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

PRESENTATION TO THE NUCLEAR WASTE TECHNICAL REVIEW BOARD

SUBJECT: HYDROGEOLOGIC UNCERTAINTIES

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Hydrogeologic uncertainties

- Overview of Yucca Mountain hydrology
- Hydrothermal flow at the repository horizon
- Temperature profiles as a function of thermal load
- Impact of hydrothermal flow on temperature distribution
- Impact of thermal load on repository performance
- Impact of thermal load on hydrogeologic uncertainties
- Conclusions
- Appendix

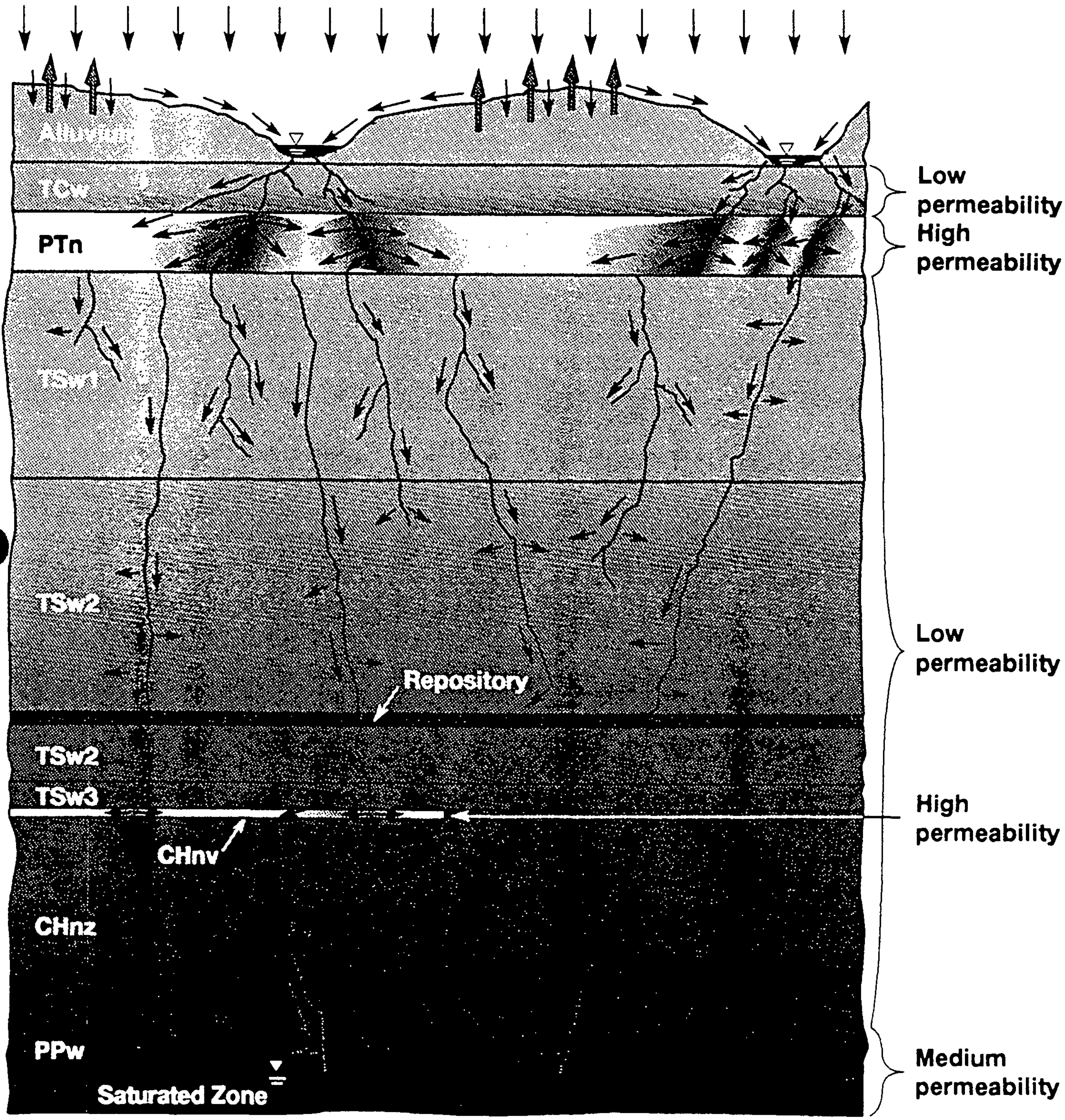
Key repository performance issues depend on hydrology

- Waste package degradation/waste form dissolution
- Radionuclide flow and transport

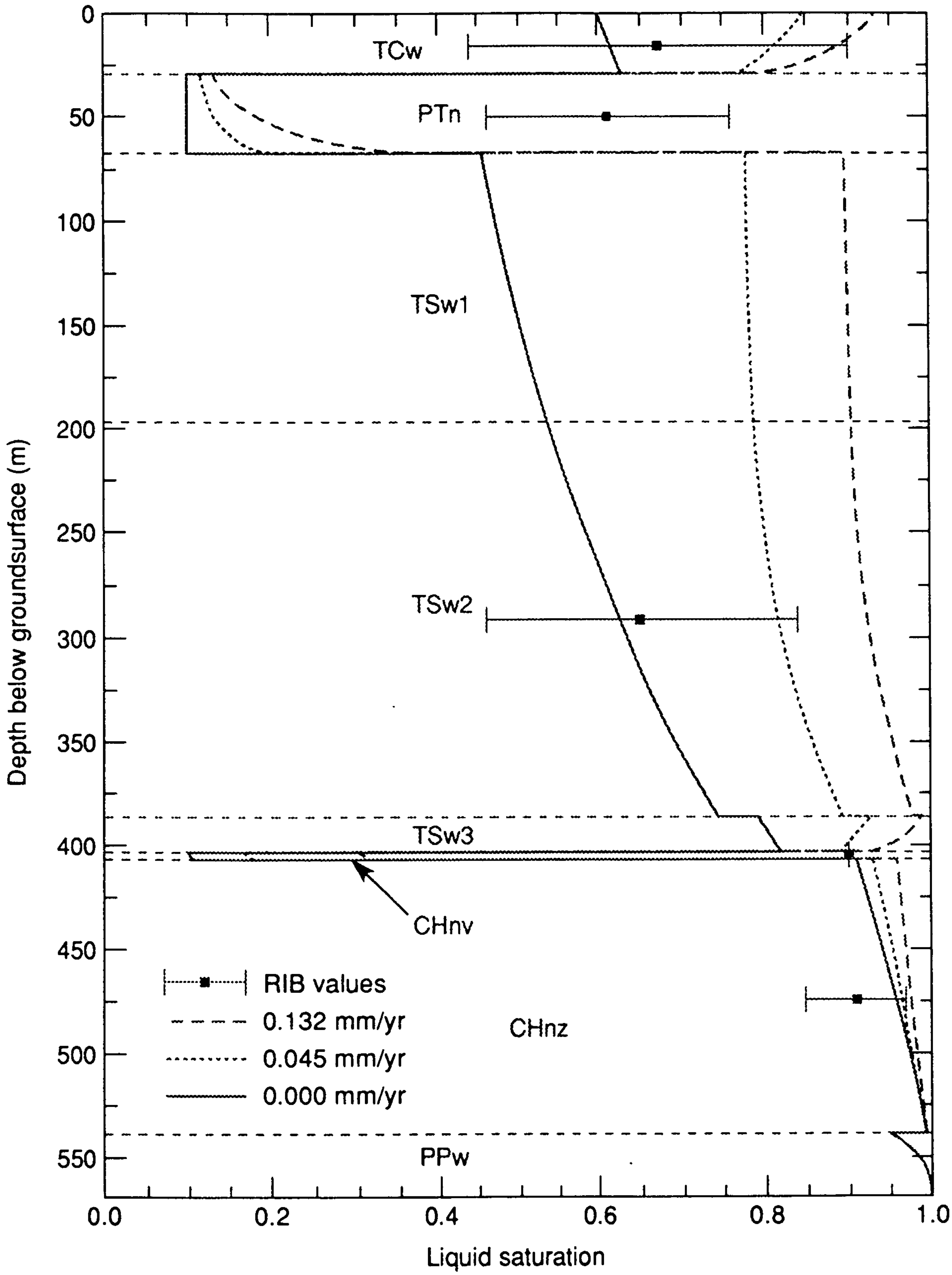
Overview of Yucca Mountain hydrology

- The key consideration is the impact of thermal load on fracture-dominated flow
  - Matrix-dominated flow will not result in significant vertical transport of radionuclides
  - Field evidence indicates fracture-dominated flow can occur to considerable depth
  - Fracture-dominated flow is only credible mechanism bringing water to waste packages and transporting radionuclides
- Boiling and dry-out greatly enhance fracture flow attenuation
  - These effects can reduce the impact of uncertainties

Episodic infiltration occurs as fracture-dominated flow in the low permeability units and matrix-dominated flow in the high permeability units



Liquid saturation profile obtained from several 1-D models of steady-state recharge flux versus saturations from the reference information base (RIB)



ES-TB-37 (6-10-91) IL

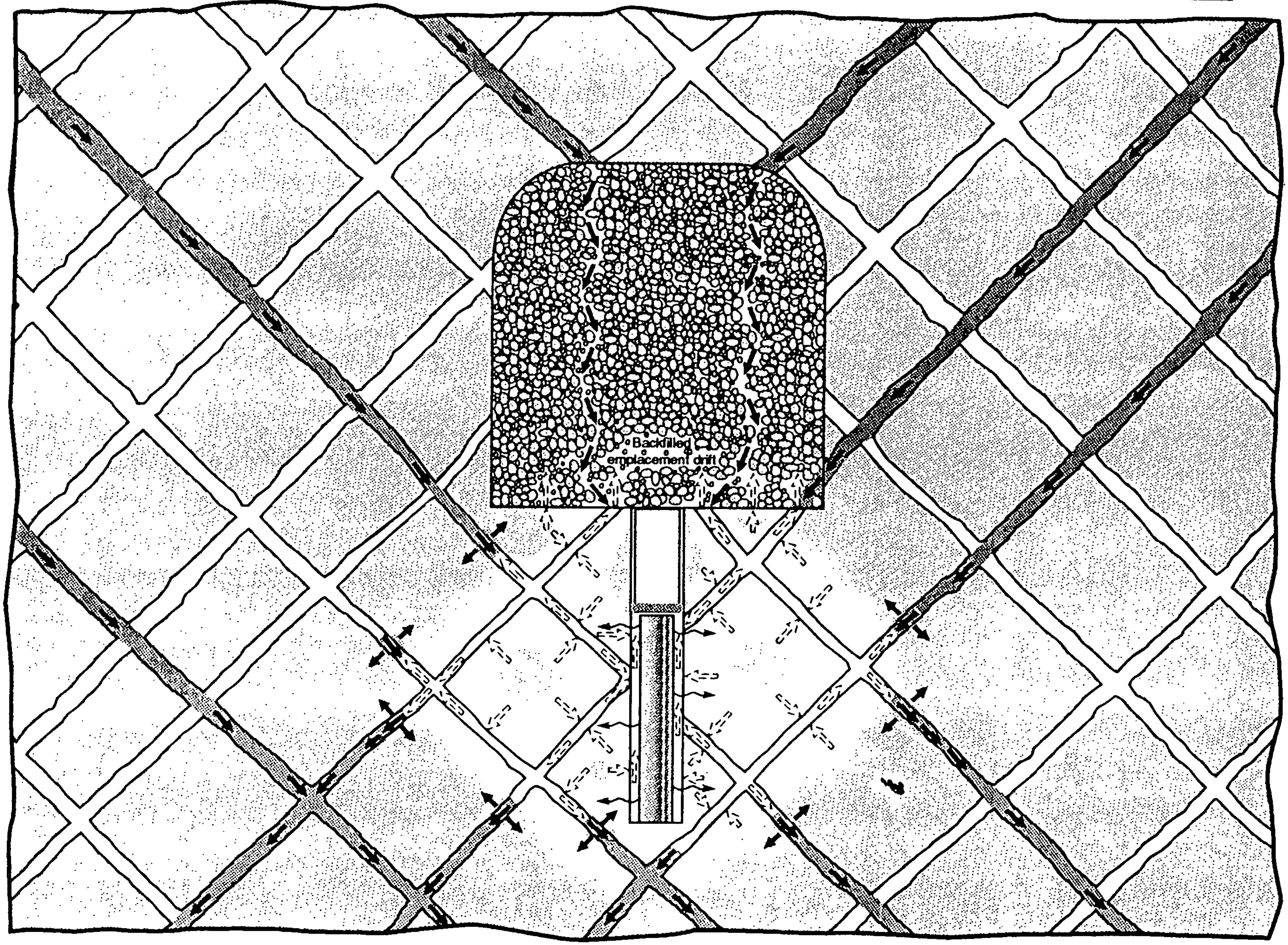
Factors mitigating liquid flow along preferential fracture pathways

- Discontinuity in fracture networks
- Liquid-phase dispersion in fracture networks
- Fracture-matrix interaction
  - For low APD's, only matrix imbibition
  - For high APD's, boiling effects and enhanced imbibition due to dry-out

Hydrothermal flow at the repository horizon

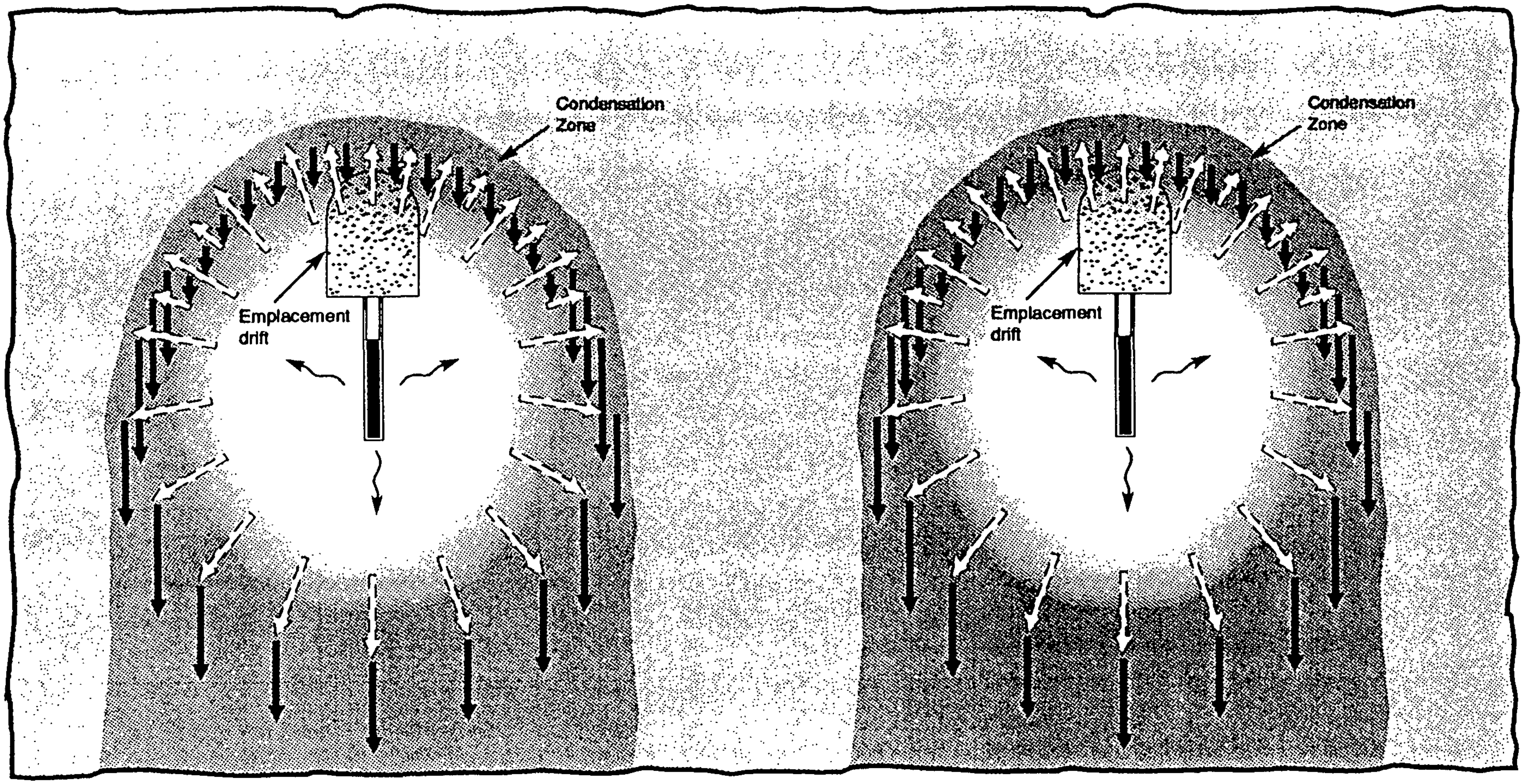
- Unsaturated, fractured tuff promotes rock dry-out by boiling
- Volume of dry-out zone is primarily dependent on thermal load and thermal properties
- Fracture-matrix properties of host rock promote rapid condensate drainage
- Volume of dry-out zone can be enhanced by alternative emplacement configurations
- The numerical models used in this study are very conservative in predicting the dry-out volume

Under hydrothermally perturbed conditions, boiling will mitigate episodic fracture flow from reaching the waste package (for up to 1000 years for a repository heat loading rate of 57 *kw/acre*) (Buscheck and Nitao, 1991)



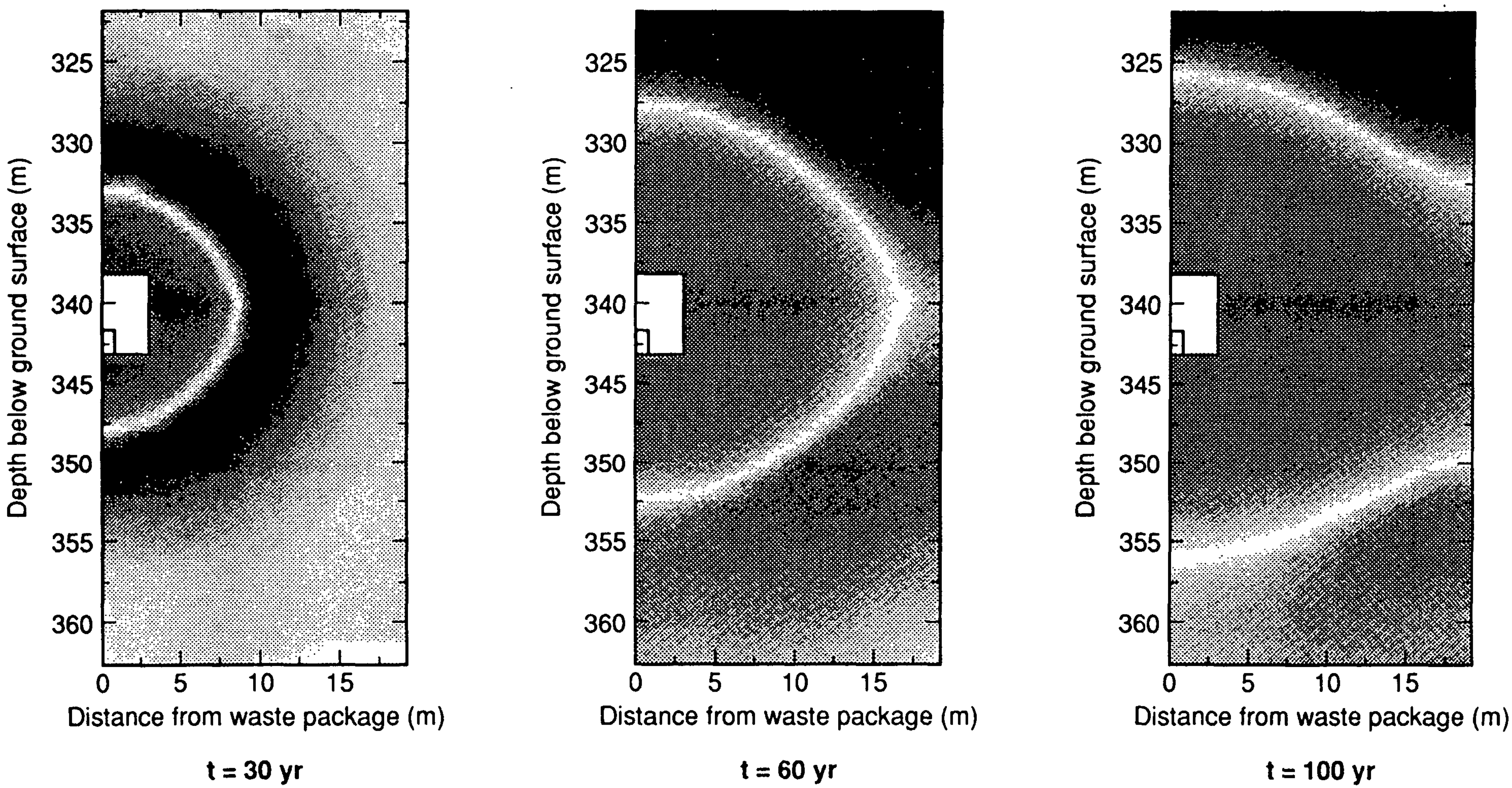
ES-TB-7 (4-20-91) IL

A "hydrothermal umbrella" is established along each of the emplacement drifts due to condensate being shed off of the sides of the boiling zone



The shedding of condensate between emplacement drifts will continue until the boiling zones coalesce approximately 80 years after emplacement

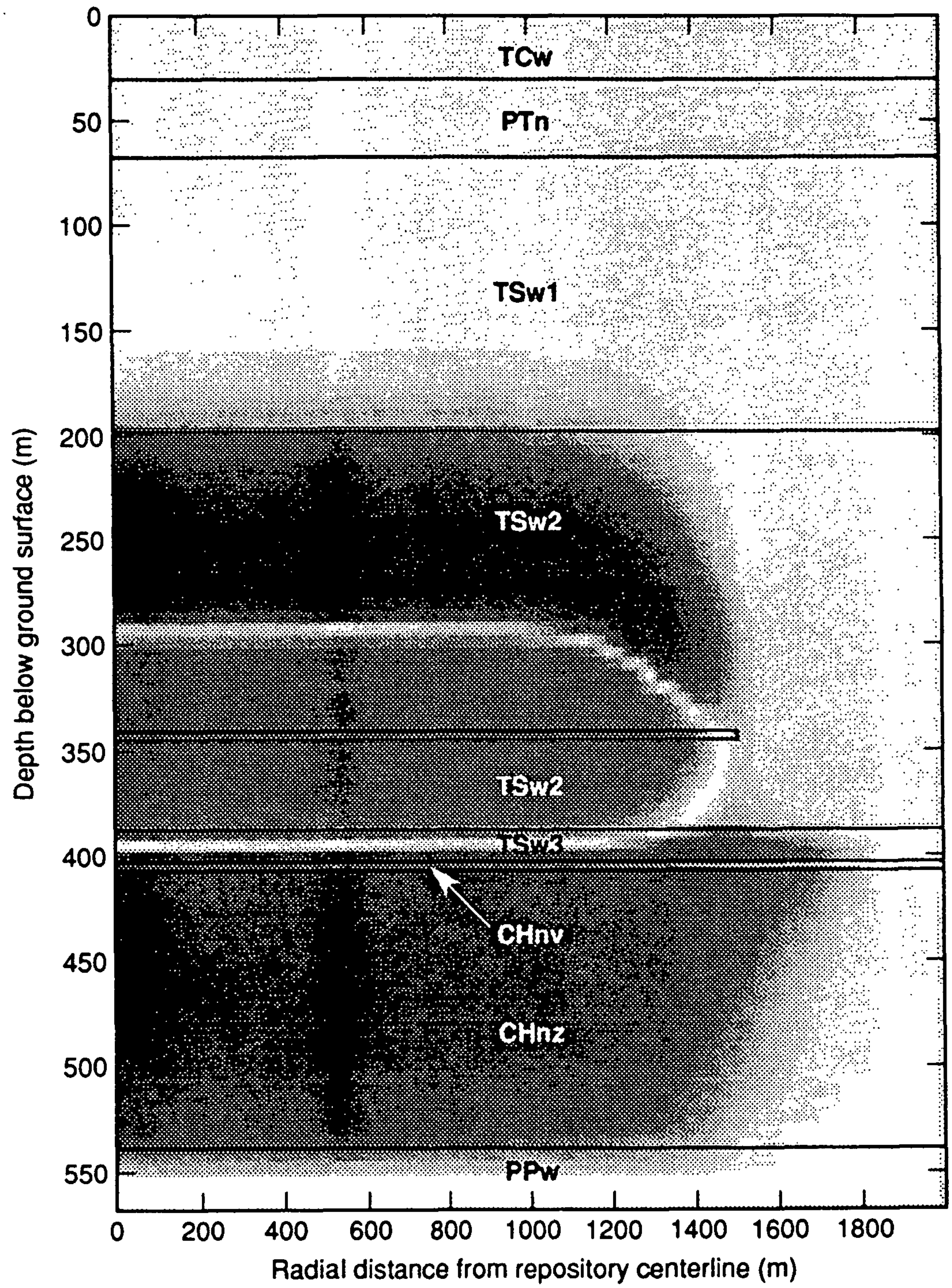
Dimensionless liquid saturation for 30-yr-old fuel, an APD of 57 kW/acre, a drift spacing of 38.4 m, and a recharge flux of 0.0 mm/yr



ES-TB-1 (9-28-91) IL

After 1000 years, boiling has resulted in a 100-m-thick dry-out zone, surrounded by a condensation zone, with condensation drainage extending to the water table

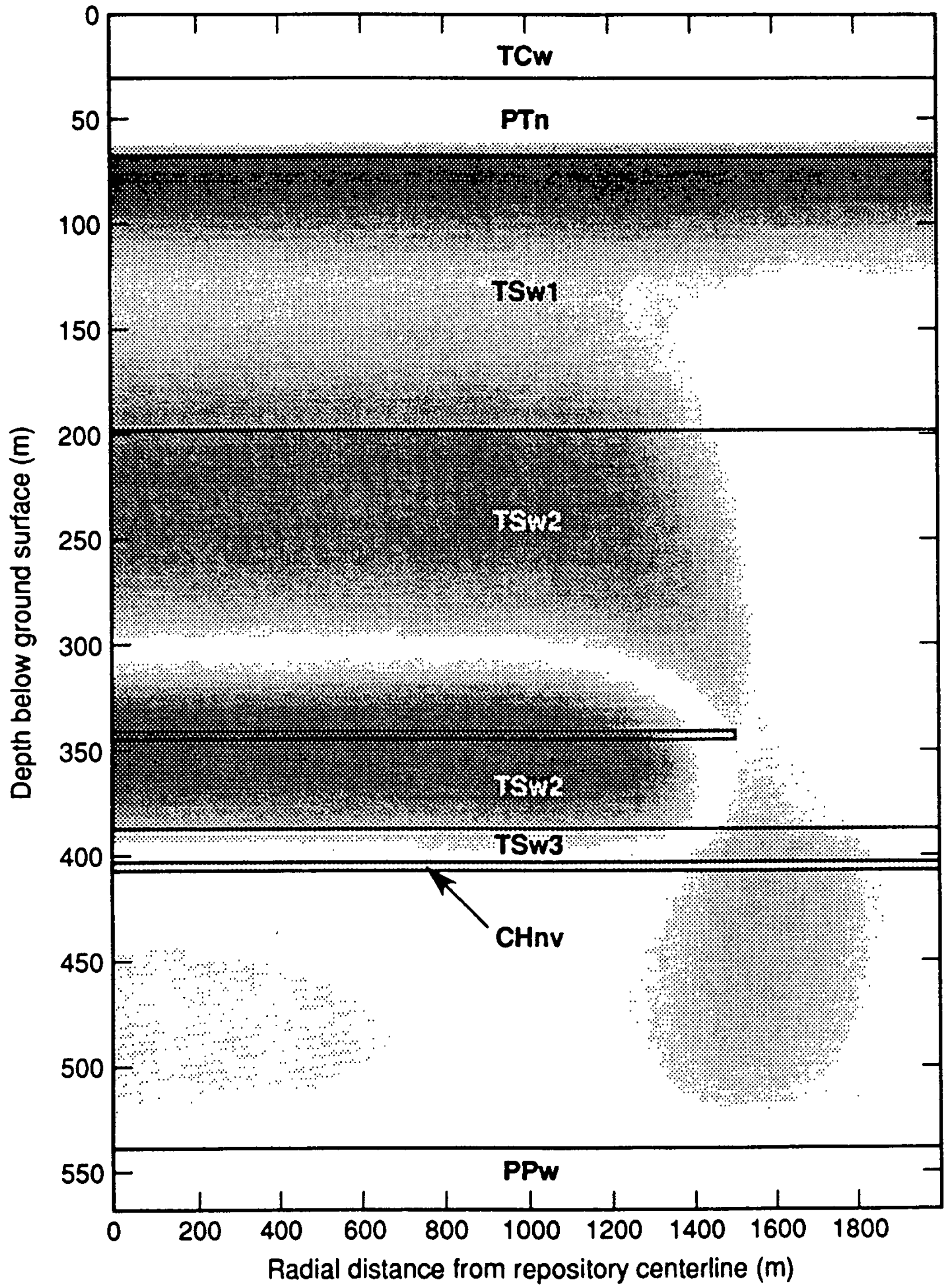
Dimensionless liquid saturation for 30-yr-old fuel, an APD of 57 kW/acre, a drift spacing of 38.4 m, and a recharge flux of 0.0 mm/yr



ES-TB-3 (9-21-91) IL

Although boiling ceased after 1800 years, most of the repository remains dry 5000 years after emplacement

Dimensionless liquid saturation for 30-yr-old fuel, an APD of 57 kW/acre, a drift spacing of 38.4 m, and a recharge flux of 0.0 mm/yr



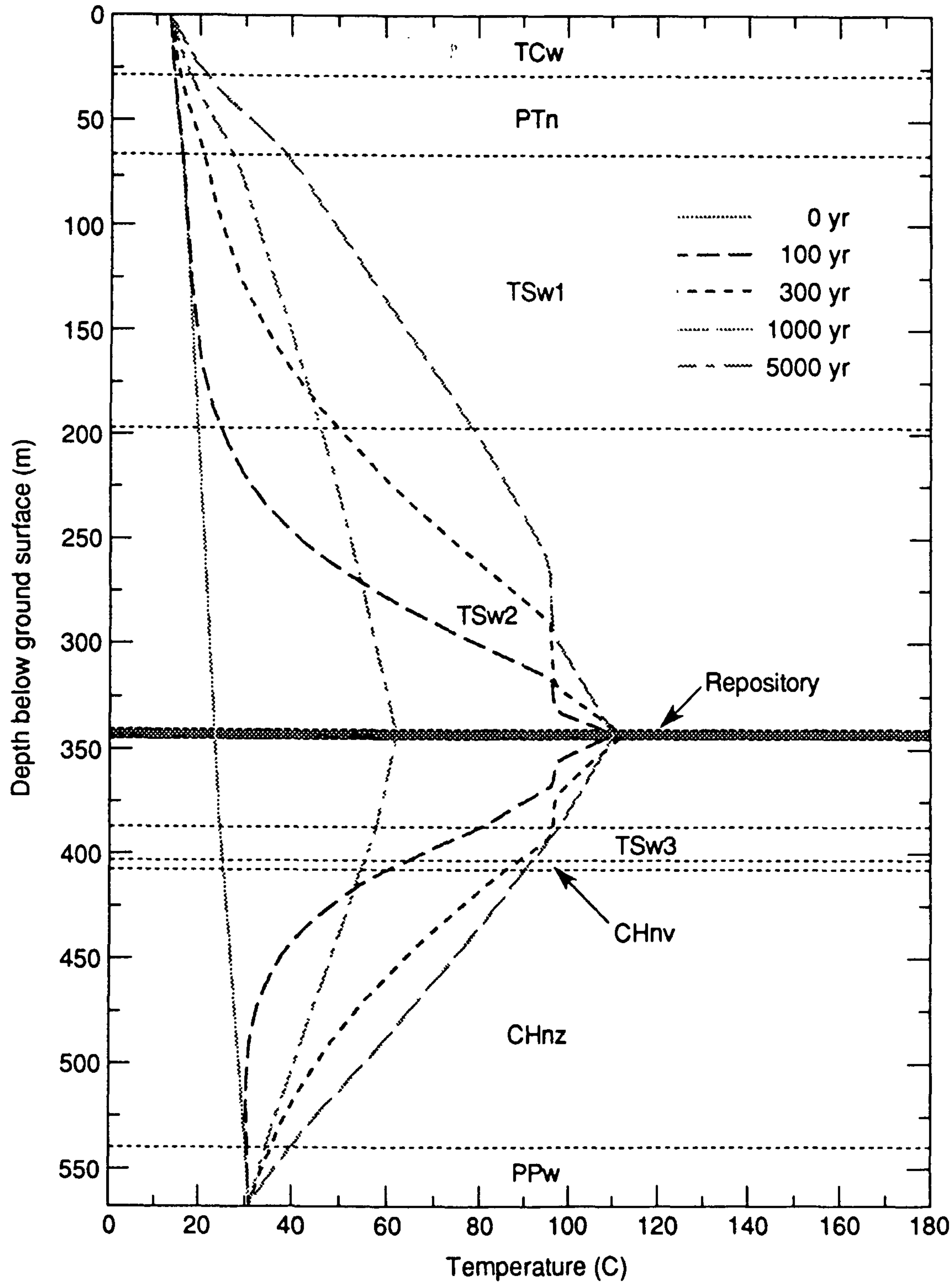
ES-TB-9 (9-27-91) IL

Temperature profiles as a function of thermal load

- Thermal disturbance reaches ground surface and water table within 300 years
- For given fuel age, temperature rise is linear in APD
- Repository temperatures are uniform within the inner two-thirds of repository area
- The emplacement drift-scale model (which accounts for local thermal load distribution) predicts temperatures similar to those in the inner two-thirds of the repository-scale model (which averages the thermal load)

Temperature profile is flattened at boiling zone (~ 96°C) and the temperature disturbance reaches ground surface 300 years after emplacement

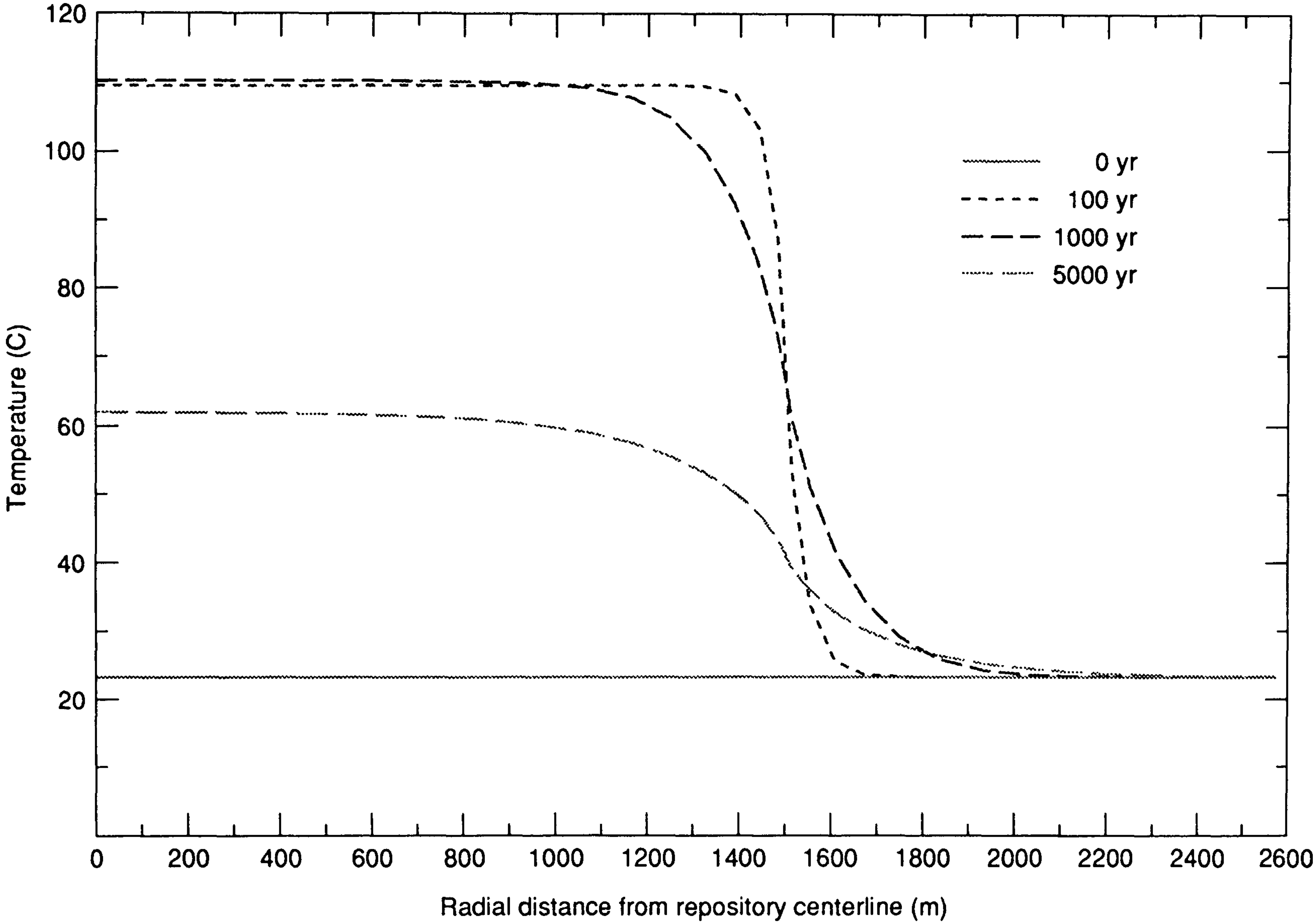
Temperature profile along repository centerline for 30-year-old fuel, an APD of 57 kW/acre, and a recharge flux of 0.000 mm/yr



ES-TB-9 (9-14-91) IL

Repository temperatures are uniform within the inner two-thirds of repository

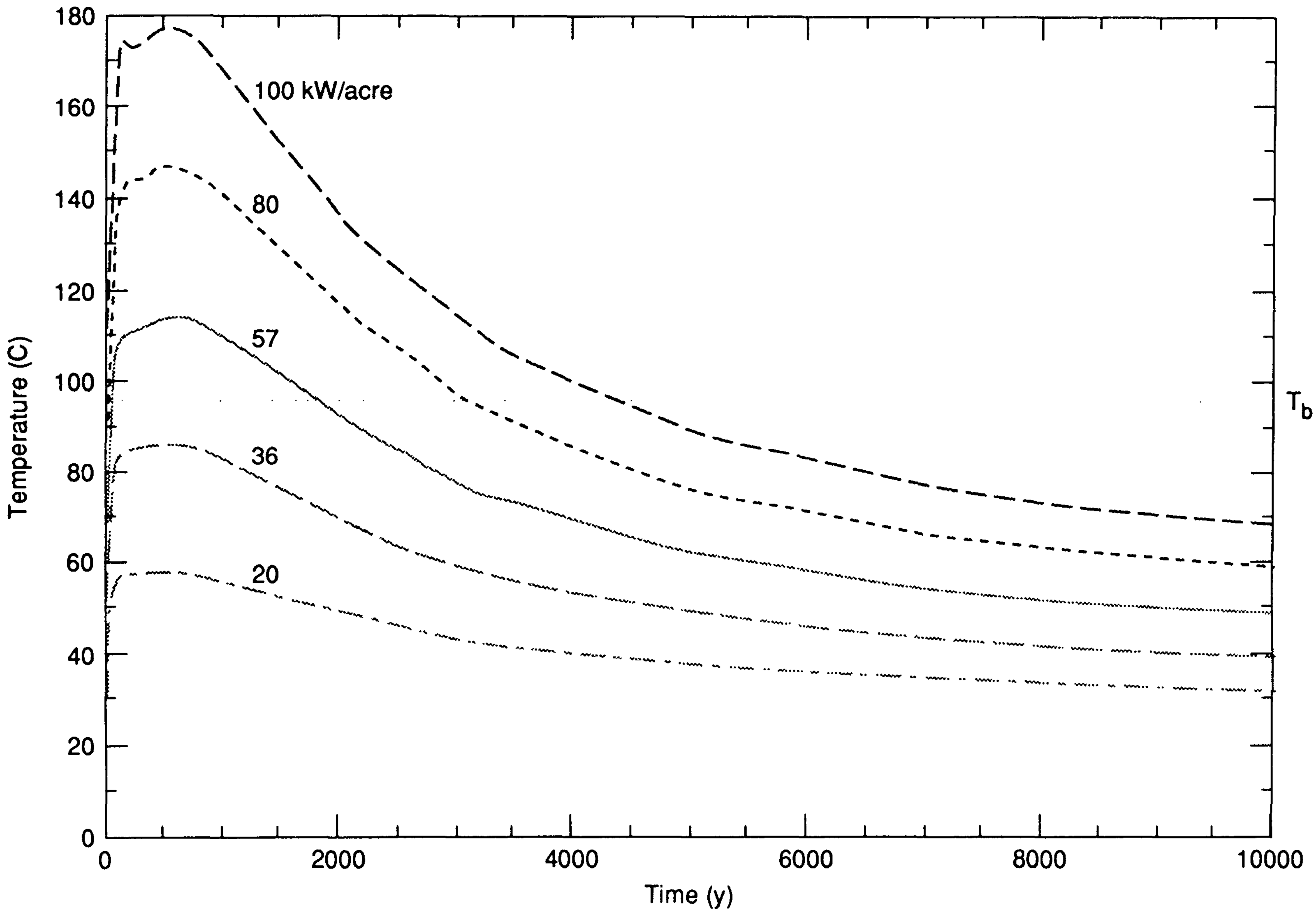
Radial temperature profile at repository horizon for 30-year-old fuel, and an APD of 57 kW/acre, and a recharge flux of 0.0 mm/yr



ES-TB-29 (9-23-91) IL

For a given age fuel, temperature rise is proportional to APD

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



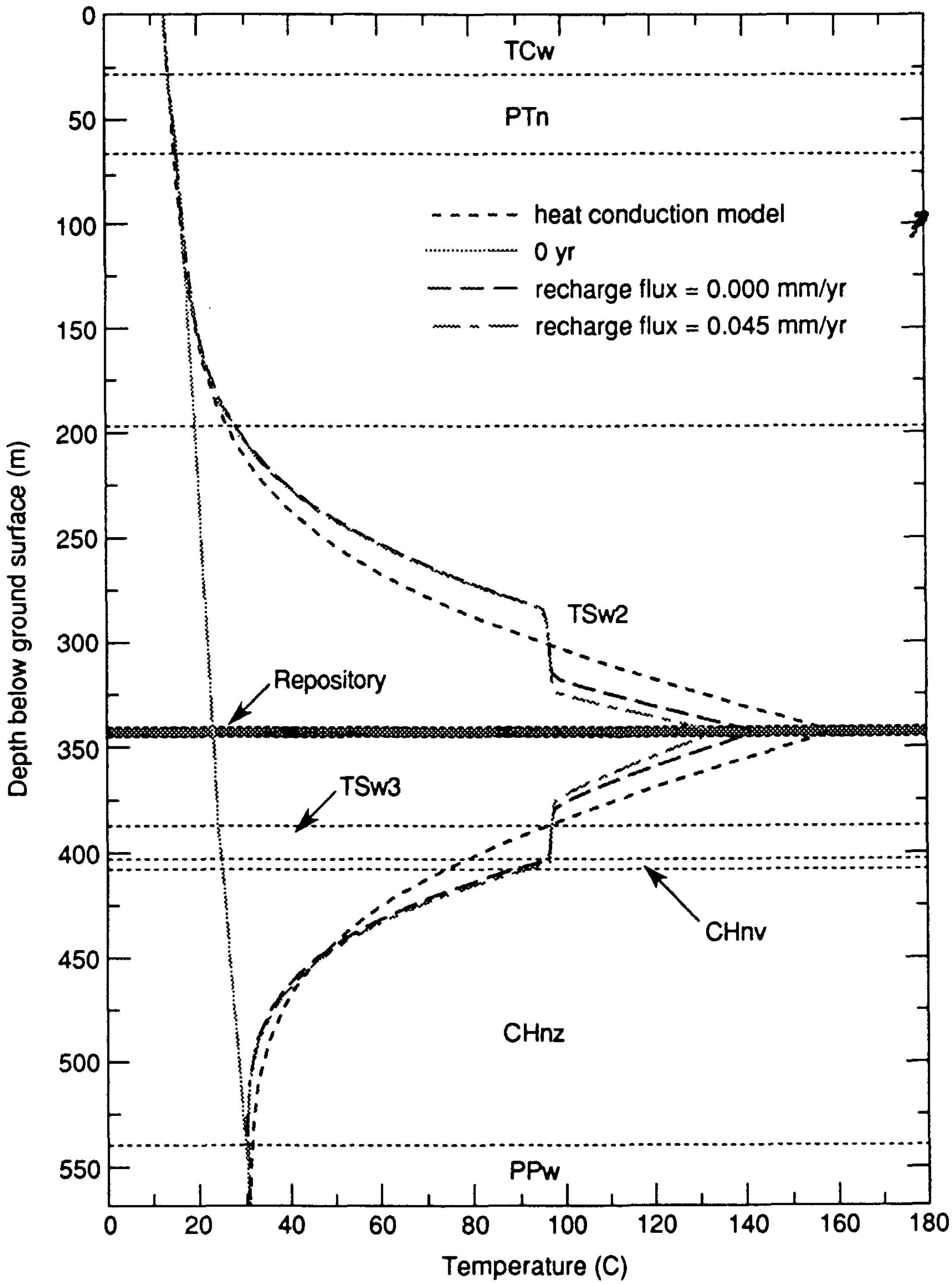
ES-TB-17 (9-14-91) IL

Impact of hydrothermal flow on temperature field

- For 30-year-old fuel and APDs up to 100 kW/acre, heat flow around the repository is dominated by heat conduction
- Temperatures in the vicinity of the waste packages decrease modestly with increasing recharge flux
- Boiling results in lower temperatures in the vicinity of the waste packages
- Heat conduction models yield
  - conservatively high temperatures in the vicinity of the waste packages
  - conservatively low temperatures with respect to the extent of the boiling zone
- Hydrothermal models predict higher temperatures in the Calico Hills units (CHnv and CHnz)

The heat conduction model yields conservatively high temperatures near the waste packages and conservatively low temperatures with respect to the extent of boiling

Temperature profile along repository centerline for 30-yr-old fuel, and APD of 57 kW/acre predicted by the hydrothermal and heat conduction models at t = 100 yr



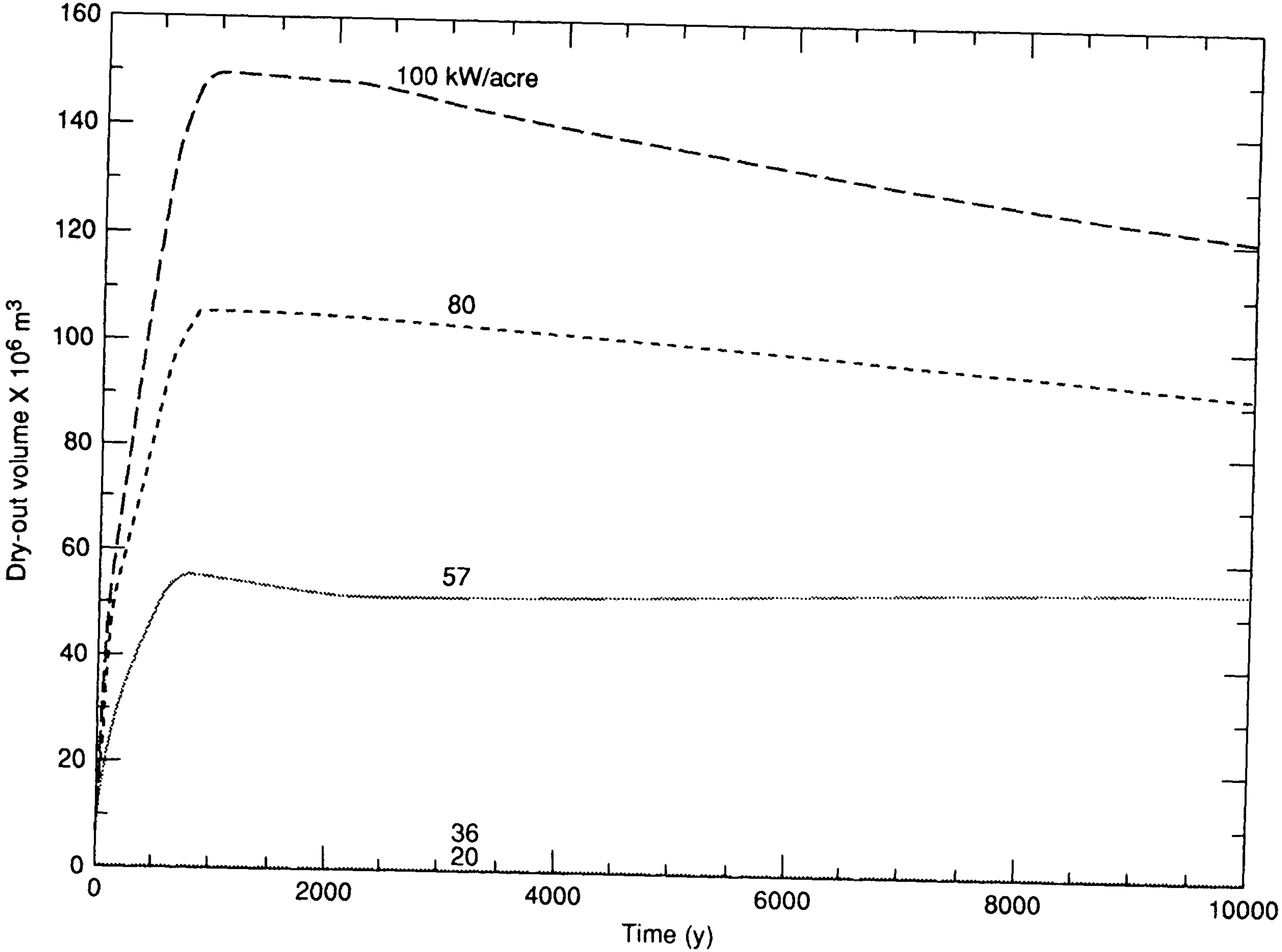
ES-TB-24 (9-23-91) IL

Impact of thermal load on repository performance

- The threshold for significant rock dry-out benefits occurs between 36 and 57 kW/acre for 30-yr-old fuel
- For low-to-medium APD's (20 to 40 kW/acre for 30-yr-old fuel) performance considerations remain with no dry-out benefits
- Substantial boiling and dry-out benefits occur for high APD's
    - Dry steam boiling conditions persist at the waste package for thousands of years
    - Rock dry-out benefits remain thousands of years after boiling ceases
- For drift emplacement, substantial dry-out benefits are obtained with minimal impact on waste package temperatures
- Even high APD's result in minimal temperature disturbance at ground surface
- Boiling conditions and rock dry-out greatly enhance fracture flow attenuation

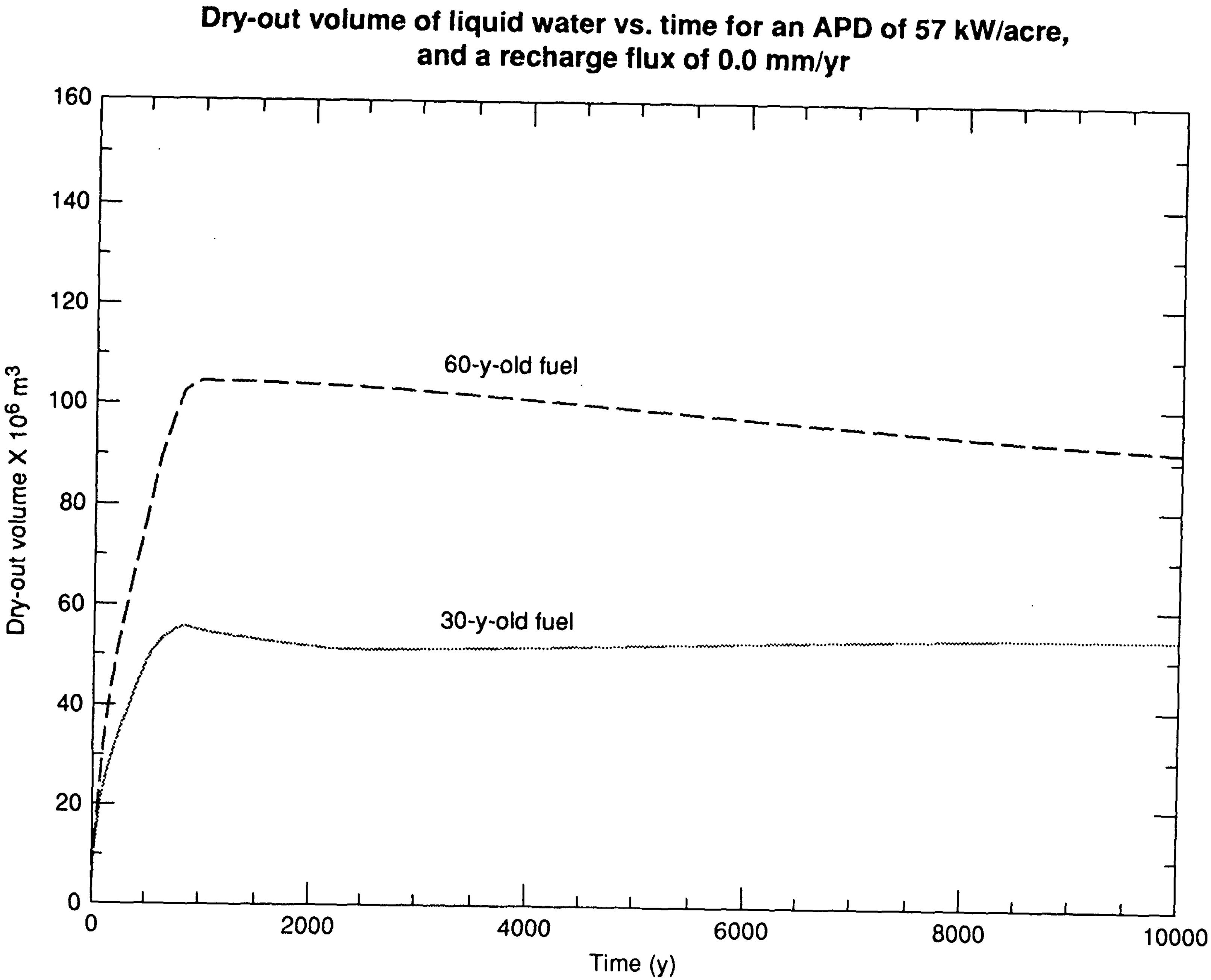
For 30-yr-old fuel, the threshold APD for significant dry-out by boiling lies between 36 and 57 kW/acre

Dry-out volume of liquid water vs. time for 30-yr-old fuel, and a recharge flux of 0.0 mm/yr



ES-TB-21 (9-21-91) IL

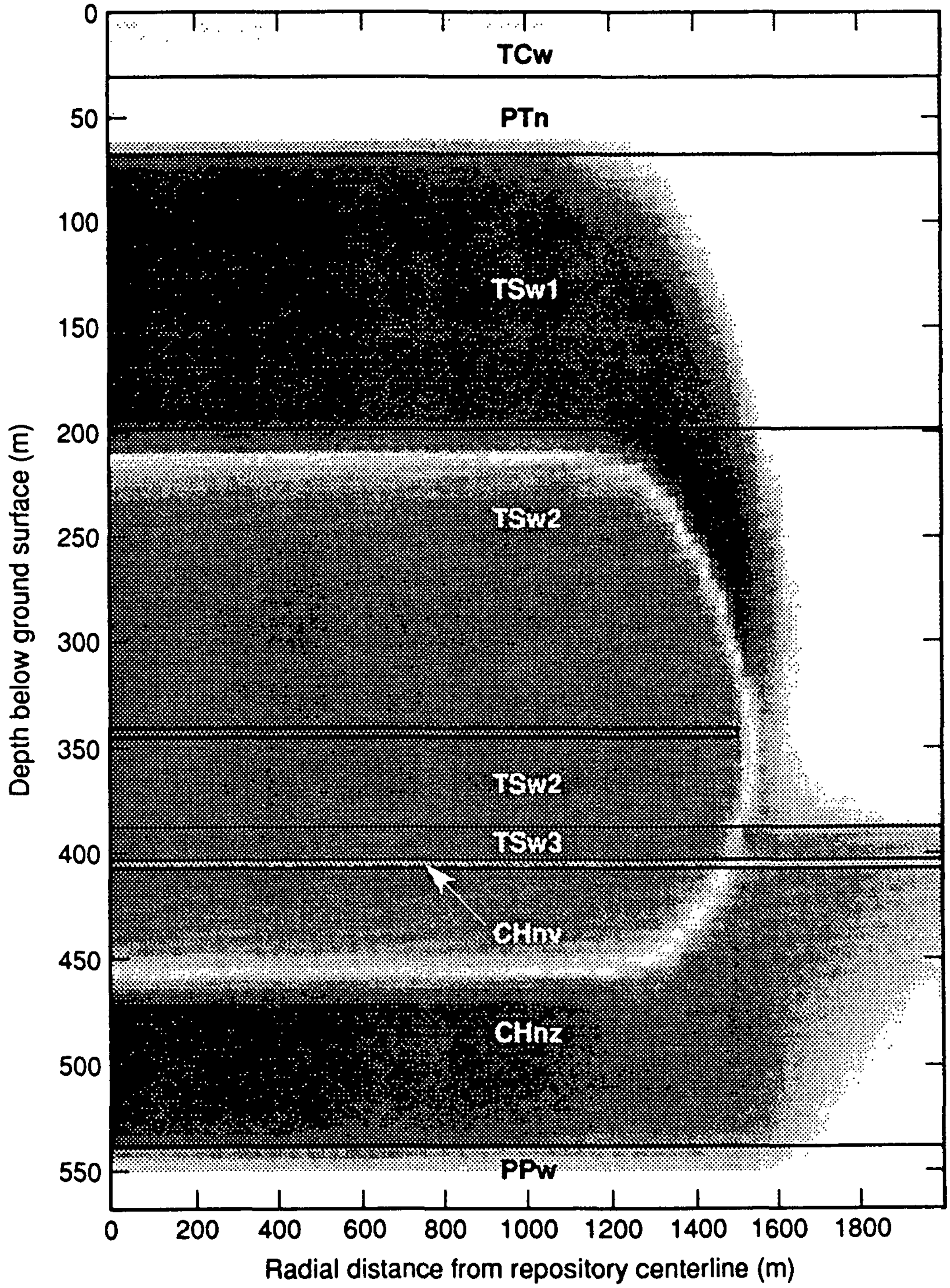
For a given APD, dry-out benefits can be substantially increased using older age fuel



ES-TB-20 (9-21-91) IL

After 1000 years, boiling has resulted in a 250-m-thick dry-out zone, surrounded by a condensation zone, with condensation drainage extending to the water table

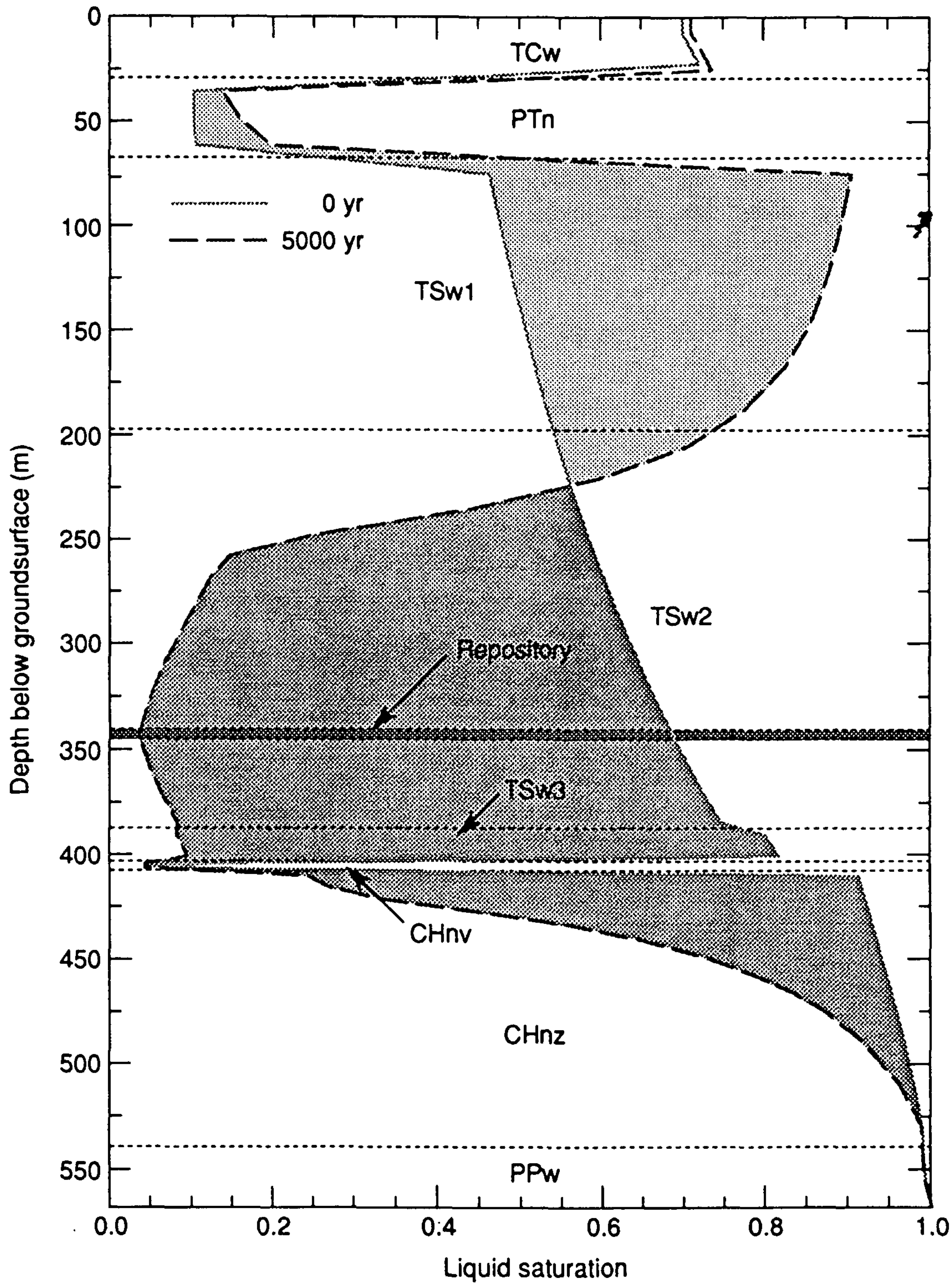
Dimensionless liquid saturation for 30-year-old fuel, an APD of 100 kW/acre, and a recharge flux of 0.0 mm/y



ES-TB-10 (9-28-91) IL

Although boiling ceased after 4200 years, a 150-m-thick dry-out zone remains, and much of the Calico Hills (CHnv and CHnz) is drier than initial saturation at t = 5000 yr

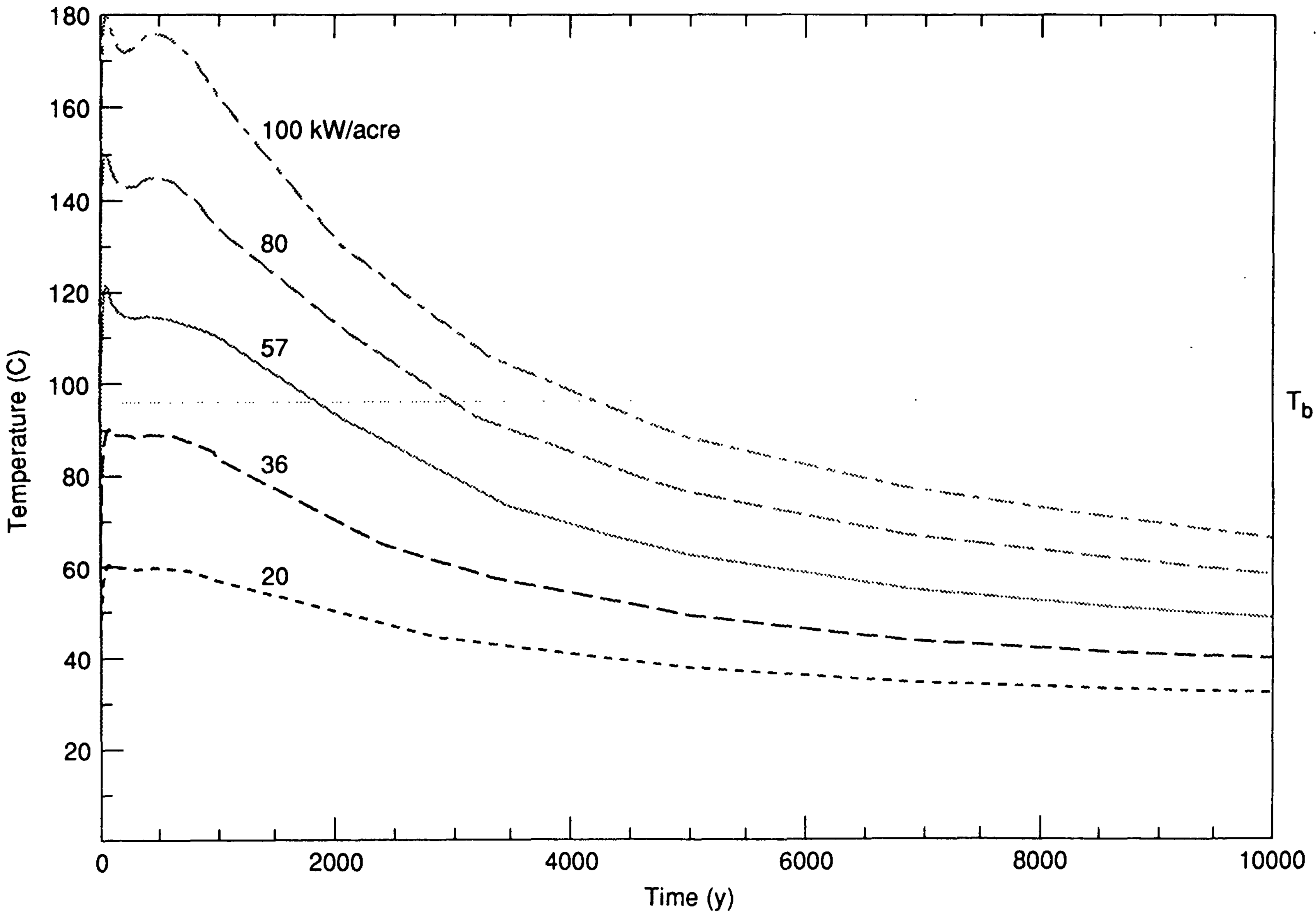
Liquid saturation profile along repository centerline for 30-yr-old fuel, an APD of 100 kW/acre, and a recharge flux of 0.0 mm/yr



ES-TB-23 (8-31-91) IL

Dry steam boiling conditions persist at waste package environment for thousands of years for high APD's

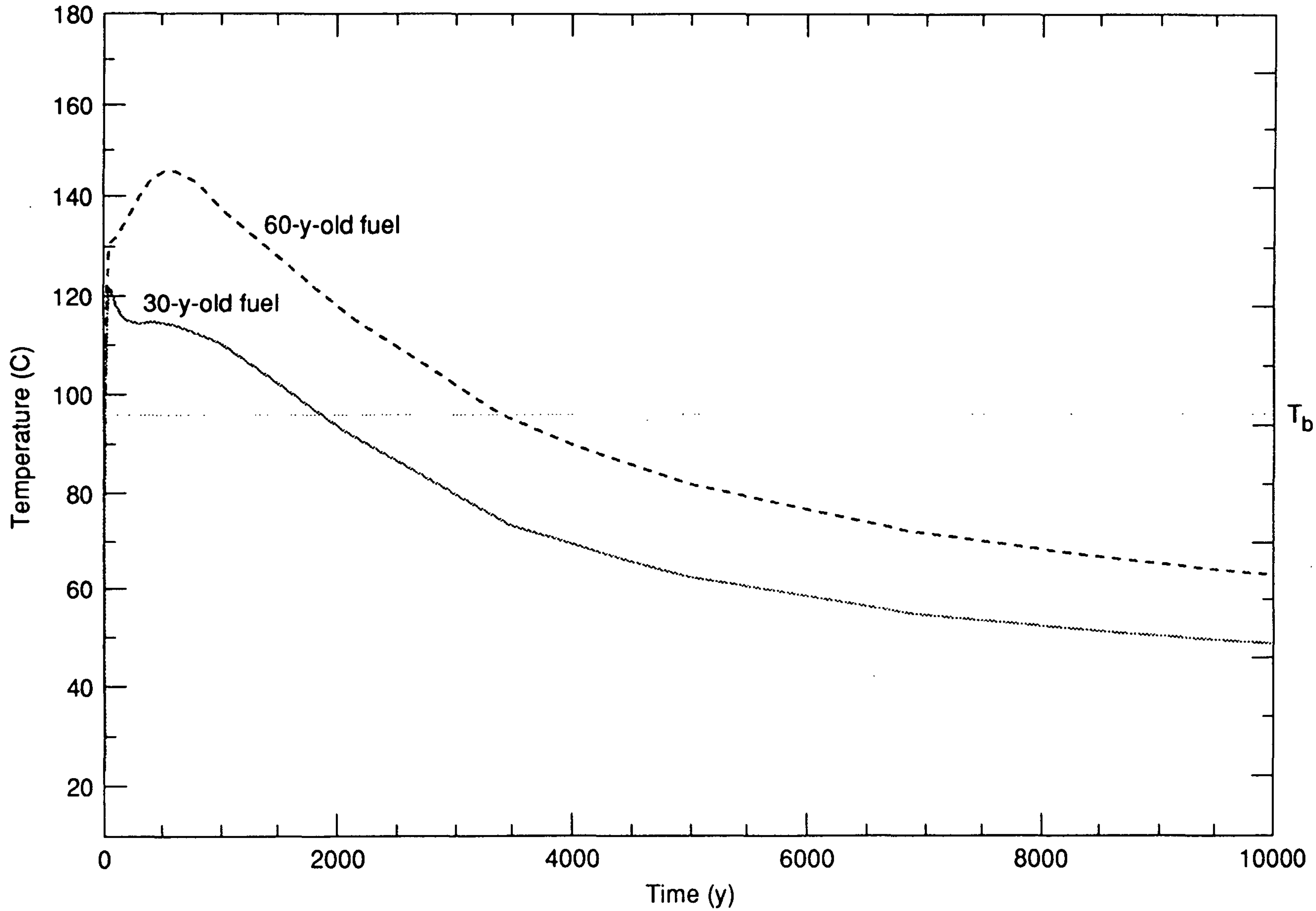
Drift wall temperature for drift emplacement of 30-yr-old fuel



ES-TB-34 (9-23-91) IL

For a given APD, the duration of dry steam boiling conditions is substantially increased using older age fuel with minimal impact on waste package temperatures

Drift wall temperature history for drift emplacement for an APD of 57 kW/acre

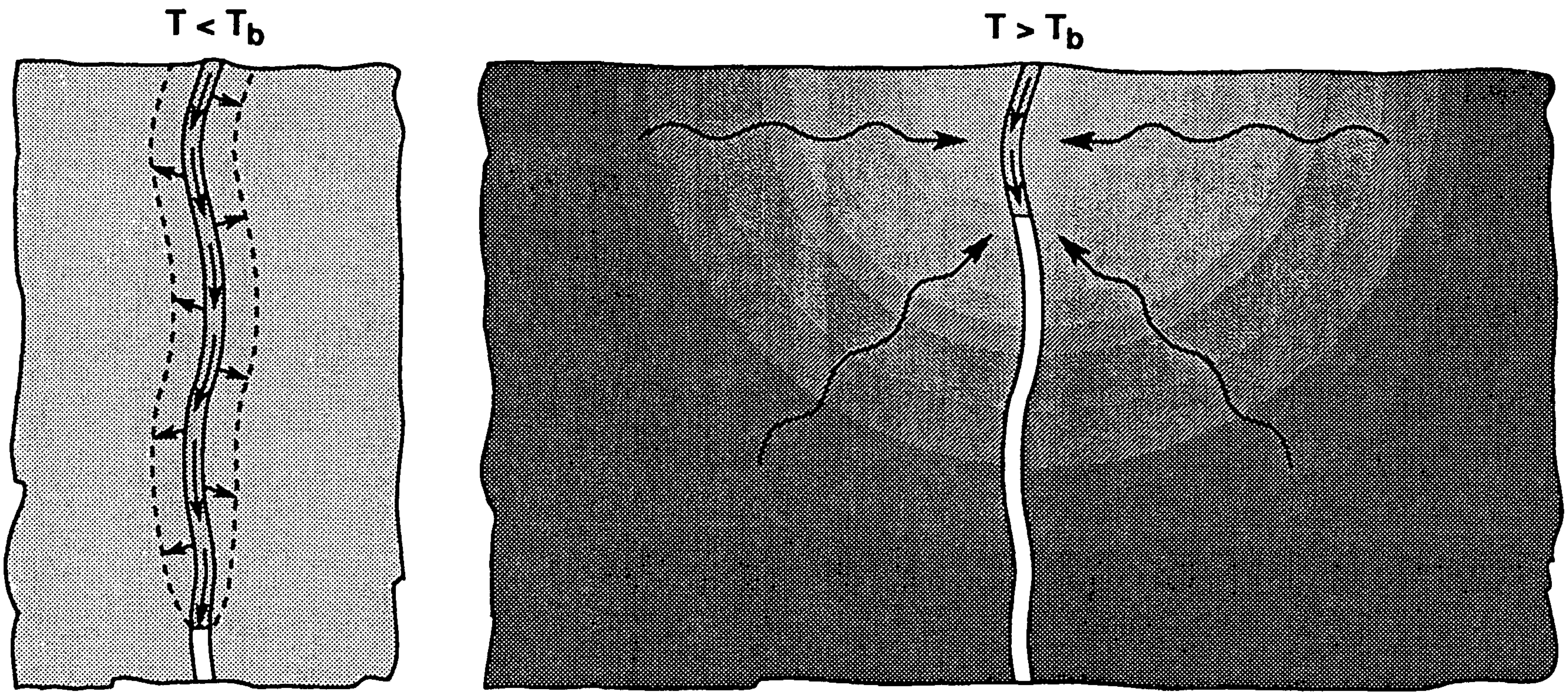


ES-TB-33 (9-23-91) IL

Ground surface temperature effects

- For 30-year-old fuel and APDs up to 100 kW/acre, heat flux at the ground surface never exceeds 1.5 W/m^2
  - Therefore, the temperature rise at the ground surface should never exceed 1°C

Above the repository horizon, the attenuation of fracture flow will be much greater for boiling conditions than for sub-boiling conditions



$V_m \equiv$ Matrix volume affecting fracture flow

$V_m (T < T_b) \sim \sqrt{D_{cap}}$

where $D_{cap} \equiv$ capillary diffusivity

for TSw2, $D_{cap} \approx 2 \times 10^{-9} \frac{m^2}{s}$

$V_m (T > T_b) \sim \sqrt{D_{th}}$

where $D_{th} \equiv$ thermal diffusivity

for TSw2, $D_{th} \approx 1 \times 10^{-6} \frac{m^2}{s}$

$$\therefore \frac{V_m (T > T_b)}{V_m (T < T_b)} \approx 22$$

ES-TB-22 (9-21-91) IL

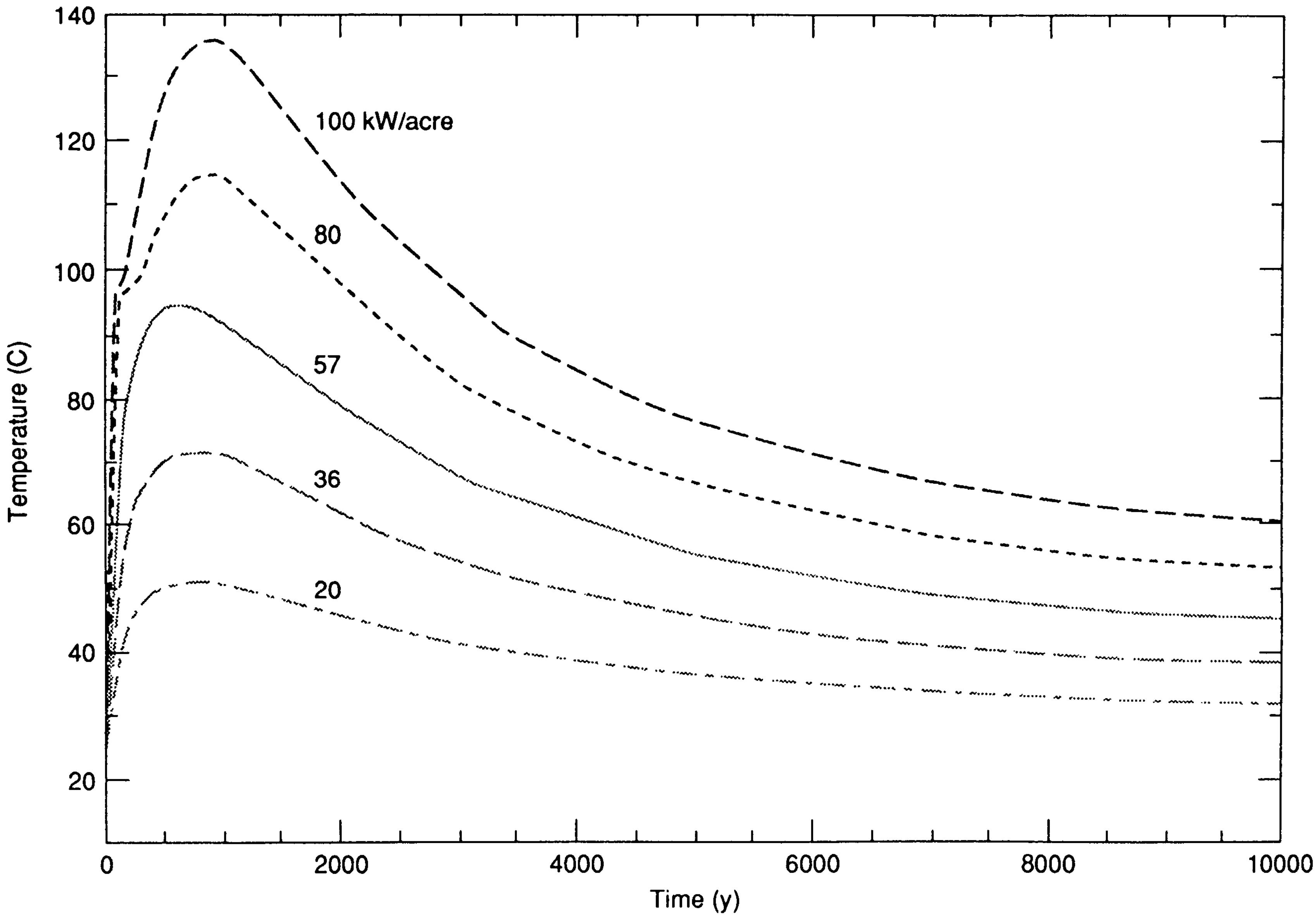
Impact of thermal load on hydrogeologic uncertainties

- For APD's as low as 20 kW/acre, the flow and transport properties of potential radionuclide pathways may be significantly altered

- The hydrologic performance of the repository is much less sensitive to hydrogeologic uncertainty at high APD's than at low APD's

For a given fuel age, temperature rise at the top of the Calico Hills (CHnv) is proportional to APD

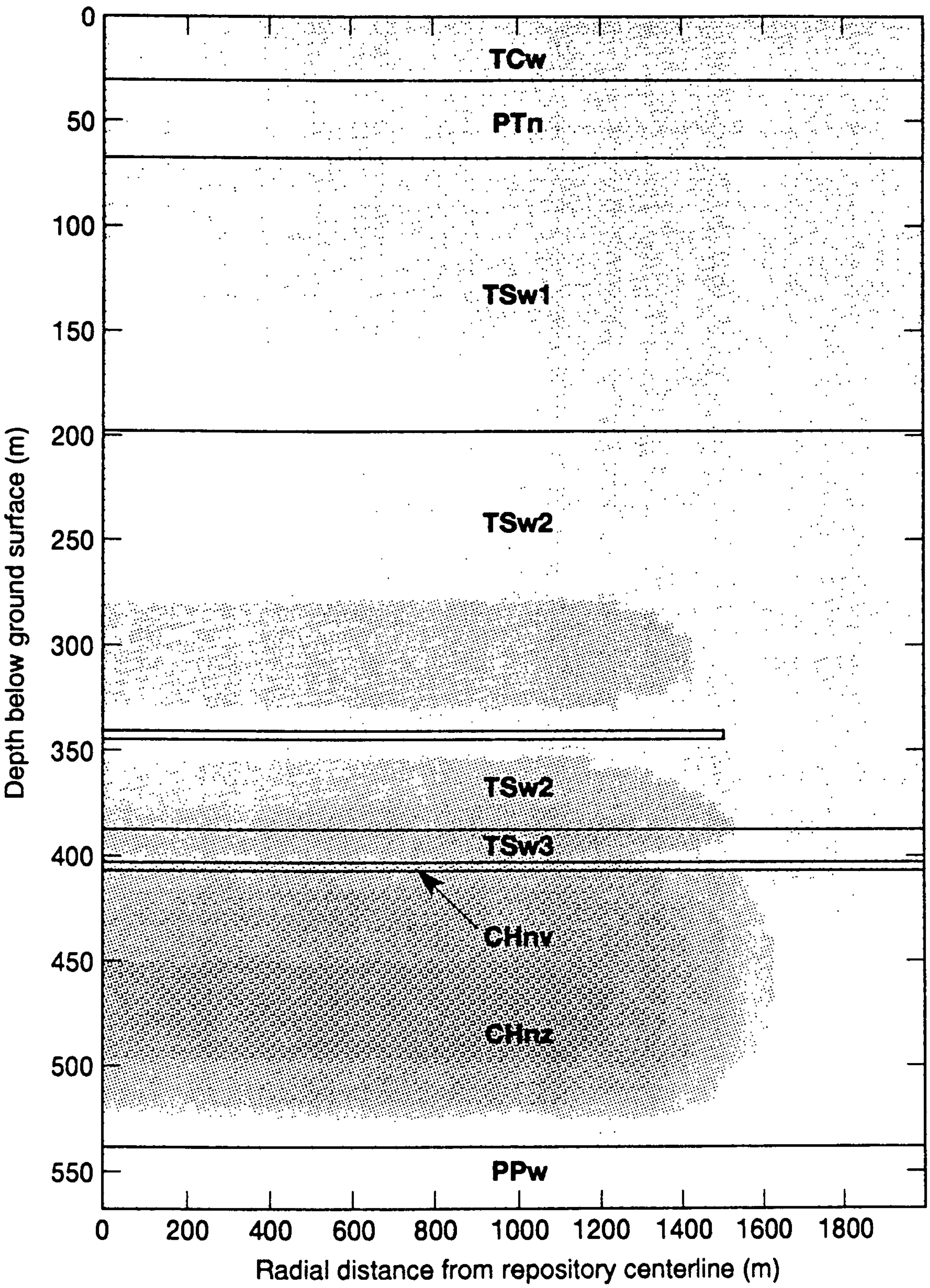
Temperature history at top of the CHnv, 60 m below the repository horizon for 30-yr-old fuel and a recharge flux of 0.0 mm/yr



ES-TB-15 (9-14-91) IL

Although boiling and dry-out benefits are negligible, condensation drainage extends all the way to the water table

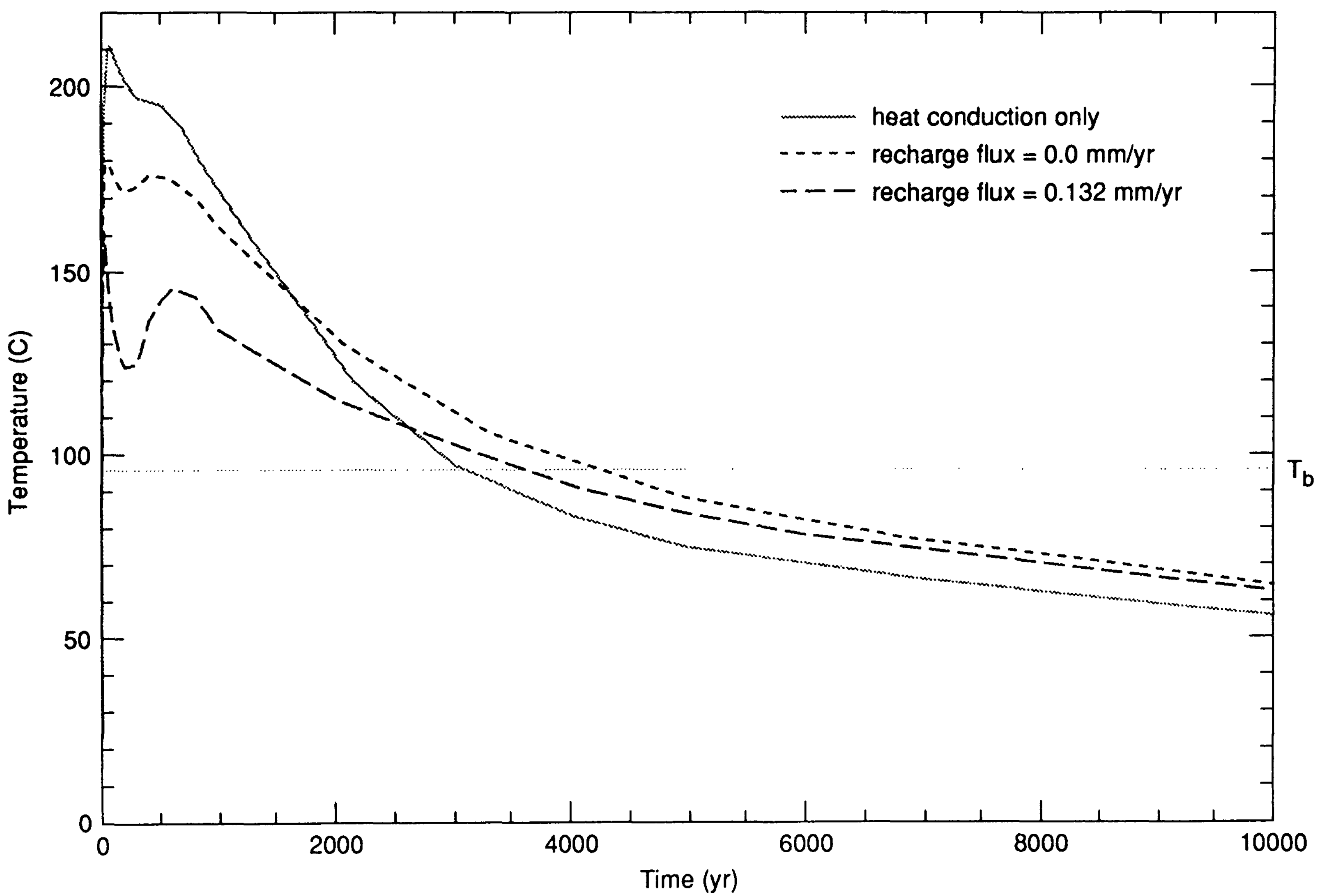
Dimensionless liquid saturation for 30-year-old fuel, an APD of 20 kW/acre, and a recharge flux of 0.0 mm/yr



ES-TB-7 (9-27-91) IL

The duration of dry steam boiling conditions is relatively insensitive to a large range in initial saturation; the heat conduction model conservatively predicts duration of boiling conditions

Drift wall temperature for drift emplacement, 30-yr-old fuel, and an APD of 100 kW/acre



ES-TB-6 (9-30-91) IL

Key hydrogeologic/geochemistry uncertainty considerations

- Zeolitization of the vitric nonwelded CHnv even at low APD's
- Alteration of flow and transport properties of fracture pathways in the zeolitized nonwelded CHnz even at low APD's
    - Impact on performance may be significant for low-to-medium APD's
    - Impact on performance is much less significant for high APD's

Key hydrogeologic/geomechanical uncertainty considerations

- Thermally-induced macro-fracturing near openings
  - may result in additional preferential pathways
  - may also result in increased liquid-phase dispersion in fracture networks
- Thermally-induced micro-fracturing out to the boiling front
  - may increase matrix capillary diffusivity, enhancing the impact of matrix imbibition on fracture flow attenuation
- Both macro- and micro-fracturing may enhance rock dry-out rate due to boiling

Conclusions

Questions 1-3: Significance of benefits/problems; associated uncertainties

- Vapor and liquid flow in fractures is the key hydrogeologic consideration
- Repository performance at higher APD's is much less sensitive to hydrogeologic variability/uncertainty
- Unsaturated, fractured tuff promotes rock dry-out by boiling and rapid condensate drainage
  - Rock dry-out volume dominated by thermal load and thermal properties
- For higher APD's and older age fuel, boiling and rock dry-out benefits persist for thousands of years
  - Promoting more favorable waste package conditions
  - Greatly enhancing fracture flow attenuation
- Performance problems remain at lower APD's with no dry-out benefits

Conclusions (continued)

Question 3: Uncertainties

- Performance modeling of high APD's is much less sensitive to hydrogeologic variability/uncertainty
- Data on fracture network properties is currently limited
- In situ test data for hydrothermal model validation is currently limited to G-Tunnel experiments

Question 4: Uncertainty resolution

- Site characterization/ESF testing/prototype testing
    - Testing under boiling conditions provides better experimental basis for model validation
    - More likely to adequately resolve uncertainties associated with high APD's than with low APD's

Appendix

With respect to fracture-matrix flow, the hydrostratigraphic units at Yucca Mountain fall into two distinct categories

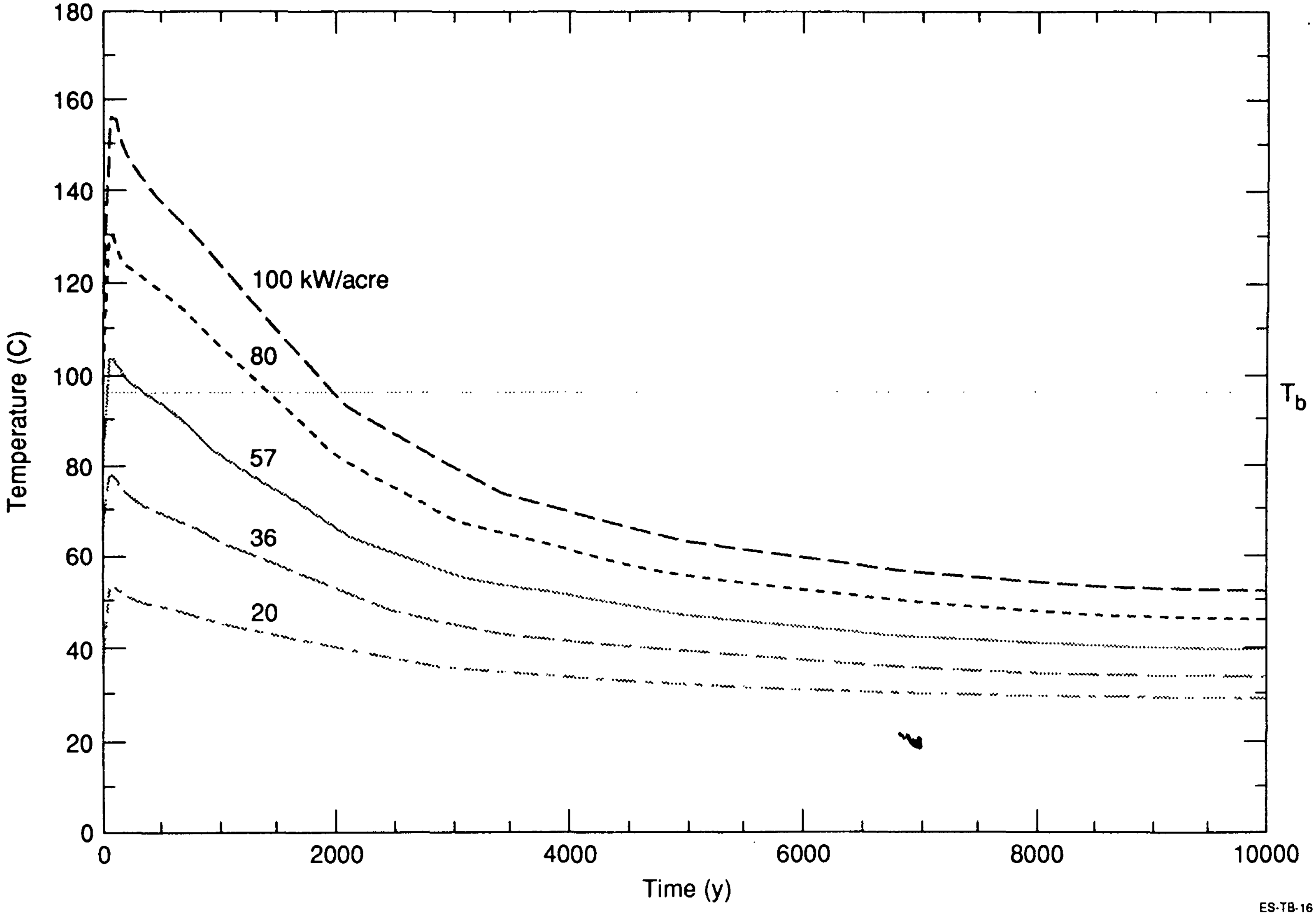
- The low matrix permeability of the welded units (TCw, TSw1, TSw2, and TSw3) and the zeolitized nonwelded unit (CHnz) promotes fracture-dominated flow (given a sufficient infiltration source)

- The high matrix permeability of the vitric nonwelded units (PTn and CHnv) generally promotes matrix-dominated flow

- The hydrostratigraphy and hydrologic property values used in this study are obtained from Klavetter and Peters (1986)

Temperatures decline more quickly at edge of repository; however, dry steam boiling conditions persist for 2000 years for an APD of 100 kW/acre

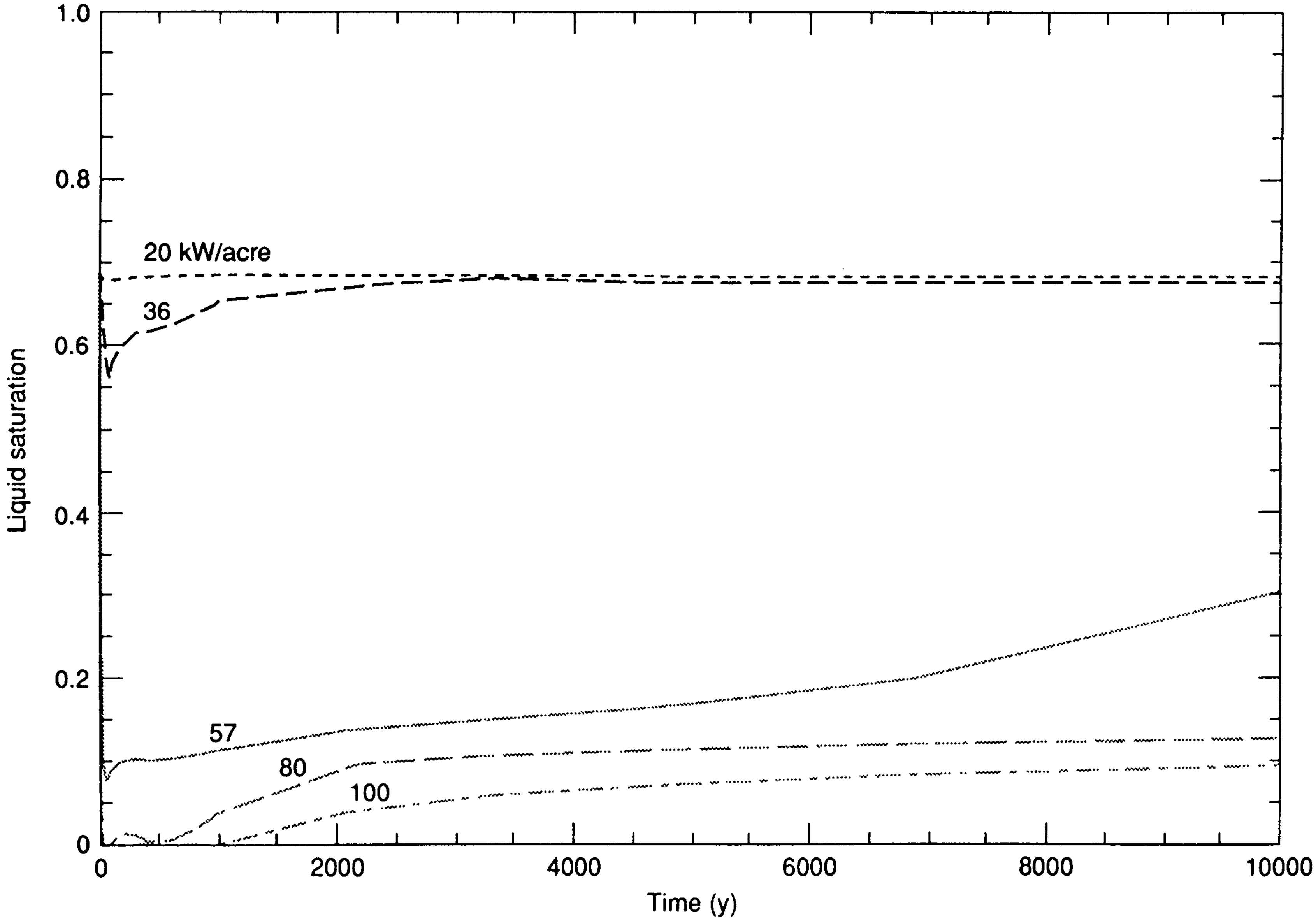
Temperature history at edge of repository for 30-yr-old fuel and a recharge flux of 0.0 mm/yr



ES-TB-16 (9-14-91) IL

For 30-yr-old fuel, the threshold APD for significant dry-out by boiling lies between 36 and 57 kW/acre

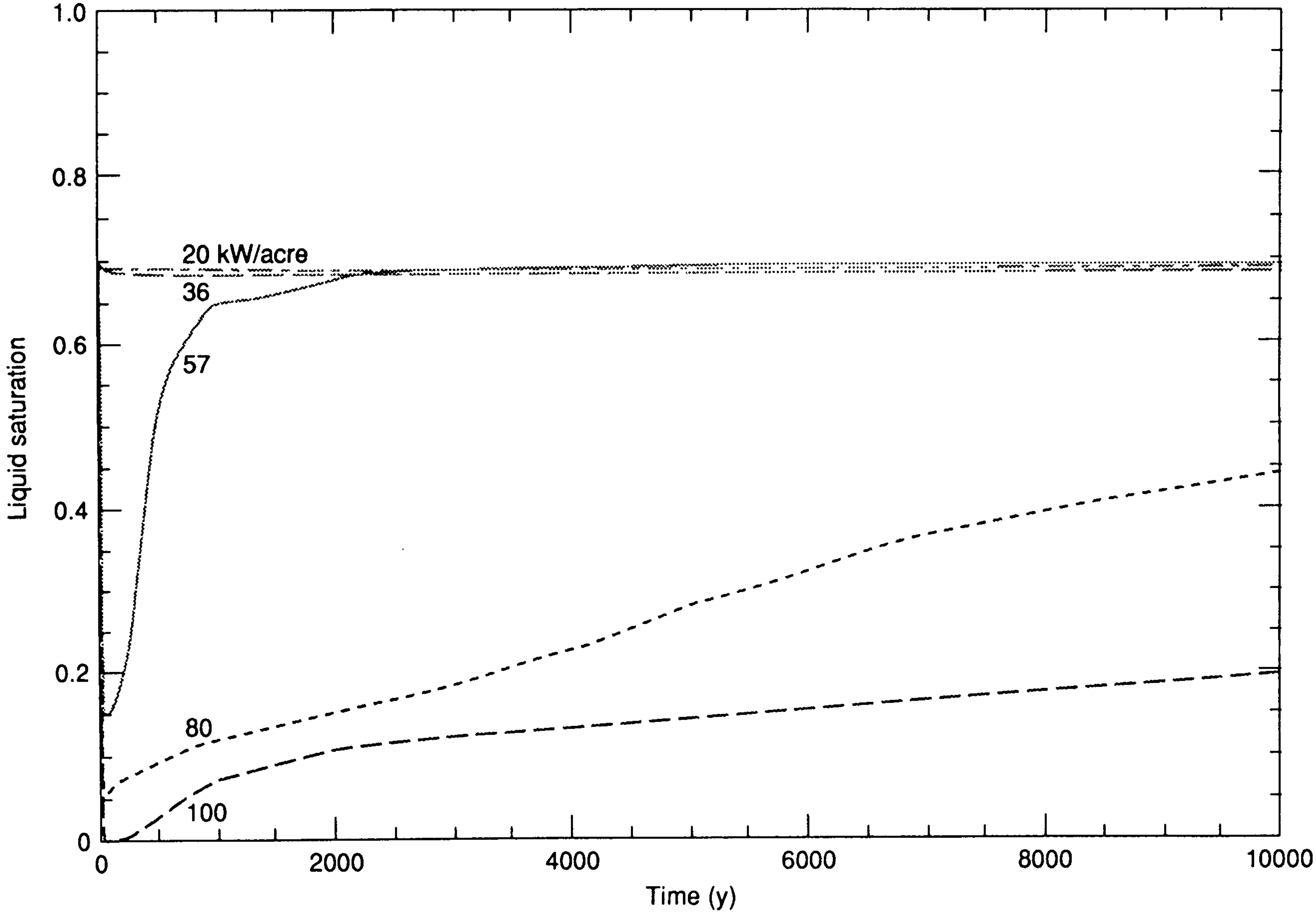
Liquid saturation history at drift wall for drift emplacement for 30-year-old fuel and a recharge flux of 0.0 mm/yr



ES-TB-36 (9-23-91) IL

Rock dry-out benefits persist at edge of repository for high APD's

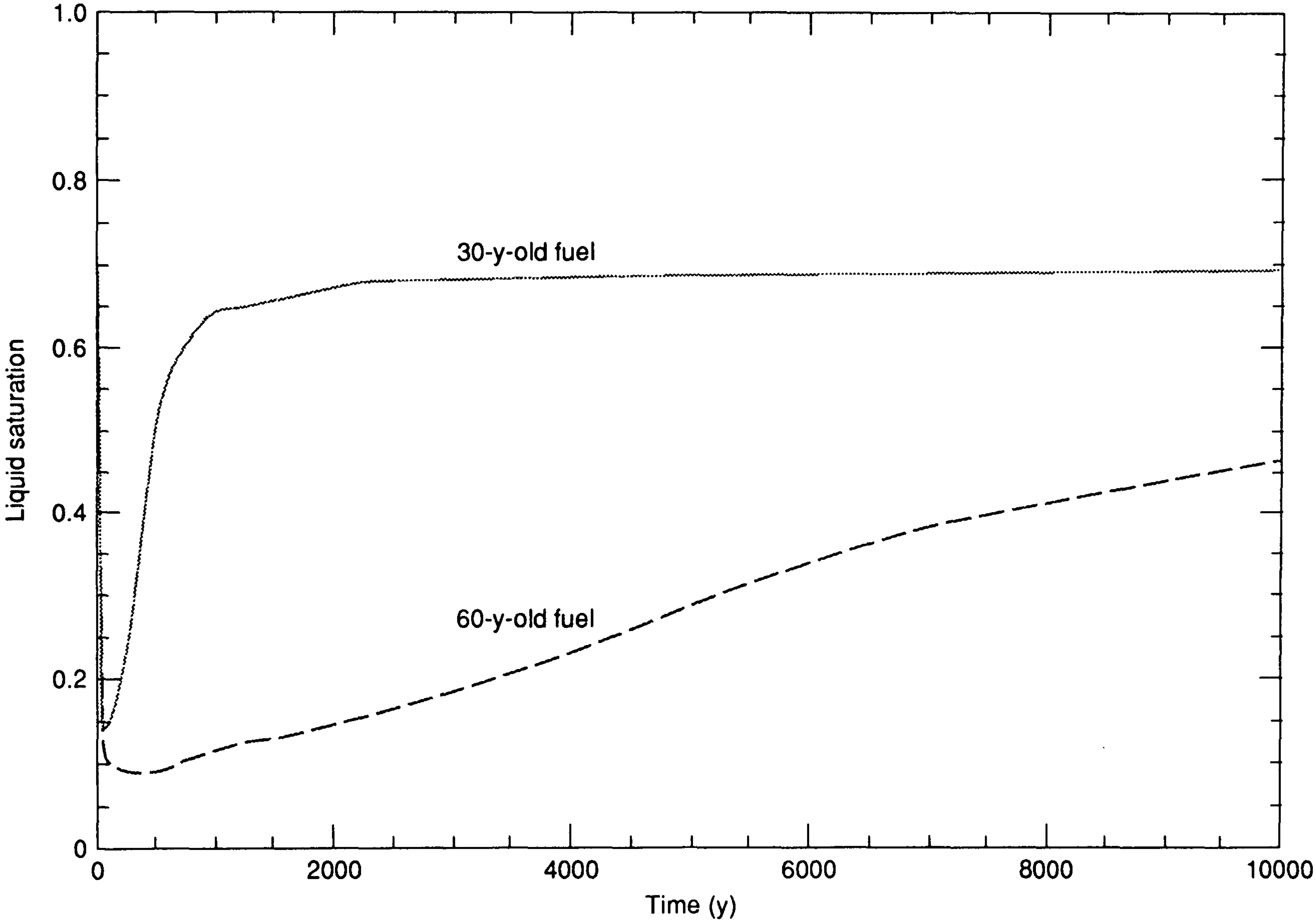
Liquid saturation at edge of repository for 30-yr-old fuel and a recharge flux of 0.0 mm/yr



ES-TB-18 (9-14-91) IL

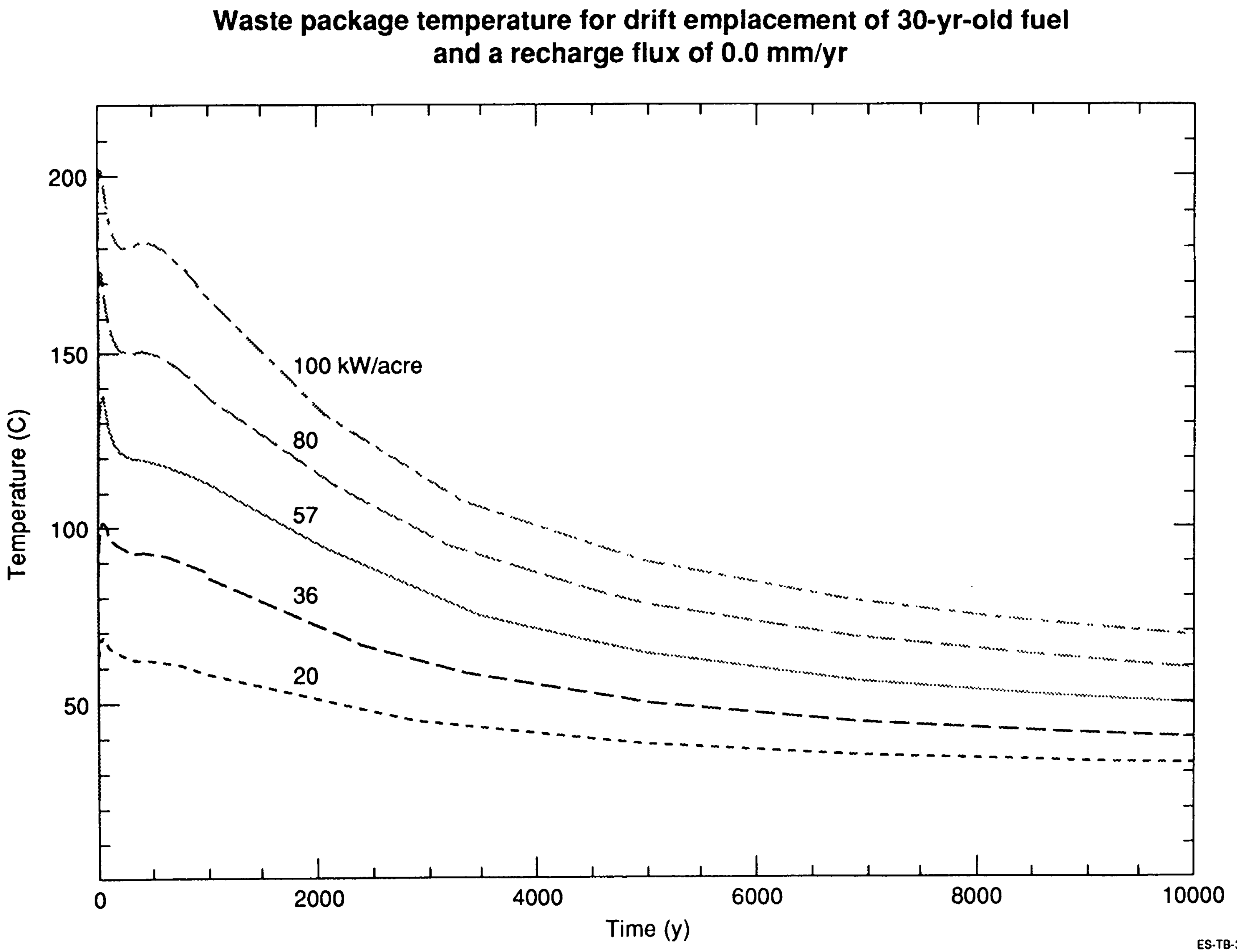
For an APD of 57 kW/acre, rock dry-out benefits persist at edge of repository for 60-yr-old fuel

Liquid saturation at edge of repository for an APD of 57 kW/acre and a recharge flux of 0.0 mm/yr



ES-TB-12 (9-14-91) IL

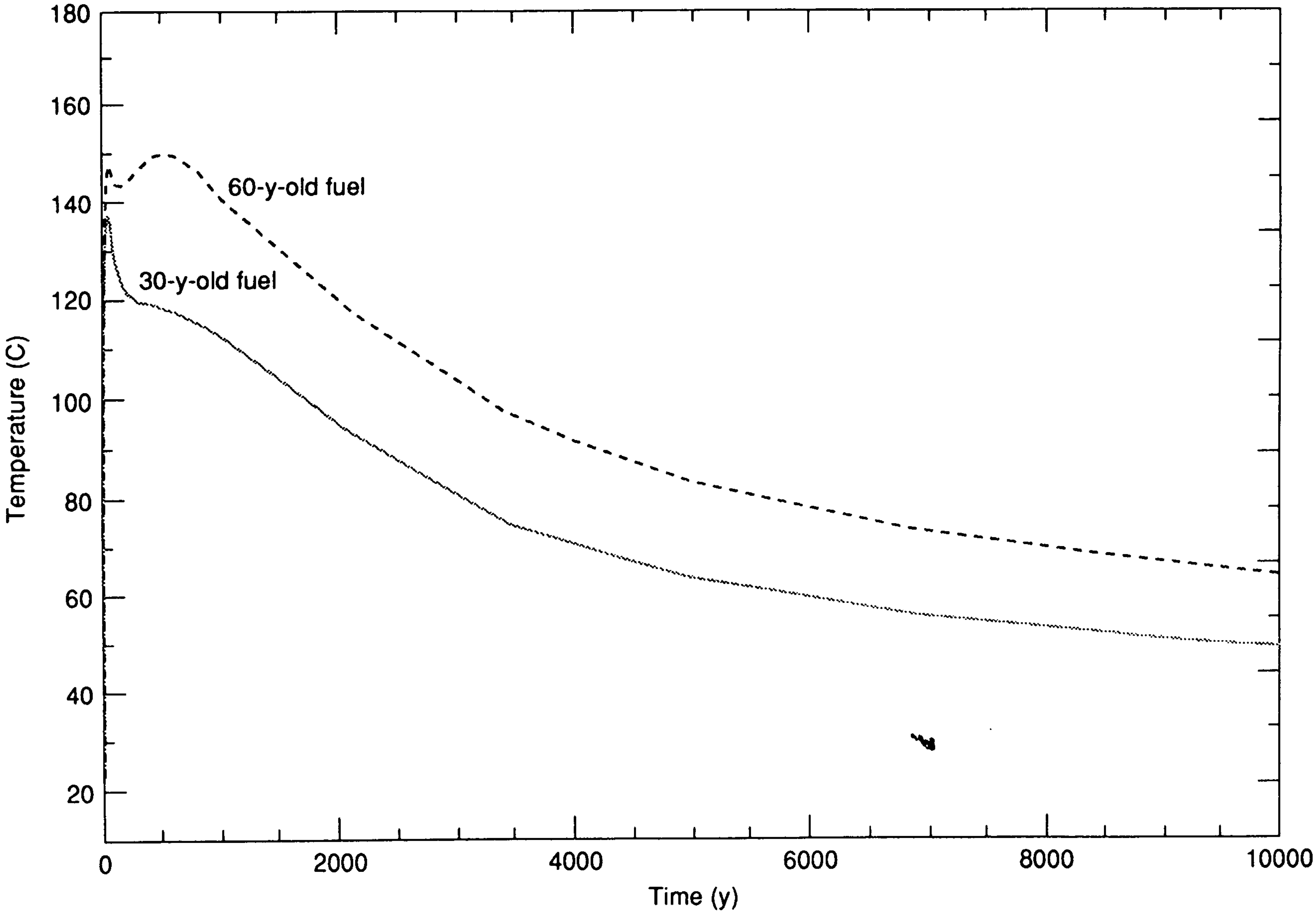
Waste package temperatures for drift emplacement are much lower than for borehole emplacement



ES-TB-31 (9-23-91) IL

Boiling and rock dry-out benefits are obtained for 60-yr-old fuel with minimal impact on waste package temperature

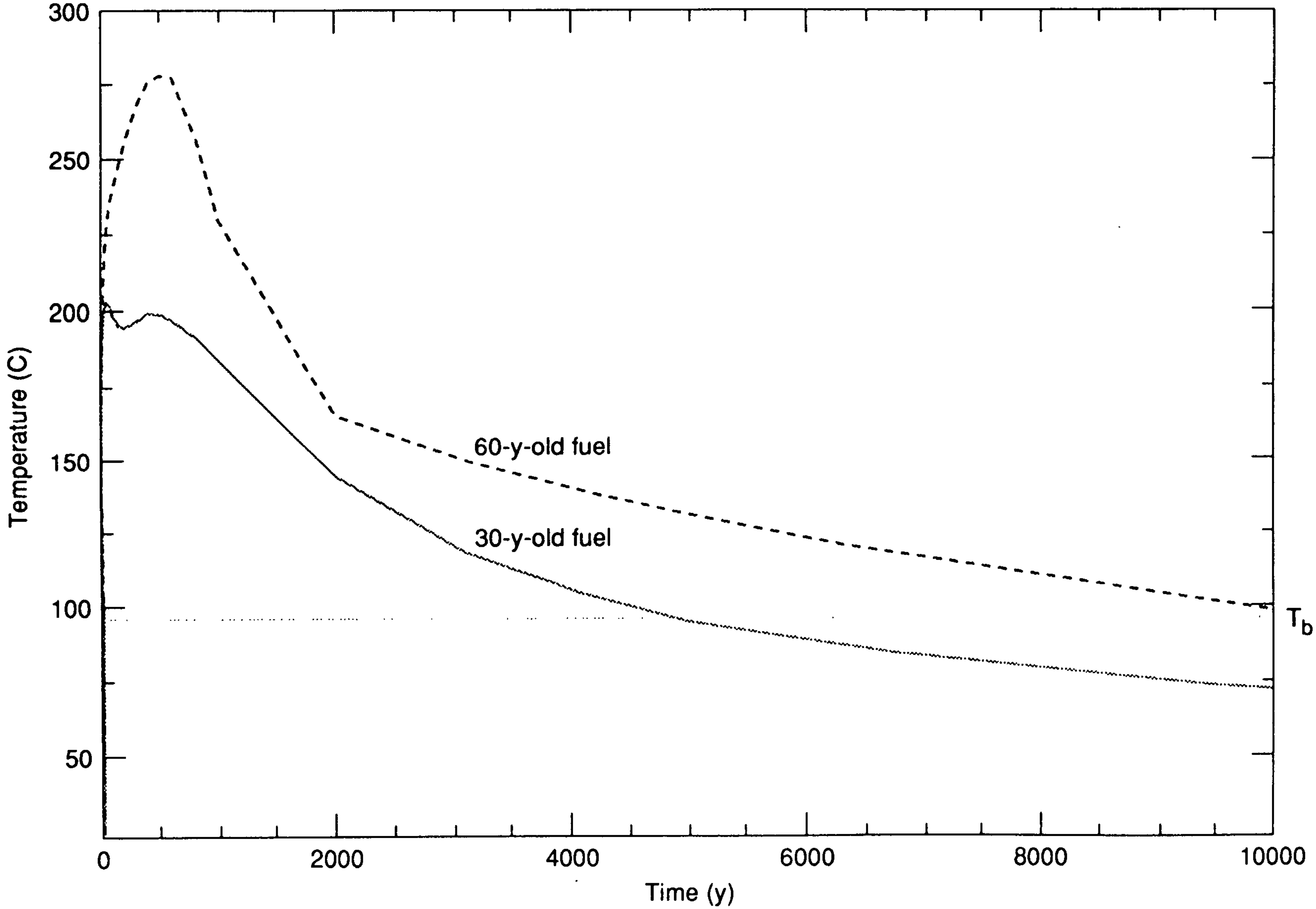
Waste package temperature for drift emplacement for an APD of 57 kW/acre and a recharge flux of 0.0 mm/yr



ES-TB-32 (9-23-91) IL

A substantial increase in boiling and dry-out benefits is obtained for 60-yr-old fuel, with dry steam boiling conditions persisting for 10000 years

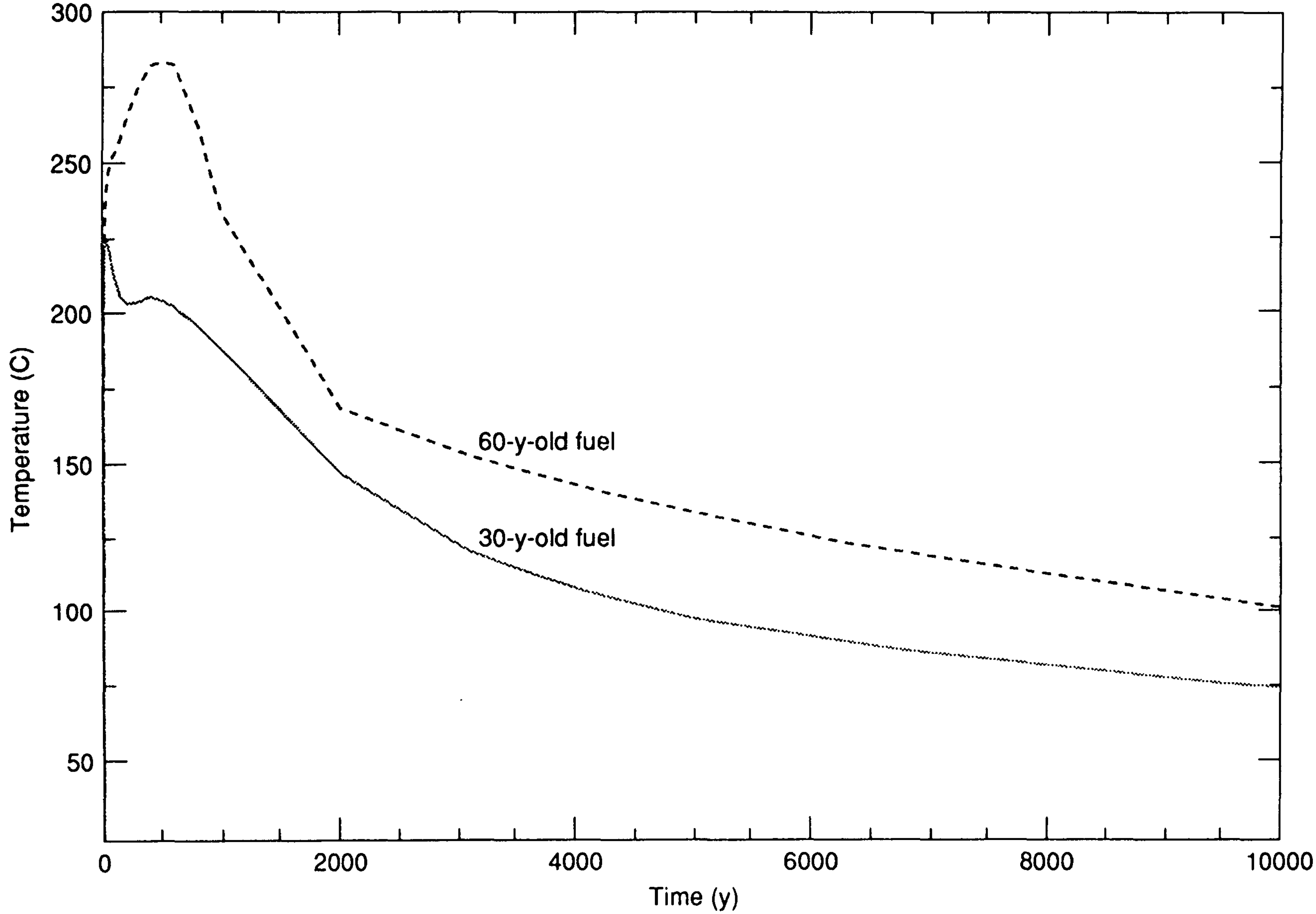
Drift wall temperature for drift emplacement for an APD of 114 kW/acre



ES-TB-4 (9-30-91) IL

Dry steam boiling conditions persist for more than 10000 years, with waste package temperatures peaking at 275°C

Waste package temperature for drift emplacement for an APD of 114 kW/acre



ES-TB-5 (9-30-91) IL