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

PRESENTATION TO THE NUCLEAR WASTE TECHNICAL REVIEW BOARD

SUBJECT: TECHNICAL CONSIDERATIONS

PRESENTER: ERIC E. RYDER

PRESENTER'S TITLE AND ORGANIZATION:
TECHNICAL STAFF
PERFORMANCE ASSESSMENT DIVISION
SANDIA NATIONAL LABORATORY
ALBUQUERQUE, NEW MEXICO

PRESENTER'S TELEPHONE NUMBER: (505) 844-9644

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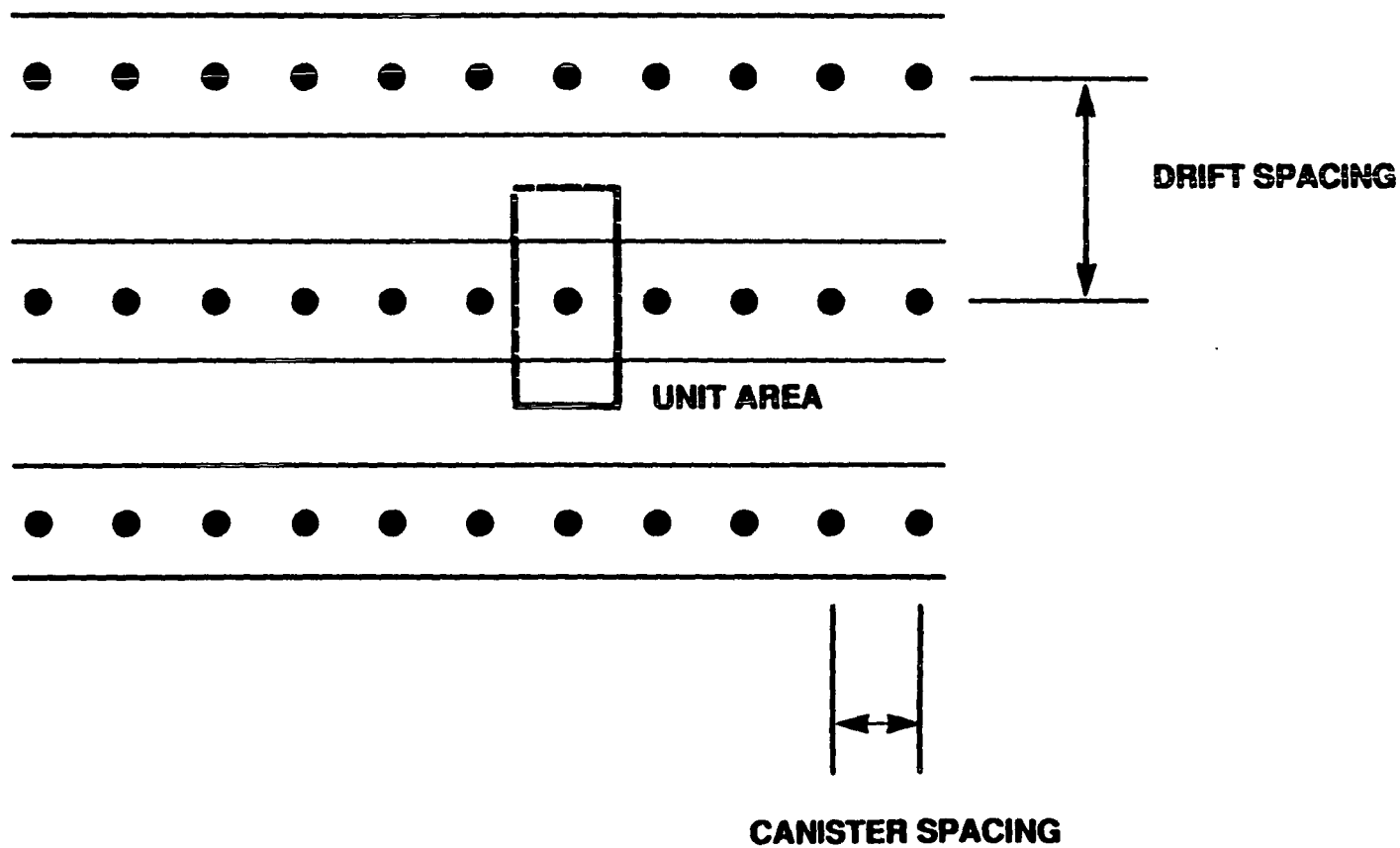
Thermal Design Considerations

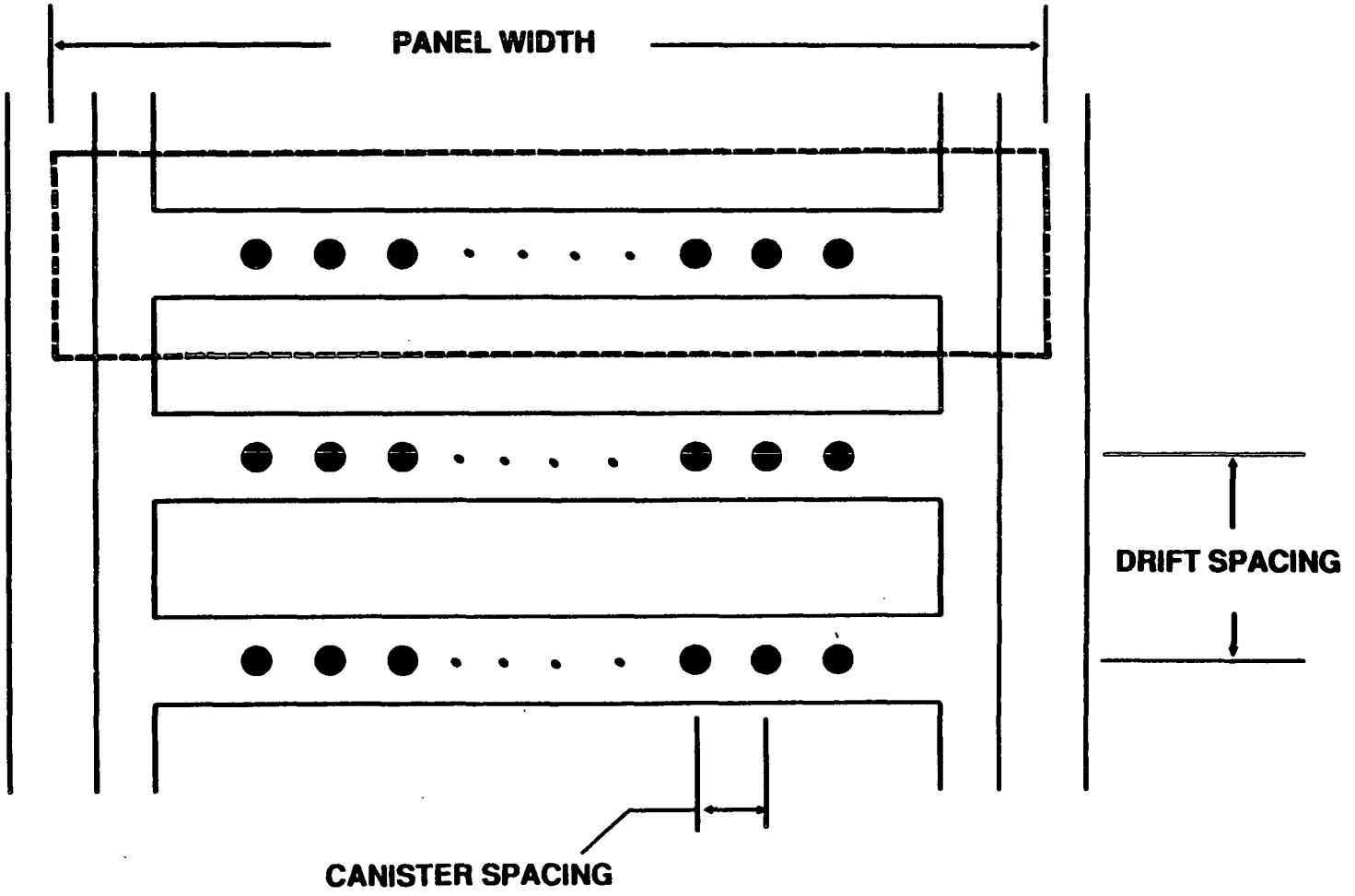
Objectives

- Discuss complexities of the repository thermal design process
- Demonstrate why there is no unique set of temperature histories that correspond to a given areal power density
- Emphasize the dependence of calculated thermal responses on model/system assumptions
- Point out some design/system changes that have occurred since the SCP

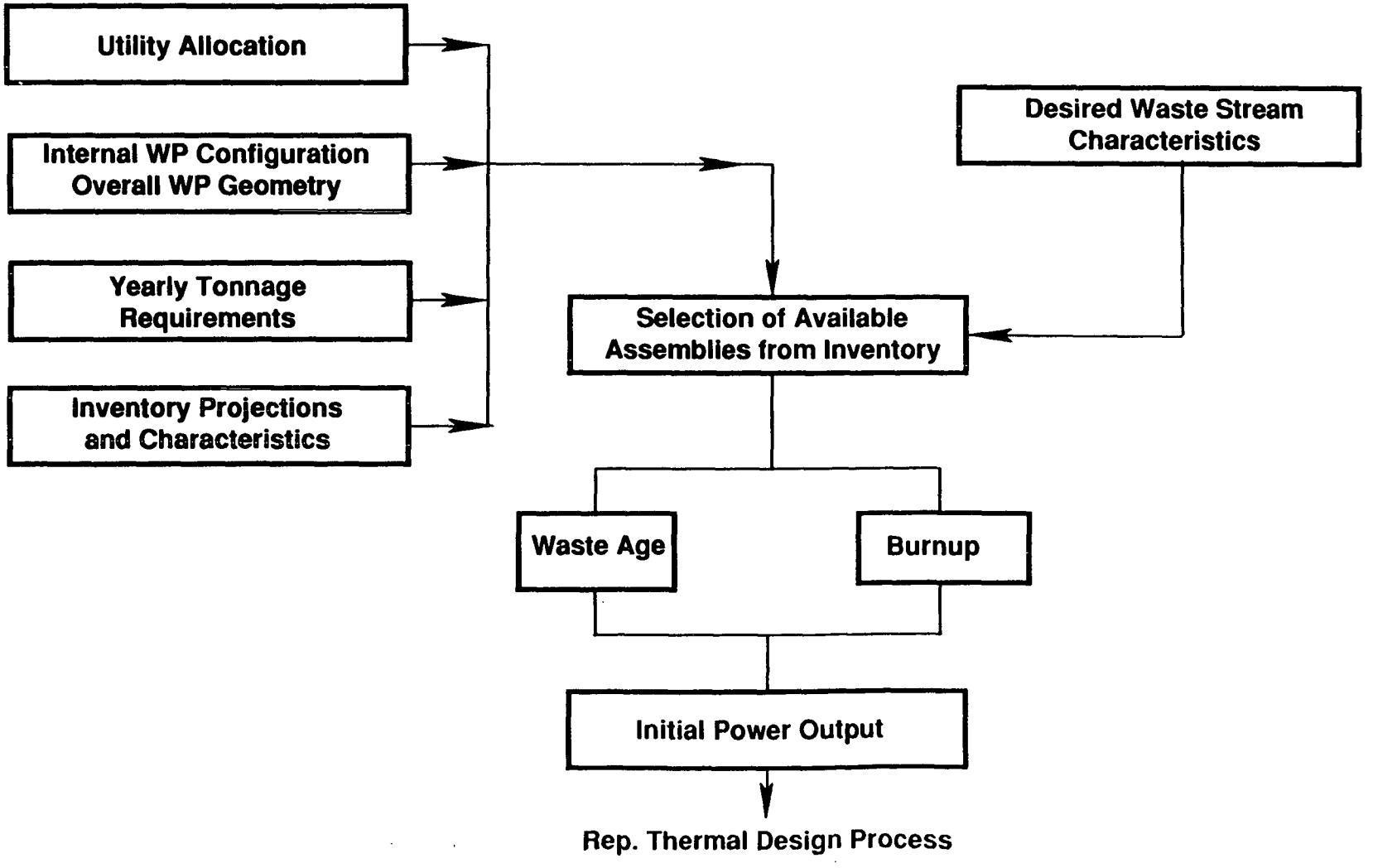
Local Areal Power Density (LAPD) = Initial Loading / Unit Area



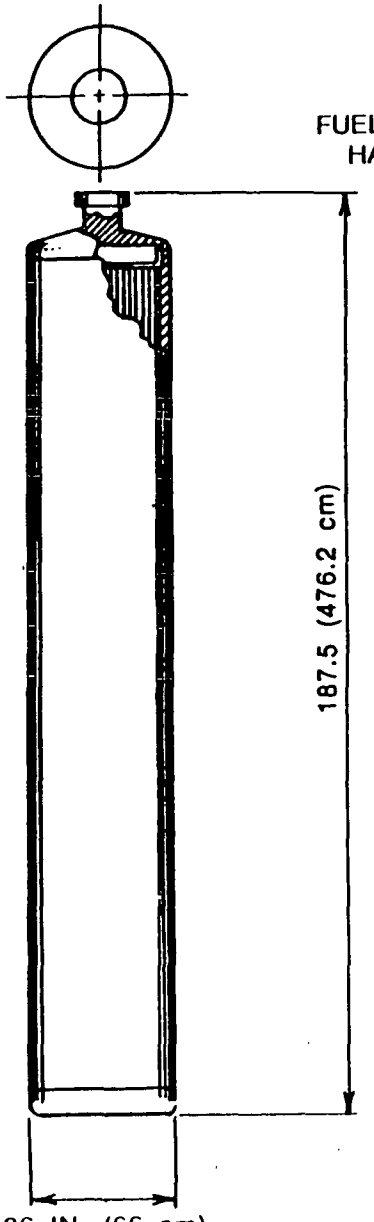
Areal Power Density (APD) = Initial Loading / Unit Area

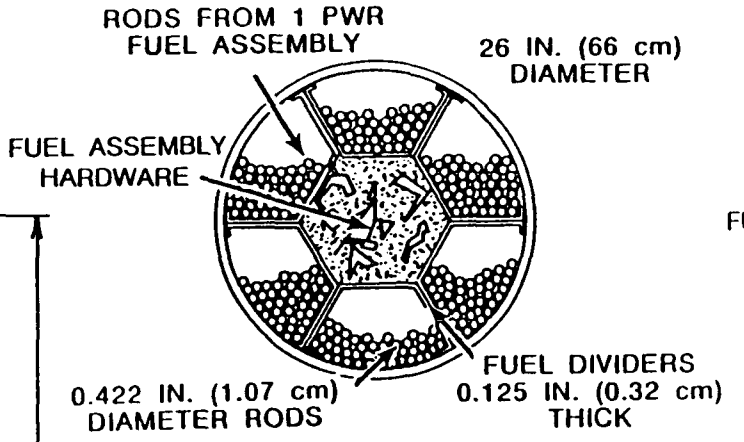


Waste Stream Characteristics

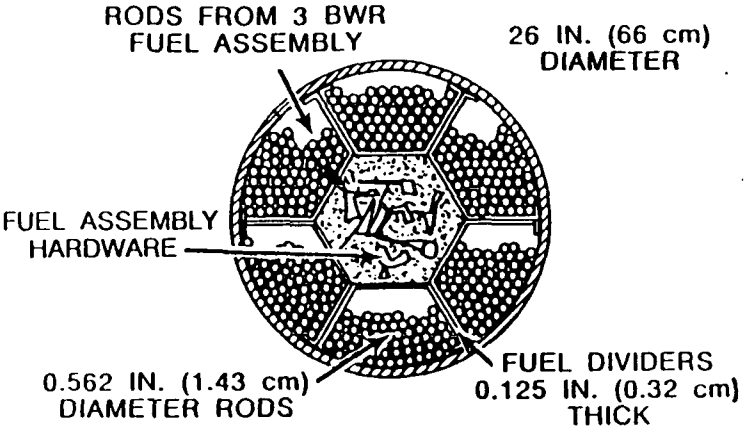


SCP Reference Waste Package Configurations

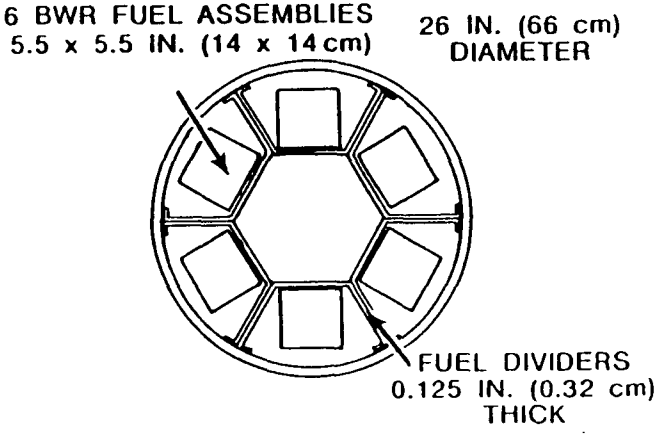




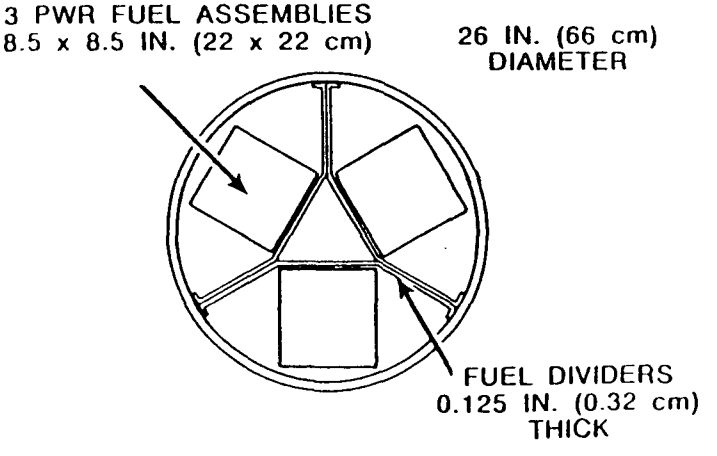
CONFIGURATION 1.
SIX CONSOLIDATED PWR ASSEMBLIES



CONFIGURATION 2.
EIGHTEEN CONSOLIDATED BWR ASSEMBLIES



CONFIGURATION 3.
SIX INTACT BWR ASSEMBLIES



CONFIGURATION 4.
THREE INTACT PWR ASSEMBLIES

PWR - PRESSURIZED WATER REACTION
BWR - BOILING WATER REACTOR

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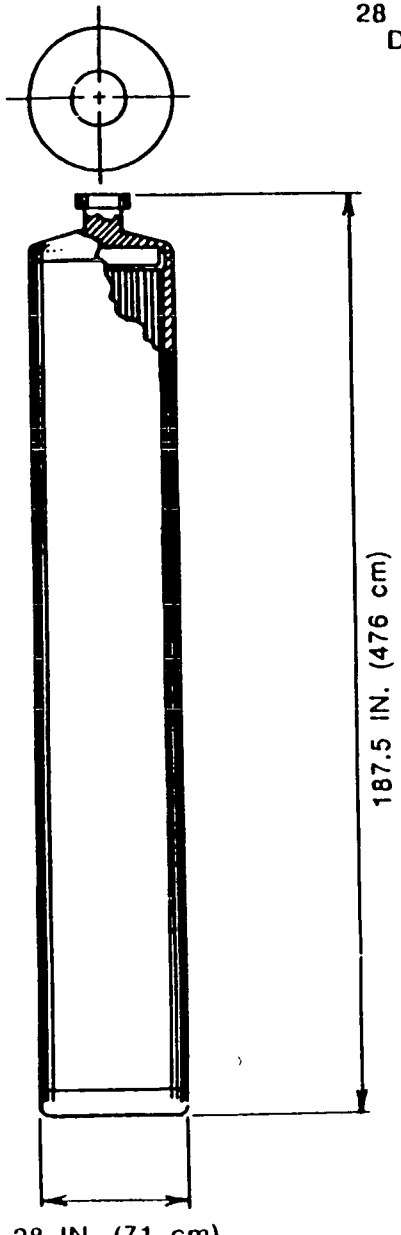
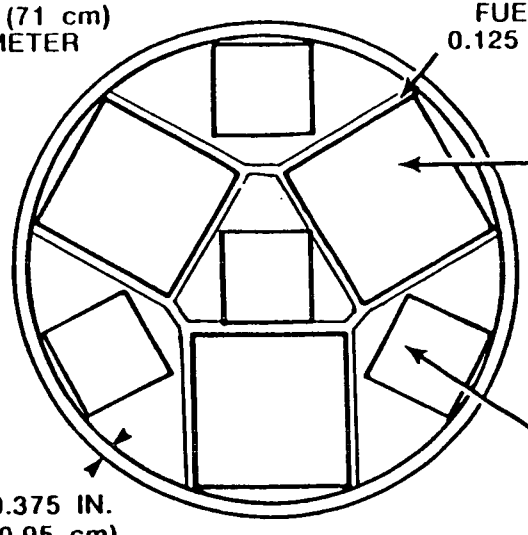
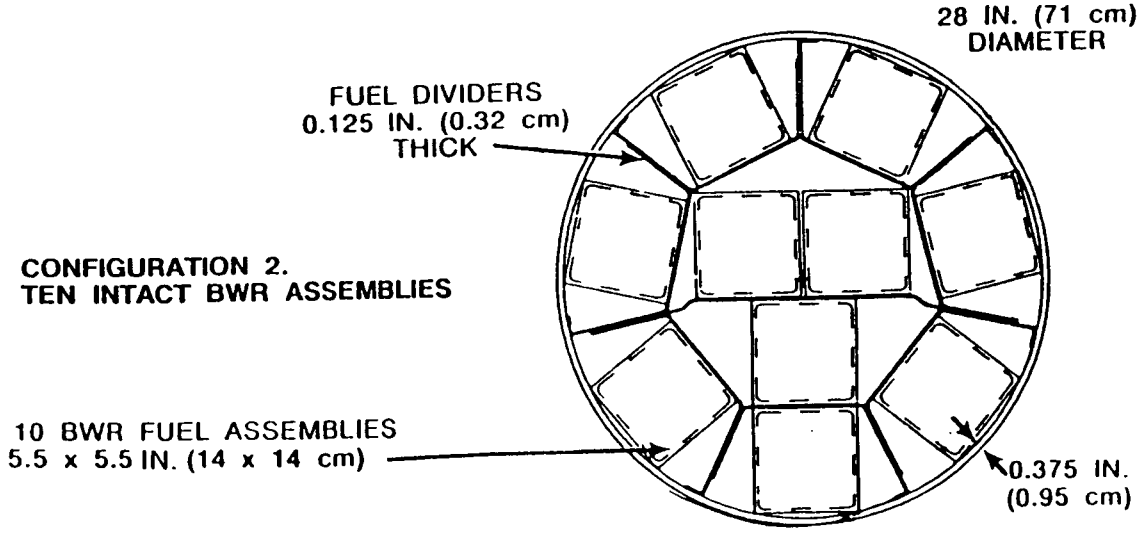
SCP Alternate Waste Pakage Configurations





CONFIGURATION 1.
THREE INTACT PWR ASSEMBLIES
FOUR INTACT BWR ASSEMBLIES



CONFIGURATION 2.
TEN INTACT BWR ASSEMBLIES

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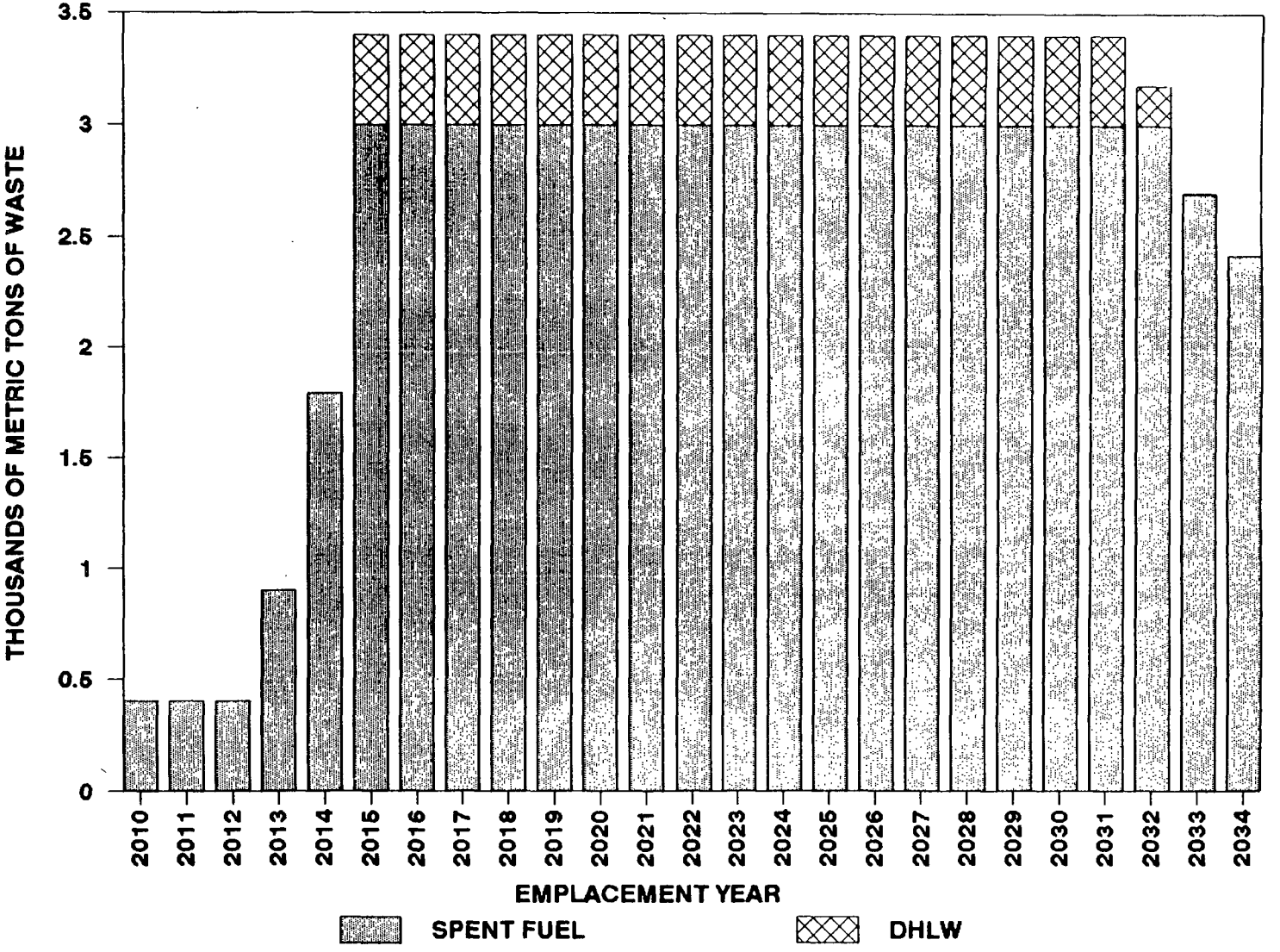
Acceptance Schedule
(Mission Plan Amendment, 1988)



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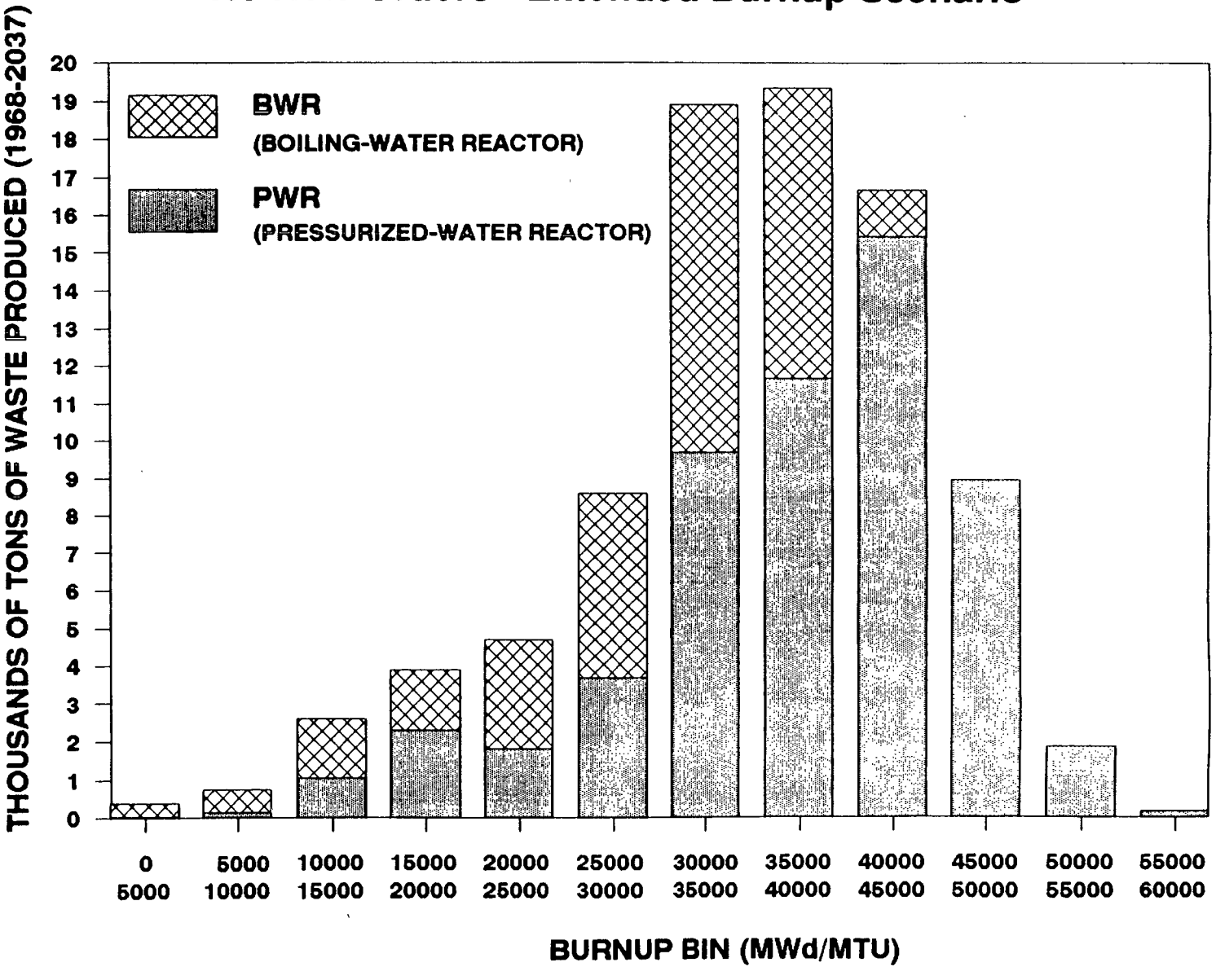
ORNL Historical and Projected Spent Fuel Inventory

(1968 - 2037)

No New Orders - Extended Burnup Scenario



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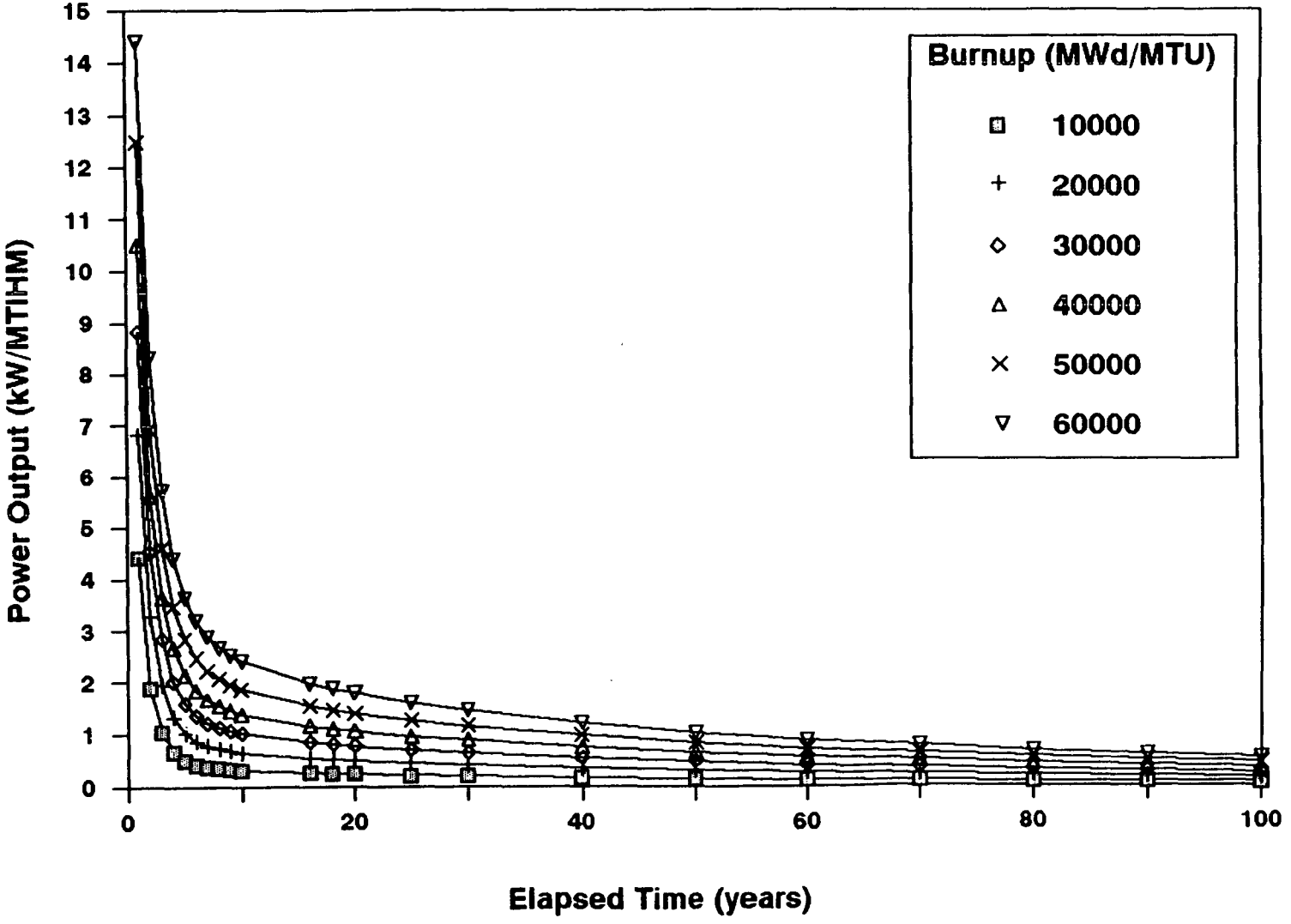
Thermal Decay Characteristics

PWR-type Waste



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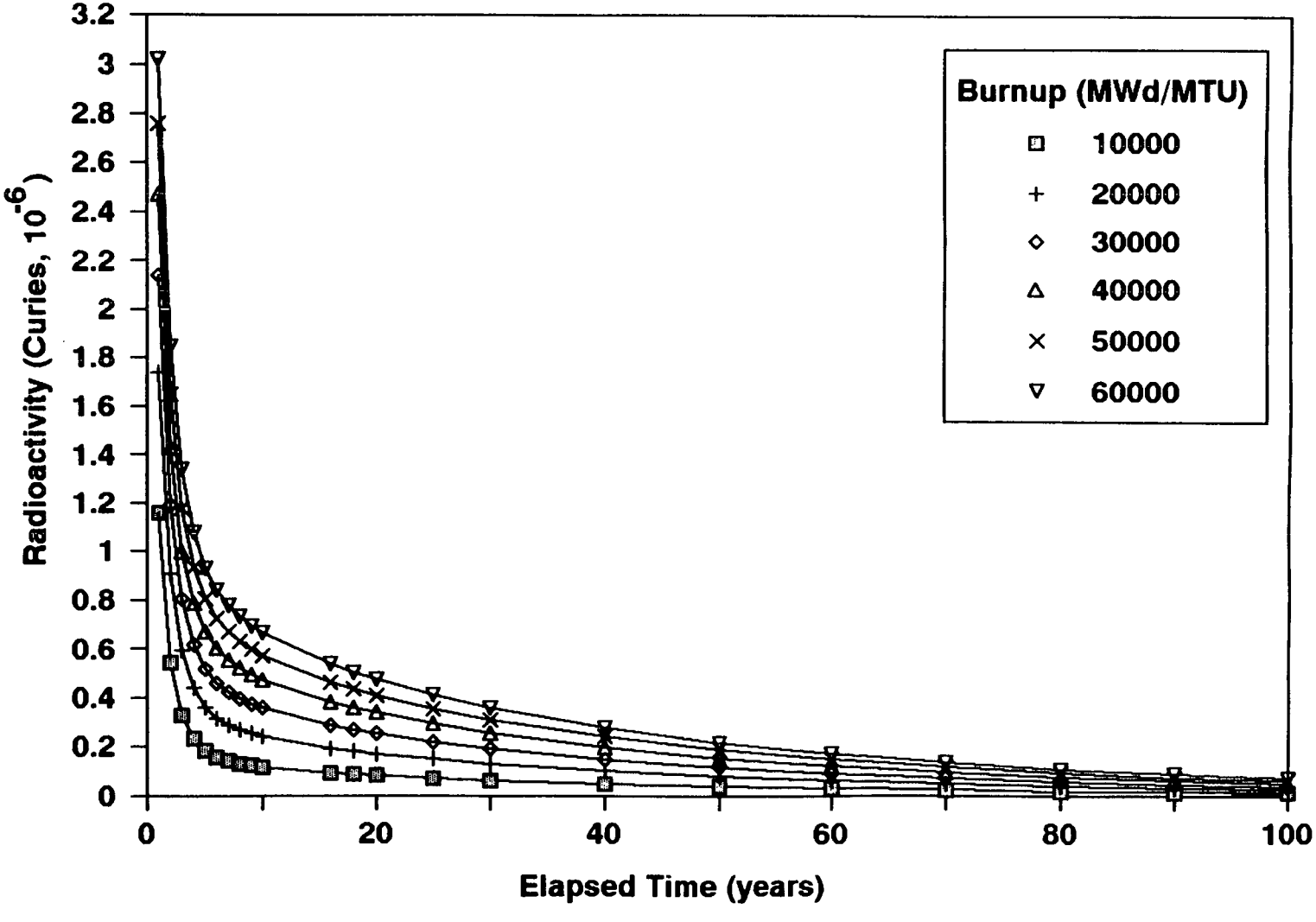
Radiological Decay Characteristics

PWR-type Waste



Desired Waste Stream Characteristics

FIFO:

Fuel is received and emplaced at the repository on an oldest-fuel-first basis

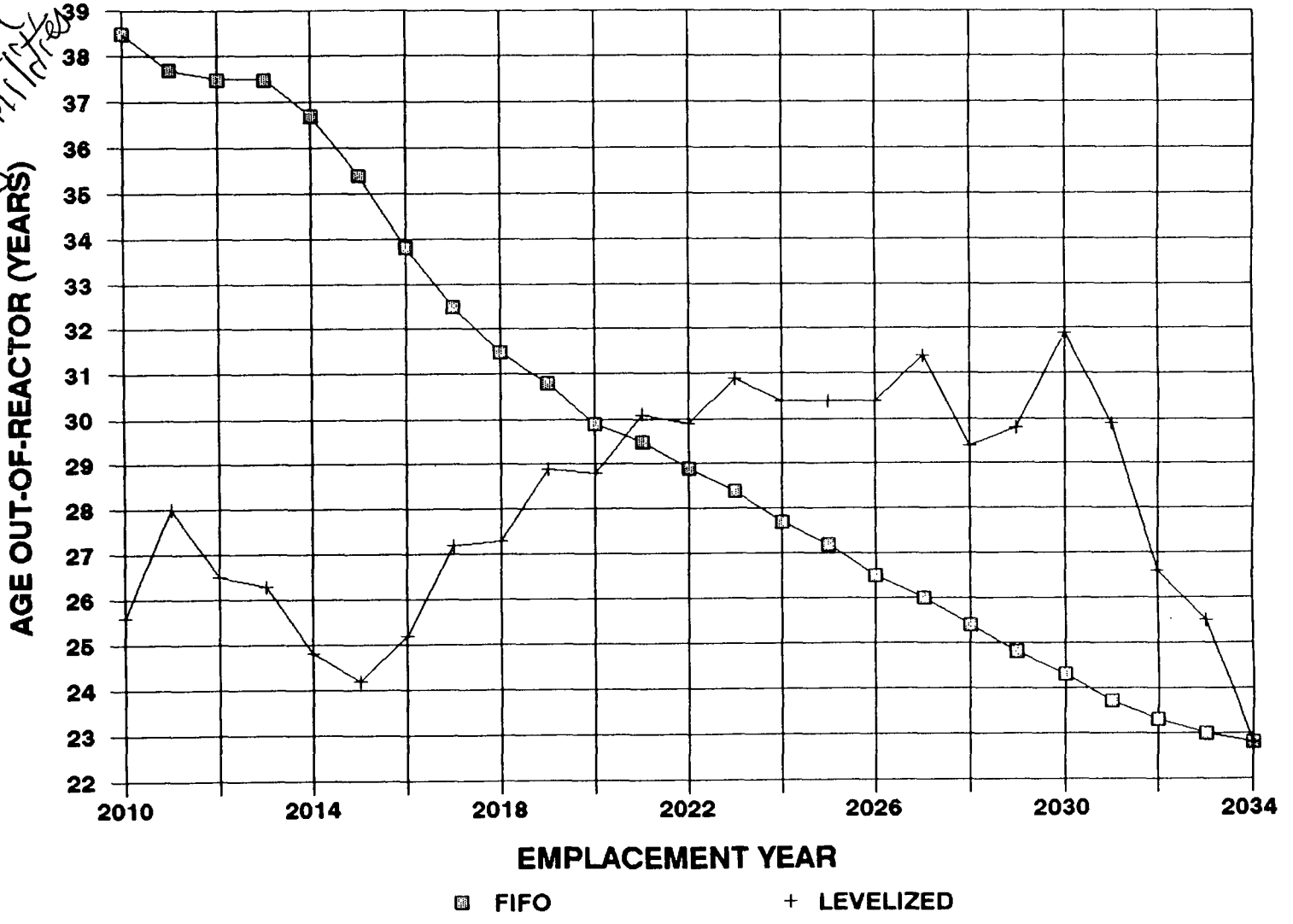
Levelized:

Fuel assemblies are chosen from the available inventory in such a manner that the initial power output and average waste age span a limited range

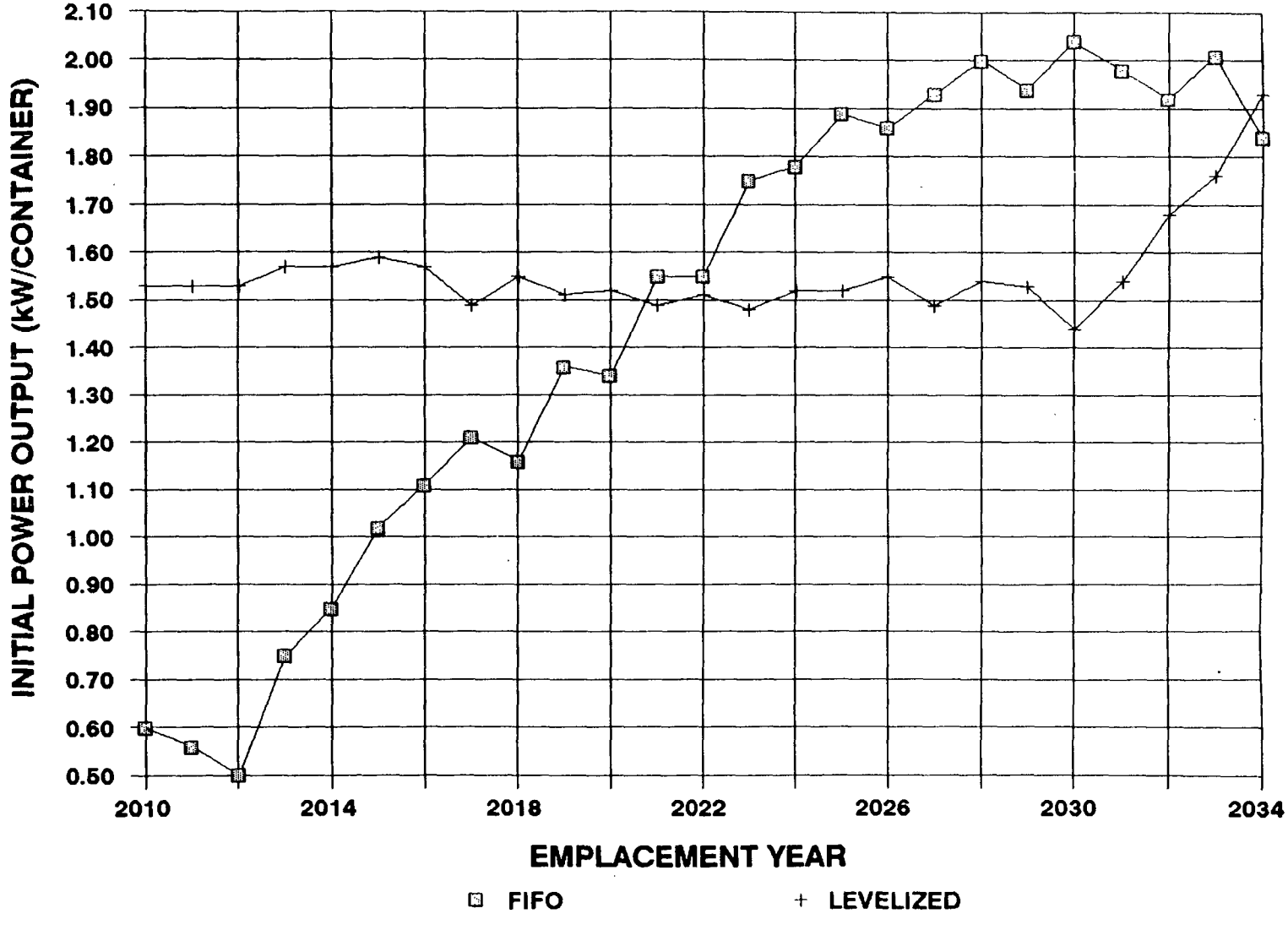
Area Minimization:

Use of the "transportation" algorithm allows assignment of costs on the basis of acres required per ton of material emplaced

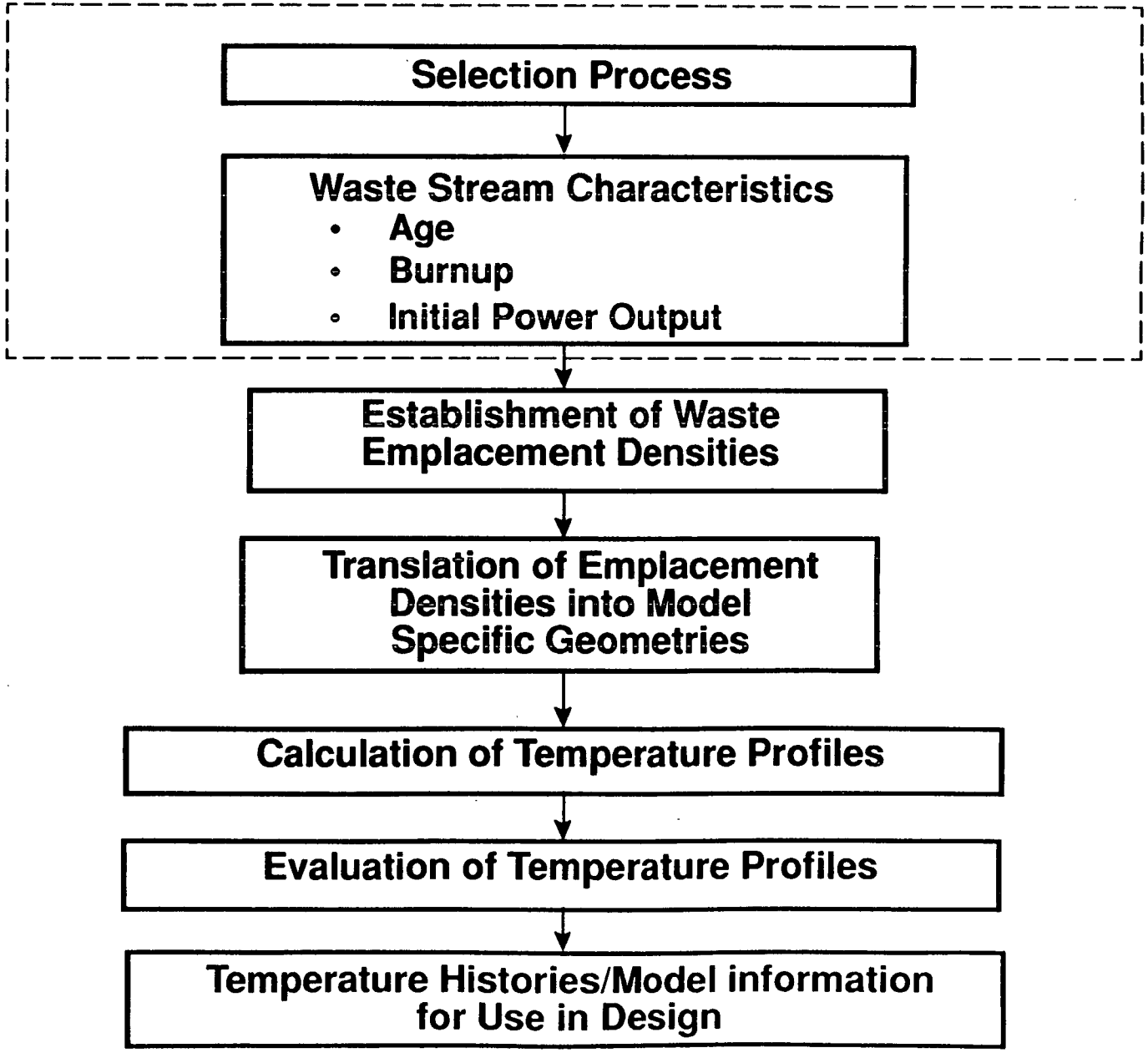
Waste Age Characteristics



Initial Power Characteristics



Repository Thermal Design Process



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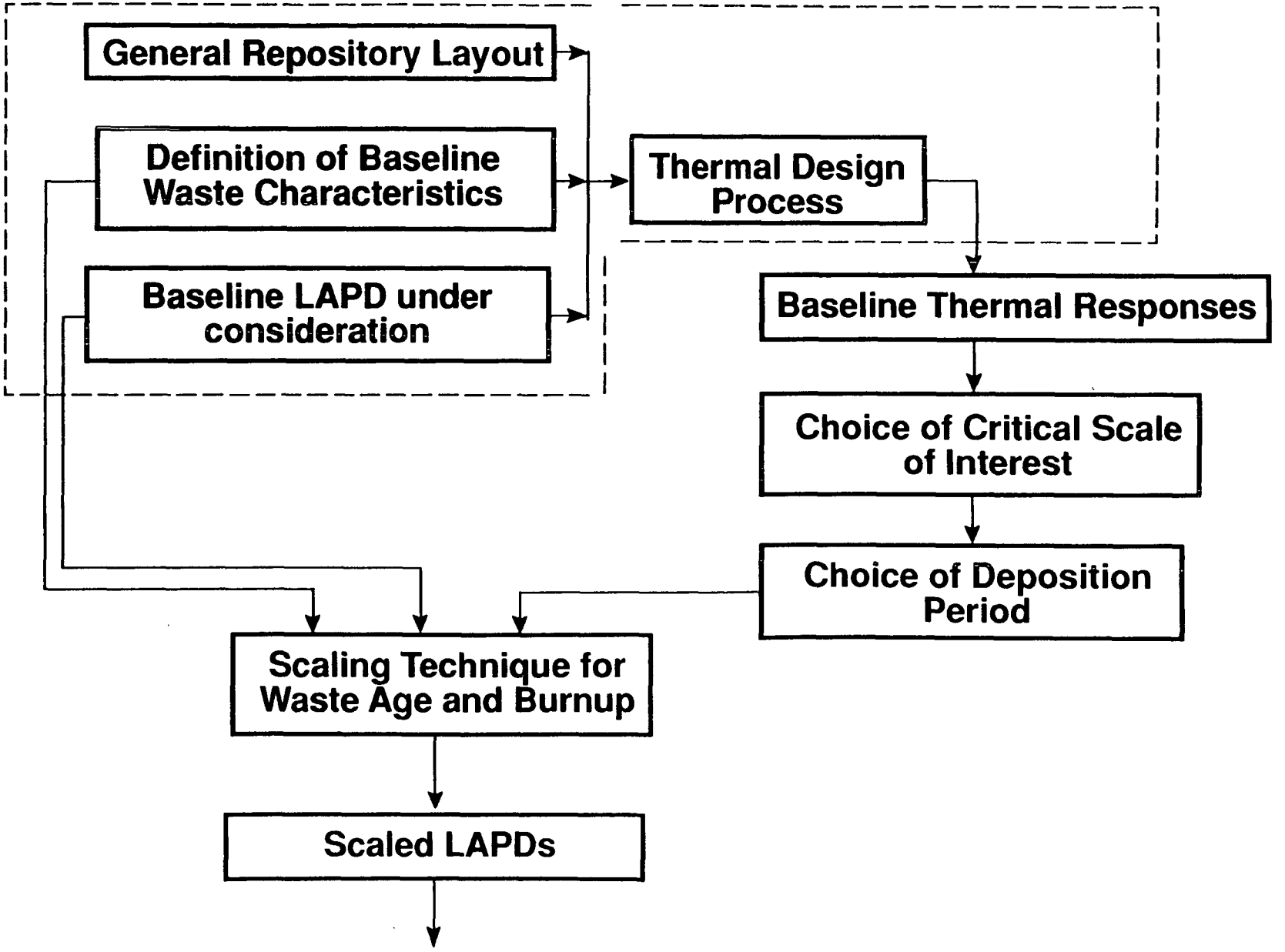
Establishment Of Waste Emplacement Densities



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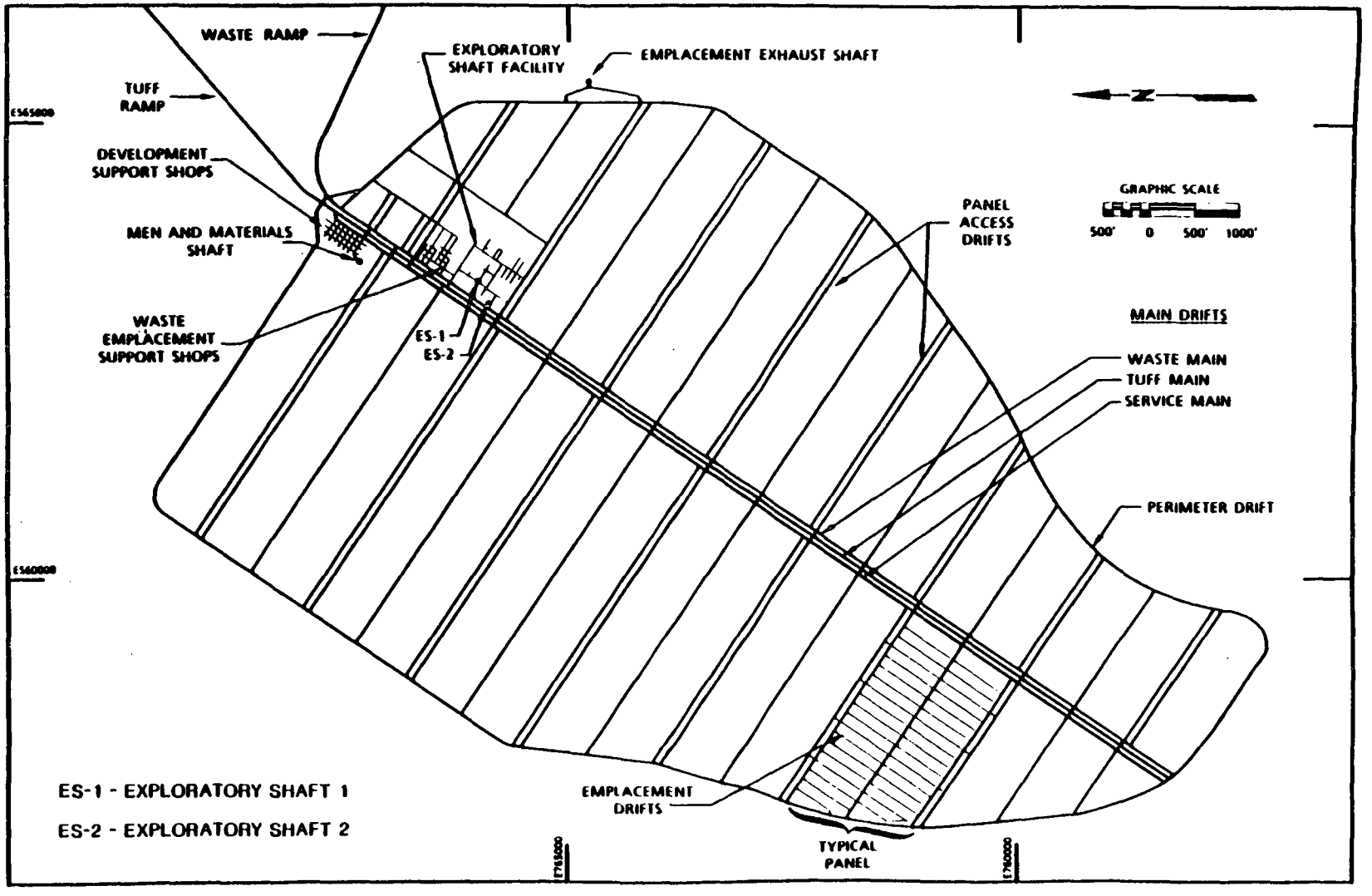
SCP/CDR Repository Layout



Baseline Waste Characteristics

- Considered to be those used by Johnstone et al. in the Unit Evaluation Study (SNL, 1984)
- Baseline waste is considered to have an age of 10 years at time of emplacement
- Closely model the power output of spent fuel with a burnup of 35,000 MWd/MTU for ages out of reactor greater than 10 years

Scaling For Waste Age And Burnup

- **Equivalent Energy Density Concept (EED)**

Bases its equivalence criterion on the assumption that an arbitrary waste will produce worst-case thermomechanical effects equal to those predicted for a baseline waste description provided that the thermal energy deposited in the host rock over a specified time (deposition period) is the same for both waste descriptions

$$Pa \cdot \int_{a}^{n+a} Na\,(t) \cdot dt = P_{base} \int_{10}^{n+10} N_{base}\,(t) \cdot dt$$

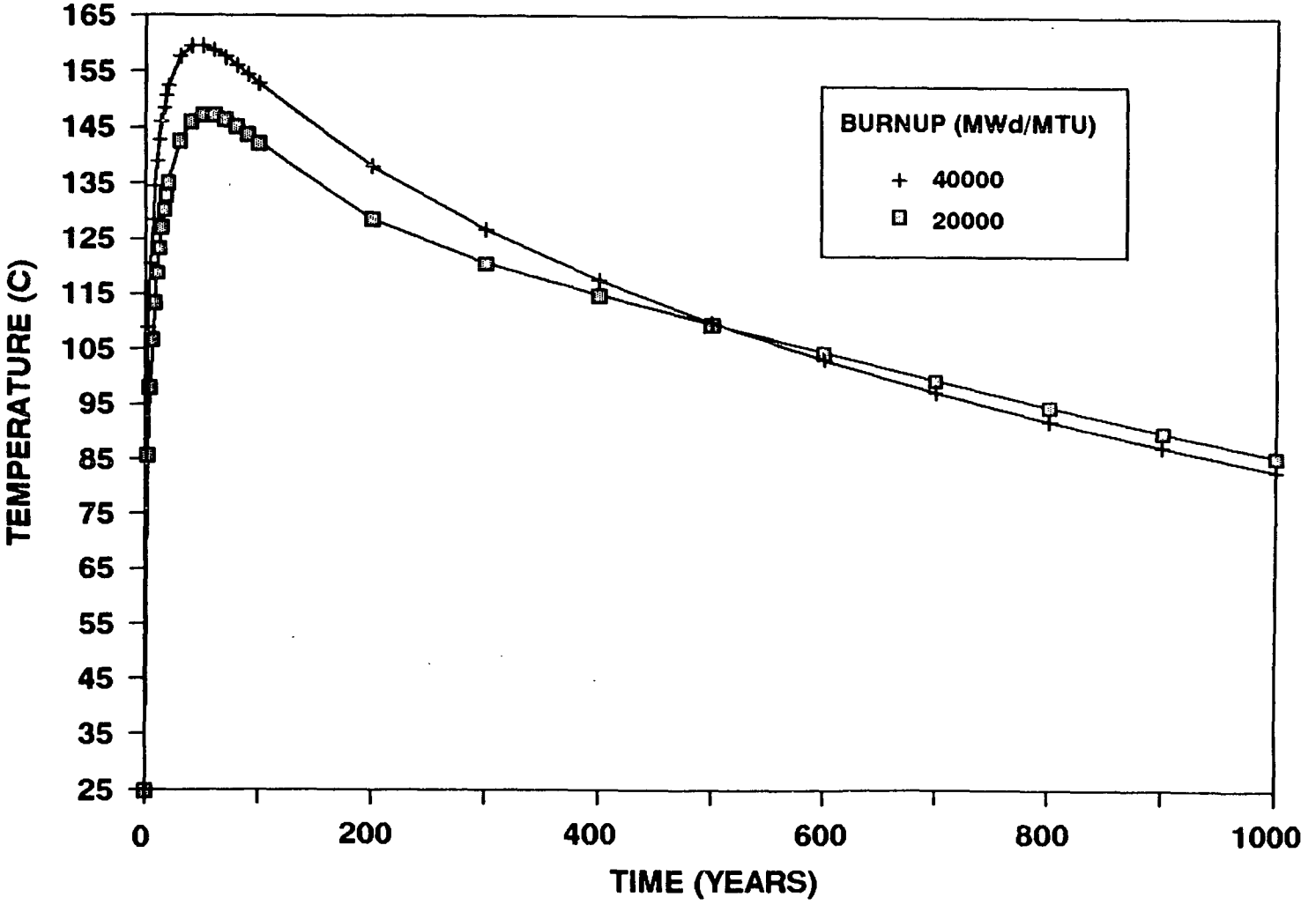
Where:

- P_{base} = Initial LAPD of baseline waste
- Pa = Scaled LAPD to be calculated
- N_{base} = Baseline thermal decay function
- Na = Thermal decay function of arbitrary waste
- a = Age of spent-fuel at emplacement
- n = Deposition period

- **Applicable on a LAPD basis**

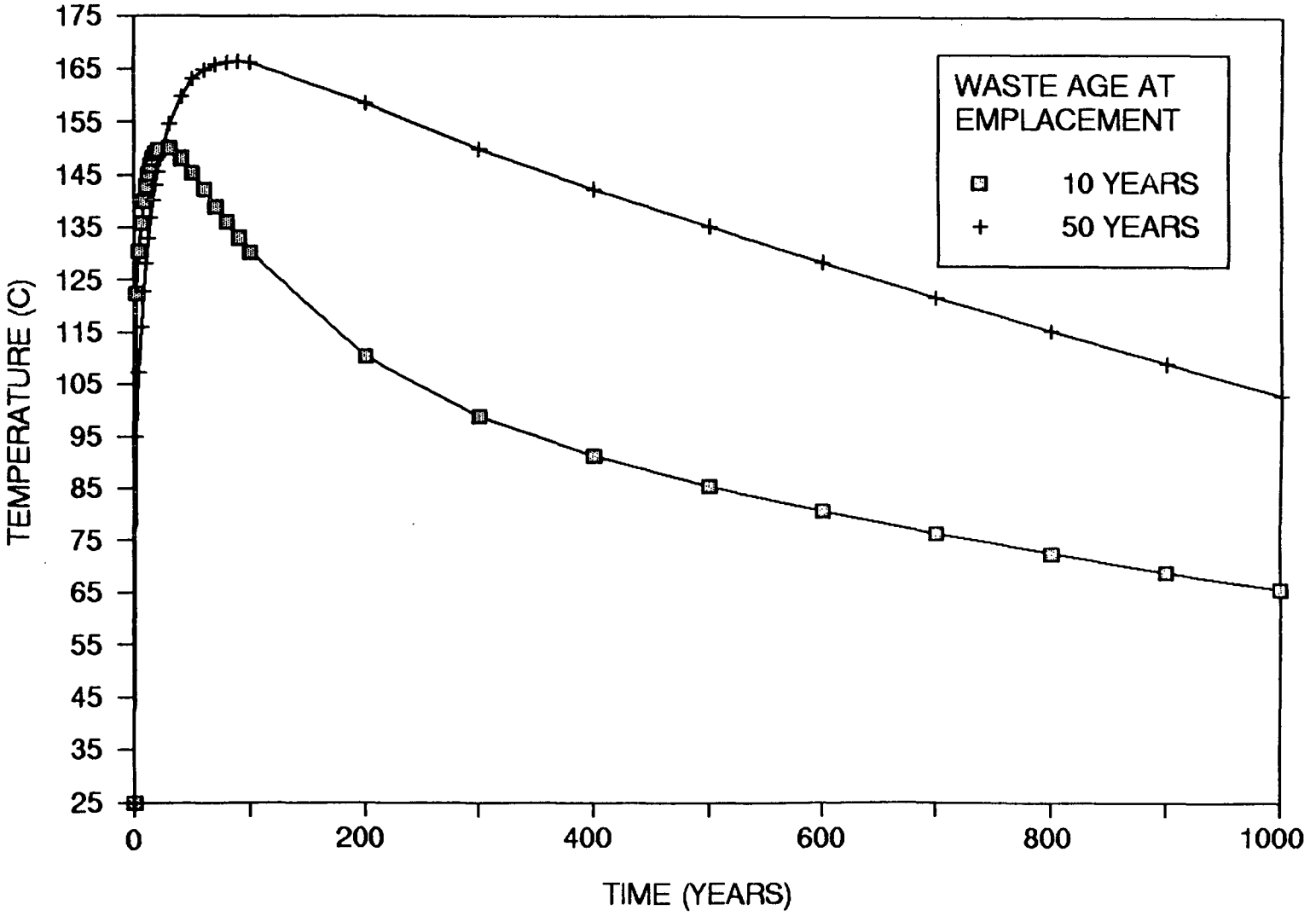
Effect Of Burnup

(Borehole Wall Response For 30-year-old PWR Spent Fuel Emplaced at an LAPD of 69.1 kW/acre)



Effect Of Waste Age

(Borehole Wall Response For Baseline Spent Fuel Emplaced at an LAPD of 69.1 kW/acre)



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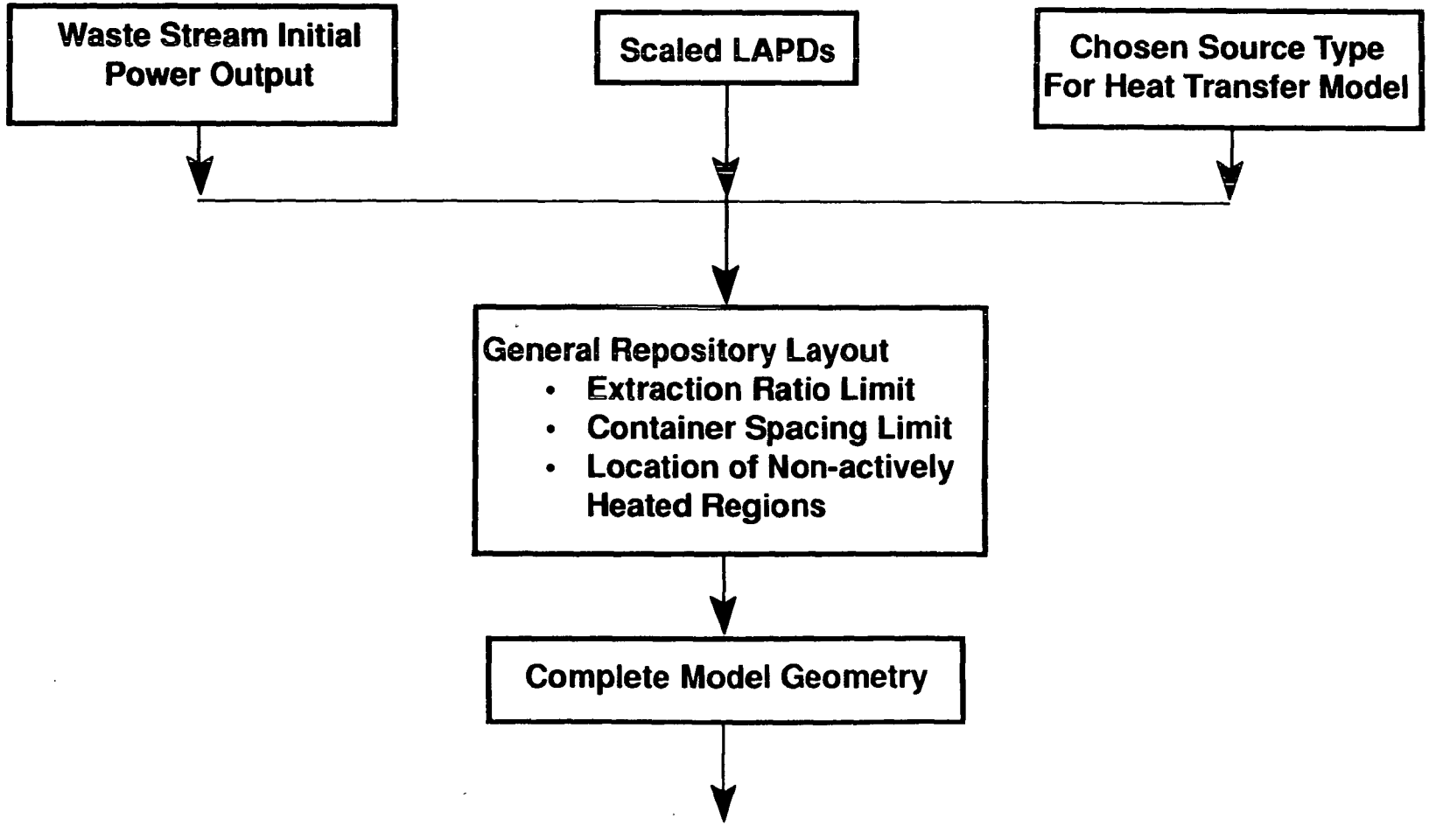
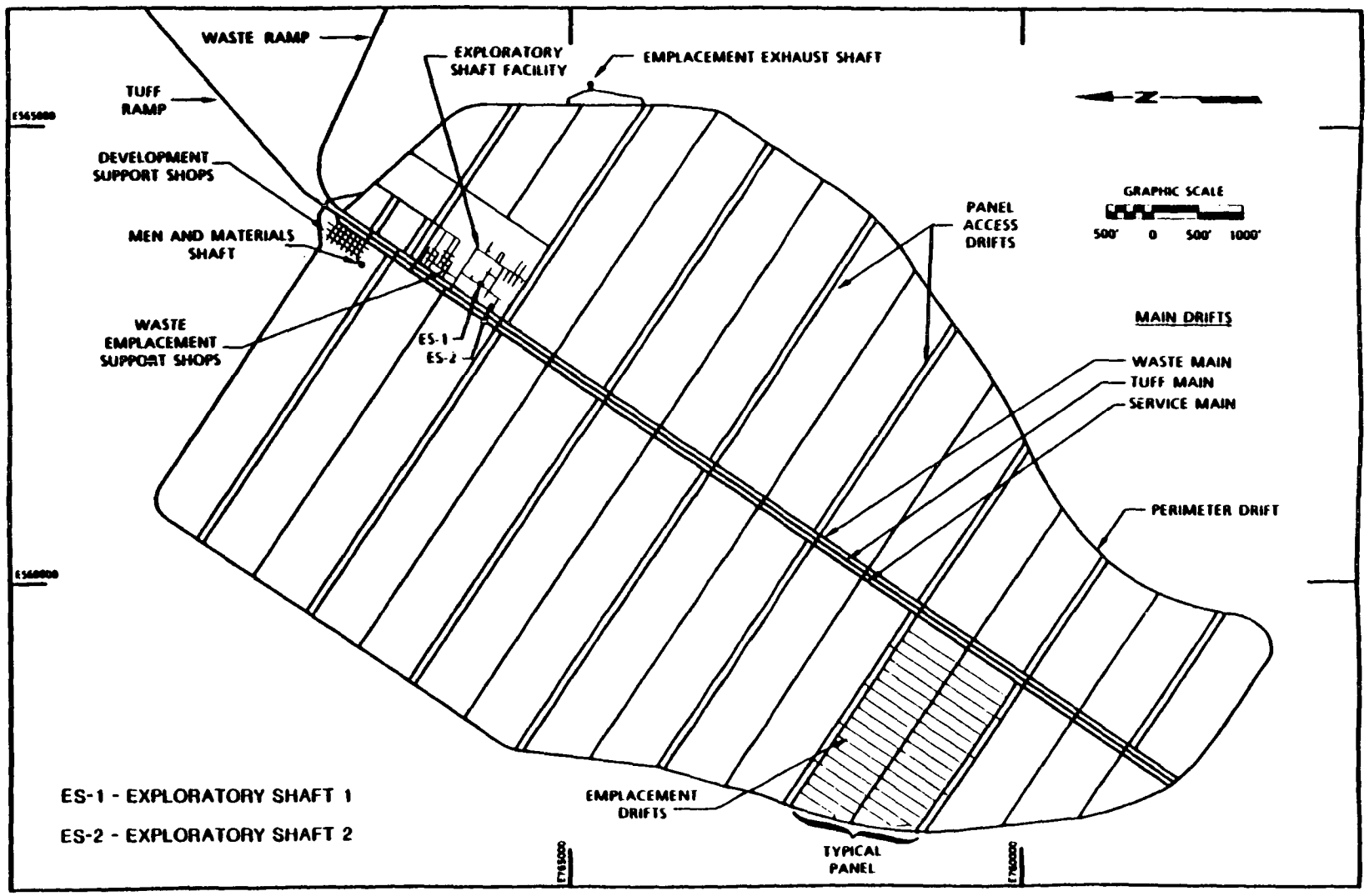
Translation of Emplacement Densities into Model Specific Geometries



SCP/CDR Repository Layout



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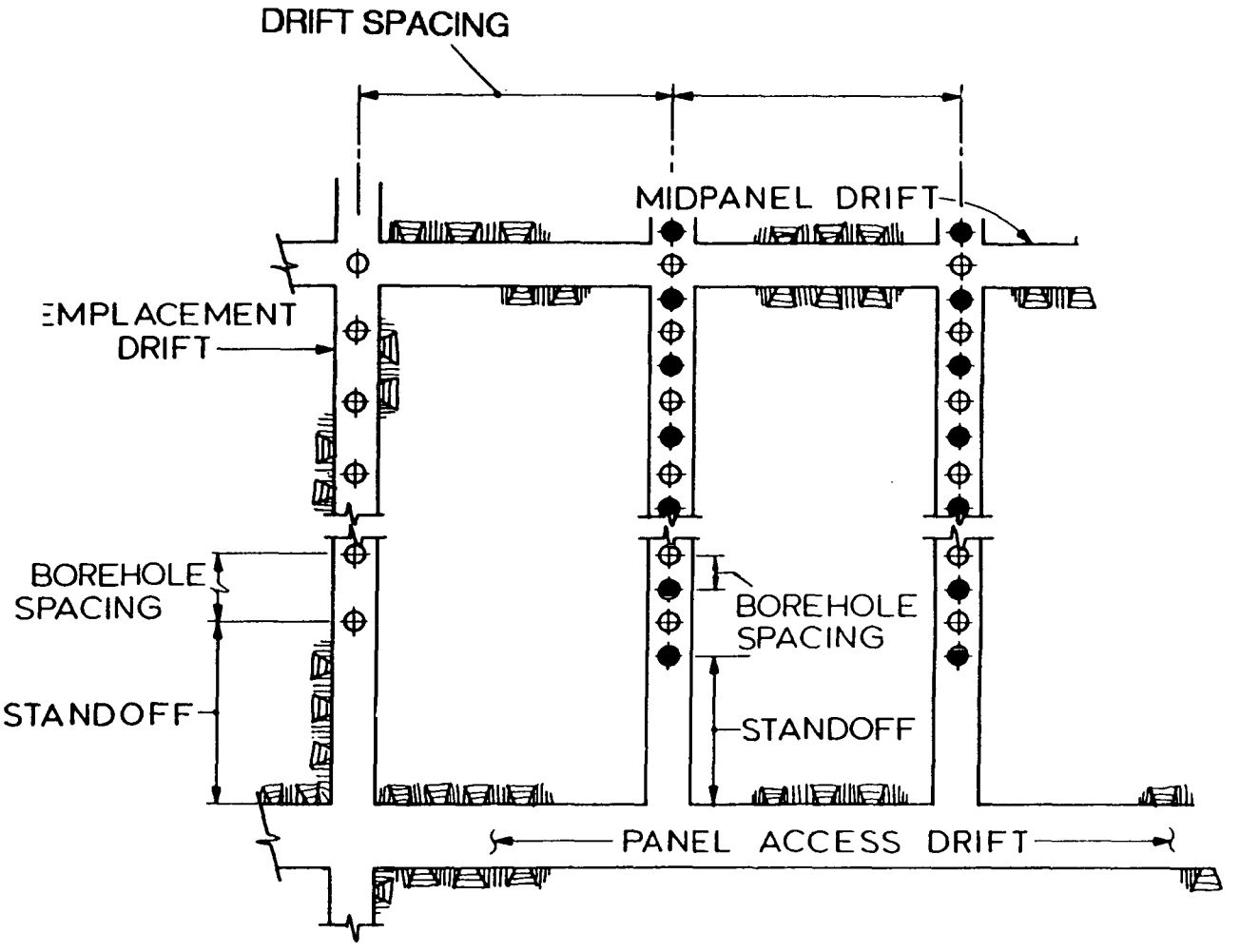
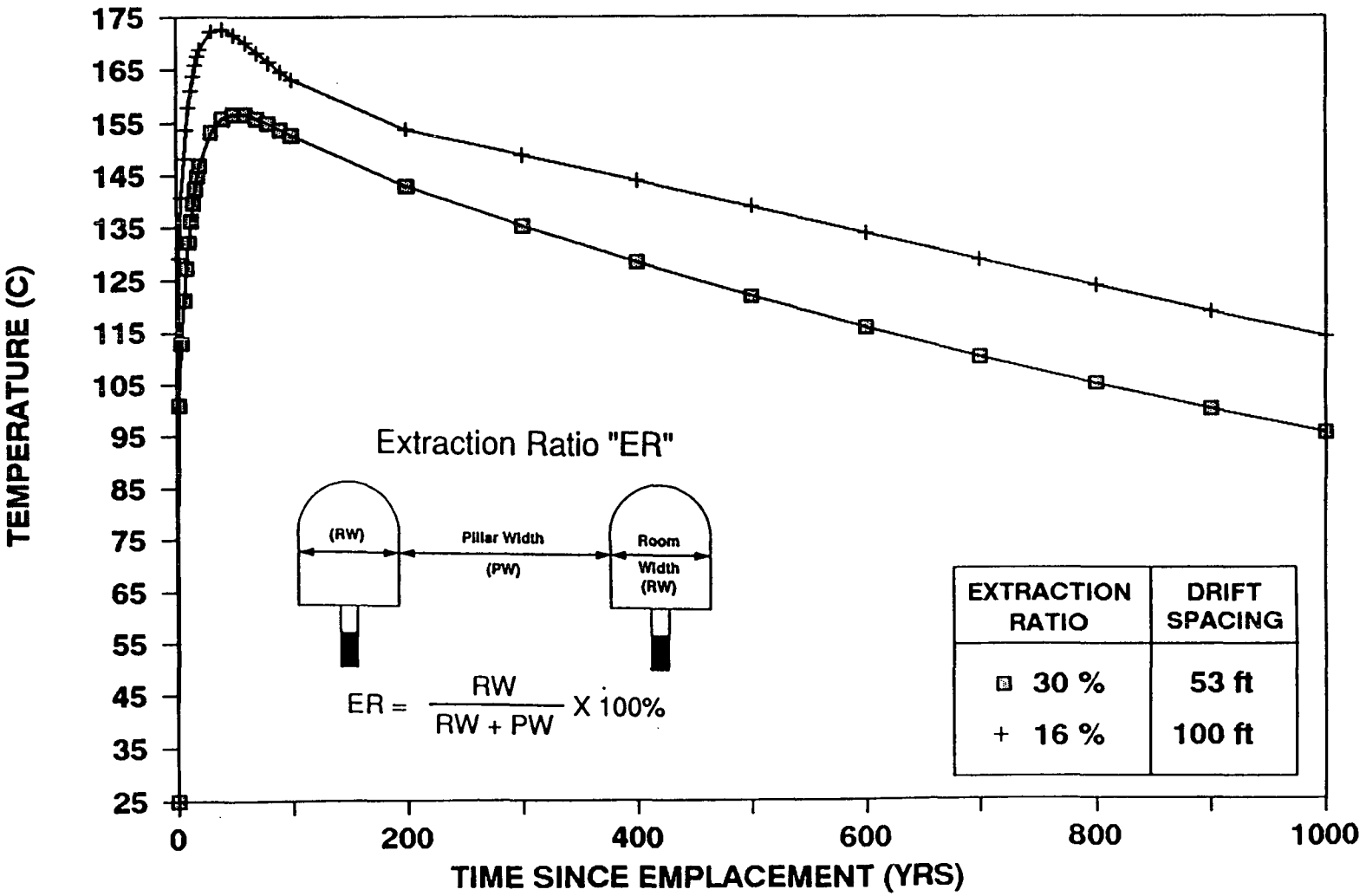
Vertical Emplacement Option



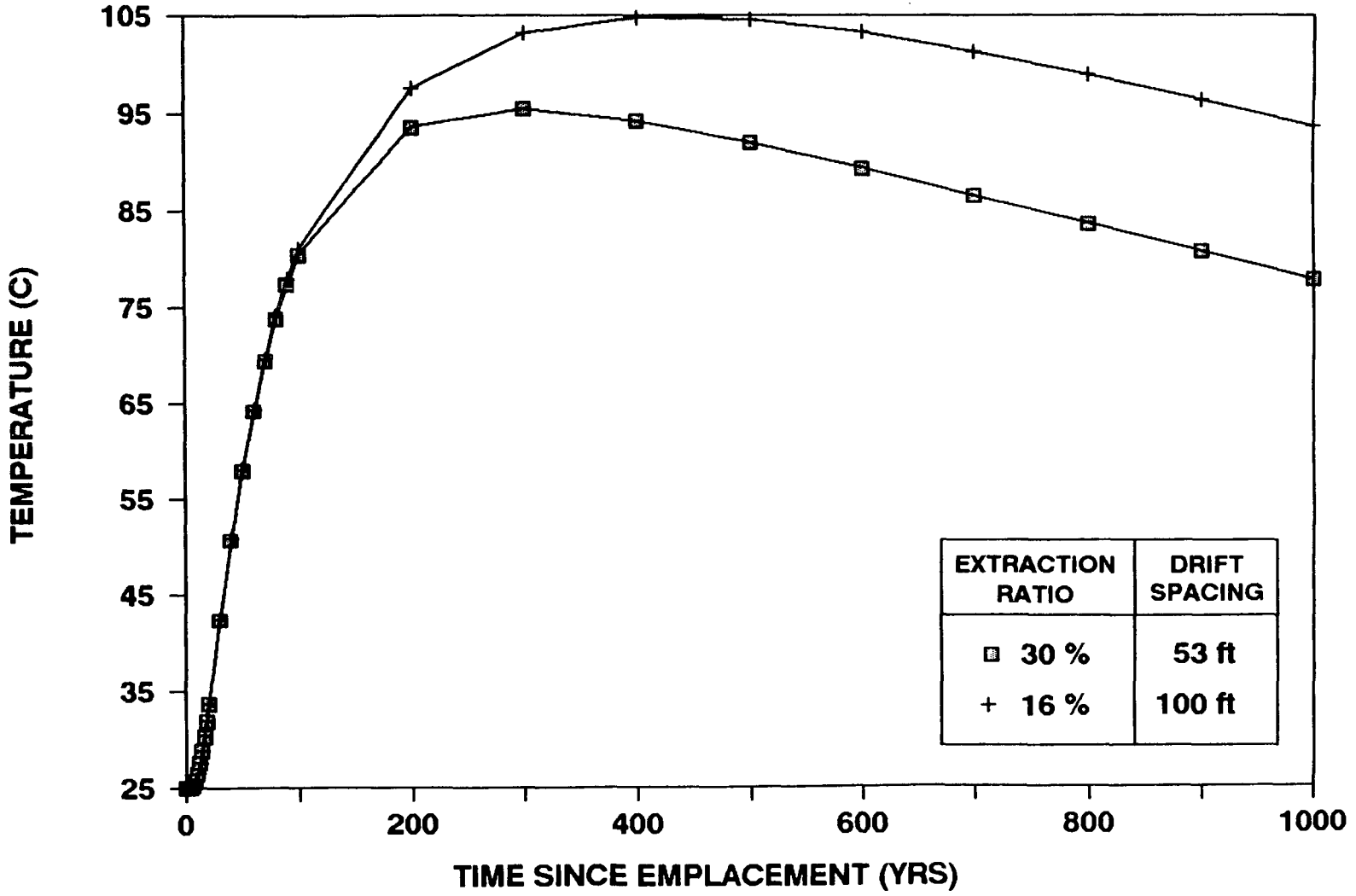
Borehole Wall Response

Baseline Waste-LAPD=69.1 kW/acre



50m Response

Baseline Waste-LAPD=69.1 kW/acre



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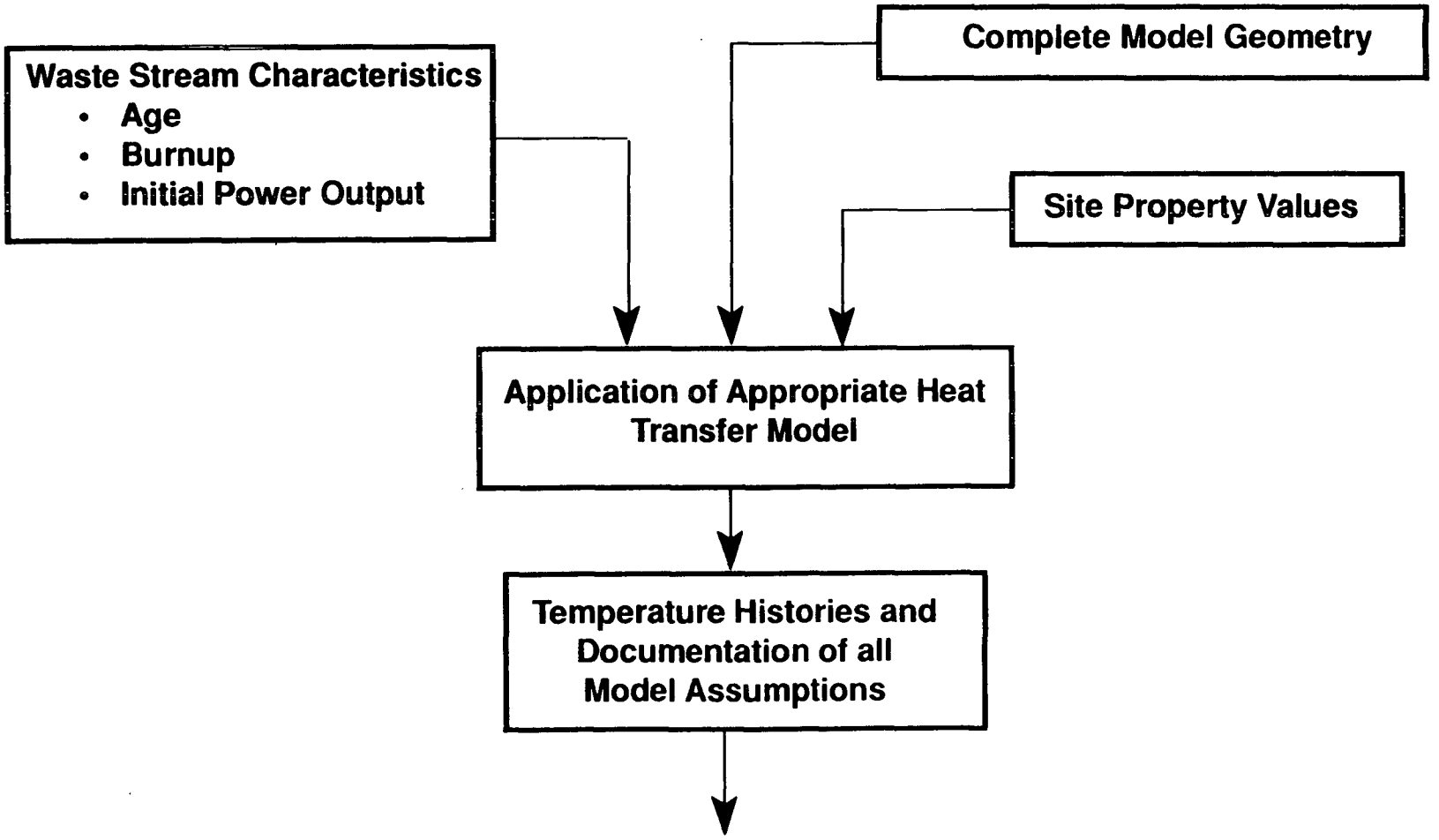
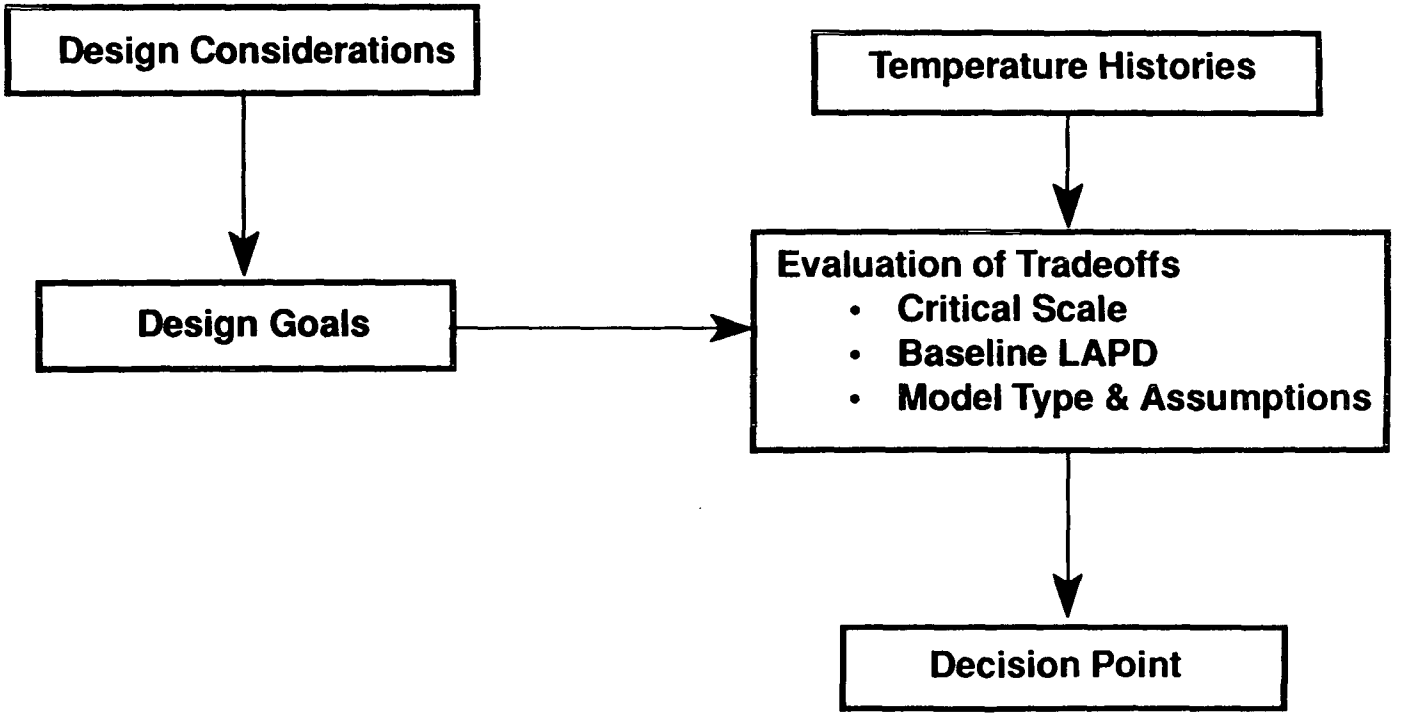
Calculation Of Temperature Profiles



Evaluation Of Temperature Profiles



Design Considerations

Near-field rock-mass integrity

Limit temperatures 1m from borehole wall

Cladding integrity

Limit temperature of container and borehole wall

Surface uplift and environmental impacts

Limit surface temperature rise/uplift

Rock stability

No intact rock failure or continuous joint slip

Design Considerations

(continued)

Extent of saturated conditions

Limit local saturation

Control use of fluids during construction

Corrosiveness of the container environment

Reduce the potential for liquid water contacting containers

Potential for mineral alteration and dehydration

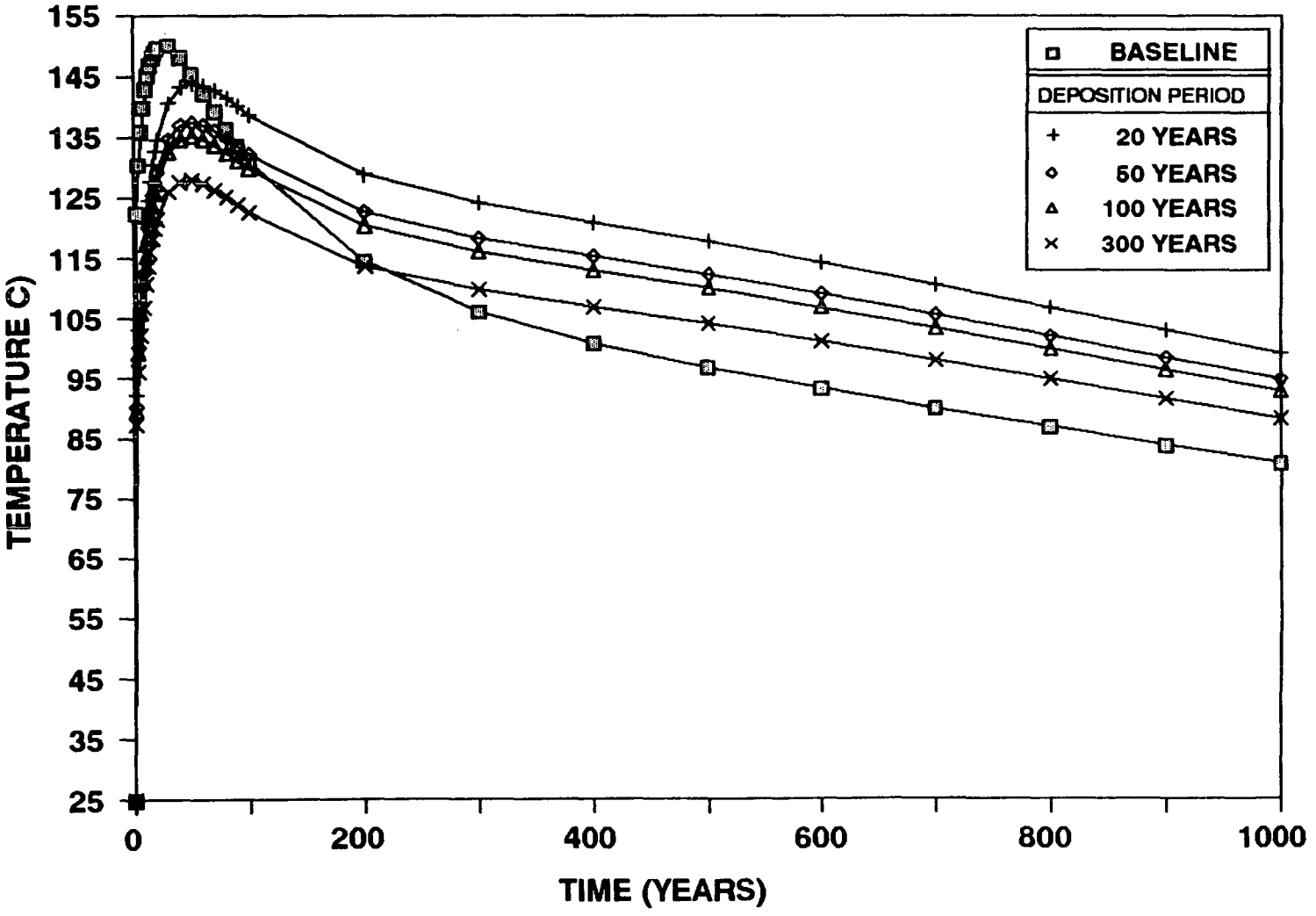
Limit temperatures in units below the emplacement unit (TSw2)

SCP Thermal Goals

Performance Measure	Goal
Cladding Integrity	Container Centerline T < 350° C Borehole Wall T < 275° C
Near-Field Rock Mass Integrity	One Meter from Borehole T < 200° C
Access Drift Wall Temperature	T_{wall} < 50° C for 50 years
Temperature Change in Adjacent Strata	TSw2 - TSw3 Interface T < 115° C
Surface Environment	Temperature Change < 6° C
Limit Corrosiveness of Canister Environment	Maximize Time Spent Above Boiling in Borehole Environment

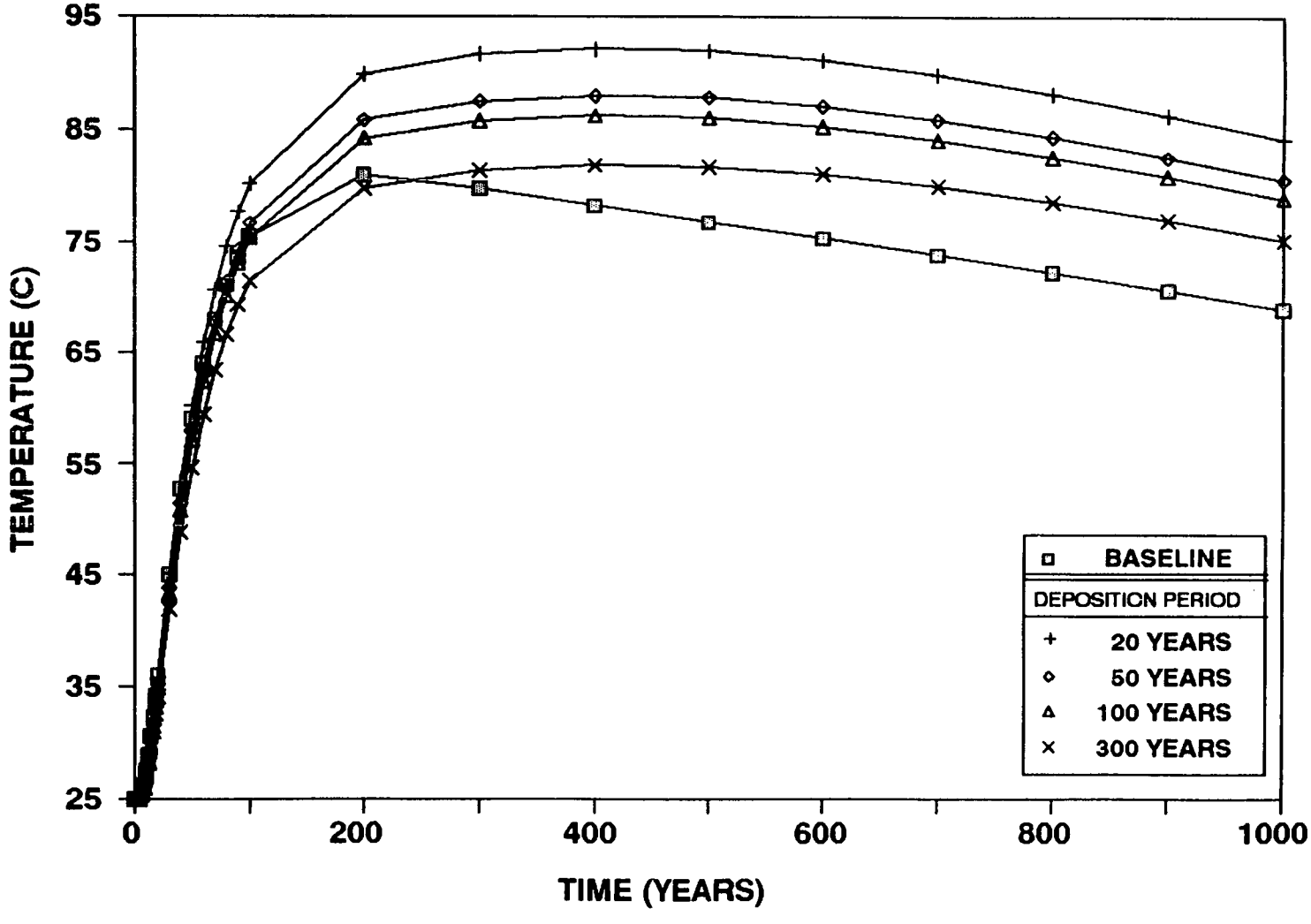
Near-Field Tradeoffs

Borehole Wall Response for 30-Year-Old 30 GWd/MTU Spent Fuel Emplaced at an Initial LAPD Scaled from a Baseline of 69.1 kW/acre



Far-Field Tradeoffs

Response 50m From Repository Floor for 30-Year-Old 30 GWd/MTU Spent Fuel Emplaced at an Initial LAPD Scaled from a Baseline of 69.1 kW/acre



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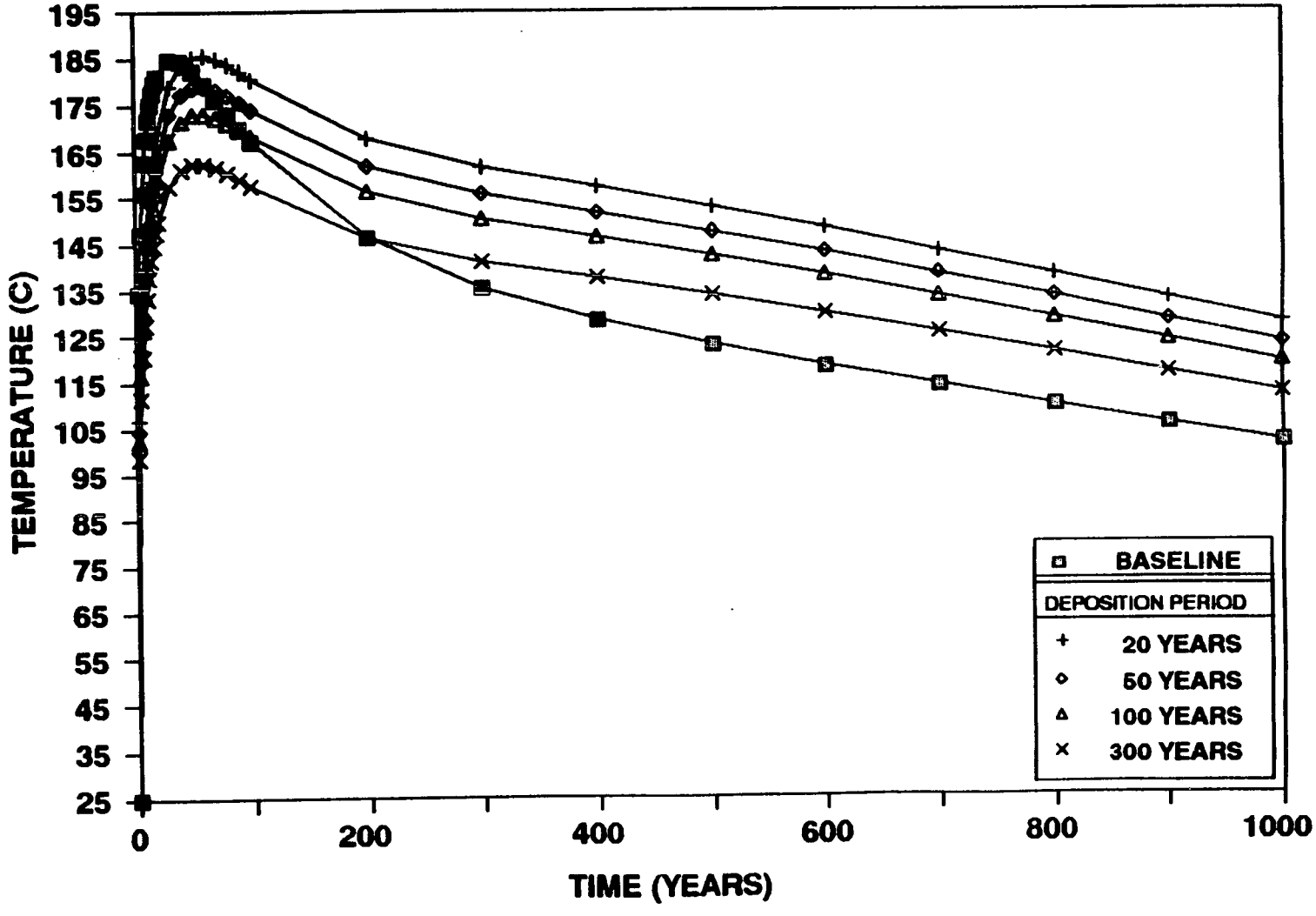
Near-Field Tradeoffs

Borehole Wall Response for 30-Year-Old 30 GWd/MTU Spent Fuel Emplaced at an Initial LAPD Scaled from a Baseline of 97 kW/acre



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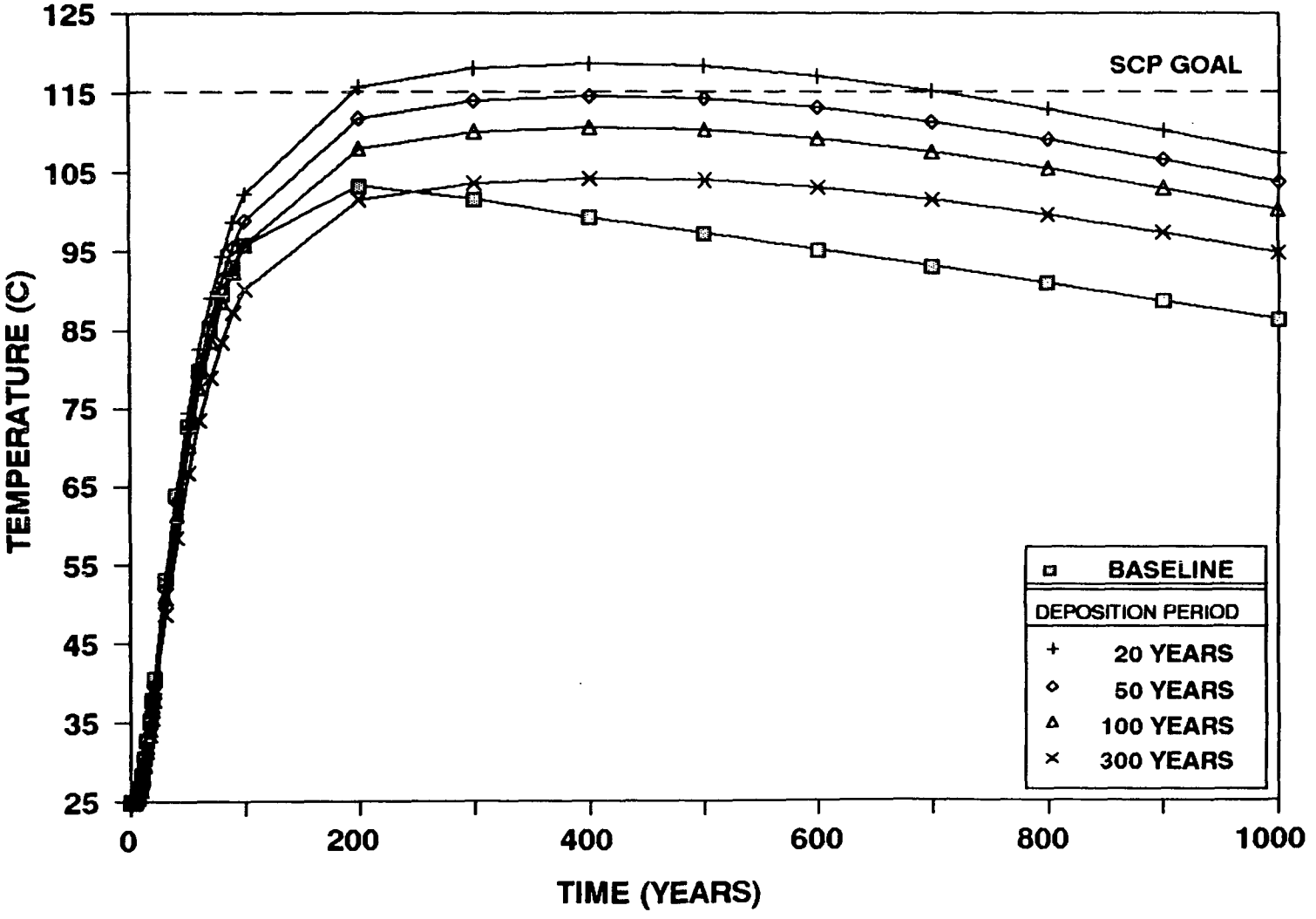
Far-Field Tradeoffs

Response 50m from Repository Floor for 30-Year-Old 30 GWd/MTU Spent Fuel Emplaced at an Initial LAPD Scaled from a Baseline of 97 kW/acre



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Example Decision Points

- Profiles indicate that temperature goals are violated in a given field. Problem traced back to choice of critical scale (deposition period)
- Waste stream characteristics not compatible with overall analysis, tradeoffs required unacceptable
- Design spacings (canister and drift, as well as standoffs) produce temperature predictions beyond current goals
- Mathematical basis of chosen model does not sufficiently capture the problem under investigation
- All criteria met, tradeoffs acceptable and documented. Recommend temperature histories/model information be examined further for possible input into the final design process

Conclusions

- Changes in the repository design/system can affect the thermal design process and resulting temperature profiles

- When comparing temperature profiles, model assumptions and tradeoffs must be accounted for

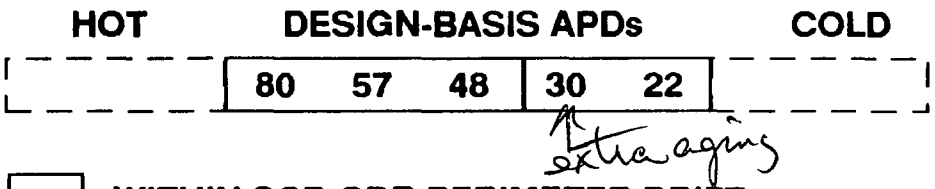
Temperature Changes Over Time

Objectives

- Show near- and far-field temperature profiles generated using a consistent set of assumptions
- Discuss trending at critical scales for APDs ranging from 20 to 80 kW/acre
- Discuss/demonstrate some effects of aging, increasing heated repository area, and modifications to the ventilation system

Organization

- DISCUSSION OF MODEL ASSUMPTIONS
- PRESENTATION OF RESULTS



OPTIONS AVAILABLE	NEAR-FIELD	FAR-FIELD
AGE FUEL	■	■
INCREASE HEATED AREA	■	
MODIFY VENTILATION SYSTEM	■	

NEAR-FIELD RESULTS

ALL APDs (80, 57, 48, 30, AND 22 kW/ACRE) FOR EMPLACEMENT WITHIN PRIMARY BLOCK (i.e., AGING TO REDUCE APD)

FAR-FIELD RESULTS

ALL APDs (80, 57, 48, 30, AND 22 kW/ACRE) FOR EMPLACEMENT WITHIN PRIMARY BLOCK (i.e., AGING TO REDUCE APD)

ALTERNATIVES

NEAR-FIELD RESPONSE TO INCREASED HEATED AREA (APPROXIMATE DESIGN-BASIS APD OF 19 kW/ACRE)

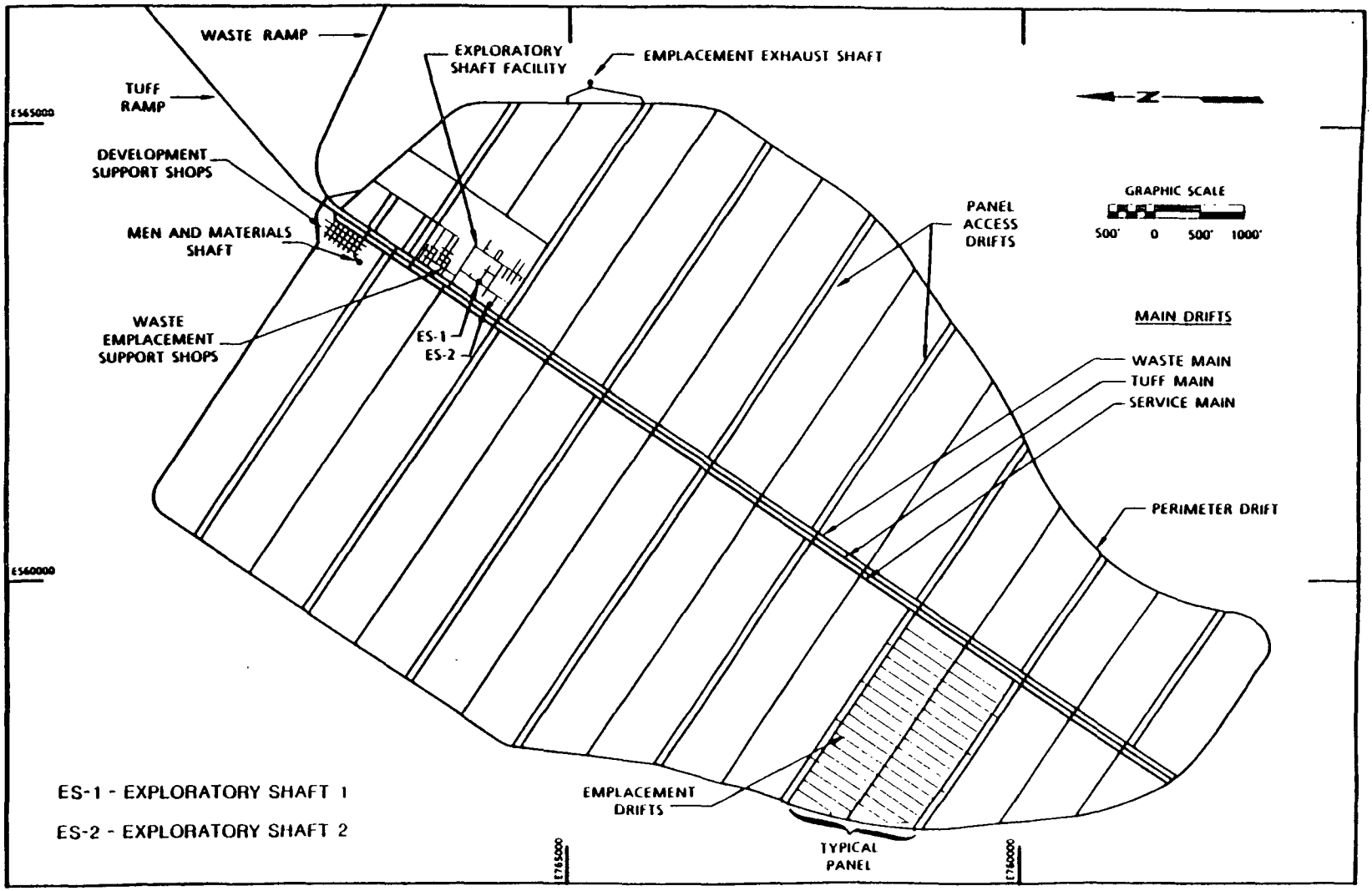
EFFECTS OF VENTILATION ON NEAR-FIELD FOR 80 kW/ACRE

Model Assumptions

- Modified version of the design published in the SCP-CDR used to represent the potential respository
- Fully stepped emplacement of spent fuel considered
- DHLW considered to be segregated in the first few drifts off the mains
- Levelized receipt schedule assumed for a 2010 start date and a hybrid canister configuration
- Surface environment modeled as a constant temperature surface
- Scaling of emplacment densities to account for waste age and burnup carried out using the Equivalent Energy Density Concept and deposition periods of 20 to 300 years
- Analytical solution (3-D linear superposition of heat generating points and cylinders) used
    - Site modeled as an infinite mass of TSw2
    - Constant material properties

$$K = 2.1 \text{ W/mK}$$
$$\rho c_p = 2.2 \text{ J/cm K}$$

SCP/CDR Repository Layout



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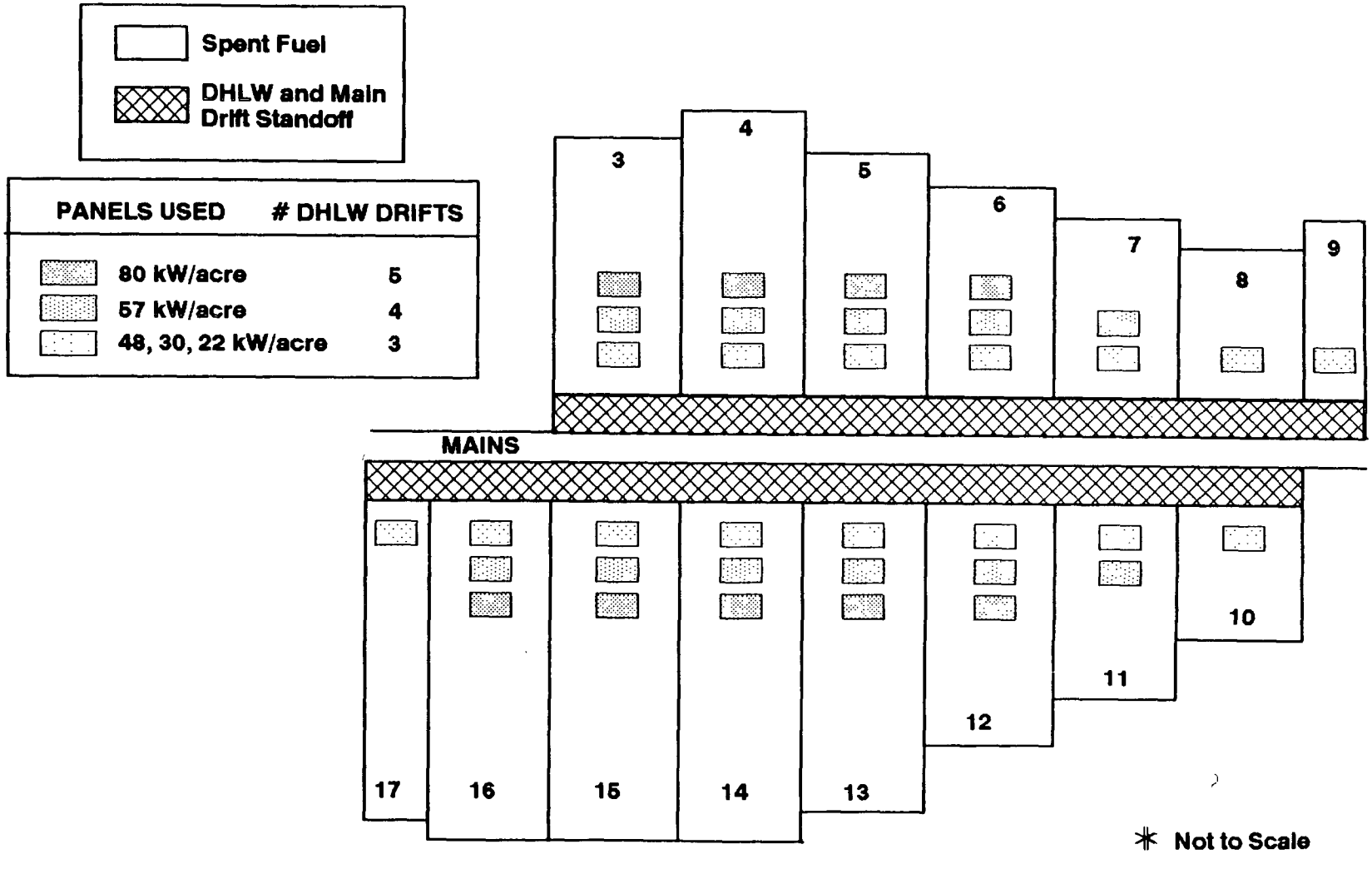
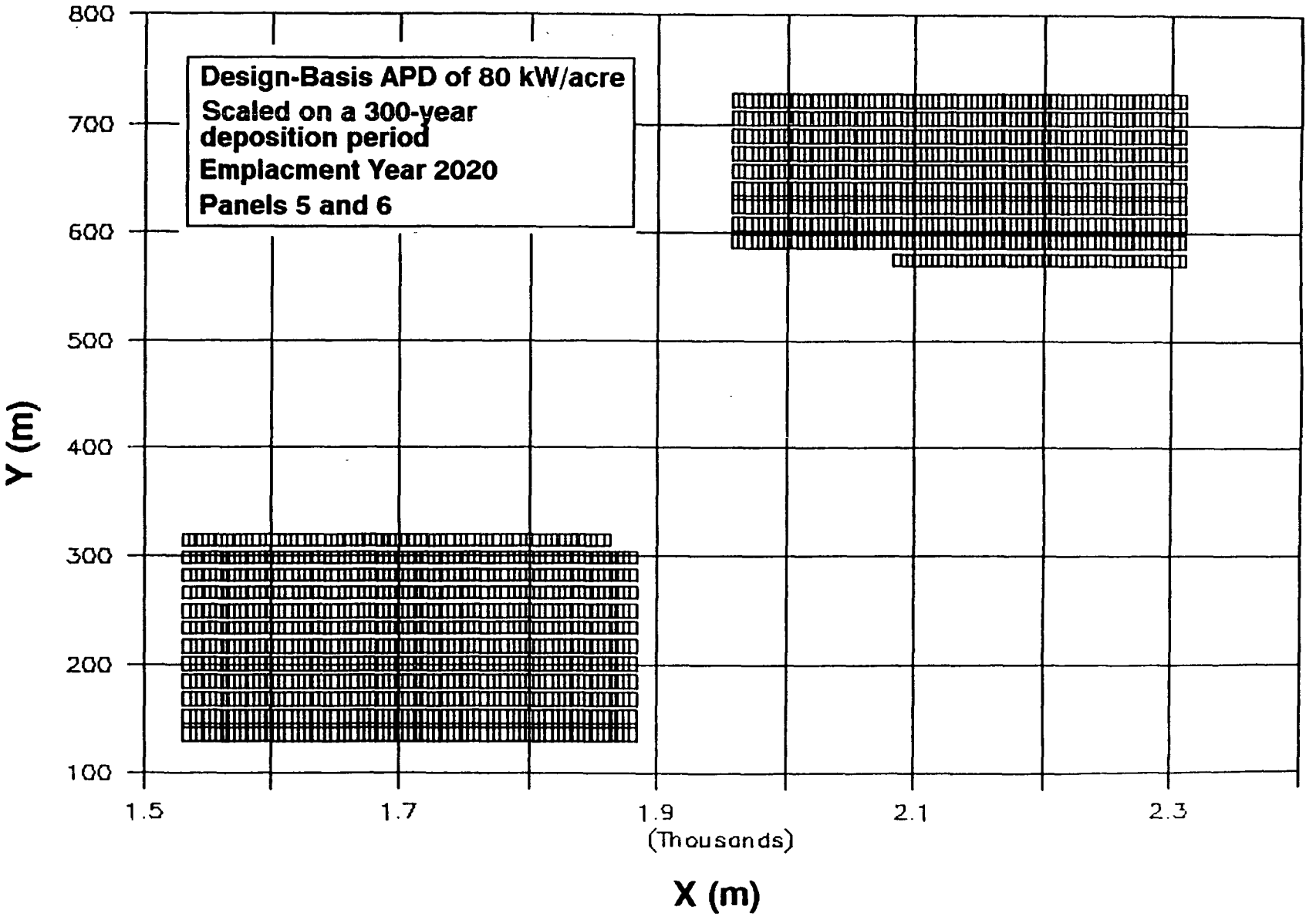
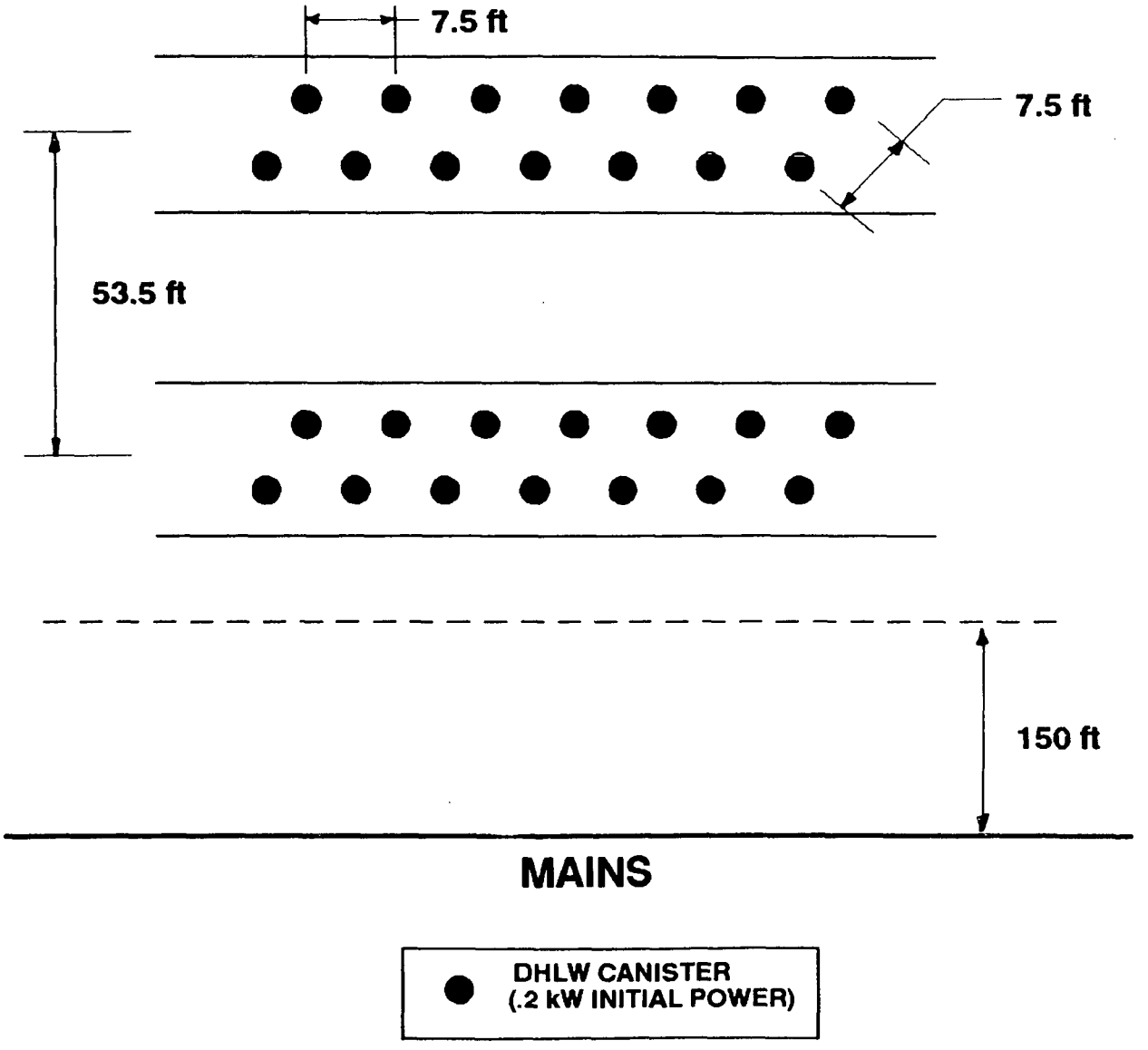
Modeled Repository (Primary Block)



Stepped Emplacement Example



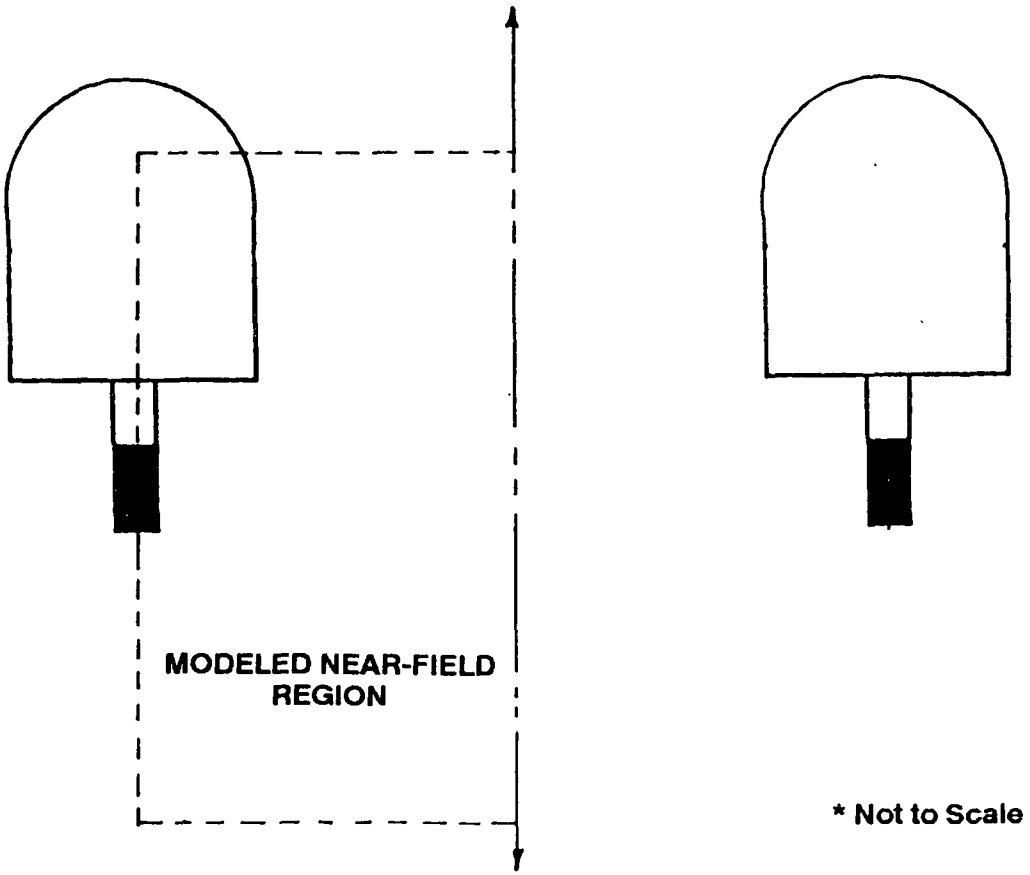
Segregration of DHLW



Modification Summary

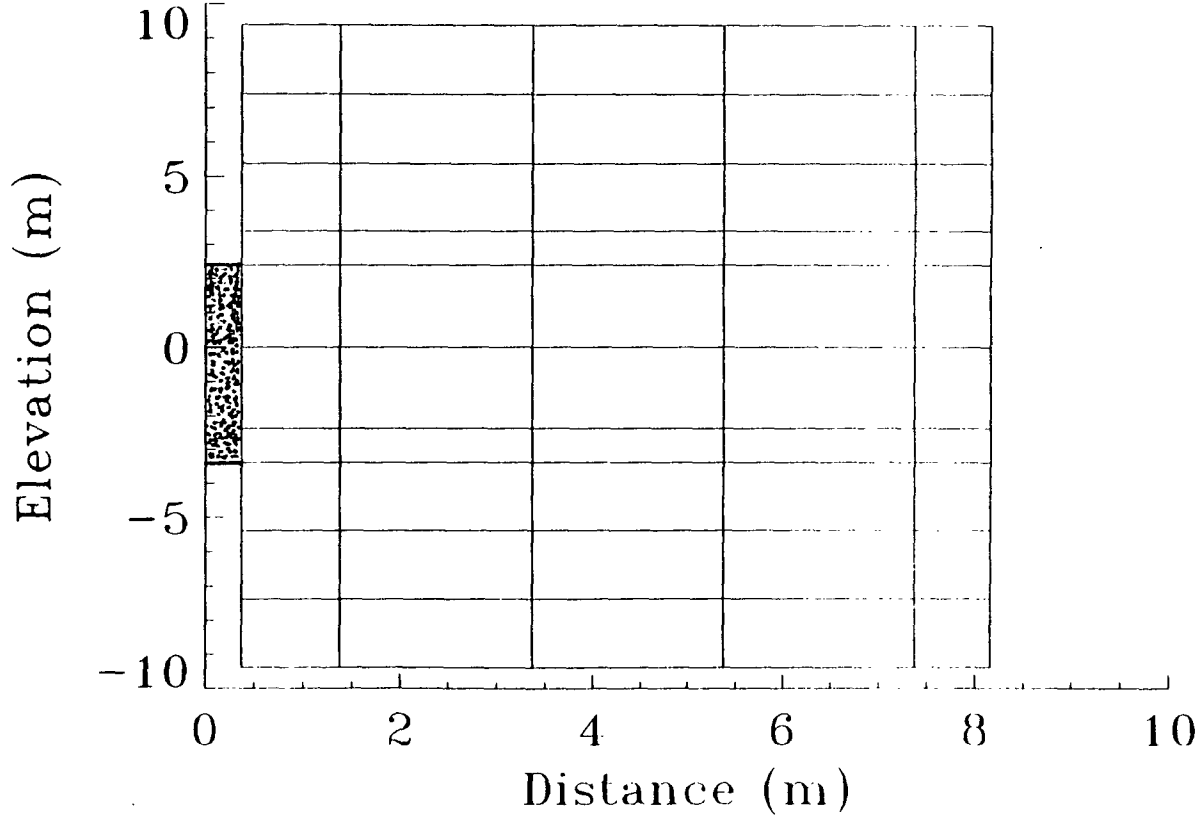
Feature	SCP-CDR Design	Modified Design
Orientation	Vertical/Horizontal	Vertical
Available Panels	17	15
Start Date	1998	2010
Receipt Schedule	FIFO	Levelized
Treatment of DHLW	Commingled	Segregated
DHLW Intial Power Output	.2 to .4 kW/container	.2 kW/container
SF Container Configuration	Consolidated	Intact Hybrid (4 BWR, 3 PWR)
Number of SF Containers	~12,000	~31,000
Average SF Age	10 years	30 to 90 years
Average SF Initial Power Output	3 kW/container	1.5 to 0.66 kW/container
Design-Basis APD	57 kW/acre	80 to 22 kW/acre
Drift Spacing	126 ft	53 ft
Container Spacing	15 ft	Variable
Standoffs from Mains	200 ft	150 ft

Near-Field Environment



* Not to Scale

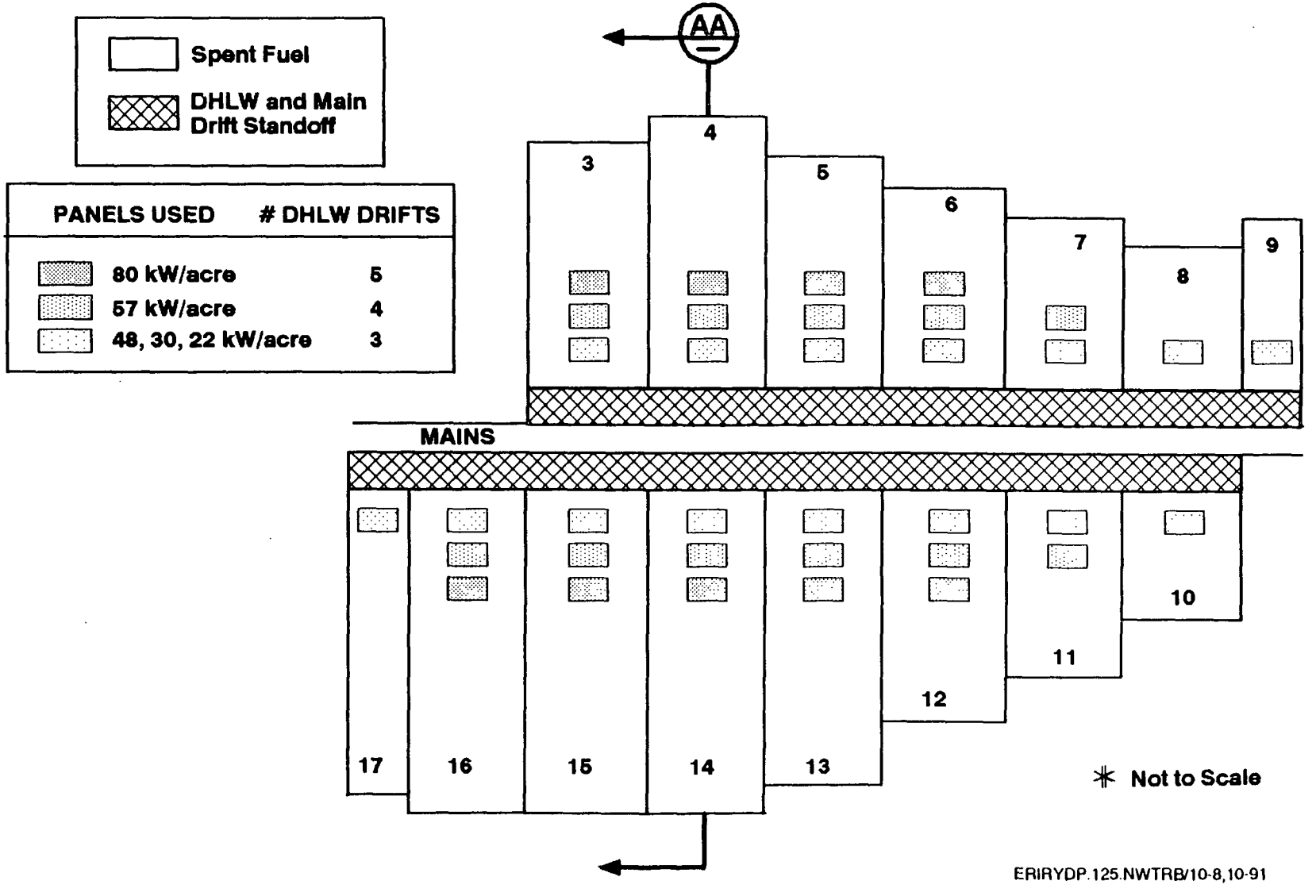
Near-Field Grid



Near-Field Peak Temperature Summary

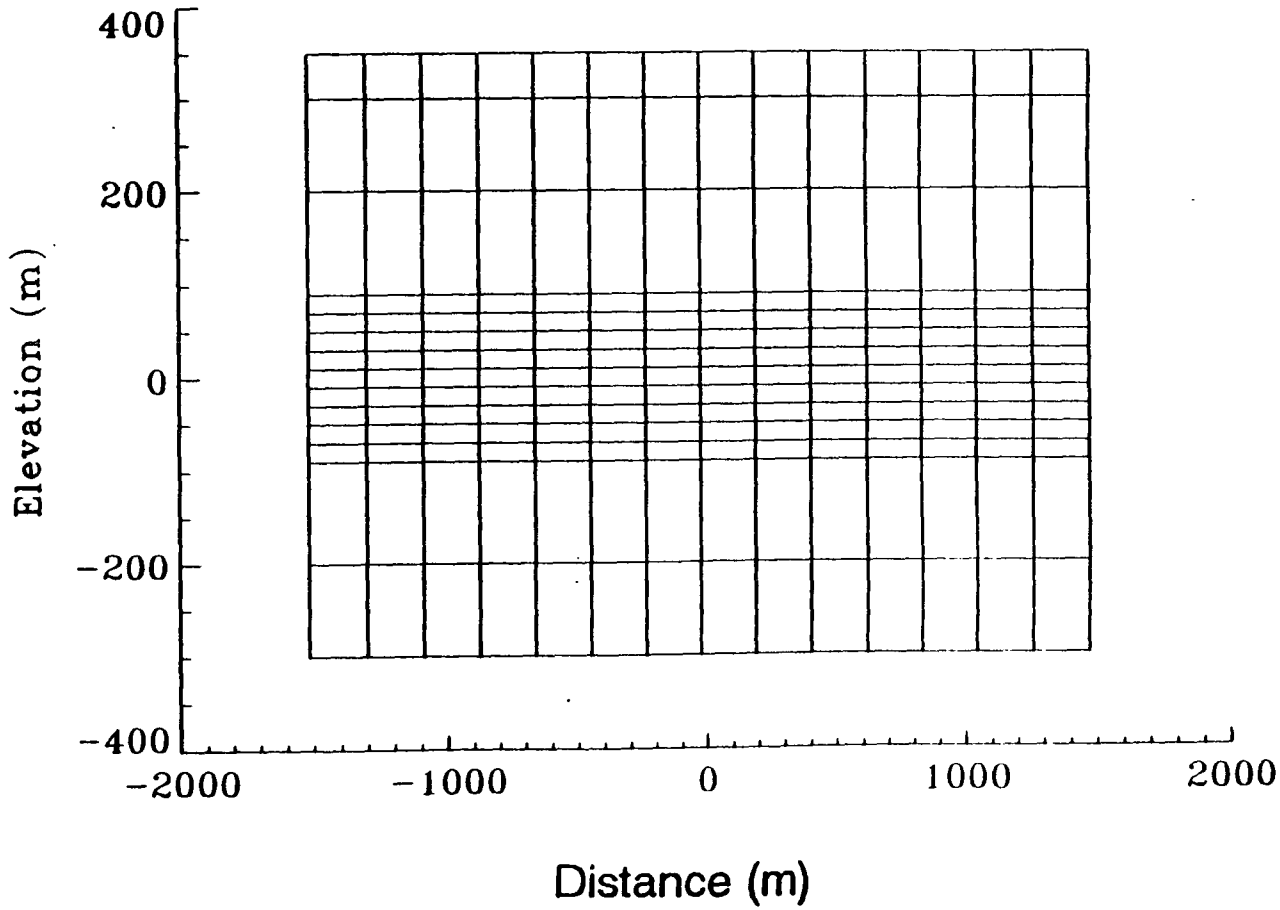
Location	Design-Basis APD (kW/acre)				
	80	57	48	30	22
	Temperature (°C)				
Borehole Wall	170	147	132	103	95
1-meter Radially	158	135	118	97	91
Time to Boiling Front Coalescence (years)	12	19	31	N/A	N/A
Average Waste Age (years)	30	30	30	60	90
Average Initial Power Output (kW/container)	1.52	1.52	1.52	0.95	0.66
Deposition Period Used (years)	300	20	20	20	20

Modeled Repository with Vertical Cross-Section AA indicated

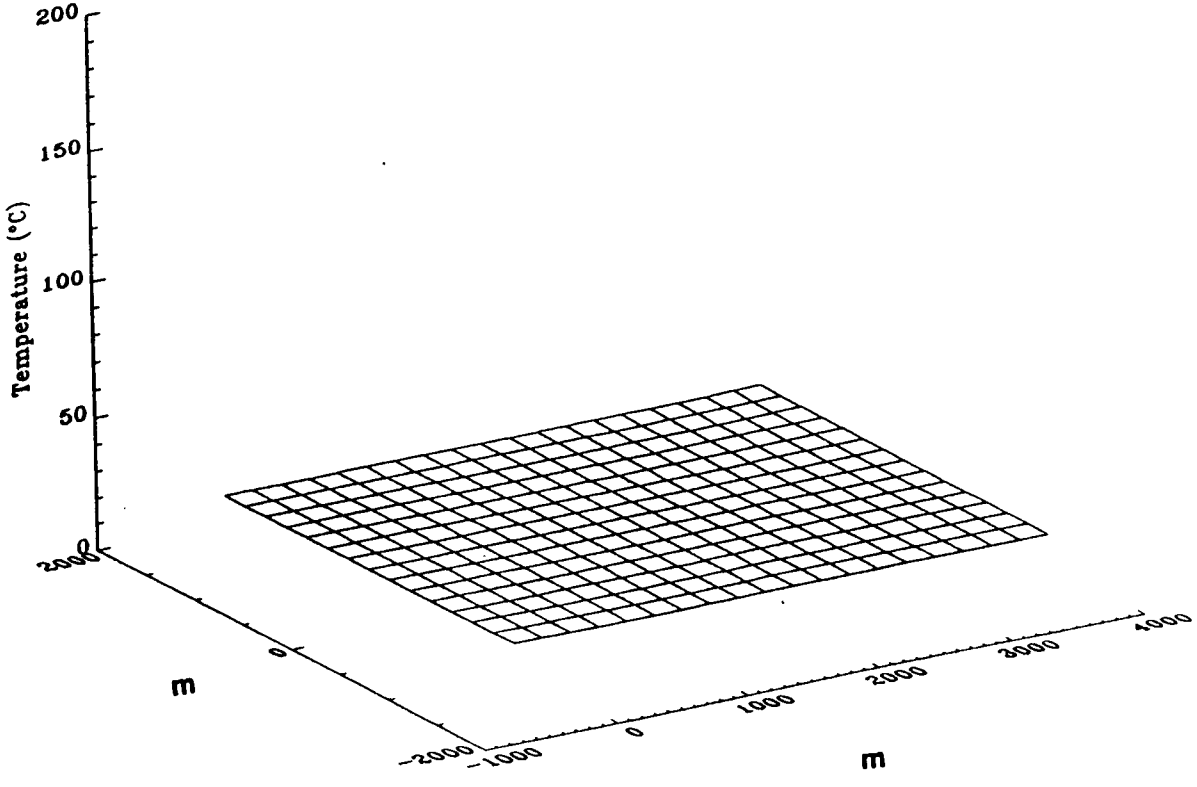


ERIRYDP.125.NWTRB/10-8,10-91

Grid for Vertical Cross-Section AA



Grid for Horizontal Cross-Section 50m Below Waste Package Centerpoints



ERIRYDP.125.NWTRB/10-8,10-91

Far-Field Peak Temperature Summary

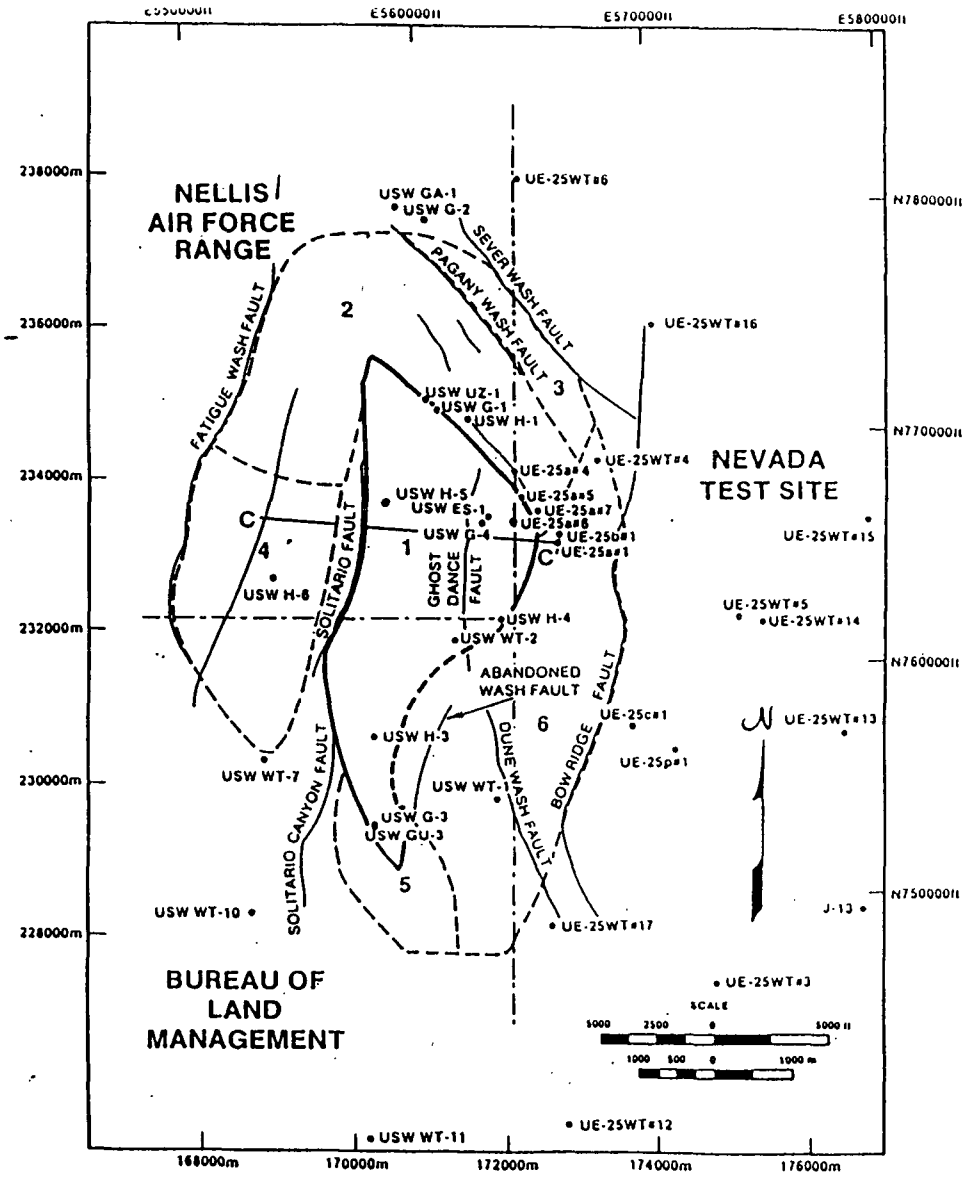
Depth Below Canister Centerpoints	Design-Basis APD (kW/acre)				
	80	57	48	30	22
	Temperature (°C)				
50 m	107	94	86	77	74
70 m	100	89	81	74	71
90 m	94	84	77	60	59
Average Waste Age (years)	30	30	30	60	90
Average Initial Power Output (kW/container)	1.52	1.52	1.52	0.95	0.66
Deposition Period Used (years)	300	20	20	20	20

Additional Options

- **Increase heated area within perimeter drift**

- **Modify ventilation system**

Available Area



Zone	Area (acres)
1	1850
2	2250
3	400
4	1500
5	500
6	2650

ERIRYDP.125.NWTRB/10-8,10-91

Ventilation Effects

- Vented emplacement drifts modeled as cylindrical heat sinks with constant strengths of 30 kW
- Centerpoint of sink placed 8.4 m above canister centerpoints
- Two near-field cases examined for a design-basis APD of 80 kW/acre
    1. Drifts vented for 5 years
    2. Drifts vented for 10 years

Summary of Results for Additional Options

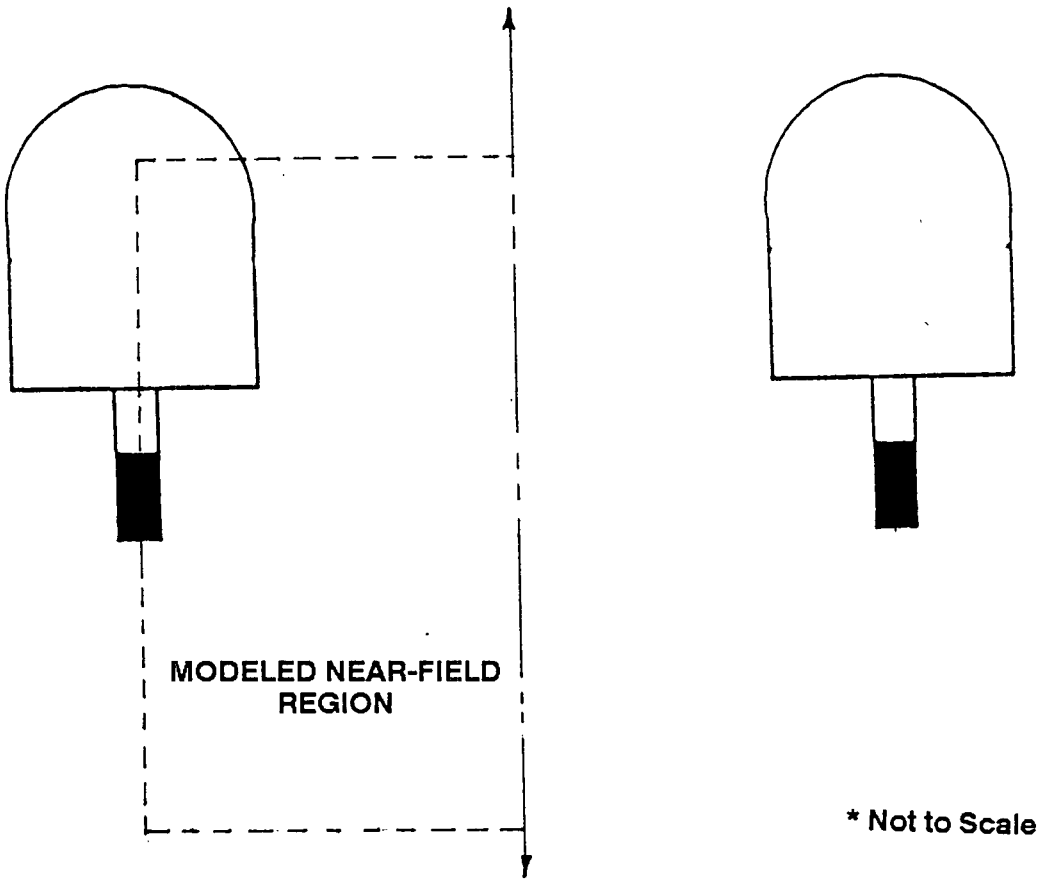
- The occurrence of a boiling front can be virtually eliminated by expanding the heated area and using receipt schedule selection to limit initial canister power output

- Ventilation can be used to mitigate the near-field thermal response, but the magnitude of the effects appear to be relatively small and short-term for other than significantly extended periods of active ventilation

The following package has been included as a supplement to video taped animations presented during the course of E. Ryder's discussions of temperature responses over time

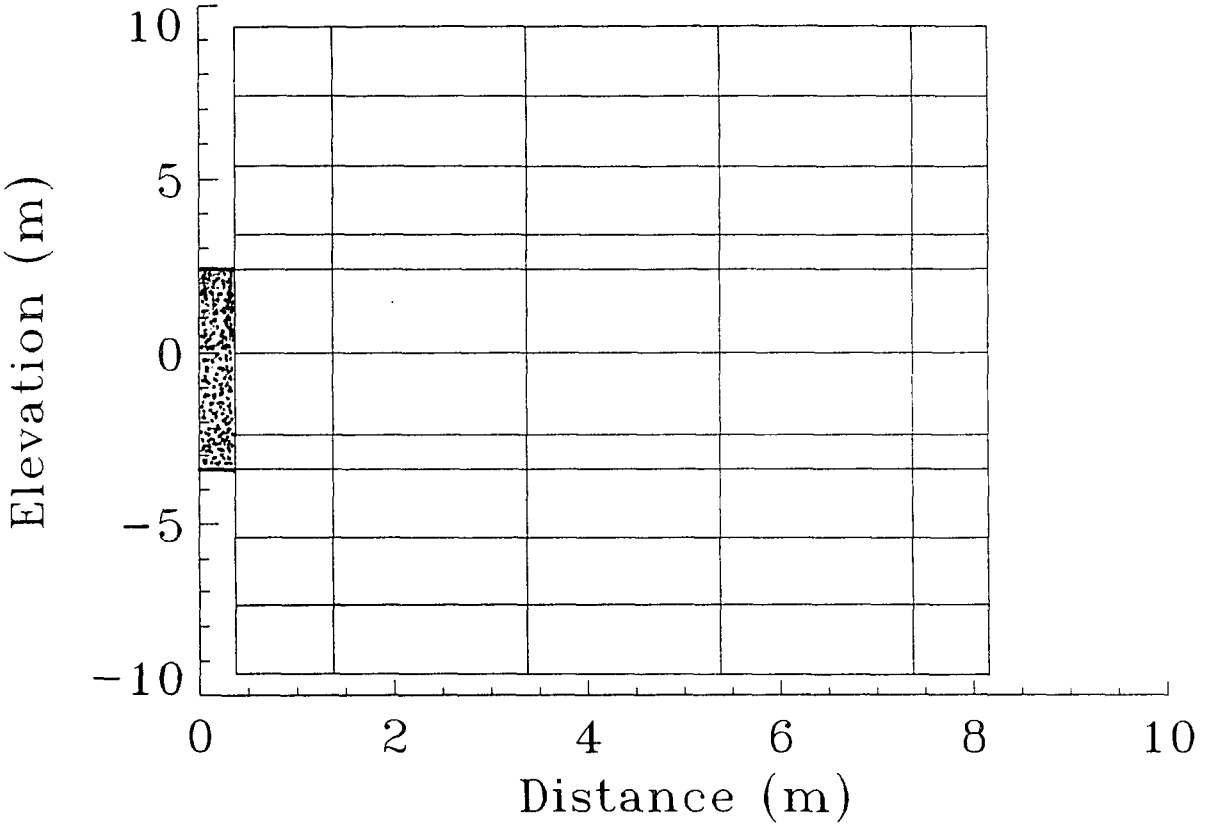
Thermal Response
Near-Field

Near-Field Environment



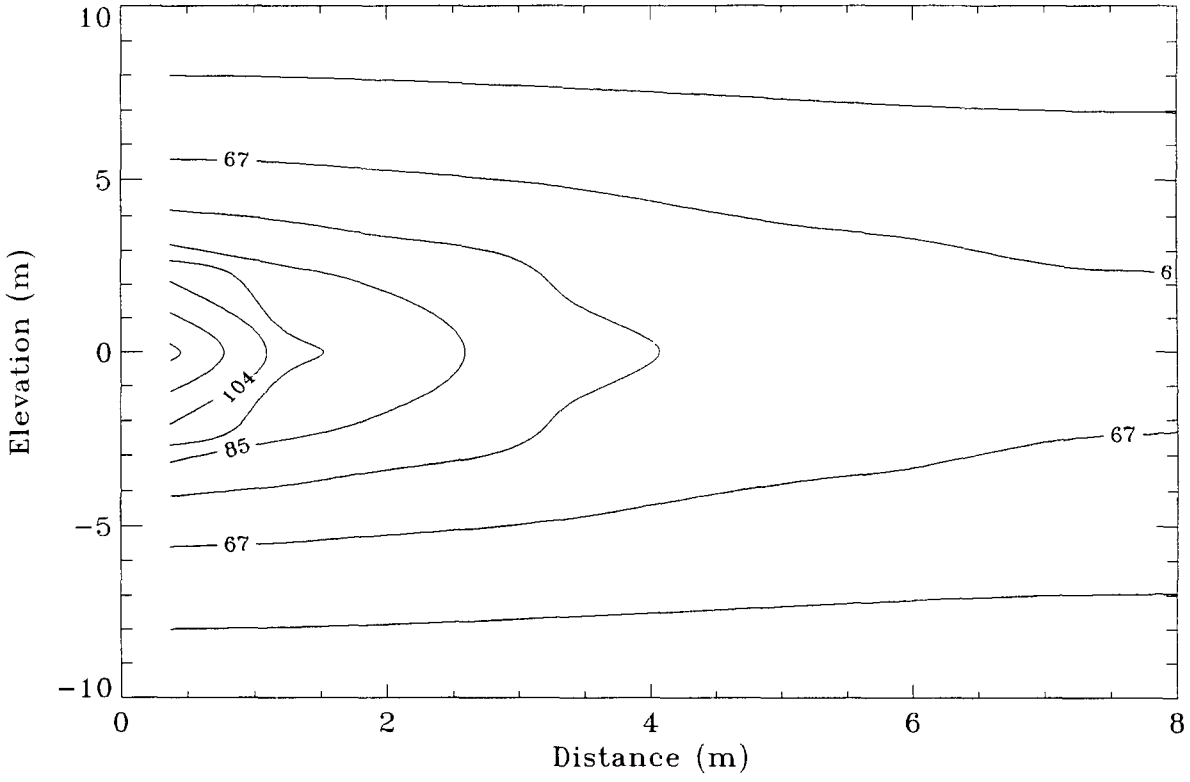
* Not to Scale

Near-Field Grid

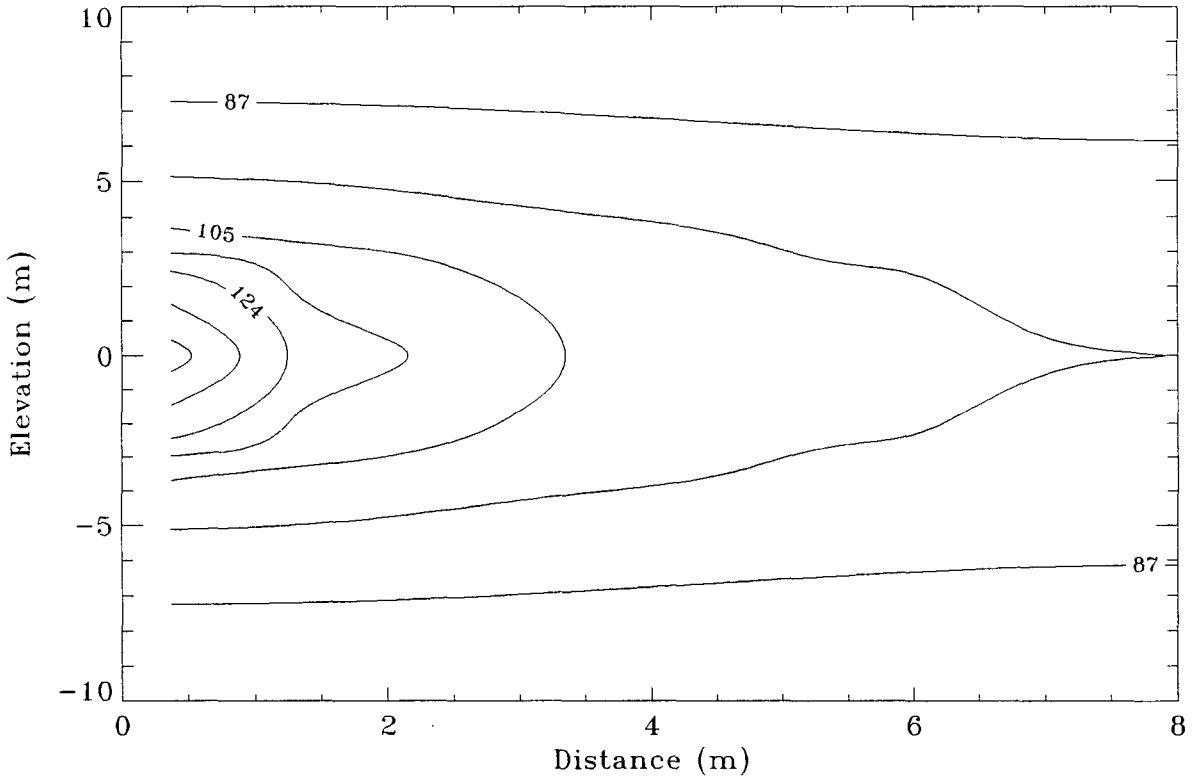


80 kW/acre
Vertical
Cross-Section

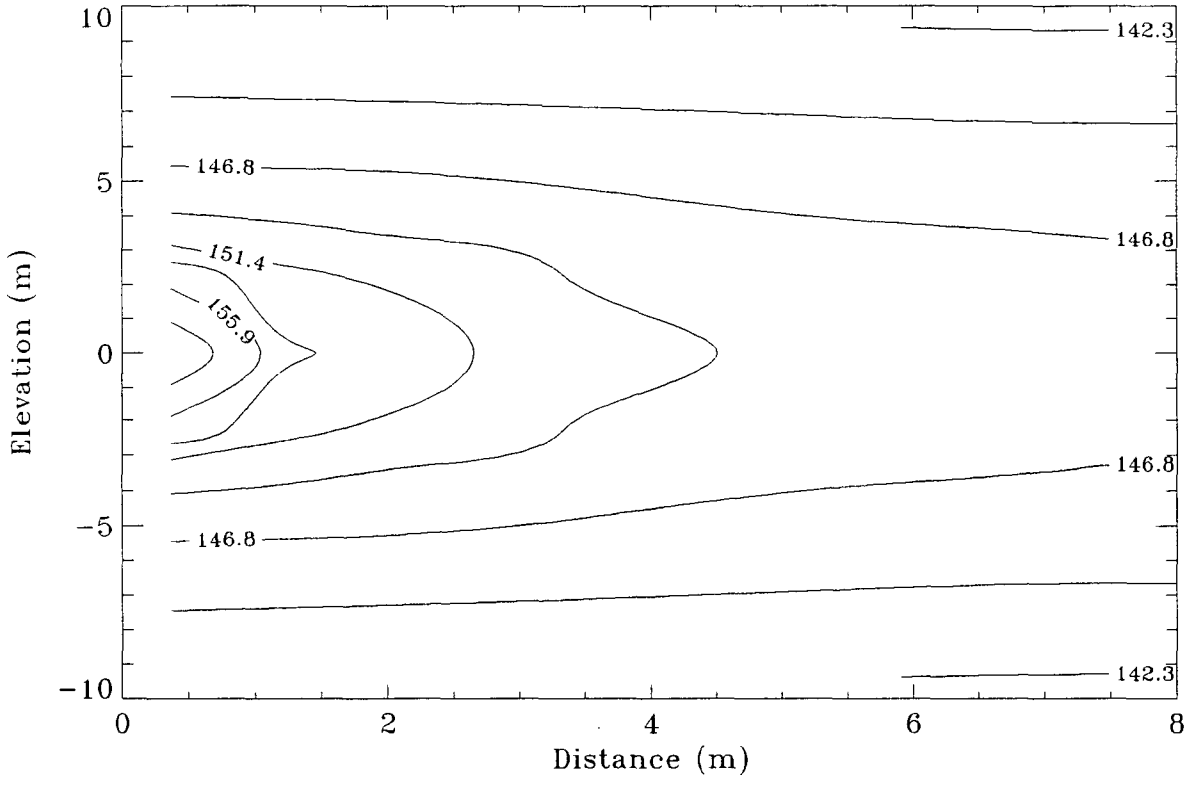
Near-Field Environment
80 kW/acre
time = 5



Near-Field Environment
80 kW/acre
time = 12

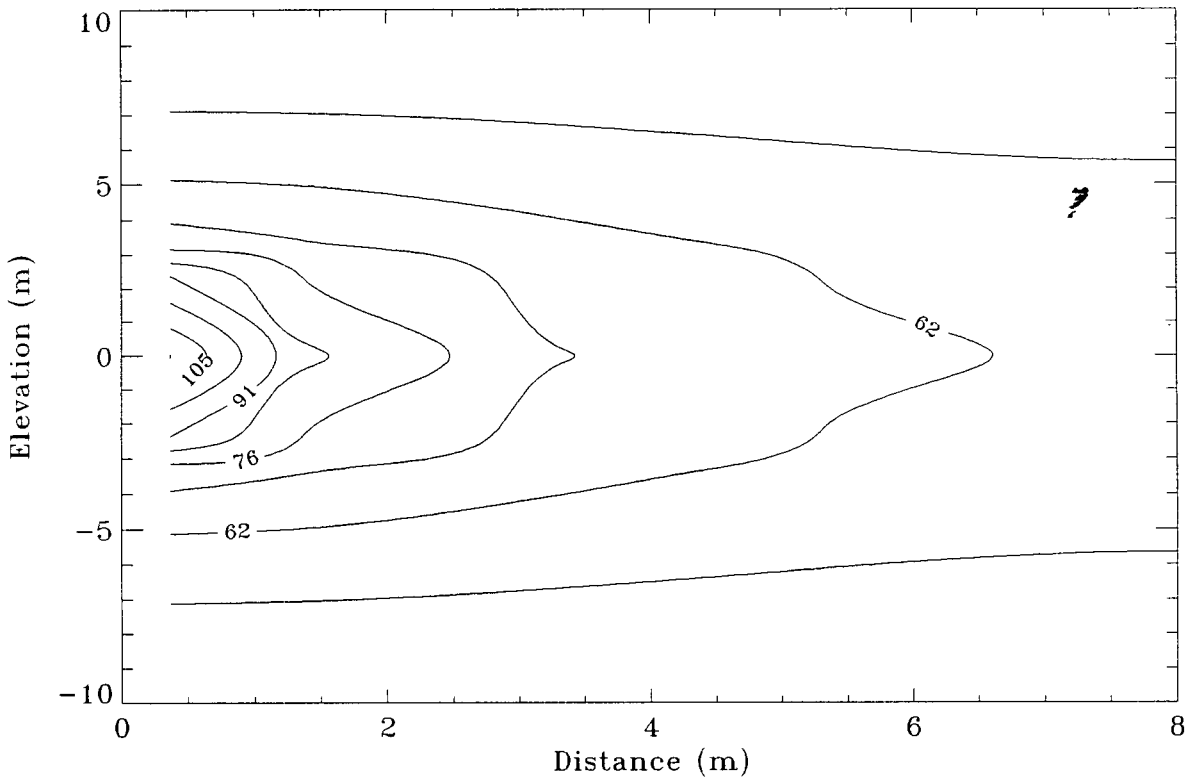


Near-Field Environment
80 kW/acre
time = 200

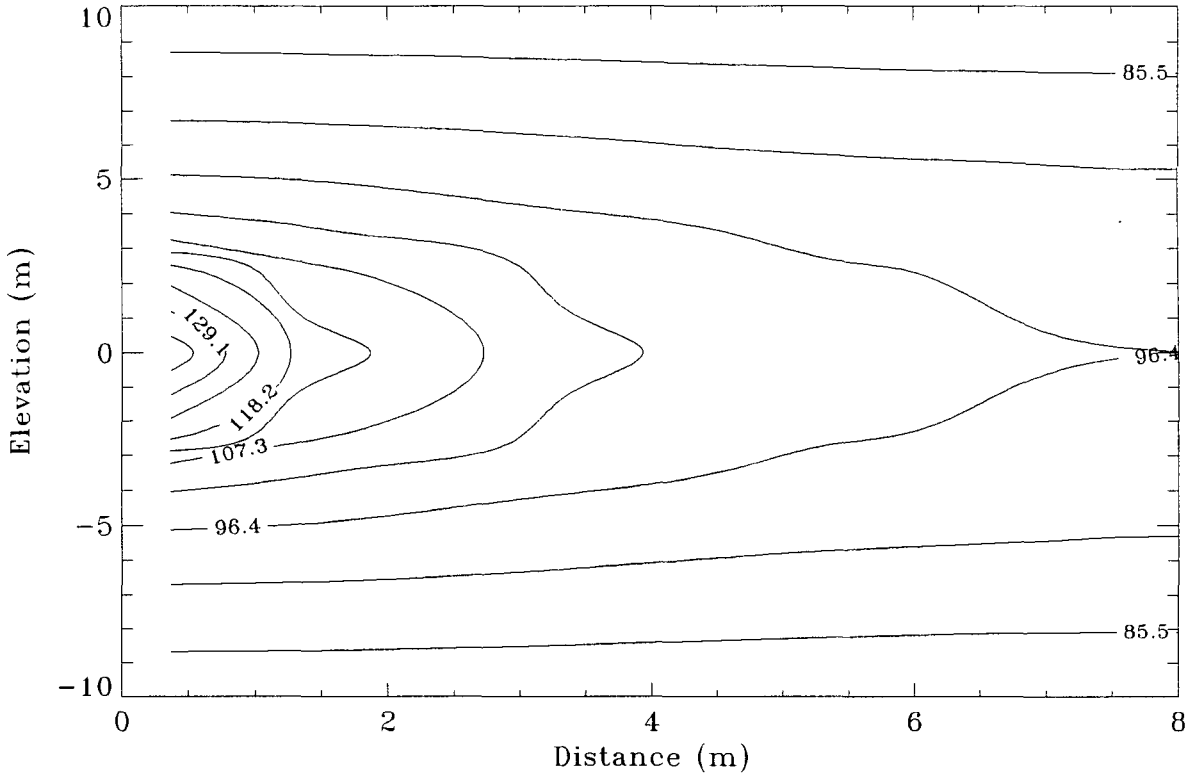


57 kW/acre
Vertical
Cross-Section

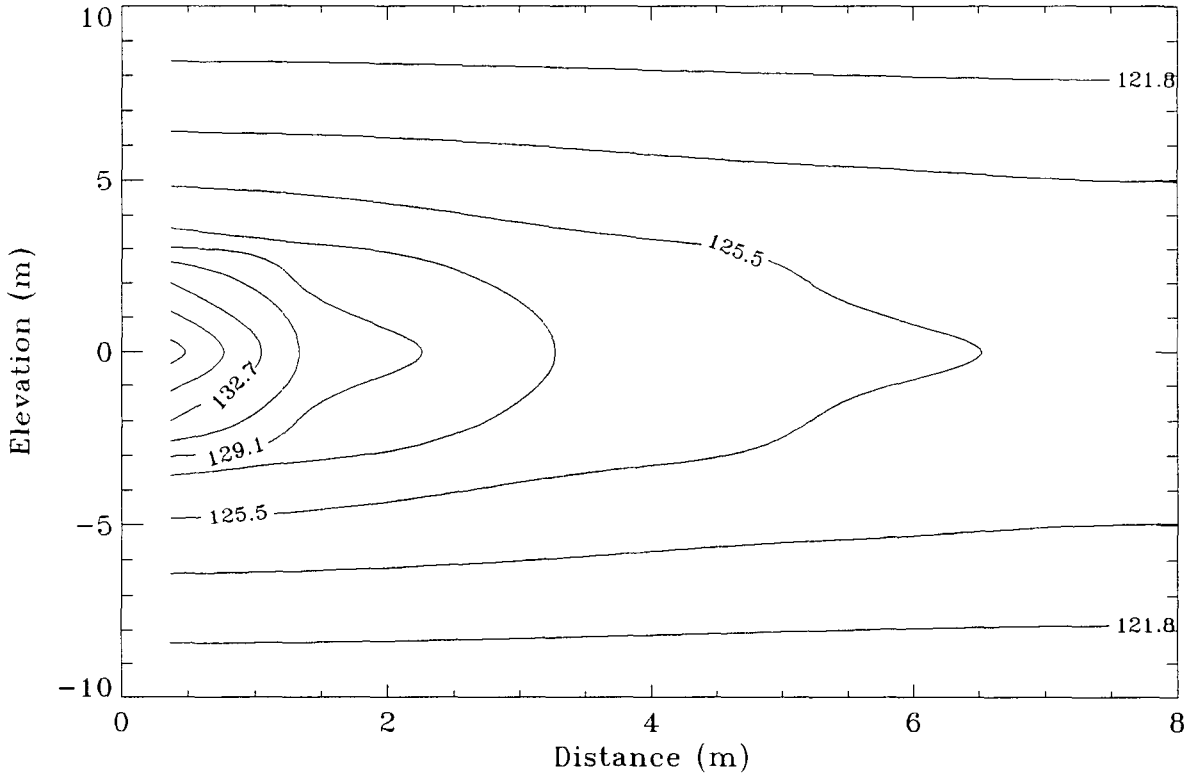
Near-Field Environment
57 kW/acre
time = 5



Near-Field Environment
57 kW/acre
time = 19

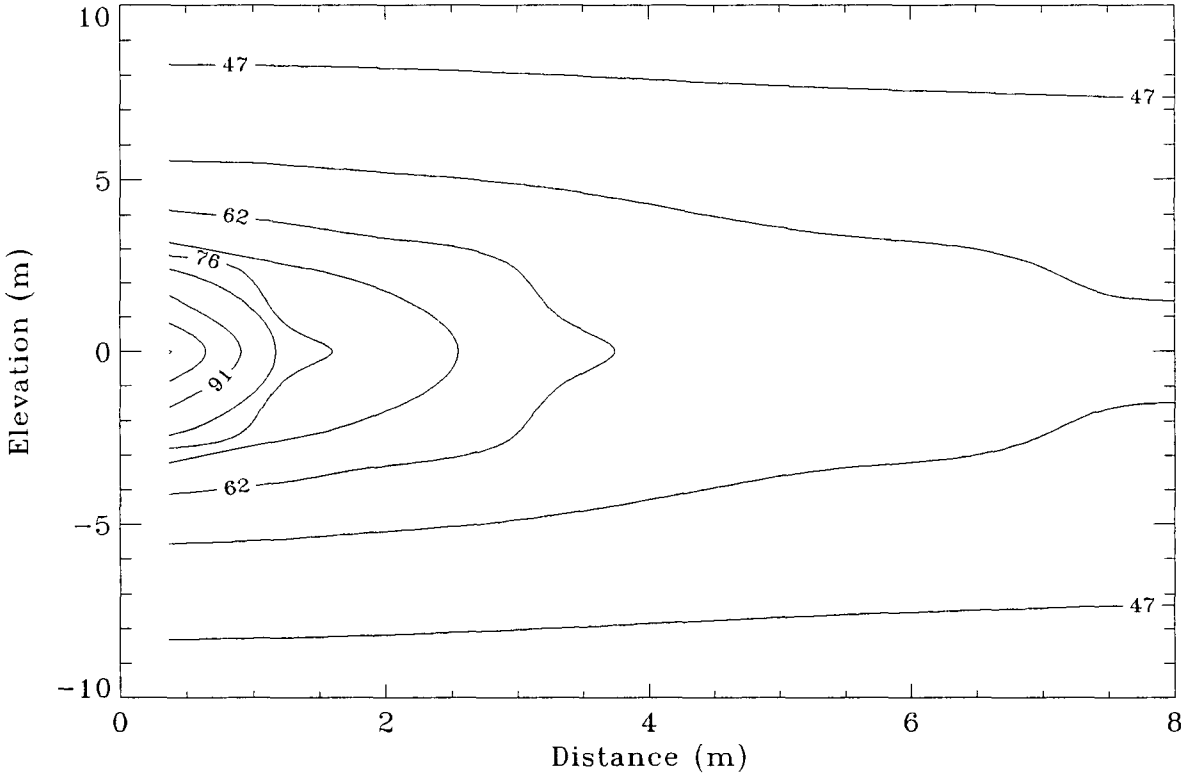


Near-Field Environment
57 kW/acre
time = 200

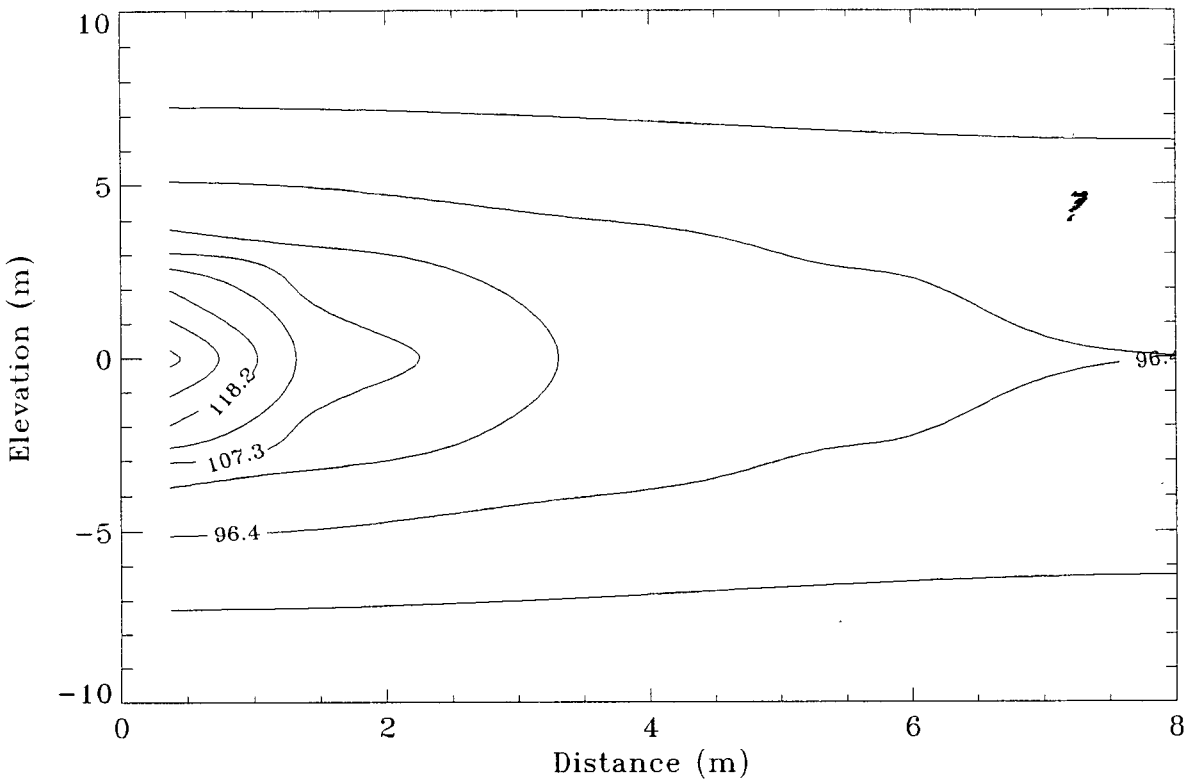


48 kW/acre
Vertical
Cross-Section

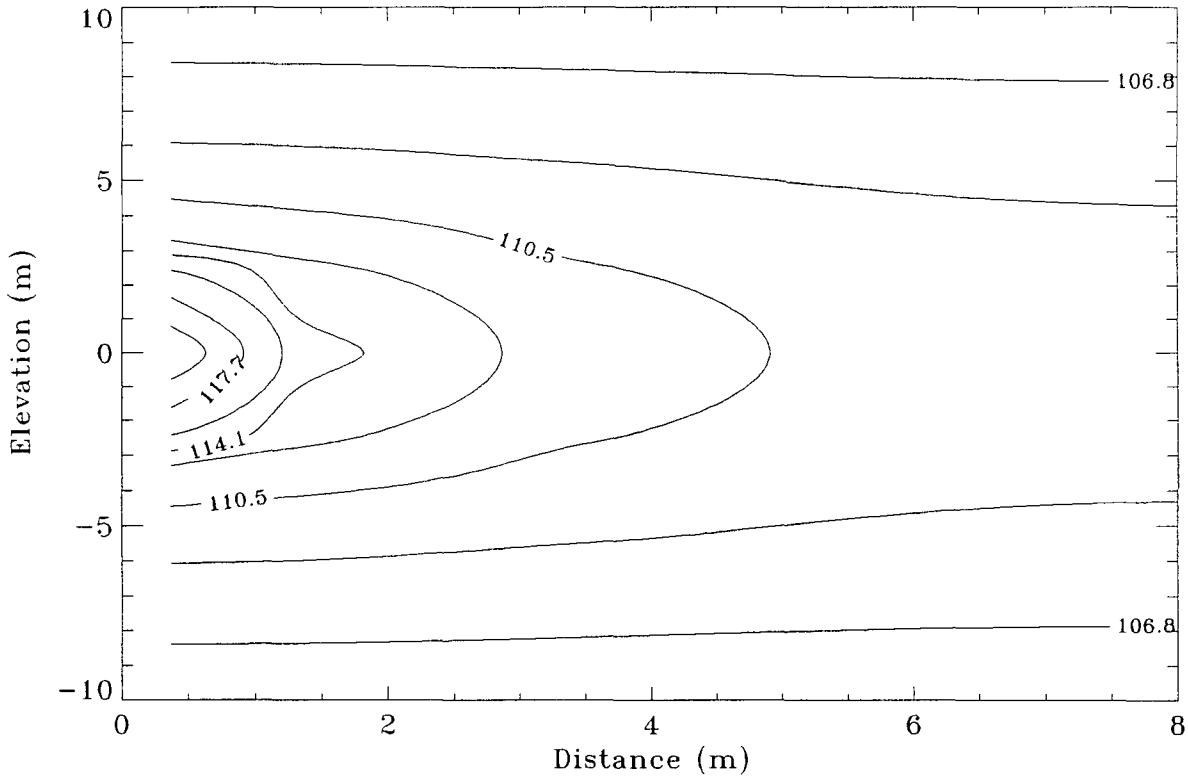
Near-Field Environment
48 kW/acre
time = 5



Near-Field Environment
48 kW/acre
time = 31

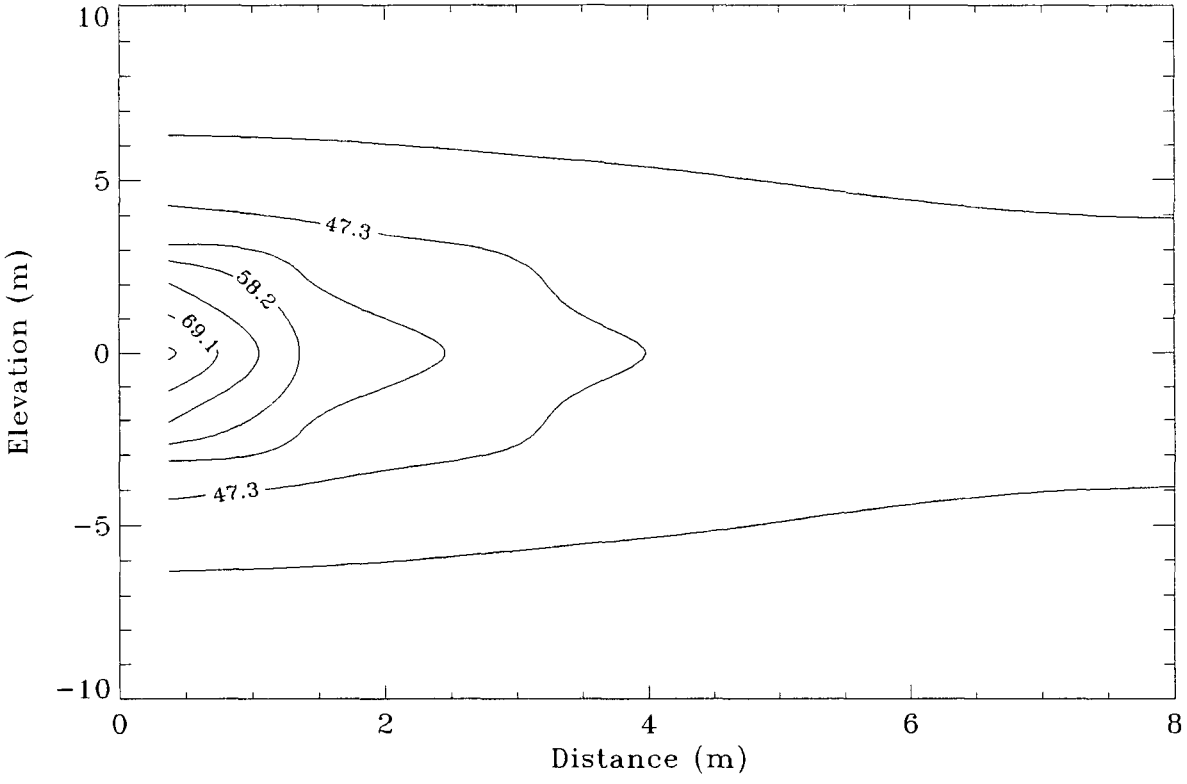


Near-Field Environment
48 kW/acre
time = 200

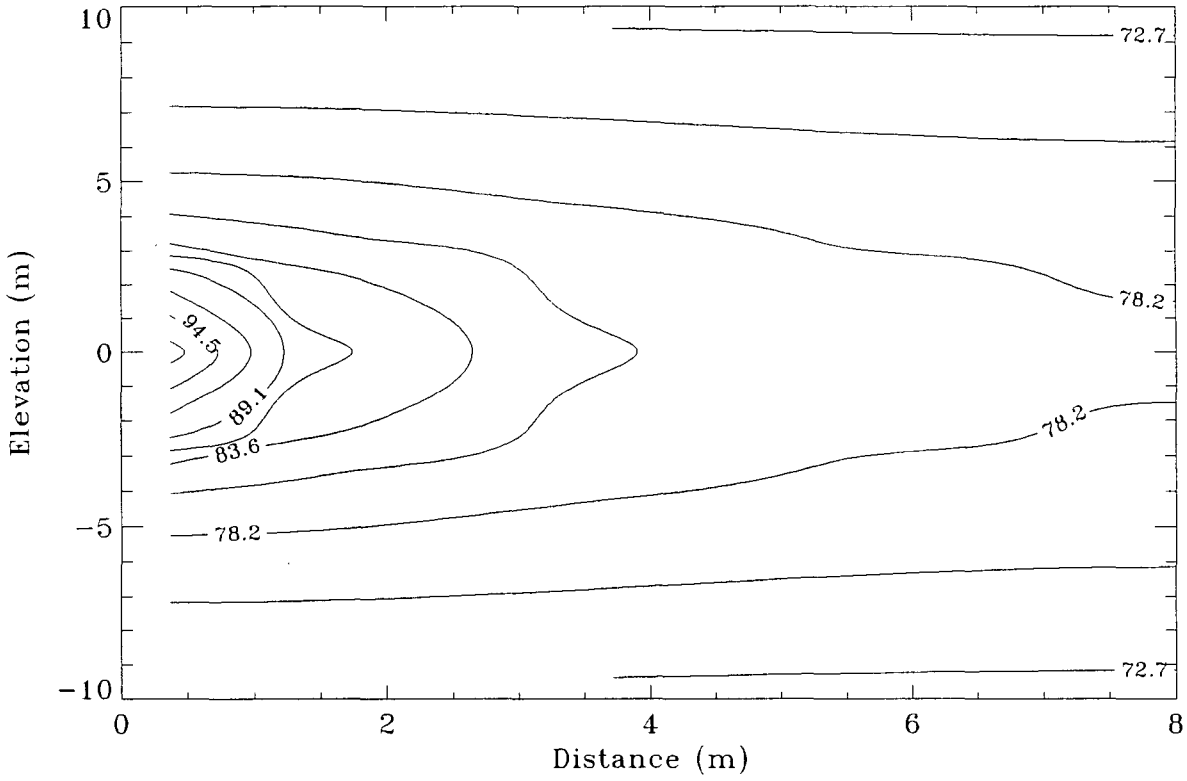


30 kW/acre
Vertical
Cross-Section

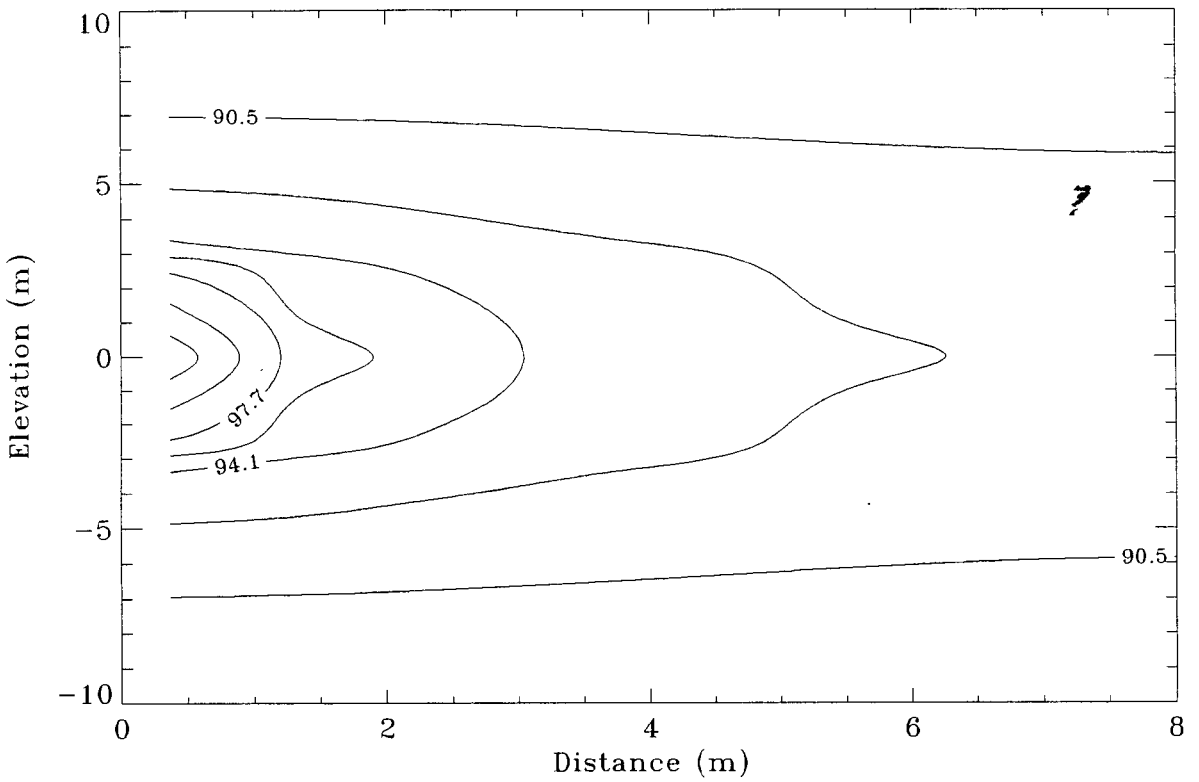
Near-Field Environment
30 kW/acre
time = 5



Near-Field Environment
30 kW/acre
time = 50

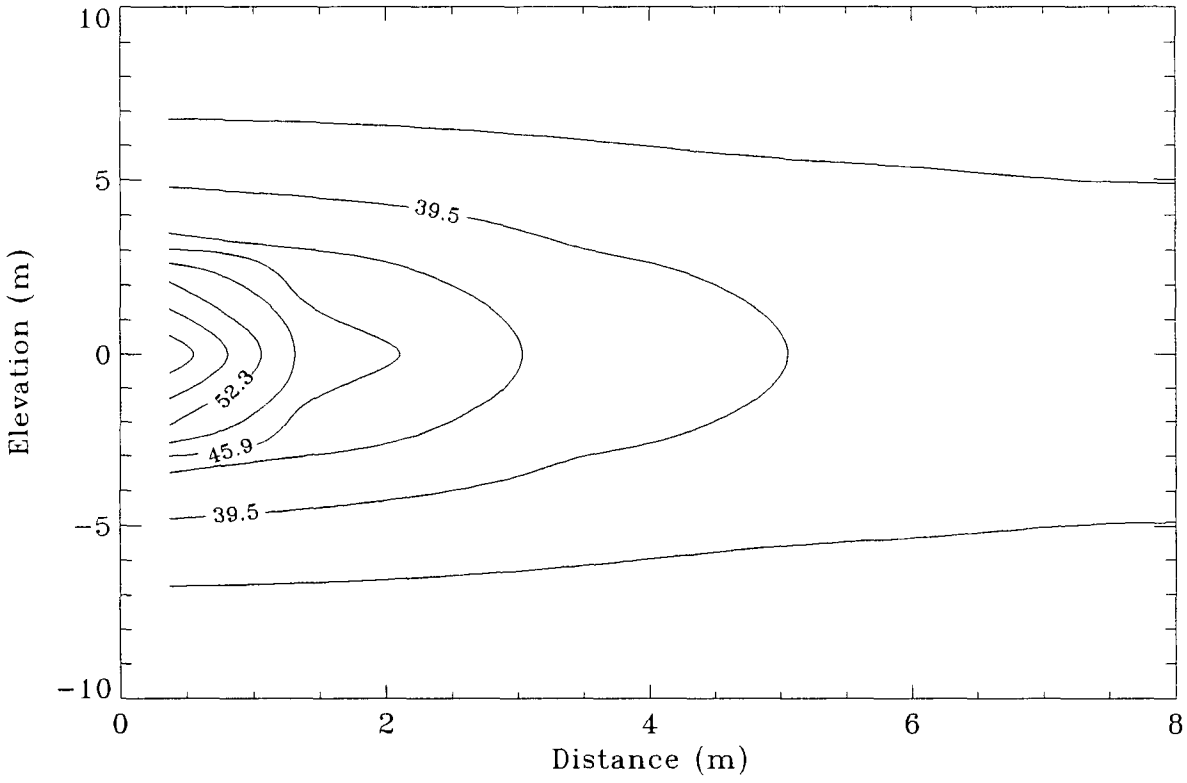


Near-Field Environment
30 kW/acre
time = 200

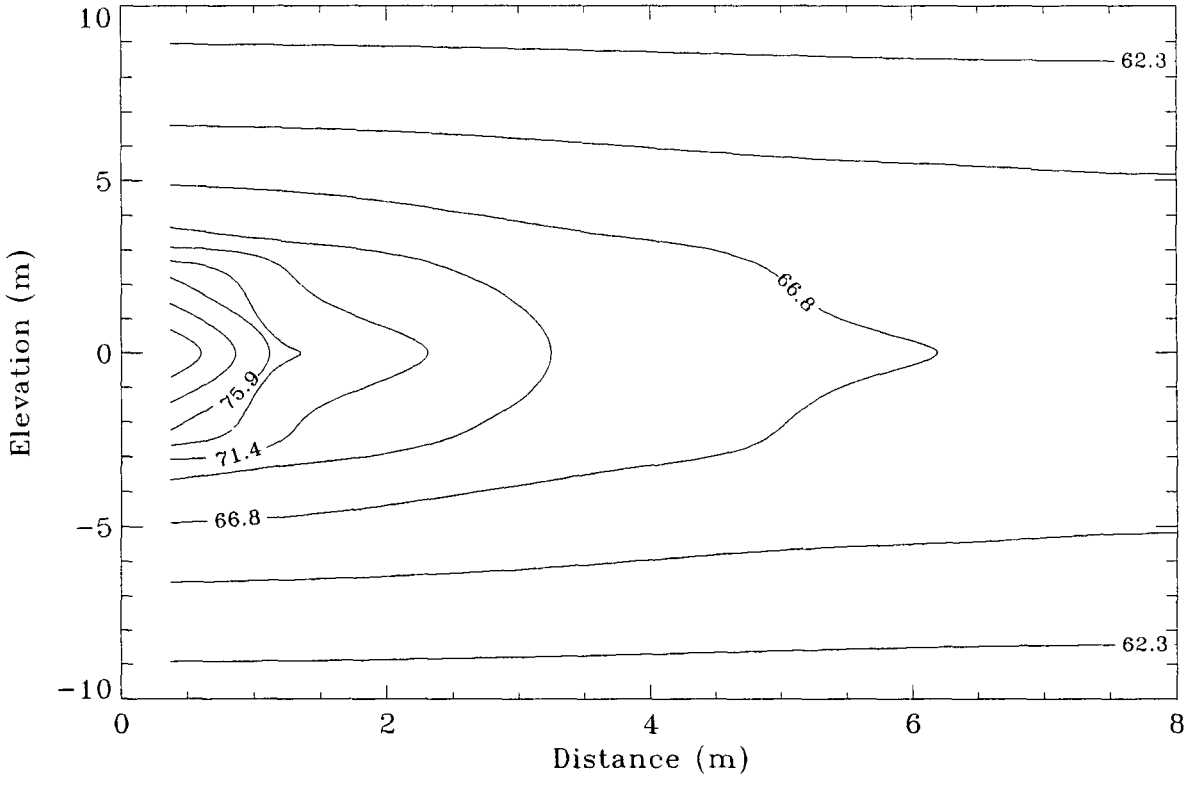


22 kW/acre
Vertical
Cross-Section

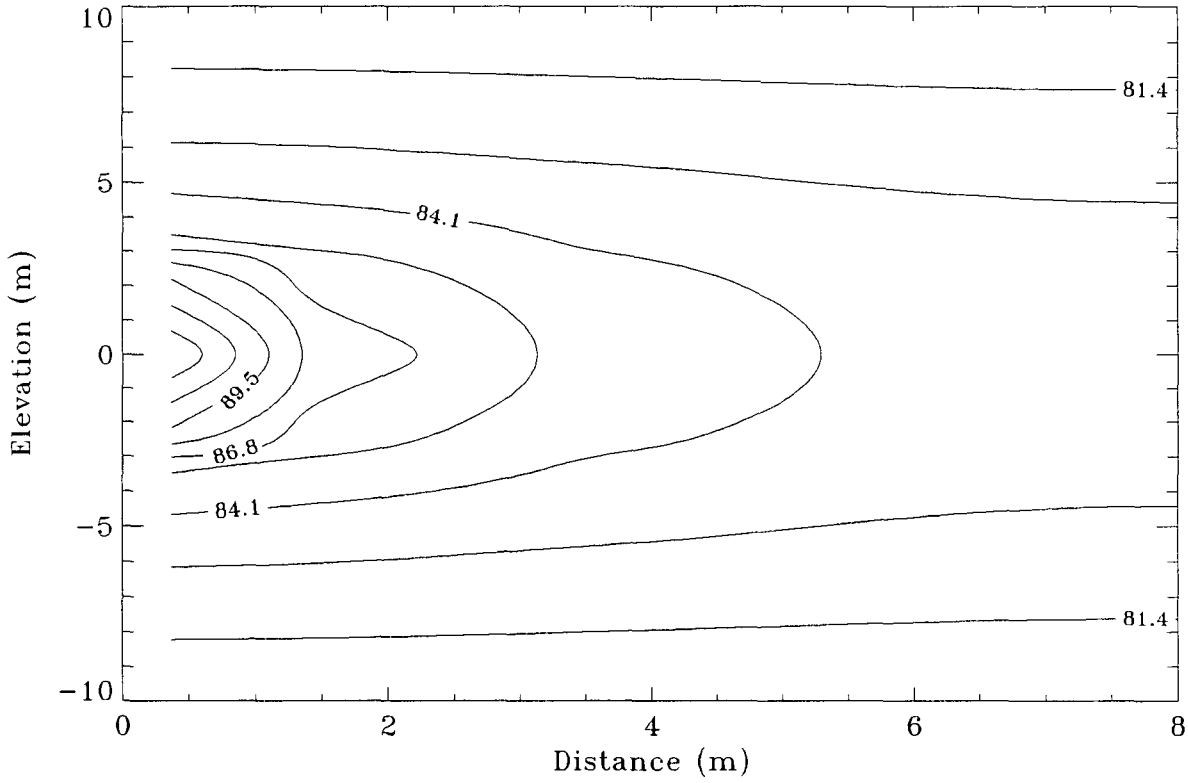
Near-Field Environment
22 kW/acre
time = 5



Near-Field Environment
22 kW/acre
time = 50

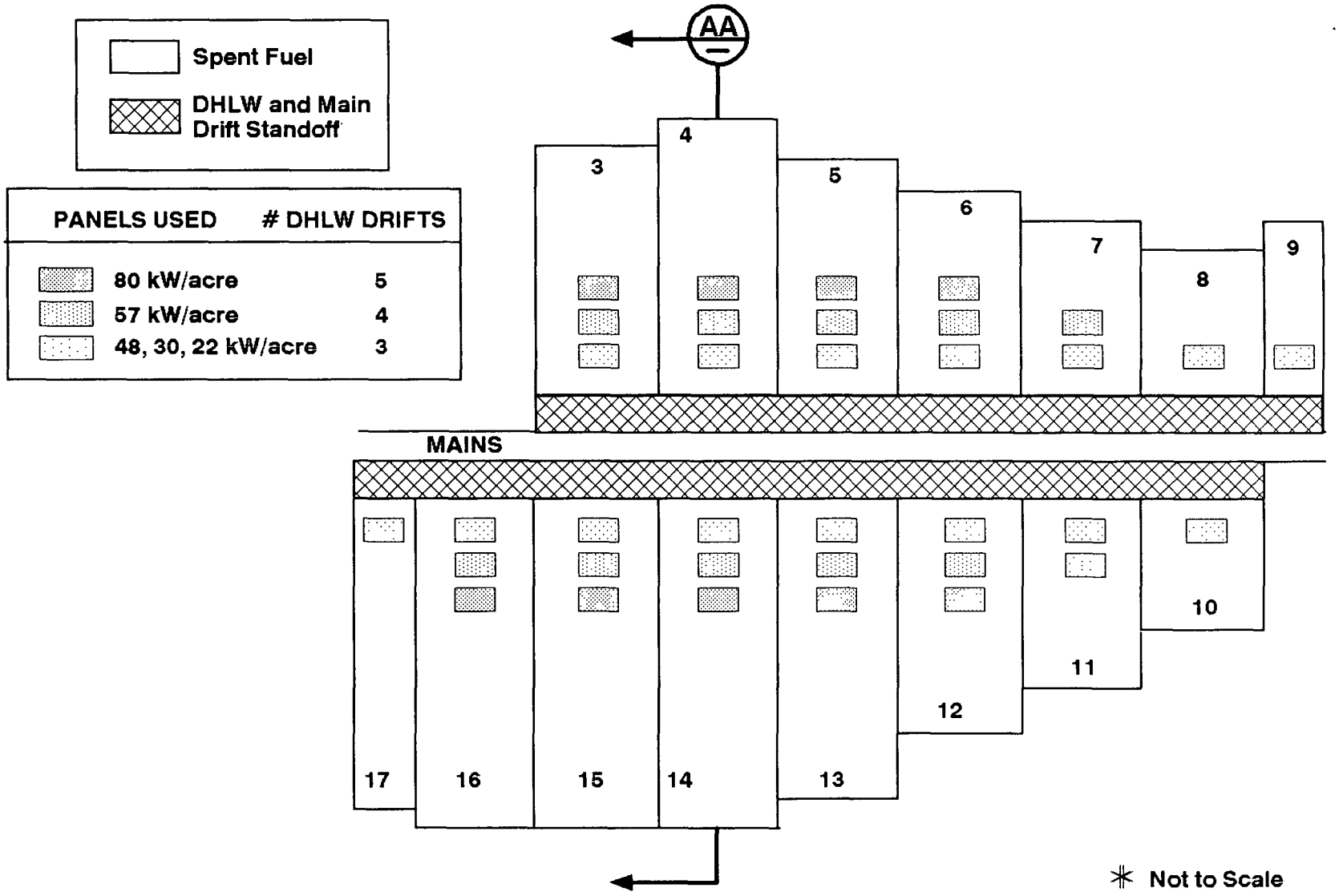


Near-Field Environment
22 kW/acre
time = 200

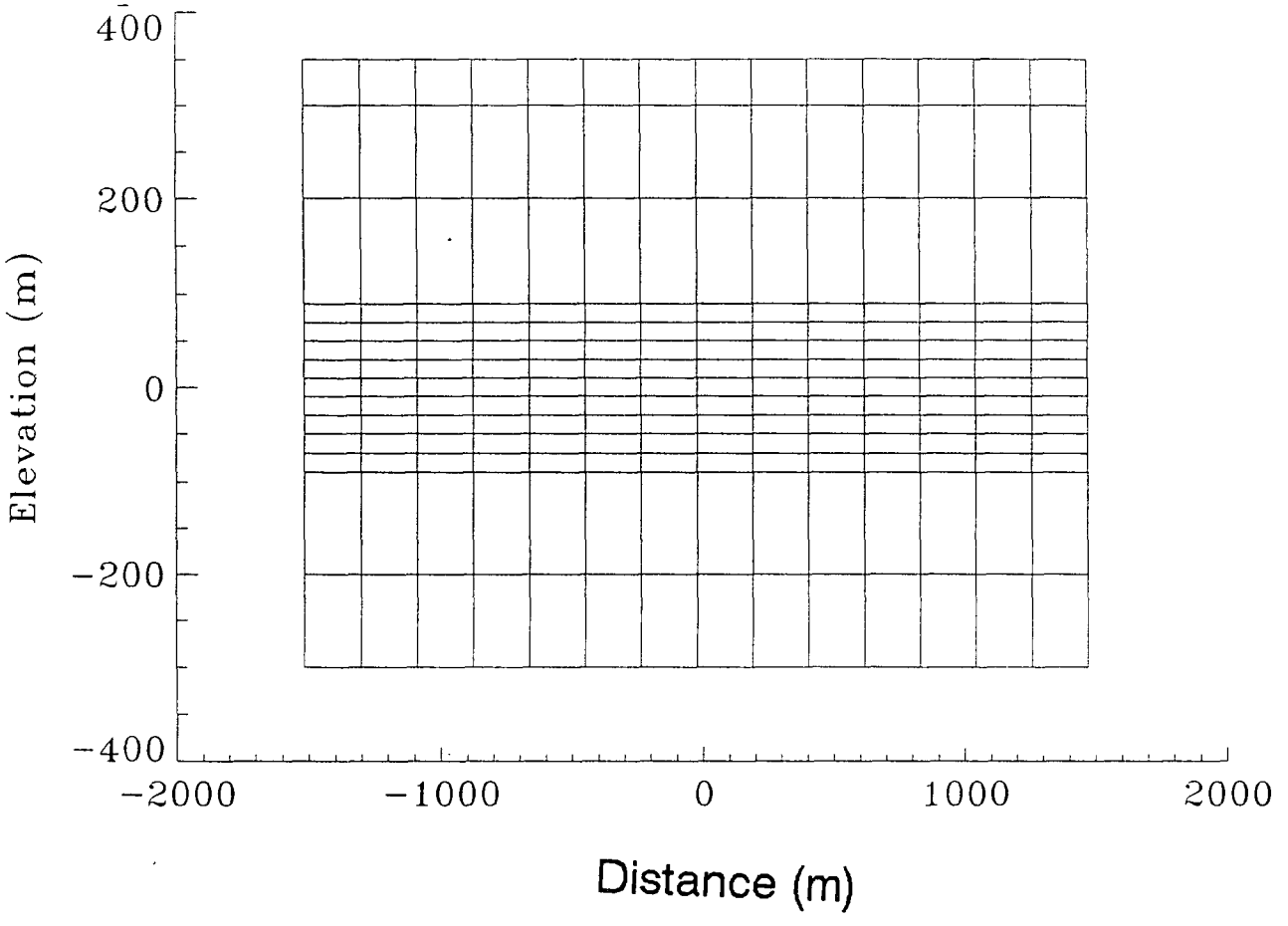


Thermal Response
Far-Field

MODELED REPOSITORY (PRIMARY BLOCK)



Grid for Vertical Cross-Section AA

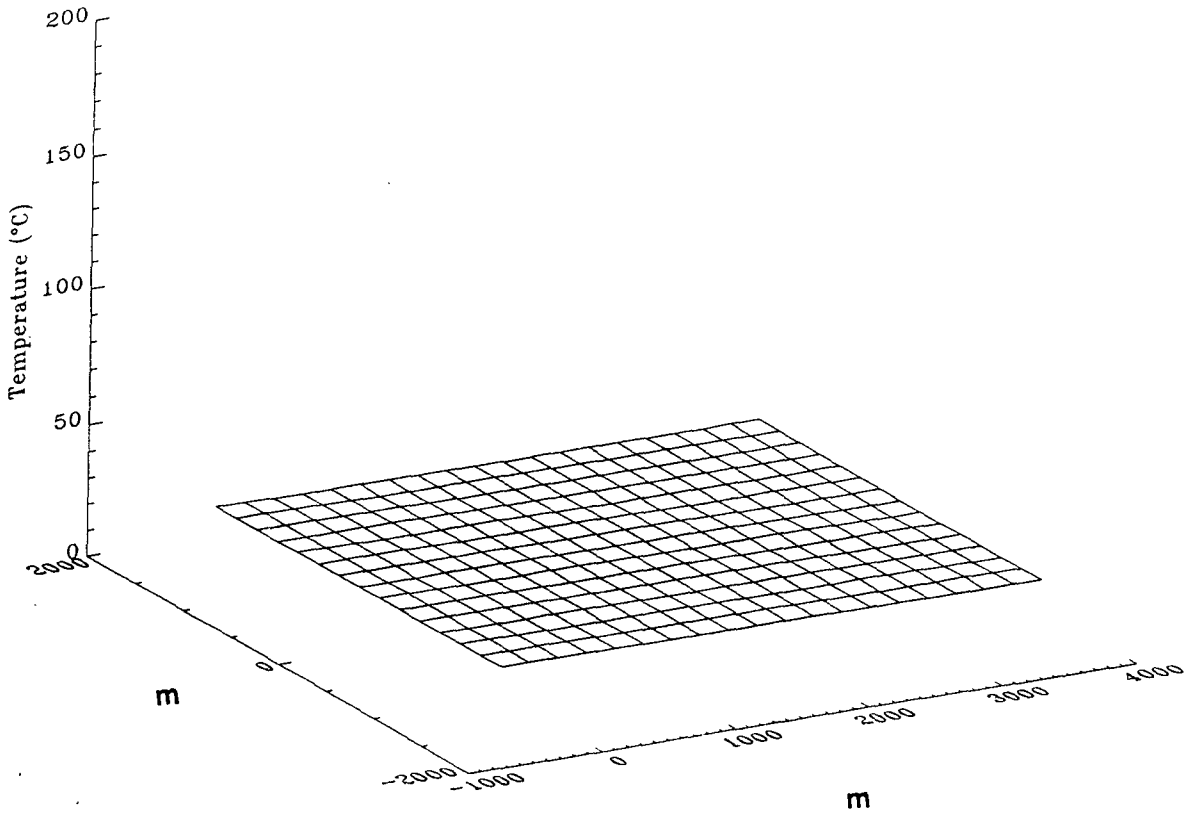


Surface at 350 m

Waste Package Centerpoints at 0 m

Constant Temperature Surface T = 18.7 C

Grid for Horizontal Cross-Section 50 m Below Waste Package Centerpoints



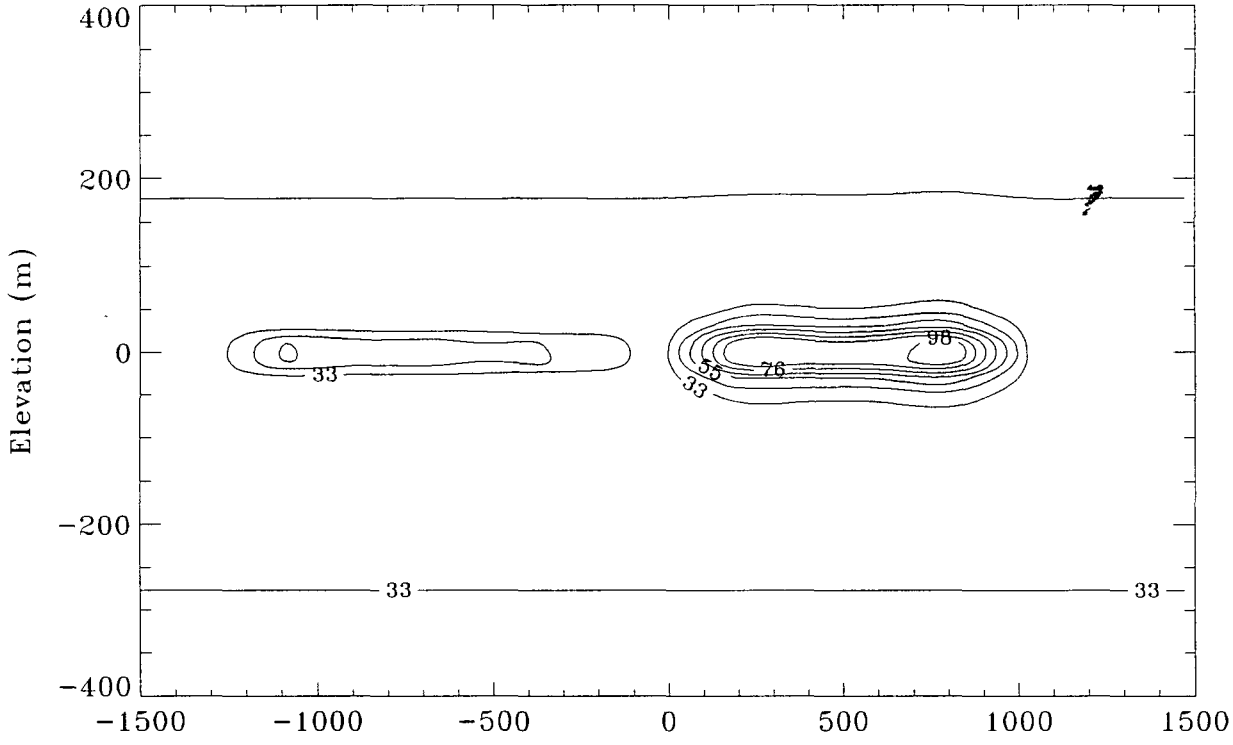
Number of Grid Points = 300

(x,y) origin approximately N767500, E564200

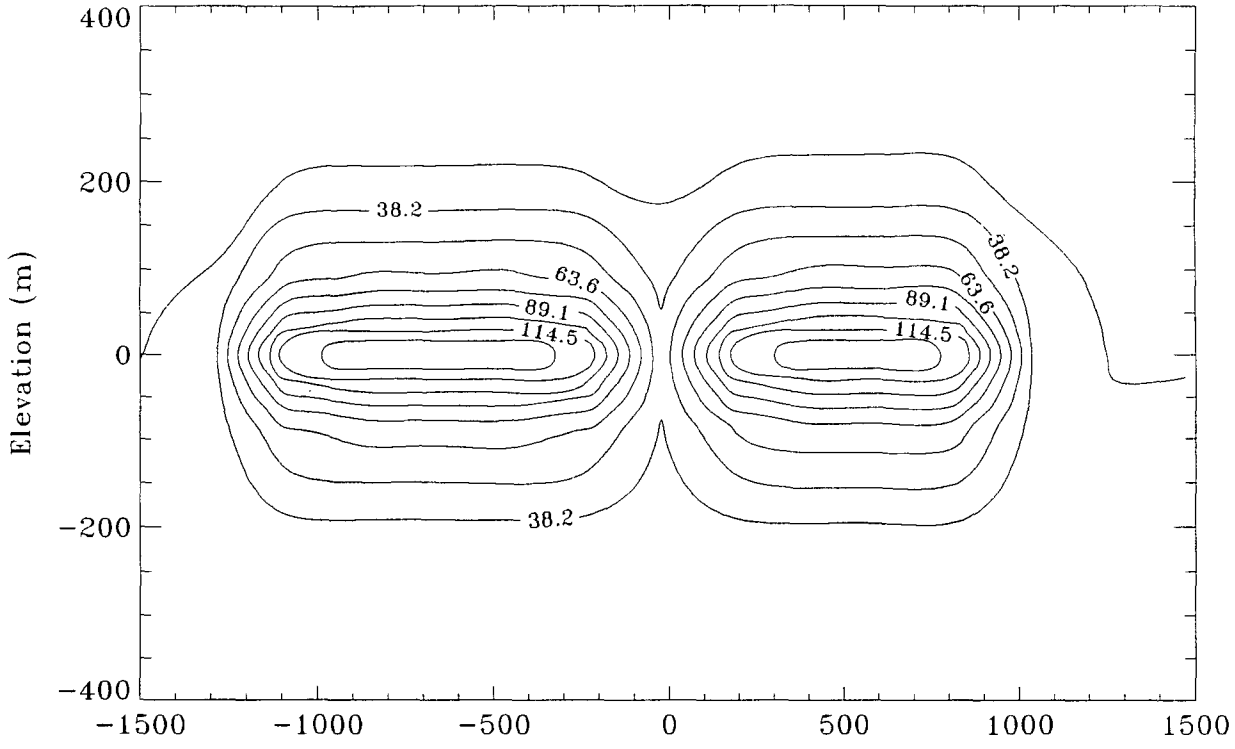
To adjust depth to repository floor reference, add 5.4 m to depth

80 kW/acre
Vertical
Cross-Section

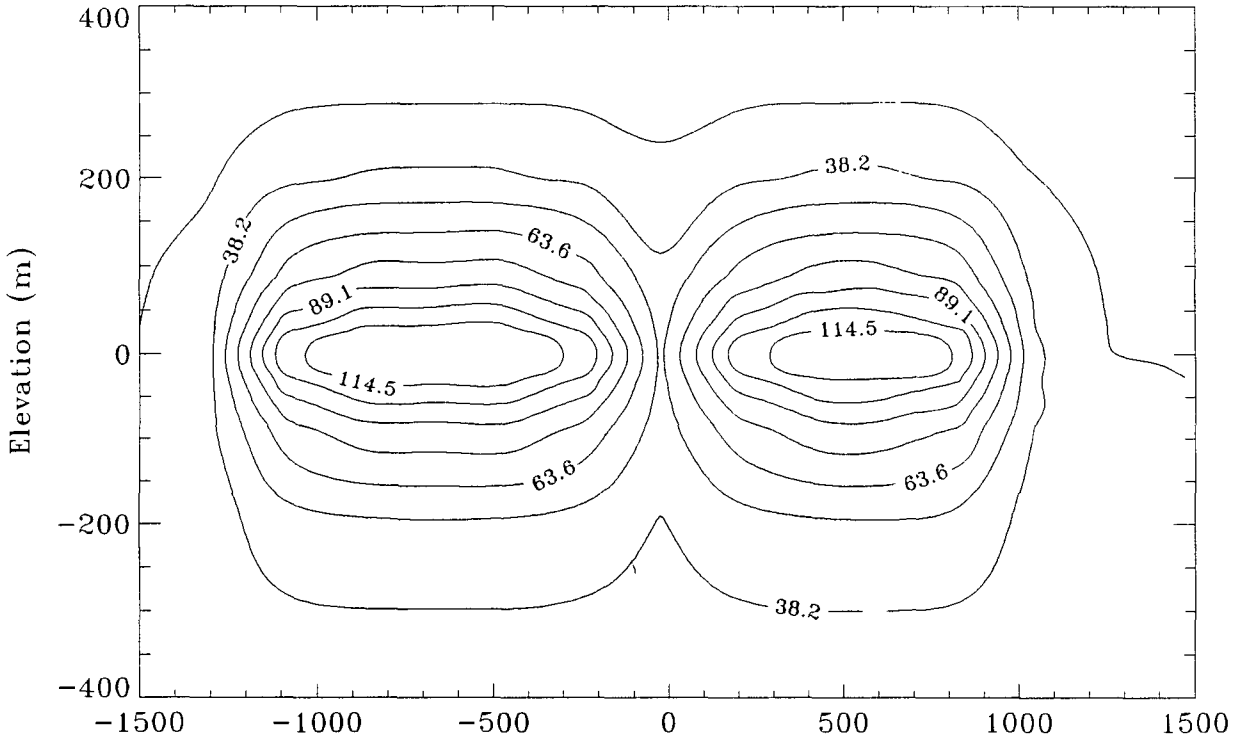
Vertical Cross-Section AA
80 kW/acre
time = 25



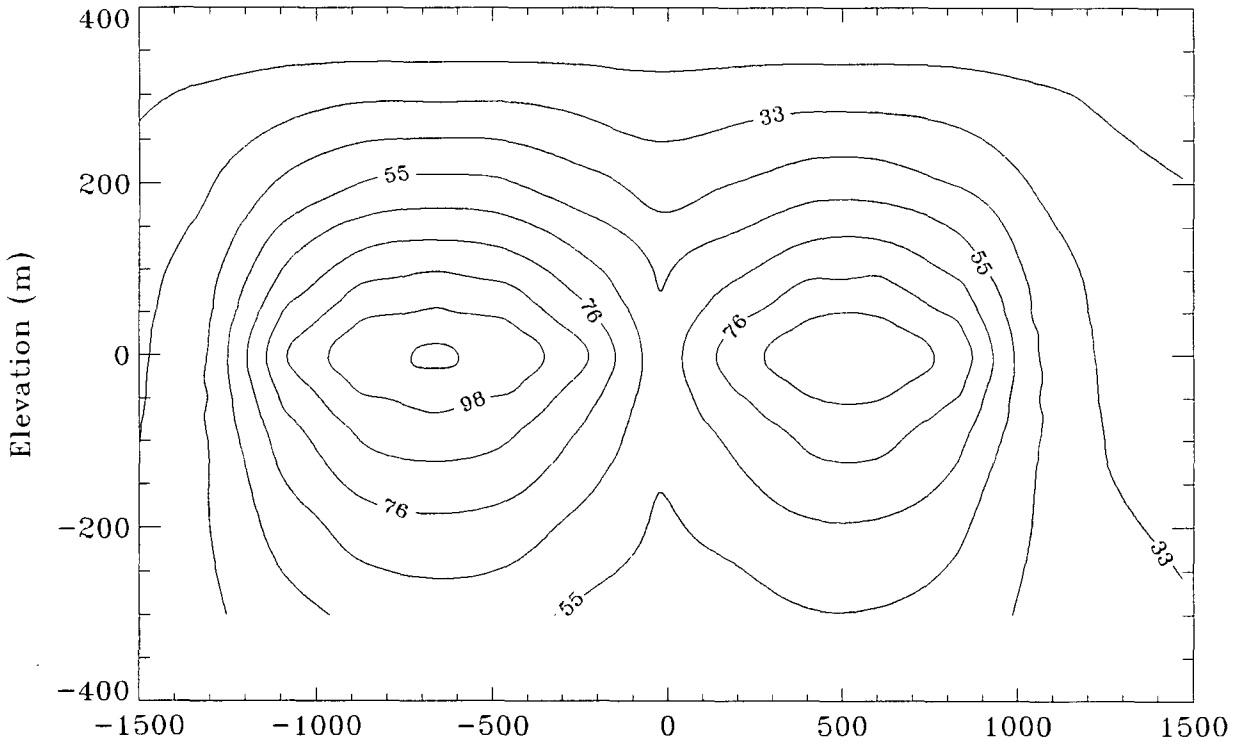
Vertical Cross-Section AA
80 kW/acre
time = 200



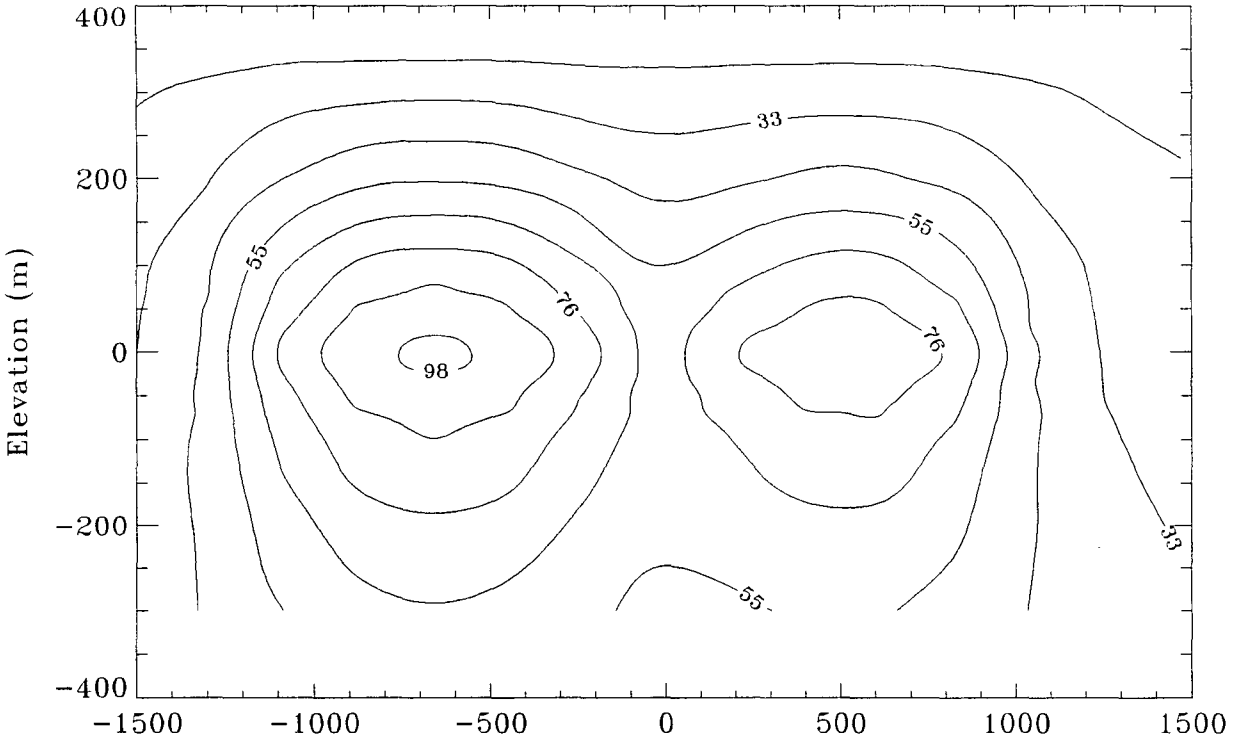
Vertical Cross-Section AA
80 kW/acre
time = 400



Vertical Cross-Section AA
80 kW/acre
time = 1400



Vertical Cross-Section AA
80 kW/acre
time = 2000



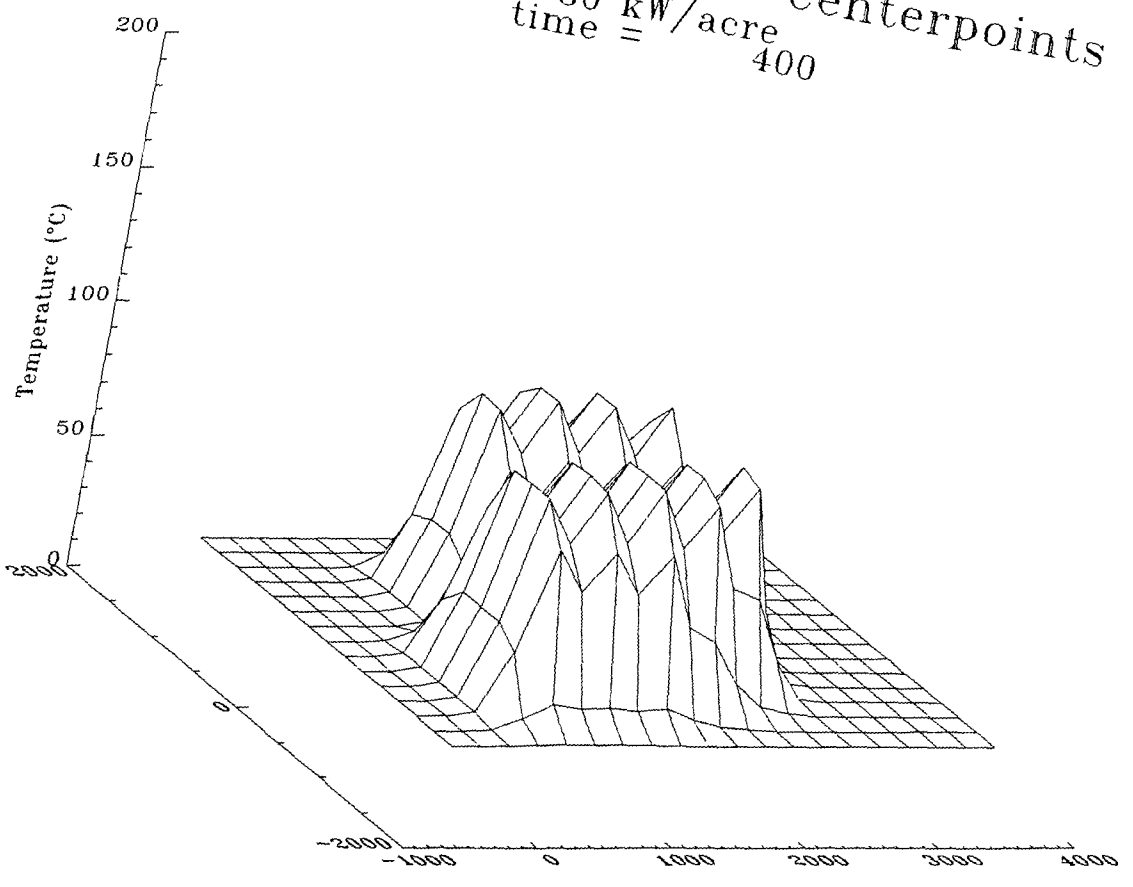
80 kW/acre

Horizontal

Cross-Section

Depth = 50 m

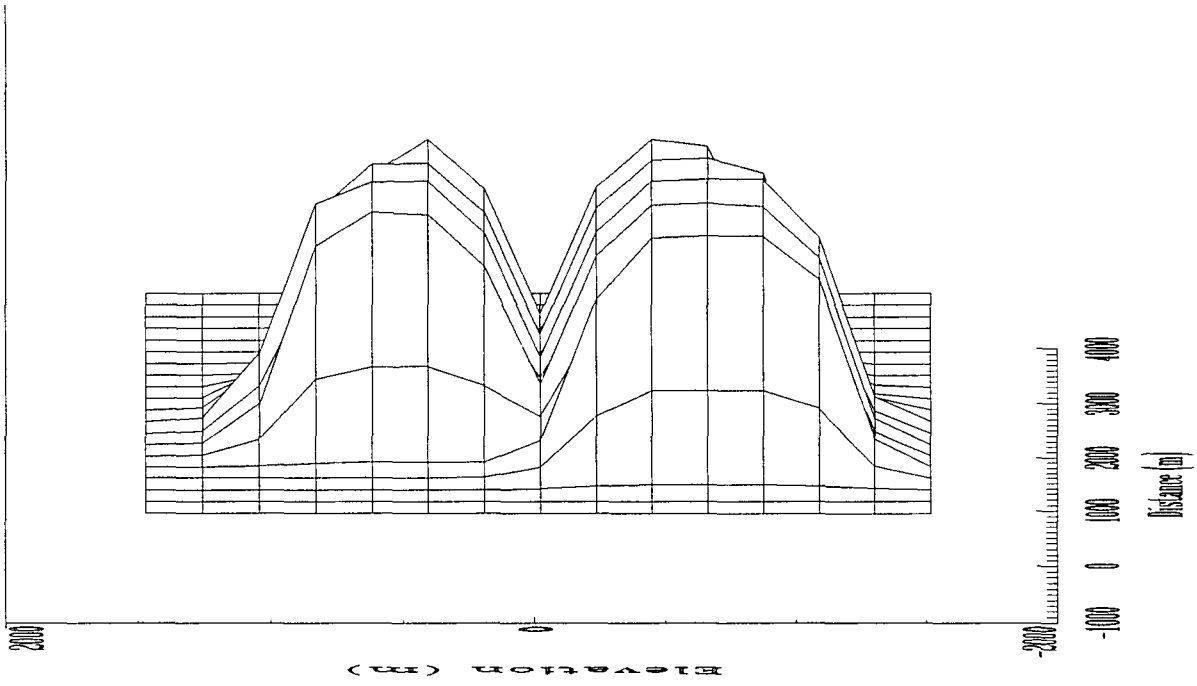
50 m From Canister Centerpoints
80 kW/acre
time = 400



50 m From Canister Centerpoints

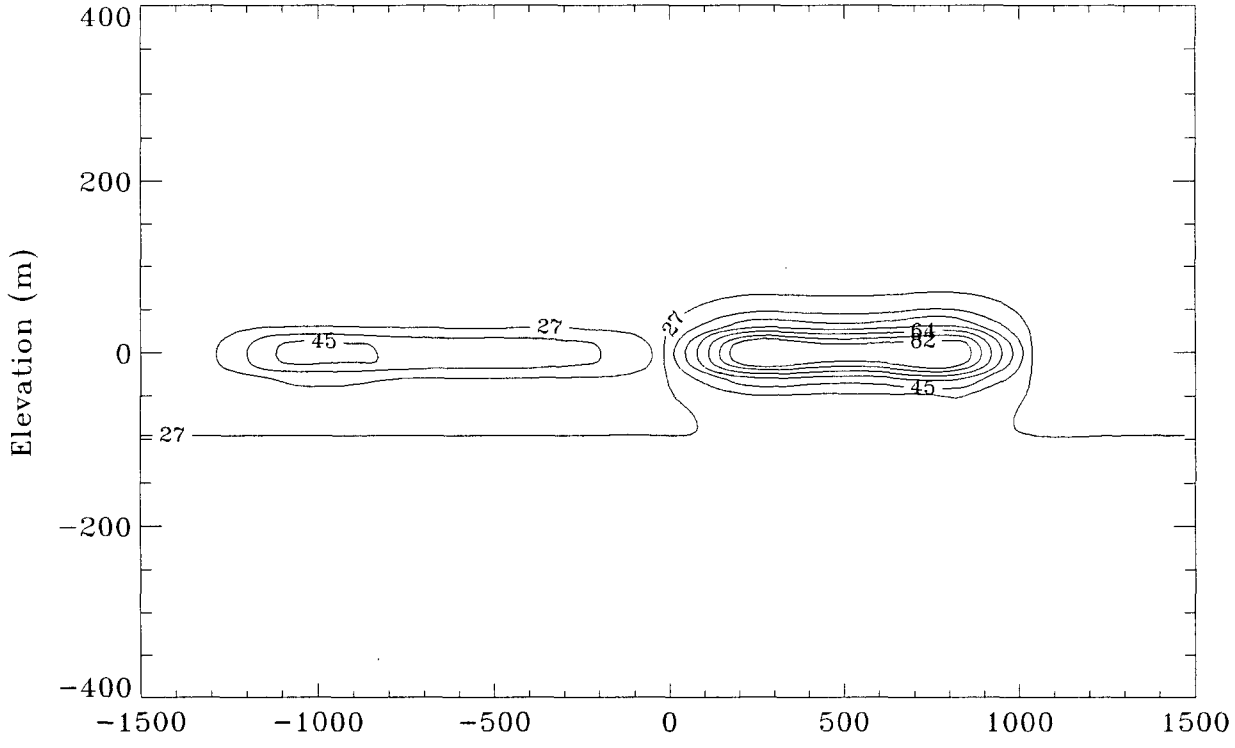
80 kW/acre

time = 400

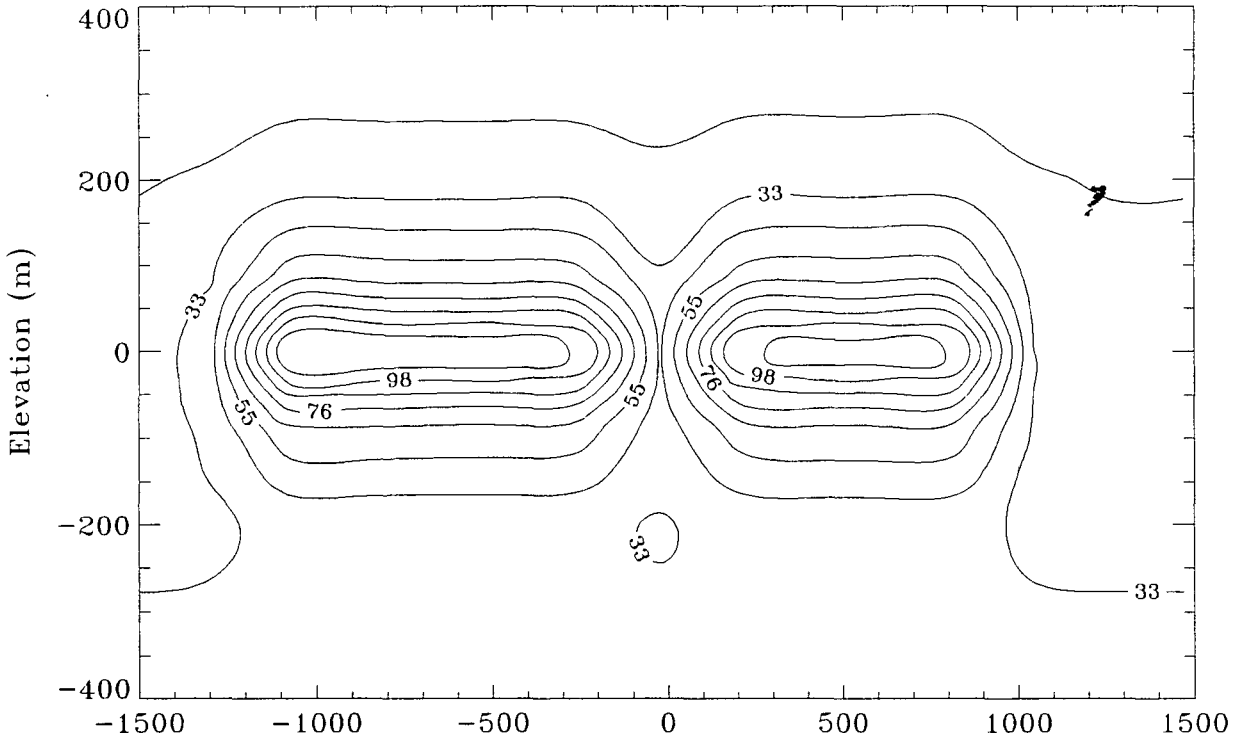


57 kW/acre
Vertical
Cross-Section

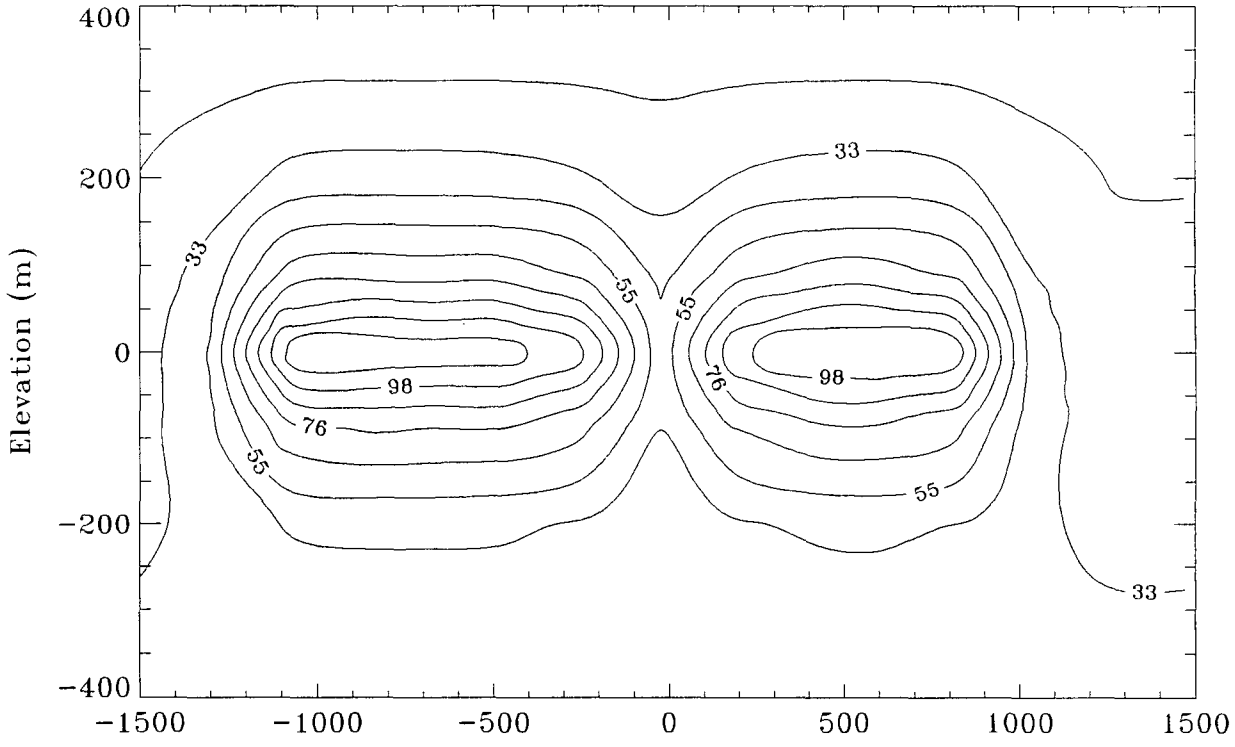
Vertical Cross-Section AA
57 kW/acre
time = 25



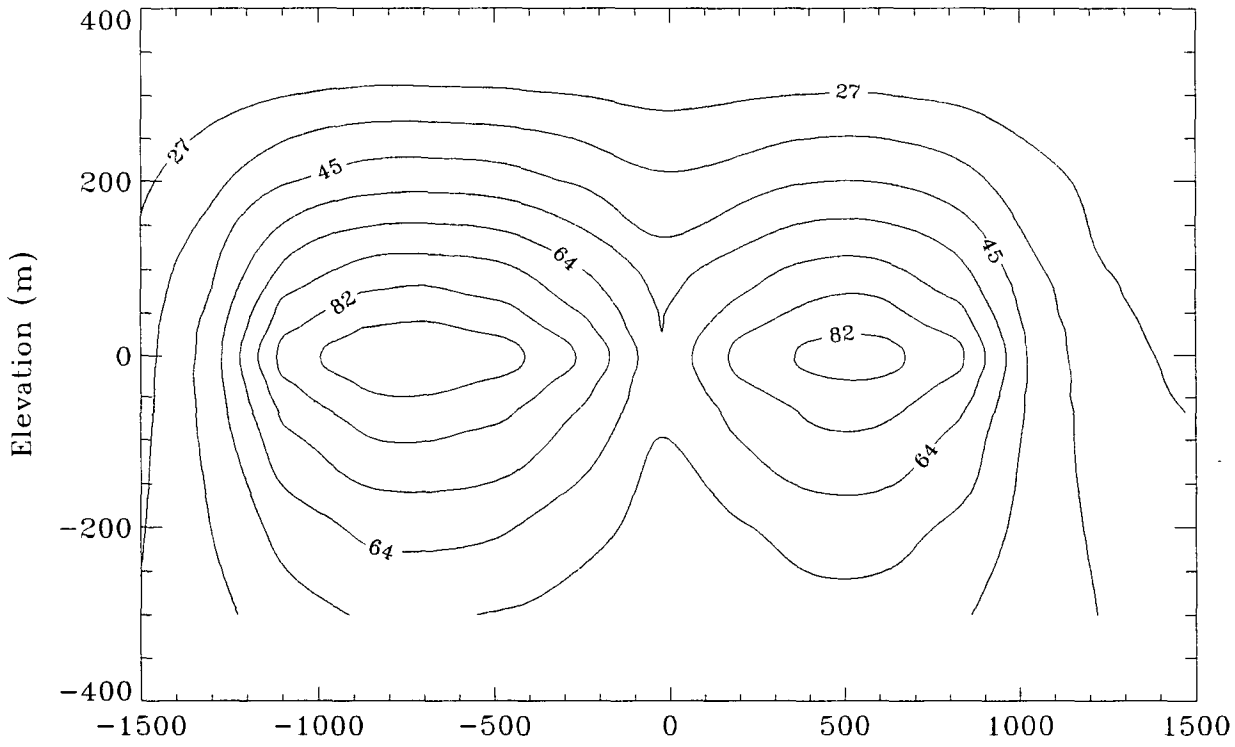
Vertical Cross-Section AA
57 kW/acre
time = 200



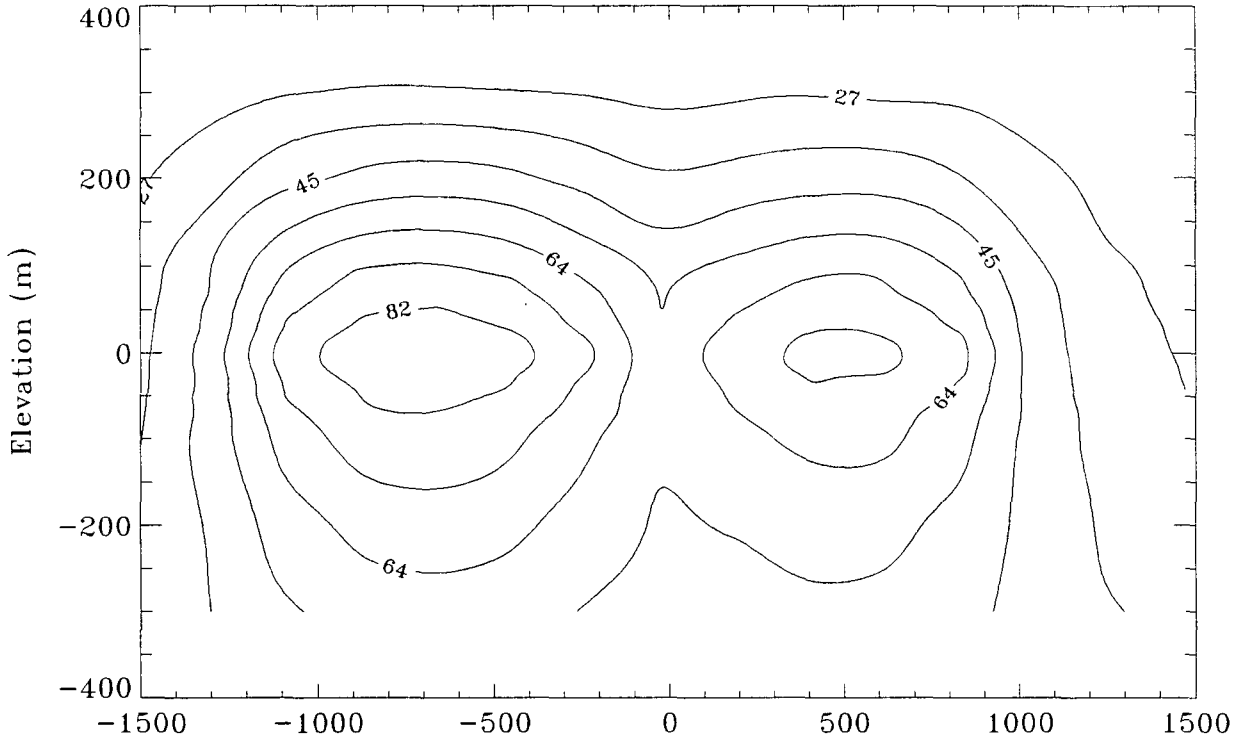
Vertical Cross-Section AA
57 kW/acre
time = 400

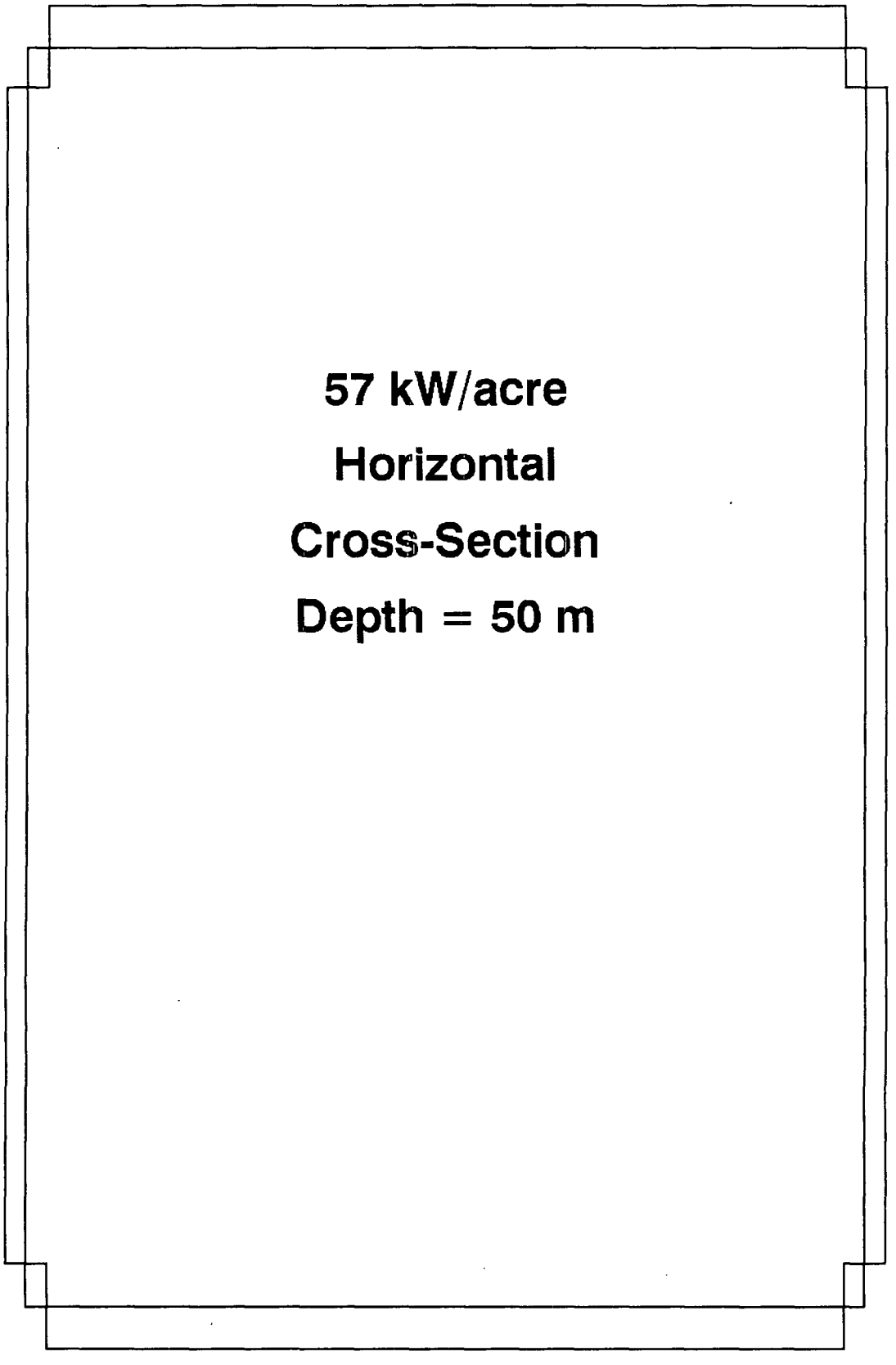


Vertical Cross-Section AA
57 kW/acre
time = 1400

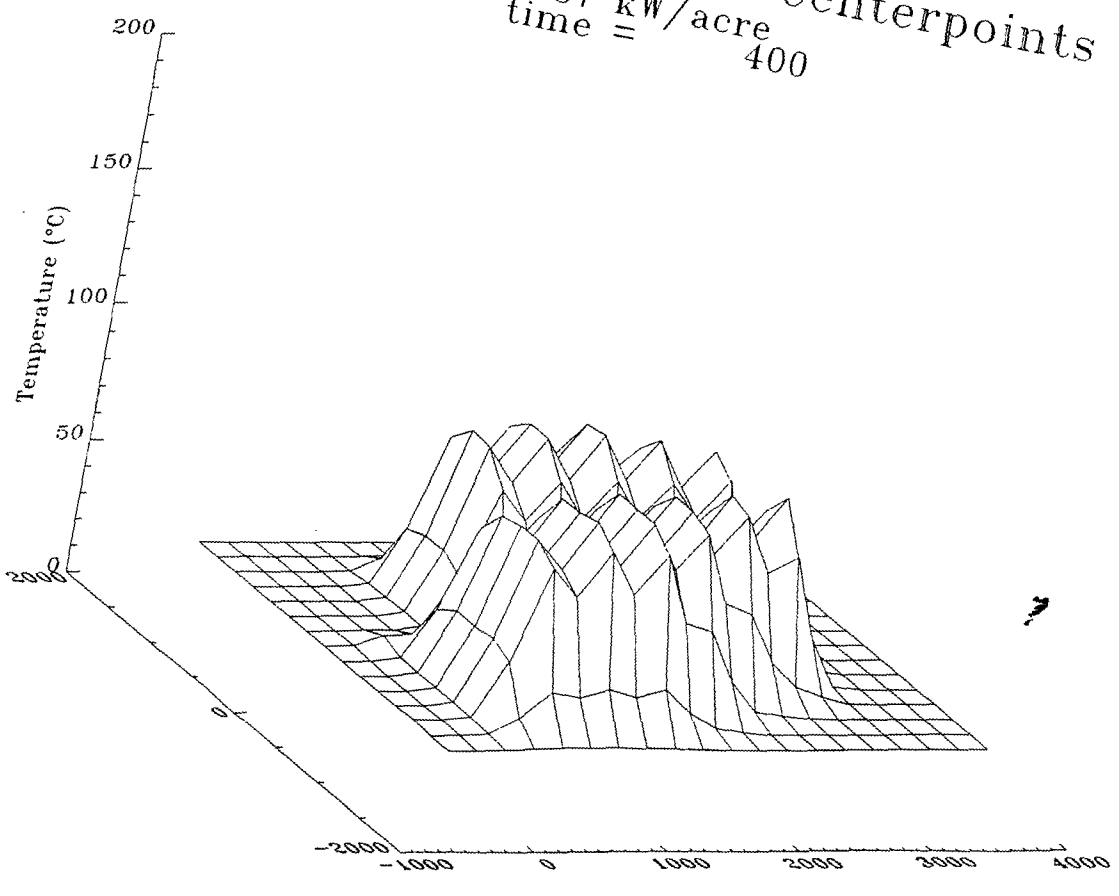


Vertical Cross-Section AA
57 kW/acre
time = 2000




57 kW/acre
Horizontal
Cross-Section
Depth = 50 m

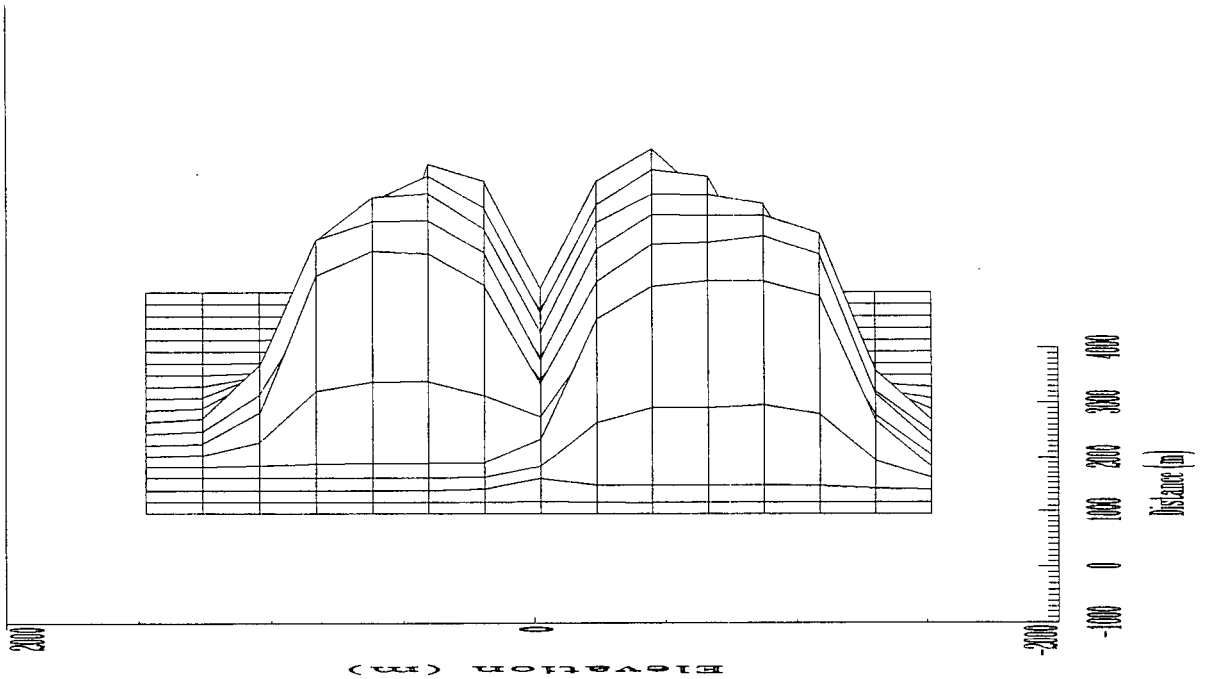
50 m From Canister Centerpoints
57 kW/acre
time = 400



50 m From Canister Centerpoints

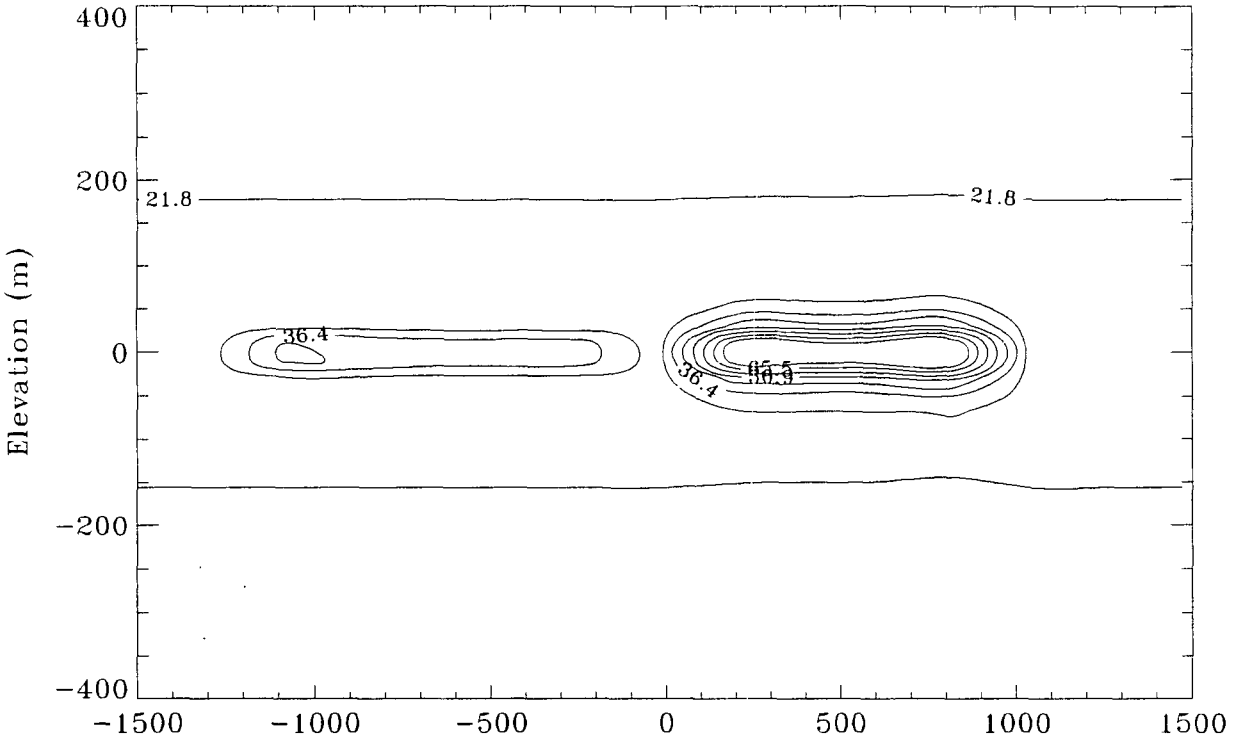
57 kW/acre

time = 400

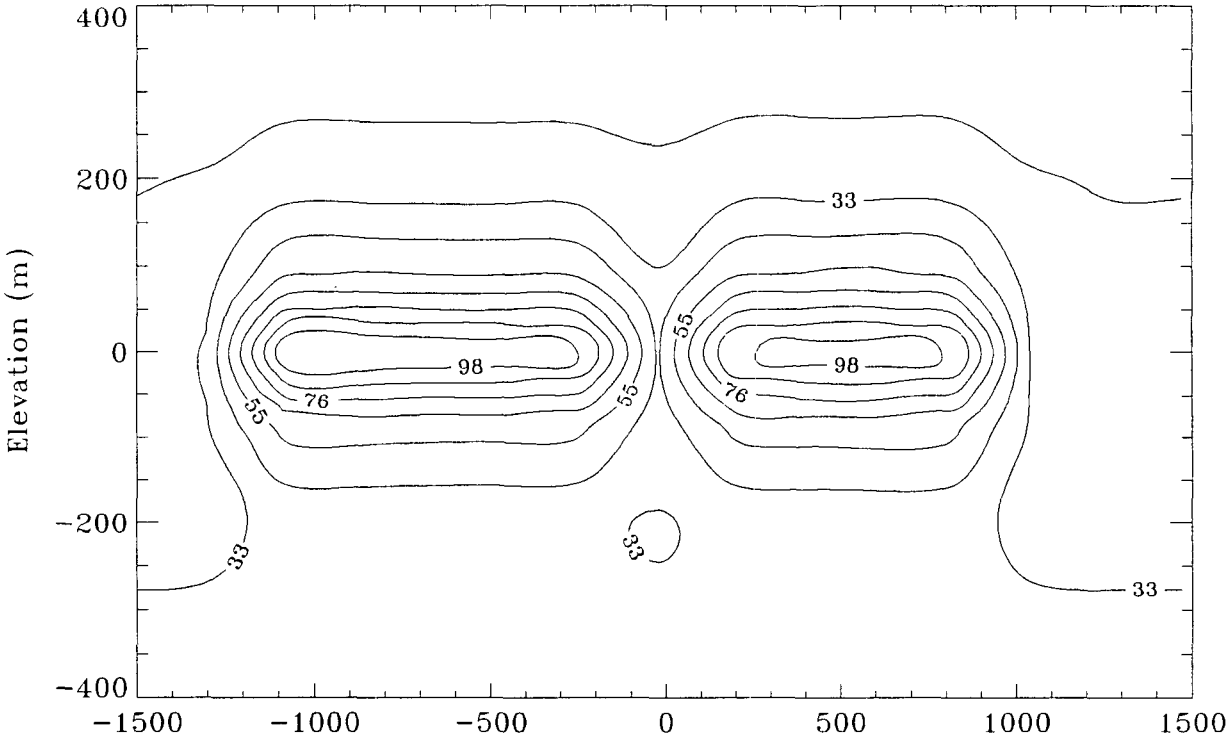


48 kW/acre
Vertical
Cross-Section

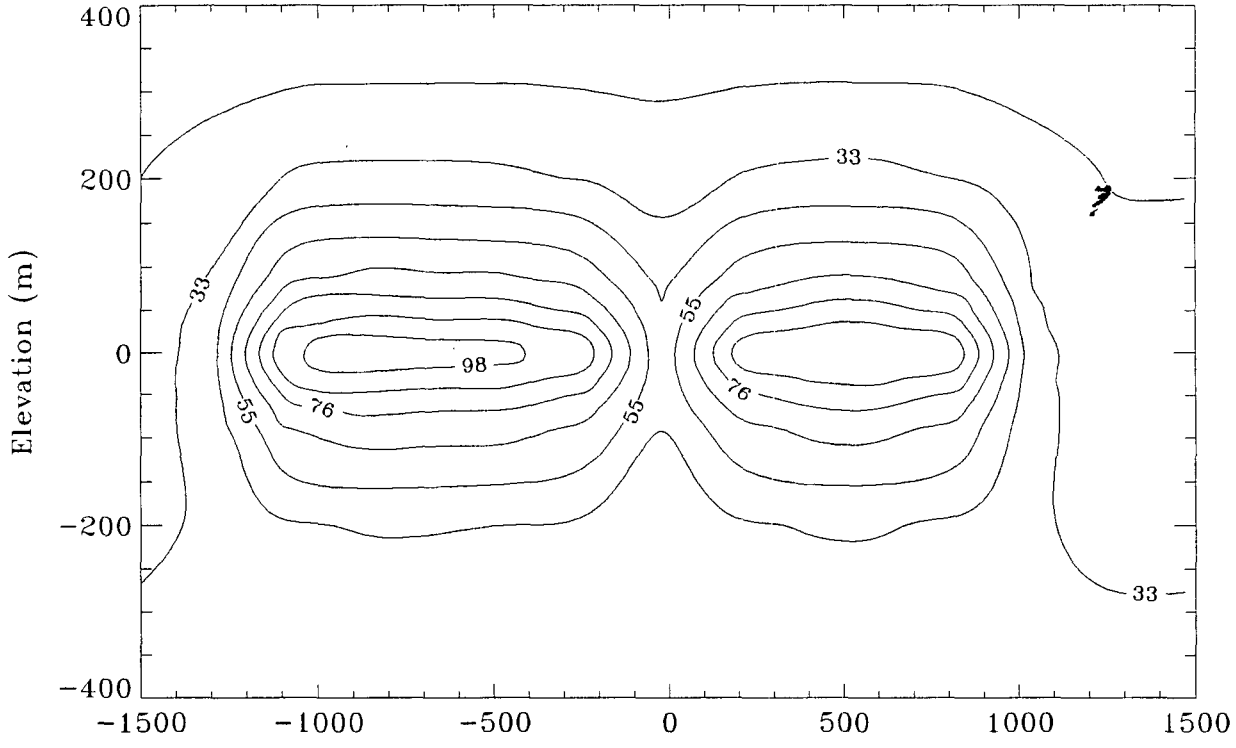
Vertical Cross-Section AA
48 kW/acre
time = 25



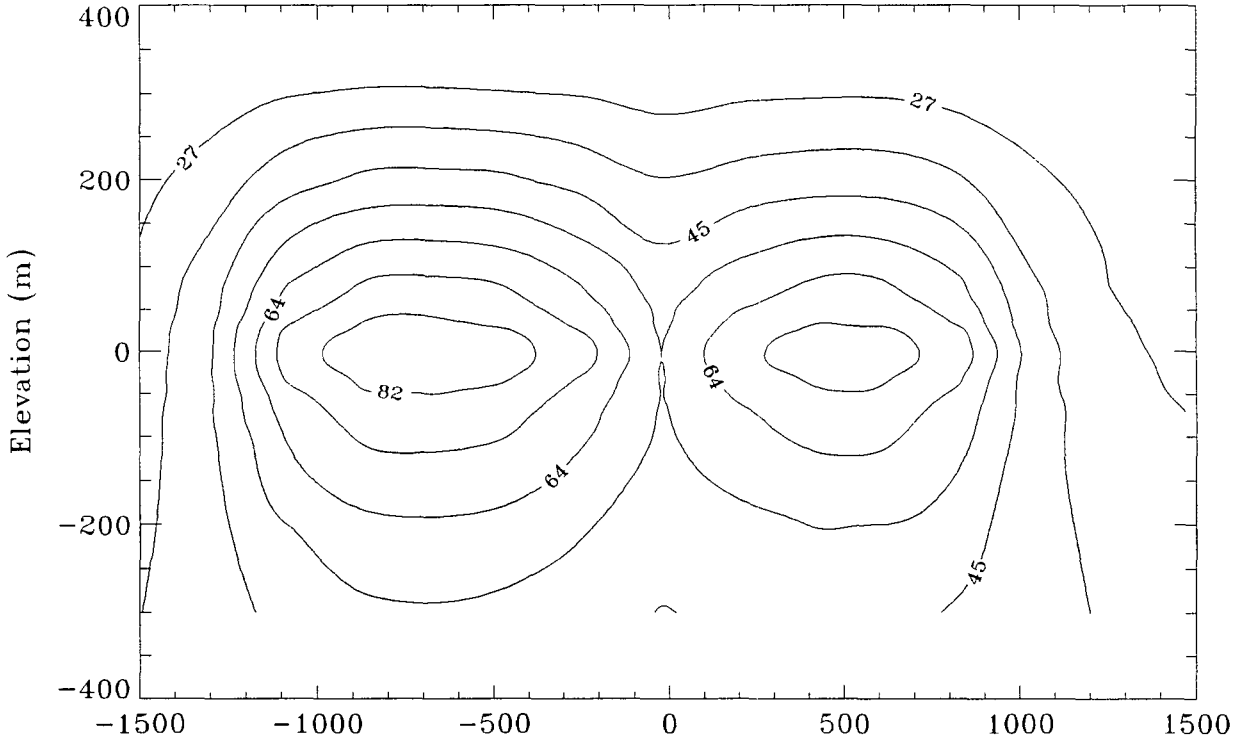
Vertical Cross-Section AA
48 kW/acre
time = 200



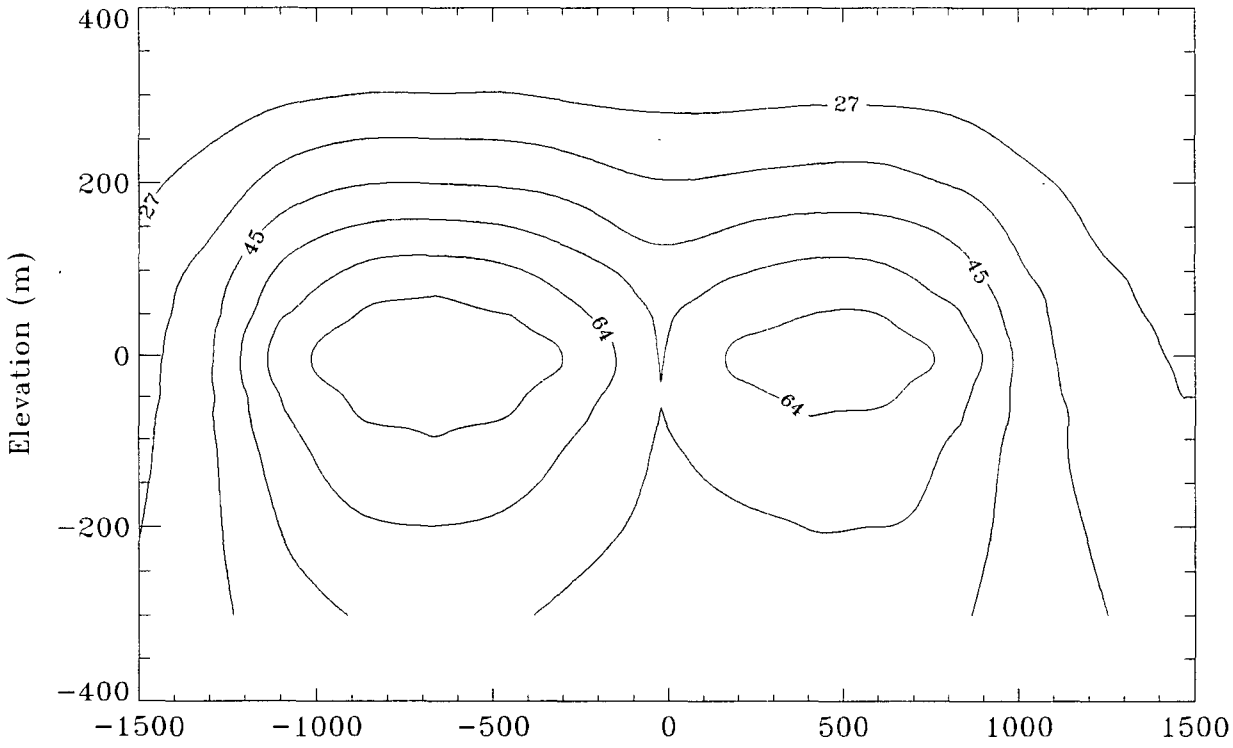
Vertical Cross-Section AA
48 kW/acre
time = 400

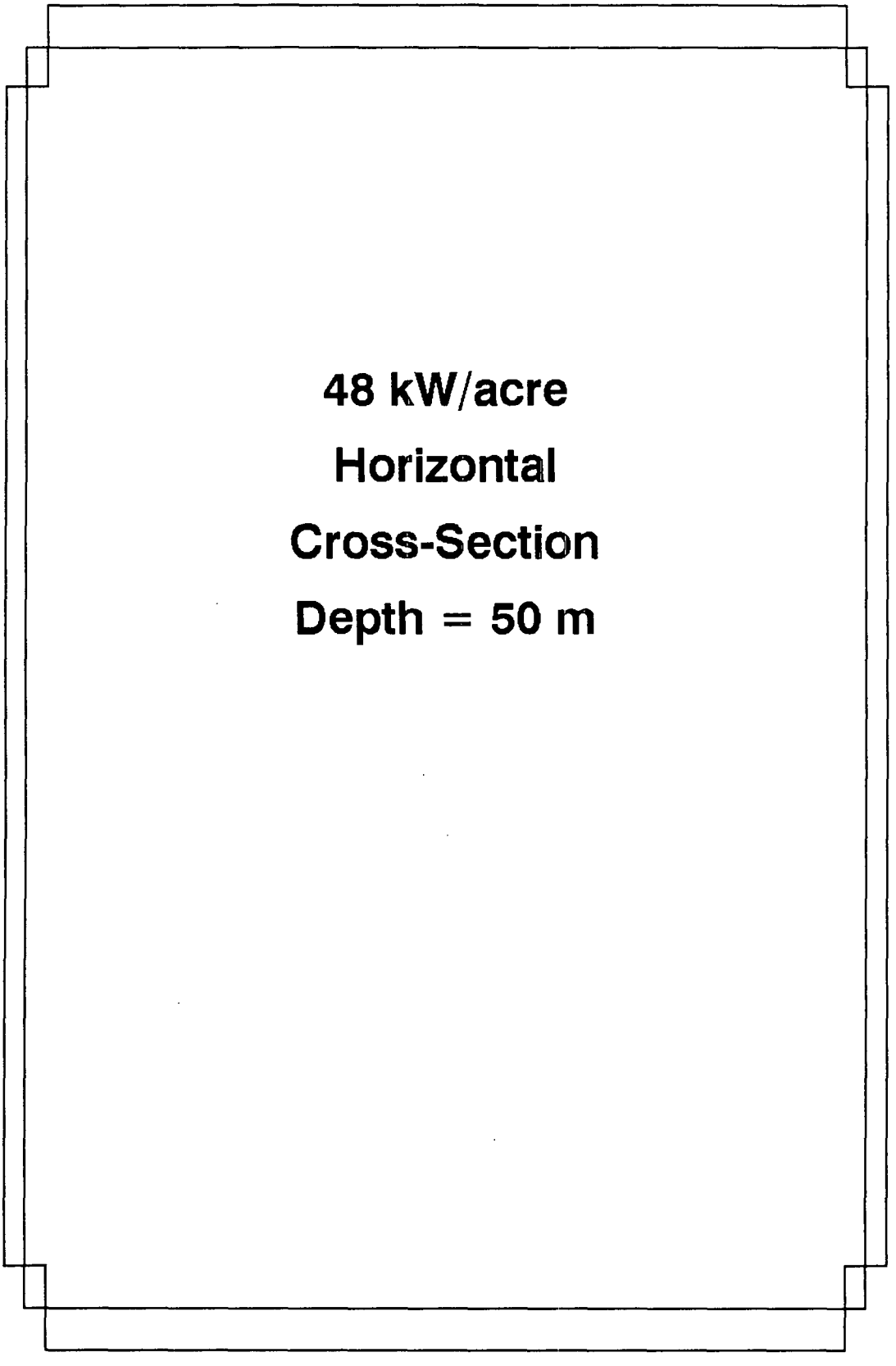


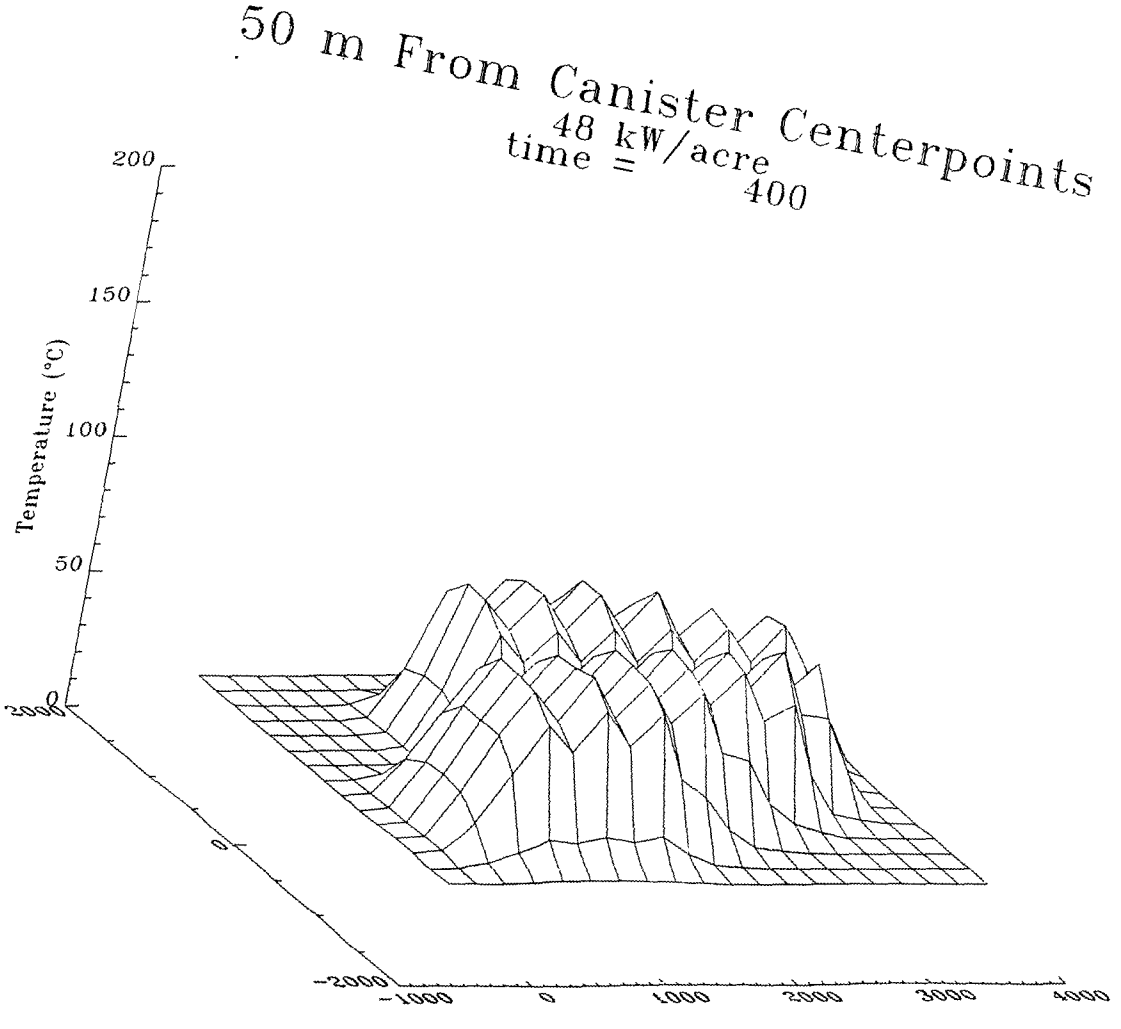
Vertical Cross-Section AA
48 kW/acre
time = 1400



Vertical Cross-Section AA
48 kW/acre
time = 2000



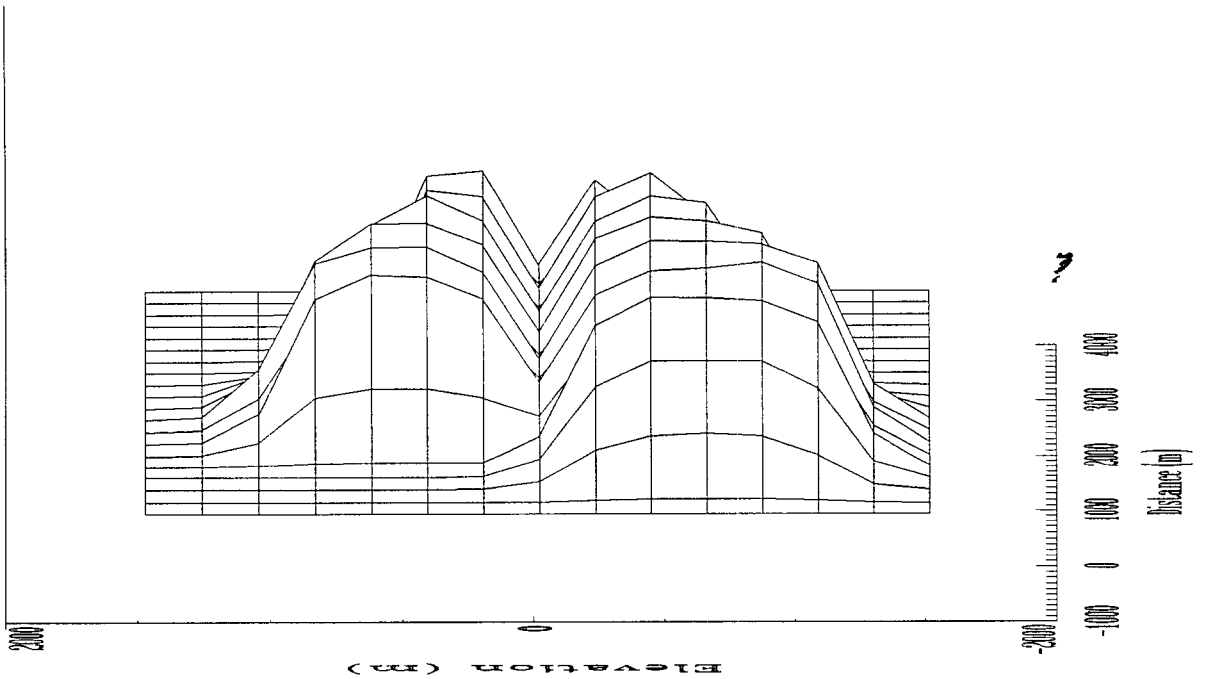

48 kW/acre
Horizontal
Cross-Section
Depth = 50 m


50 m From Canister Centerpoints
48 kW/acre
time = 400
Temperature (°C)
200
150
100
50
0
-2000
0
2000
-1000
1000
3000
4000

50 m From Canister Centerpoints

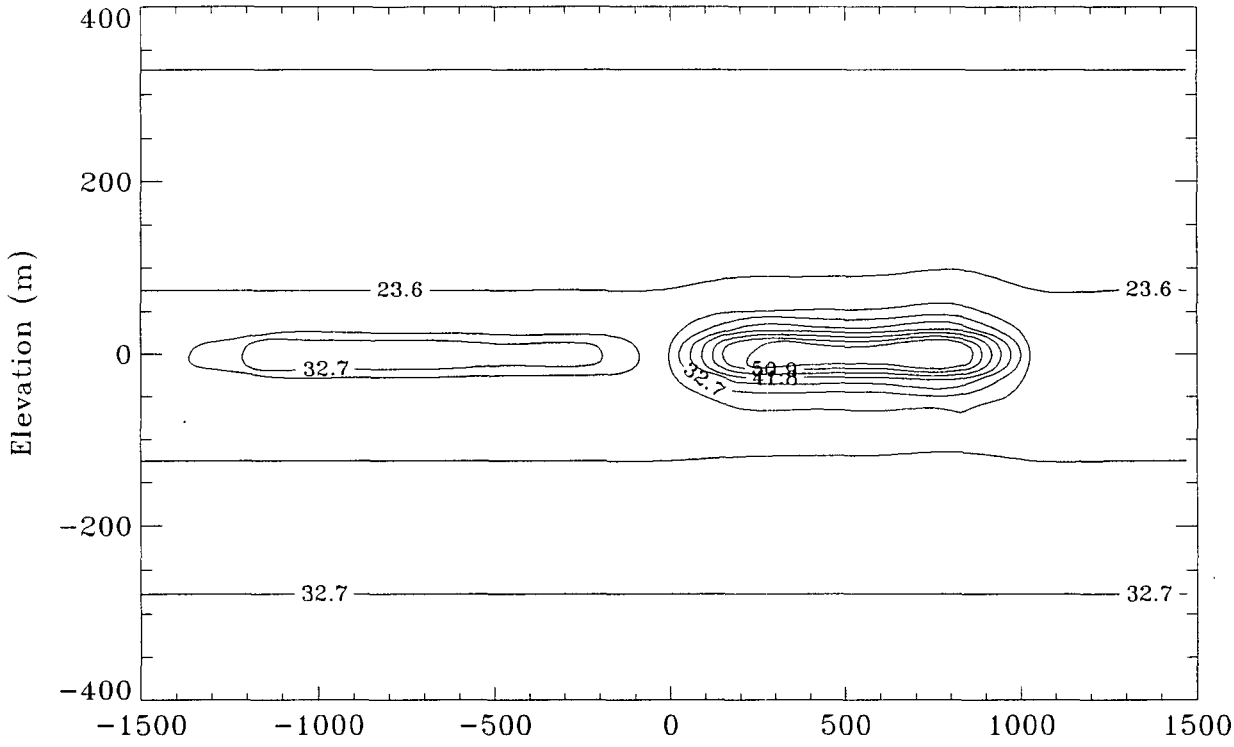
48 kW/acre

time = 400

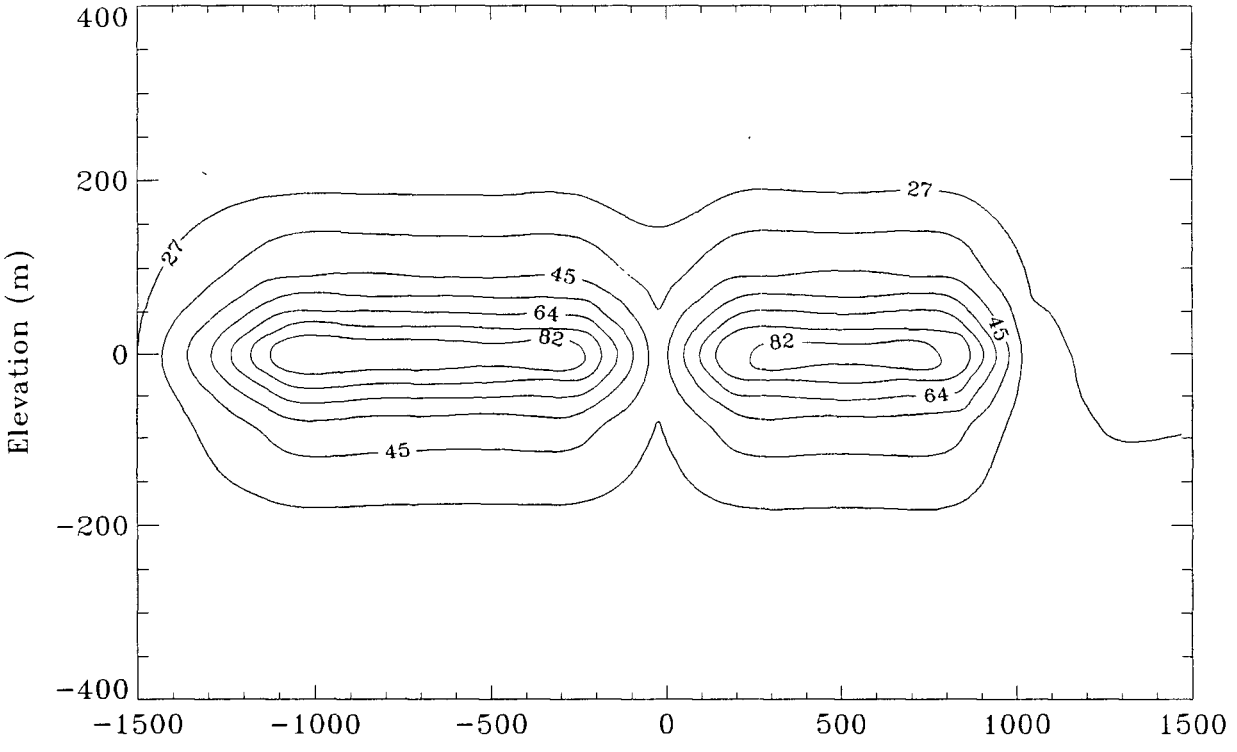


30 kW/acre
Vertical
Cross-Section

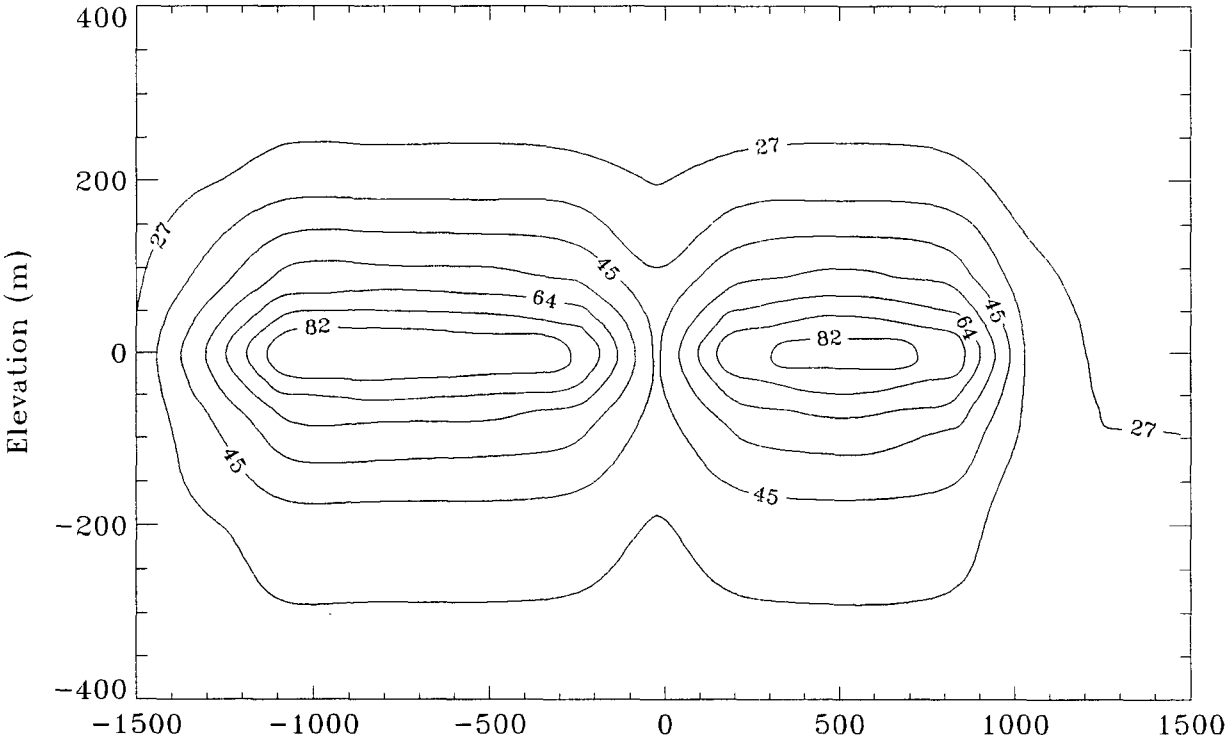
Vertical Cross-Section AA
30 kW/acre
time = 25



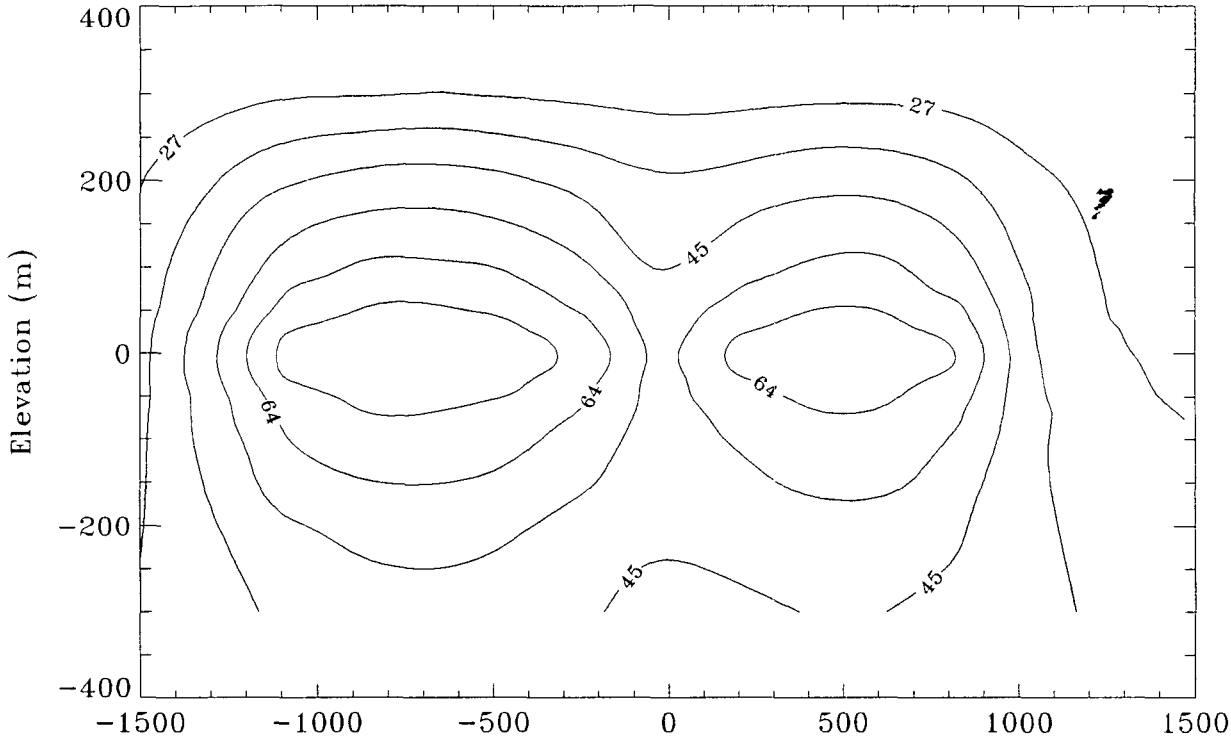
Vertical Cross-Section AA
30 kW/acre
time = 200



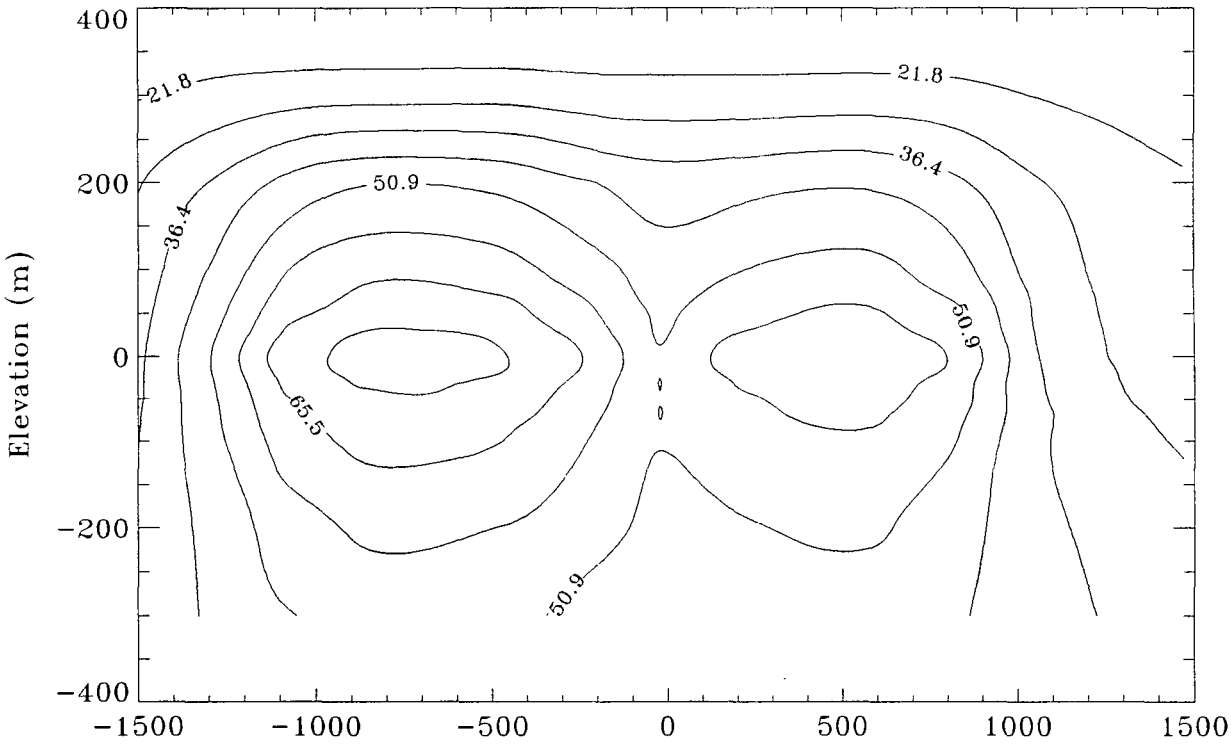
Vertical Cross-Section AA
30 kW/acre
time = 400

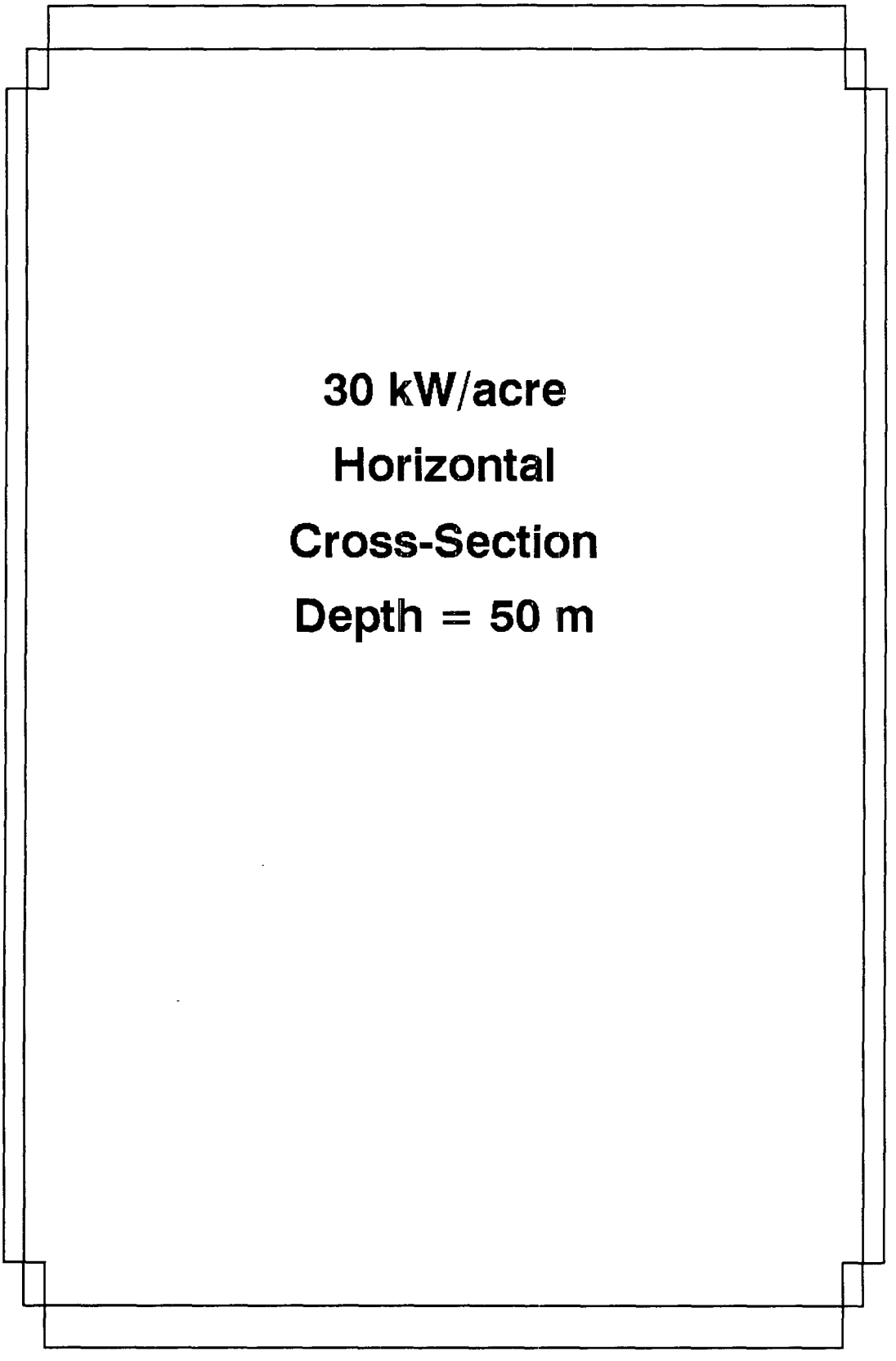


Vertical Cross-Section AA
30 kW/acre
time = 1400



Vertical Cross-Section AA
30 kW/acre
time = 2000

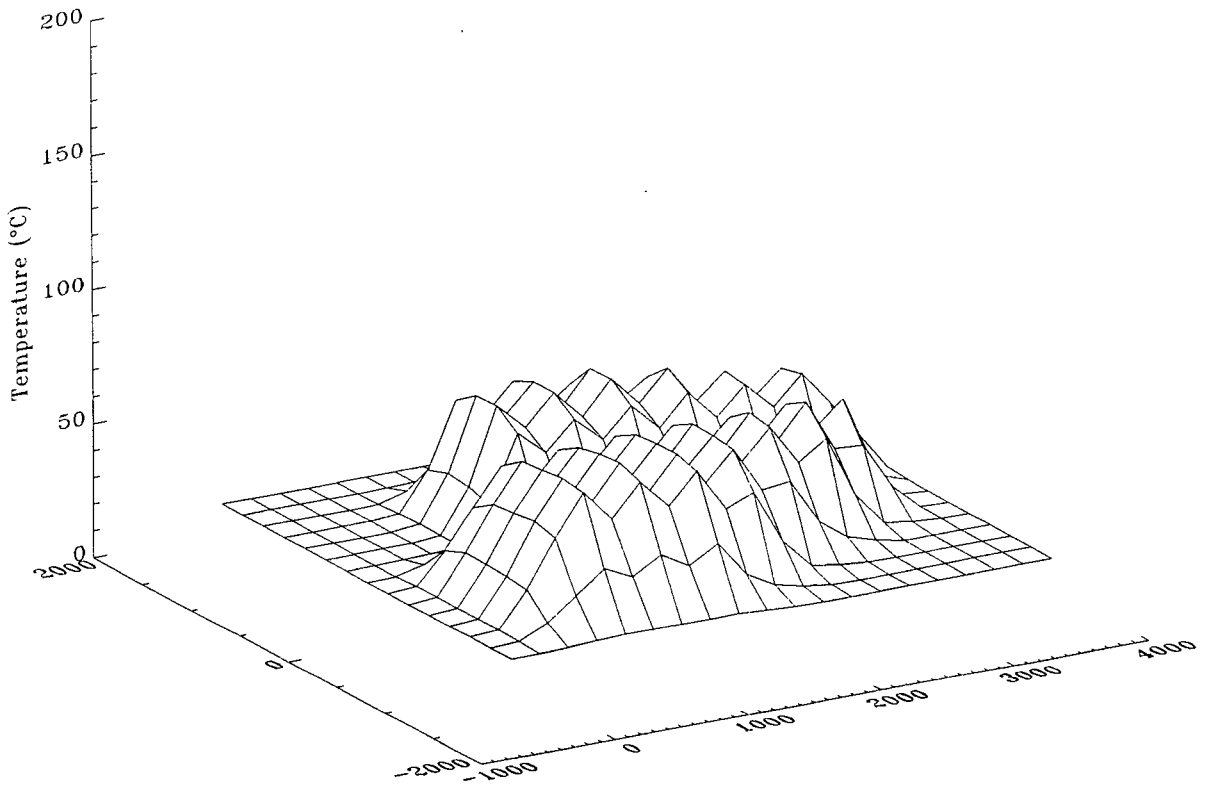



30 kW/acre
Horizontal
Cross-Section
Depth = 50 m

50 m From Canister Centerpoints

30 kW/acre

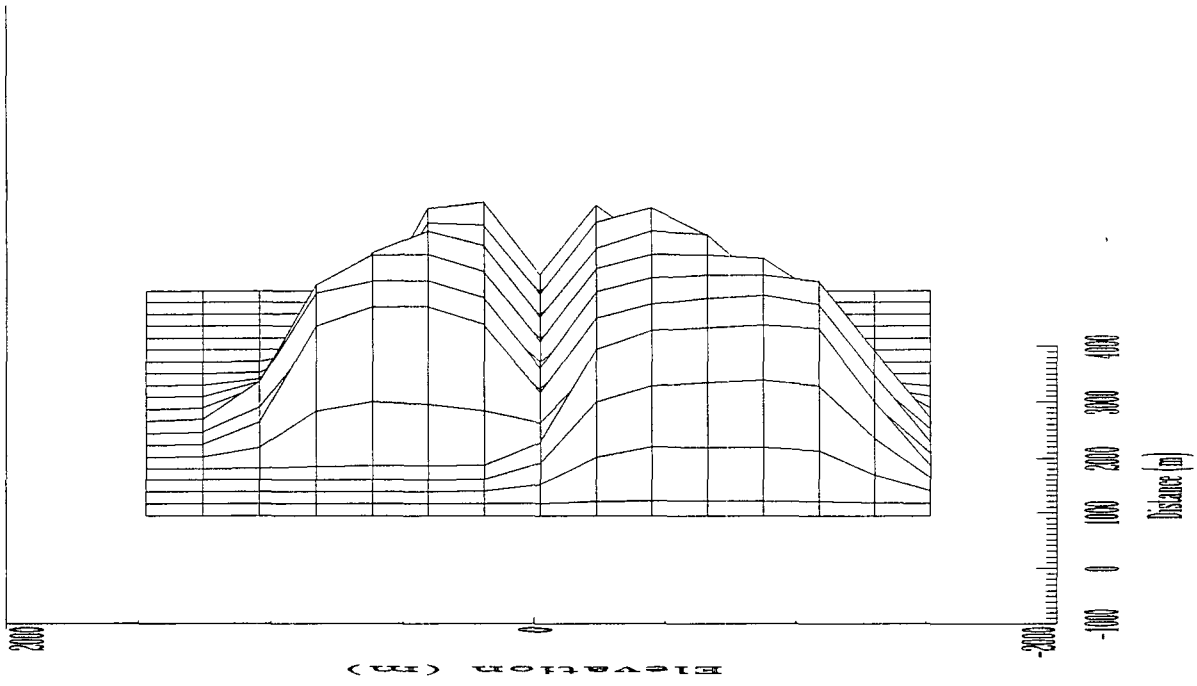
time = 400



50 m From Canister Centerpoints

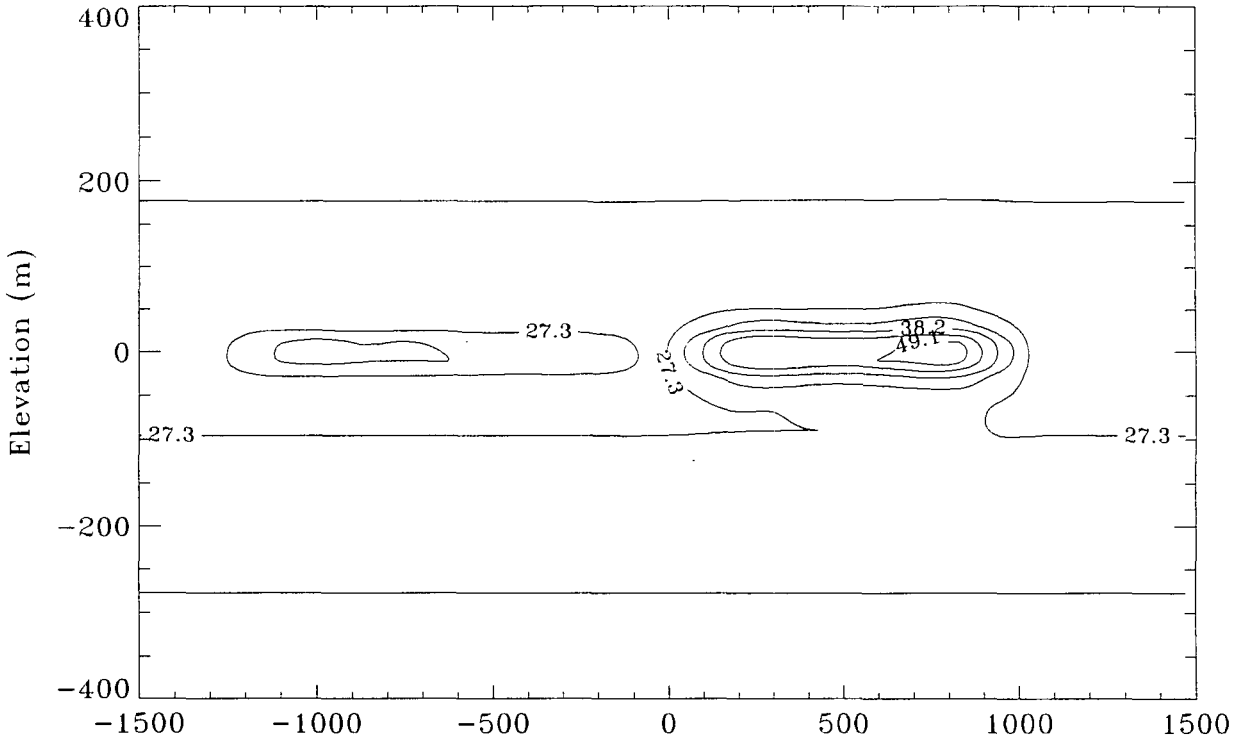
30 kW/acre

time = 400

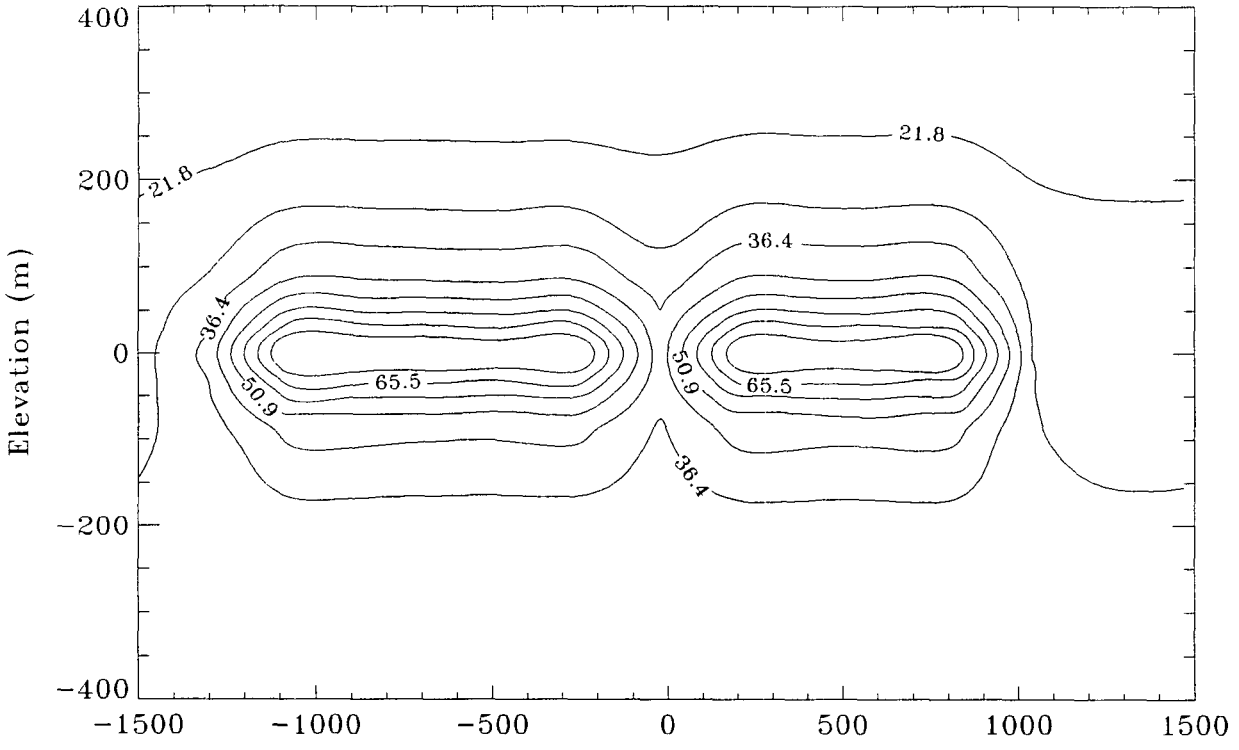


22 kW/acre
Vertical
Cross-Section

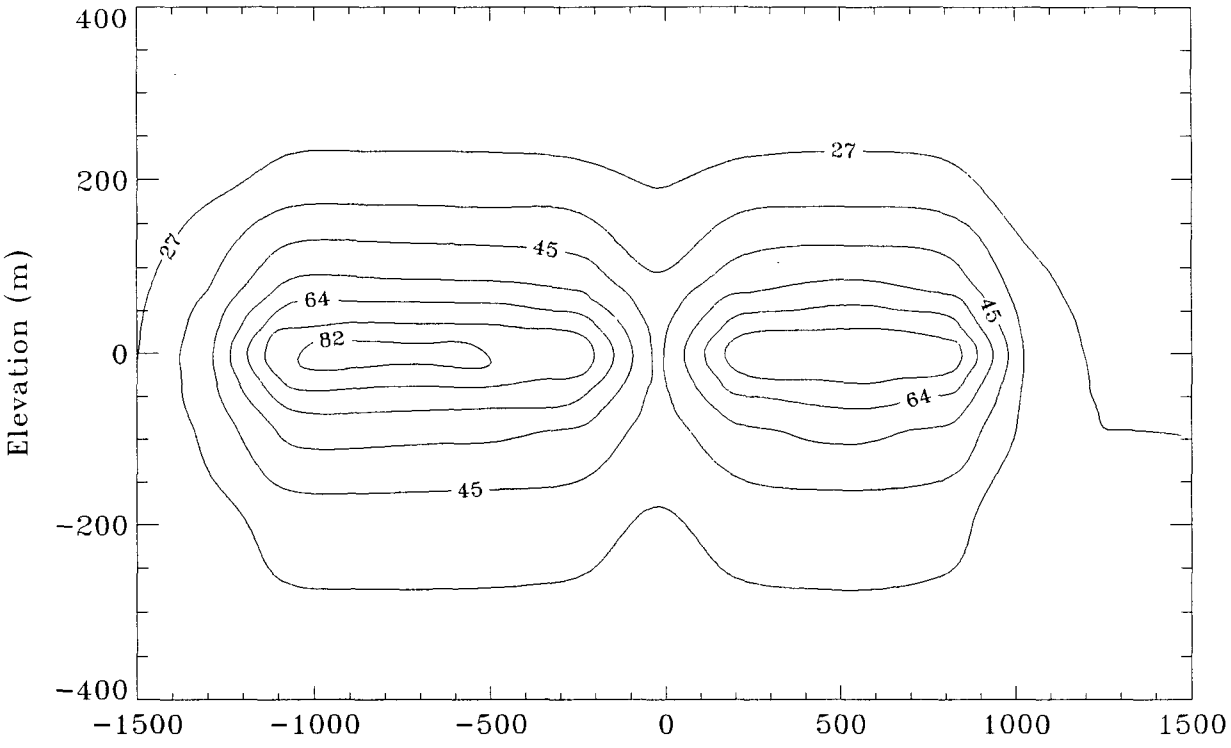
Vertical Cross-Section AA
22 kW/acre
time = 25



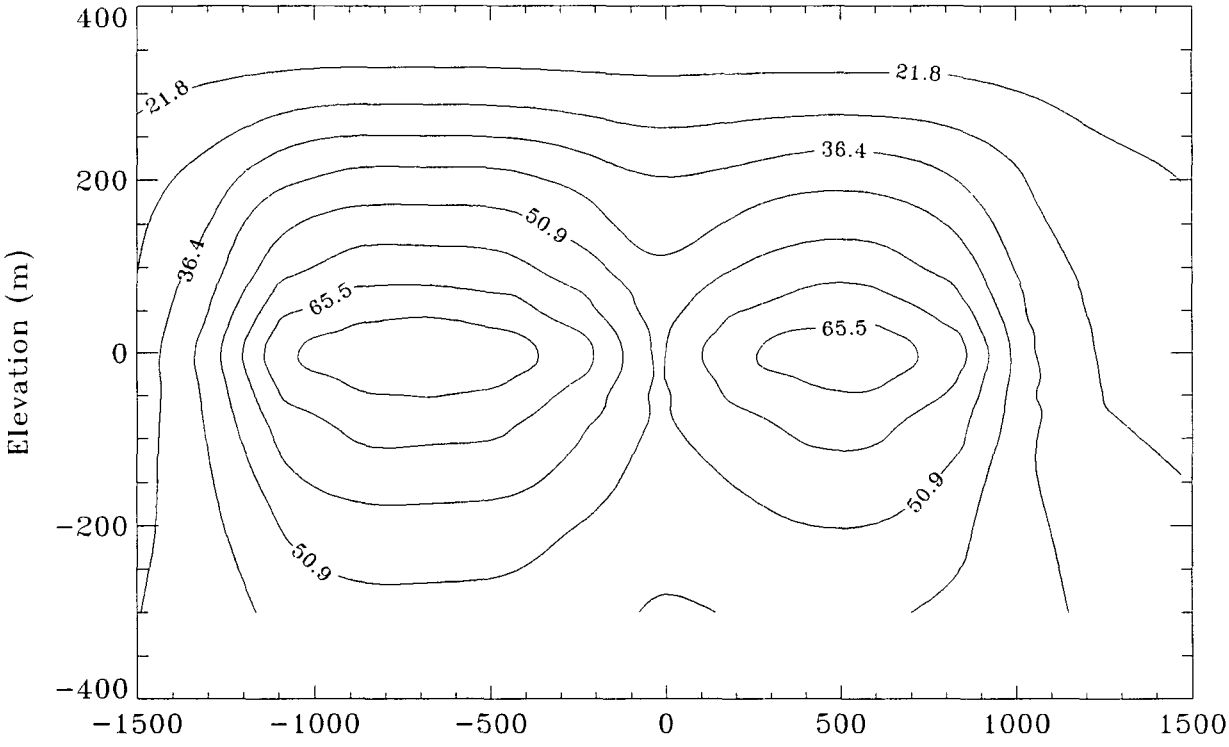
Vertical Cross-Section AA
22 kW/acre
time = 200



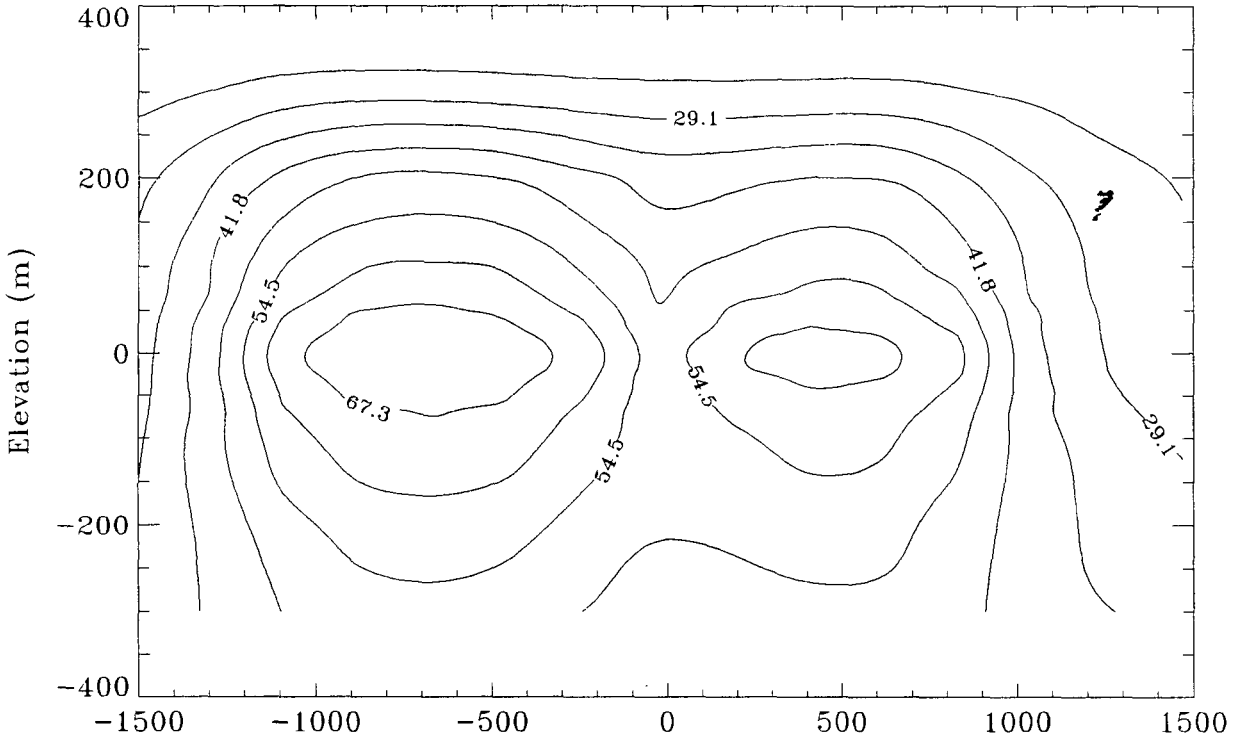
Vertical Cross-Section AA
22 kW/acre
time = 400

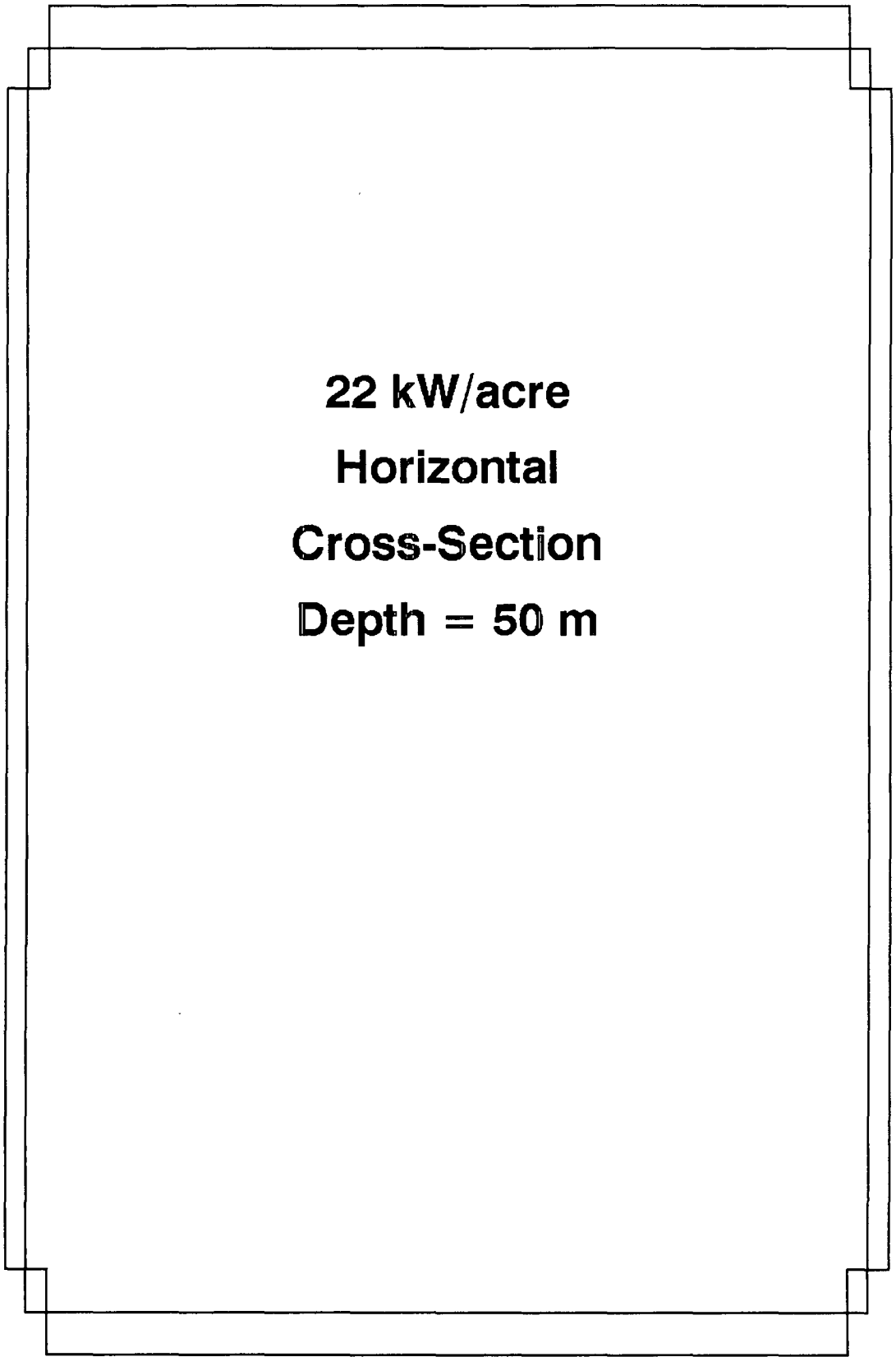


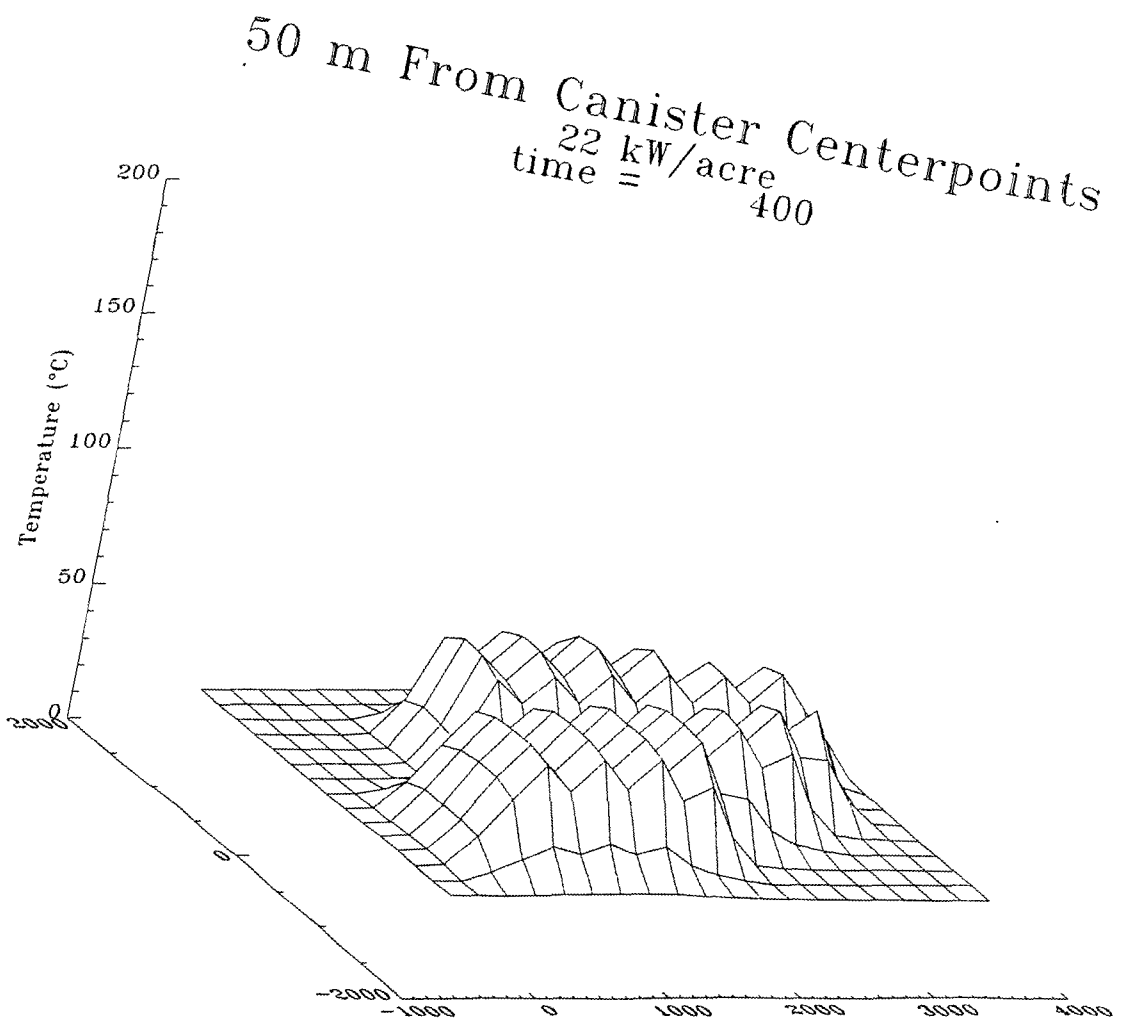
Vertical Cross-Section AA
22 kW/acre
time = 1400



Vertical Cross-Section AA
22 kW/acre
time = 2000



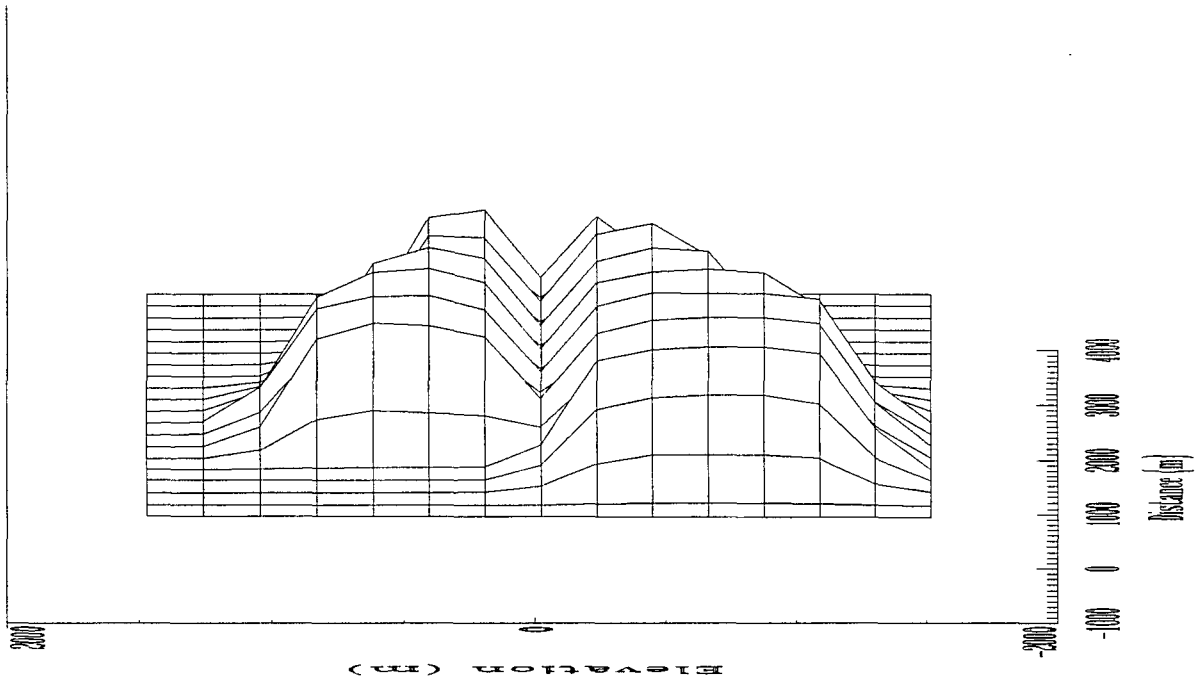

22 kW/acre
Horizontal
Cross-Section
Depth = 50 m


50 m From Canister Centerpoints
22 kW/acre
time = 400
Temperature (°C)
200
150
100
50
0
-2000
0
1000
2000
3000
4000

50 m From Canister Centerpoints

22 kW/acre

time = 400



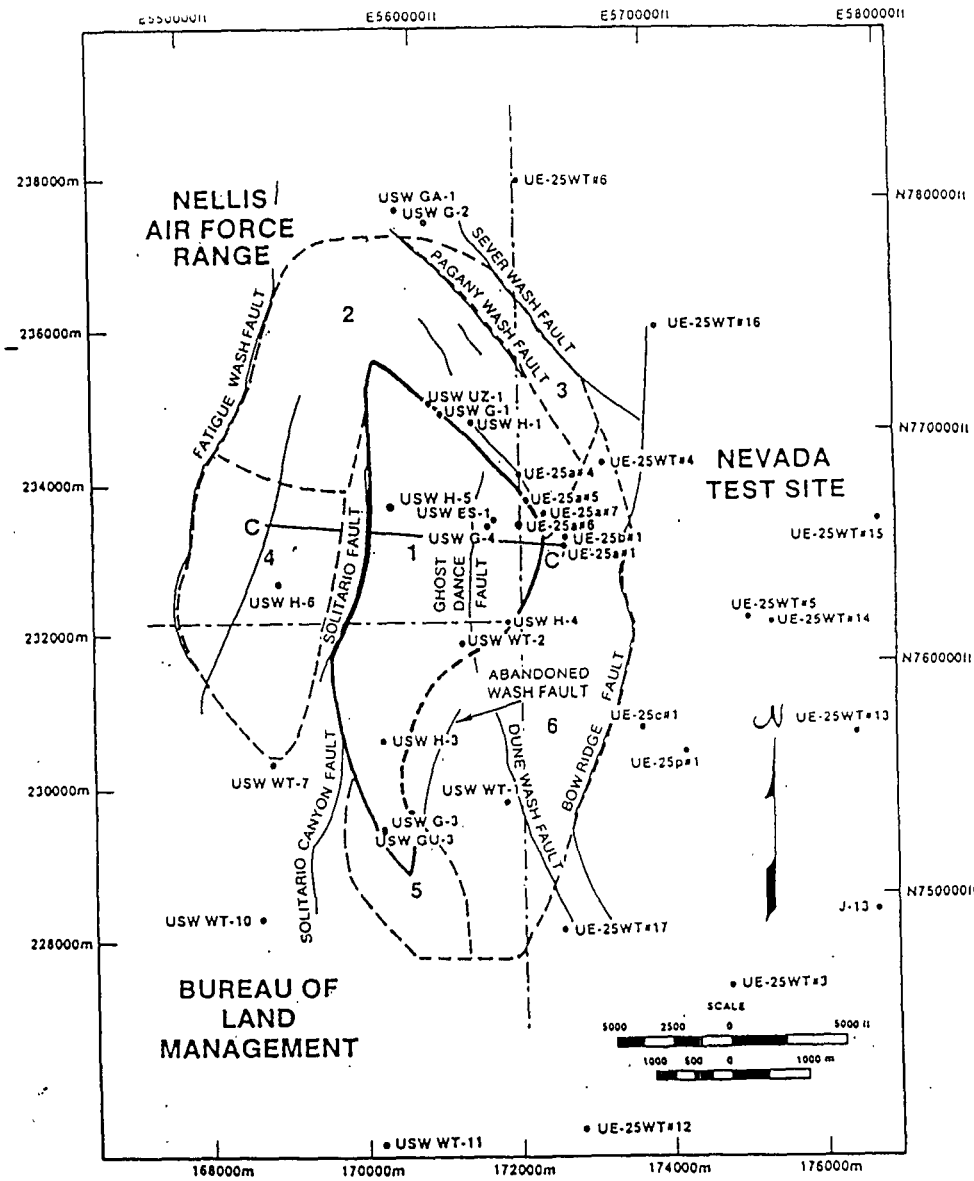
Additional Options

Increase Heated Area

Modify Ventilation System

Increase Heated Area

Available Area



Zone	Area (acres)
1	1850
2	2250
3	400
4	1500
5	500
6	2650

* SAND84-0175

Near-Field Response to Increased Heated Area

- 2010 start date
- Constant design-basis APD (unscaled) = 19 kW/acre
- Square Array:

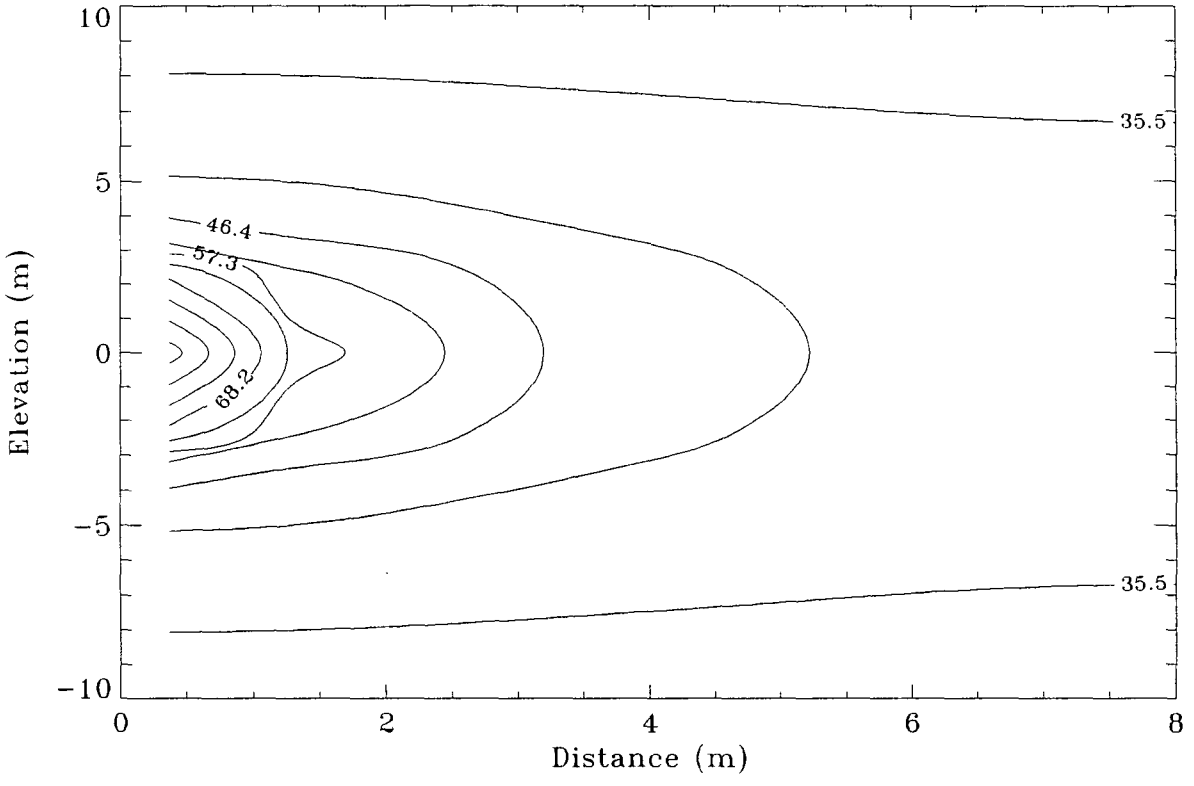
  16.3 m (53 ft) waste package spacing
  16.3 m (53 ft) drift spacing

- Average waste characteristics (Levelized receipt)

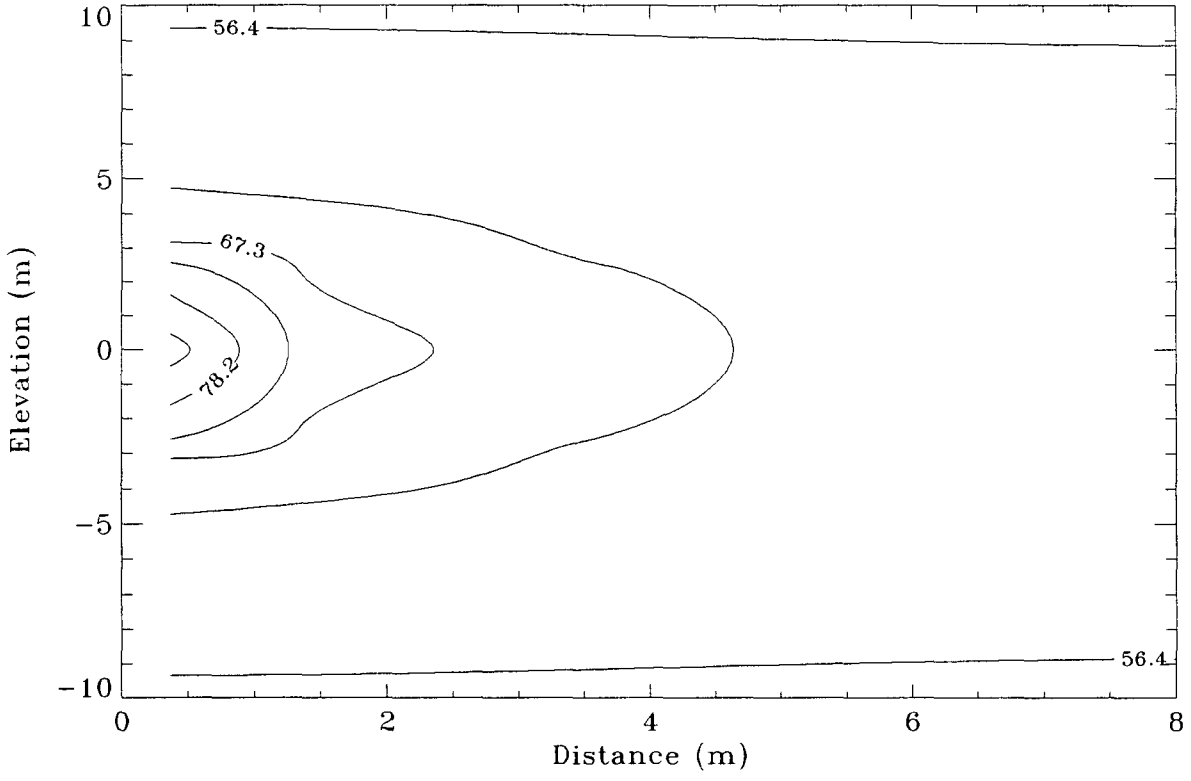
  1.52 kW/container
  30 years out-of-reactor

- Heated area requirements = 2100 acres

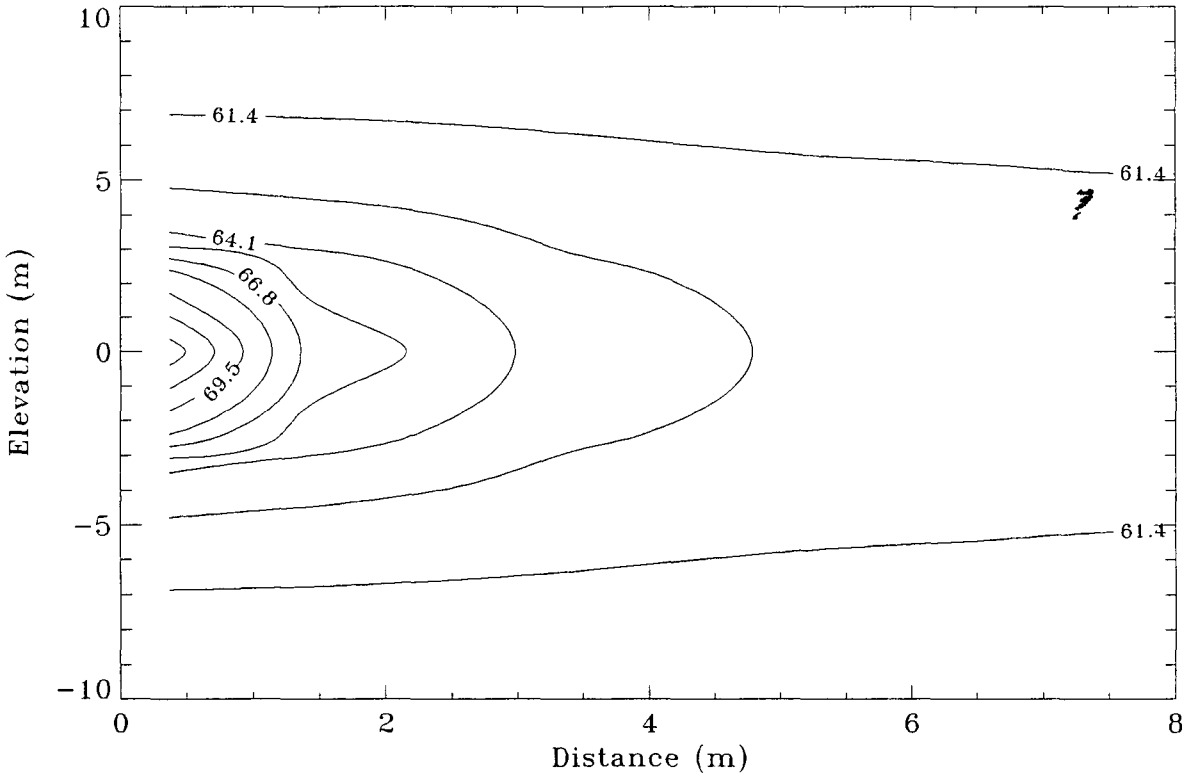
Near-Field Environment: Extended Area
19 kW/acre (unscaled)
time = 5



Near-Field Environment: Extended Area
19 kW/acre (unscaled)
time = 50



Near-Field Environment: Extended Area
19 kW/acre (unscaled)
time = 200



Modify Ventilation System

Near-Field Response to Modified Ventilation System

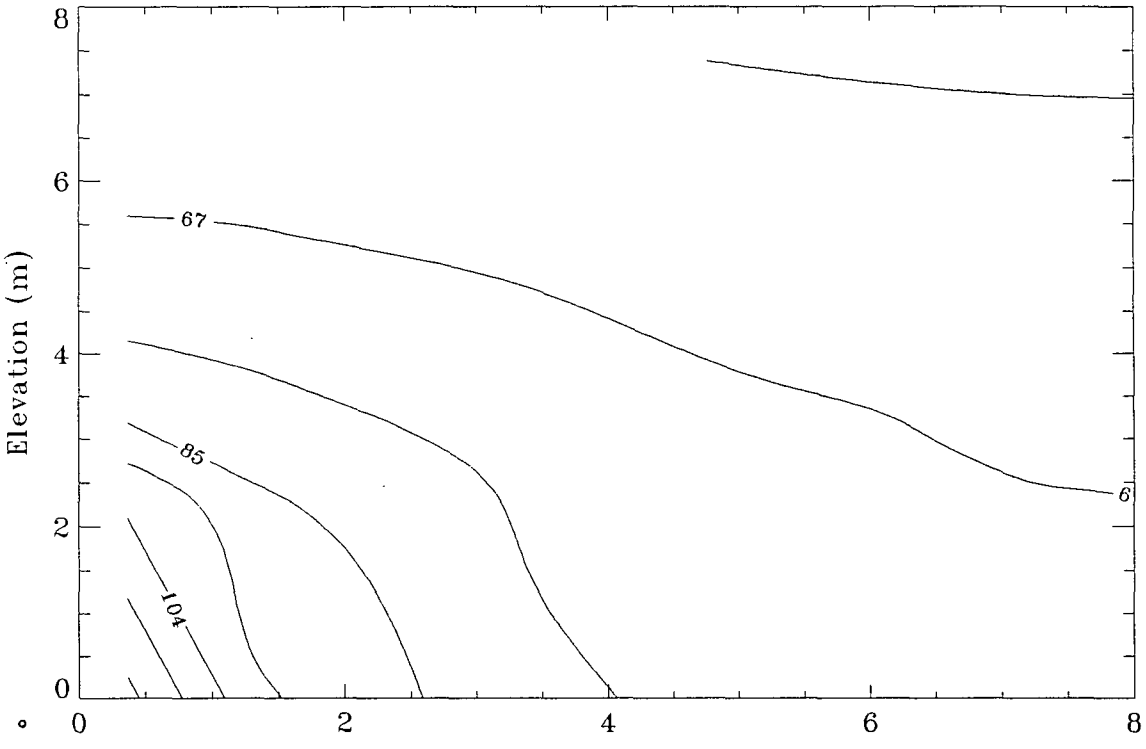
- 2010 start date
- Design-basis APD = 80 kW/acre
- Scaling done on a 300 year deposition period
- Average waste characteristics (Levelized receipt)

  1.52 kW/container
  30 years out-of-reactor
- Ventilation modeled as equivalent sink = 30 kW
- Three cases:

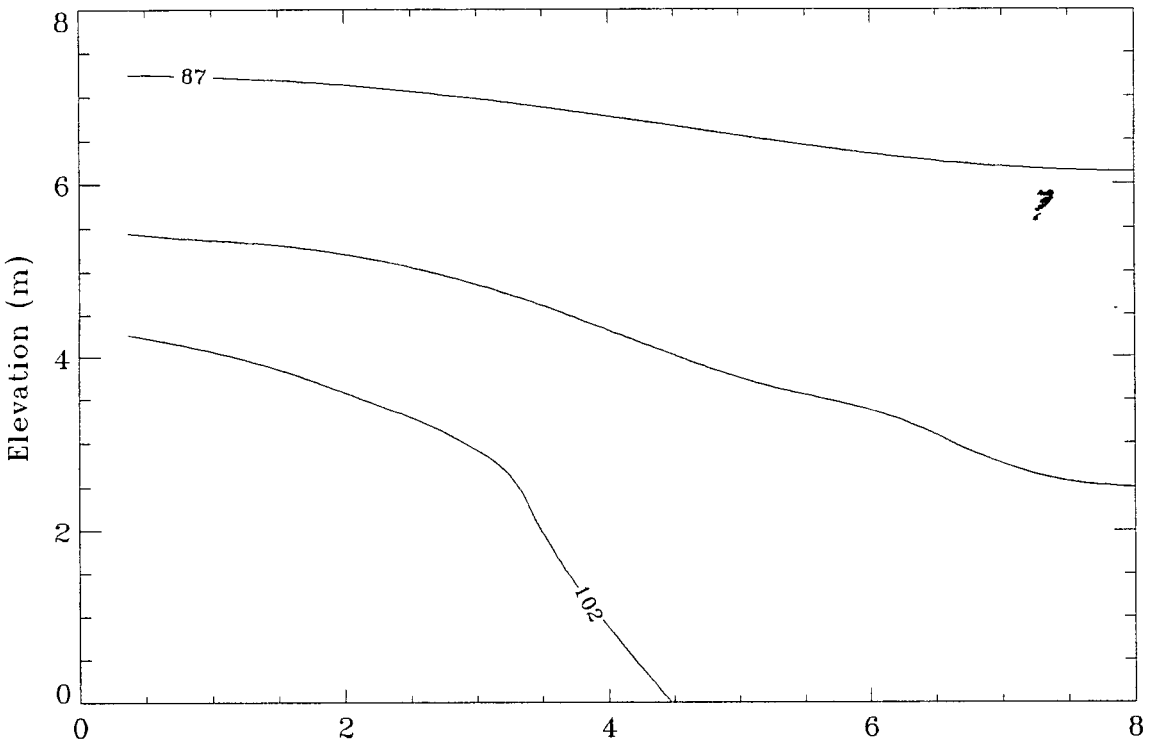
  1. Unvented
  2. Vented for 5 years
  3. Vented for 10 years

Case I: Unvented

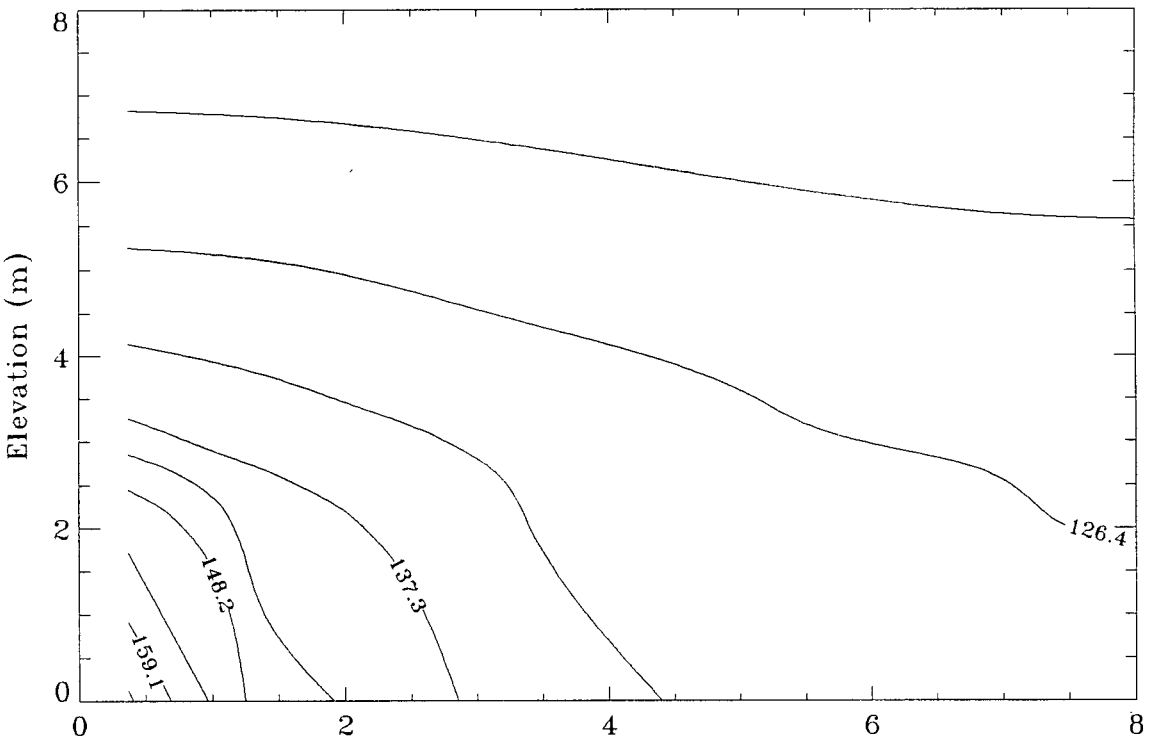
Near-Field Environment
80 kW/acre (unvented)
time = 5



Near-Field Environment
80 kW/acre (unvented)
time = 12

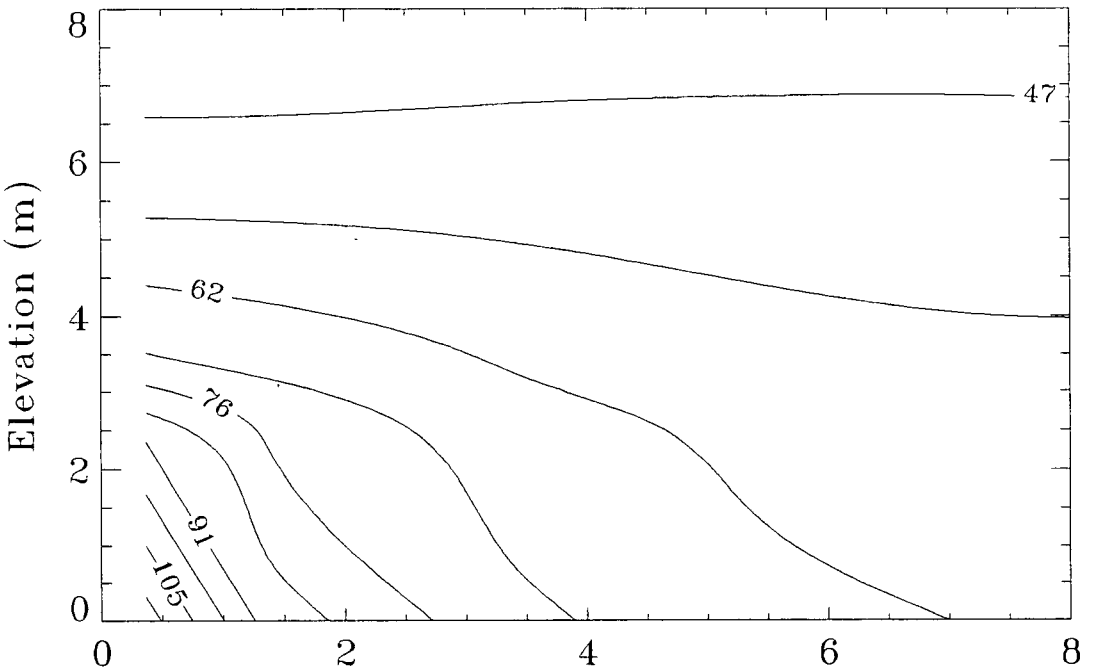


Near-Field Environment
80 kW/acre (unvented)
time = 30

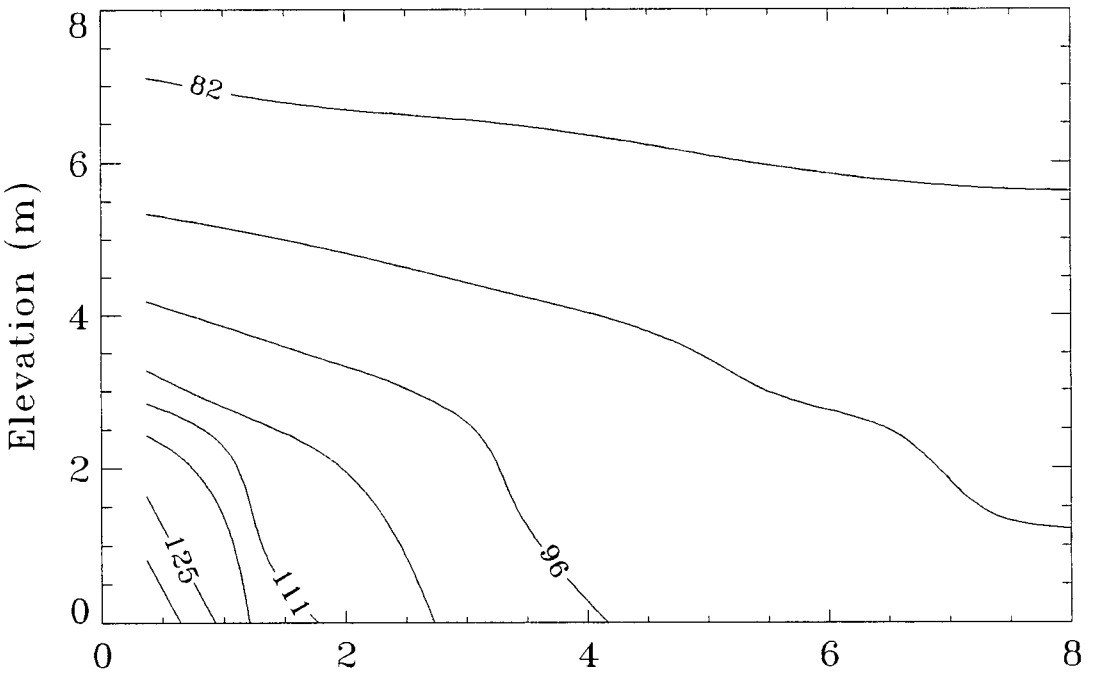


Case II: Vented 5 Years

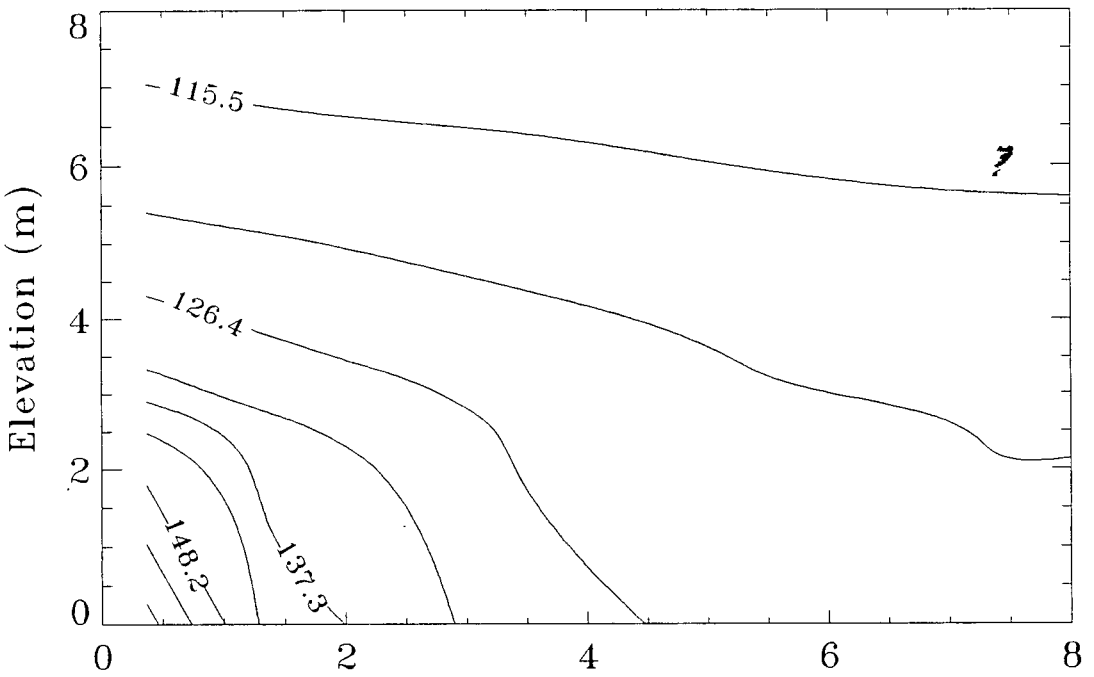
Near-Field Environment
80 kW/acre (vented 5 yrs)
time = 5



Near-Field Environment
80 kW/acre (vented 5 yrs)
time = 12

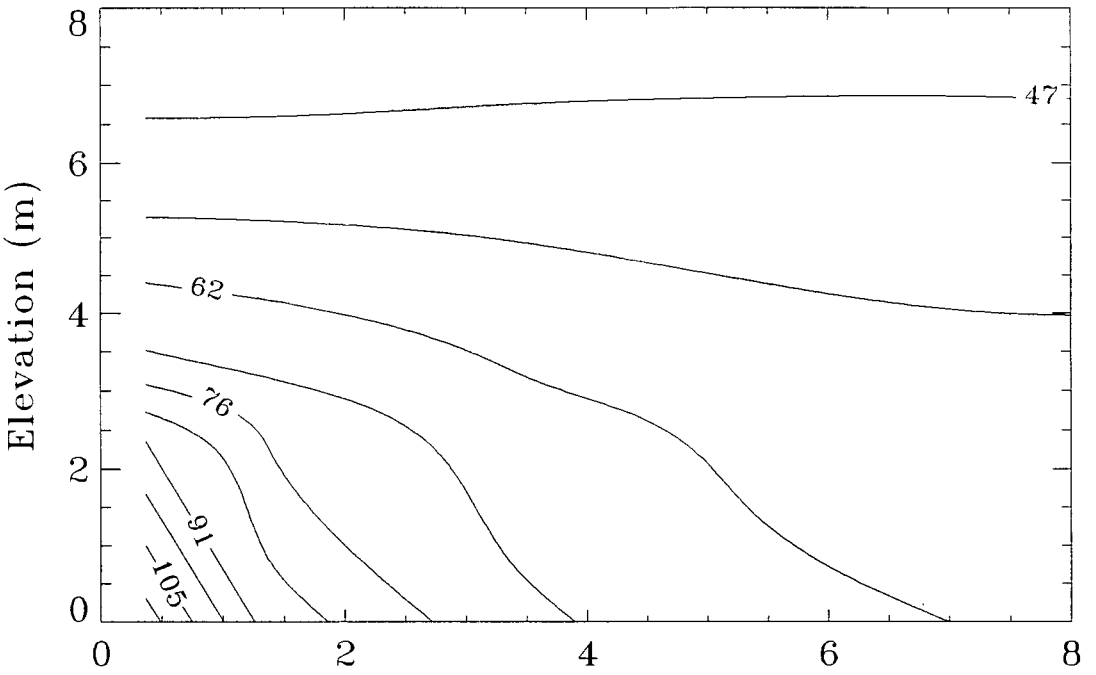


Near-Field Environment
80 kW/acre (vented 5 yrs)
time = 30

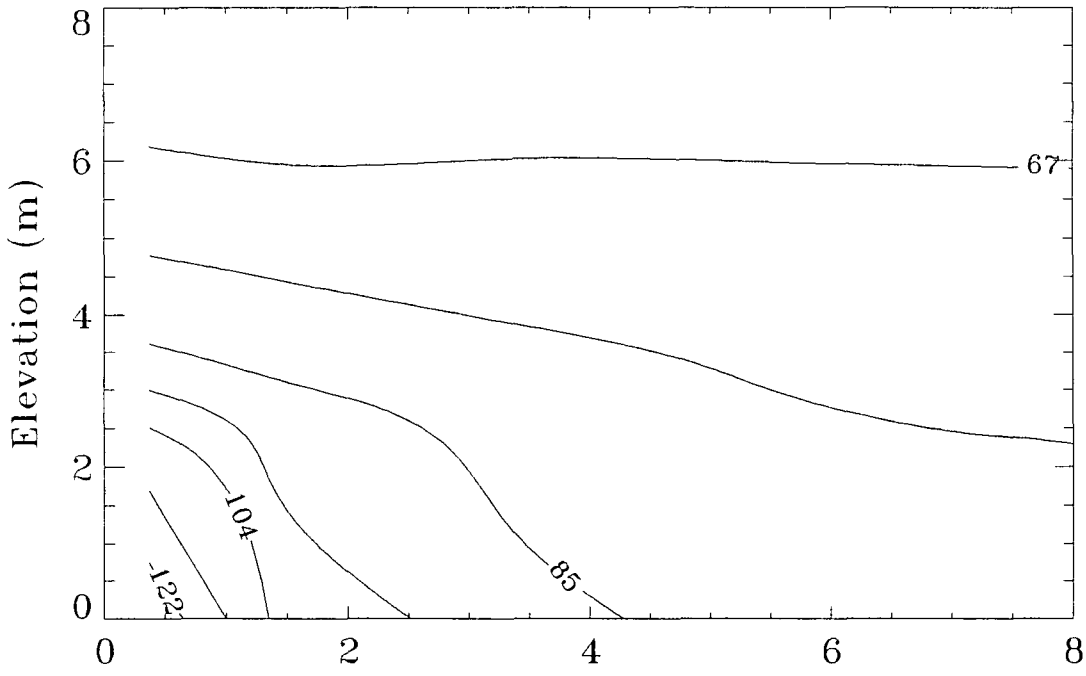


Case III: Vented 10 Years

Near-Field Environment
80 kW/acre (vented 10 yrs)
time = 5



Near-Field Environment
80 kW/acre (vented 10 yrs)
time = 12



Near-Field Environment
80 kW/acre (vented 10 yrs)
time = 30