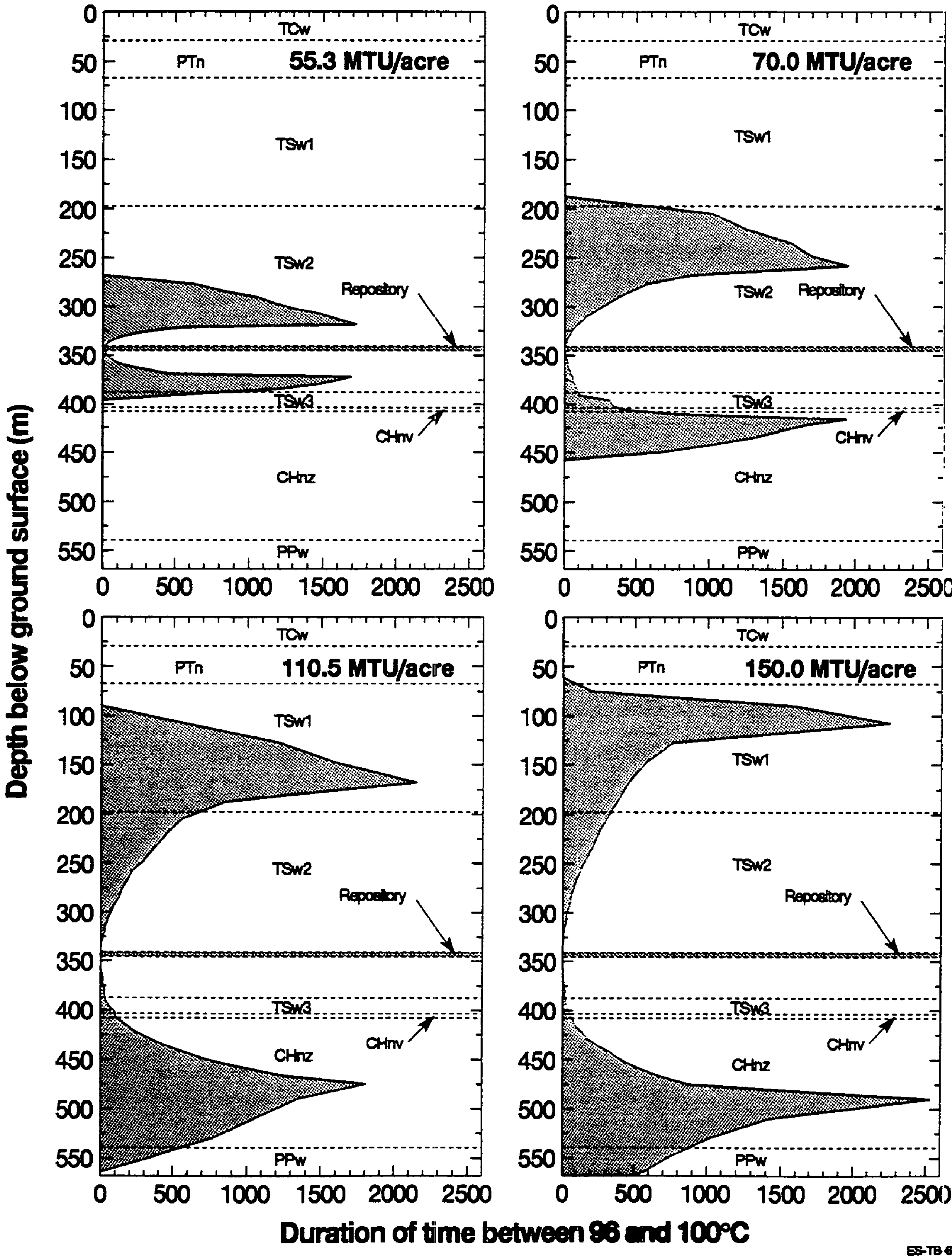
77.4 MTU/acre
30-yr-old SNF; 57 kW/acre

154.7 MTU/acre
30-yr-old SNF; 114 kW/acre

ES-TB-15abc (4-10-93) IL

The depth intervals where geochemical alteration due to refluxing may occur depend strongly on AML

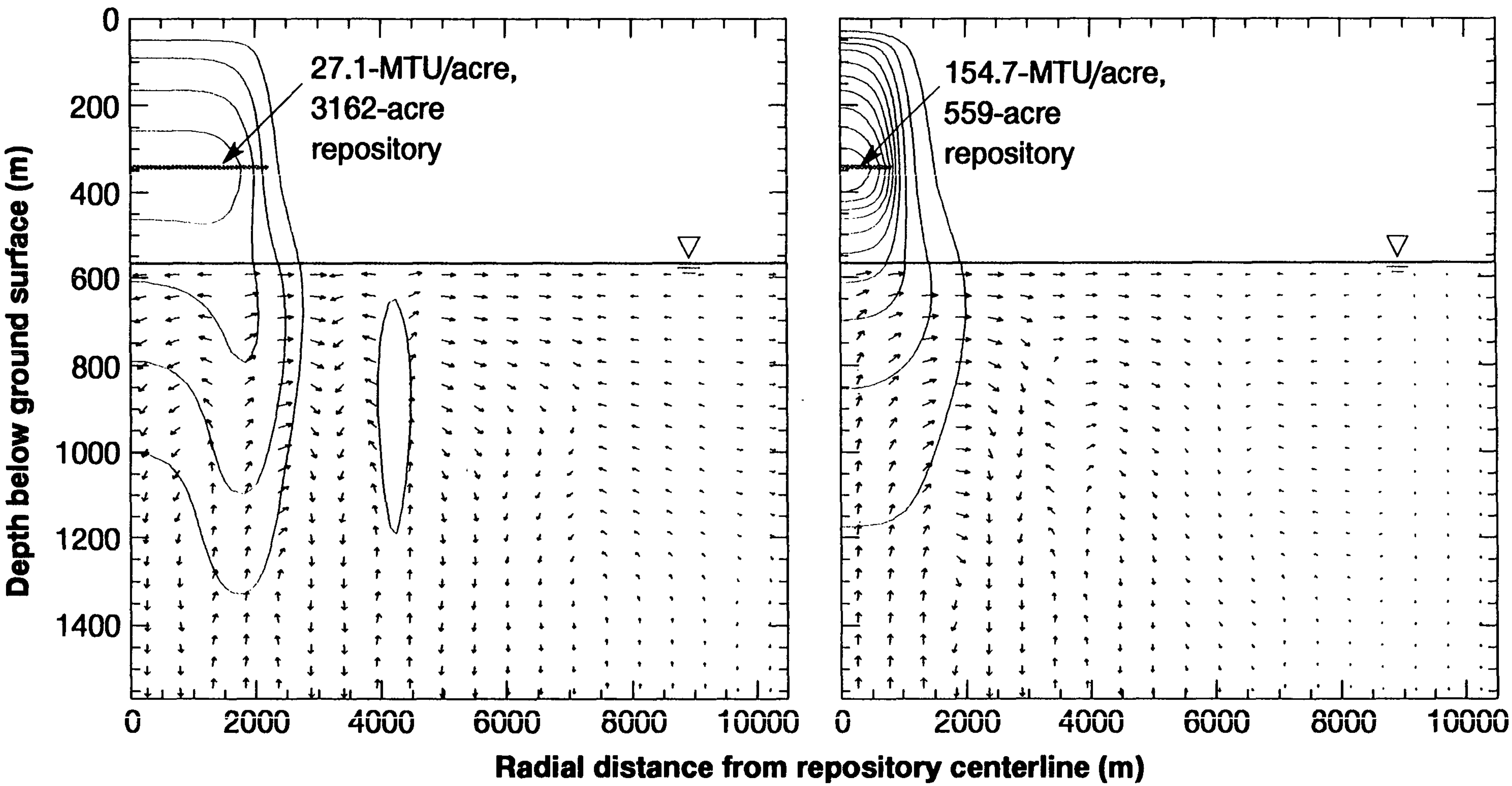
the duration of time between 96 and 100°C along the repository centerline for 22.5-yr-old SNF



ES-TB 6a-d (11-12-94) IL

Repository heat drives liquid-phase buoyant convection in the saturated zone (SZ) that will dominate SZ transport for tens of thousands of years

temperature buildup contours and liquid-phase velocity vectors at 5000 yr



ES-TB-2ab (10-14-94) IL

Coupling investigations Sequence

Through testing identify which linkages are important. Work towards adequate coupling (full coupling may be unrealistic and unnecessary)

- Thermal-mechanical
- Thermal-hydrological
- Thermal-geochemical
- Mechanical-hydrological
- Hydrologic-geochemical
- Add second level of coupling
  - Thermal-hydrological-mechanical
  - Thermal-hydrological-geochemical
  - Thermal-mechanical-geochemical

Objectives of Thermal Tests

- Identify processes (physics) to be included in mechanistic models (early tests)
- To develop necessary empirical model(s) if mechanistic models are unavailable
- To build confidence in modelling ability
  - Representativeness of model abstractions
  - Appropriateness of assumptions and boundary conditions
- To gather rock mass property data or characterization where can't gather from other sources
- To characterize heterogeneity of system or assist in model building

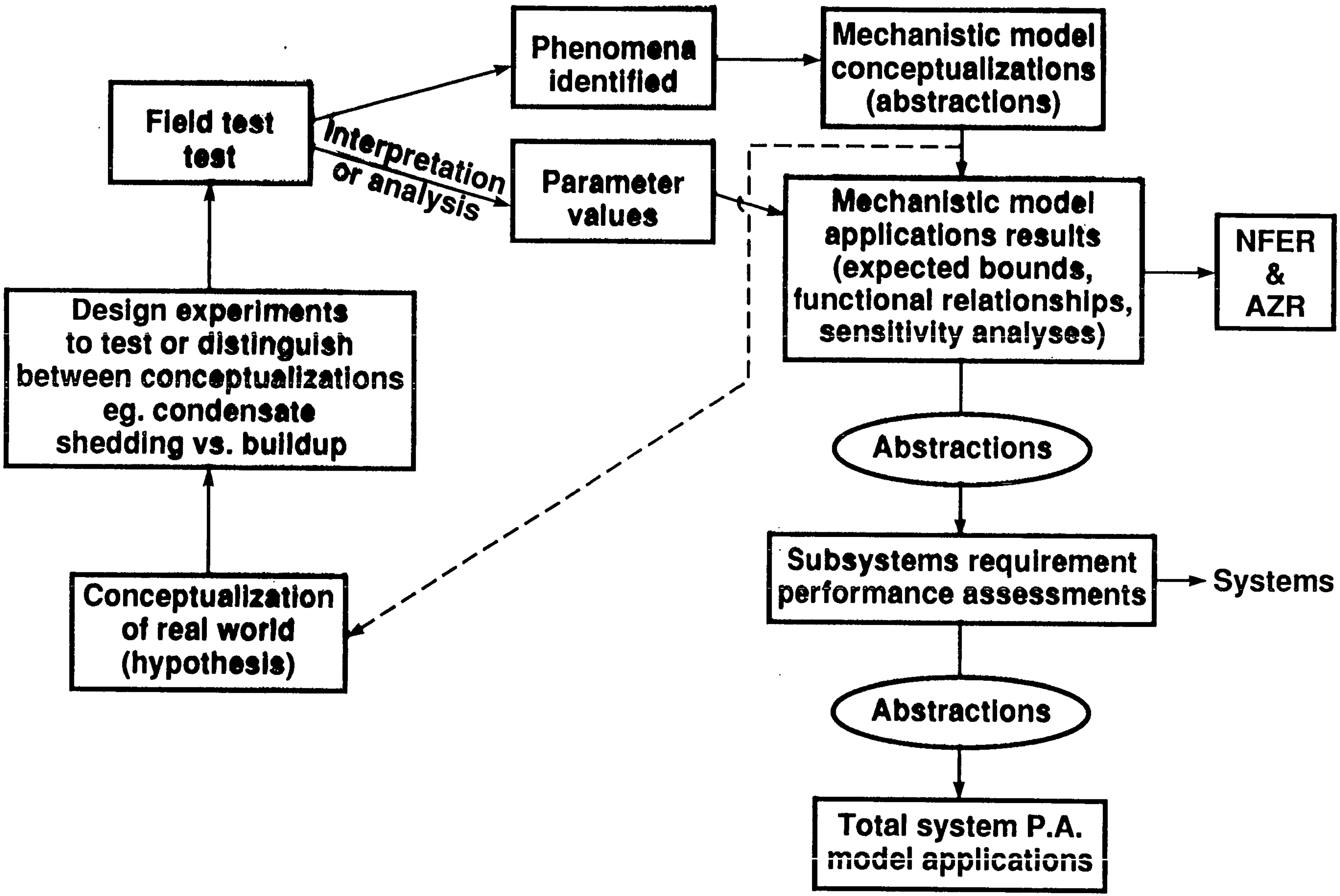
Test Strategy

Scale	Purpose
Lab Scale Core - 1/2 m hours to days (some long-term)	Property Measurements Matrix Processes Single-Fracture Processes
Block Scale 1/2 m to 3-5 m	Multiple-Fracture Processes Fracture Interconnectivity Phenomena Coupled Processes
In Situ Scale	
ESF tests (30M - 100M) 1 - 3 yrs	Site characterization *In Situ* but overdriven Coupling–THMC Model Testing
Large Scale (>100 m, 7-10 yrs)	Scaling Effects, Natural Heterogeneity Impacts
Repository Scale (50 - 100 yrs)	Performance Confirmation, Representative scale Coupling, Mountain scale Heterogeneity

Intended Use of Testing Results

- Depends on which test and its schedule
  - Prototype or early testing to identify overall processes (e.g., dryout, condensate shedding, etc.)
  - ESF tests to consider impact of fracture networks, potential for condensate shedding under resonable design options, test of modeling ability, bulk properties for use in LA, etc.
- Determine thermal transfer mechanisms
- Investigate relationships such as temperature and dryout, condensate development and drainage, geochemical and geomechanical process impact on hydrologic properties, etc.
- Investigate material performance in representative conditions

Field testing role



The temporal and spatial extent of the *heat-driven flow regime* in the UZ depend on site properties and thermal design

For both the minimally-disturbed (MD) and extended-dry (ED) repository concepts, the primary factors include:

- the importance of buoyant gas-phase convection
- the importance of binary gas-phase diffusion
- heterogeneity in the network of gas- and liquid-phase pathways
- heterogeneity in the heat load distribution (particularly for an MD repository)
- the repository depth below ground surface
- drift ventilation
- SNF aging

The Use of Hypothesis Testing in Model Validation

- **Our models have utilized idealizations of:**
  - the repository thermal load
  - the distribution of thermo-hydrological properties
  - boundary and initial conditions
- **No individual model of the repository-UZ-SZ system is itself a "valid" representation**
- **However, the combined use of complementary models and analyses provides a means to**
  - evaluate the impact of our assumptions,
  - identify critical dependencies,
  - evaluate worst-case scenarios,
  - and develop fundamental hypotheses, which can be addressed by subsequent analysis and testing

Hypothesis testing can help determine whether a low-AML repository is capable of avoiding significant heat-mobilized fluid flow in the UZ

The primary hypotheses concern:

- **L-1** whether mountain-scale, buoyant, gas-phase convection significantly affects UZ moisture movement
- **L-2** whether sub-repository-scale, buoyant, gas-phase convection significantly affects UZ moisture movement
- **L-3** whether binary gas-phase diffusion significantly affects UZ moisture movement
- **L-4** whether heterogeneity in the heat load distribution and/or gas- and liquid-phase pathways focus enough condensate drainage to cause water to drip onto WPs

For AMLs that significantly mobilize fluid, these hypotheses address how that mobilization occurs

Resolution of these hypotheses will require both above- and below-boiling heater tests

Hypothesis testing can help determine the extent to which a high-AML repository is capable of generating conditions that benefit WP integrity and reduce the potential for radionuclide dissolution and transport

The primary hypotheses concern:

- **H-1** whether heat conduction dominates heat flow
- **H-2** whether above-boiling temperatures correspond to a significant reduction in *RH* and the absence of mobile liquid water near WPs
- **H-3** how long re-wetting the WP environment to humid conditions lags behind the end of the boiling period
- **H-4** whether enough condensate buildup occurs to significantly impact drying and re-wetting

Resolution of these hypotheses will require heater tests conducted under both above- and below-boiling conditions

Value of Heater Test Information for Hypothesis Testing

Hypothesis	Lab-Scale Tests	Large-Block Test	Early *In Situ* Tests	Main *In Situ* Tests	Performance Confirmation Tests
L-1	L	L	P	S	C
L-2	L	L	S	C	C
L-3	P	S	S	C	C
L-4	L	P	S	S	C
H-1	P	P	S	C	C
H-2	P	P	S	C	C
H-3	L	P	S	S	C
H-4	L	P	S	S	C

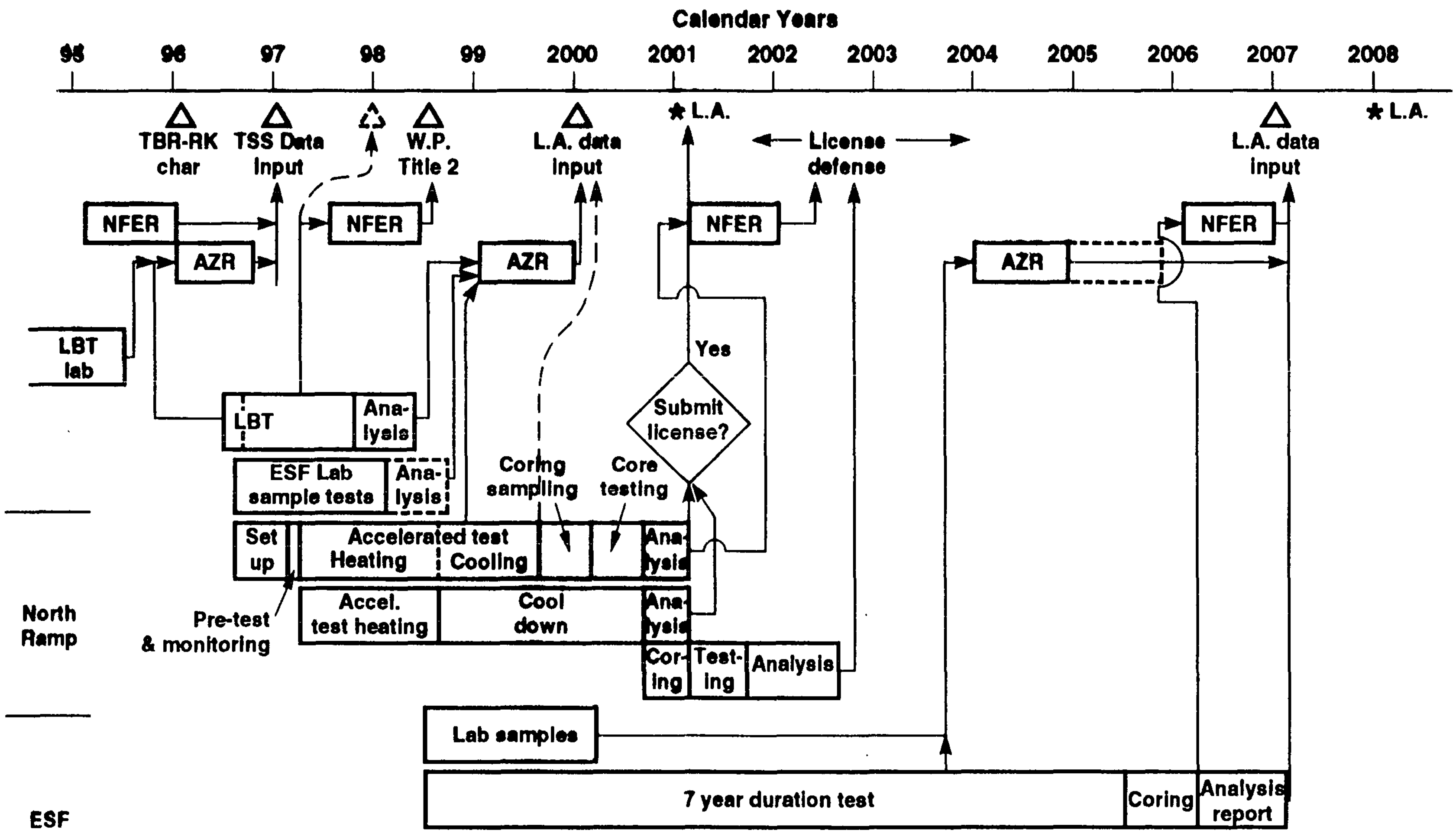
L = limited information, P = preliminary indication,
S = substantial understanding, C = confirmation

ES-TB-3 (11-12-94) Chart

Chronology of Testing

- SFT-C thermal-mechanical (some hydrology)
- Oricle test of fracture hydrology and geophysical techniques
- G-Tunnel Hydrology dye study and HFEM
- G-Tunnel horizontal heater test (mainly thermal-hydrological)
- LBT Thermal-hydrological-geochemical-geomechanics
- EBSFT all of above plus characterization of YM

Long range plan for field testing



TBR – Technical Basis Report

NFER – Near-Field Environment Report

AZR – Altered Zone Report

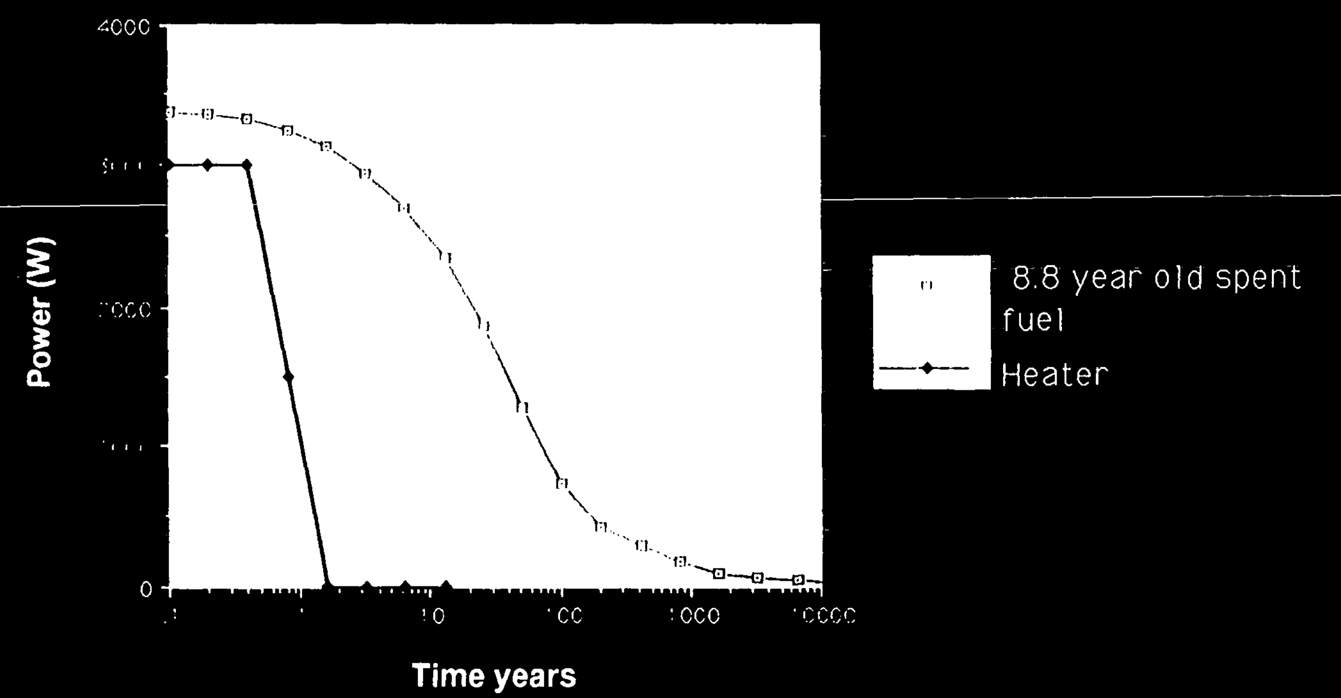
ES11/14/94DW#12-01

U. S. DEPARTMENT OF ENERGY

OCRWM

YUCCA MOUNTAIN PROJECT

Heater power cycle is highly accelerated



Conclusions of Geomechanics

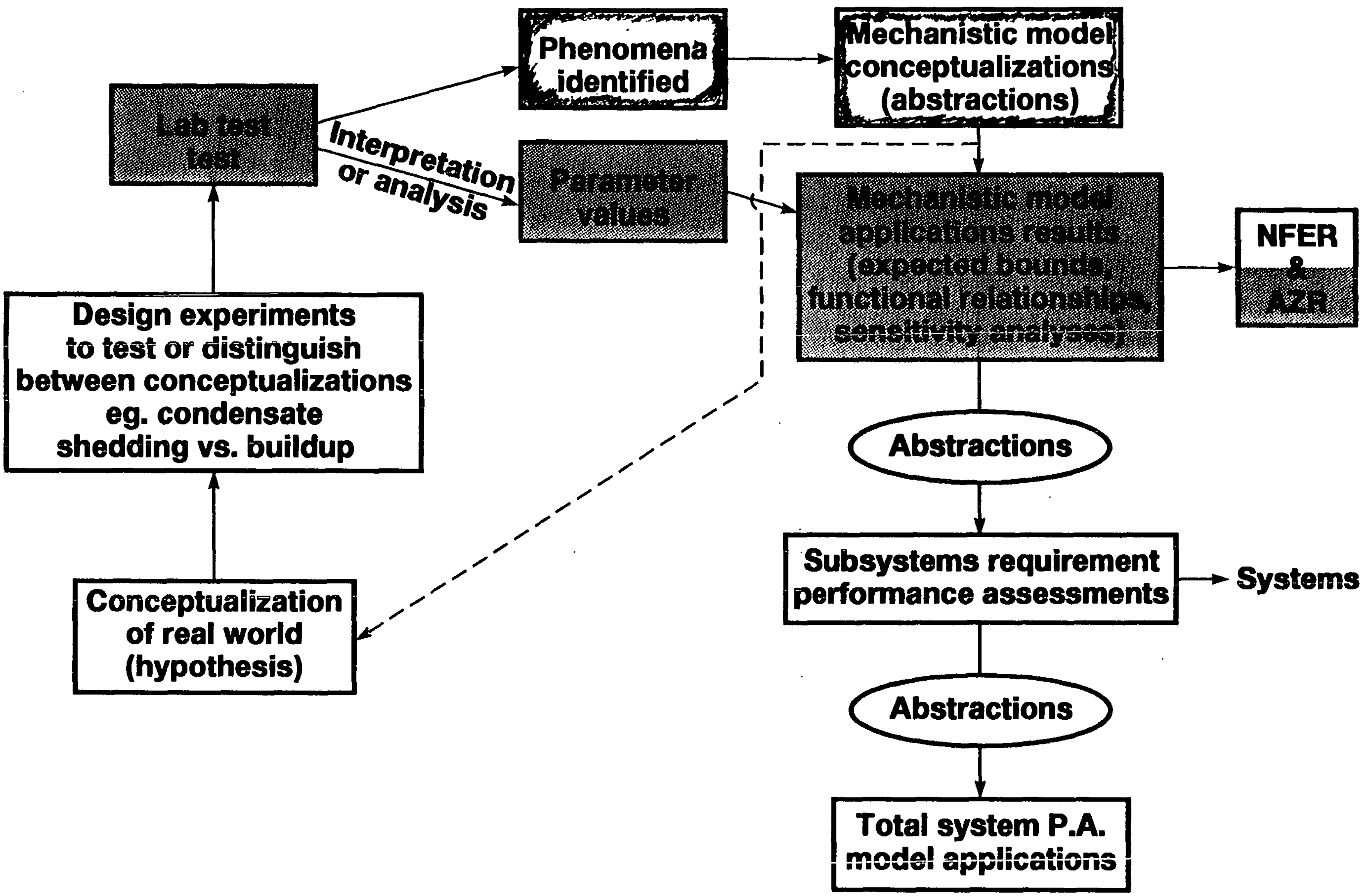
During thermal phase, essentially elastic (including shear zones)

During cooling, early phase elastic; later phase inelastic

Modulus differences associated with alteration, weathering, and fracturing

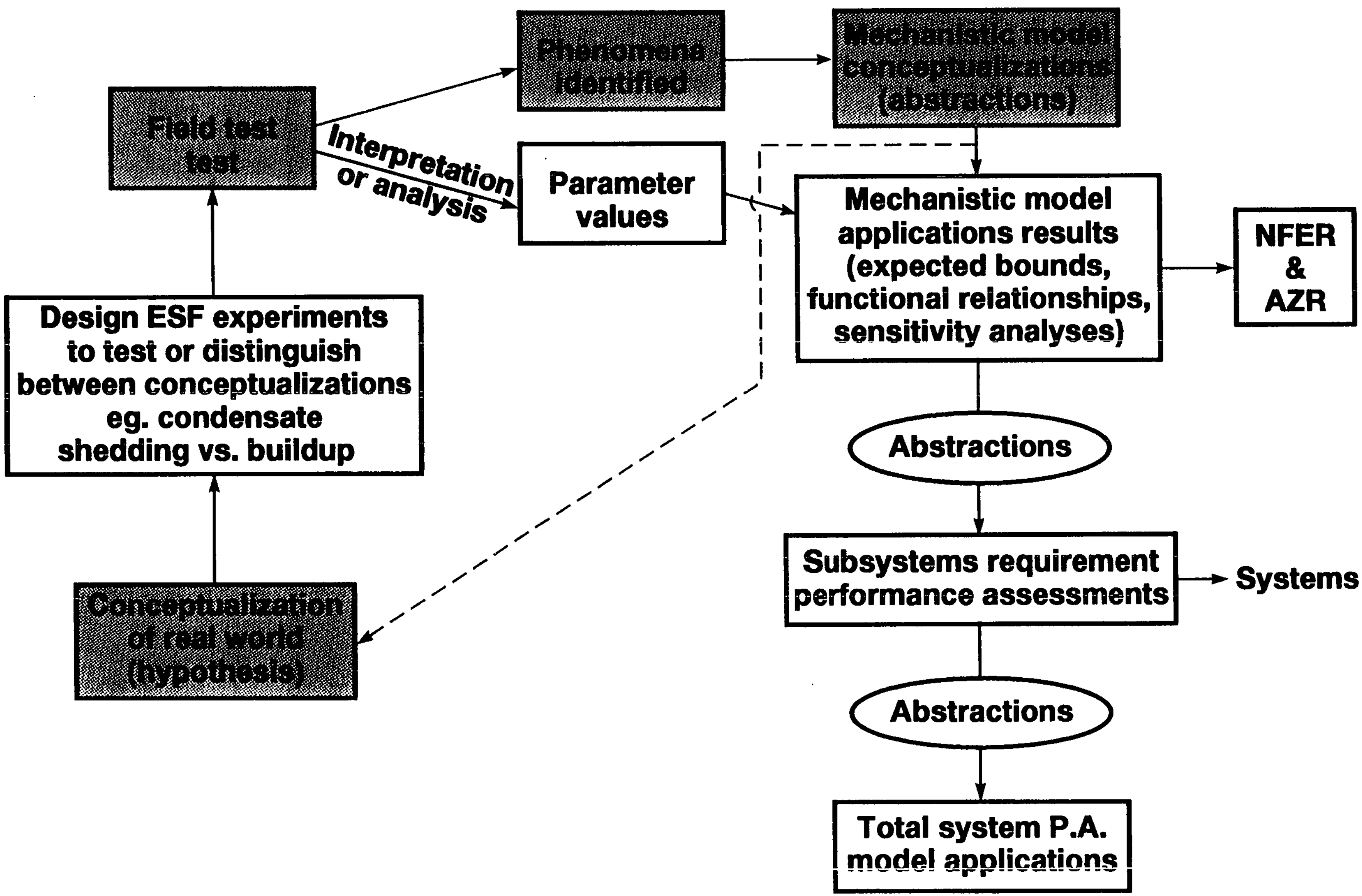
Response to excavation fundamentally different from response during thermal heating and cooling

Lab Testing Role – small blocks (up to 1 m) from ridge



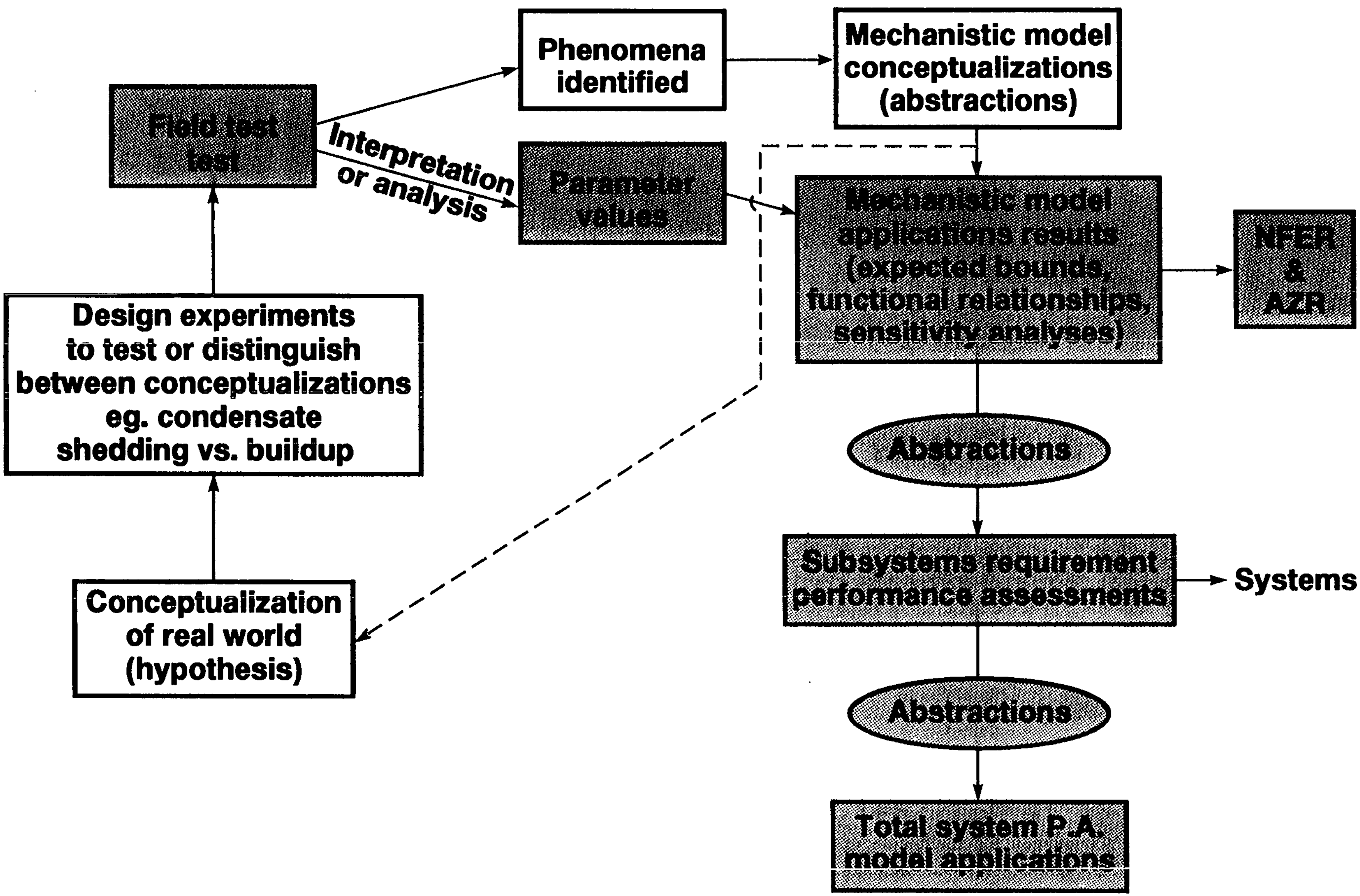
ES11/2/94DW#11-05

Field testing role – Large Block Test



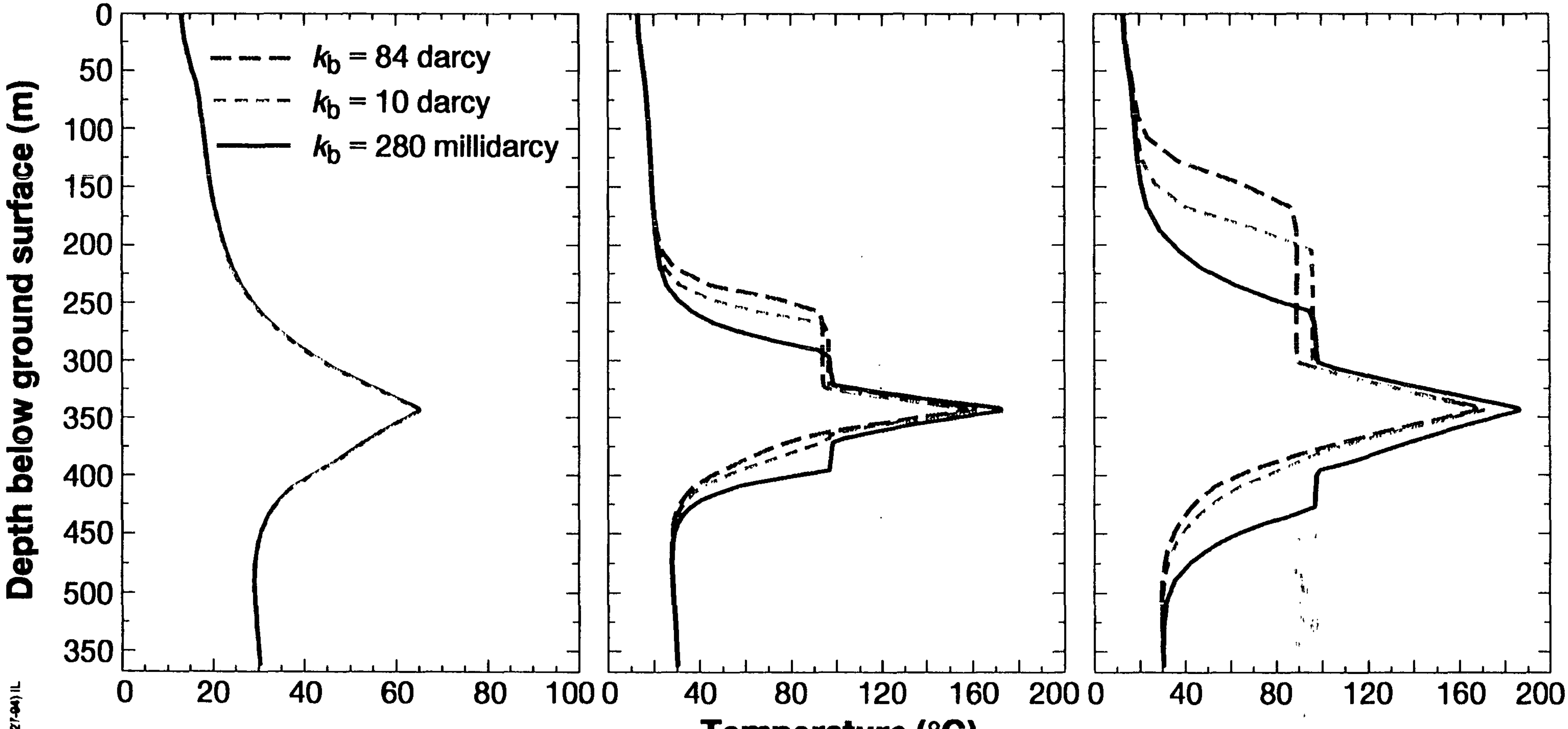
ES11/2/94DW#11-06

ESF: Engineered Barrier System



The temperature distribution during the performance confirmation period is highly diagnostic of the significance of mountain-scale, buoyant gas-phase convection for high (above-boiling) Areal Mass Loadings (AMLs), while it is not for low (below boiling) AMLs; diagnosing the significance of mountain-scale, buoyant, gas-phase convection for low AMLs will require the use of above-boiling heater tests and/or emplacing some region(s) of the repository with an above-boiling AML

vertical temperature profile through repository center for indicated AMLs and times



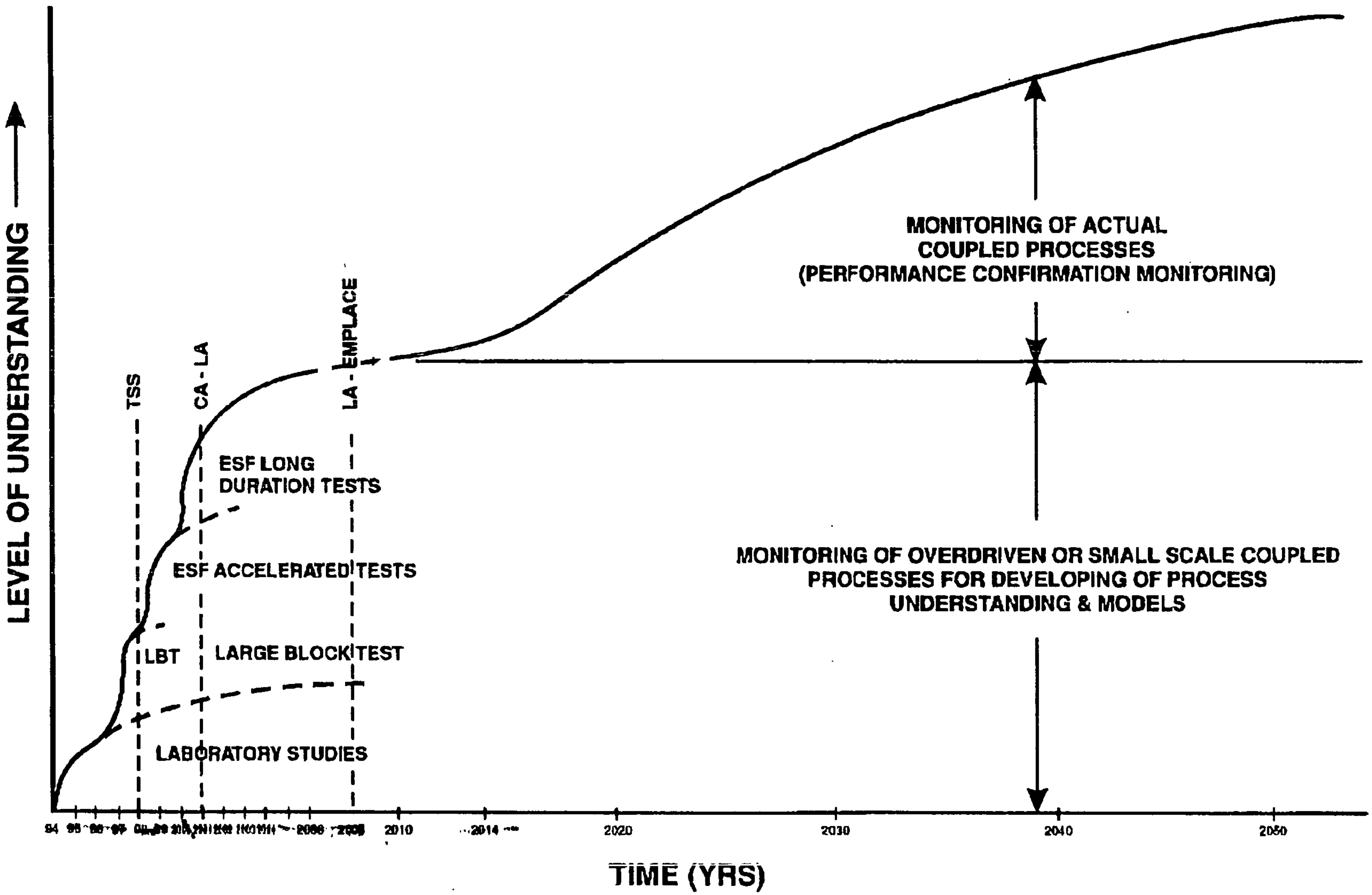
AML = 24.2 MTU/acre
t = 100 yr

AML = 110.5 MTU/acre
t = 50 yr

AML = 110.5 MTU/acre
t = 100 yr

ES-TB-3abc (8-27-94) IL

Maturation of Understanding of Environment



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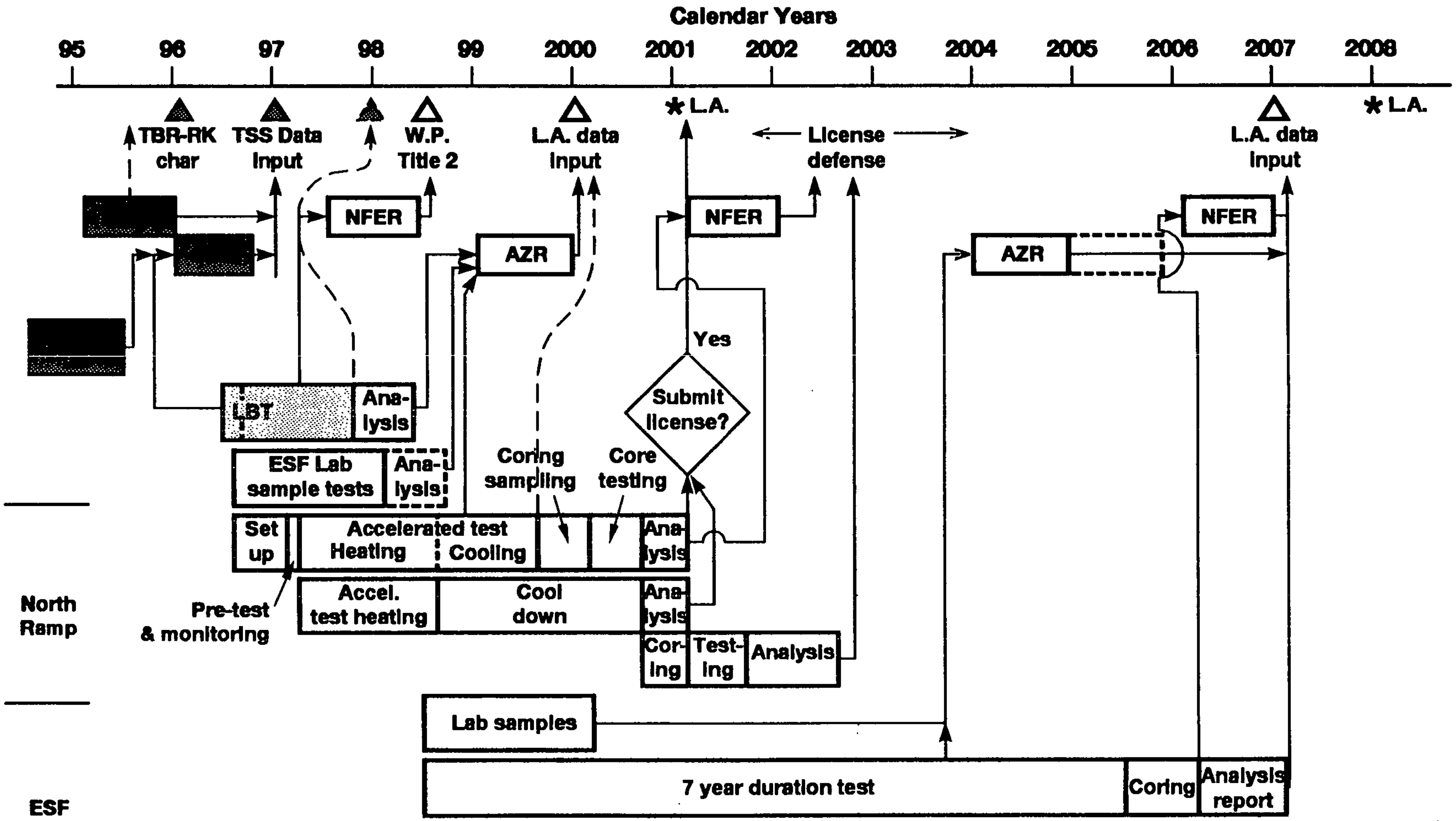
Field testing inputs to TSS



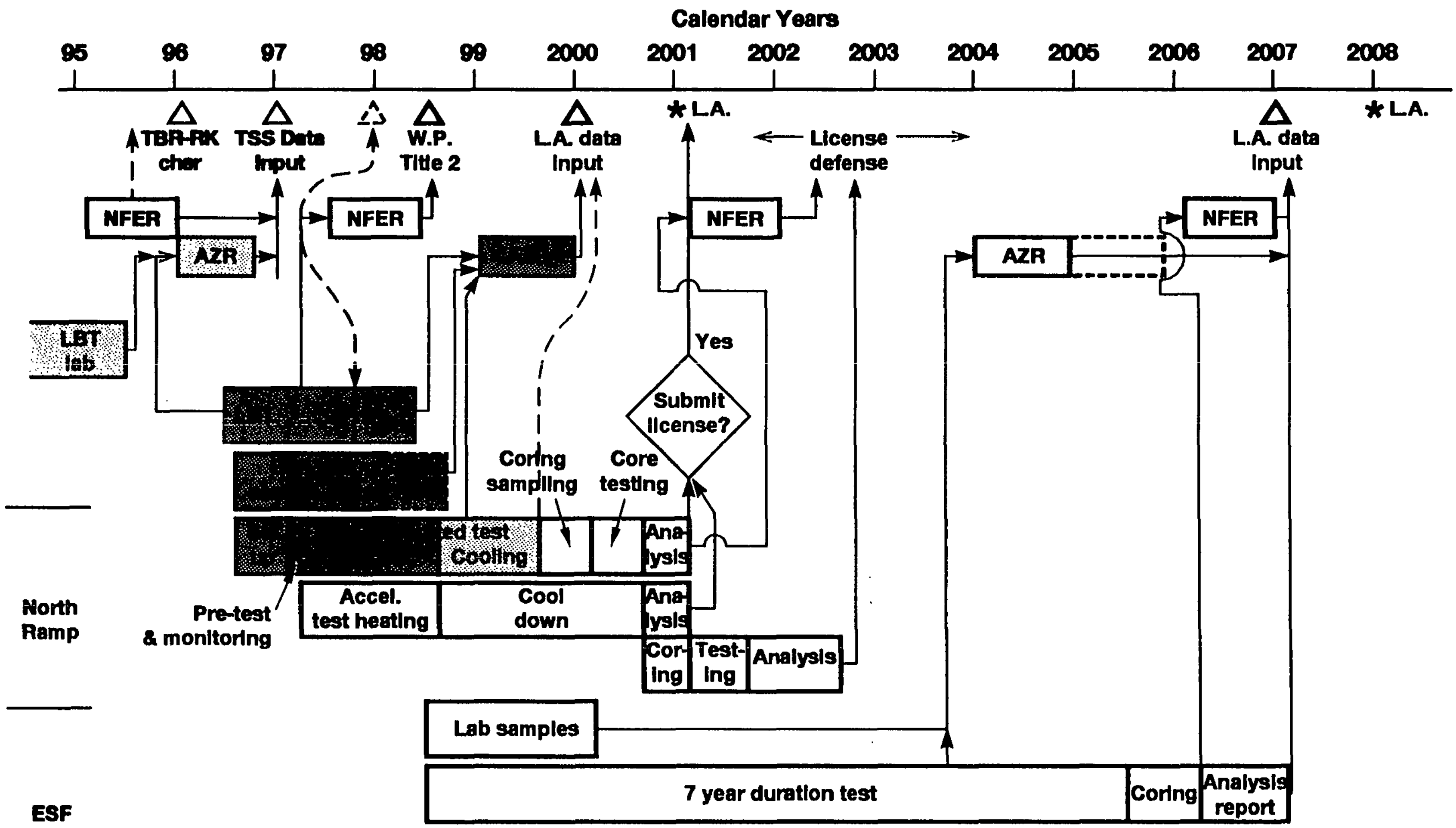
TBR – Technical Basis Report

NFER – Near-Field Environment Report

AZR – Altered Zone Report

ES11/14/94DW#12-02

Field testing inputs to 2001 LA

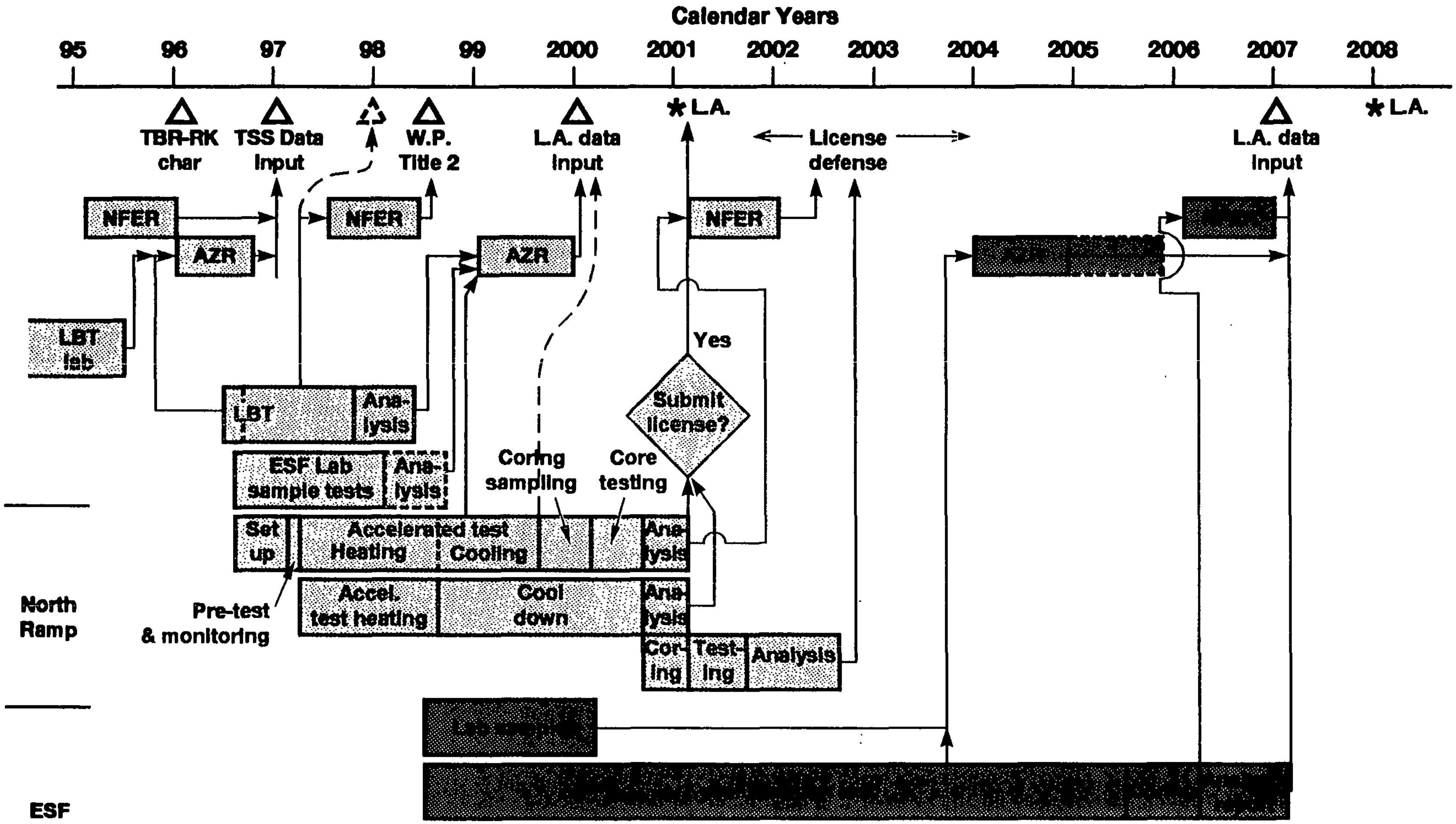


TBR – Technical Basis Report

NFER – Near-Field Environment Report

AZR – Altered Zone Report

Field testing inputs to 2008 LA

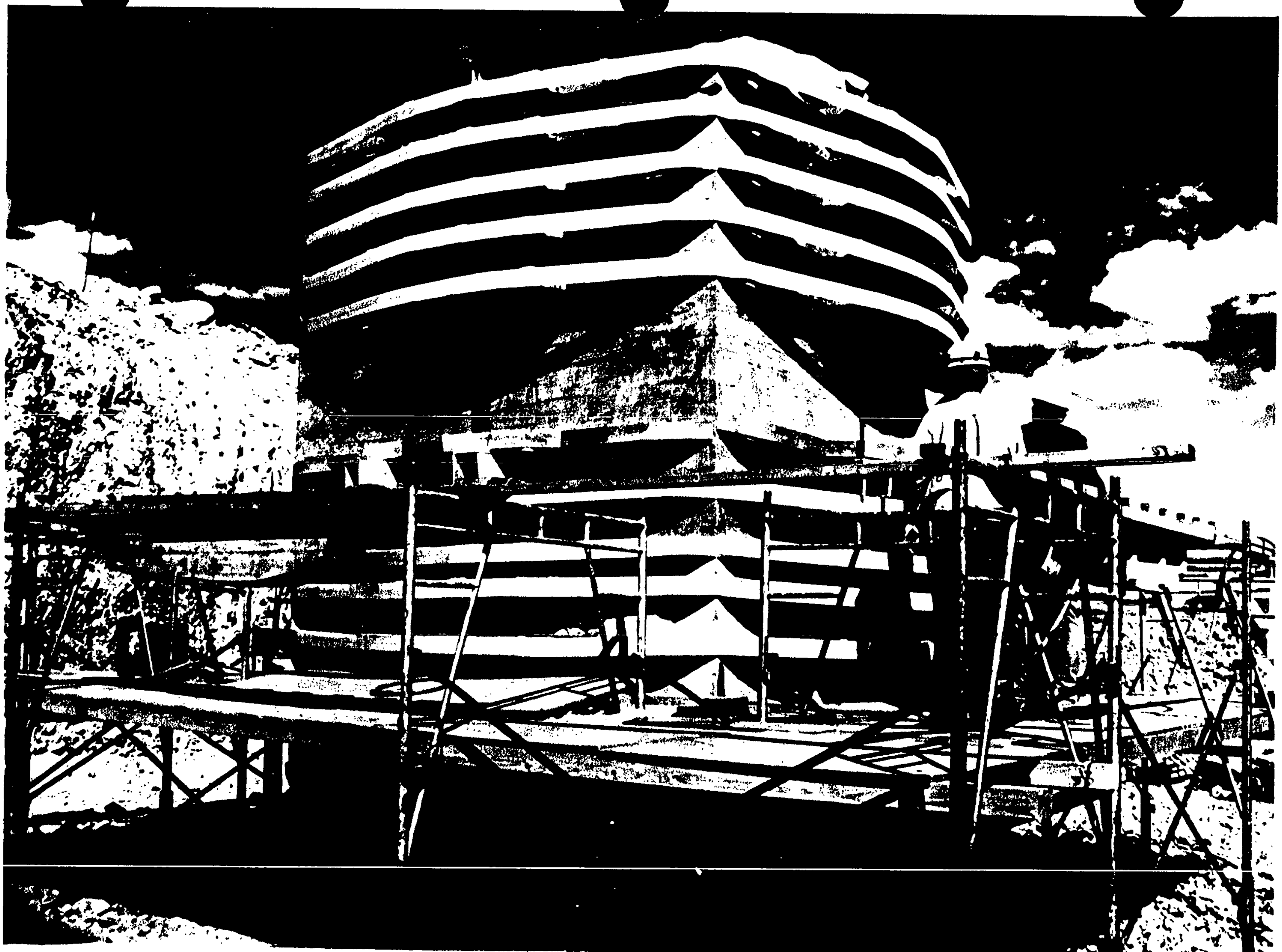


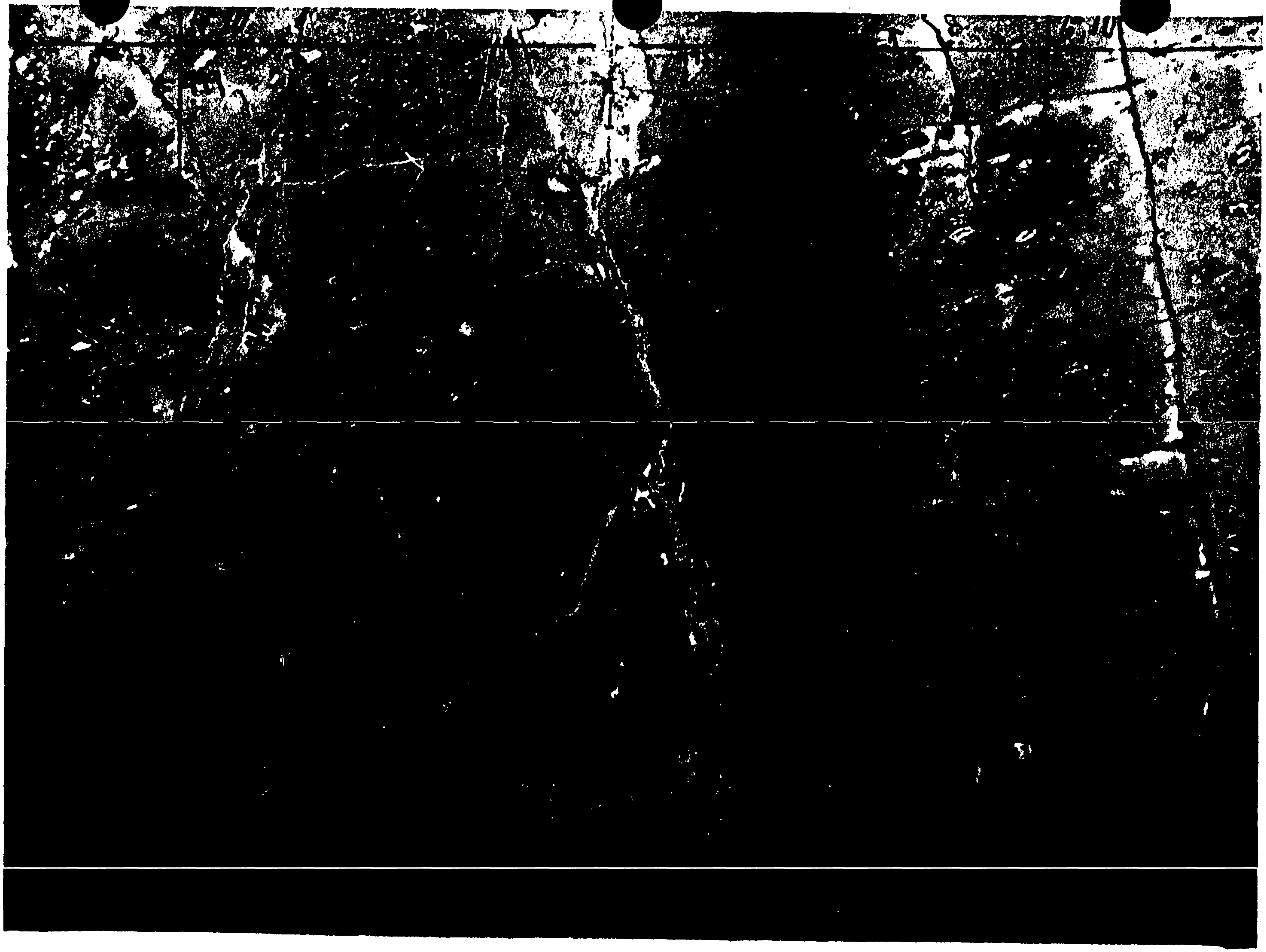
TBR – Technical Basis Report

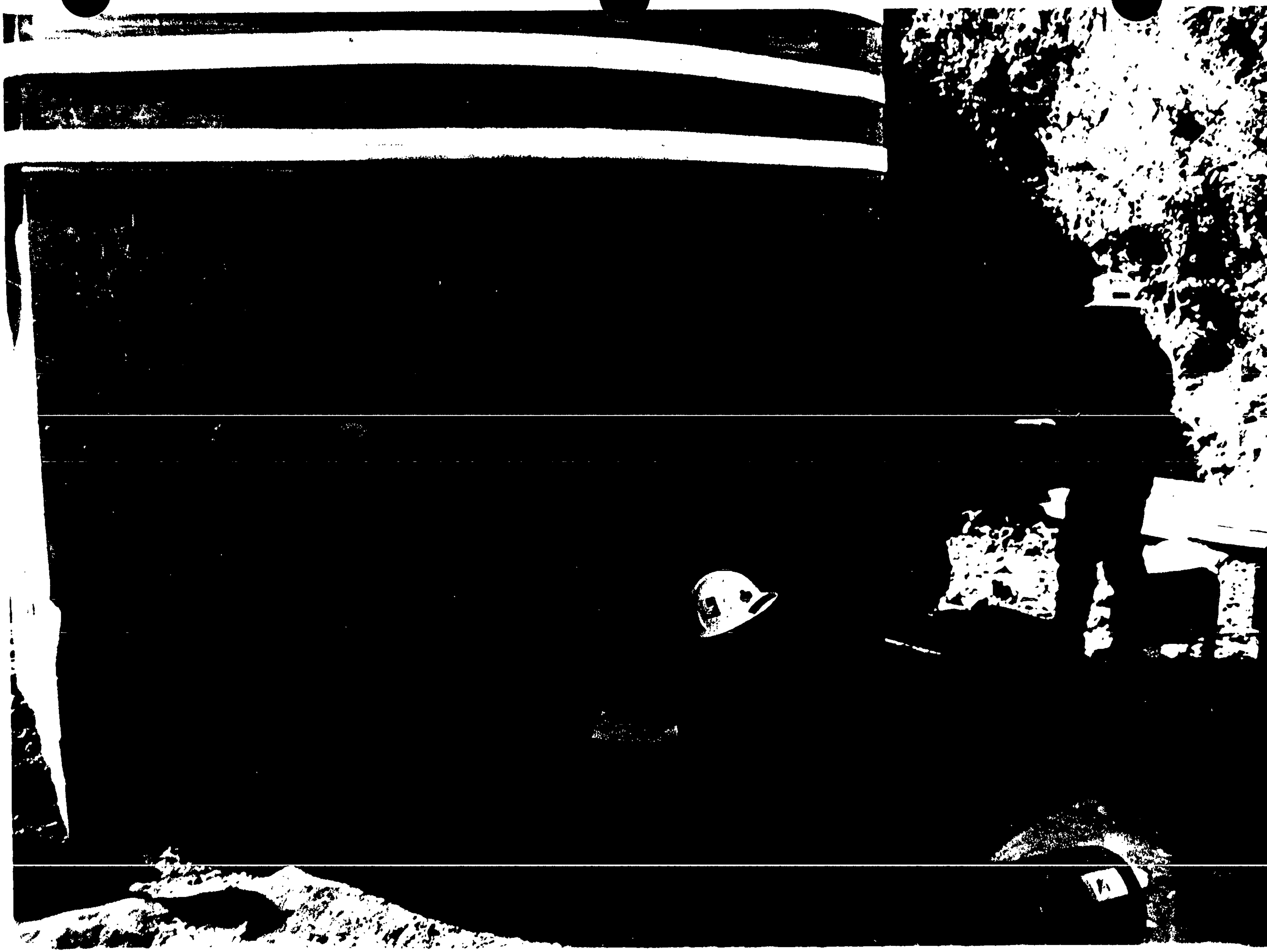
NFER – Near-Field Environment Report

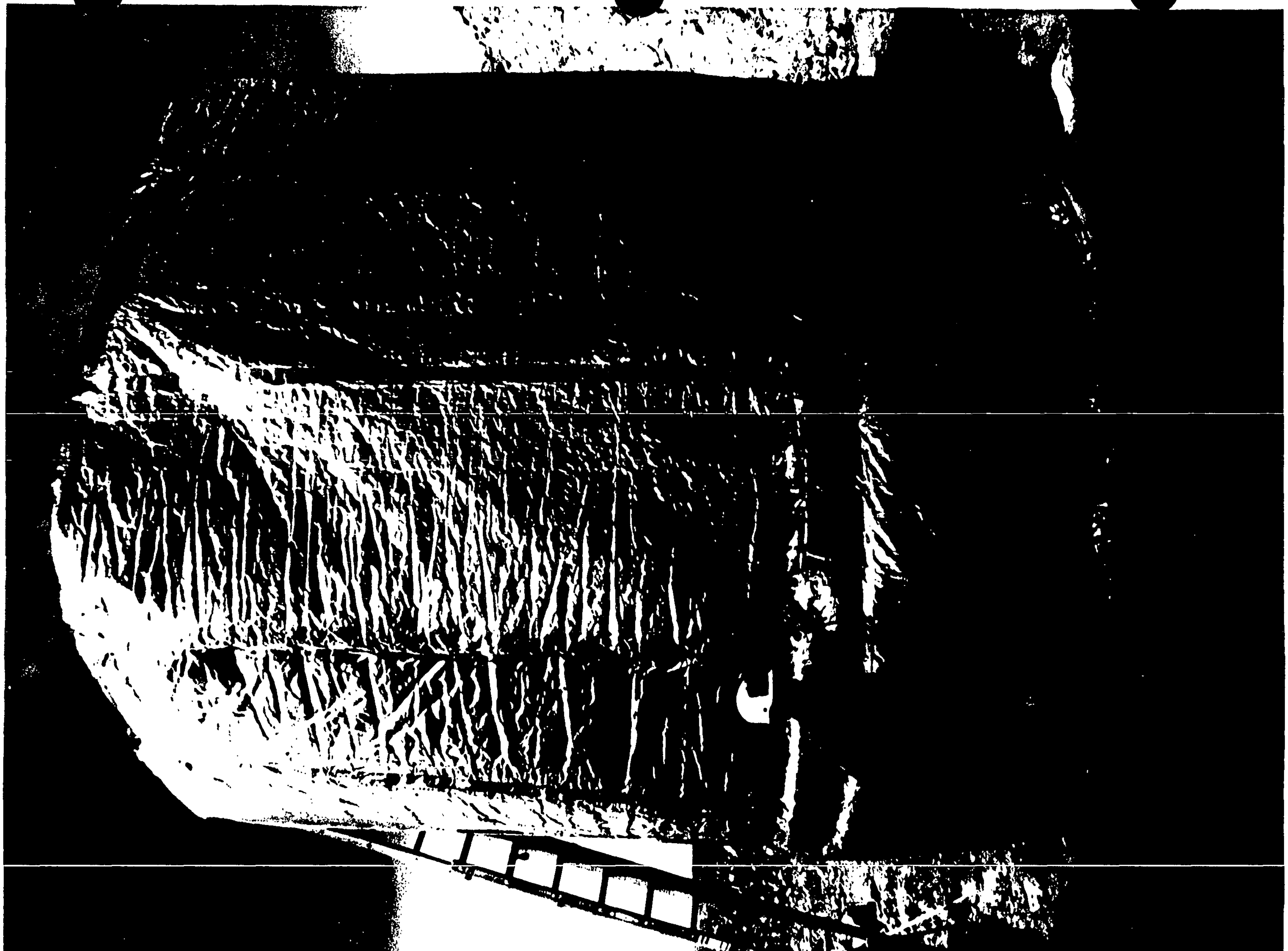
AZR – Altered Zone Report

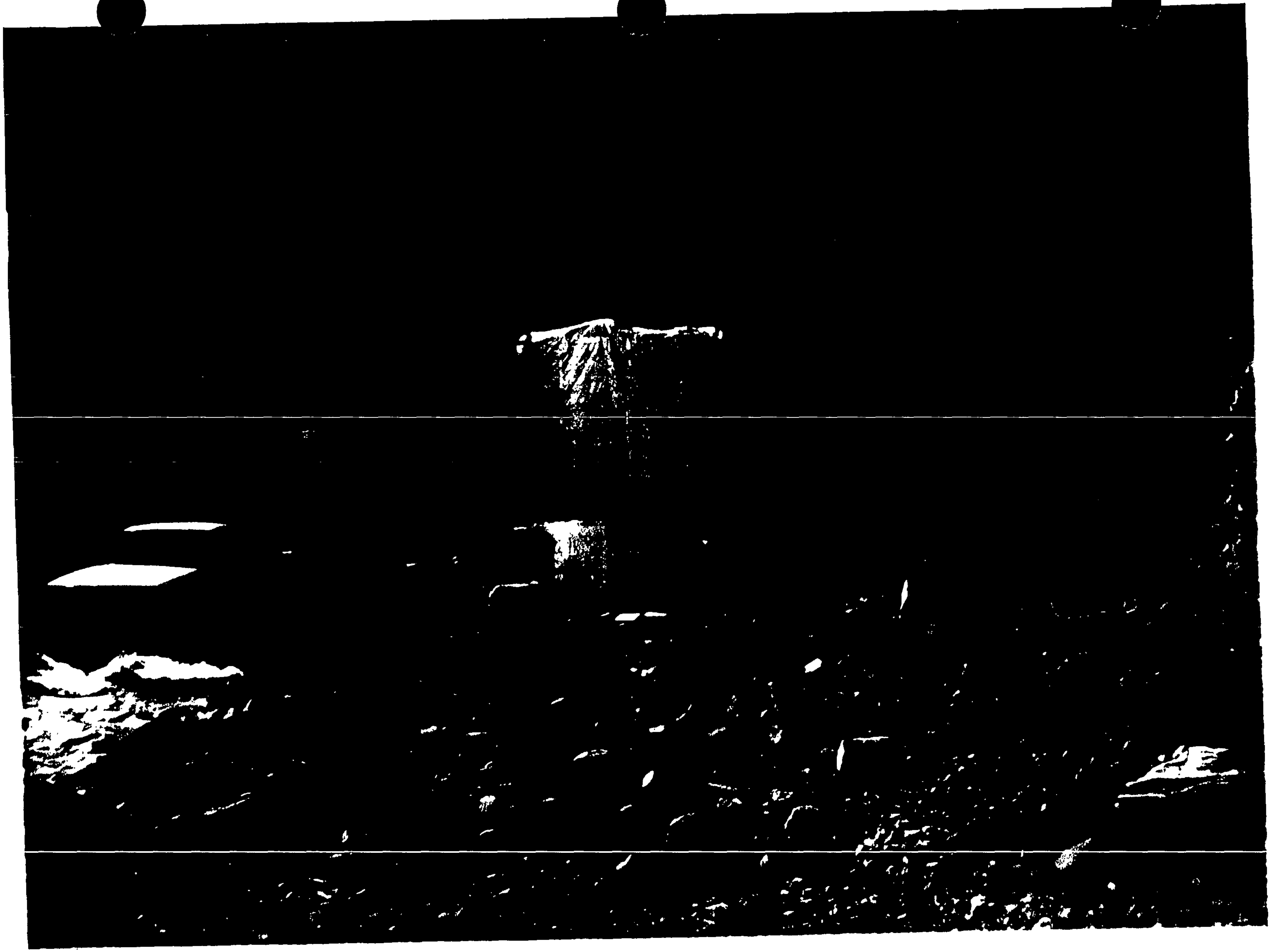
ES11/14/94DW#12-04







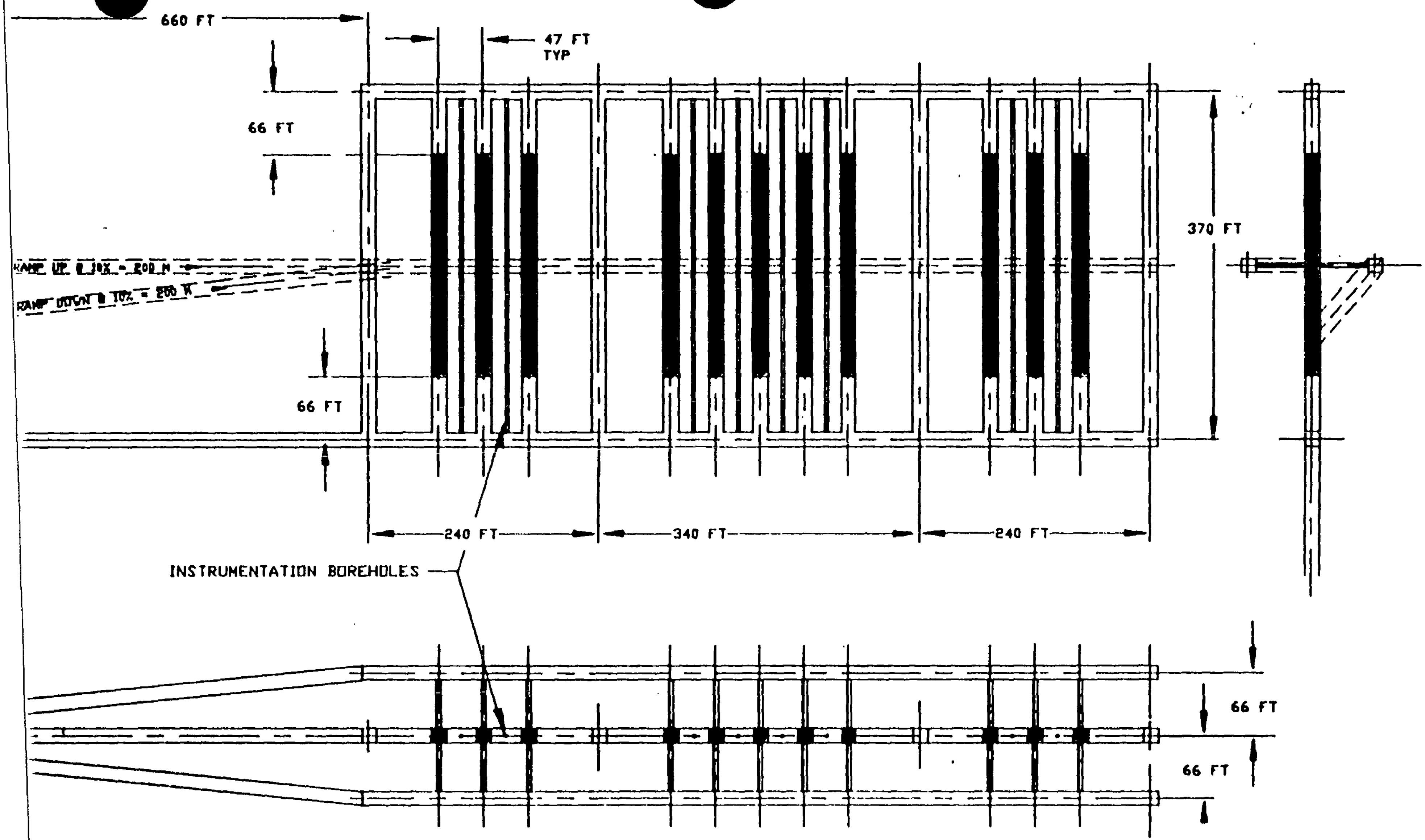




Criteria for Design of Waste Package Environment Tests

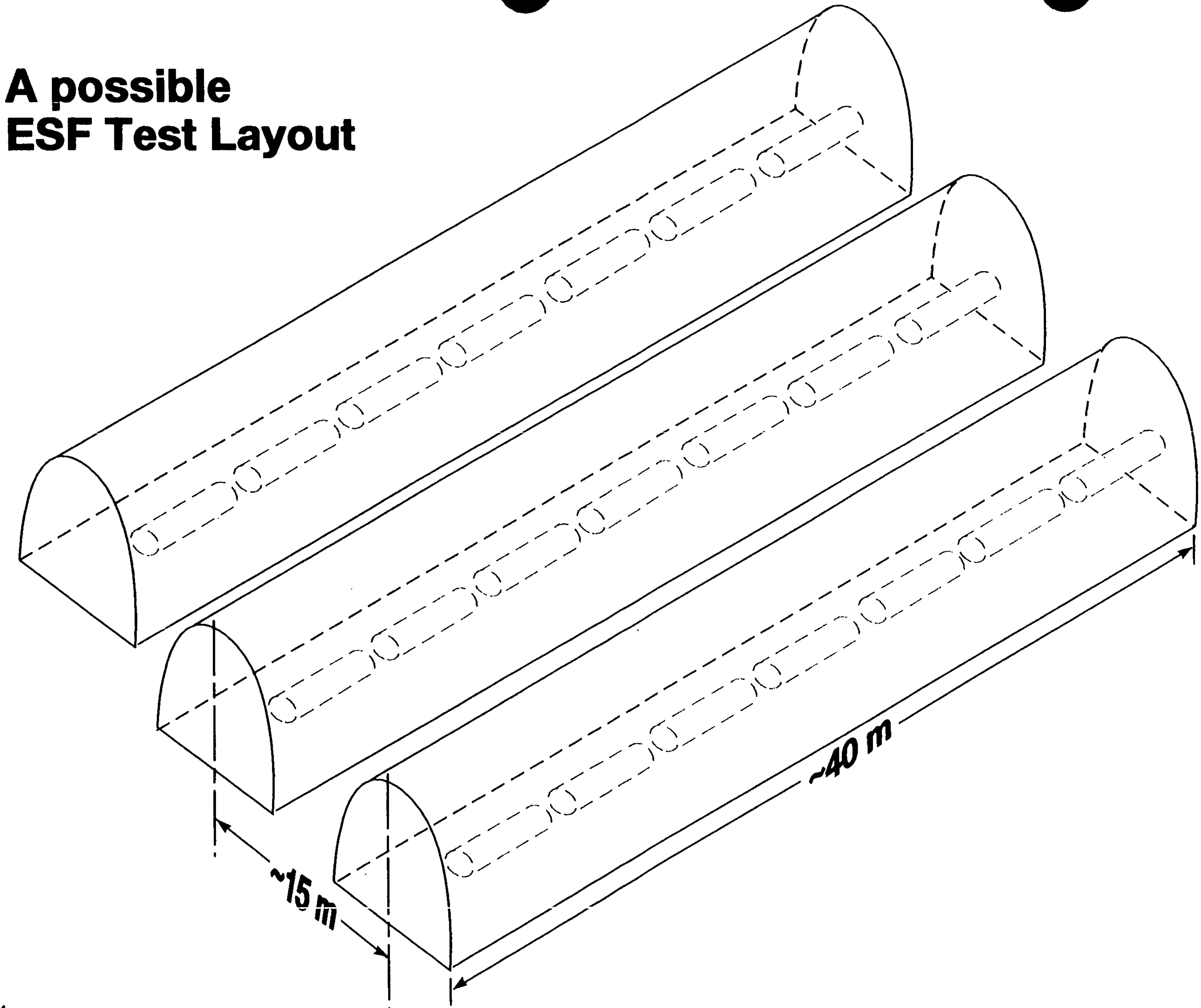
- Volume of the dry-out zone
  - G-Tunnel ~0.75 m
  - Small percentage of fractures responsible for majority of flow
- Peak rock temperatures
  - Above 200 degrees can have phase transition
  - Representative of possible repository ranges
- Velocity of dry-out front
  - Lab tests of up to one-year duration required
- Size and duration of condensate zone

DGW:mvl
102-94



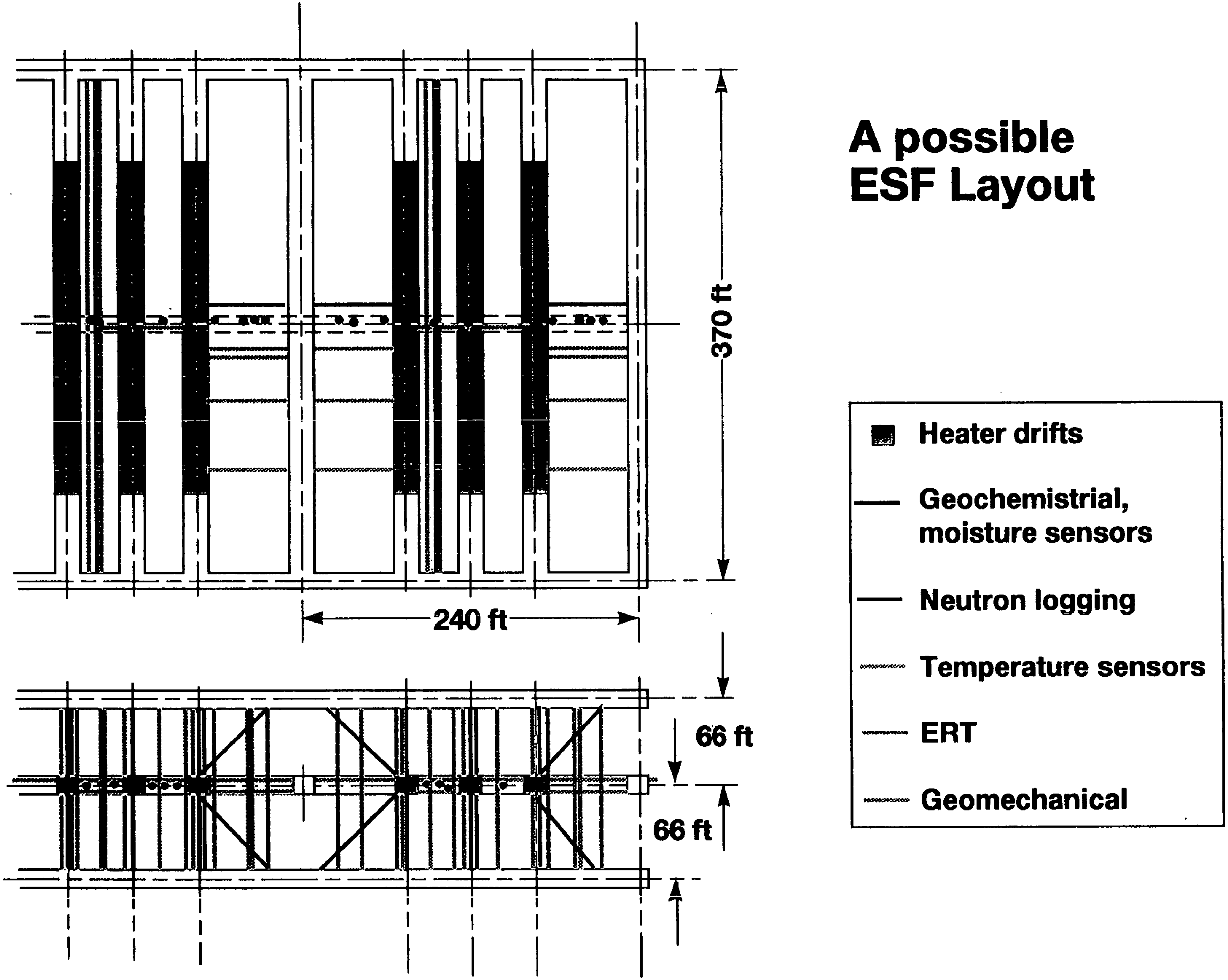
PRELIMINARY LAYOUT OF ESF TESTS

A possible ESF Test Layout



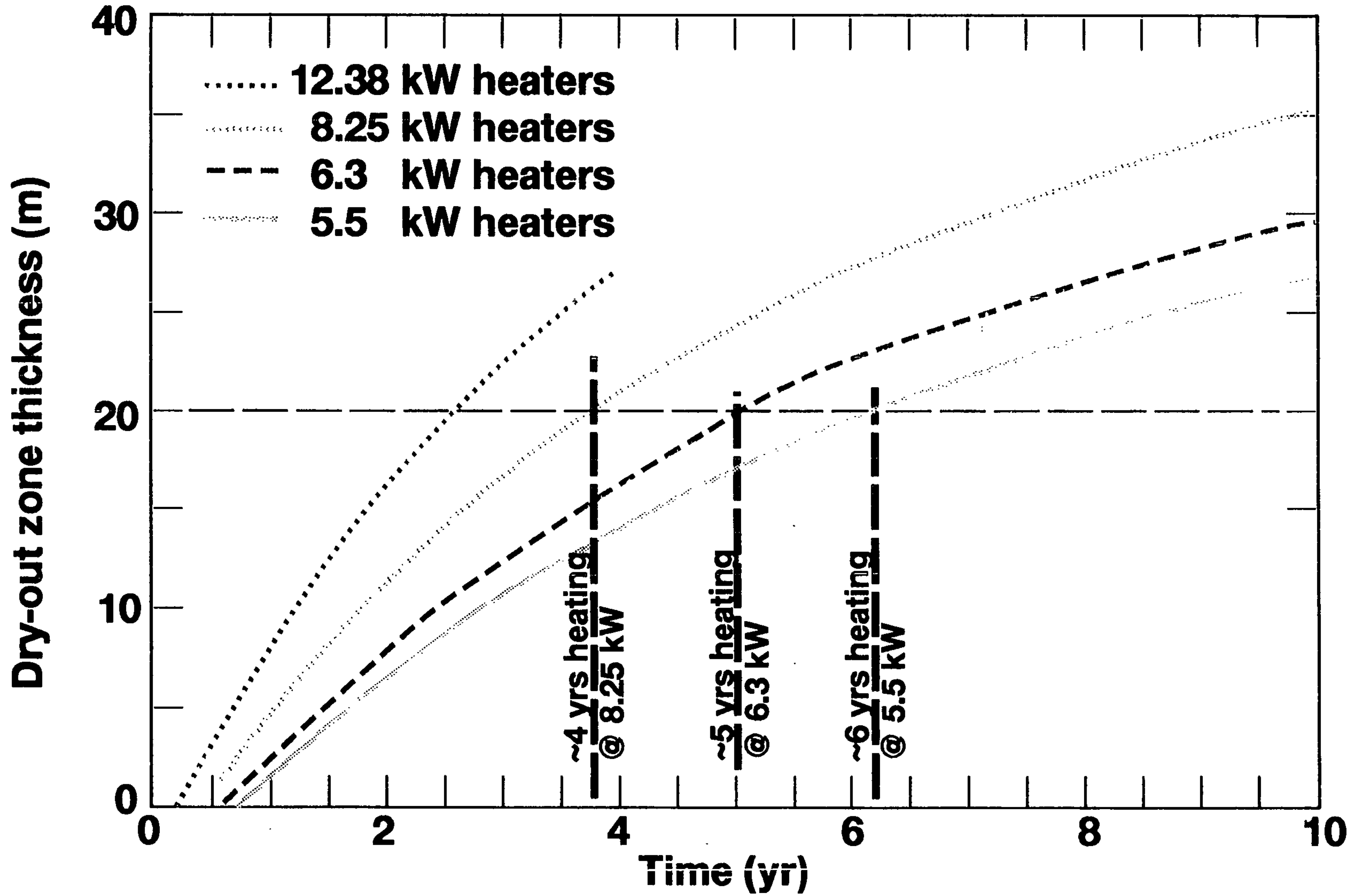
ES11/14/94DW#8-04

A possible ESF Layout



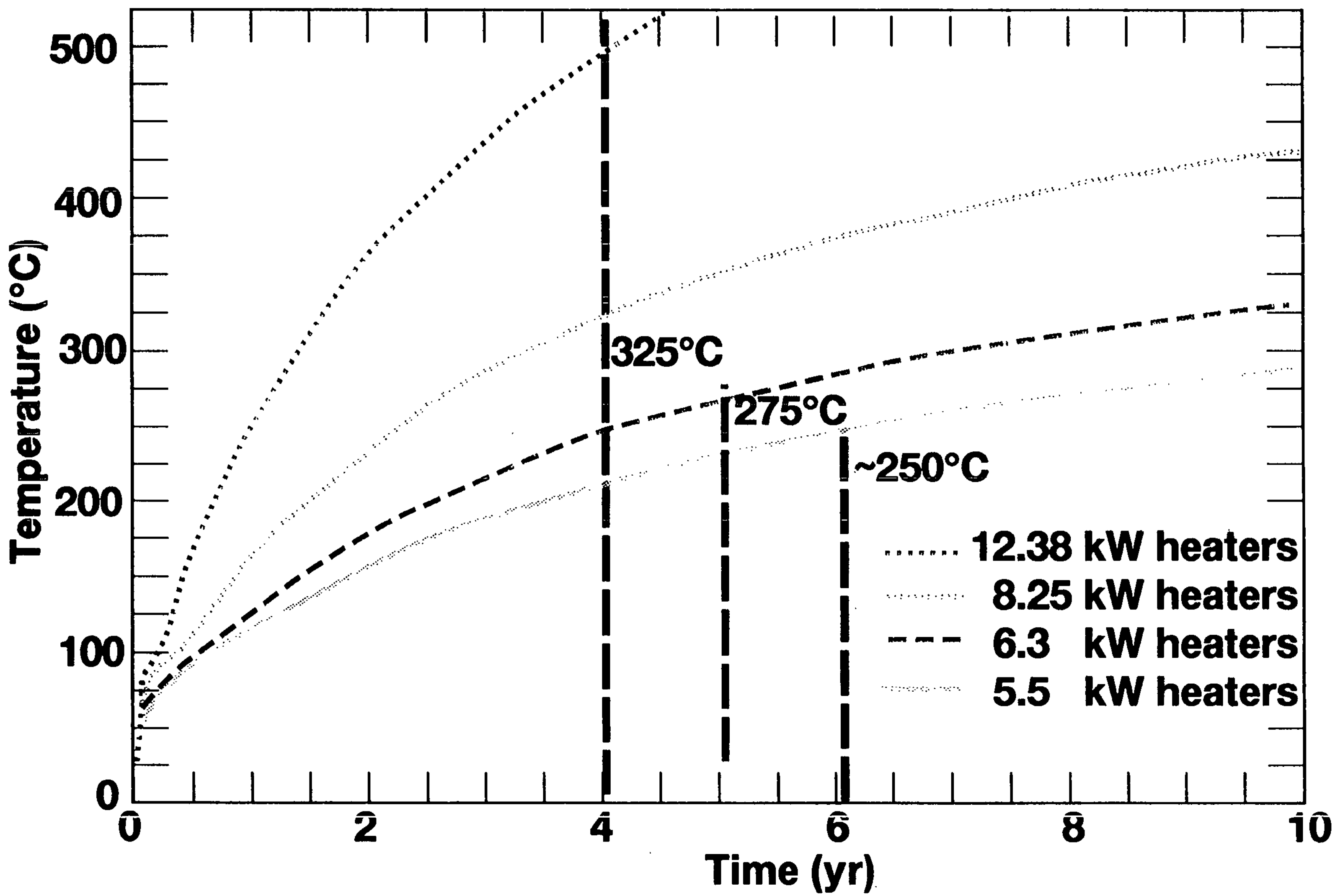
ES-09/10/93-WL#9-01

Duration of heating for 10 m radius dryout.
(Central drift midpoint)



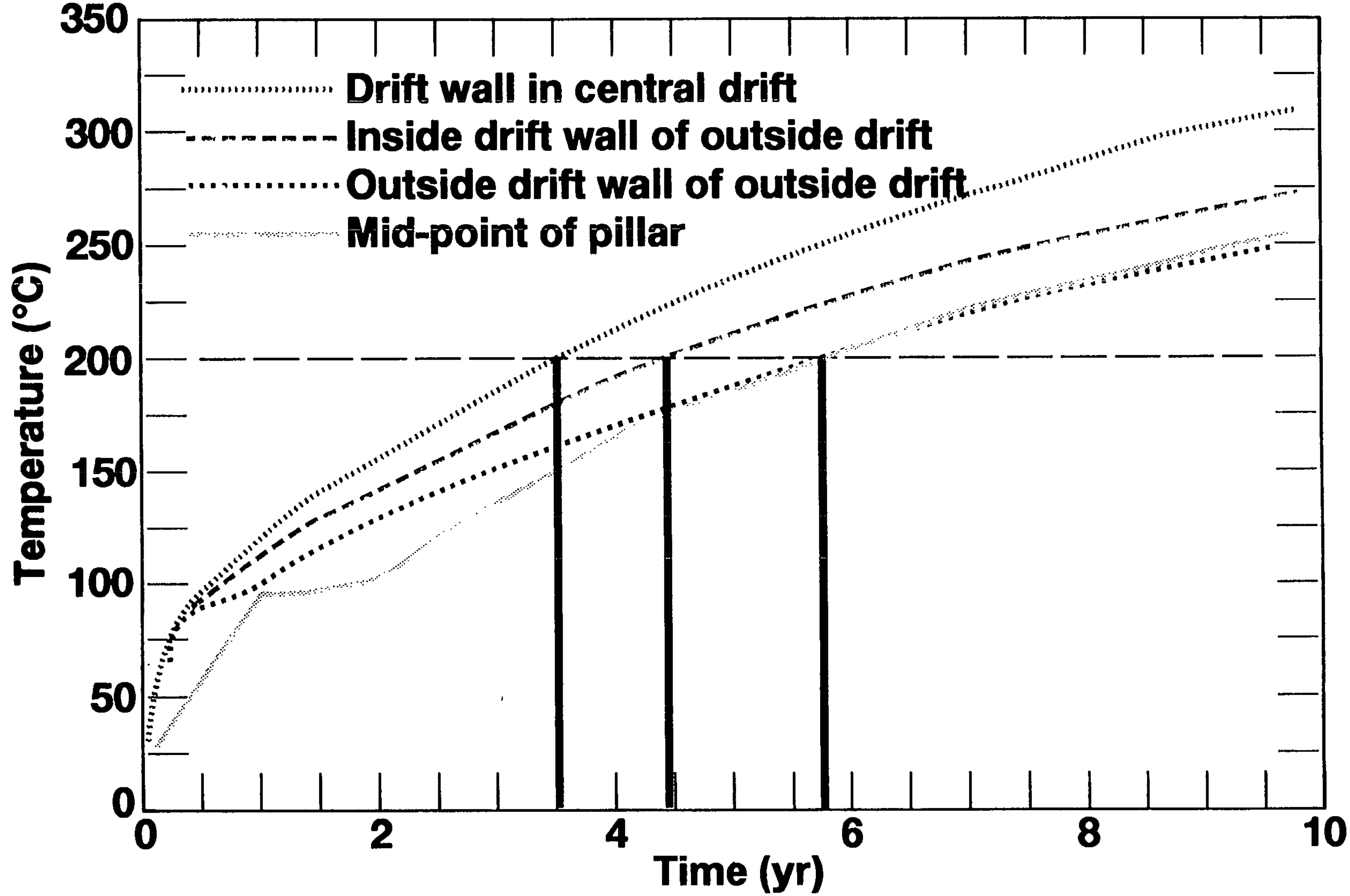
Es-05/27/93-DW#8-06

ESF Drift Wall Temperatures vs heater output
(Central Drift at Midpoint)



Es-05/27/93-DW#8-05

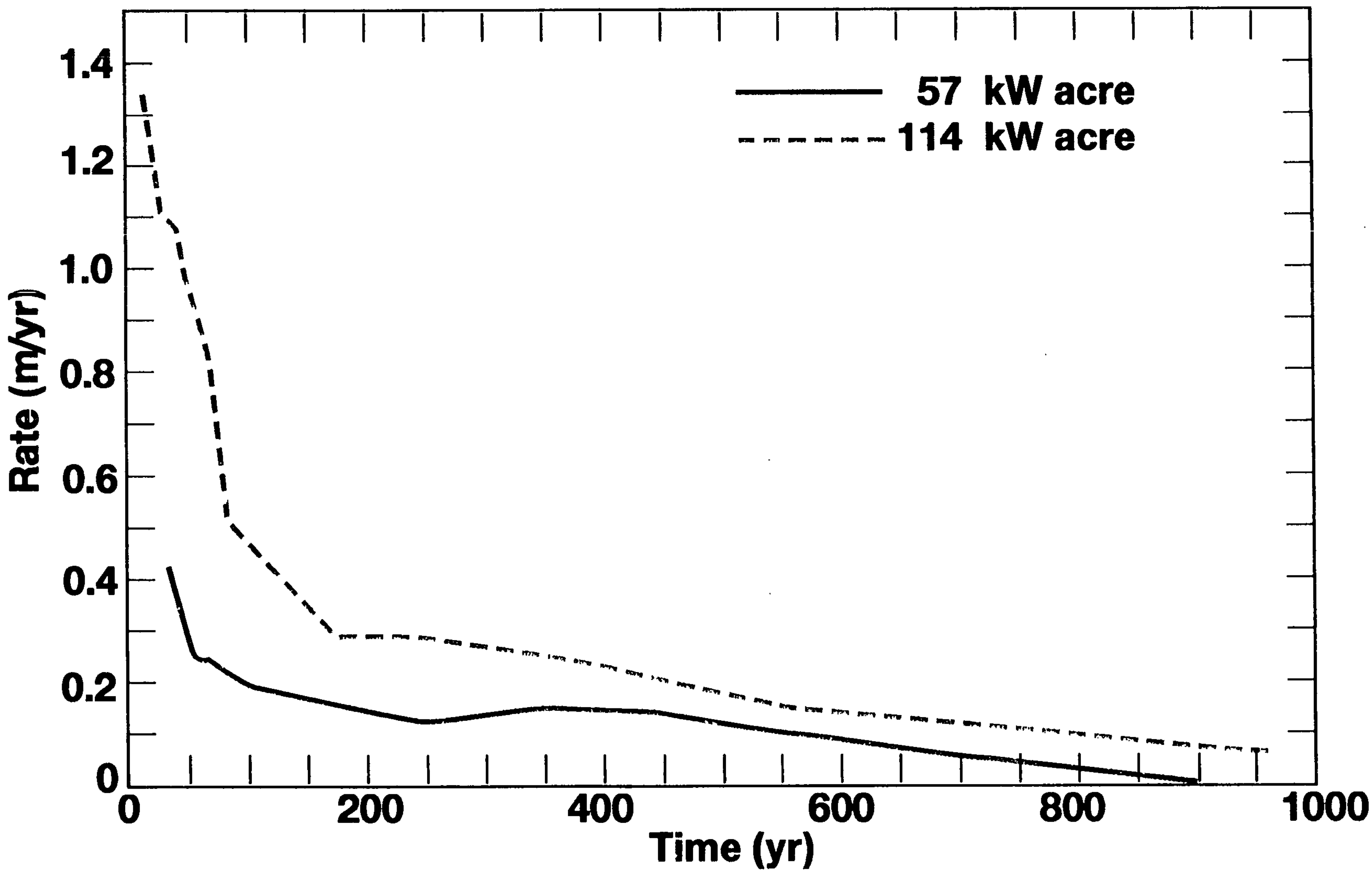
ESF Heating duration that will not exceed 200°C
(6.3 kW heaters)



Es-05/27/93-DW#8-04

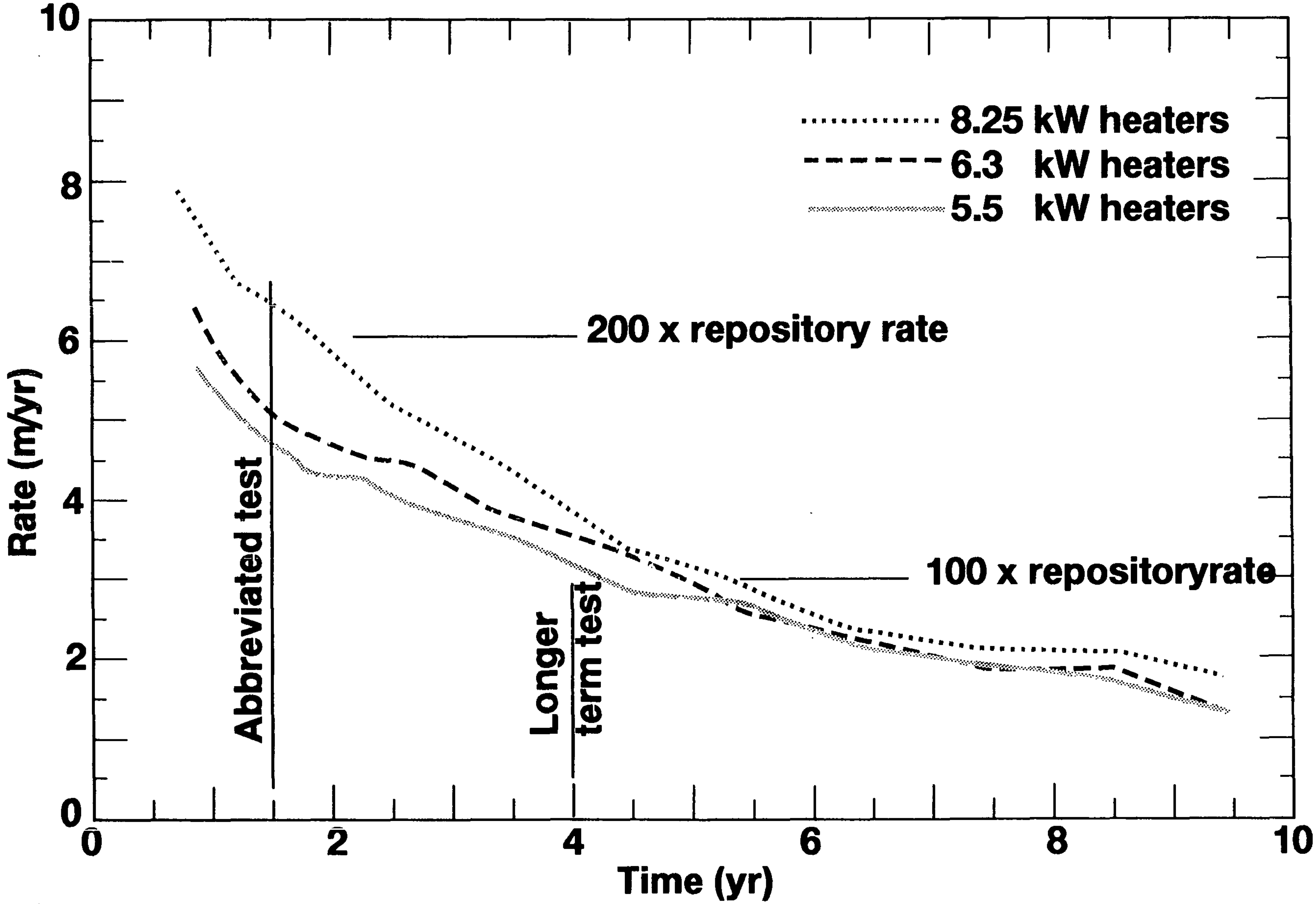
Rate of advance of dry-out front

Repository centerline, 30-yr-old fuel and recharge flux of 0.0 mm/yr



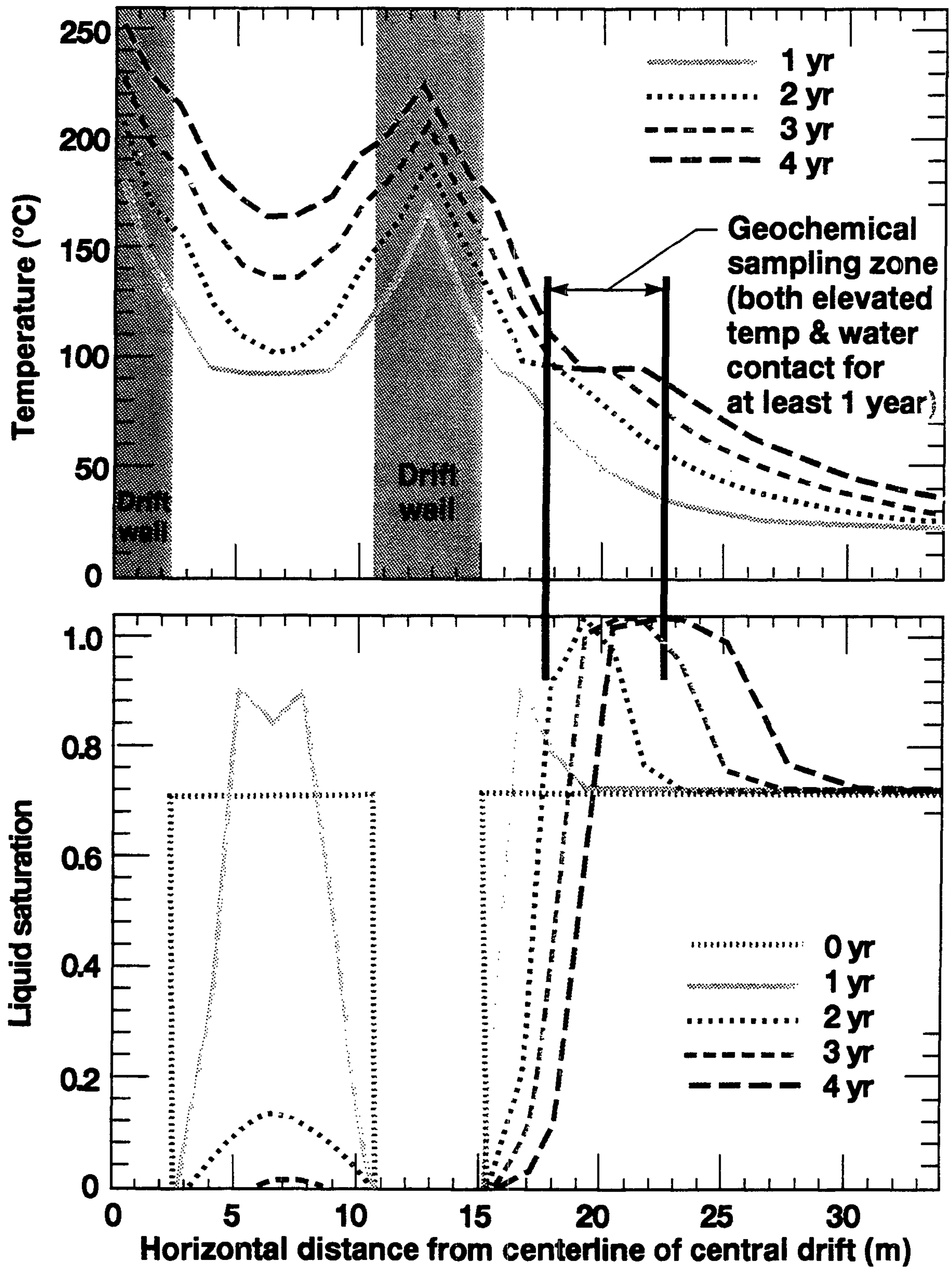
Ee-05/27/93-DW#8-03

Rate of Advance of dry-out front, ESF tests



Es-05/27/93-DW#8-01

Sampling regimes, ESF tests
(6.3 kW heaters)



ES-05/27/93-DIW#8-02