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

NUCLEAR WASTE TECHNICAL REVIEW BOARD
FULL BOARD MEETING

SUBJECT: UNDERGROUND HEATER TESTS

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LLNL Thermal Test Team Leaders

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Tom Buscheck	- Task Leader: Geohydrology
Bill Glassley	- Task Leader: Geochemistry
Annemarie Meike	- Task Leader: Man Made Materials

Summary of *In Situ* Coupled Test Program

Test Name	Processes	Duration (yrs)	Temp (°C)	Information Needs	Perf. Obj.	Characteristics
Axisymmetric	T	<2	250	Fracture flow Dryout front Δ K	2001	Single heater Simple geometry
Heated Block	T-M	<2	200	Fracture prop. Rock mass strength, deformation thermal exp.	2001	Controlled boundary conditions
Thermal Stress	T-M-H	<2	To thermal stress failure	Rock mass behavior and Δ K, mmm, NFE	2001	Simulates in-drift emplacement
Abbreviated Heater	T-H	3	200	Fracture properties Δ K, NFE , dry-out	Post-2001	Isolated and sealed
Long-term Heater	T-M-H-C	4-7	200	Rock-mass behavior changes in mineralogy, water chemistry hydrologic properties	Post-2001	3-D access

Synopsis of Program Approach for MGDS

	TSS/DEIS - 1998	LA/CA - 2001	CA - 2004	ULA/R&P - 2008	L/R&P - 2010	Perf. Confirm. *
NAT.BAR.EVAL.						
GWTT	Bounded	Sub. Finished		Final		
Scenarios	Bounded	Bounded		Sub. Finished		Final
Subsystem Analyses	Bounded	Sub. Finished		Final		Updated
TSPA Source Term	Bounded Model	Bounded Model		Complete		Confirmed
Post Cl. TSPA	Bounded	Bounded		Sub Finished		Final
REPOSITORY DESIGN	ACD	Title I	Title II	Title III	Title III	Title III
Backfill/Seals		Title I (Flex)		Demonstrated		Decision
Materials Inter'n	Bounded	Bounded	Mat'l's Sel.			
Retrievability		Title I	Proof of Princ.	Demonstrated		
Ar. Pwr. Den.	Bounded	Bounded		APD Decision		Final APD
Emplace. Mode		Title I		Decision		
Precl. P.A.	Bounded	Sub. Finished		Final		
Lag Storage	ACD	Title I	Title II	Title III		
Rail Spur	CD		Title I/II	Title II/III	Title III	
WASTE PKG. DESIGN	ACD/Title I	Title II (P'type)	Full Scale	P'type Tested/Title III	Title III	Oper'ns Conf.
Sub Cmp Con		Complete		Updated		
Criticality Con.		Complete		Updated		
Contr. Rel.	Bounded	Conserv. Calcs		Complete		
Materials	Concepts	Determined		Test Complete		Model Confirmed
Waste Form		Srce Term Bnd'd		Final Srce Term		
EBS Thermal	Concepts	Bounded				

*** Performance confirmation program is required to start during site characterization and continue until permanent closure (10 CFR 60.140 (b))**

MDVGAF1.CDR.129/11-9-94

Rationale for Early Thermal Testing In PA

- The Program Approach began with the assumption that much testing could be deferred until post LA. Then each major milestone was considered to determine minimum testing requirements.

- The 2001 license application is a request for the NRC to allow DOE to begin construction of underground facilities consistent with one or more thermal loading design, construction, operational concepts and performance strategies.

- DOE must show reason to believe the thermal response of the site will allow safe construction and operation, this requires a bounded thermo-mechanical model.

- DOE must show reason to believe the thermal response of the site is consistent with the post-closure performance strategy. This requires a bounded hydro-thermal model.

- Early thermal test data provides the technical basis for the thermal adequacy of the license application design.

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

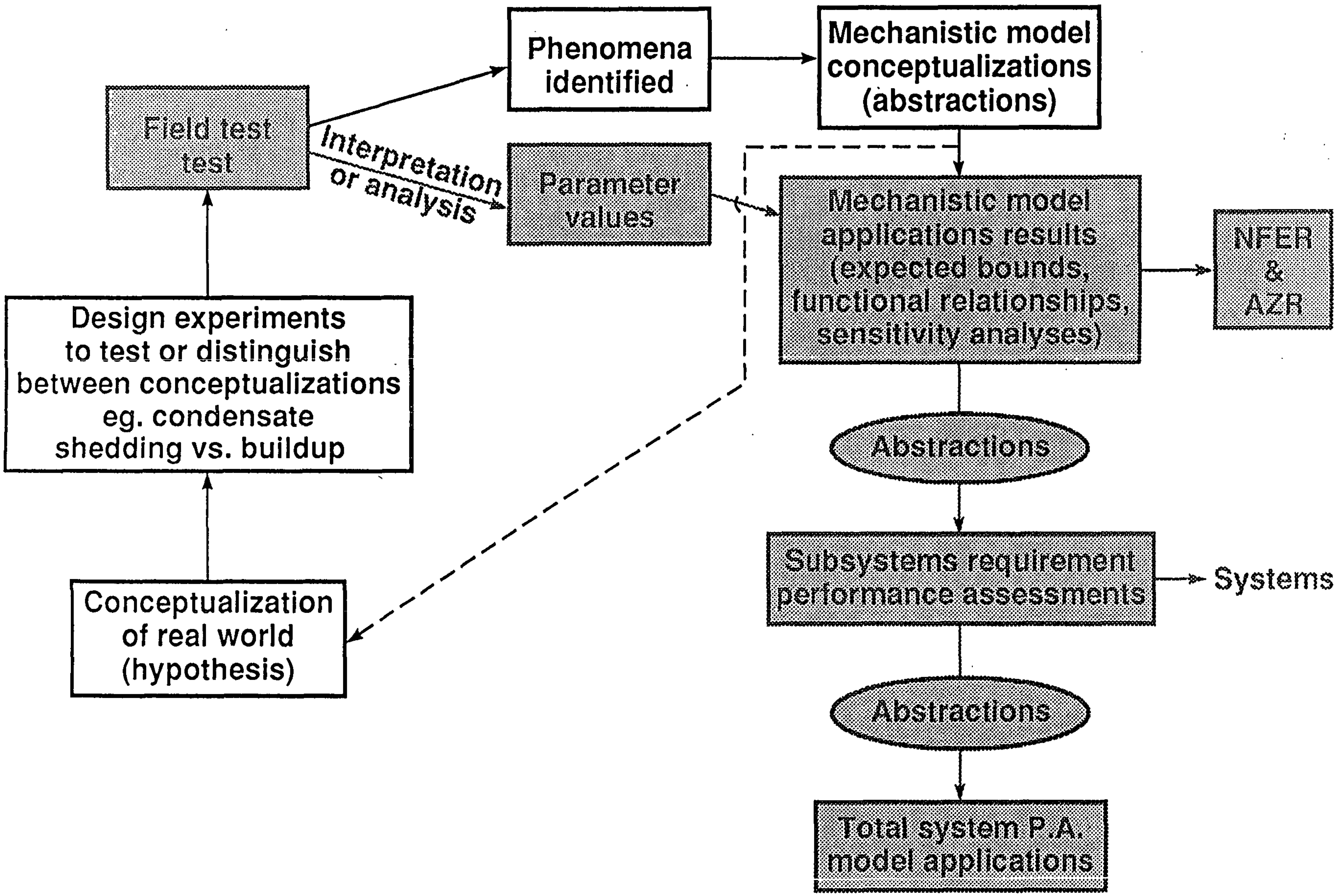
Resolution of these hypotheses will require heater tests conducted under both above- and below-boiling conditions

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

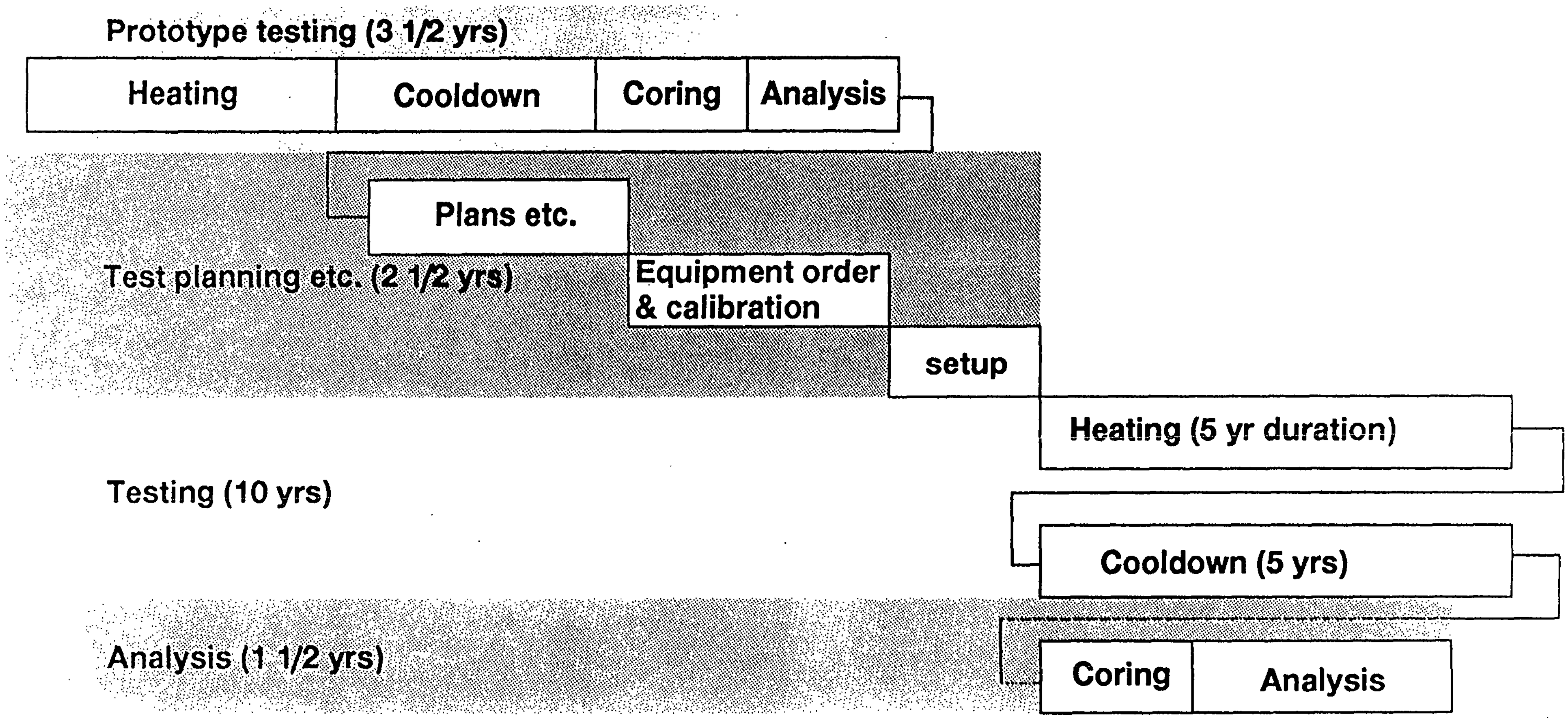
L = limited information, P = preliminary indication,
S = substantial understanding, C = confirmation

ESF: Engineered Barrier System

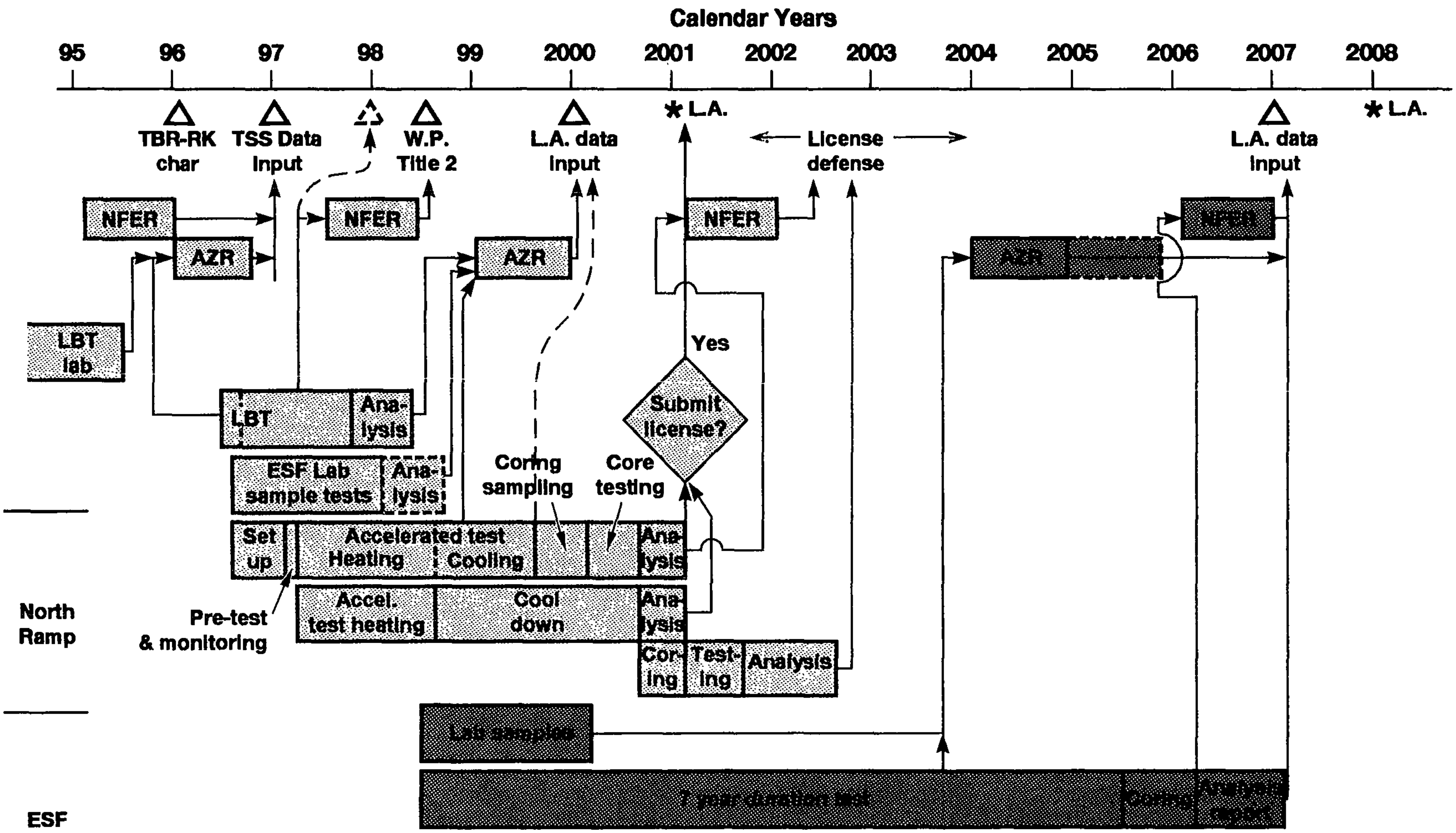


ES11/2/94DW#11-04

Ideal Strategy (no schedule constraints)



Field testing inputs to 2008 LA



TBR – Technical Basis Report

NFER – Near-Field Environment Report

AZR – Altered Zone Report

ES11/14/94DW#12-04

The major challenge facing *in situ* heater tests

- Because of time limitations, heater tests must be accelerated relative to actual repository thermal loading conditions

- How much can the heating rate be accelerated without distorting the critical coupling between hydrothermal flow and geochemistry and geomechanics?

Criteria for determining the size and duration of *in situ* heater tests

- Velocity of the dry-out front
- Spatial extent and duration of hydrothermal perching of condensate
- Peak rock temperatures
- Time rate of change of temperature
- Dry-out zone volume

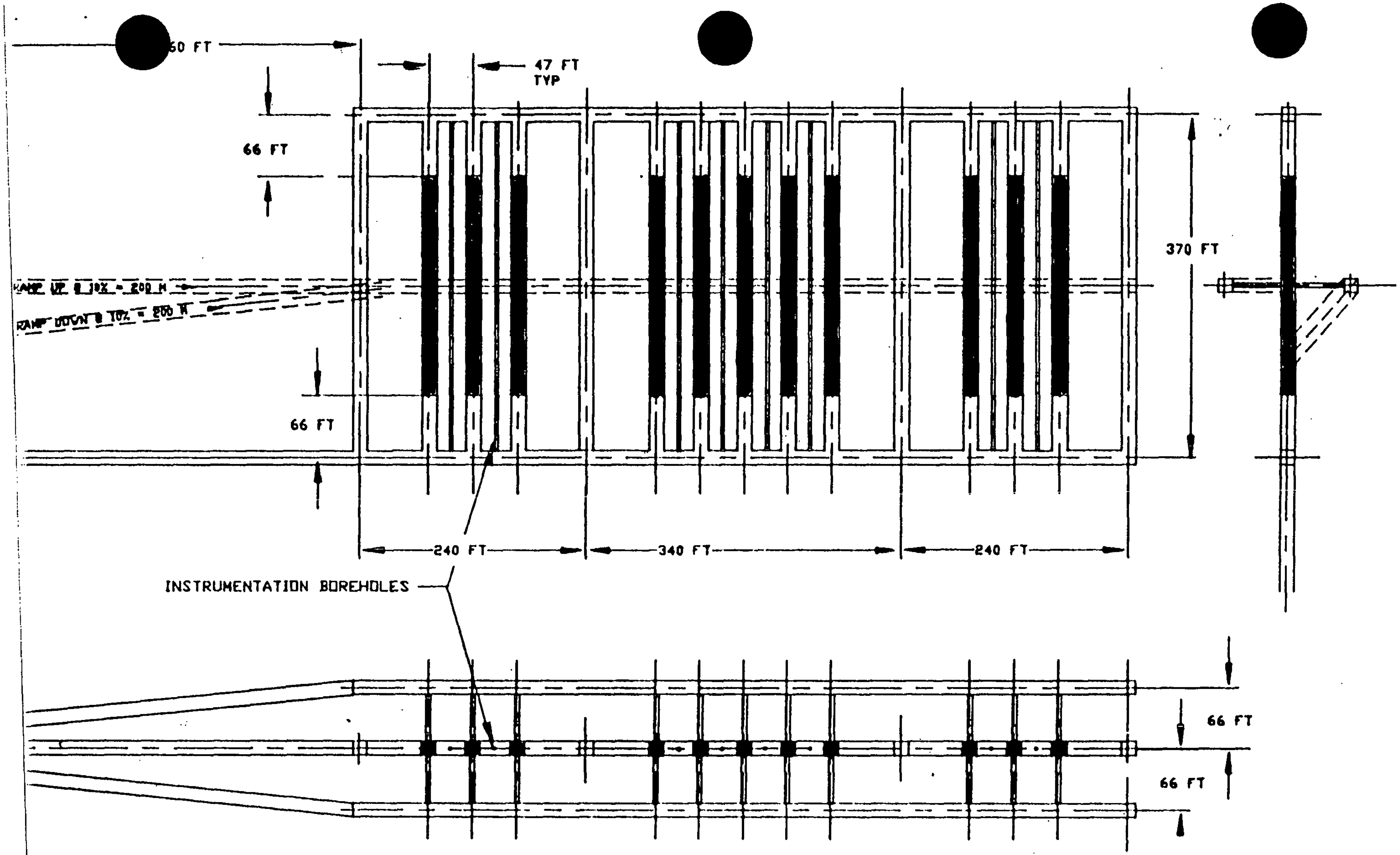
Evolving Test Plans

Originally (LRP-1989), EBS field test plans called for a large-scale, long-term heater test using 11 parallel drifts (3/5/3) with 3-D access provided by drifts above and below, with a test duration of 7-10 years.

More recent schedule pressures resulted in splitting off a smaller more accelerated test (3 years), run in parallel with a larger and longer test.

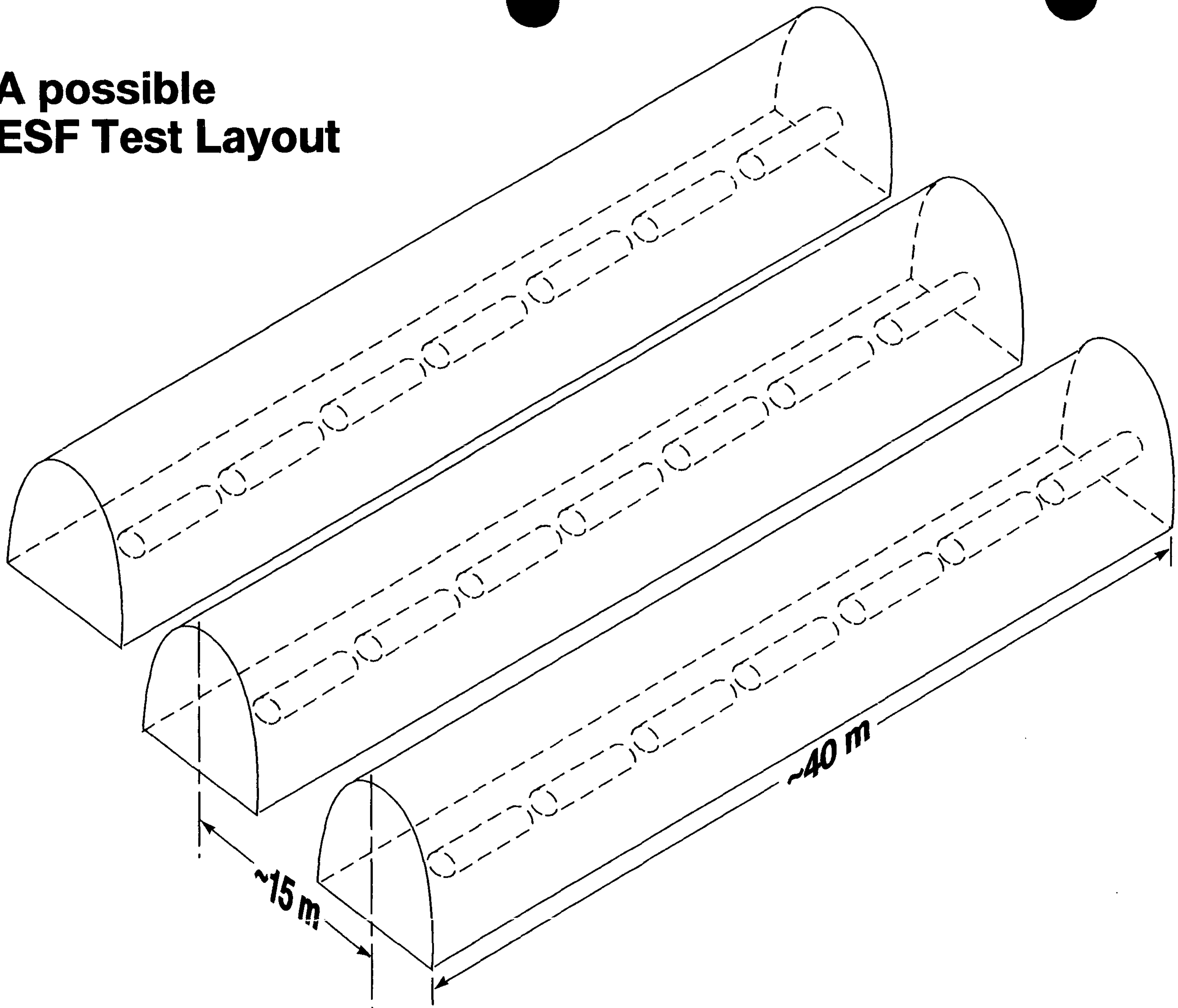
The new Program Approach plans for a 2 year accelerated test prior to LA followed by a larger and longer test.

There is current interest in adding small single drift or borehole test which could be fielded in multiple locations to assess hydrothermal response in differing bulk permeability rocks. This would be of most value to assess dominant processes in the lower thermal loading regimes which may be more sensitive to rock heterogeneity.



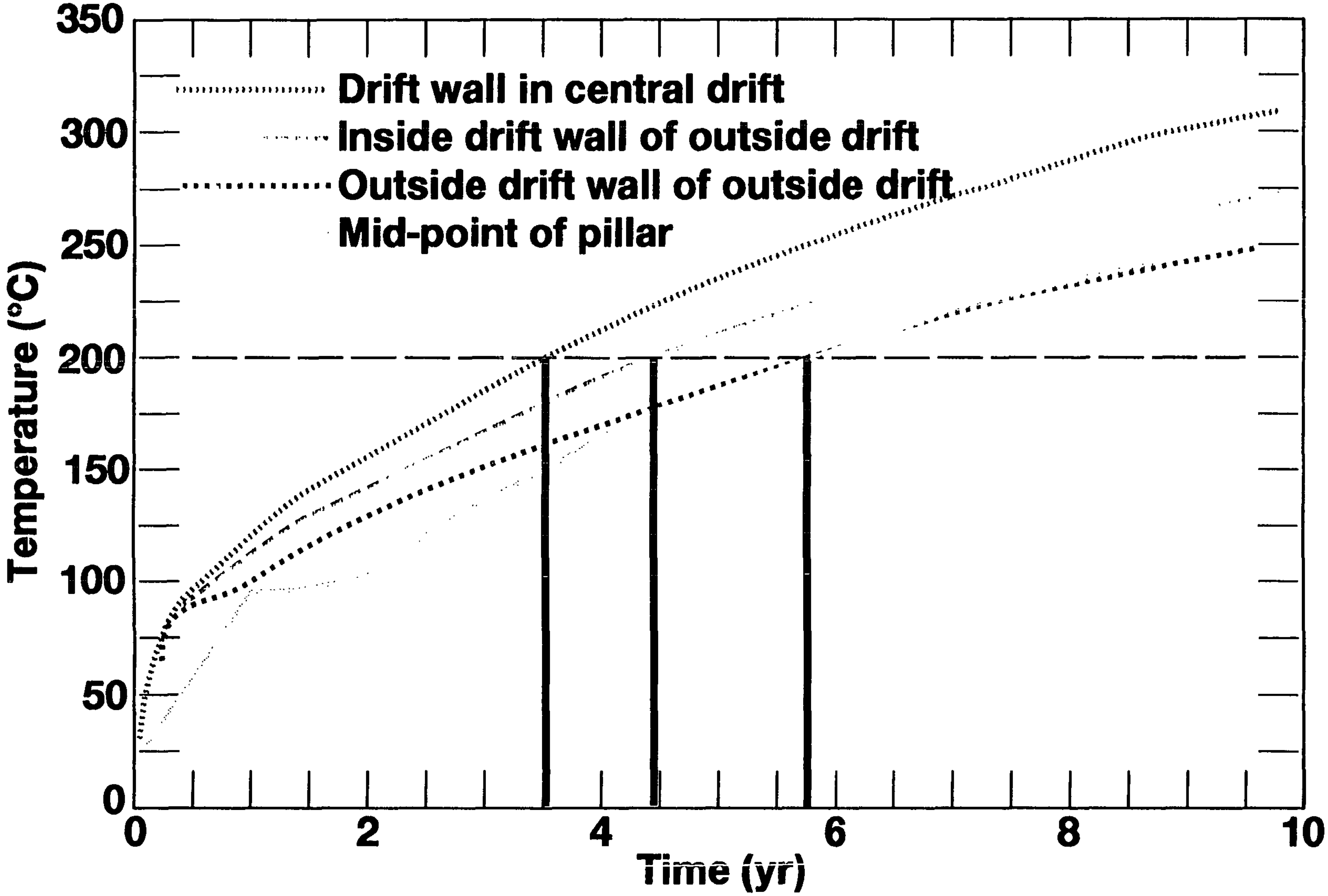
PRELIMINARY LAYOUT OF ESF TESTS

A possible ESF Test Layout



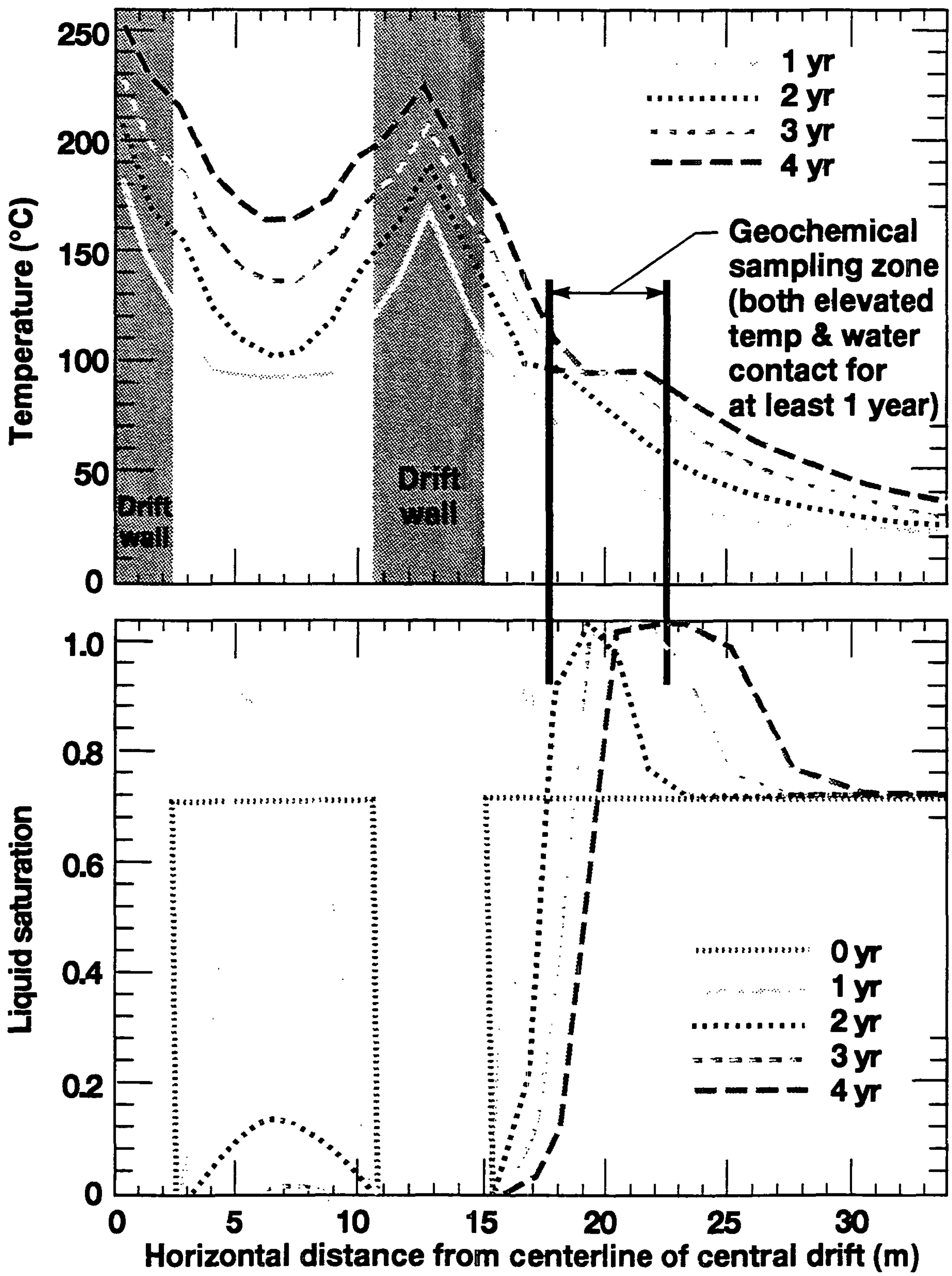
ES11/14/94DW#8-04

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



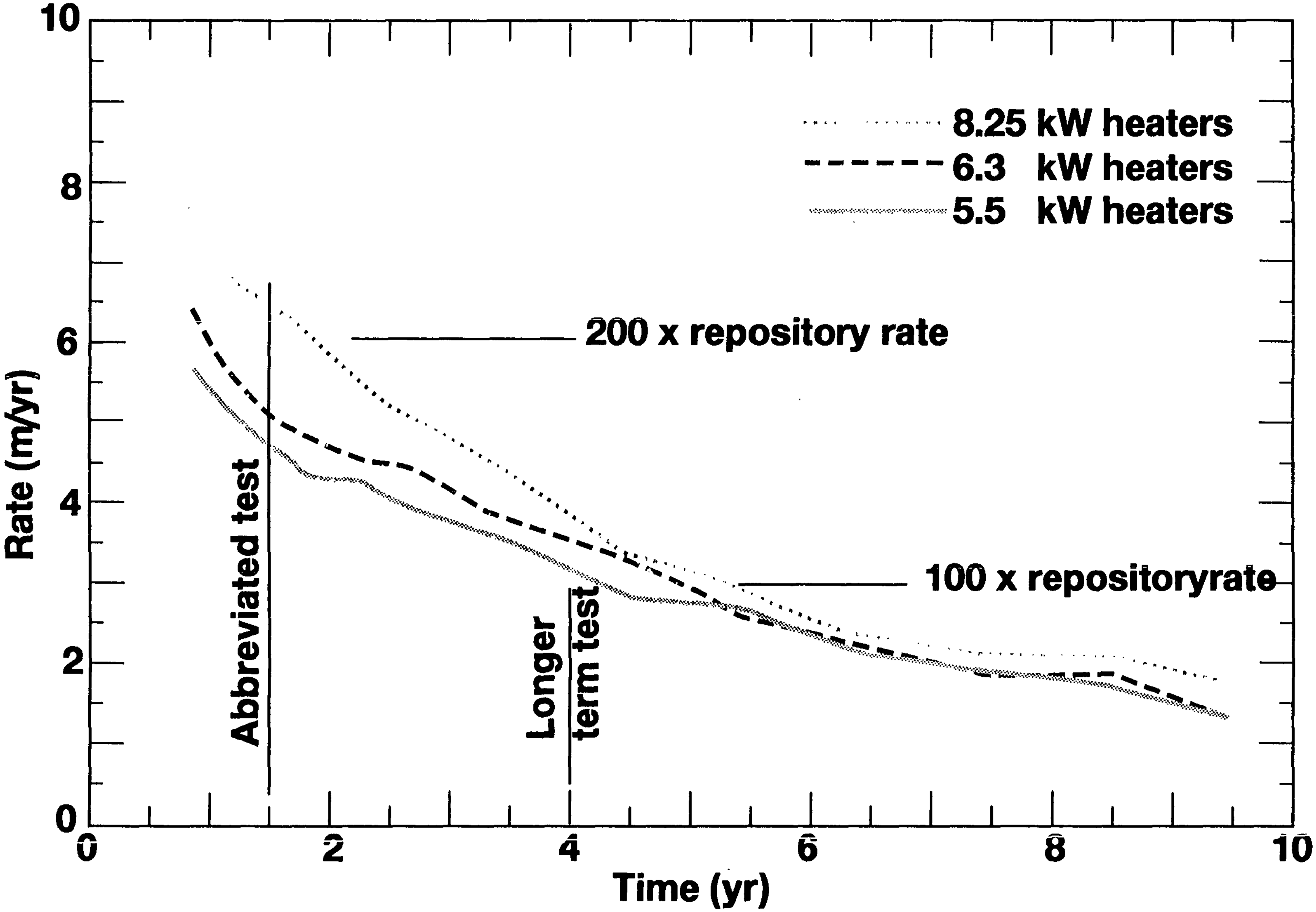
Ee-05/27/93-DW#8-04

Sampling regimes, ESF tests (6.3 kW heaters)



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

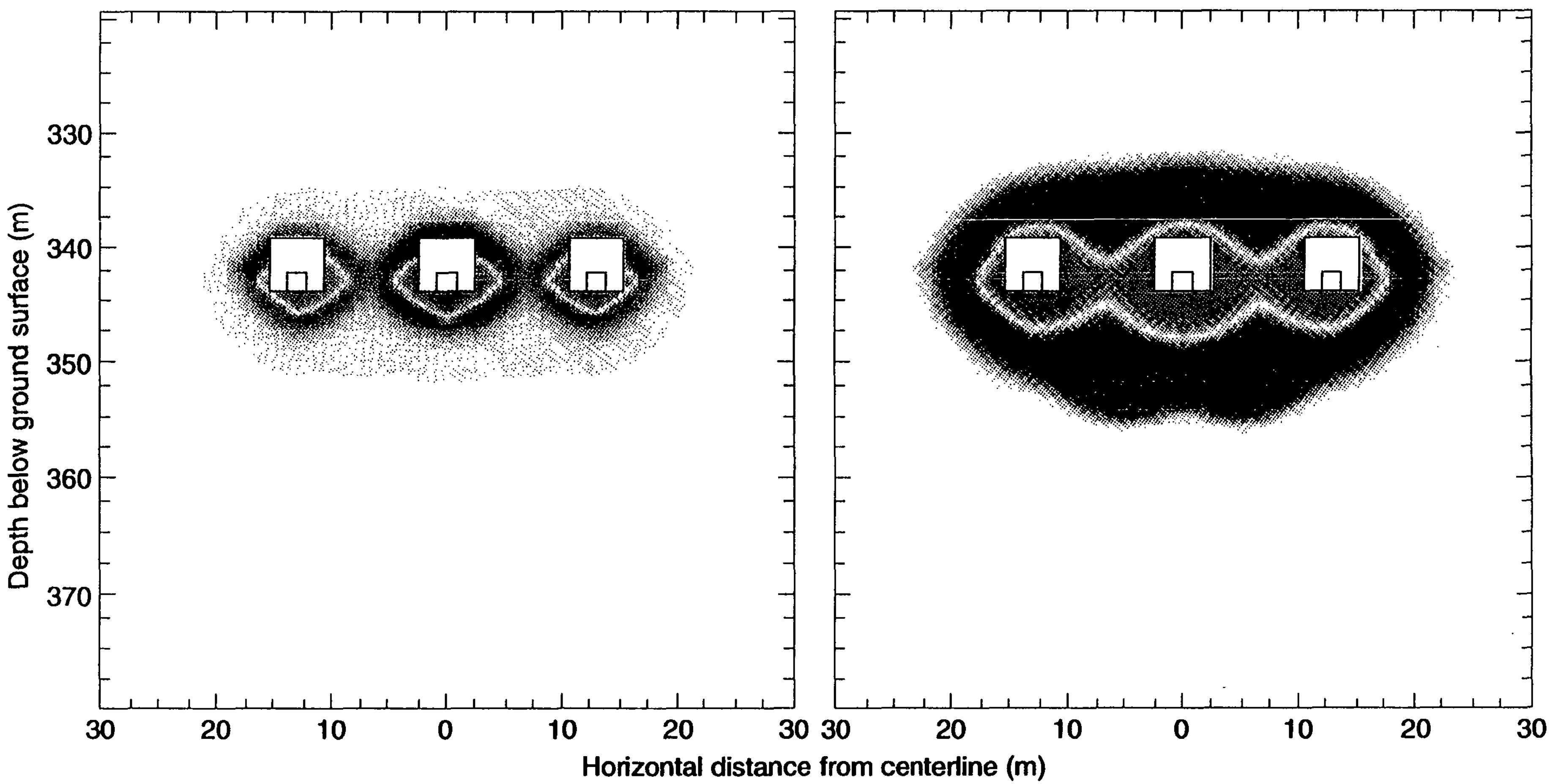
Rate of Advance of dry-out front, ESF tests



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

During an *in situ* heater test coalescence of the dry-out zones between heater drifts begins to occur within two years

Dimensionless liquid saturation contours for an array of three heater drifts on 12.8 m center-to-center spacing, each with a constant heat source of 1.0 kW/m

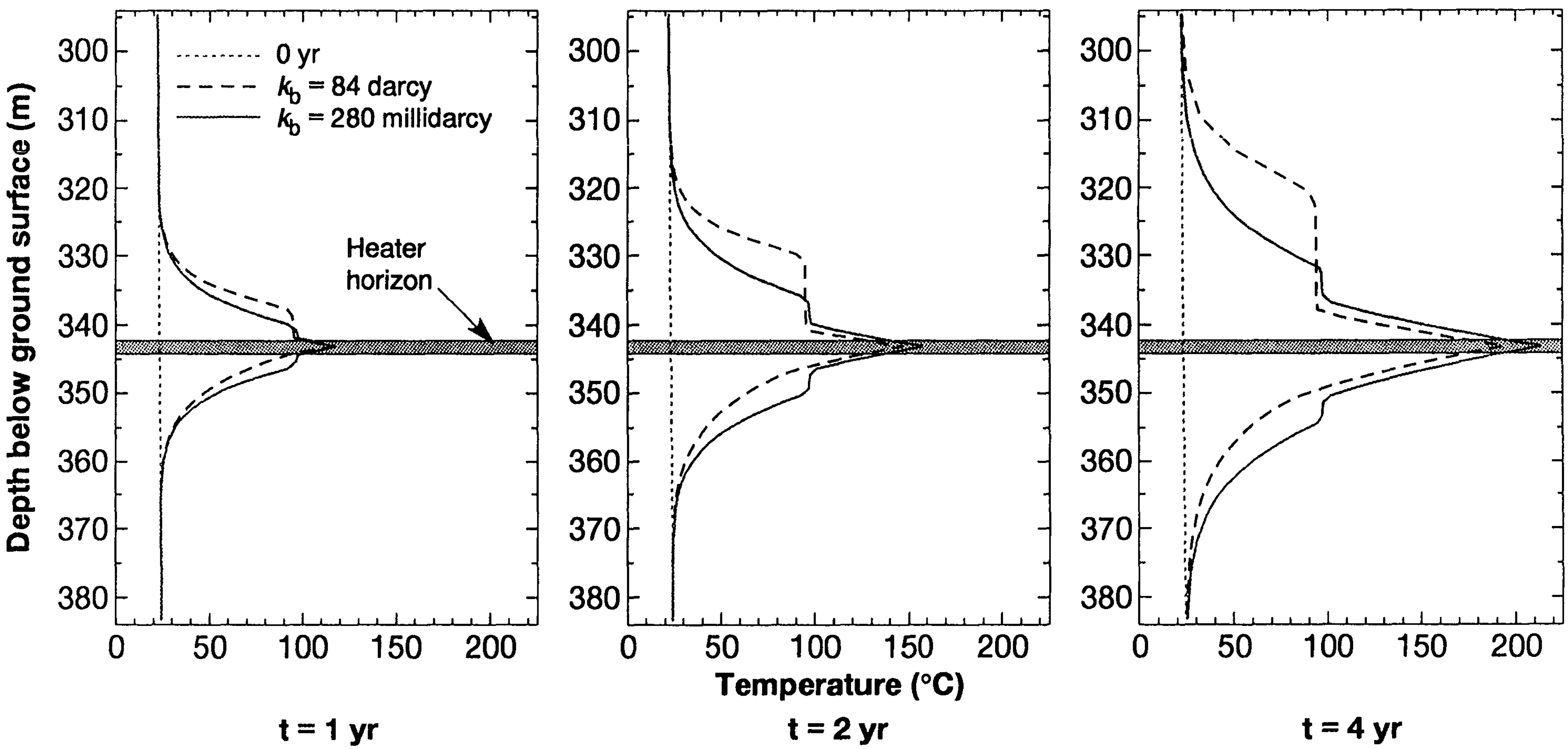


t = 1 yr **t = 2 yr**

ES-TB-8ab (7-1-92) IL

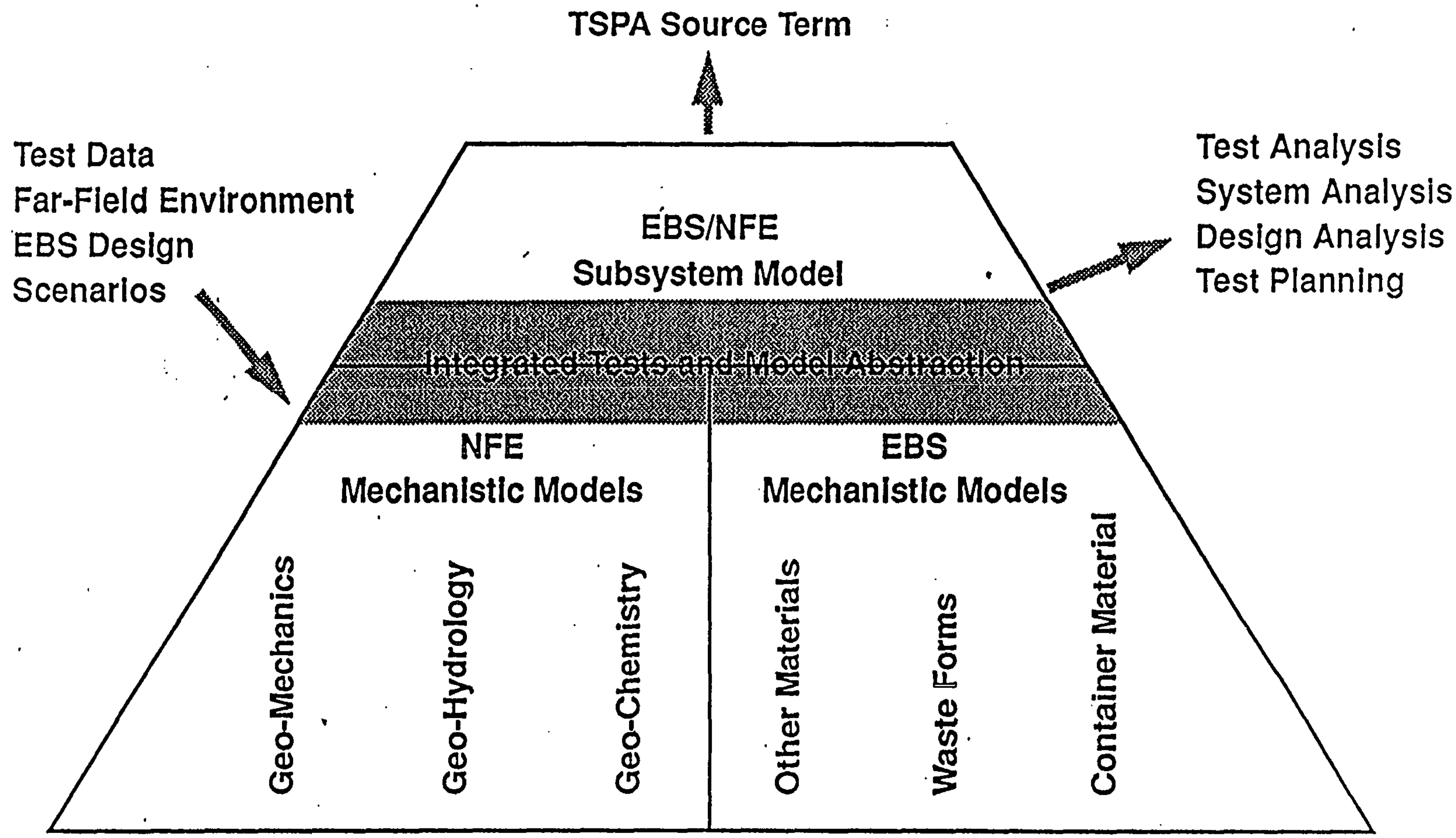
When buoyant, gas-phase convection dominates vapor flow, all vapor flow and condensation is driven above the heater horizon, resulting in a strongly asymmetrical vertical temperature profile

vertical temperature profile at midpoint of the central heater drift in an array of three heater drifts each containing seven 5.5-kW heaters for k_b = 84 darcy

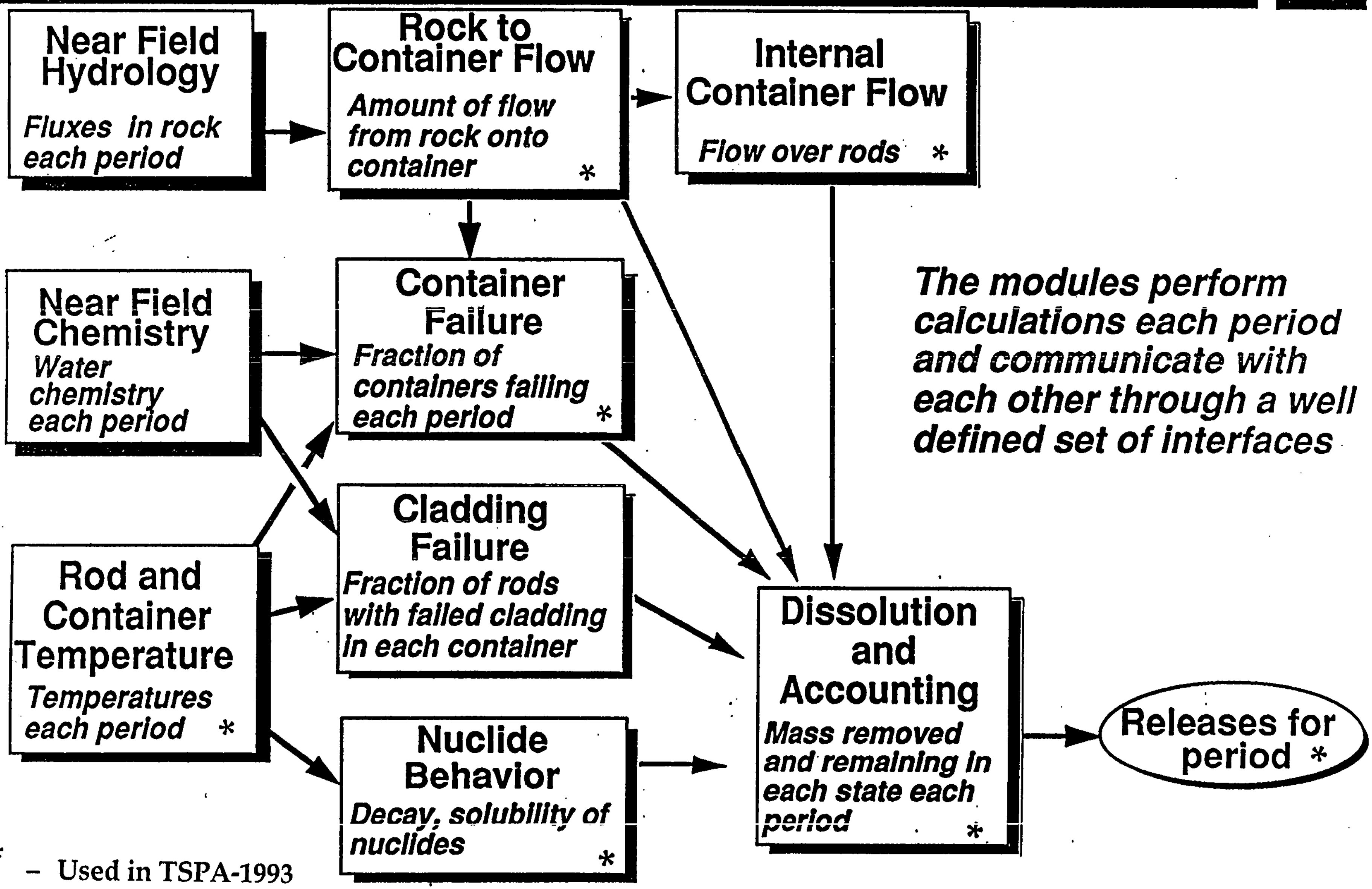


ES-TB-13abc (3-19-94) IL

EBS/NFE Subsystem PA Models



YMIM consists of a set of modules which represent basic EBS processes



The modules perform calculations each period and communicate with each other through a well defined set of interfaces

* – Used in TSPA-1993

Current EBS/NFE PA Development

Feature/Process	TSPA-1 (1991)	TSPA-1993
Waste package	Small, thin wall	Small thin wall Large multiple material
Emplacement	Borehole	Borehole In drift
Thermal Loading	Implicit 57 kw/acre	Explicit: 28.5, 57, 114 kw/acre
Container performance	Arbitrary failure history Isothermal after 1000 yr.	Deterministic Temperature dependent Oxidation, General aqueous corr. Stochastic localized corrosion
Waste form performance	Isothermal, arbitrary rate	Temperature dependent Oxidation, Alteration, Dissolution
Near Field Environment	Isothermal, 'ambient'	Hydrothermal flux modeling Temperature dependent Dry out effects Reflux effects

Many thermal and coupled processes have not yet been included

- No Hydrothermally driven water contact modes included
- No Near Field Geochemistry details included
- No Extended Dry Out effects included
- No Man Made Materials effects included

Summary

The in-situ EBS/NFE test planning is evolving with the program approach.

Early accelerated tests will provide the basis for the thermal strategies in the license application for construction.

Longer term tests will provide the basis for the final thermal loading selection and the license application for operation.

Test plans are being developed to resolve hypotheses regarding thermal response at both ends of the thermal loading regime.

Tests will provide the basis for models of coupled processes and the response of both the near field natural system and of materials used in the EBS.

Tests results are coupled to model development and application, design decisions and analyses, and licensing documentation.