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

NUCLEAR WASTE TECHNICAL REVIEW BOARD
FULL BOARD MEETING

SUBJECT: WASTE PACKAGE ENVIRONMENT THERMAL TESTS

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"A Critical Issue...

DOE's theoretical, untested understanding

of the magnitude and consequences of...evaporation and condensation...of moisture...adjacent to the emplaced waste...."

Sixth Report to the U.S. Congress and the U.S. Secretary of Energy, Nuclear Waste Technical Review Board, December 1992

Test Strategy

Scale	Purpose
Lab Scale Core - 1 ft. hours to days (some long-term)	Property Measurements Matrix Processes Single-Fracture Processes Limited Model Testing
Block Scale 1 ft. to 3-5 m.	Multiple-Fracture Processes Fracture Interconnectivity Phenomena Coupled Processes

In Situ Heater Tests

ESF Tests (up to few 100 ft.)	Site characterization *In Situ* Hydrothermal/Geochemical/ Geomechanical Responses
Large Scale	Scaling Effects, Natural Heterogeneity Impacts
Repository Scale Monitoring	Performance

Laboratory Scale

- **Small geometrical scale (core size/bench scale)**
  - Property measurements--mainly matrix
  - Intact matrix processes
  - Single fracture processes
  - Uniform or "porous media" processes
- **Short duration**
  - Usually hours or days
  - Some (geochemistry) for longer durations

Block Scale Tests

- **Relatively small scale (up to 3-5m) with durations of about 1 yr**
  - **Processes with coupling between matrix and fracture system**
  - **Interaction of multiple fractures (focus on small scale; therefore less heterogeneity)**
  - **Characterization/testing technique evaluations**

Note: Shorter duration and early testing will support early decisions

Large Scale *In Situ* Tests

- **Scale of 100s of feet; durations from 1 year to 5 to 7 years**
  - **Characterize response of Yucca Mountain to emplacement**
  - ***In situ* rock-mass (large-scale) property characterization**

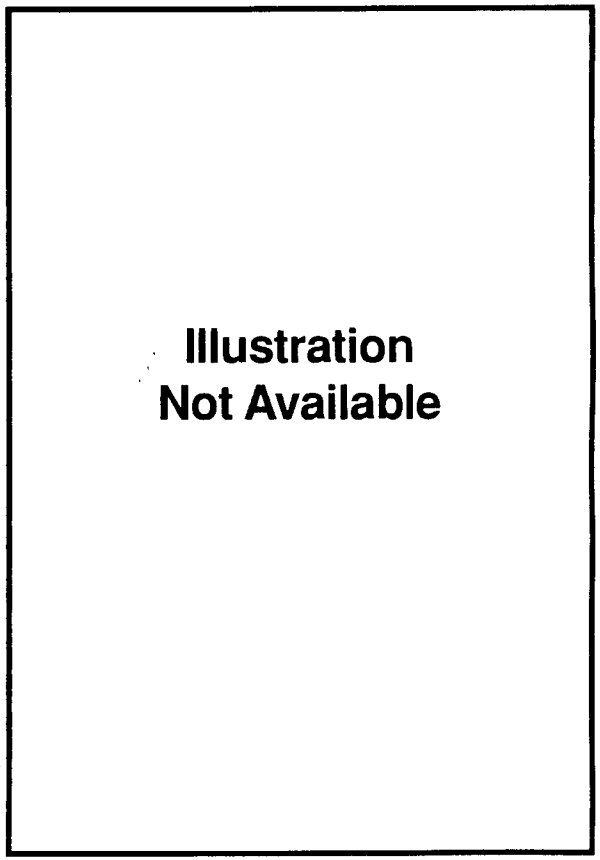
Note: Shorter duration supports license application
Longer duration tests support defense of license

Performance Confirmation Monitoring

- **Repository or mountain scale; long duration (50-200 years)**
  - **Large-scale characterization or response to tie with large-scale geologic analogues**
  - **Confirmation of early portions (200 years) of very long-term predictions (10,000- to 100,000-year predictions)**

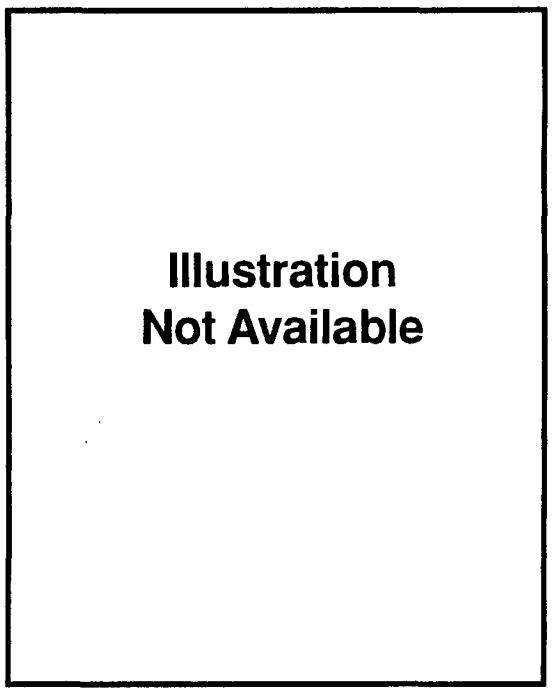
Measurements Confirm Elements of the Conceptual Model

- Dry region around heater, drying increases toward heater
- Saturation "halo" next to dry region and later dries, as rock gets hotter
- Radius of dry region matched prediction of 0.6-0.7 m; total change is 0.16 g/cc
- Fractures have measurable effect on drying/condensation front; re-wetting primarily along fractures
- Measured temperatures close to predictions; slight fracture effect, where boiling occurs

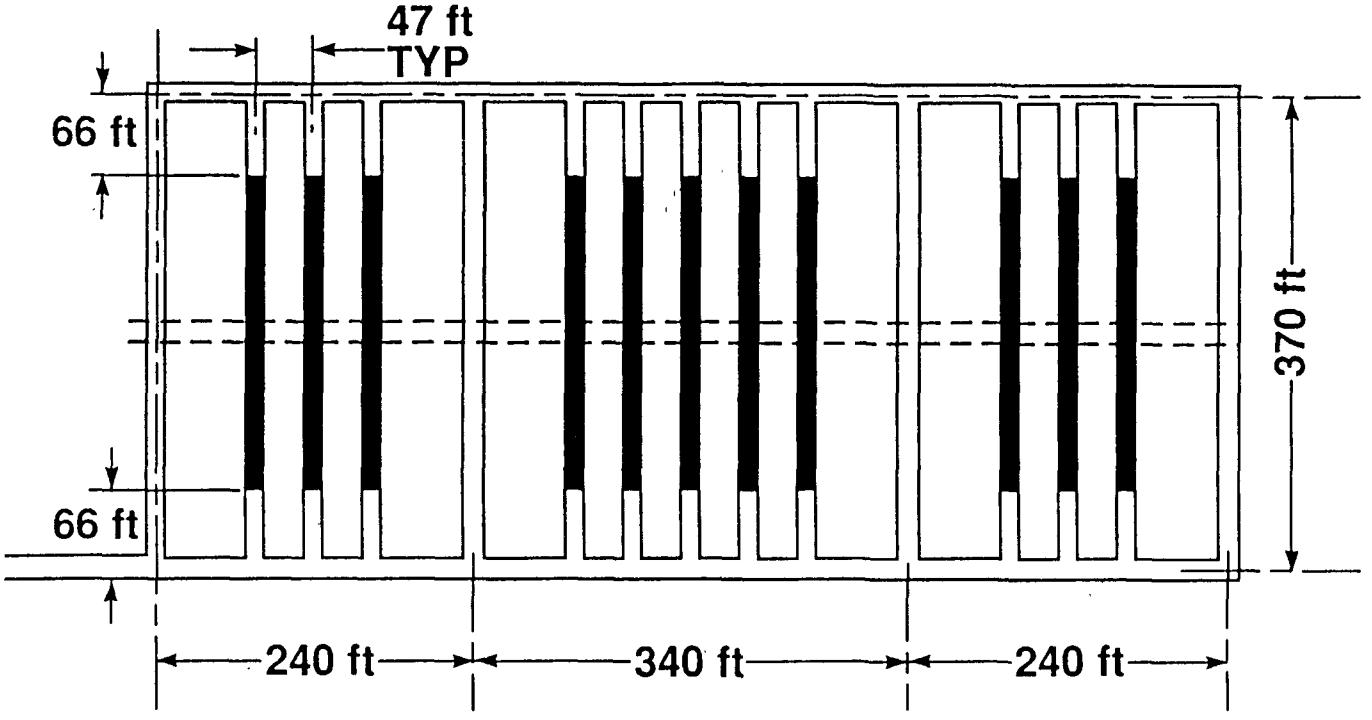


There Were Some Surprises

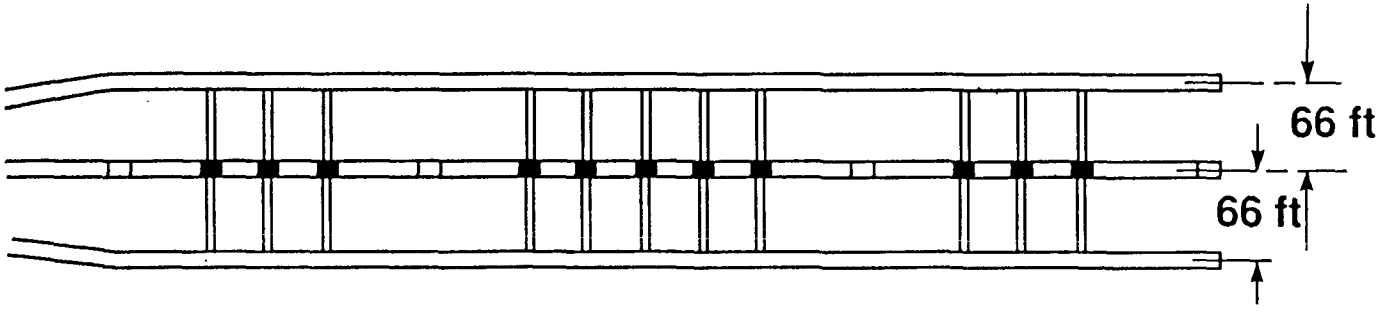
- **Below-heater rock dried faster, as temperatures increased**
  - Gravity, fractures
- **Above-heater rock rewetted faster, as temperatures decreased**
  - Steeper moisture gradient, gravity
- **Capillary condensation played a major role during re-wetting**
- **Slight increases in rock permeability**
- **Several measurement problems: corrosion, inadequate calibration process, inconsistent results**



Layout of ESF Tests



Plan



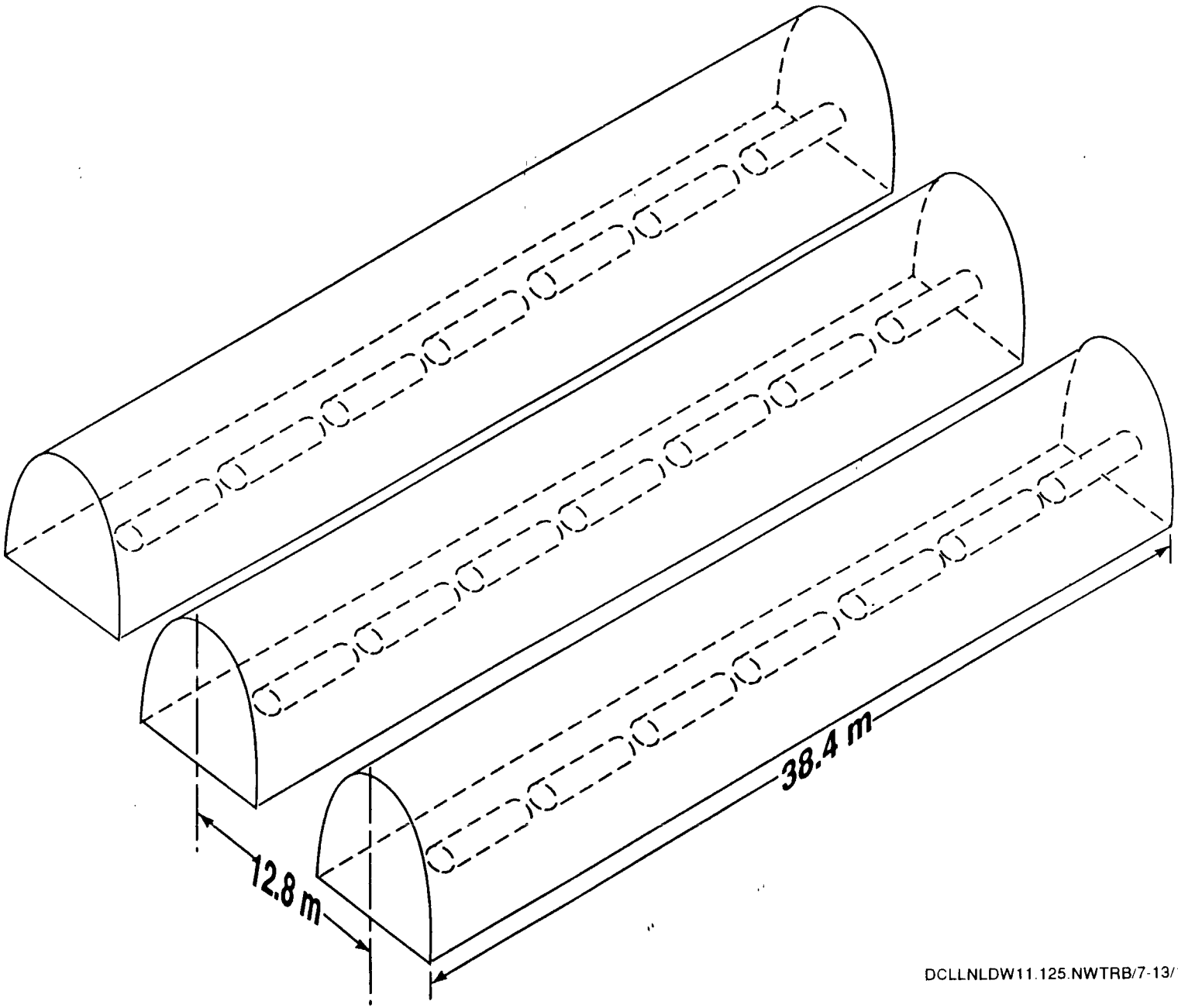
Cross-section

DCLLNLDW9.125.NWTRB/7-13/14-93

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
- Velocity of dry-out front
  - Lab tests of up to 1-year duration required
- Size and duration of condensate zone
- Time rate of change of temperature

ESF Test Layout



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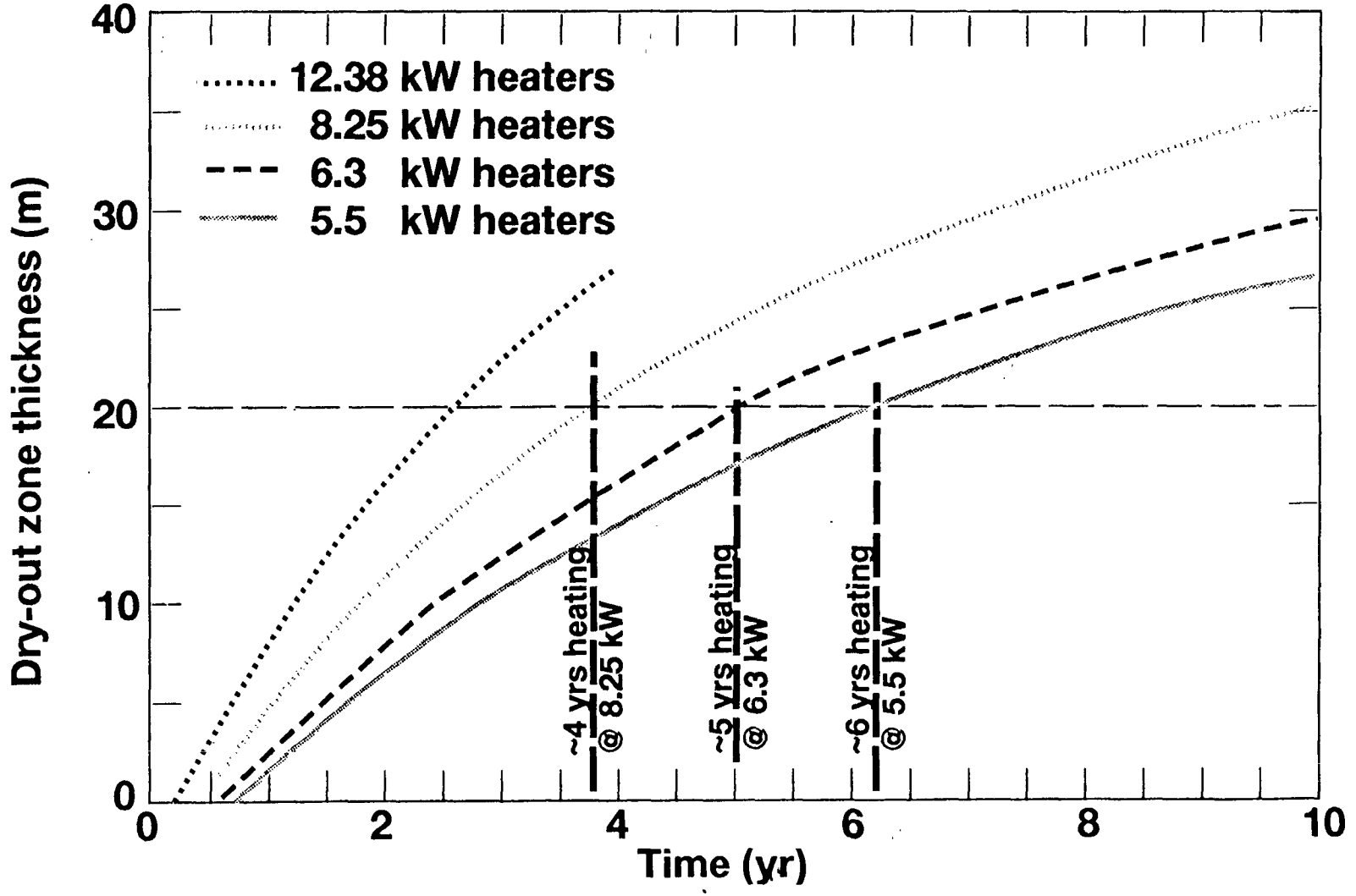
Duration of Heating for 10-m Radius Dryout
(Central Drift Midpoint)



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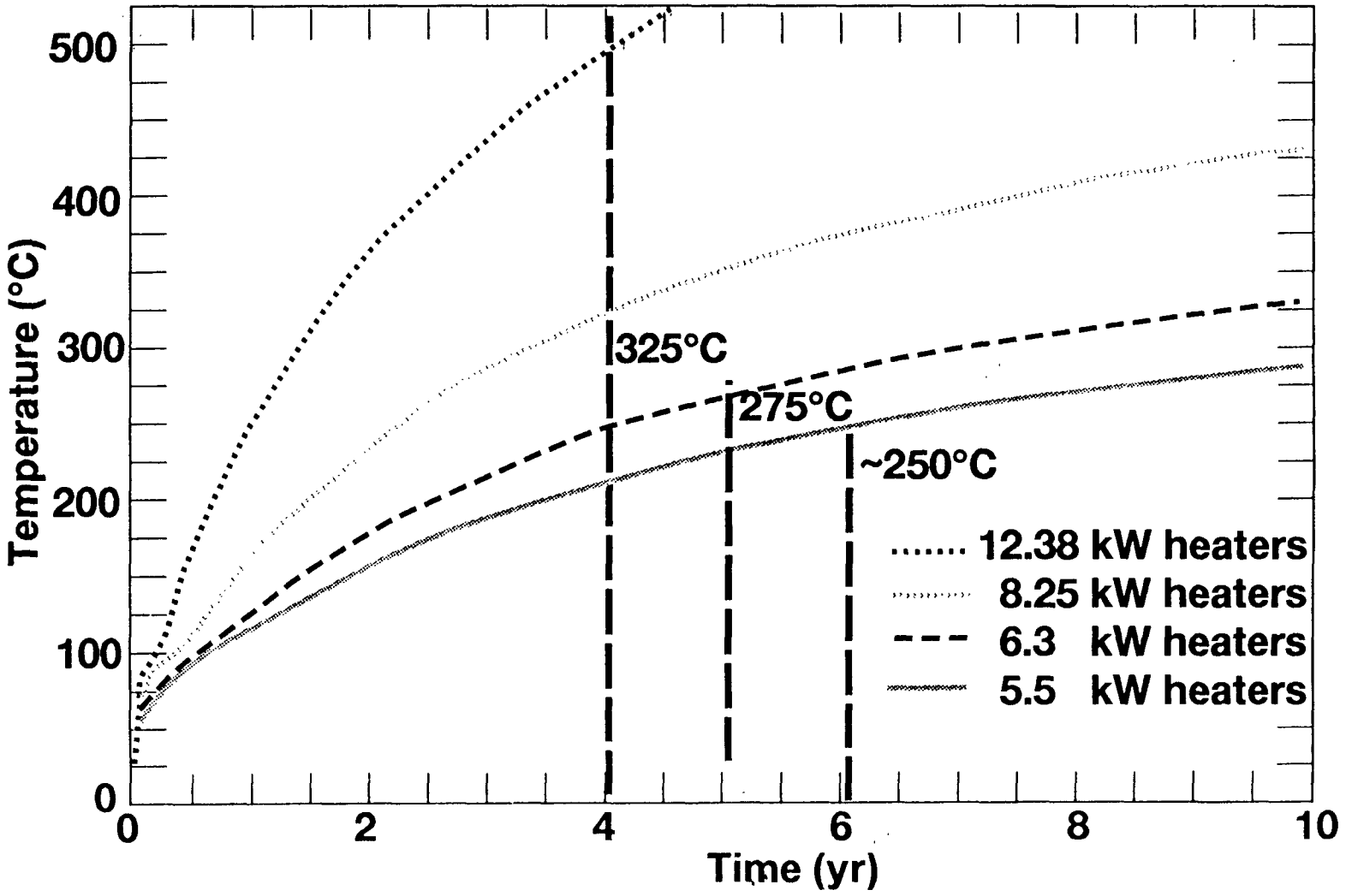
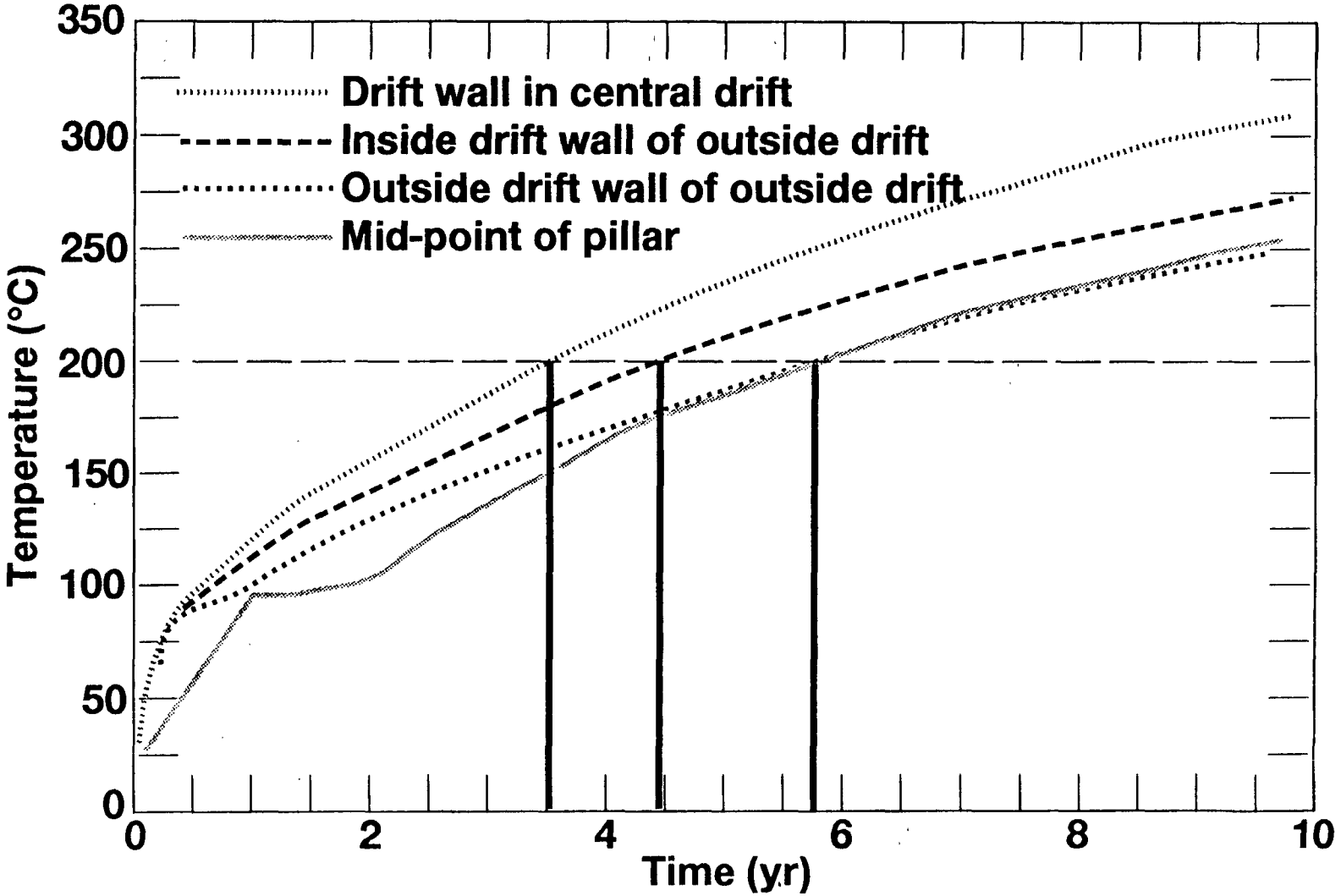
ESF Drift Wall Temperatures vs. Heater Output

(Central Drift at Midpoint)



ESF Heating Duration that will not Exceed 200 °C
(6.3 kW Heaters)



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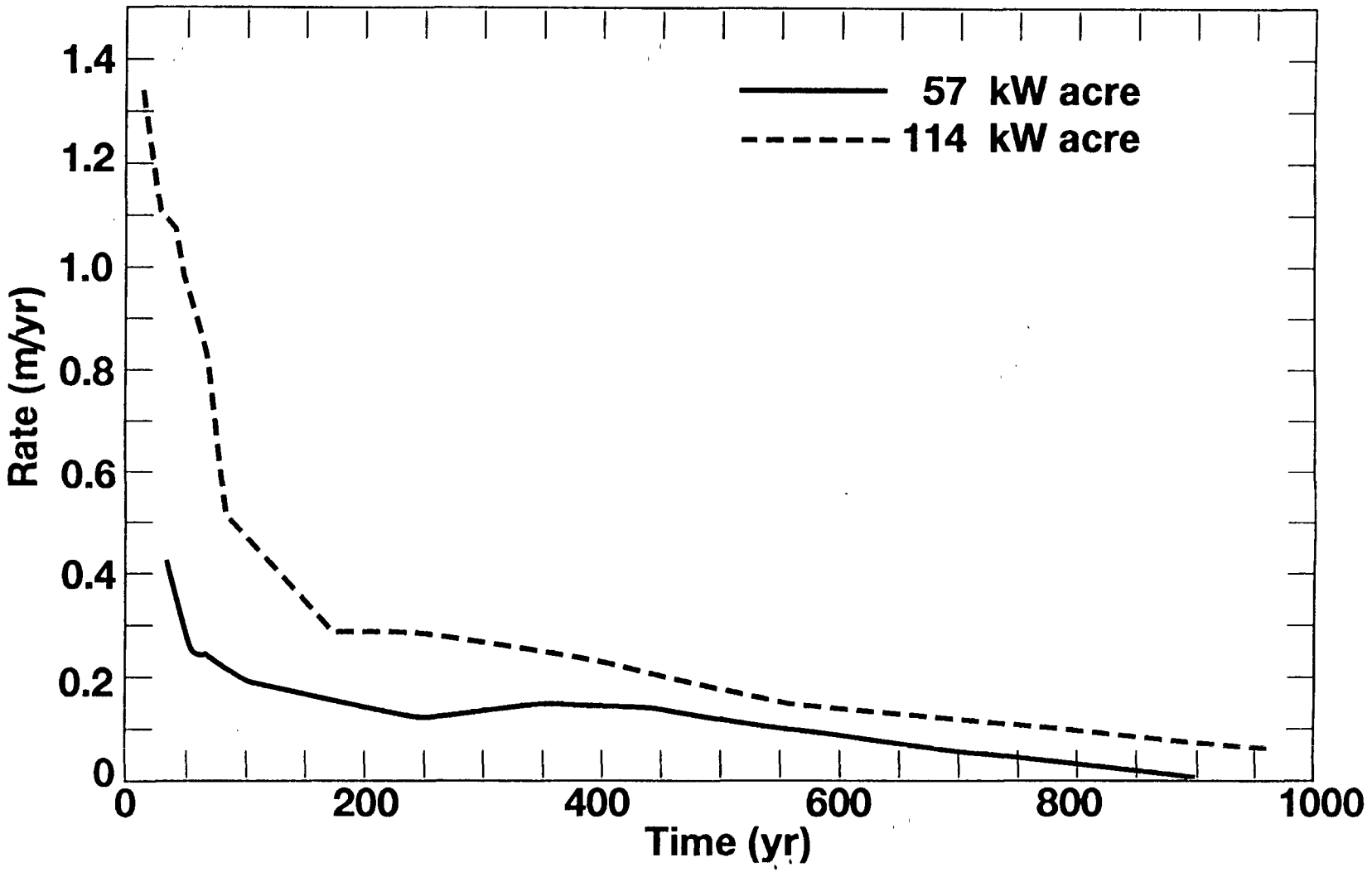
Rate of Advance of Dry-Out Front

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



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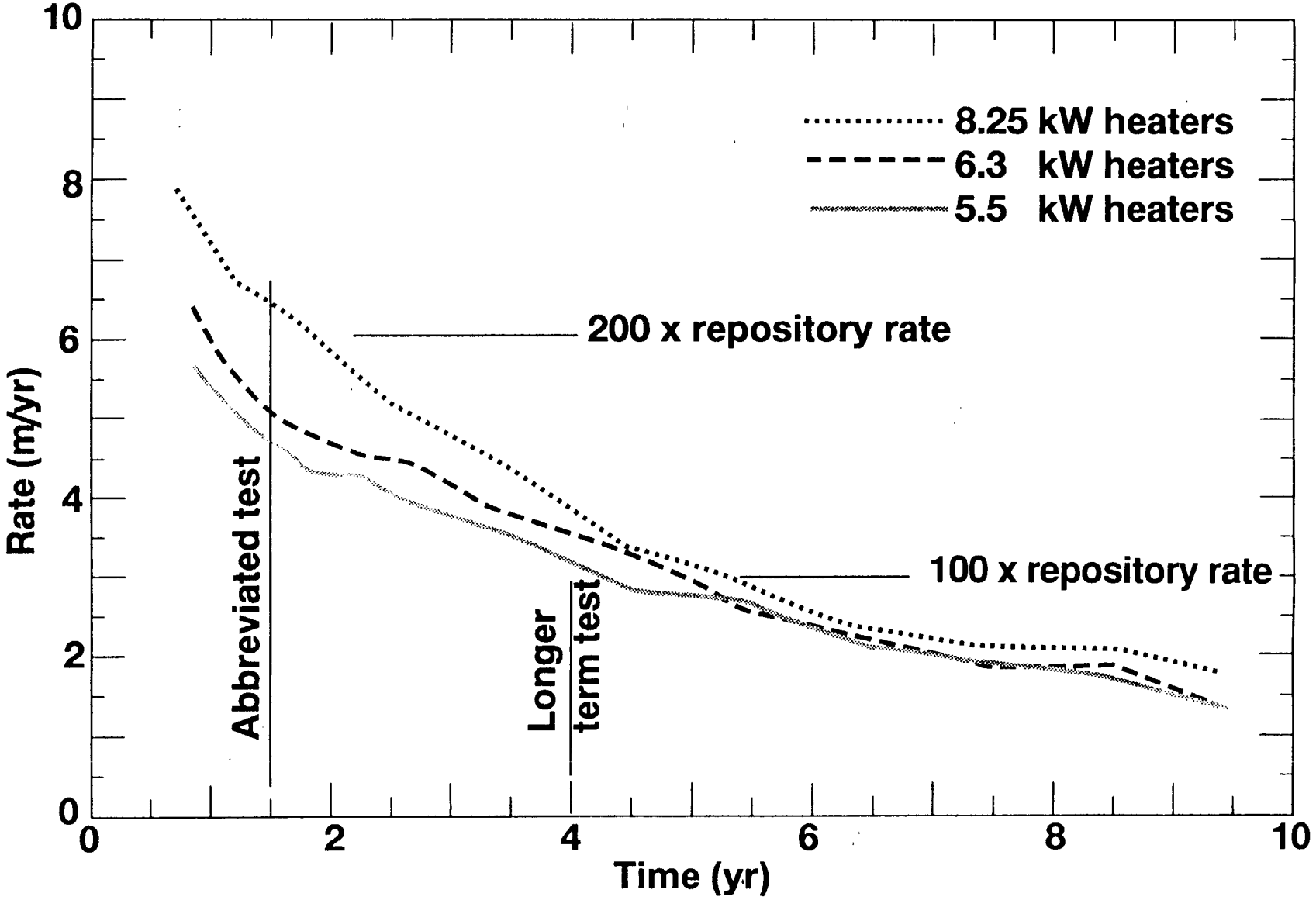
Rate of Advance of Dry-Out Front: ESF Tests



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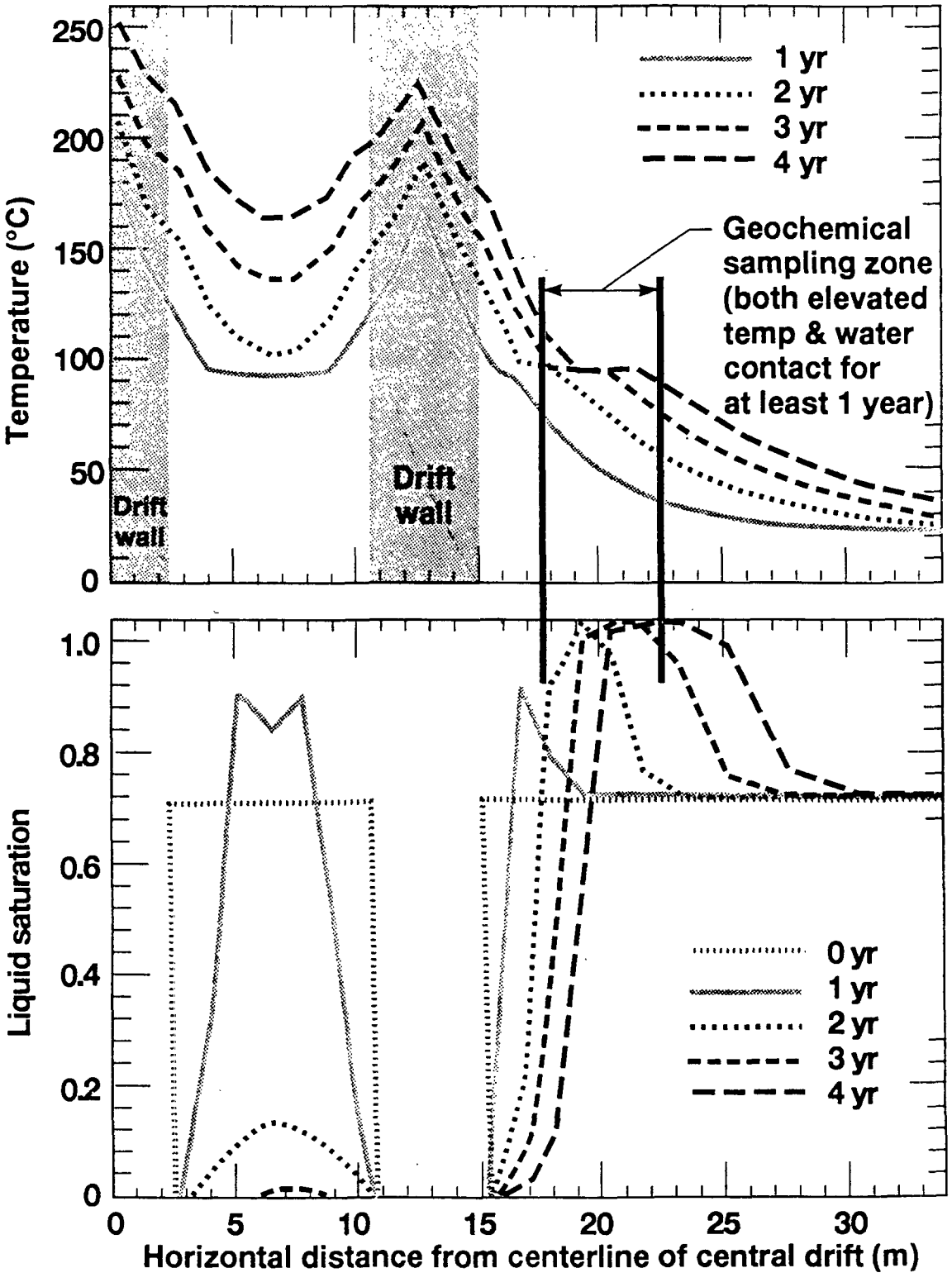
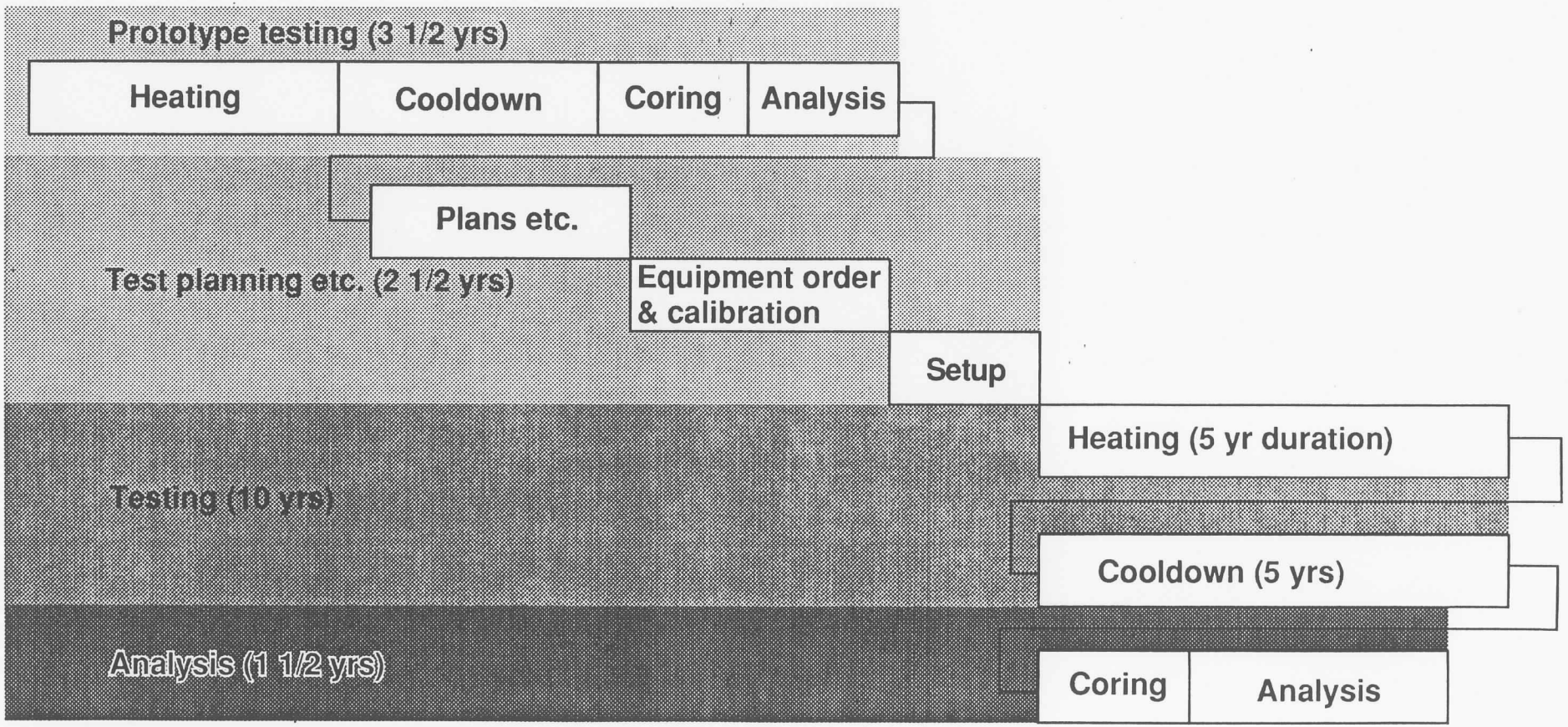
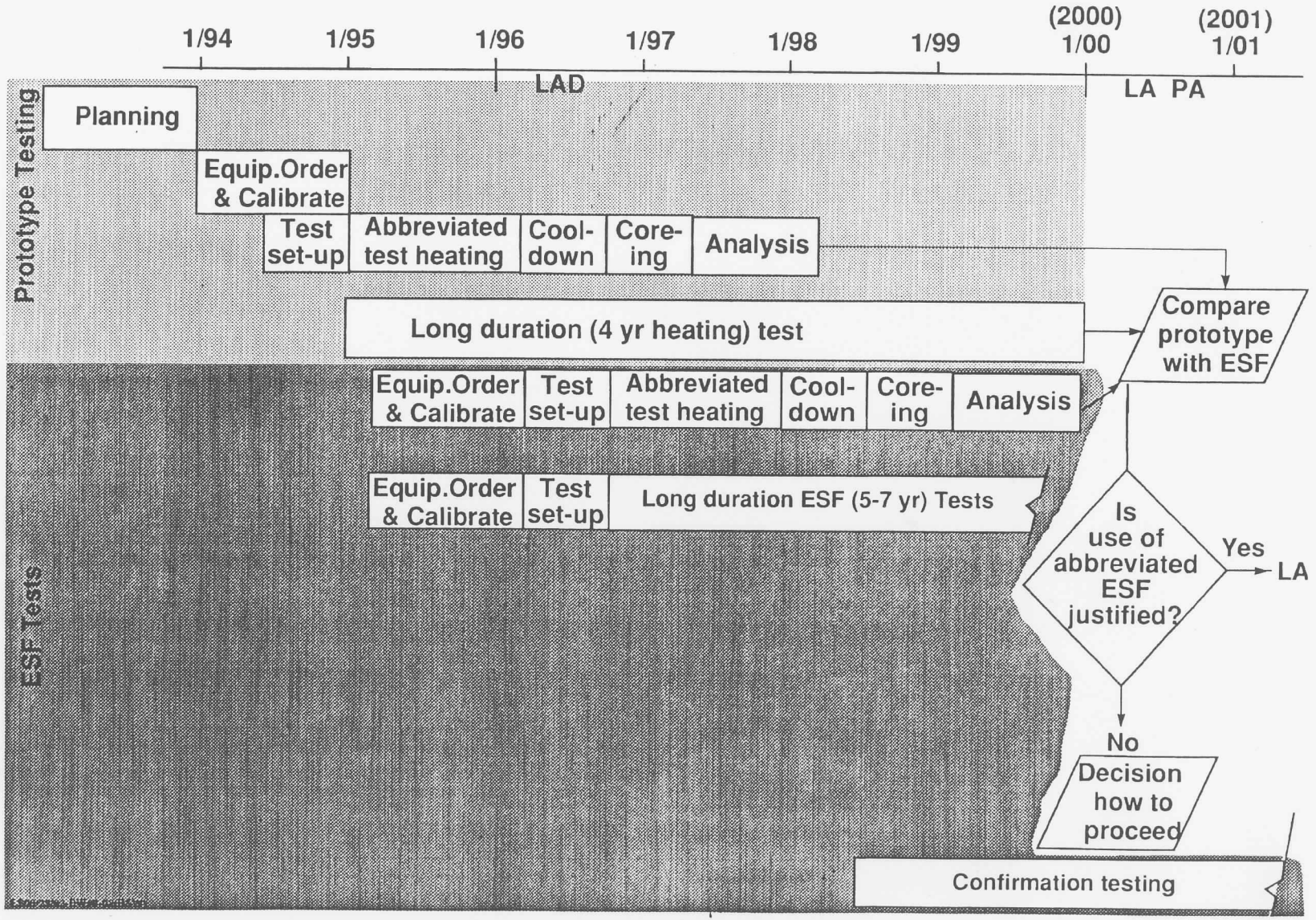
Sampling Regimes: ESF Tests (6.3 kW heaters)



Ideal Strategy



Strategy with Off-Block Prototype Testing



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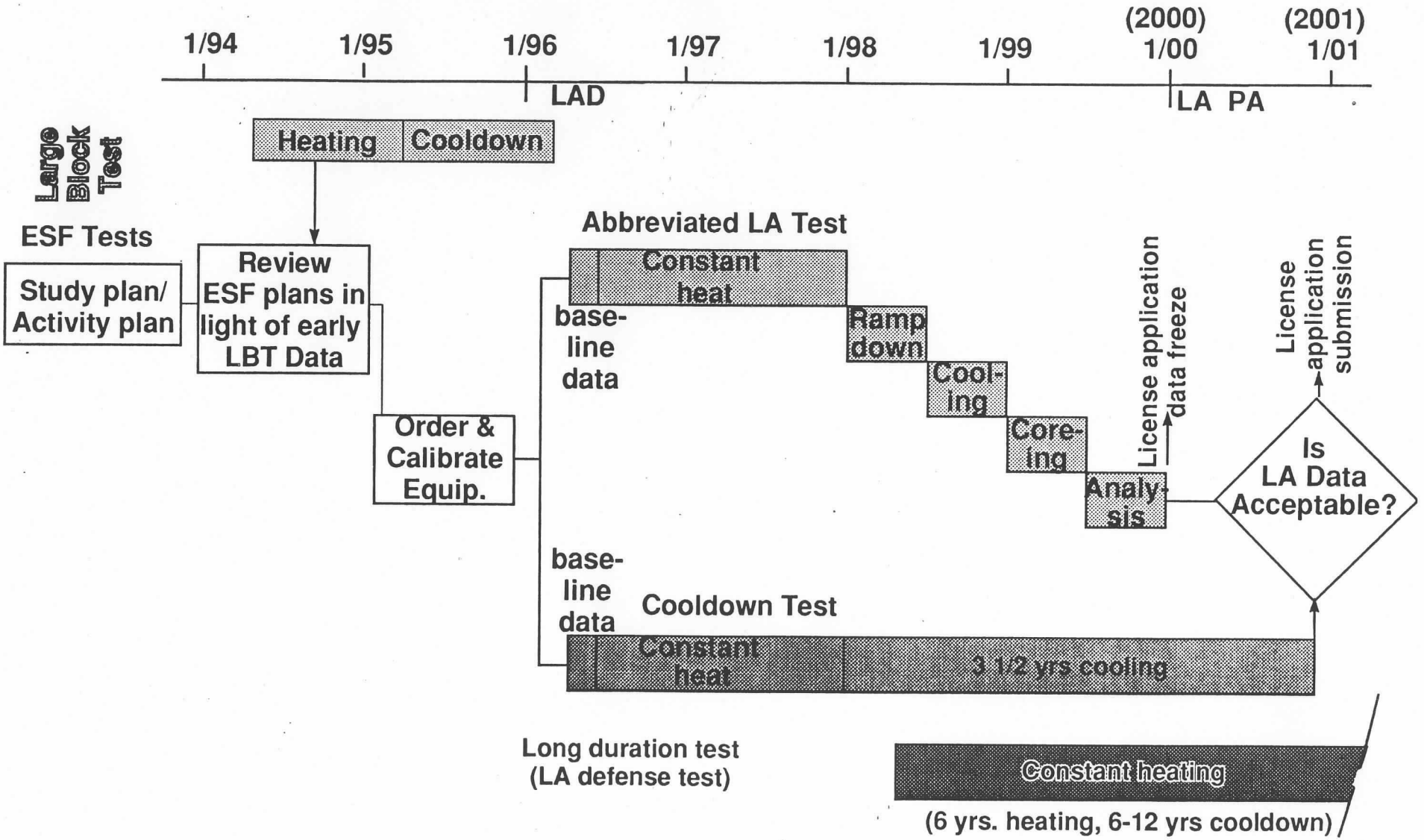
Strategy Using Large Block Test



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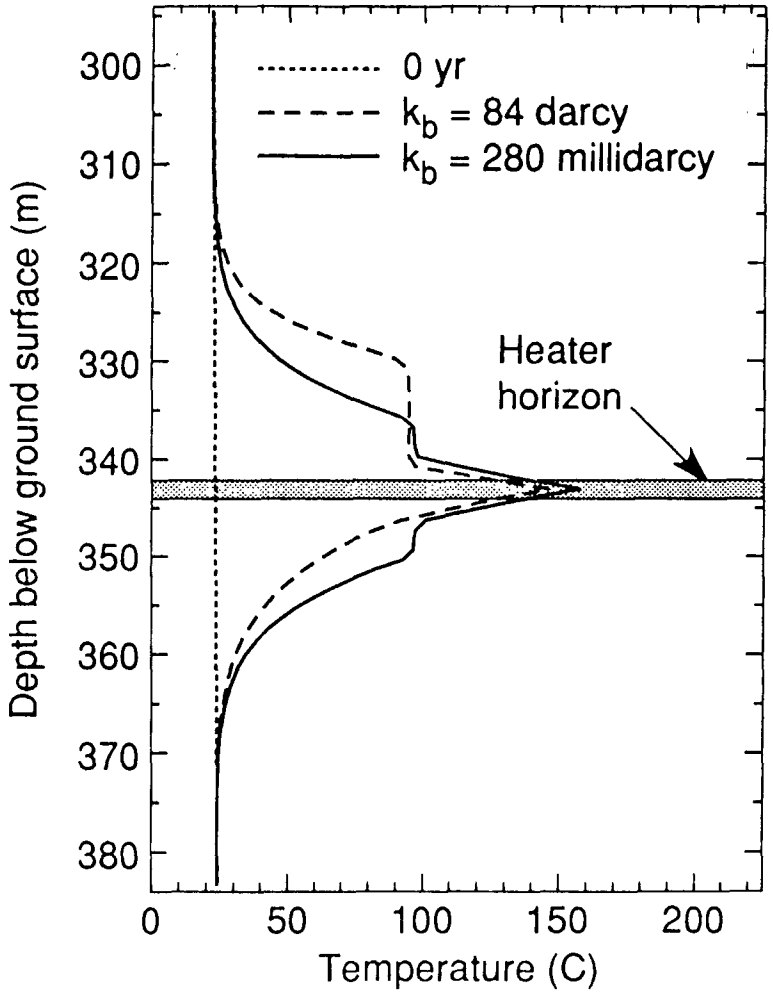
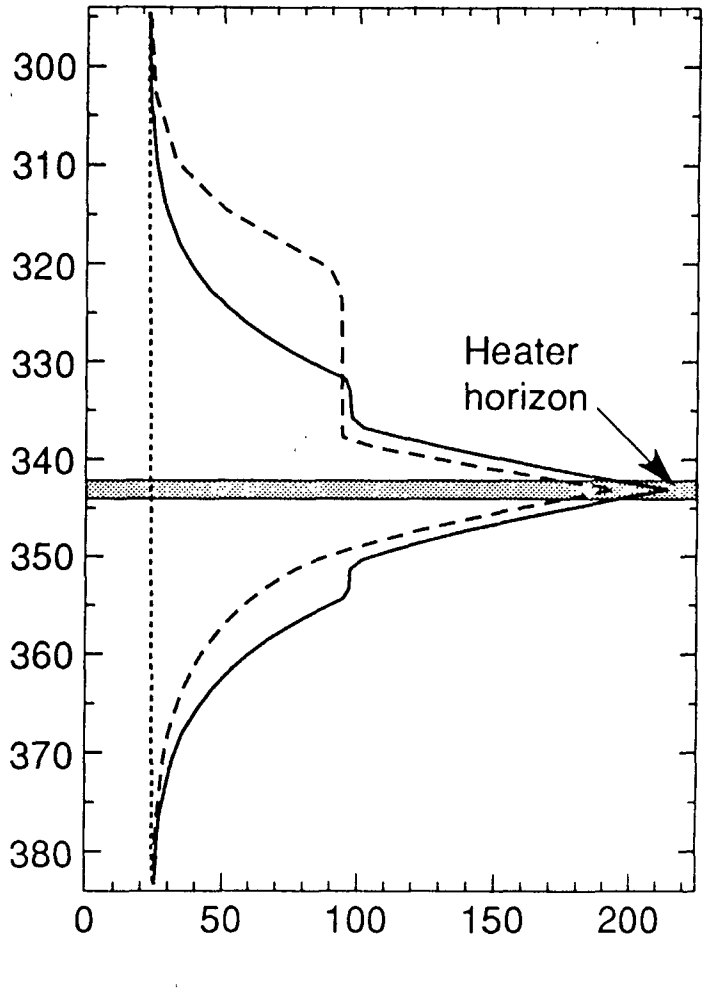
Measurements can Readily Distinguish Convection-Dominated vs. Conduction-Dominated



t = 2 yr



t = 4 yr

DCLLNLDW21 125.NWTRB/7-13/14-93

In situ Heater Tests Can Test Fundamental Hypotheses

(1) Conditions where heat conduction dominates heat flow

(2) Whether above-boiling temperatures remove all mobile liquid water

(3) Whether fracture density and connectivity are sufficient for rock dry-out

(4) Whether re-wetting significantly lags the end of boiling

(5) Conditions where large-scale, buoyant, gas-phase convection may dominate

The large block test will provide valuable information pertaining to all five hypothesis tests, particularly to hypotheses 2, 3,and 4

Issues Requiring Testing Before ESF Testing

- **Validation test independent of those used for characterization (property values, etc.) data, and developing or testing models**

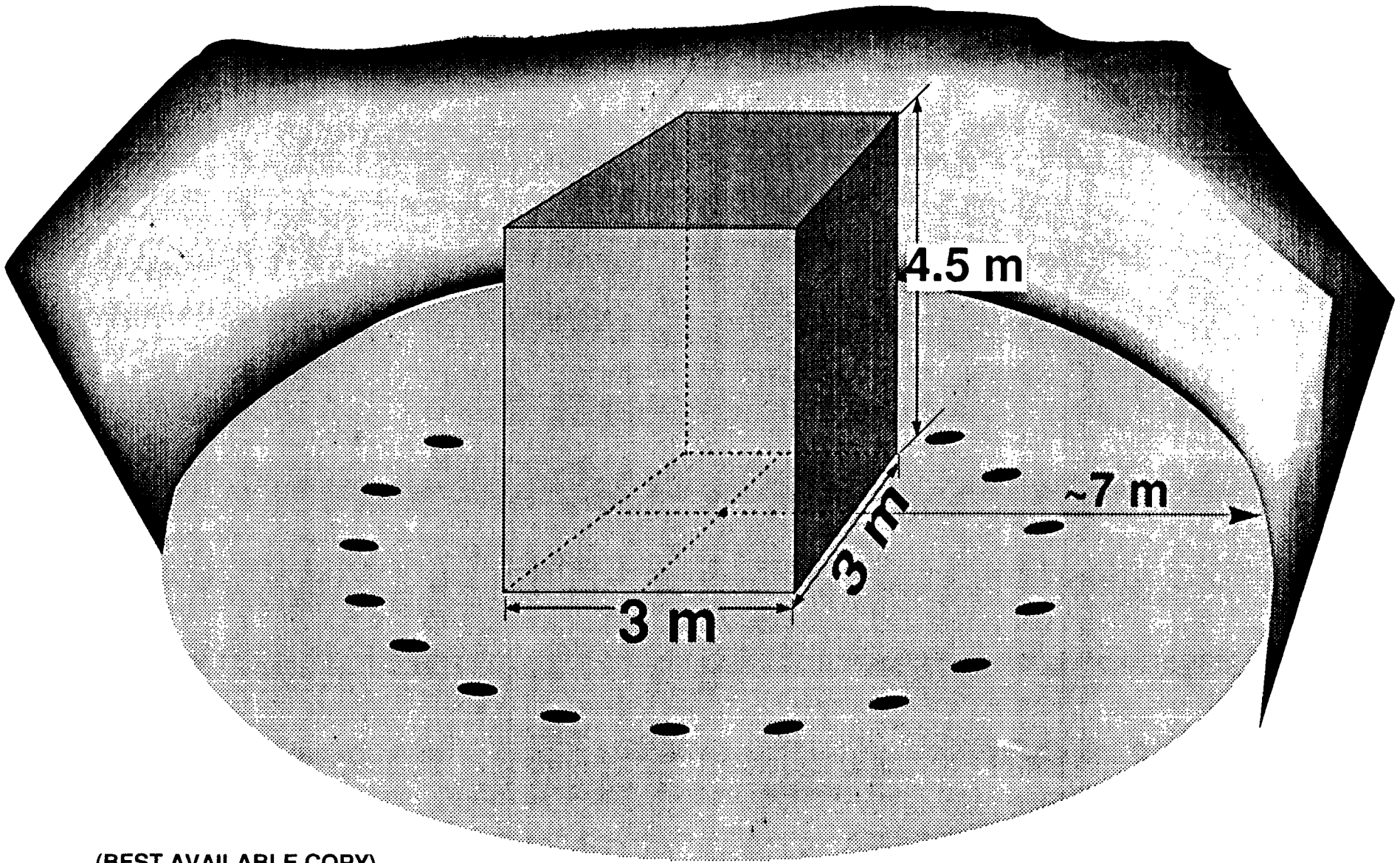
  Developing and testing require "tweaking knobs" in the models to understand physics. Validation test design relies on scoping calculations; therefore, the physics must be appropriate prior to testing

- **Early decisions based on model predictions (e.g thermal loading, MPC, emplacement strategy) require that processes important to the outcomes be incorporated into models. The models have not been demonstrated adequately**

- **ESF test planning**

  - **Confidence in models used for planning of ESF tests**
  - **Instrument and technique evaluation prior to ESF test**
  - **Evaluation of scaling effects**

A Block Isolated from Outcrop



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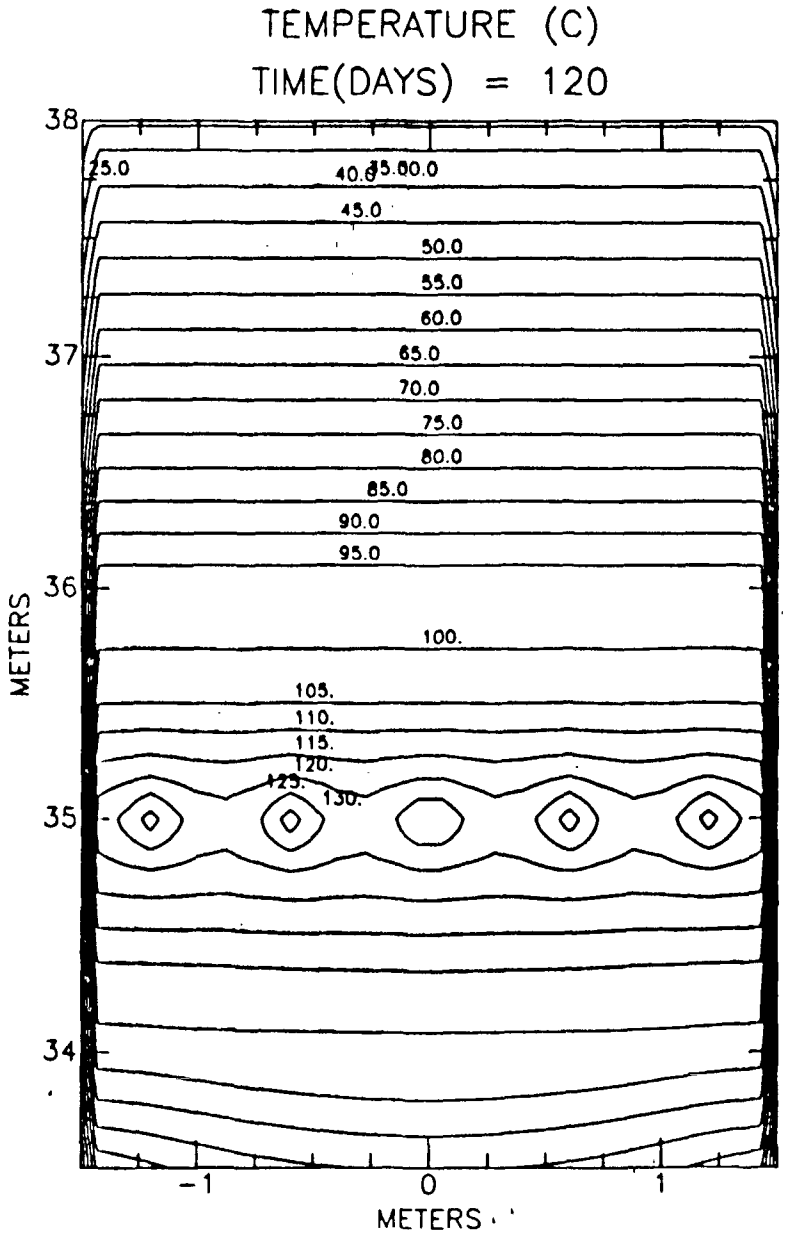
Large Block Test, Run No. 2, x-z Model, 5-23-93



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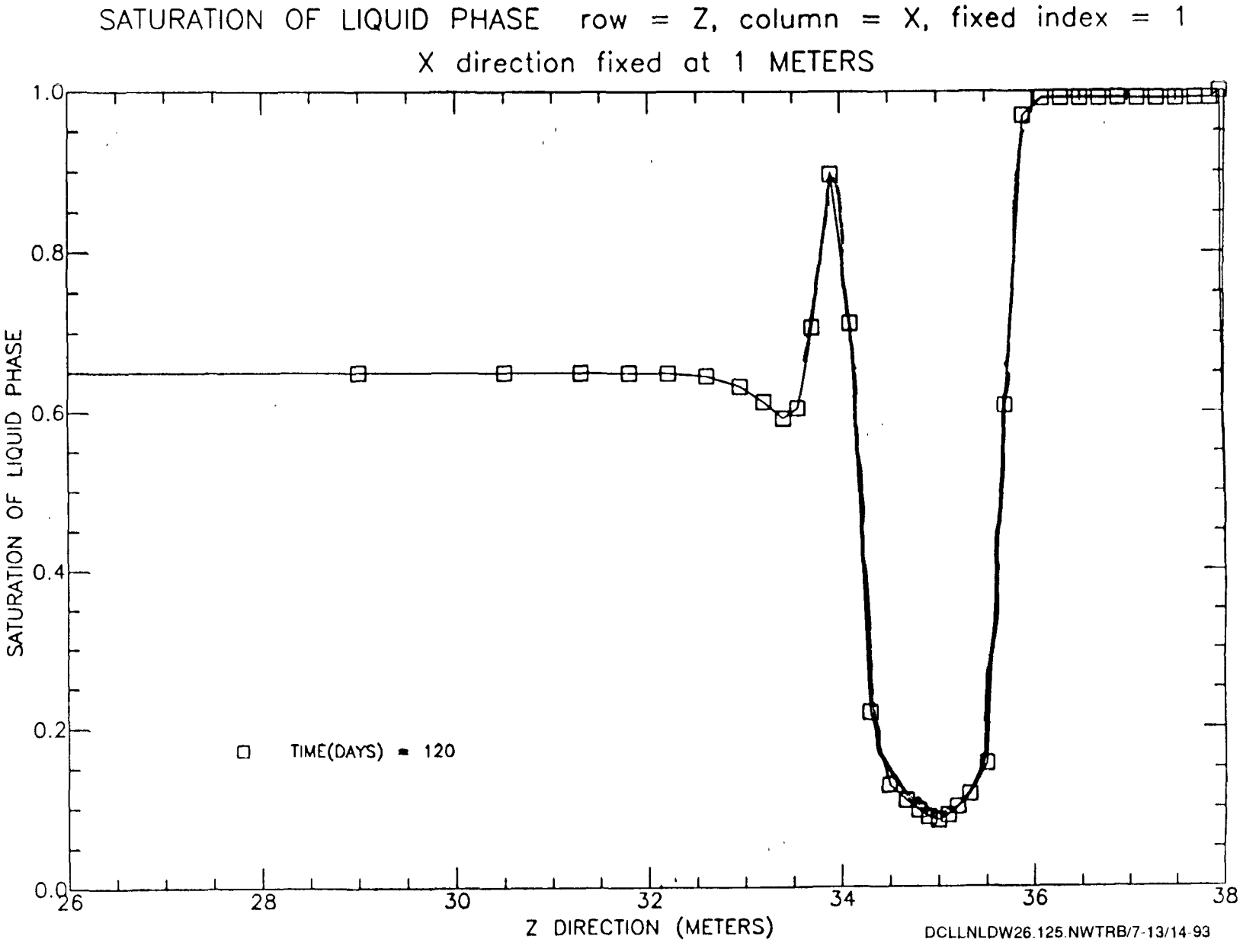
Large Block Test, Run No. 2, x-z Model, 5-23-93



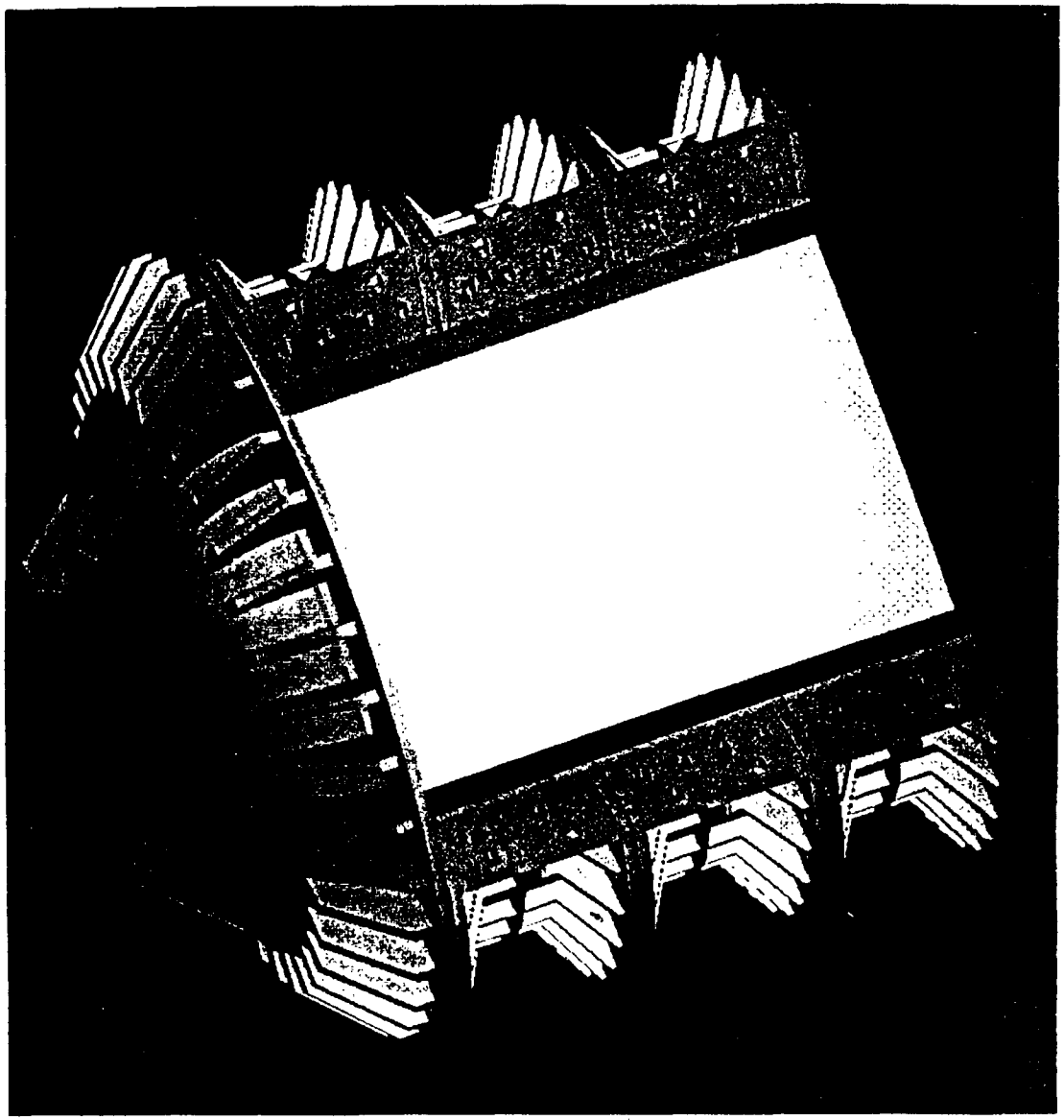
Grid Diagram

Photo

Photo

Diamond Belt Saw

Photo



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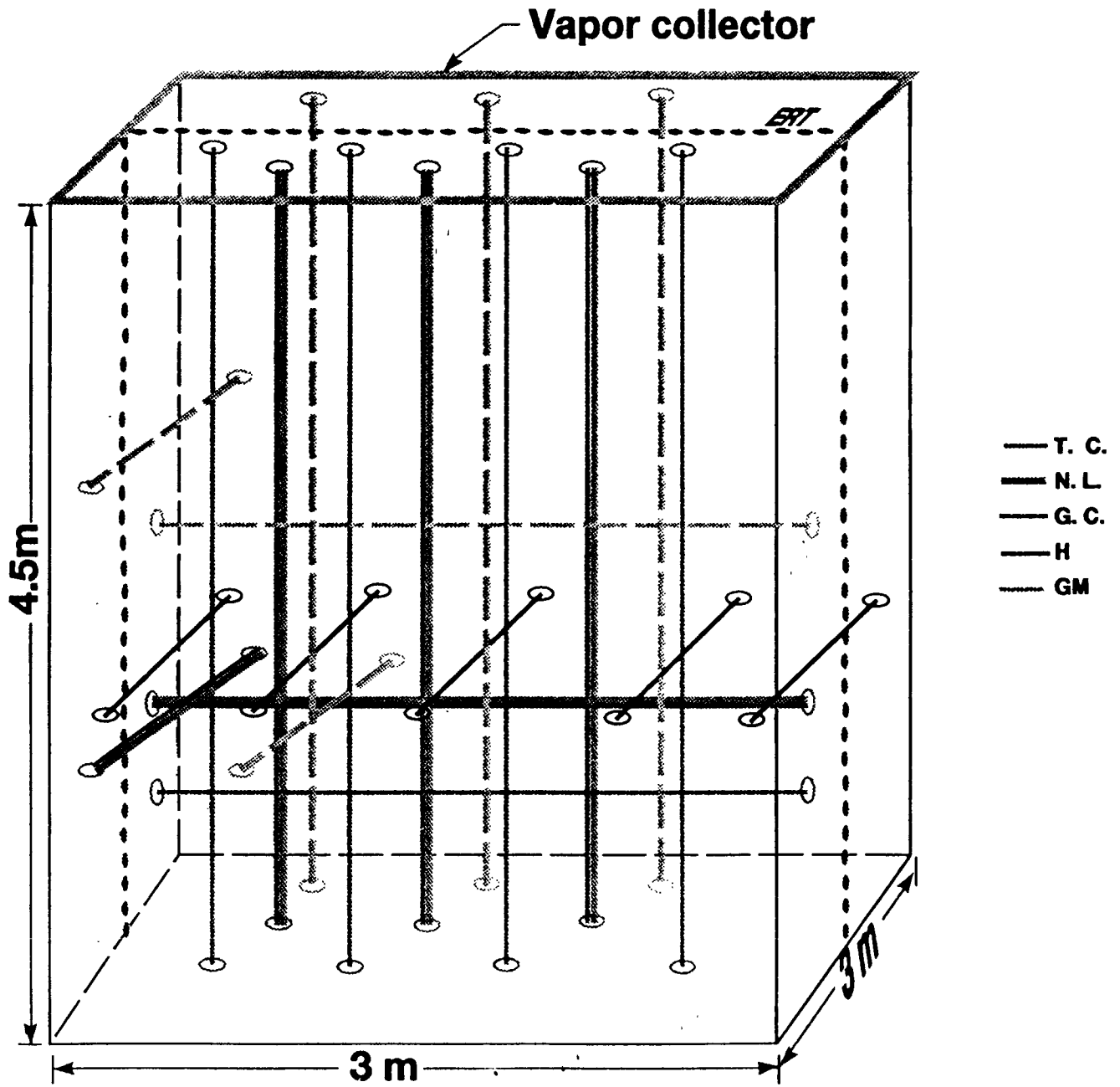

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