SAND 86 - 7005

TABLE 1

GEOMETRIC DATA FOR VERTICAL EMPLACEMENT OPTION

	Design Analyzed (ft)		Conceptual Design[d] (ft)
Drift Dimension			
Width	16.0[a]	(4.88m)	16.0
Height	22.0[a]	(6.71m)	22.0
Radius of Roof Arch	9.0[b]	(2.74m)	9.5[e]
Container Borehole Dimensions			
Depth	25.00[a]	(7.62m)	25.0
Diameter	2.42[a]	(0.74m)	2.42
Panel Dimensions			
Waste Standoff from Access Drift Wall	77.5[a]	(23.62m)	92.5
Access Drift Width	21.0[a]	(6.40m)	21.0
Emplacement Drift Spacing	112.0[c]	(34.14m)	126.0
Barrier Pillar Width	63.0[a]	(19.20m)	63.0
Panel Width	1400.0[a]	(426.72m)	1400.0

Source references:

[a]Mansure and Stinebaugh (1985).
[b]Parsons, Brinckerhoff, Quade and Douglas (1985).
[c]Mansure and Ortiz (1984).
[d]MacDougall (1986) - Spent Fuel Emplacement
[e]Parsons, Brinckerhoff, Quade and Douglas (1986).

TABLE 2

GEOMETRIC DATA FOR HORIZONTAL EMPLACEMENT OPTION

	Design Analyzed (ft)		Conceptual Design[d] (ft)	
Drift Dimension				
Width	18.0[a]	(5.49m)	23.0	
Height	13.0[a]	(3.96m)	13.0	
Radius of Roof Arch	10.2[b]	(3.11m)	14.0	
Container Borehole Dimensions				
Waste Standoff from Emplacement Drift Centerline	117.50[a]	(35.81m)	145.5[e]	44
Length	682.00[a]	(207.87m)	363.0	111
Diameter	2.75[a]	(0.84m)	2.5	
Panel Dimensions				
Panel Width	1400.0[a]	(426.72m)	1400.0	
Panel Depth	985.0[c]	(300.23m)	748.0	

Source references:

[a]Mansure and Stinebaugh (1985).
[b]Parsons, Brinckerhoff, Quade and Douglas (1985).
[c]Mansure and Ortiz (1984).
[d]MacDougall (1986) - Spent Fuel Emplacement
[e]Parsons, Brinckerhoff, Quade and Douglas (1986).

TABLE 3

DATA FOR THERMAL AND THERMAL/MECHANICAL ANALYSES OF EMPLACEMENT DRIFTS

Property	Value
Rock Mass	
Specific Gravity[a]	2.34 g/cc
Young's Modulus[a]	15.1 GPa
Poisson's Ratio[a]	0.2
Thermal Conductivity[a] (25 to 100 deg. C temp range)	2.07 W/m·K
Thermal Capacitance[a]	2.25 J/cm^3 K
Thermal Expansion[a] (*10^6) (25 to 200 deg. C temp range)	10.7C°$^{-1}$
Horiz./Vert. In situ Stress[b]	0.55
Ground Surface Temperature[c]	16.0°C
Temperature Gradient[d]	0.0239°C/m
Rock Matrix[a]	
Unconfined Compressive Strength of Rock	75.4 MPa
Tensile Strength	-9.0 MPa
Angle of Internal Friction	29.2°
Joints[a]	
Joint Cohesion	1.0 MPa
Joint Coefficient of Friction	0.8 (38.7°)
Joint Angle (Frequently Assumed Value)	90° (Vertical)

References:

[a]Nimick et al. (1984).
[b]Bauer, Holland and Parrish (1985)
[c]Eglinton and Dreicer (1984).
[d]Sass and Lachenbruch (1982).

TABLE 4

NORMALIZED COEFFICIENTS FOR THE POWER DECAY FUNCTION FOR PWR AND BWR SPENT FUEL MIX

Exponential Components	Normalized Strength, a_i $t^a = 0$ yr	Normalized Strength, a_i $t = 8.55$ yr	Time Exponent, b_i (yr^{-1})
1	0.03120	0.15602	0.00135
2	0.13920	0.59787	0.01914
3	0.04920	0.15227	0.05188
4	0.78270	0.09384	0.43768

[a]Time, t, is given with respect to time of removal of spent fuel from the reactor.

TABLE 5

RESULTS OF PRELIMINARY ANALYSES OF THE HORIZONTAL EMPLACEMENT OPTION--DATA FOR 100 YR AFTER EMPLACEMENT

Description of Model	Number of Sources in Half Model	Free Surface Condition	Temp. at Panel Center (°C)[b]	Total Initial Stress Horizontal (MPa)	Total Initial Stress Vertical (MPa)
Single Panel	35	None	35.89	12.21	5.81
		Isothermal Only	35.89	12.49	5.52
		Free (1,000 m[a])	35.89	11.90	5.07
		Free (2,000 m)	35.89	11.86	5.07
Extended Panel	12	None	34.11	13.38	4.27
		Isothermal Only	34.11	13.83	3.38
		Free (1,000 m)	34.11	12.77	3.30
Three Panels	35 + 10	None	35.95	13.94	4.08
		Isothermal Only	35.95	14.40	3.63
		Free (1,000 m)	35.95	13.25	3.25
		Free (2,000 m)	35.95	13.05	3.24

[a]The lengths specified here refer to the extent of the boundary elements used to model the ground surface above the repository, measured from the repository centerline.
[b]Ambient Temperature = 23.2°C

TABLE 6

THERMAL ANALYSES PERFORMED USING THE DOT COMPUTER CODE

Time (Yr)	Time Steps (Yr)	Number of Steps	Time Increment For Power Decay Function[a] (Yr)
VERTICAL EMPLACEMENT			
	UNVENTILATED		
0-10	0.005	2,000	0.10
10-35	0.010	2,500	0.35
35-100	0.065	1,000	1.00
	VENTILATED		
0-1	0.0010	1,000	0.1
1-10	0.0025	3,600	1.0
10-35	0.0100	2,500	3.5
35-100	0.0500	1,300	1.0
HORIZONTAL EMPLACEMENT			
	UNVENTILATED		
0-10	0.010	1,000	0.10
10-35	0.025	1,000	0.35
35-100	0.065	1,000	1.00
	VENTILATED		
0-10	0.0100	1,000	0.10
10-35	0.0250	1,000	0.35
35-100	0.0650	1,000	1.00

[a]The power decay function describing the strength of the heat sources has been tabulated for various times. The strength at any particular time between the tabulation times is determined by interpolating linearly within the appropriate time increment.

TABLE 7

RESULTS OF THERMAL ANALYSES OF UNVENTILATED VERTICAL EMPLACEMENT DRIFT USING ALTERNATIVE EFFECTIVE THERMAL CONDUCTIVITIES

Effective Thermal Conductivity W/m.K	Drift Perimeter Temperatures 10 Yr After Waste Emplacement[a]		
	Crown (°C)	Midfloor (°C)	Midwall (°C)
25	72.2	77.0	74.7
50	73.4	75.9	74.7
100	73.9	75.2	74.6

[a] The tabulated values of temperature were obtained by performing analyses, using the DOT code. For each analysis 2,000 time steps of 0.005 yr were used to reach the total simulation time of 10 yr.

TABLE 8

RESULTS OF BOUNDARY-ELEMENT ANALYSES OF THE VERTICAL EMPLACEMENT DRIFT

Time (Yr)	0	5	10	20	35	50	100	150	200
[a]Crown Displacement (cm)	-0.078	-0.804	-0.172	-0.041	0.611	1.487	3.528	4.794	5.742
Midfloor (cm) Displacement (cm)	0.507	1.132	0.244	-0.218	-1.102	-2.095	-4.229	-5.474	-6.394
[b]Total Vertical Closure (cm)	0.429	0.328	0.072	-0.259	-0.491	-0.608	-0.701	-0.680	-0.652
Midwall Displacement	0.115	0.244	0.381	0.546	0.655	0.701	0.718	0.677	0.645
Midwall Closure (cm)	0.230	0.488	0.762	1.092	1.310	1.402	1.436	1.355	1.290
Crown Stress (MPa)	5.757	15.790	25.100	36.840	44.800	48.500	50.210	48.240	46.330
Midfloor Stress (MPa)	0.730	5.184	11.180	18.410	23.150	25.310	26.250	25.070	23.950
Midwall Stress (MPa)	8.453	8.648	5.873	2.163	0.307	-1.507	-2.340	-1.981	-1.559
Crown Temp. (C)	23.0	46.1	60.7	78.8	92.3	99.0	104.0	102.5	100.8
Midfloor Temperature (C)	23.0	75.4	91.3	104.2	112.9	116.1	114.3	109.9	106.9
Midwall Temperature (C)	23.0	58.6	73.6	90.6	102.1	107.2	109.0	106.1	103.8

The following supplemental information is provided to clarify the meaning of various response measures.

[a]Boundary element normal displacement.

[b]Closure is negative if the dimension increases.

TABLE 9

RESULTS OF FINITE-ELEMENT ANALYSES OF THE VERTICAL EMPLACEMENT DRIFT

Emplacement Type and Location	Unventilated Drift				Ventilated Drift			
	t=0 yr	10 yr	35 yr	100 yr	t=0 yr	10 yr	35 yr	100 yr
[a]Crown Displacement (cm)	-0.191	2.330	5.826	10.382	-0.191	1.411	2.482	2.960
Midfloor Displacement (cm)	0.235	2.341	5.299	0.9332	0.235	1.739	2.730	3.225
[b]Total Vertical Closure (cm)	0.426	0.011	-0.527	-1.050	0.426	0.328	0.248	0.265
Midwall Displacement (cm)	-0.113	-0.399	-0.687	-0.791	-0.113	-0.187	-0.218	-0.204
Midwall Closure (cm)	0.226	0.800	1.374	1.582	0.226	0.374	0.436	0.408
[c]Crown Stress (MPa)	5.75	28.48	47.78	54.28	5.75	11.23	12.56	11.60
Midfloor Stress (MPa)	0.80	10.38	23.13	28.30	0.80	0.26	2.76	3.55
Midwall Stress (MPa)	8.16	4.99	-1.24	-3.84	8.16	6.01	5.05	5.78
Crown Temp. (C)	23.0	73.4	101.8	108.5	23.0	23.0	23.0	23.0
Midfloor Temp (C)	23.0	75.9	103.6	109.3	23.0	23.0	23.0	23.0
Midwall Temp (C)	23.0	74.7	102.8	109.0	23.0	23.0	23.0	23.0
[d]Factors of Safety:								
Crown	7.2	1.9	1.3	1.2	7.2	4.0	3.6	3.9
Midfloor	43.7	4.1	2.1	1.8	43.7	83.2	13.7	11.0
Midwall	5.1	7.6	60.8	11.4	5.1	6.6	7.8	6.9

The following supplemental information is provided to clarify the meaning of various response measures.

[a]Displacements are considered positive if in the positive coordinate direction.

[b]Closure is negative if the dimension increases.

[c]Stresses are extrapolated to the nodal points using computed values at the element gauss points and assuming a linear variation of stress within the element. Compressive stresses are positive.

[d]These are the stress/strength ratios for the rock mass.

TABLE 10

RESULTS OF BOUNDARY-ELEMENT ANALYSES OF THE HORIZONTAL EMPLACEMENT DRIFT

Time (Yr)	0	5	10	20	35	50	100	150	200
[a]Crown Displacement (cm)	0.149	0.225	0.896	1.152	2.093	2.698	4.126	5.068	5.772
Midfloor Displacement (cm)	0.317	0.032	−0.796	−1.264	−2.341	−3.002	−4.433	−5.326	−5.990
[b]Total Closure (cm)	0.466	0.257	0.100	−0.112	−0.248	−0.304	−0.307	−0.258	−0.218
Midwall Displacement (cm)	0.036	0.135	0.207	0.304	0.364	0.389	0.385	0.355	0.329
Midwall Closure (cm)	0.072	0.270	0.414	0.608	0.788	0.778	0.770	0.710	0.658
Crown Stress (MPa)	3.600	9.647	14.380	21.430	26.790	29.720	32.120	31.40	30.390
Midfloor Stress (MPa)	−0.749	3.385	6.564	11.130	14.410	16.070	17.080	16.350	15.570
Midwall Stress (MPa)	12.640	7.448	3.704	−1.059	−3.691	−4.497	−3.400	−1.628	−0.111
Crown Temp. (C)	23.0	23.3	25.0	30.6	39.0	45.8	58.9	64.5	67.2
Midfloor Temperature (C)	23.0	23.3	25.0	30.7	39.0	45.8	59.0	64.5	67.2
Midwall Temperature (C)	23.0	23.3	25.1	30.8	39.1	46.0	59.0	64.5	67.2

The following supplemental information is provided to clarify the meaning of various response measures.

[a]Boundary element normal displacement.
[b]Closure is negative if the dimension increases.

TABLE 11

RESULTS OF FINITE-ELEMENT ANALYSES OF THE HORIZONTAL EMPLACEMENT DRIFT

Emplacement Type and Location	Unventilated Drift				Ventilated Drift			
	t=0 yr	10 yr	35 yr	100 yr	t=0 yr	10 yr	35 yr	100 yr
[a]Crown Dis- placement (cm)	-0.184	1.410	3.910	7.251	-0.184	1.419	3.912	7.097
Midfloor Dis- placement (cm)	0.273	1.478	3.638	6.899	0.273	1.499	3.621	6.683
[b]Total Vertical Closure (cm)	0.457	0.068	-0.272	-0.352	0.457	0.080	-0.291	-0.414
Midwall Dis- placement (cm)	-0.036	-0.224	-0.397	-0.453	-0.036	-0.222	-0.399	-0.459
Midwall Closure (cm)	0.073	0.448	0.794	0.906	0.073	0.444	0.798	0.918
[c]Crown Stress (MPa)	3.81	15.52	28.82	36.15	3.81	16.43	27.23	30.88
Midfloor Stress (MPa)	-0.71	7.23	15.55	19.37	-0.71	7.60	14.86	17.21
Midwall (Stress (MPa)	11.84	2.58	-4.63	-5.17	11.84	3.24	-5.78	-8.81
Crown Temp- erature (C)	23.0	25.0	38.7	58.3	30.0	30.0	30.0	30.0
Midfloor Temp (C)	23.0	25.0	38.7	58.3	30.0	30.0	30.0	30.0
Midwall Temp (C)	23.0	25.0	38.7	58.3	30.0	30.0	30.0	30.0
[d]Factors of Safety:								
Crown	10.4	3.0	1.9	1.6	10.4	2.9	1.9	1.8
Midfloor	51.6	5.8	3.0	2.5	51.6	5.6	3.1	2.7
Midwall	3.7	14.4	8.1	7.3	3.7	11.6	6.3	3.9

The following supplemental information is provided to clarify the meaning of various response measures.

[a]Displacements are considered positive if in the positive coordinate direction.

[b]Closure is negative if the dimension increases.

[c]Stresses are extrapolated to the nodal points using computed values at the element gauss points and assuming a linear variation of stress within the element. Compressive stresses are positive.

[d]These are the strength/stress ratios for the rock mass.

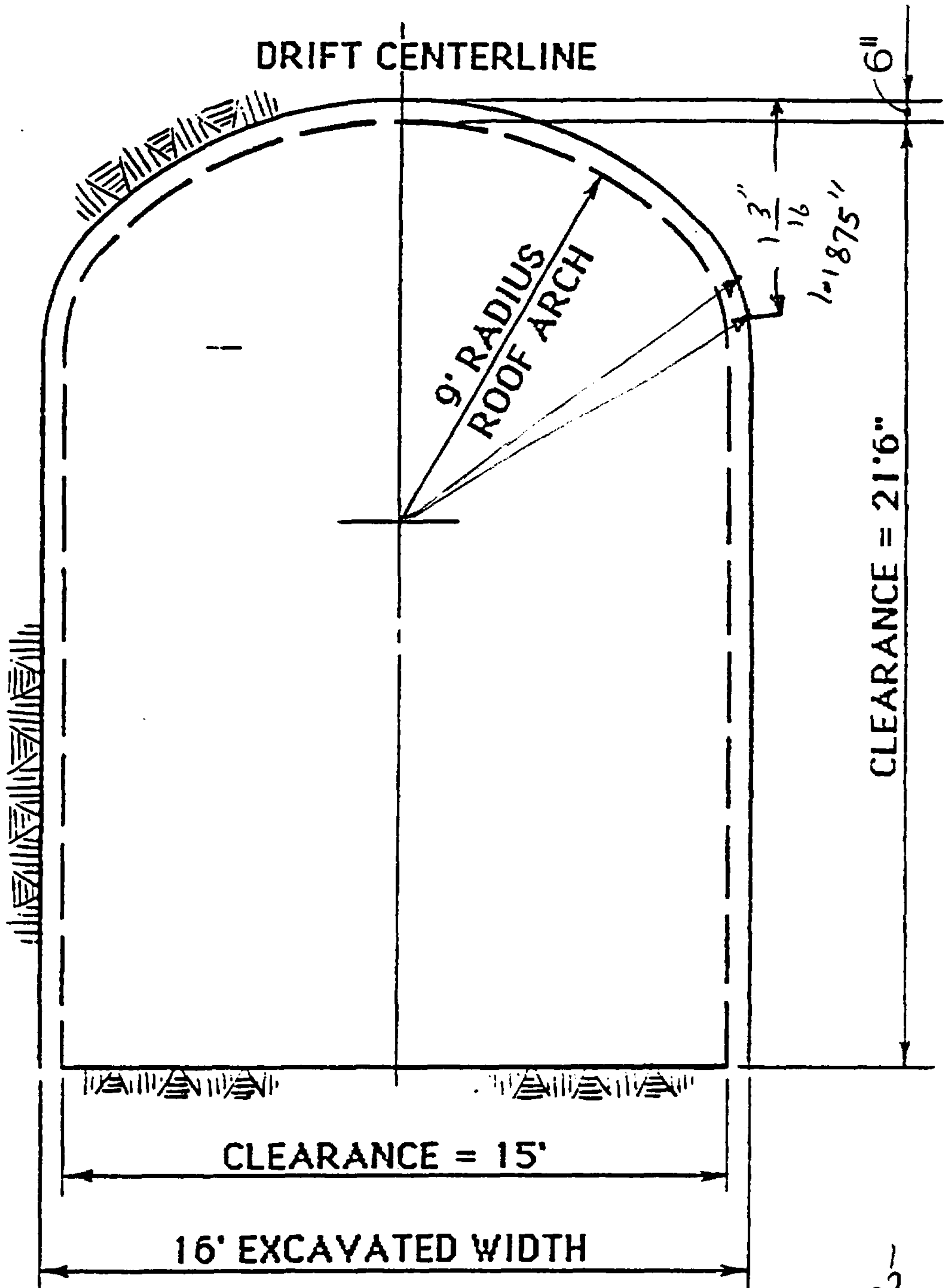


Figure 1. Design of Drift for Vertical Emplacement of Waste Container of Spent Fuel

$2\frac{1}{2}$" = $5\frac{7}{8}$"

~~5.375~~"

5.875

5.875

1.1875

$2\frac{1}{2}$

x

Roof arch point

$x = \frac{1.1875 \times 2\frac{1}{2}}{5.875}$

$= 4.45$ ft

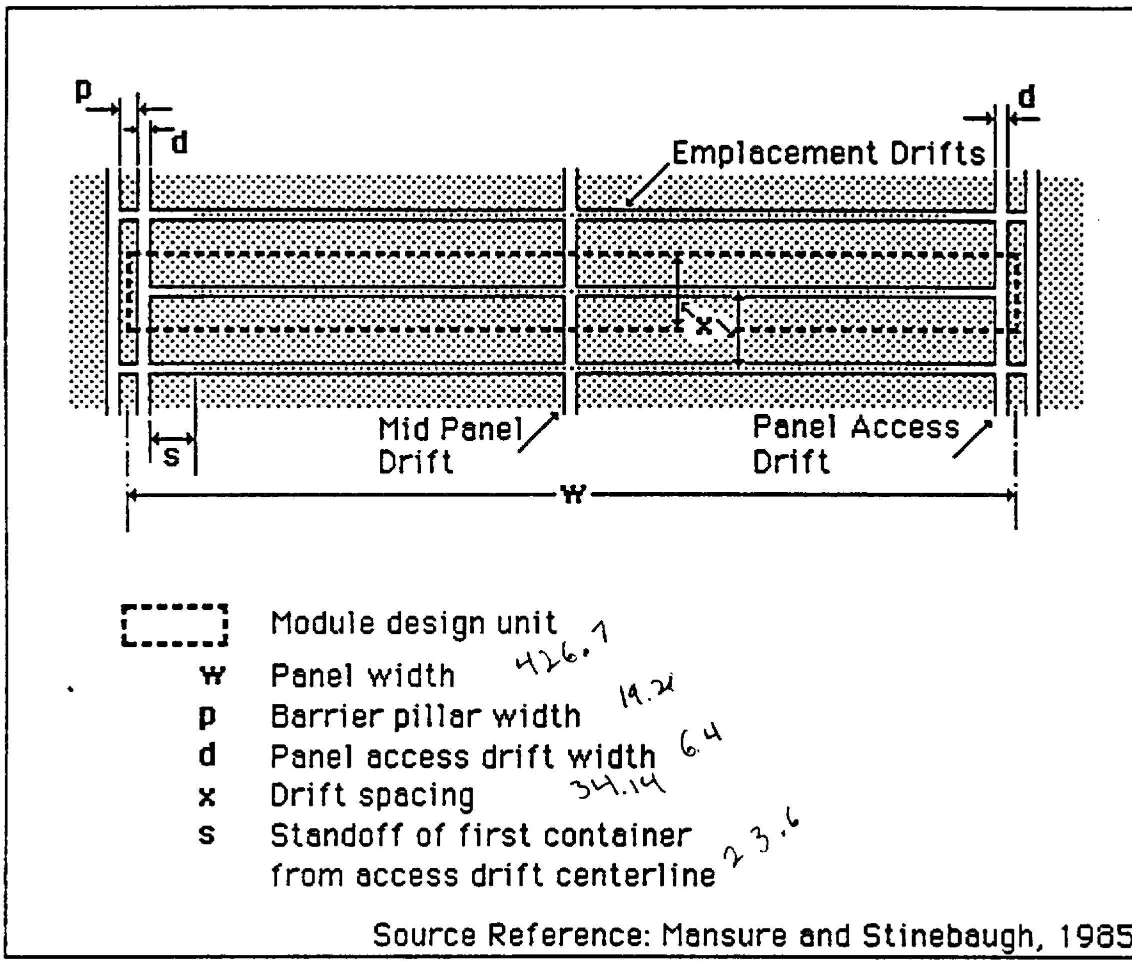


Figure 2. Design Module of Vertical Emplacement Panels

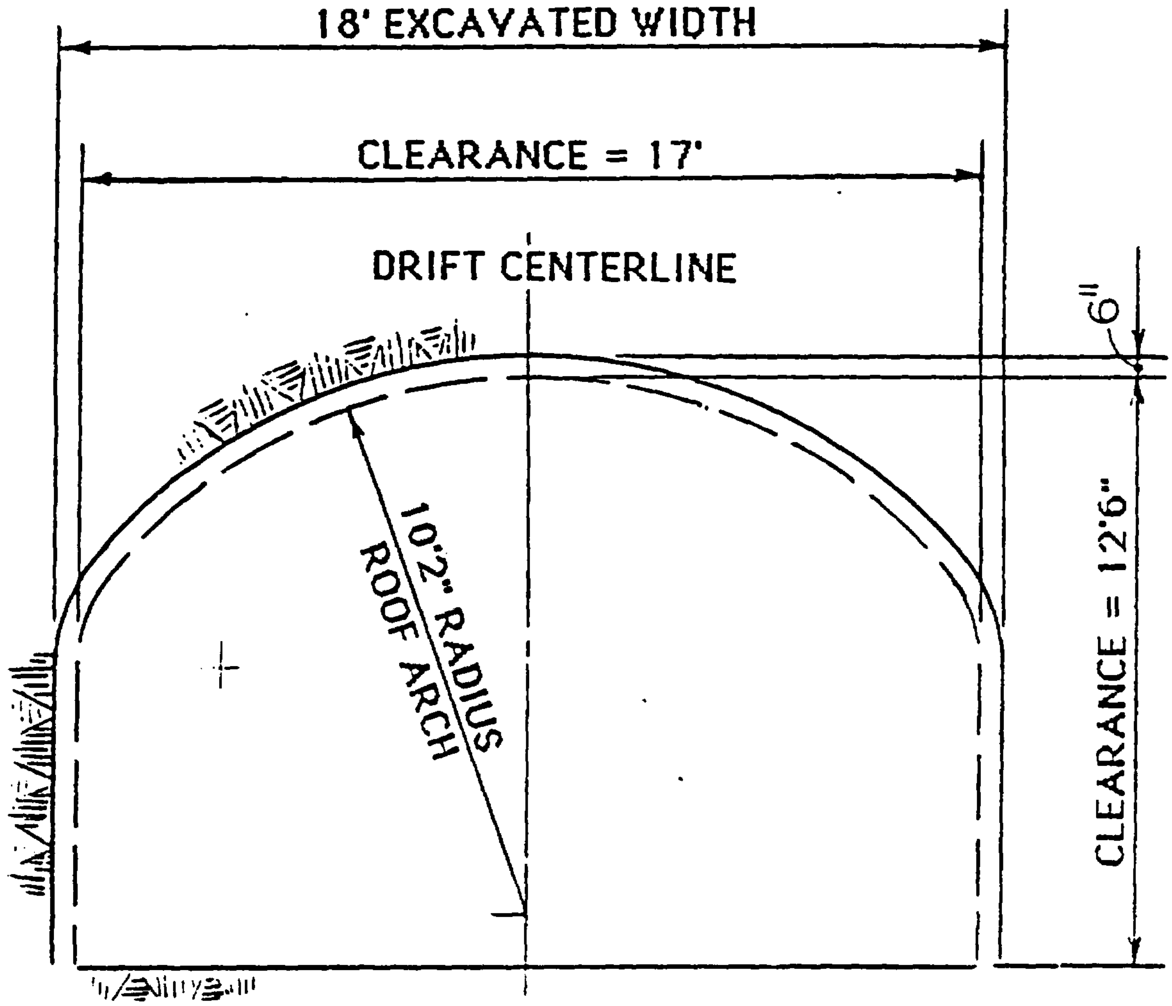


Figure 3. Design of Drift for Horizontal Emplacement of Waste Container of Spent Fuel

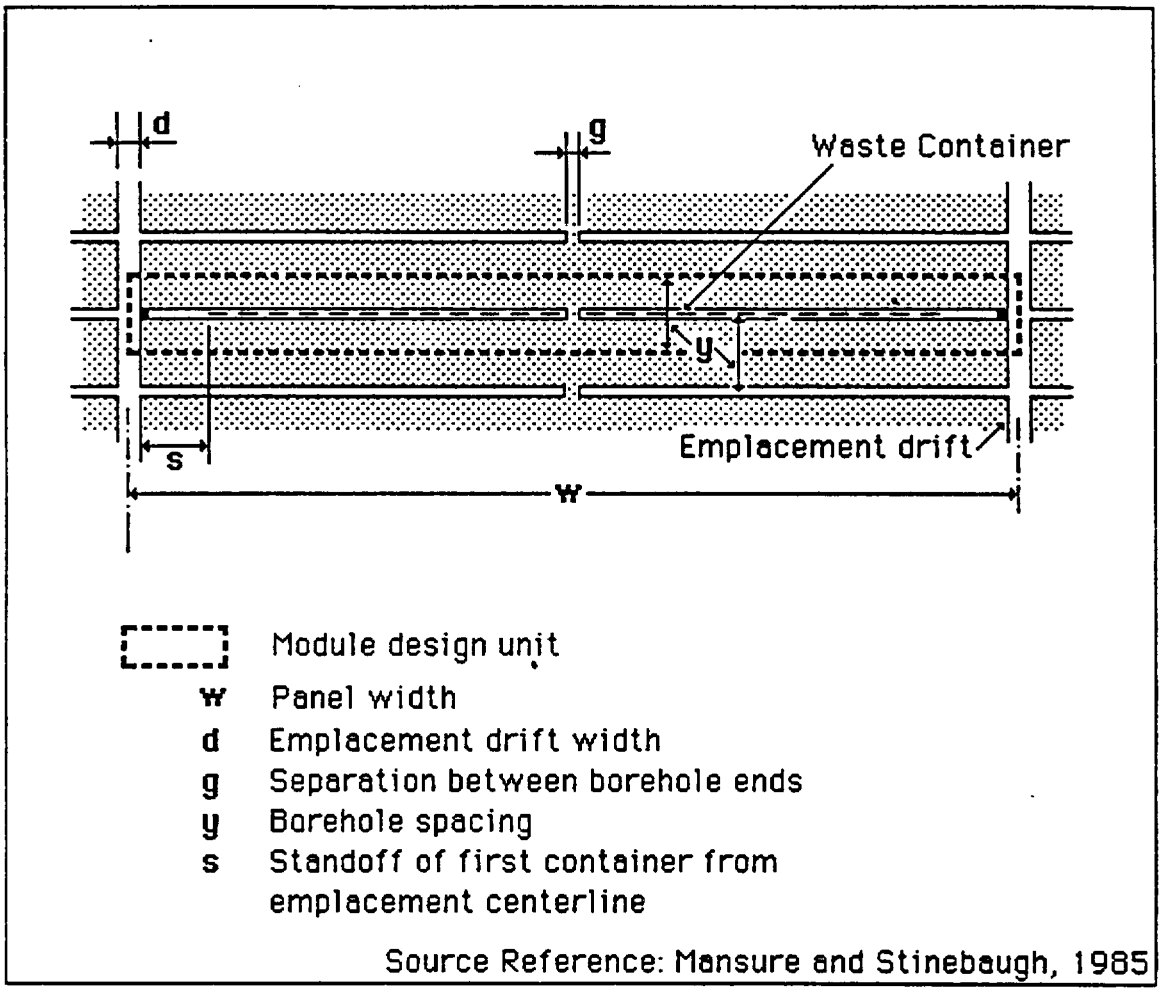


Figure 4. Design Module of Horizontal Emplacement Panels

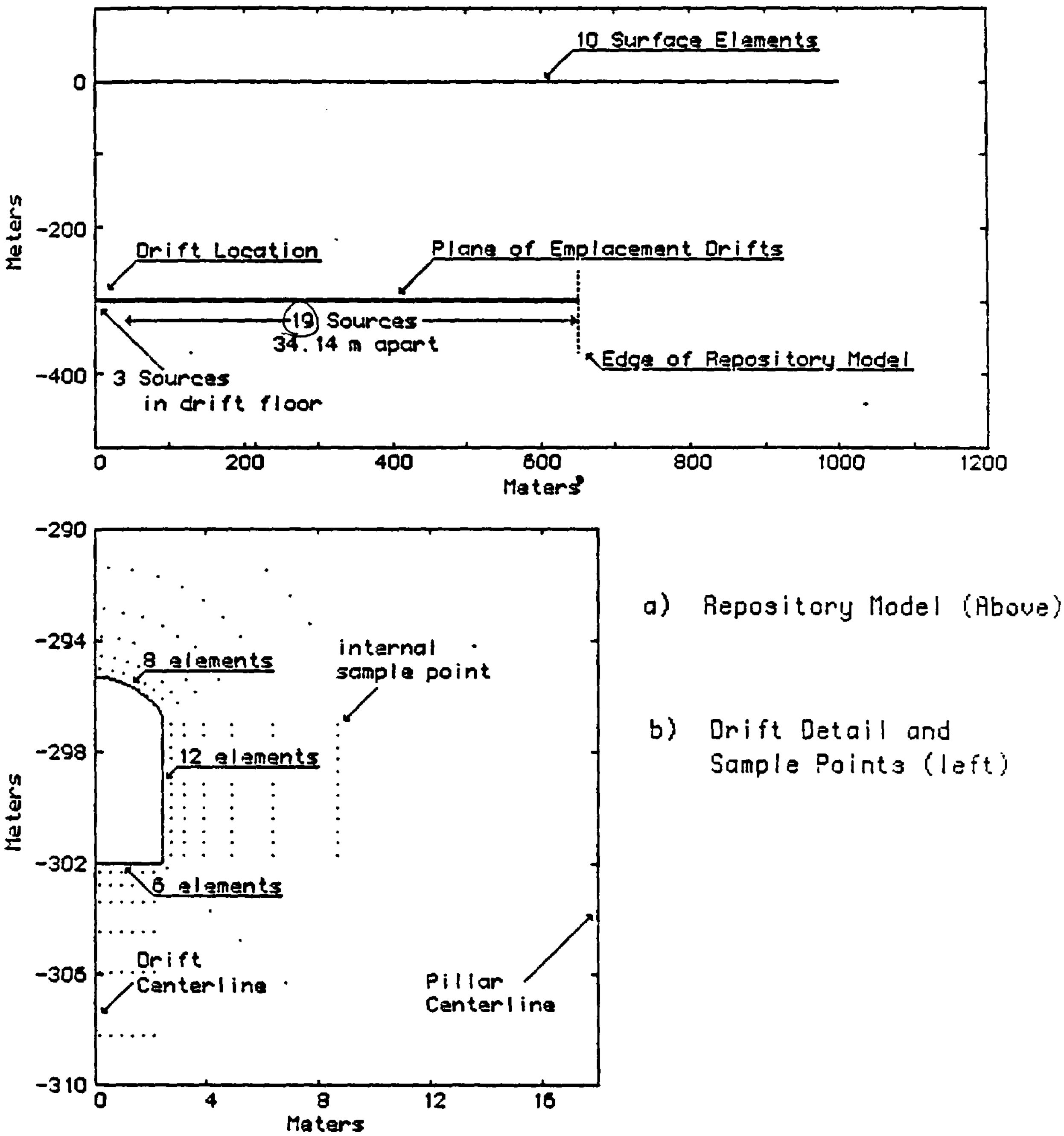


Figure 5. Boundary-Element Model for Analysis of Vertical Emplacement
(a) Complete
(b) Drift Detail and Sample Points

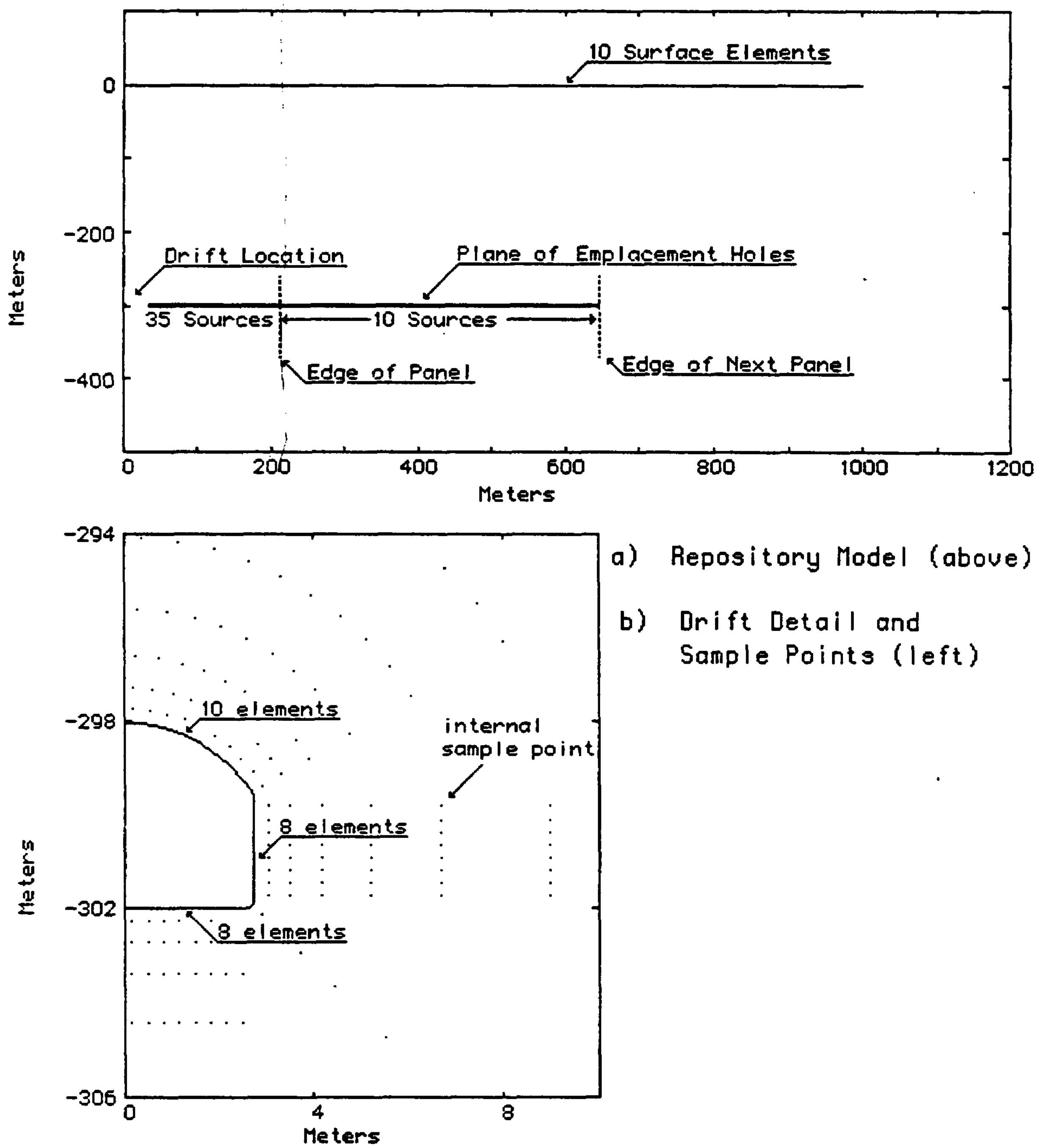


Figure 6. Boundary-Element Model for Analysis of Horizontal Emplacement
(a) Complete
(b) Drift Detail and Sample Points

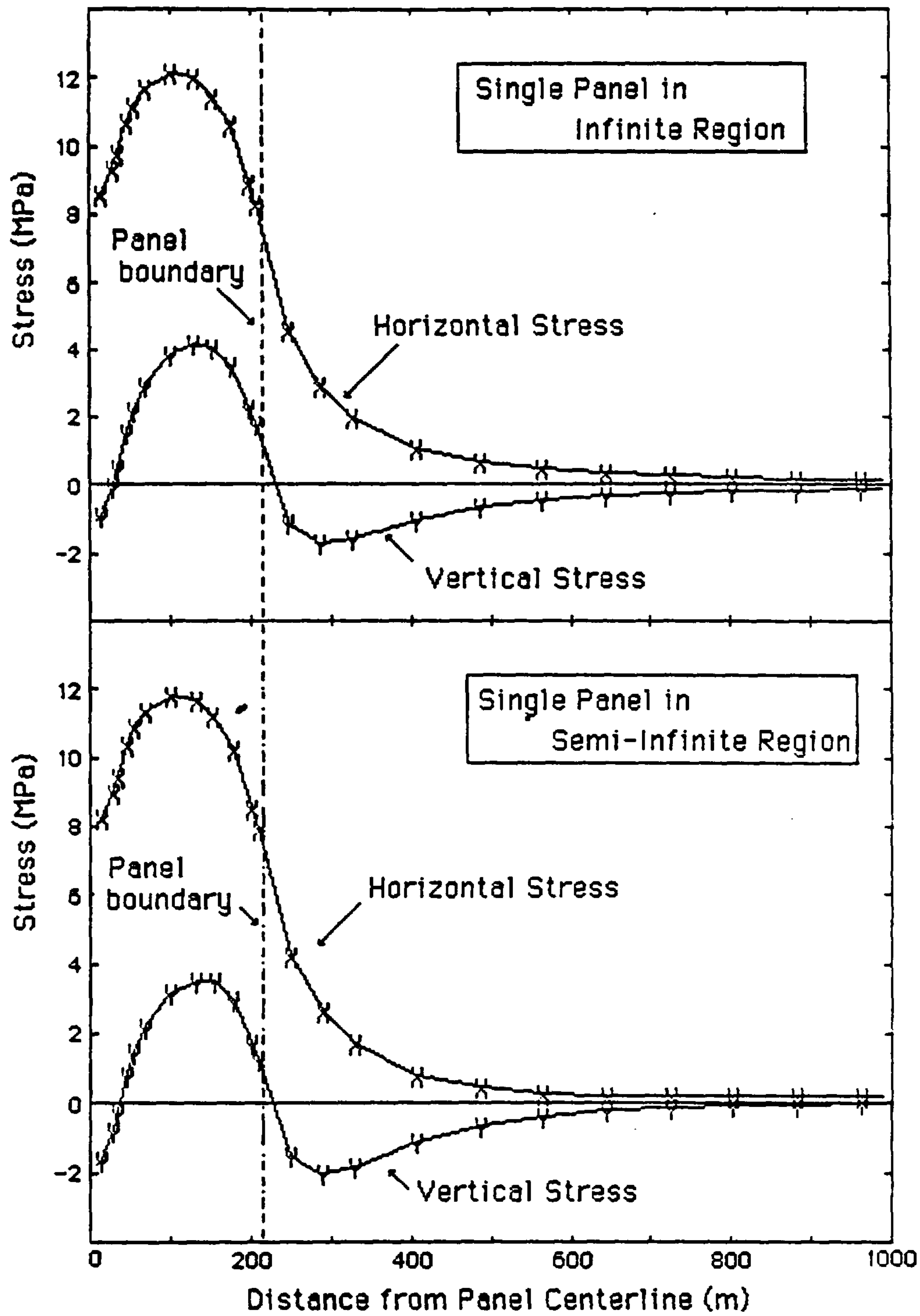


Figure 7. Thermally Induced Stresses in the Plane of a Single Panel 100 Yr After Waste Emplacement in Horizontal Boreholes

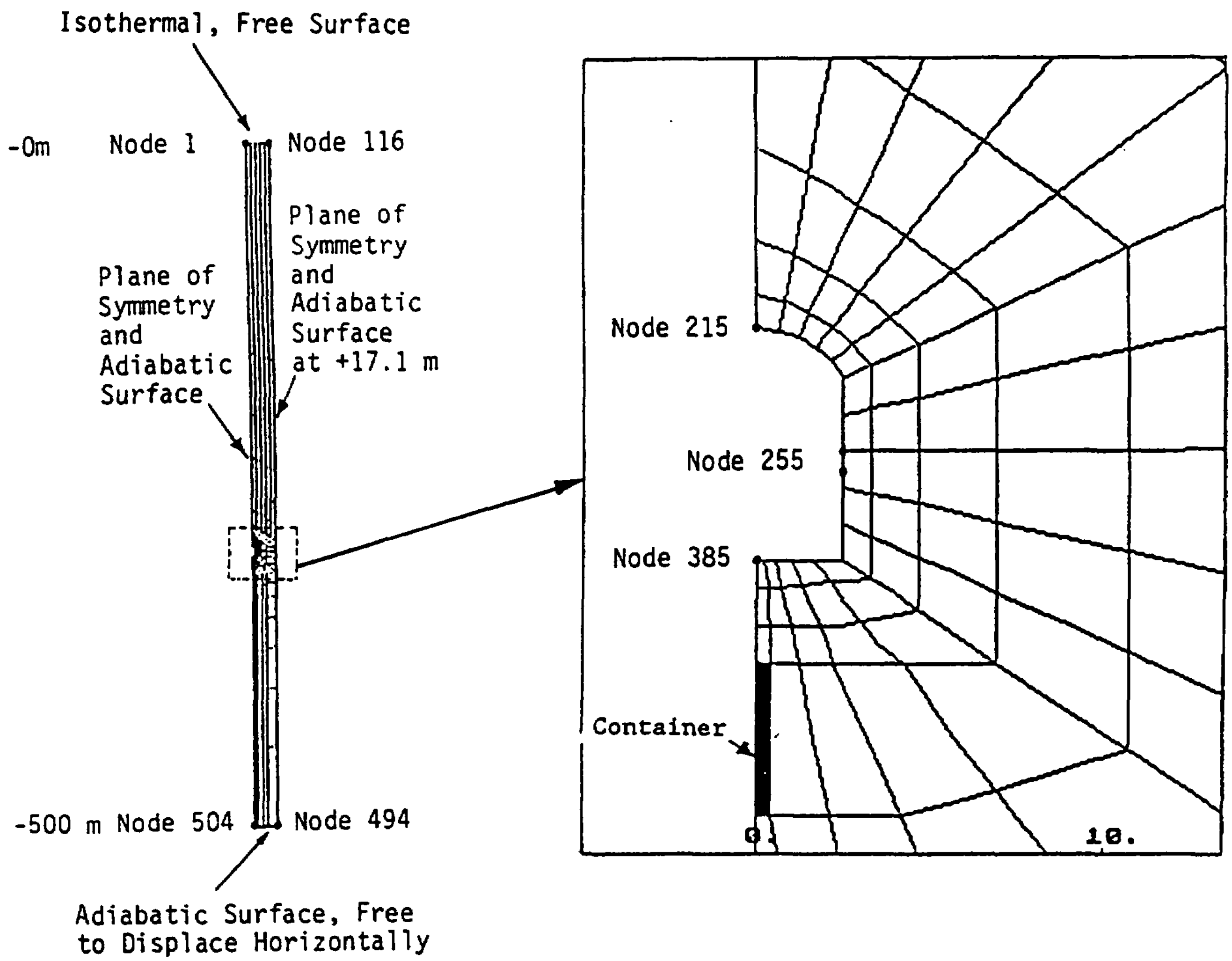


Figure 8. Finite-Element Model for Analysis of Vertical Emplacement
(a) Complete Mesh
(b) Details of Mesh around Drift

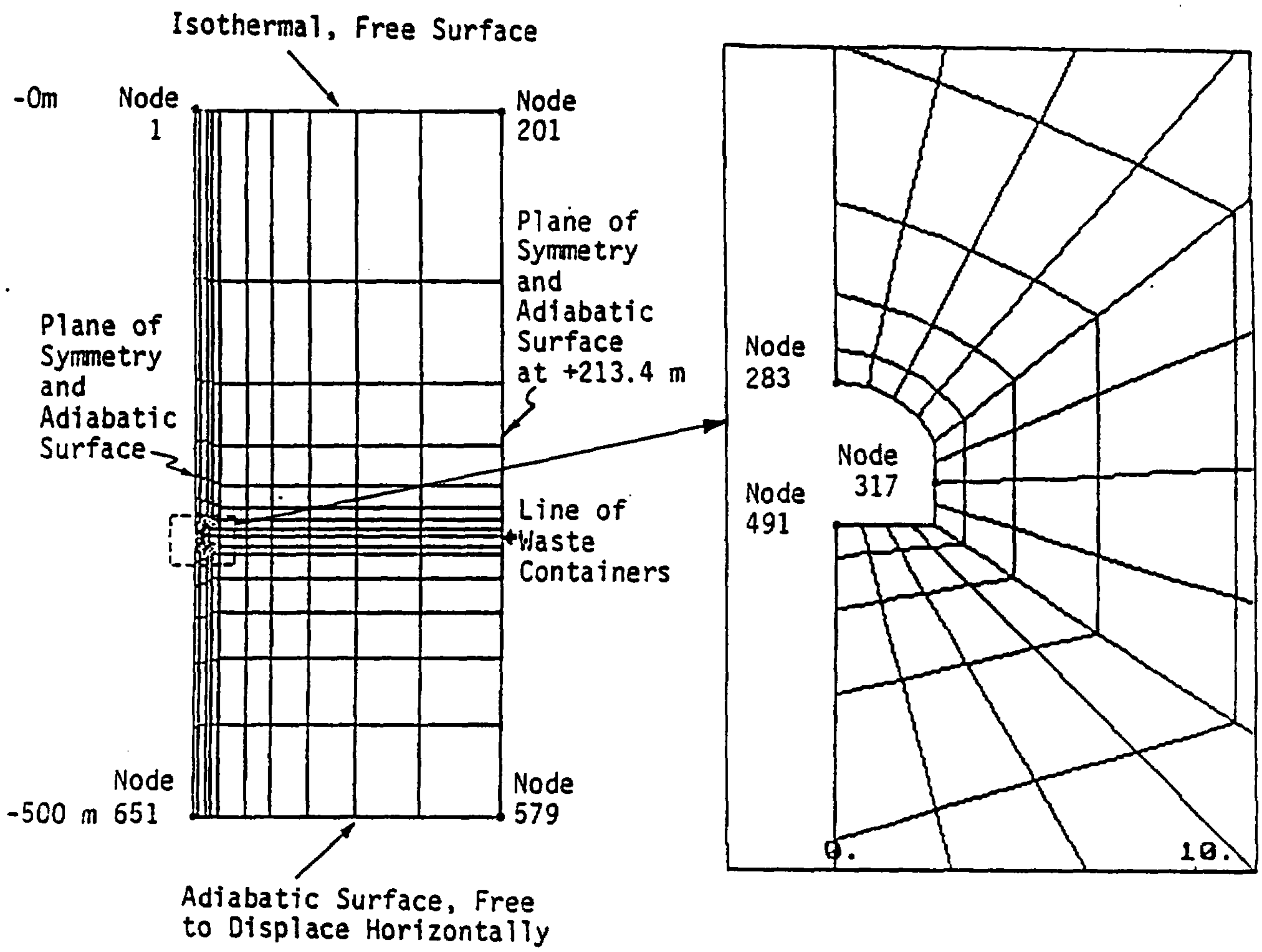


Figure 9. Finite-Element Model for Analysis of Horizontal Emplacement
(a) Complete Mesh
(b) Details of Mesh around Drift

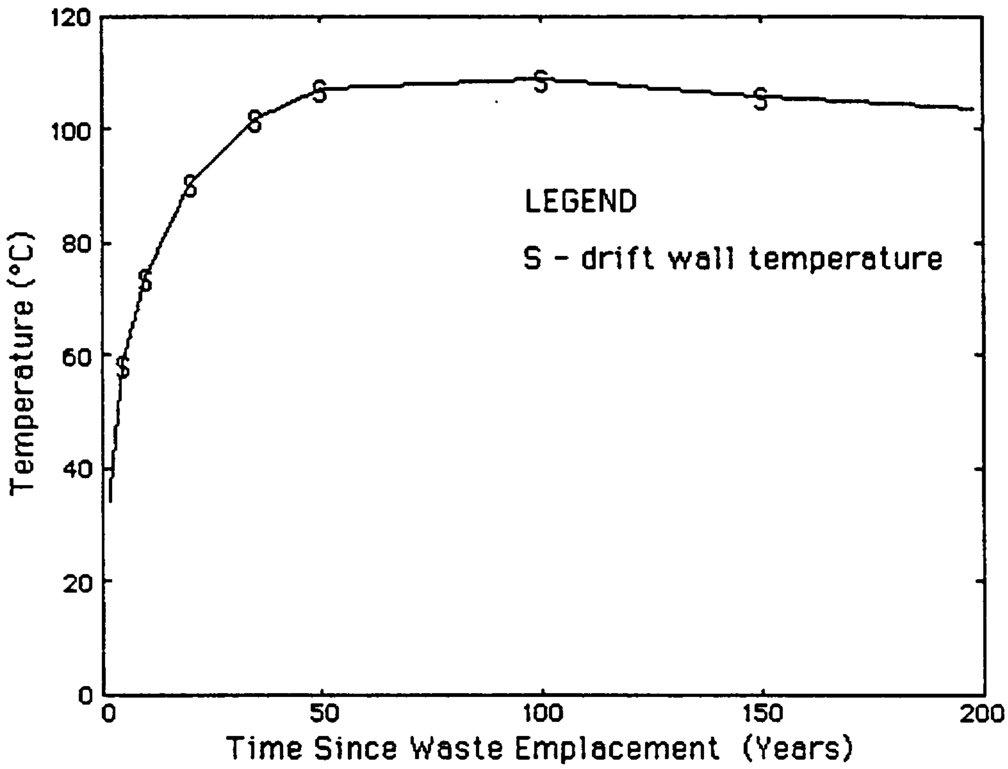


Figure 10. Boundary-Element Predictions of Wall Temperatures of the Vertical Emplacement Drift - Unventilated Drift

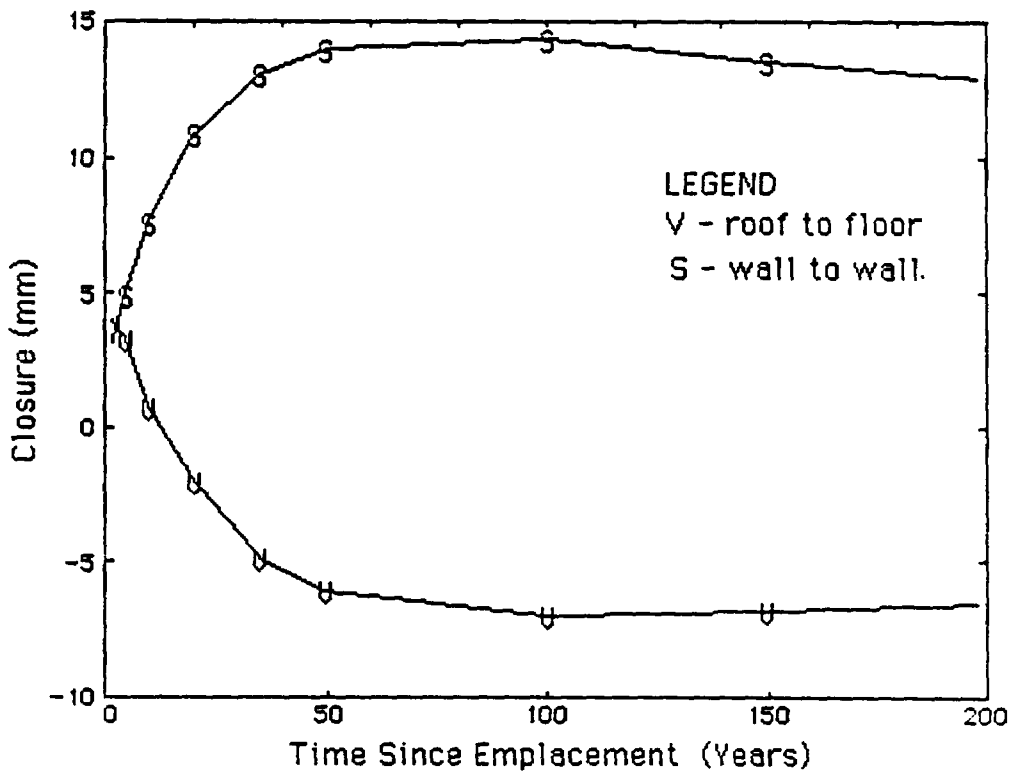


Figure 11. Boundary-Element Predictions of Vertical and Horizontal Closures of the Vertical Emplacement Drift - Unventilated Drift

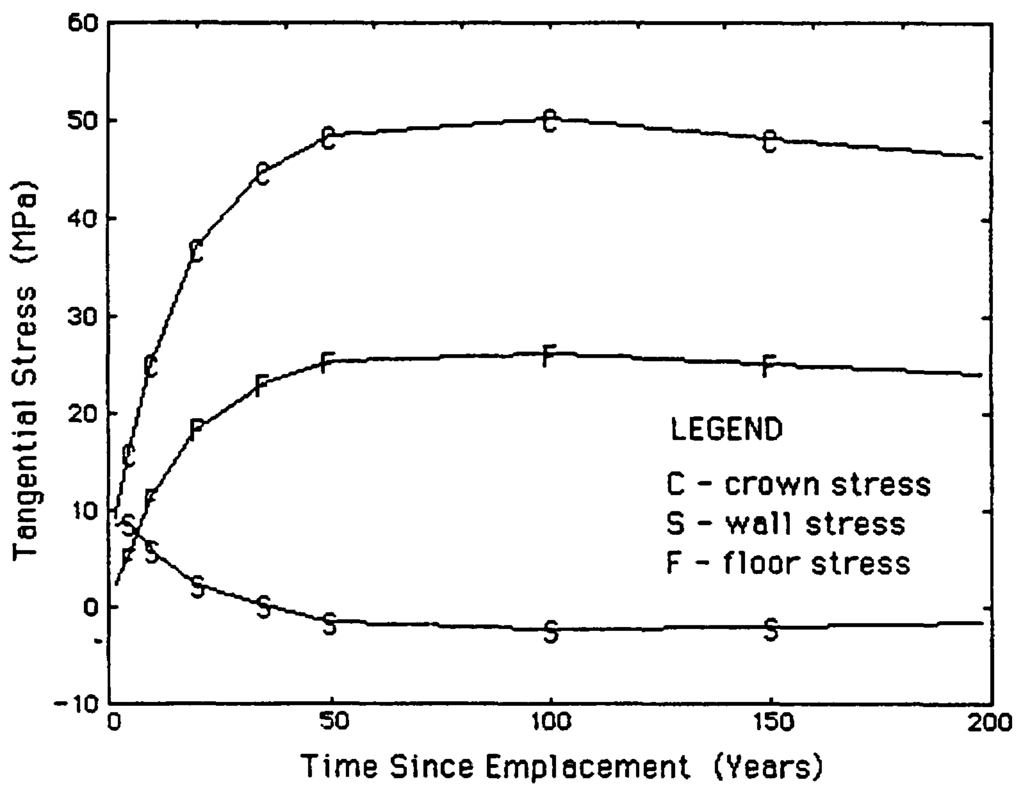


Figure 12. Boundary-Element Predictions of Tangential Stresses at Selected Points Around the Vertical Emplacement Drift - Unventilated Drift

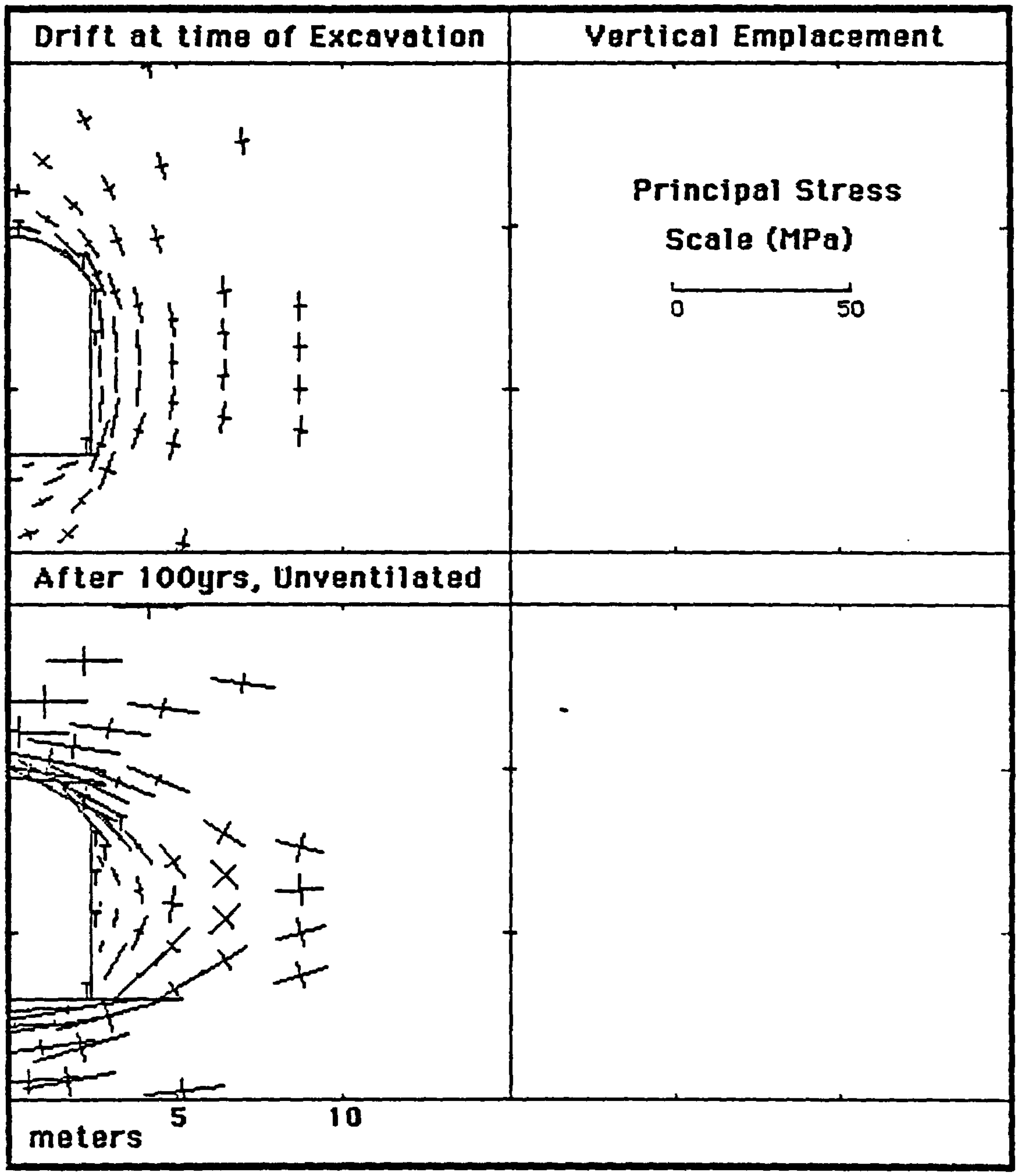


Figure 13. Boundary-Element Predictions of Principal Stresses in the Vicinity of the Vertical Emplacement Drift - Unventilated Drift

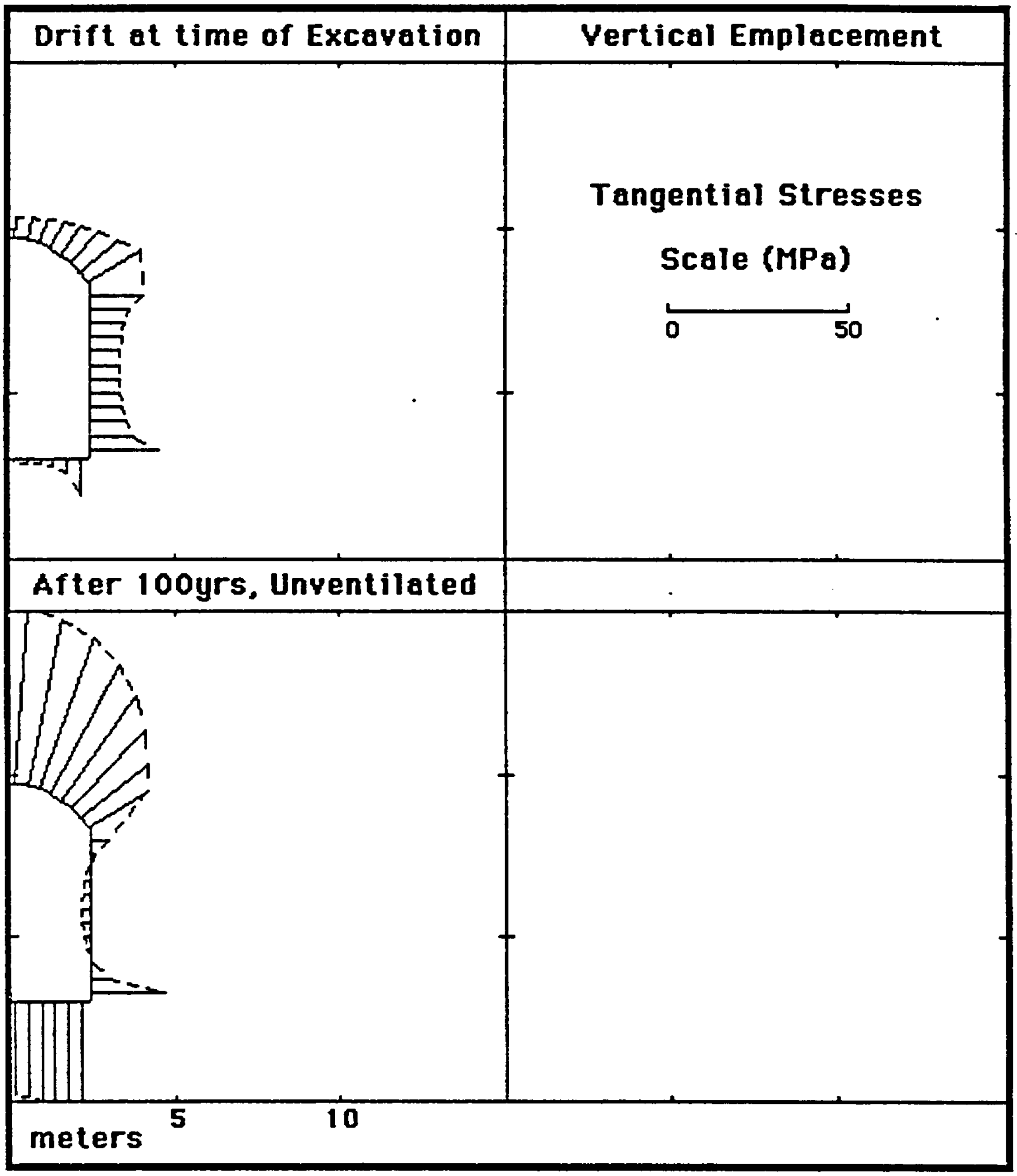


Figure 14. Boundary-Element Predictions of Tangential Stress Distribution Around the Vertical Emplacement Drift - Unventilated Drift

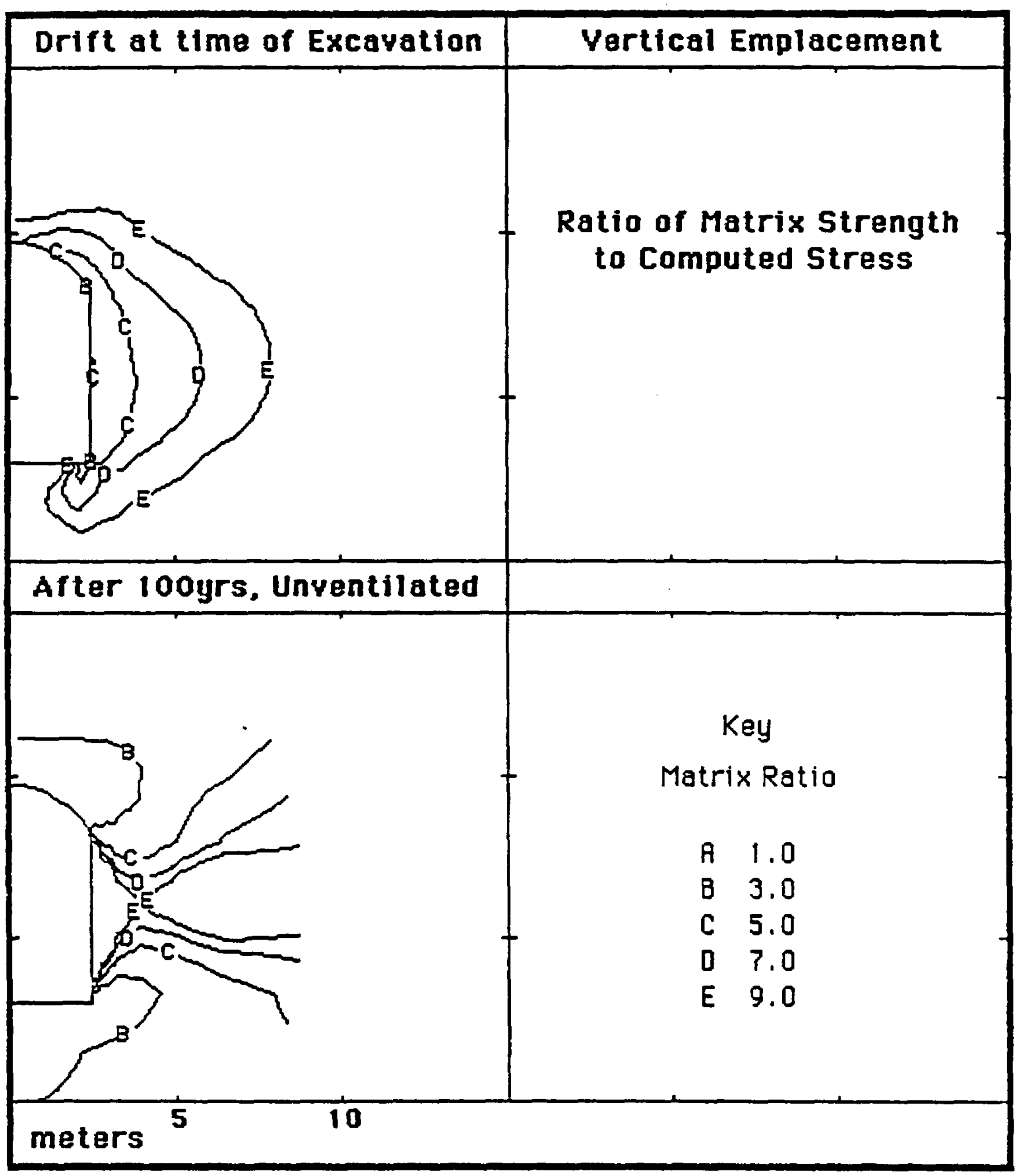


Figure 15. Boundary-Element Predictions of the Ratio Between the Matrix Strength and Stress Around the Vertical Emplacement Drift - Unventilated Drift

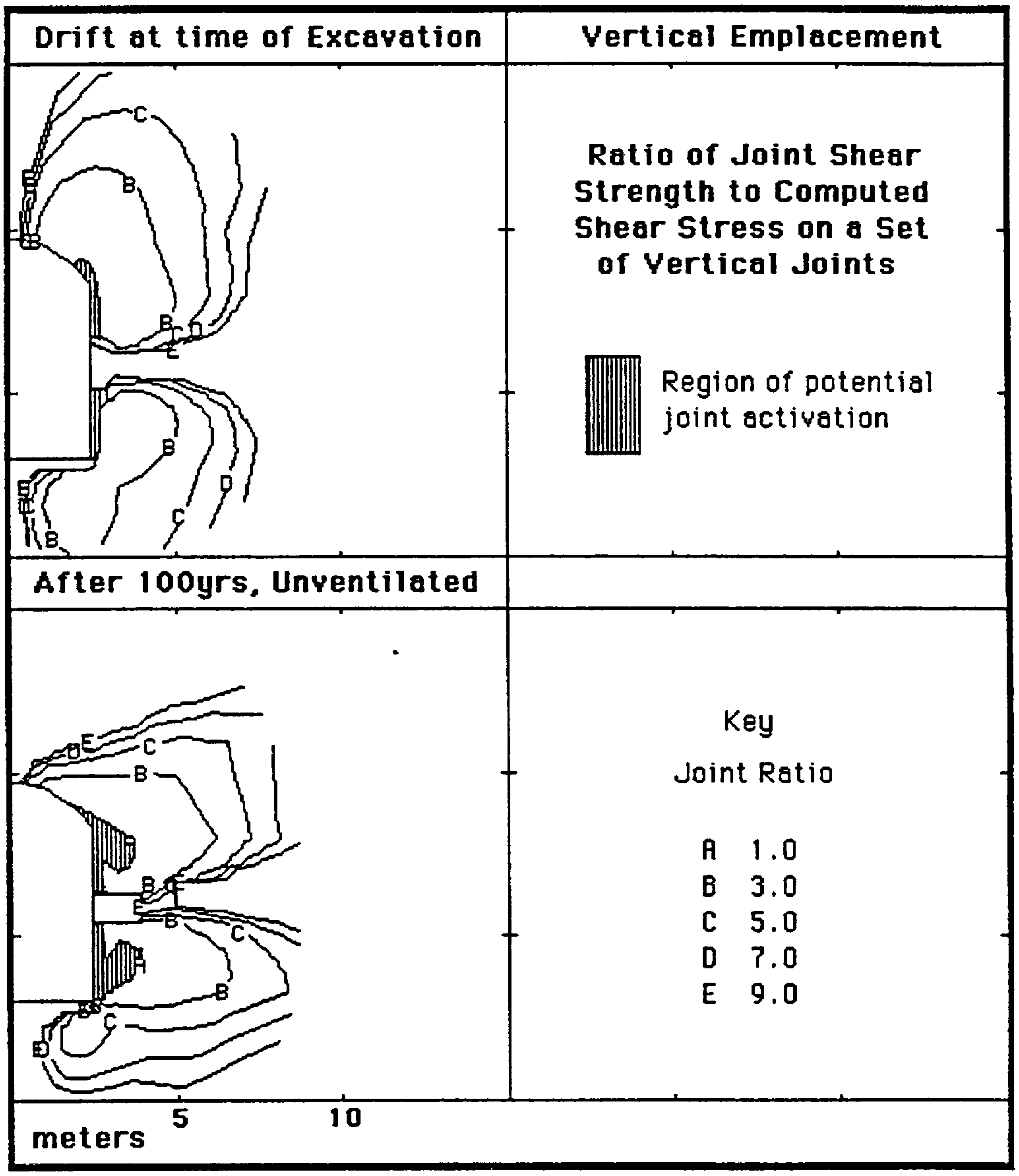


Figure 16. Boundary-Element Predictions of the Ratio Between the Joint Strength and Stress Around the Vertical Emplacement Drift - Unventilated Drift

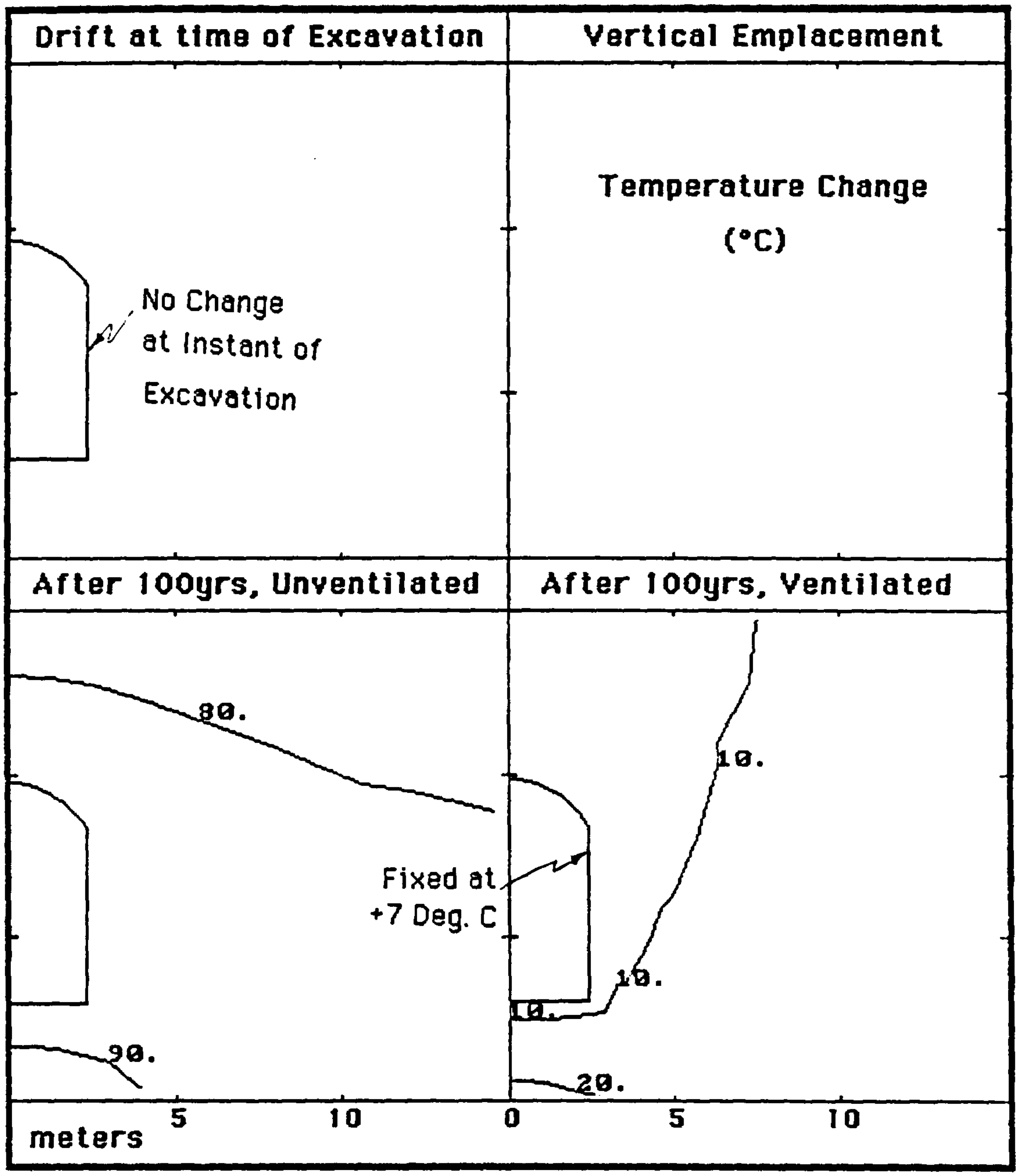


Figure 17. Finite-Element Predictions of the Temperature Change in the Vicinity of the Vertical Emplacement Drift 100 Yr After Waste Emplacement

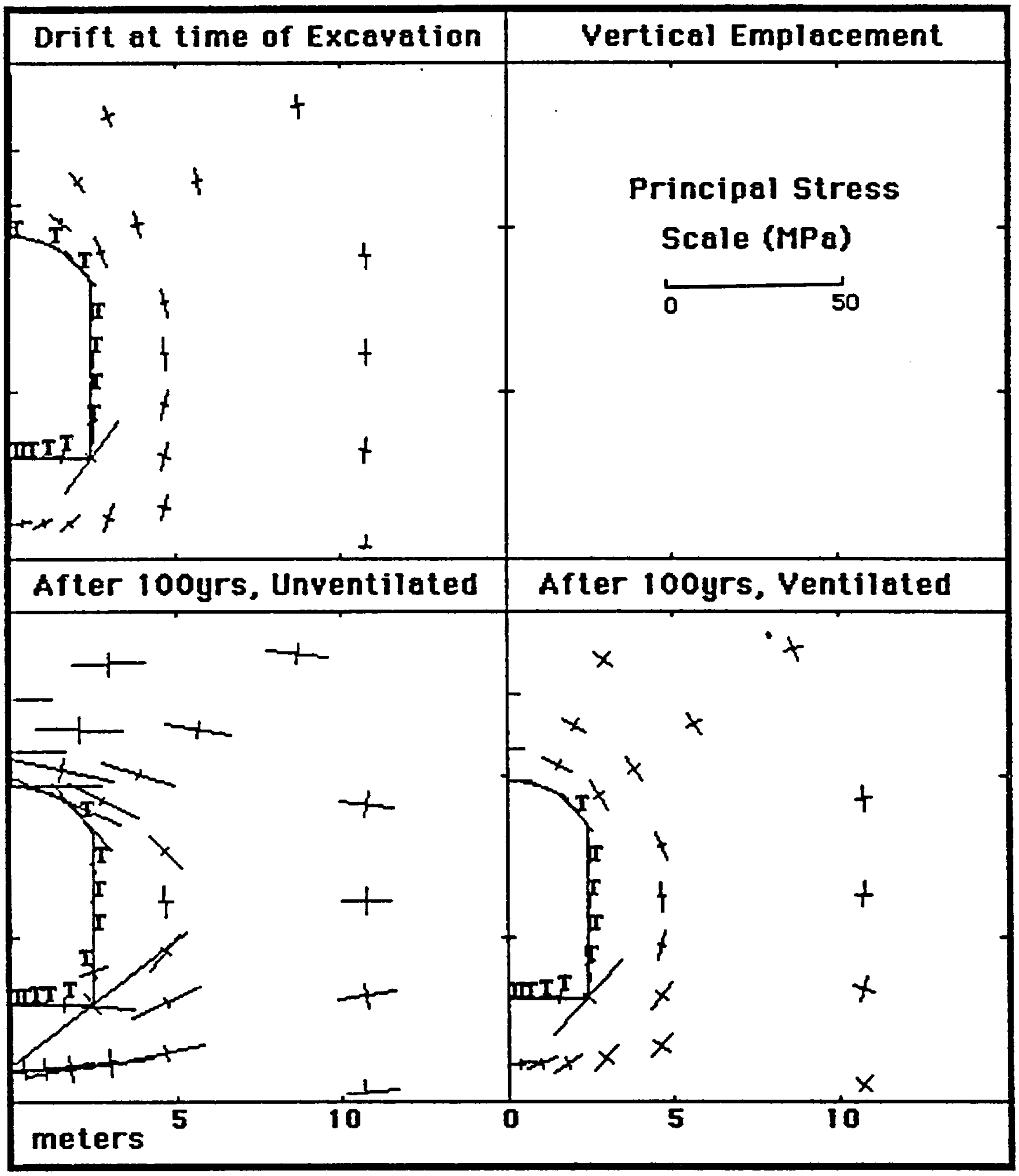


Figure 18. Finite-Element Predictions of the Principal Stresses in the Vicinity of the Vertical Emplacement Drift

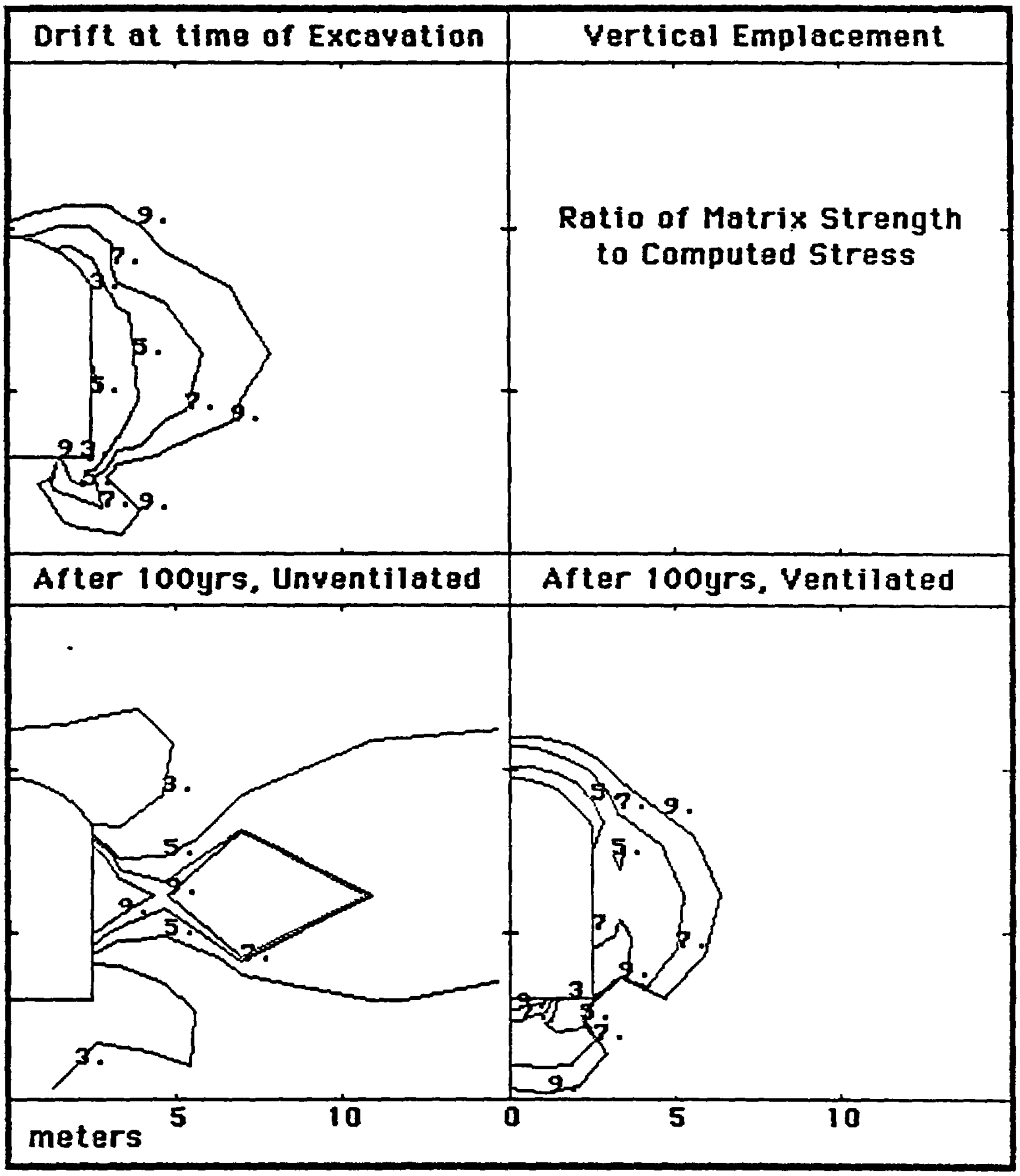


Figure 19. Finite-Element Predictions of the Ratio Between Matrix Strength and Stress Around the Vertical Emplacement Drift

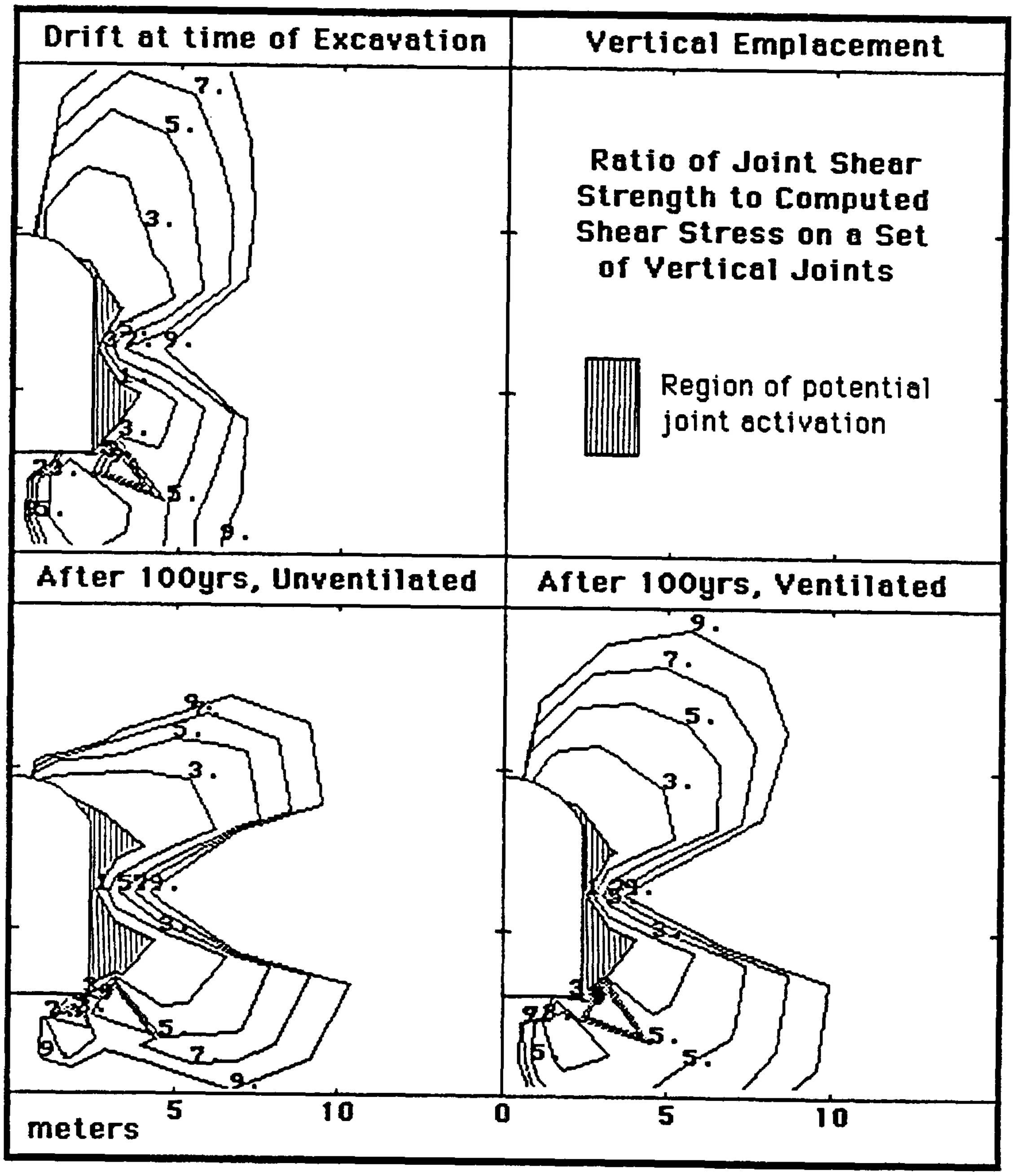


Figure 20. Finite-Element Predictions of the Ratio Between Joint Strength and Stress Around the Vertical Emplacement Drift

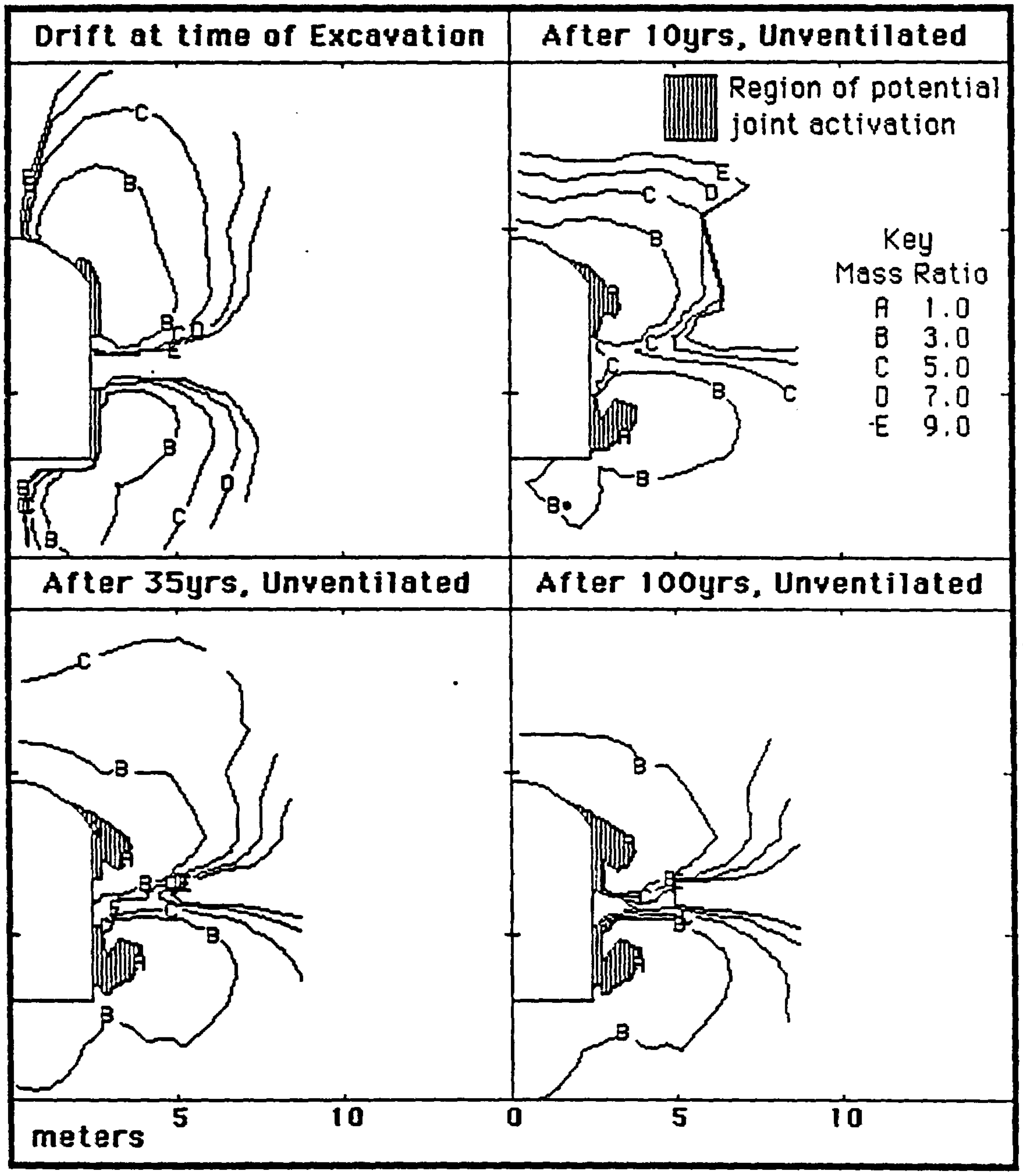


Figure 21. Boundary-Element Predictions of the Ratio Between Joint Strength and Stress Around an Unventilated Vertical Emplacement Drift, at Times up to 100 Yr After Waste Emplacement

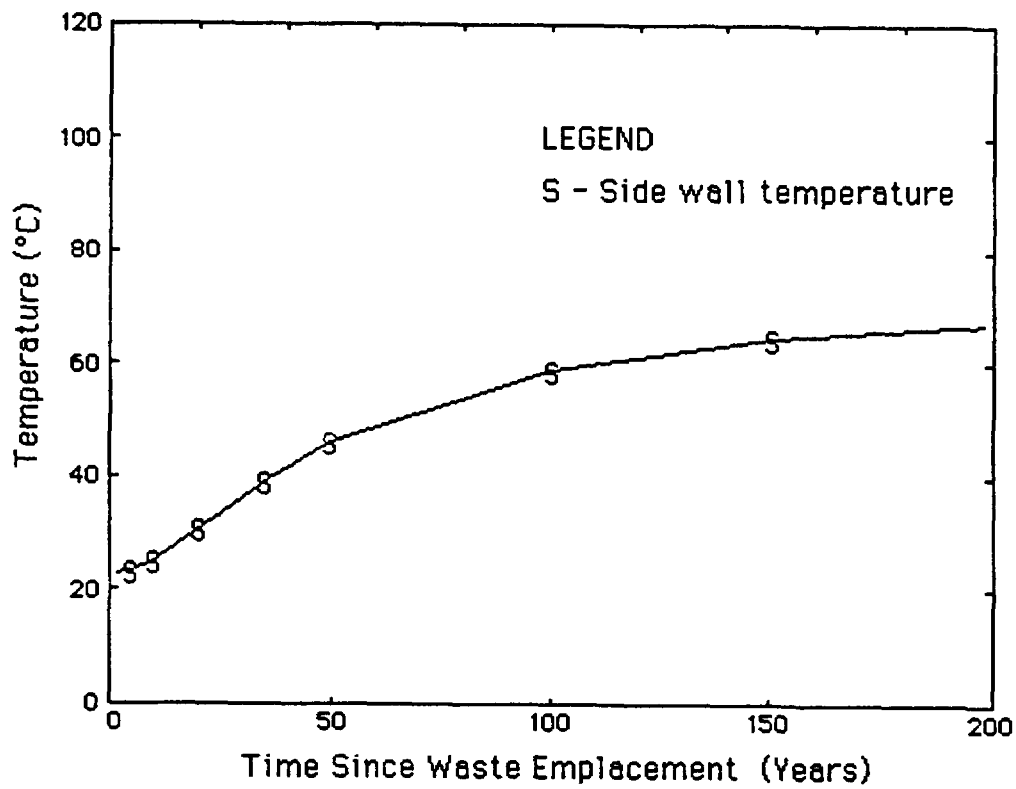


Figure 22. Boundary-Element Predictions of Wall Temperatures of the Horizontal Emplacement Drift - Unventilated Drift

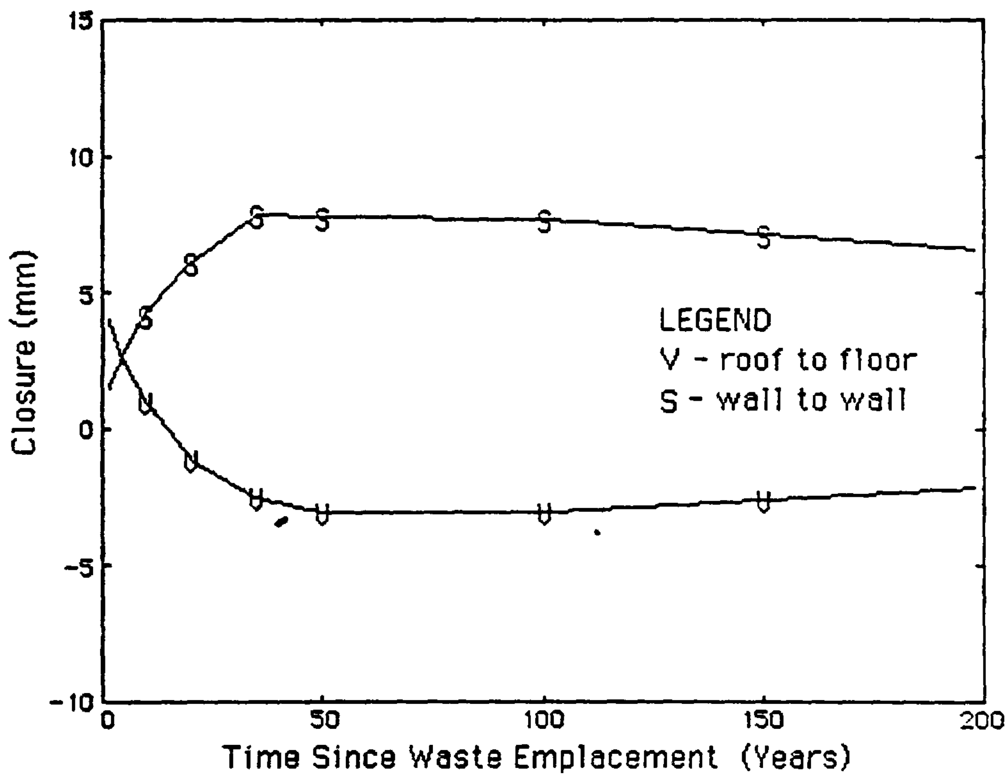


Figure 23. Boundary-Element Predictions of Vertical and Horizontal Closures of the Horizontal Emplacement Drift - Unventilated Drift

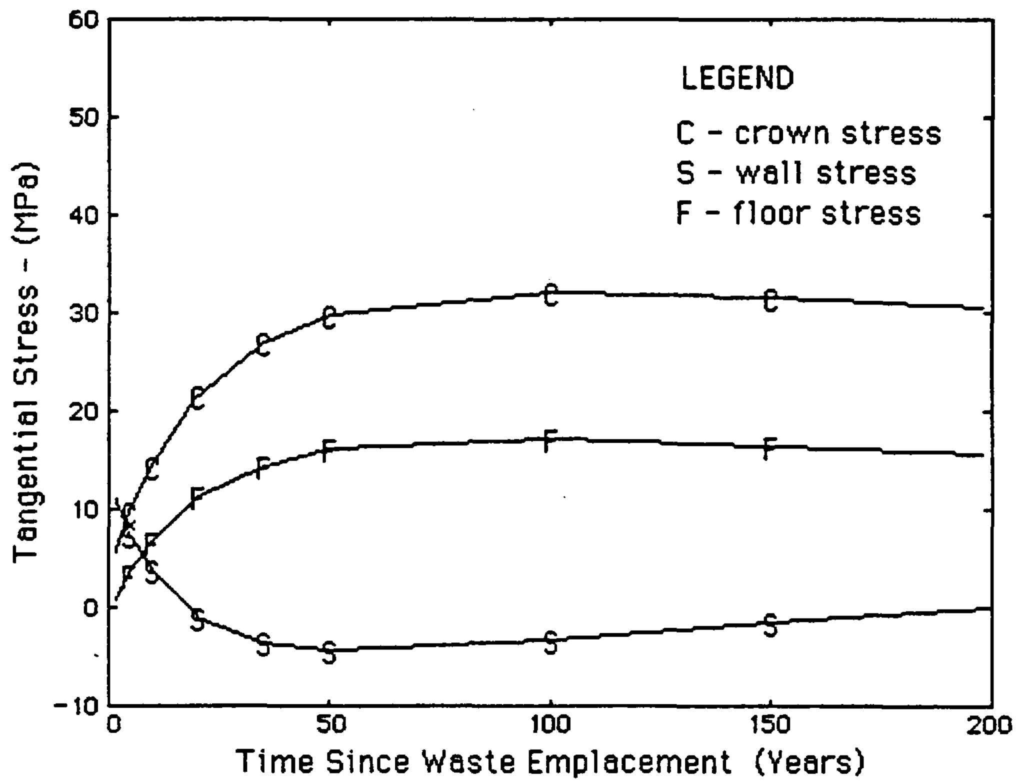


Figure 24. Boundary-Element Predictions of Tangential Stresses at Selected Points Around the Horizontal Emplacement Drift - Unventilated Drift

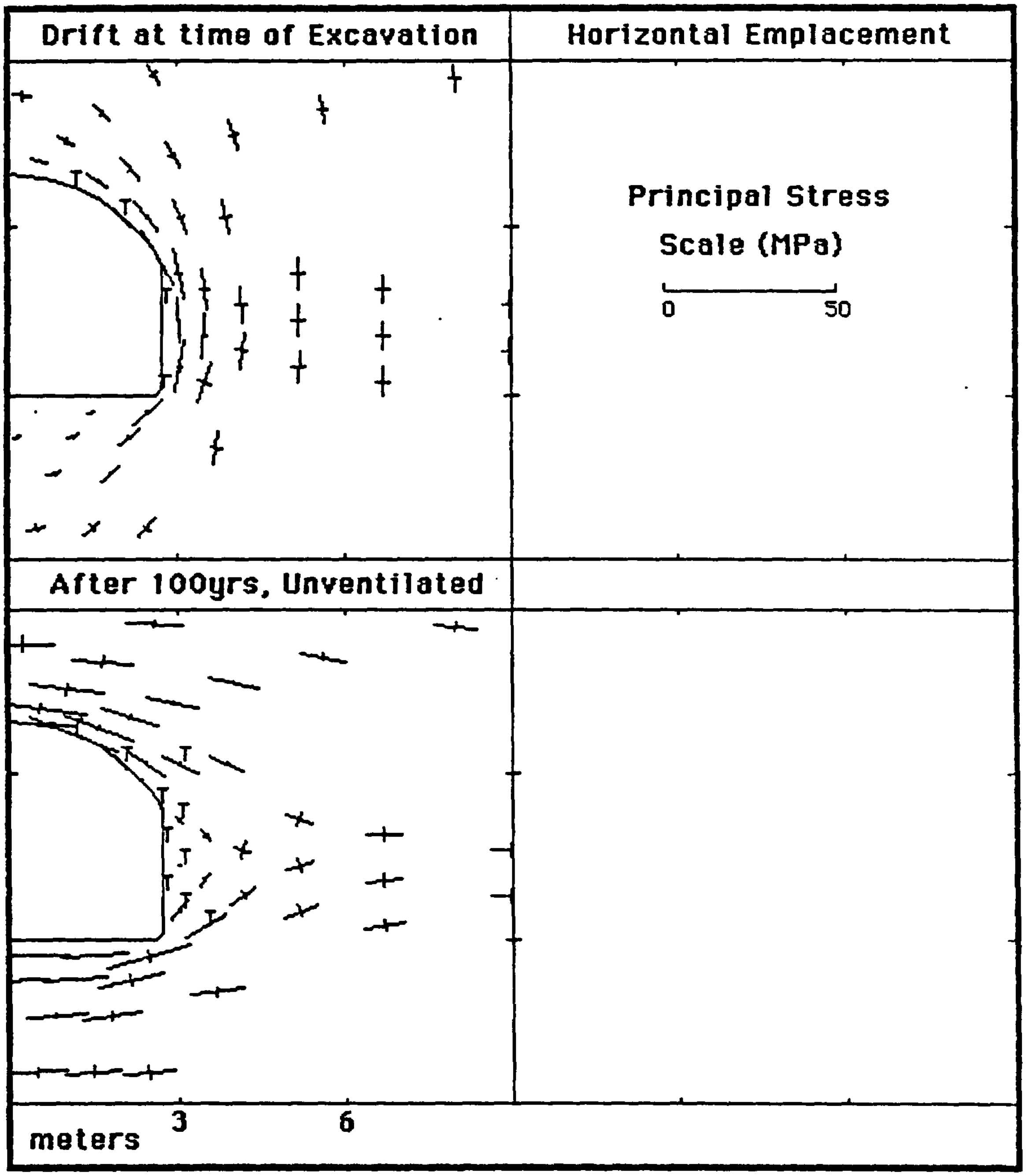


Figure 25. Boundary-Element Predictions of Principal Stresses in the Vicinity of the Horizontal Emplacement Drift - Unventilated Drift

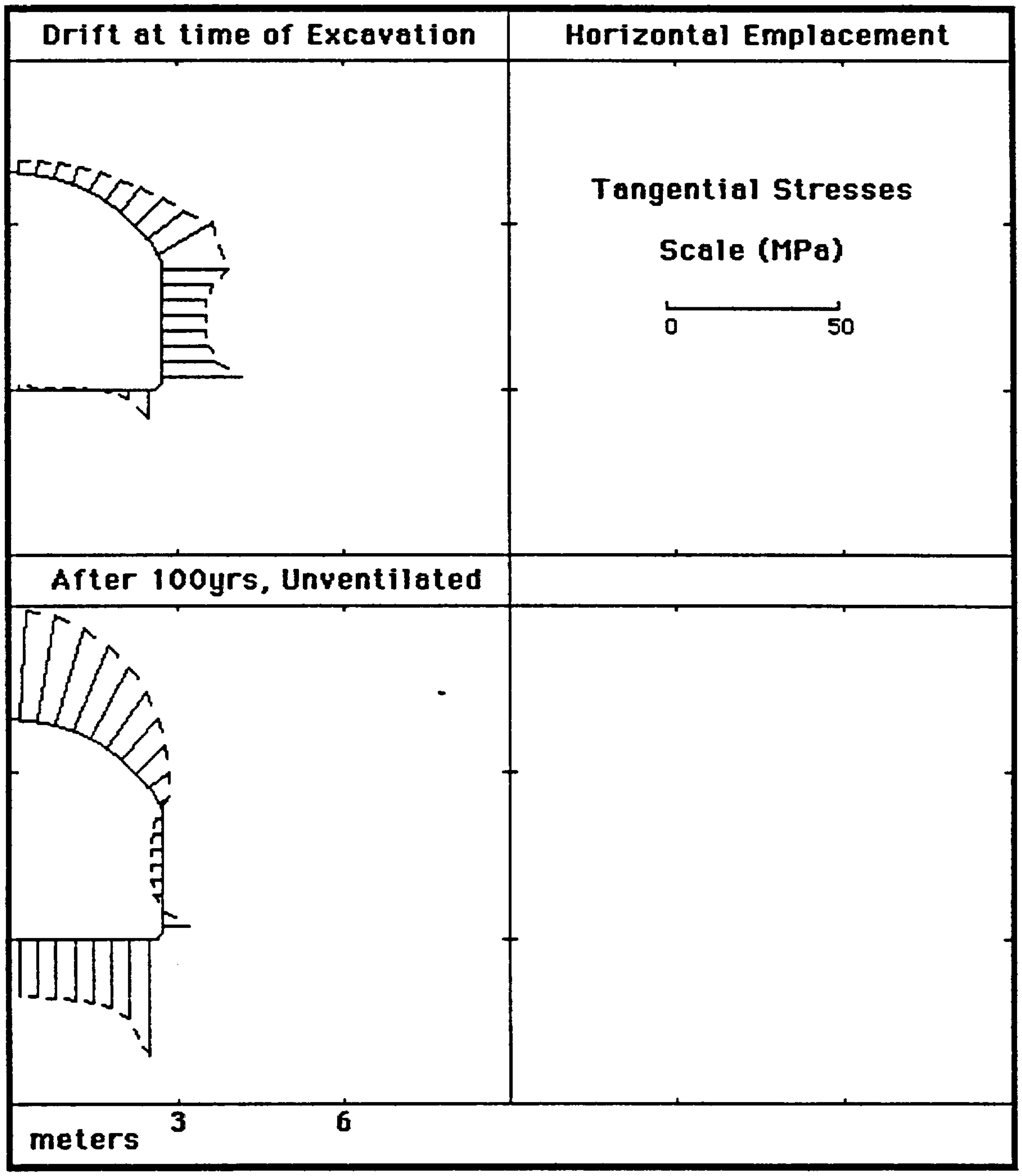


Figure 26. Boundary-Element Predictions of Tangential Stress Distribution Around the Horizontal Emplacement Drift - Unventilated Drift

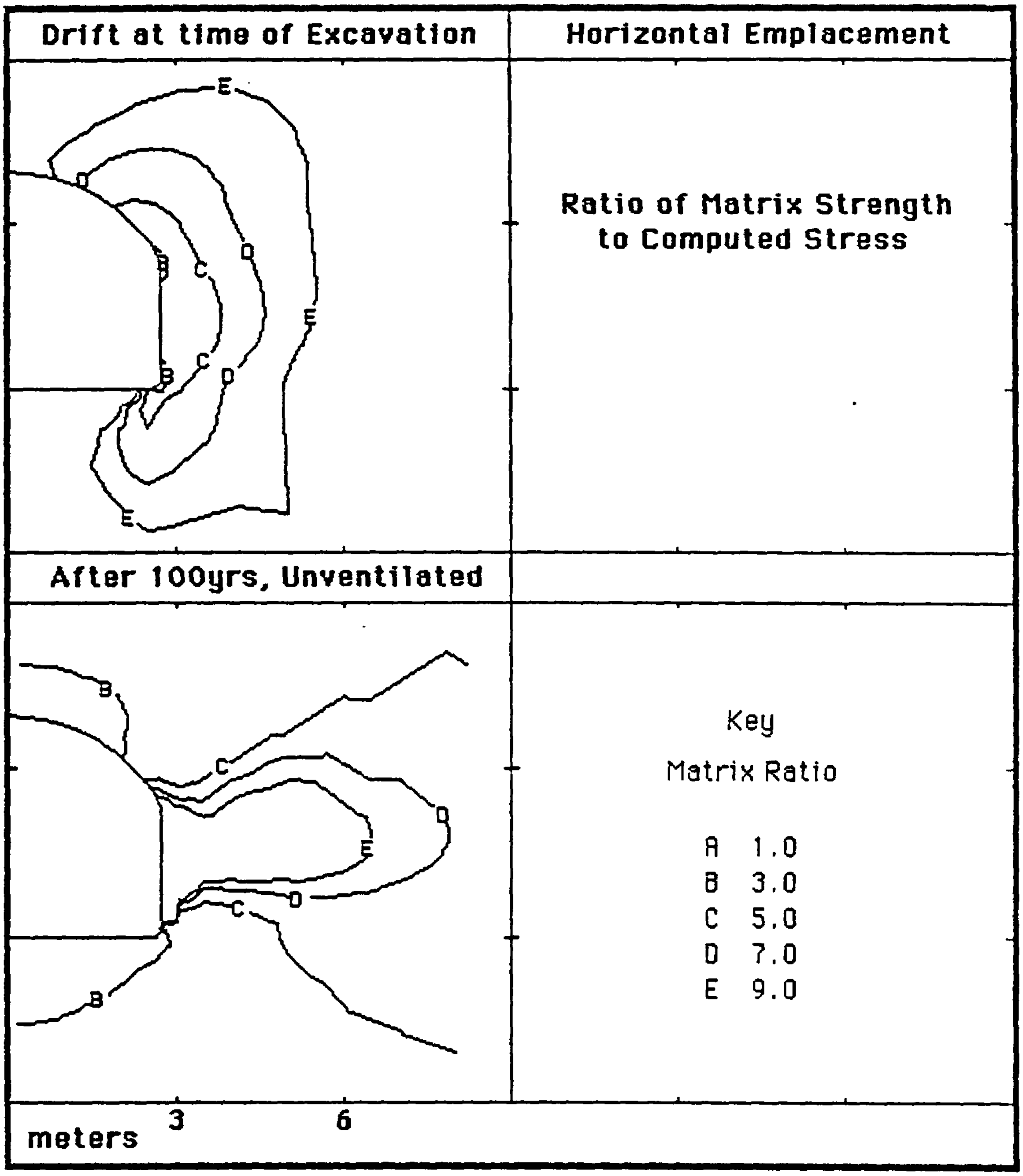


Figure 27. Boundary-Element Predictions of the Ratio Between the Matrix Strength and Stress Around the Horizontal Emplacement Drift - Unventilated Drift

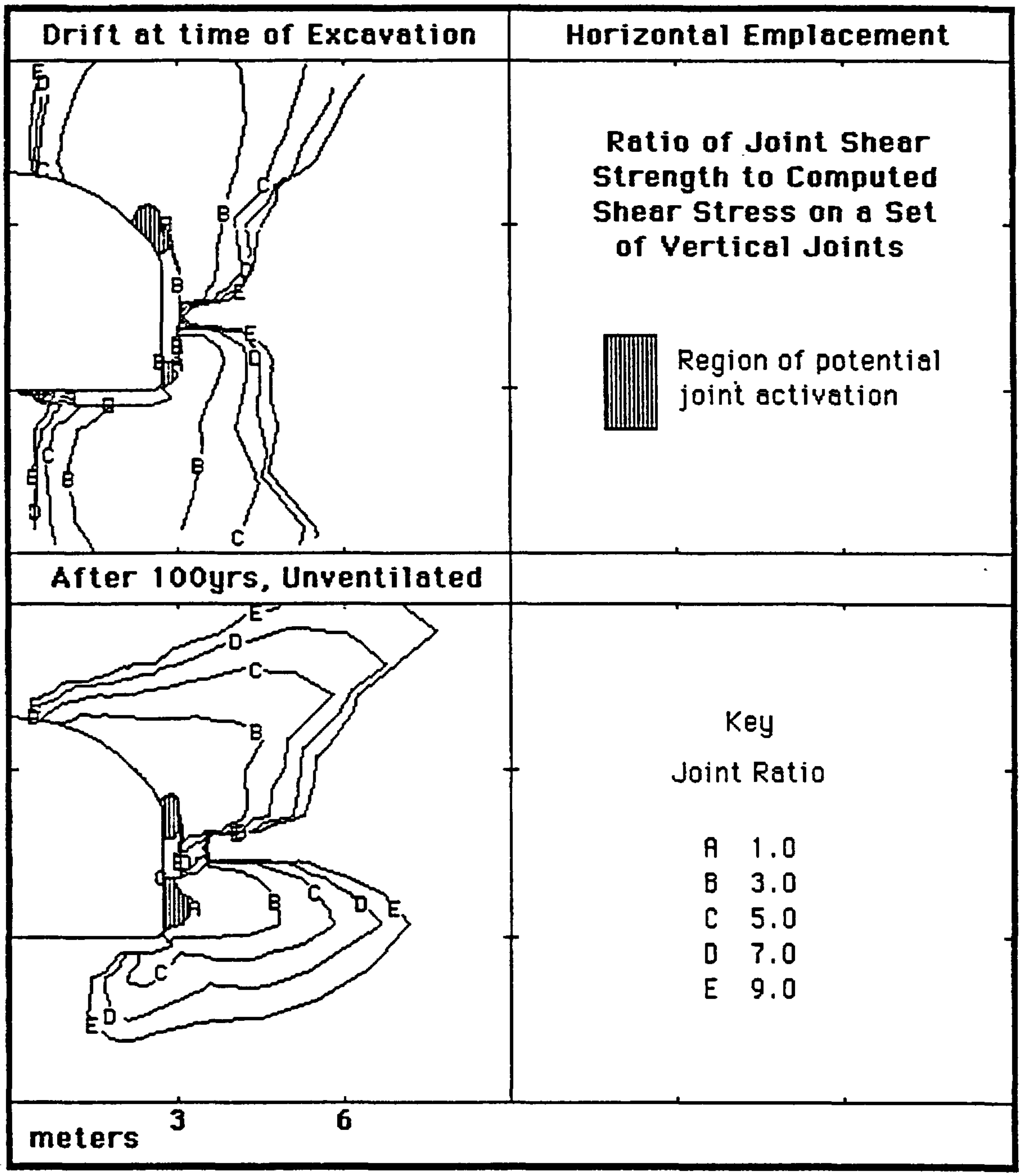


Figure 28. Boundary-Element Predictions of the Ratio Between the Joint Strength and Stress Around the Horizontal Emplacement Drift - Unventilated Drift

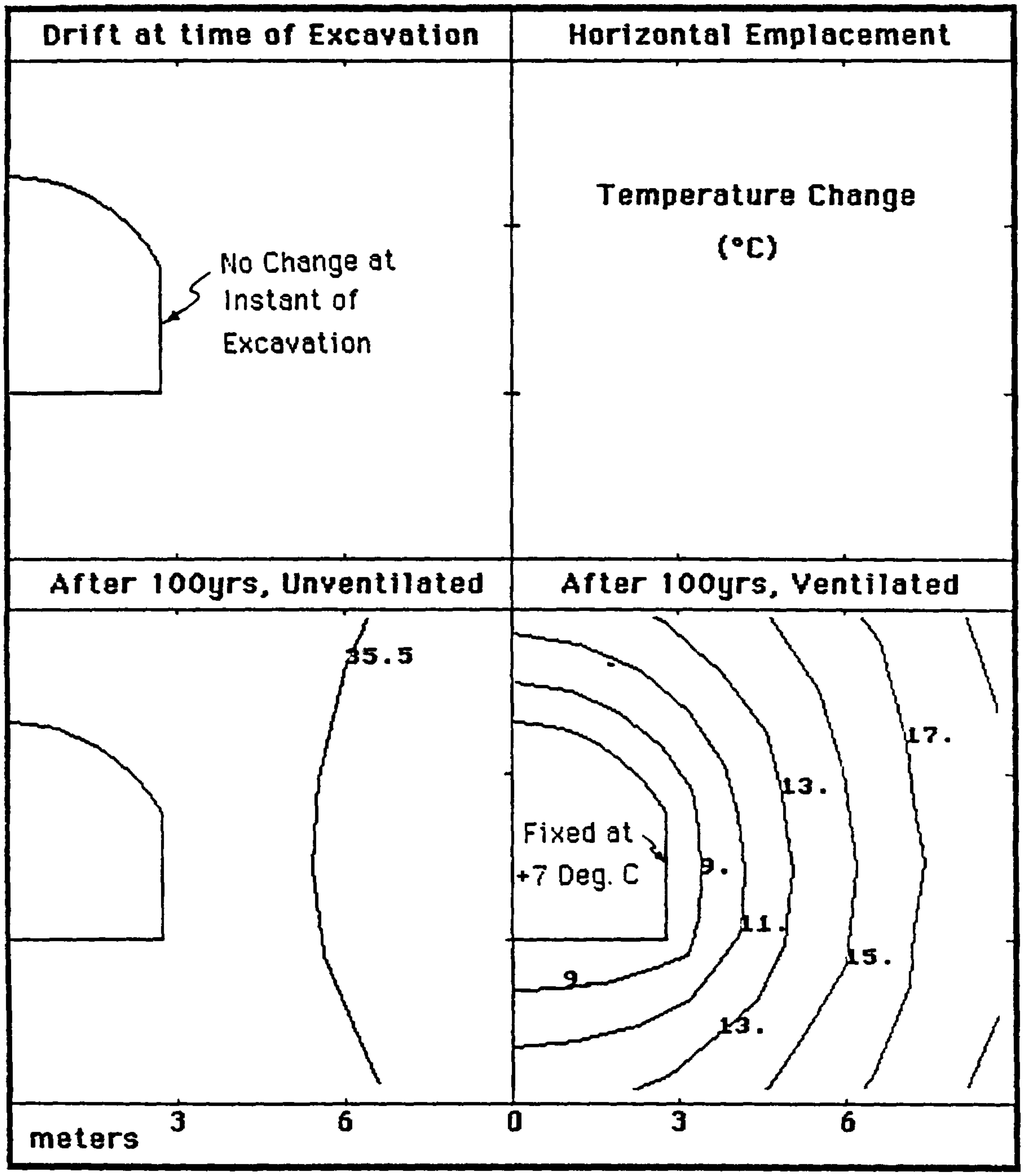


Figure 29. Finite-Element Predictions of the Temperature Changes in the Vicinity of the Horizontal Emplacement Drift 100 Yr After Waste Emplacement

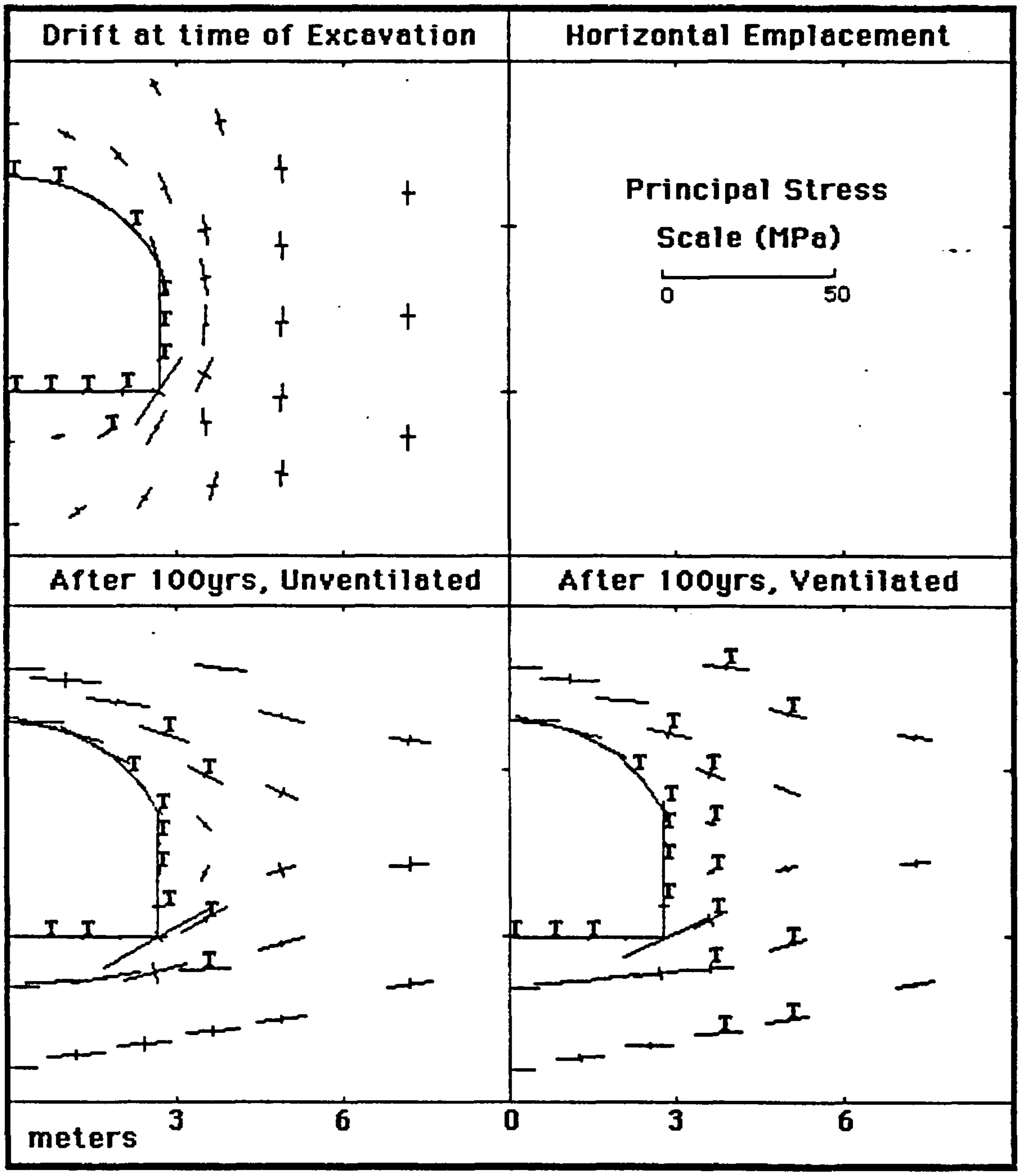


Figure 30. Finite-Element Predictions of the Principal Stresses in the Vicinity of the Horizontal Emplacement Drift

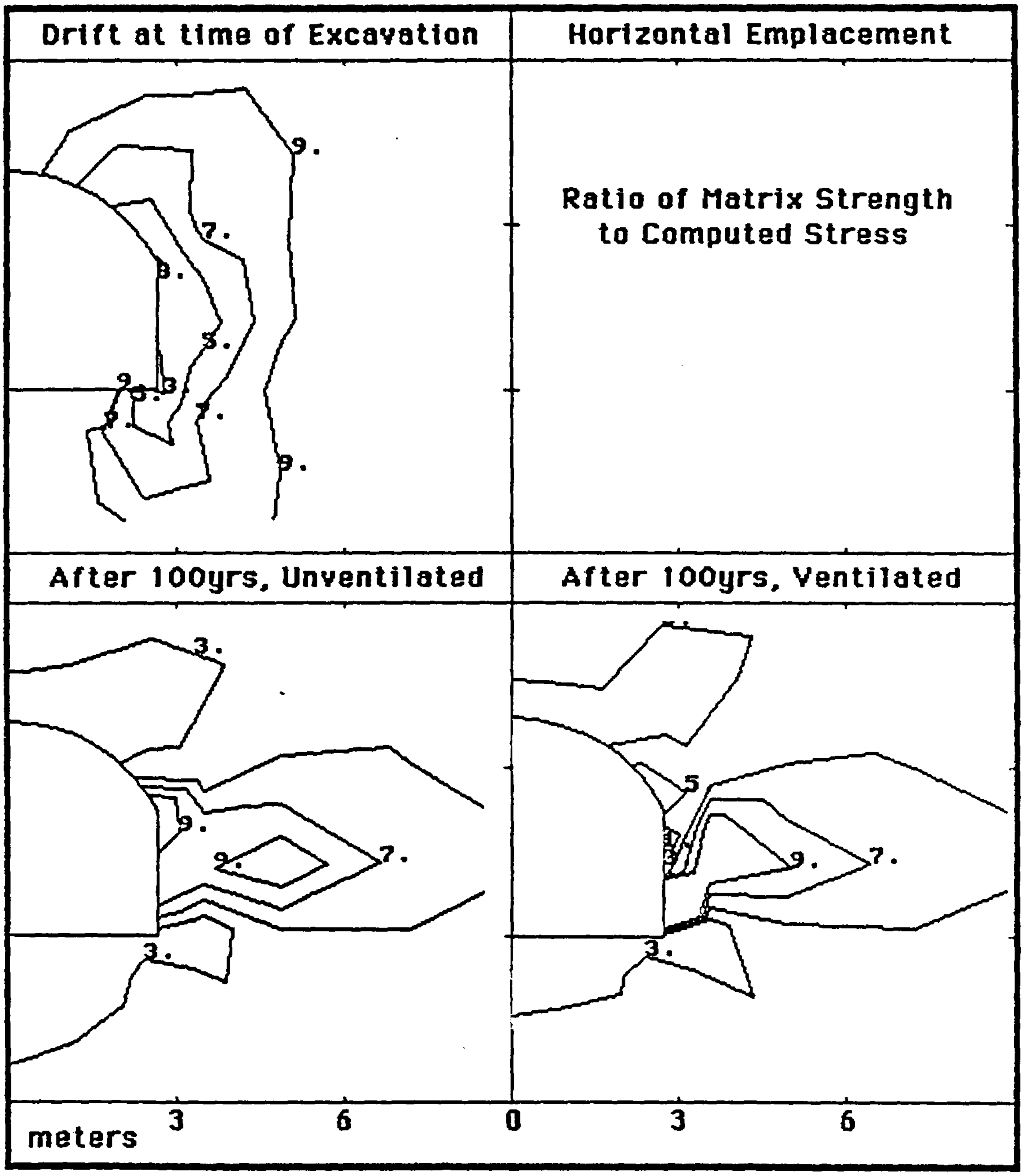


Figure 31. Finite-Element Predictions of the Ratio Between Matrix Strength and Stress Around the Horizontal Emplacement Drift

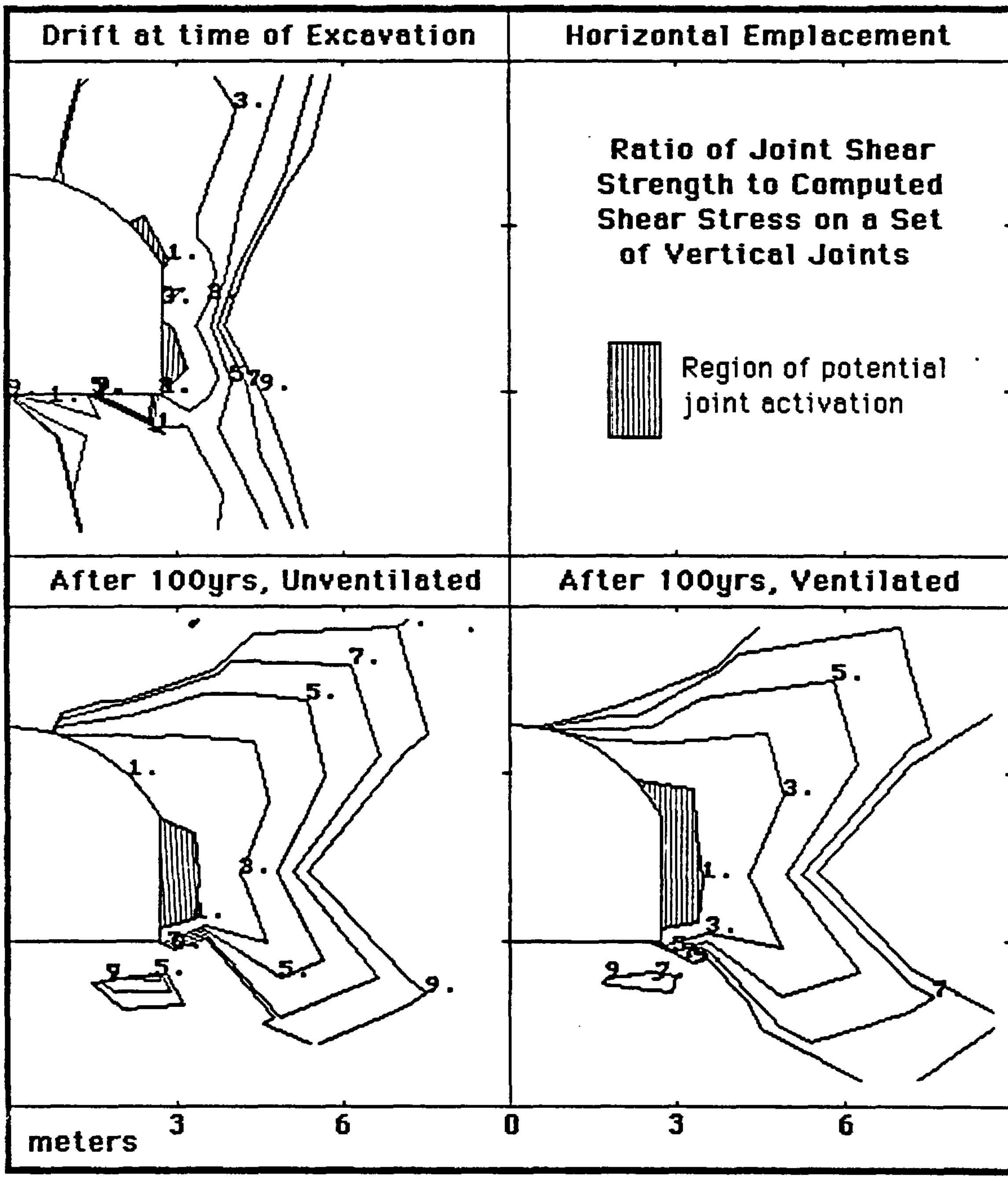


Figure 32. Finite-Element Predictions of the Ratio Between Joint Strength and Stress Around the Horizontal Emplacement Drift

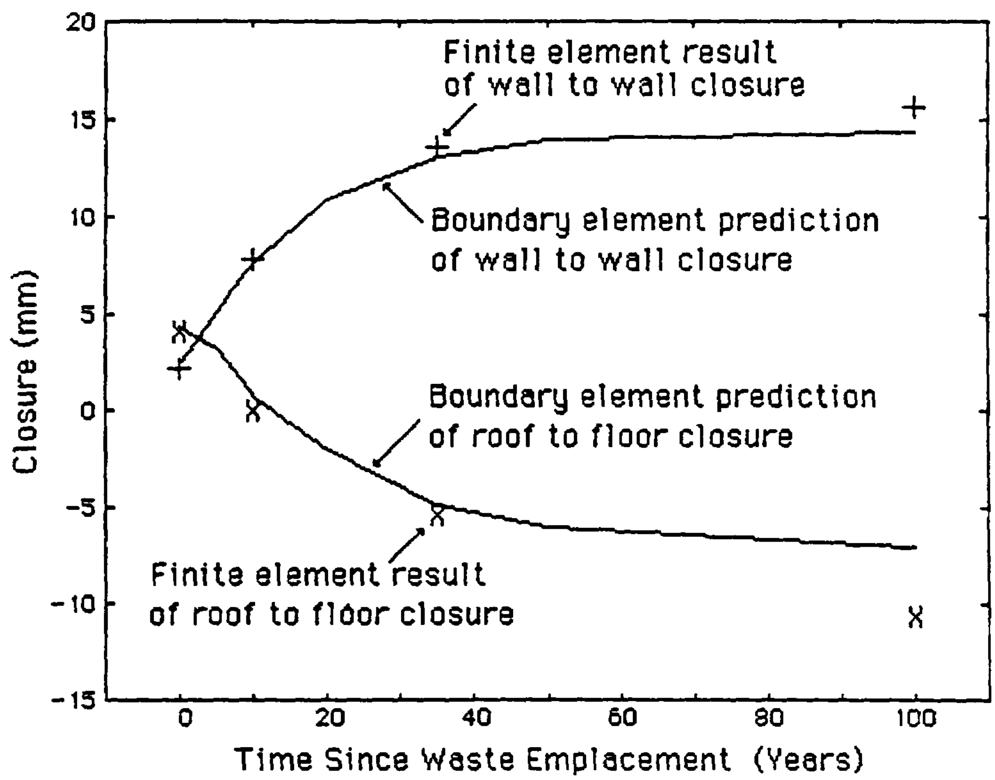


Figure 33. Comparison of Closure Histories For the Drift with No Ventilation, Computed Using Boundary-Element and Finite-Element Models: Vertical Emplacement

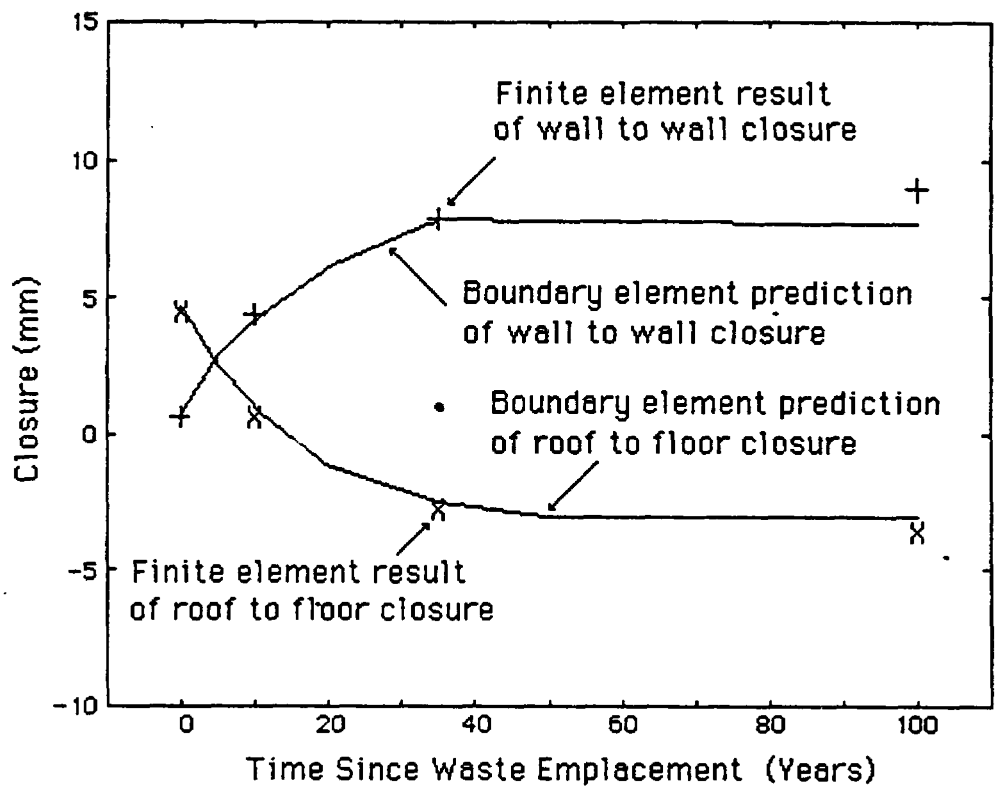


Figure 34. Comparison of Closure Histories for the Drift With No Ventilation, Computed Using Boundary-Element and Finite-Element Models: Horizontal Emplacement

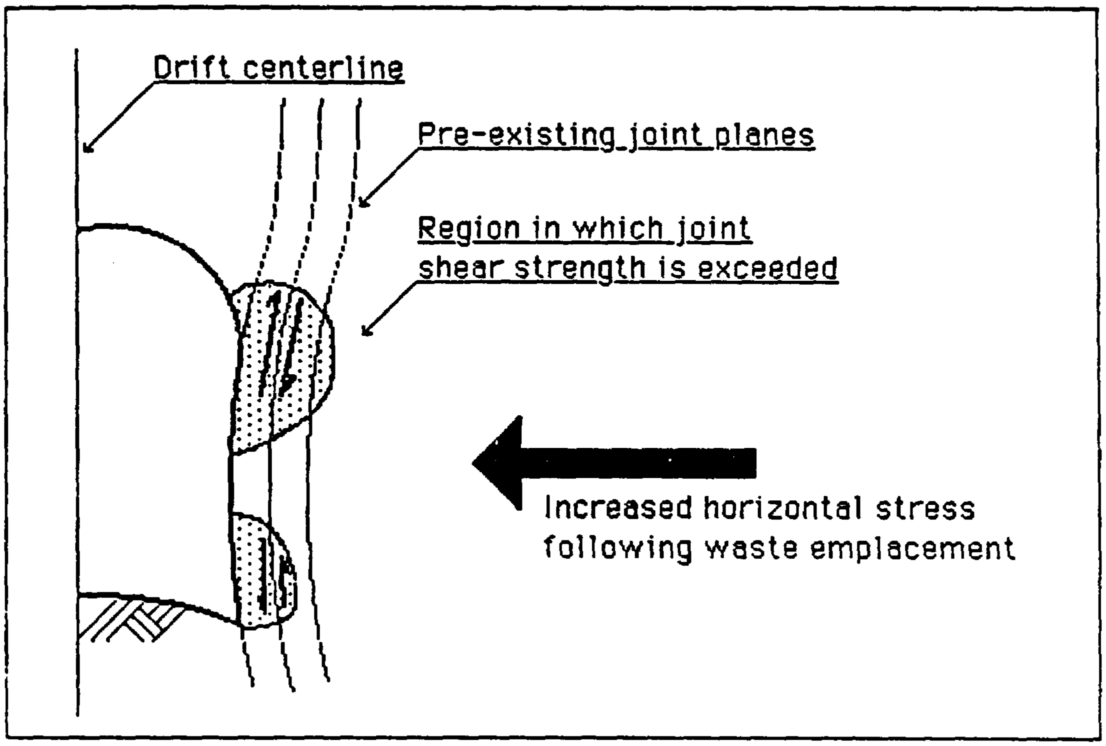


Figure 35. Temperature Histories for Point in the Interior of the Rock Mass

SAND86-7005

REFERENCE THERMAL AND THERMAL/MECHANICAL ANALYSES OF DRIFTS FOR VERTICAL AND HORIZONTAL EMPLACEMENT OF NUCLEAR WASTE IN A REPOSITORY IN TUFF

C.M. St. John
J.F.T. Agapito and Associates, Inc.

Please replace pages 72, 73, and 74 in your copy of this report with the attached new pages. Thank you.

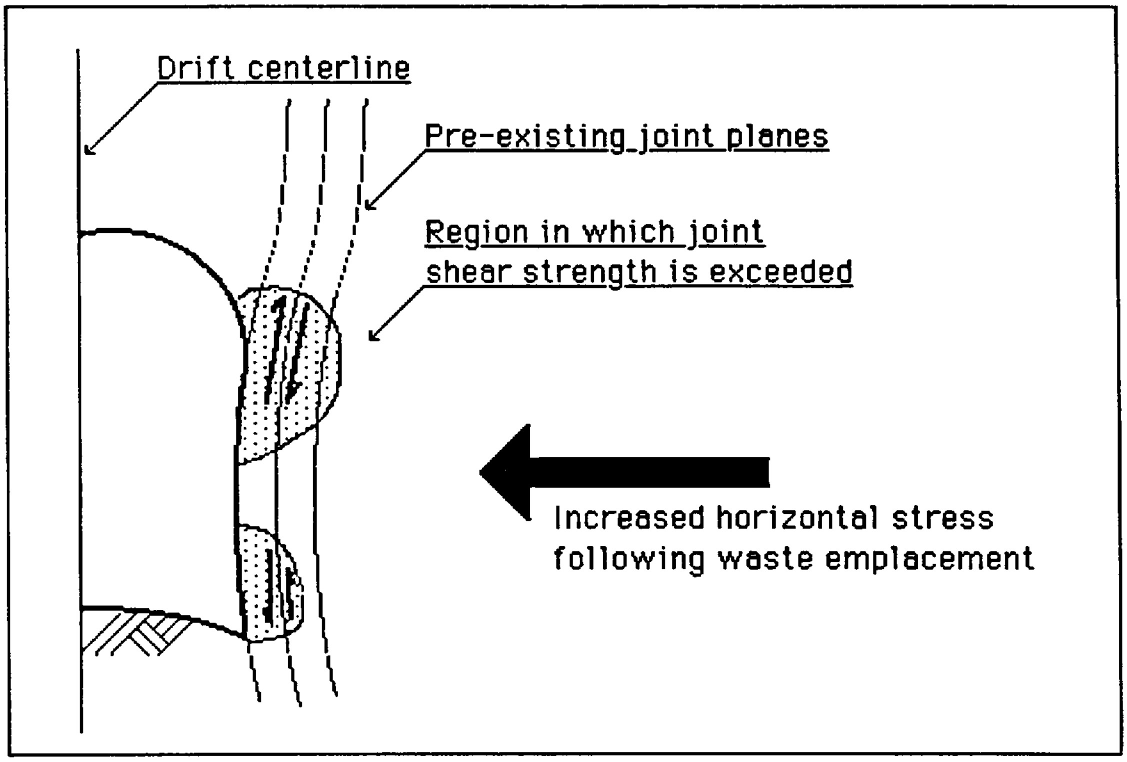


Figure 35. Conceptual Interpretation of the Development of Regions in which the Shear Stress on Vertical Joints Exceeds their Shear Strength

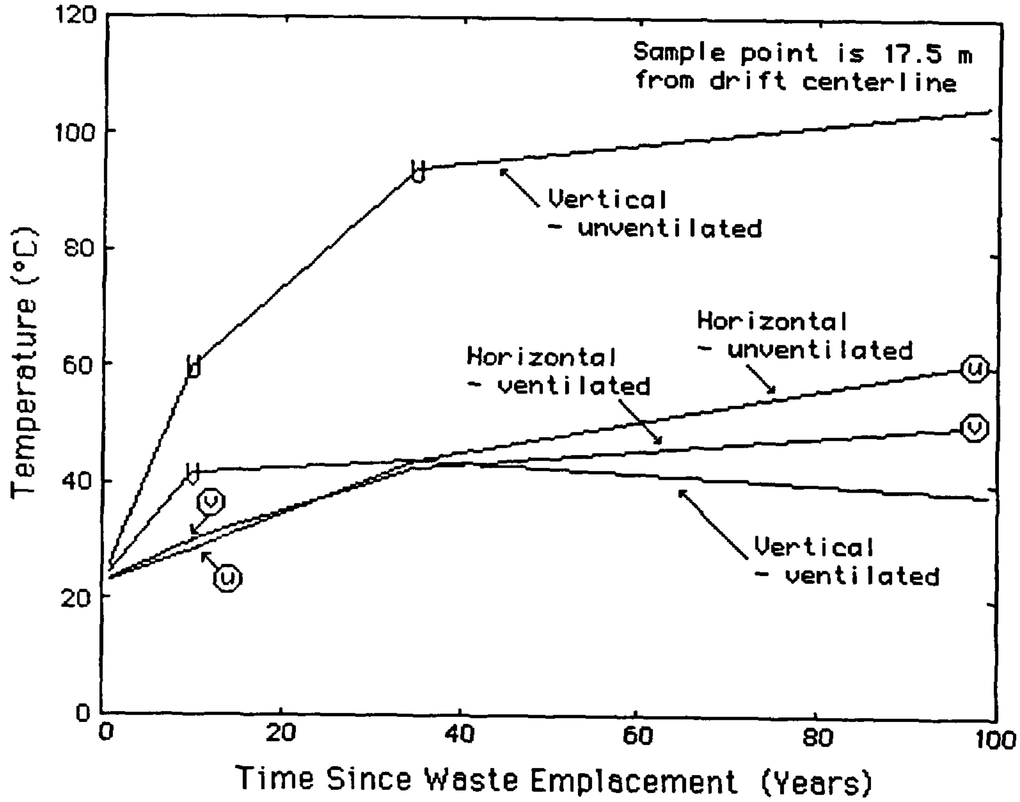


Figure 36. Temperature Histories for Point in the Interior of the Rock Mass

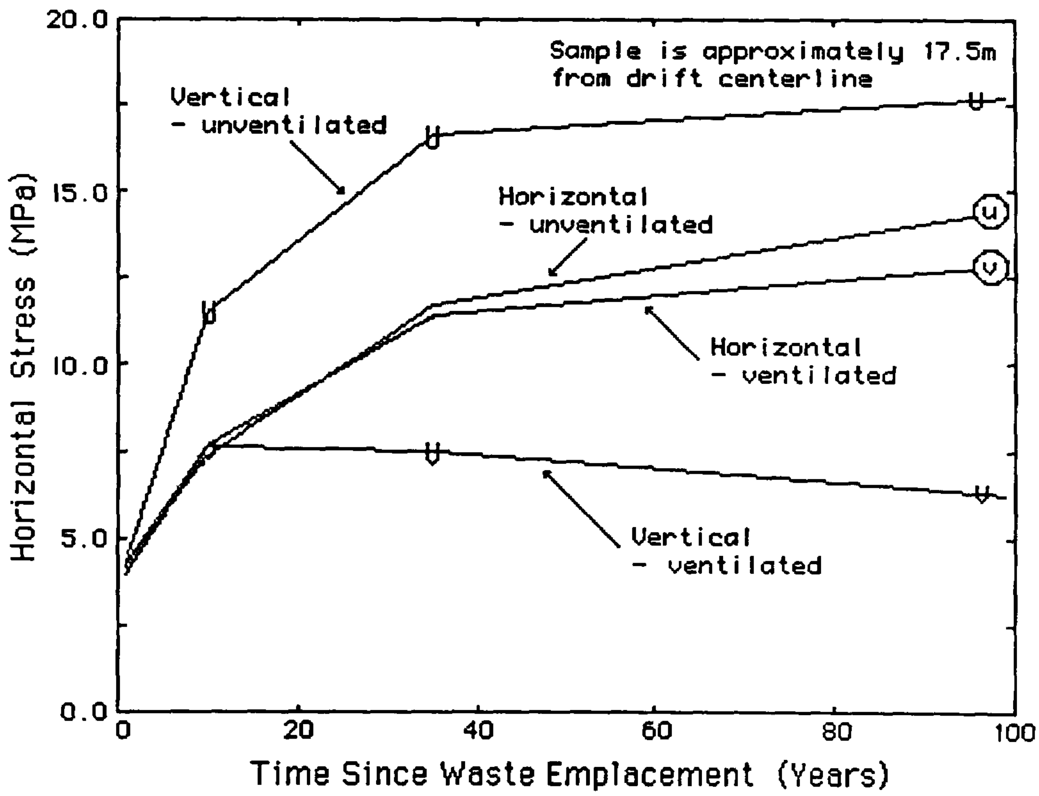


Figure 37. Approximate Histories of the Horizontal Stresses to which the Waste Emplacement Drifts are Subjected

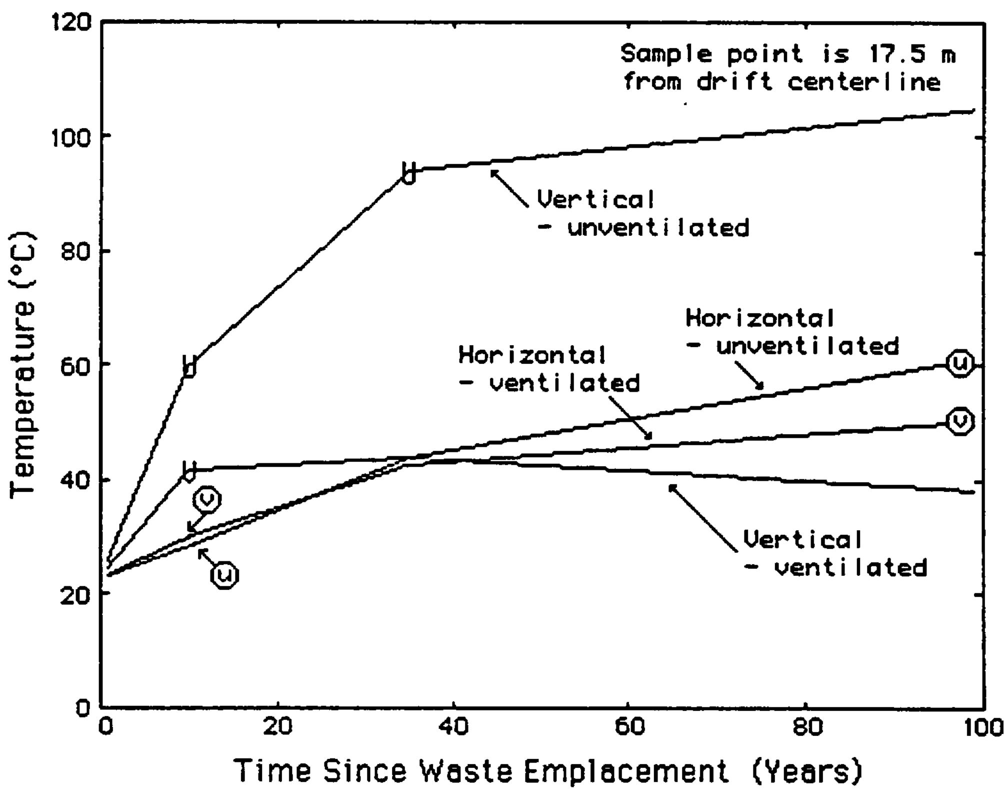


Figure 36. Approximate Histories of the Horizontal Stresses to which the Waste Emplacement Drifts are Subjected

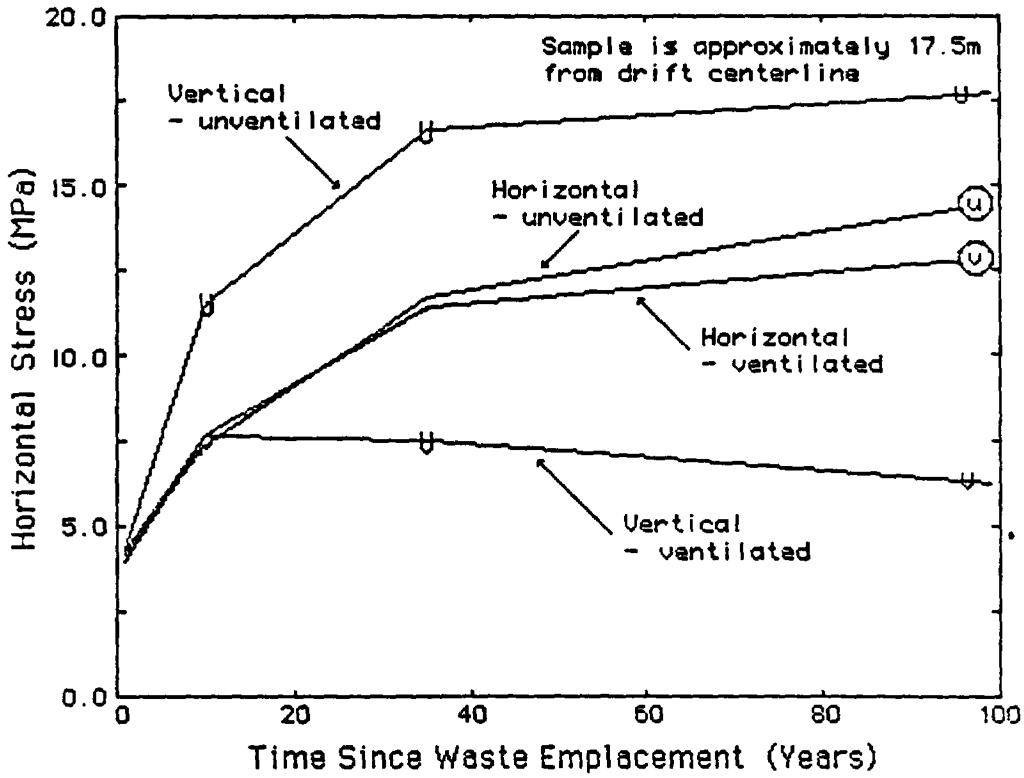


Figure 37. Conceptual Interpretation of the Development of Regions in which the Shear Stress on Vertical Joints Exceeds their Shear Strength

APPENDIX A

BOUNDARY-ELEMENT ANALYSES OF VERTICAL EMPLACEMENT

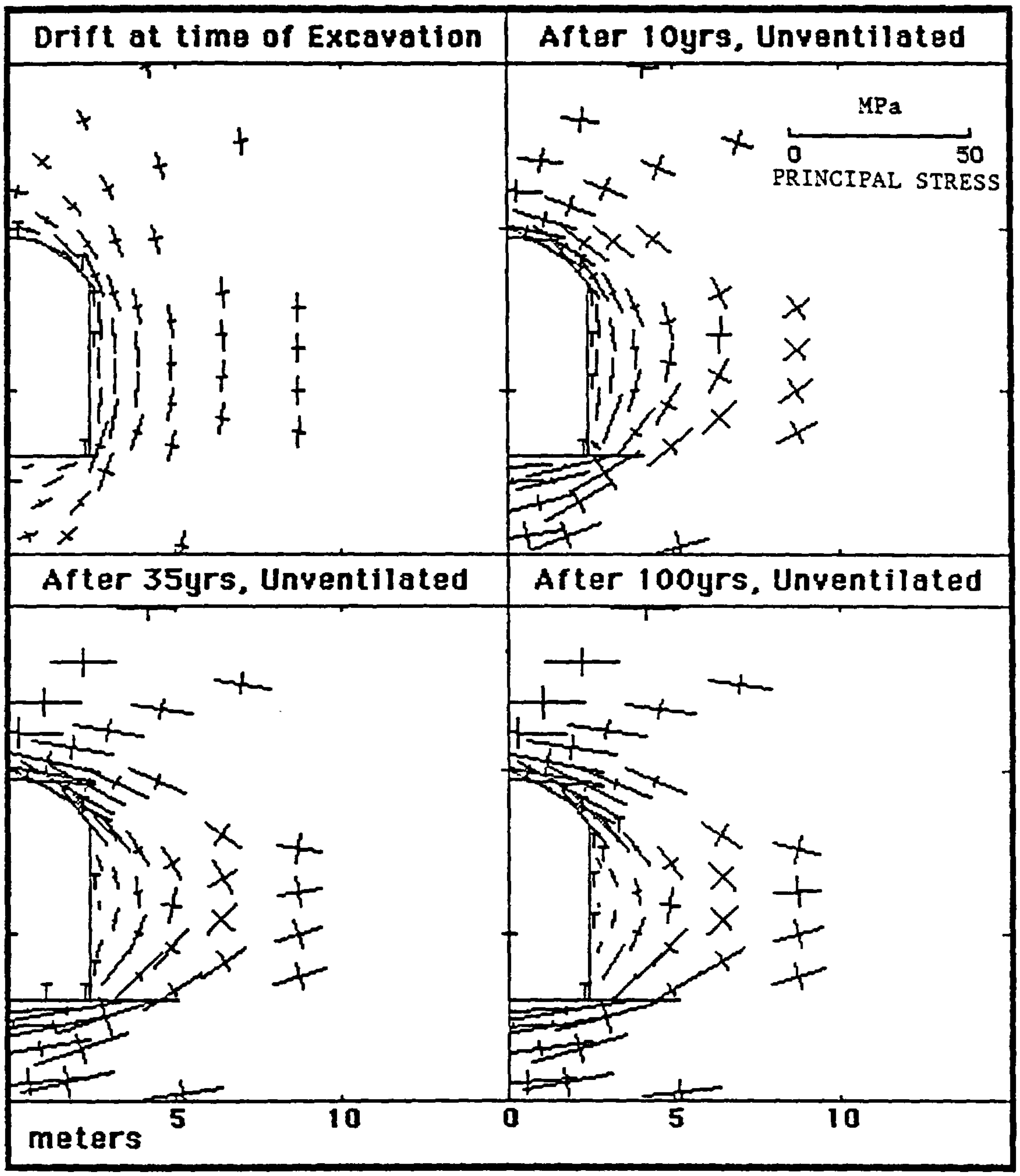


Figure A.1 Boundary-Element Predictions of Principal Stresses in the Vicinity of the Vertical Emplacement Drift, at Times up to 100 Yr After Waste Emplacement - Unventilated Drift

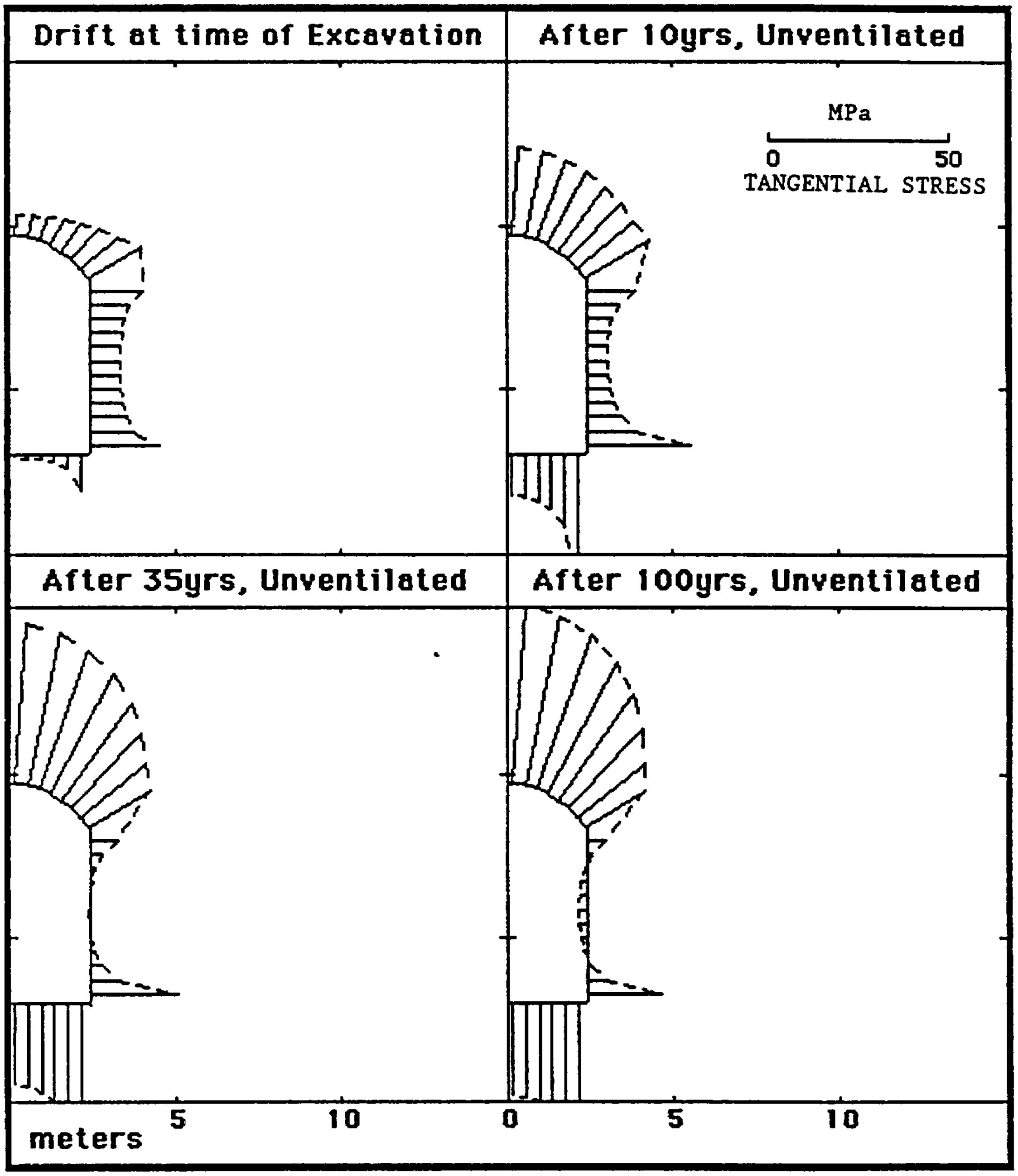


Figure A.2 Boundary-Element Predictions of Tangential Stress Distribution Around the Vertical Emplacement Drift, at Times up to 100 Yr After Waste Emplacement - Unventilated Drift

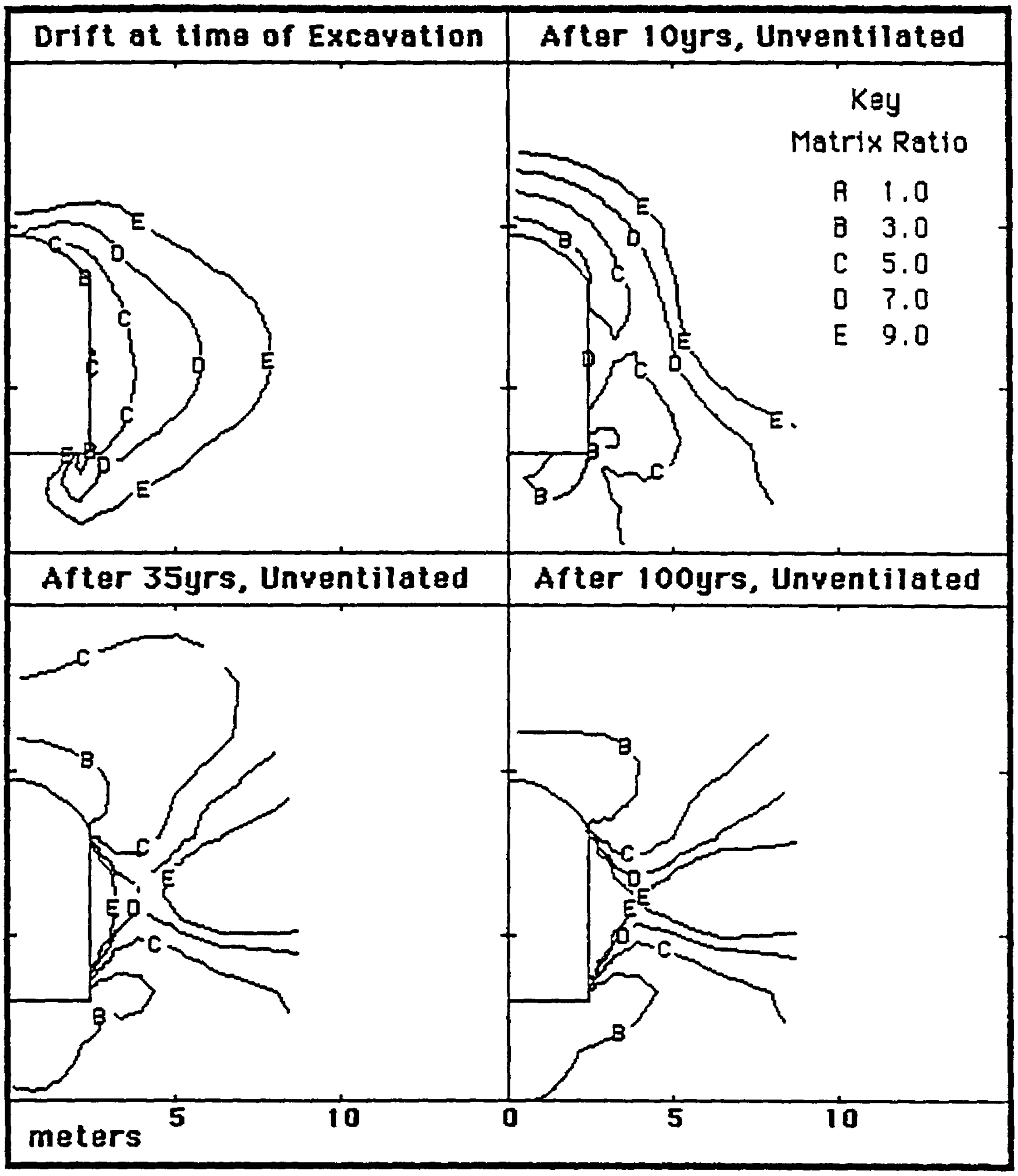


Figure A.3 Boundary-Element Predictions of the Ratio Between the Matrix Strength and Stress Around the Vertical Emplacement Drift, at Times up to 100 Yr After Waste Emplacement - Unventilated Drift

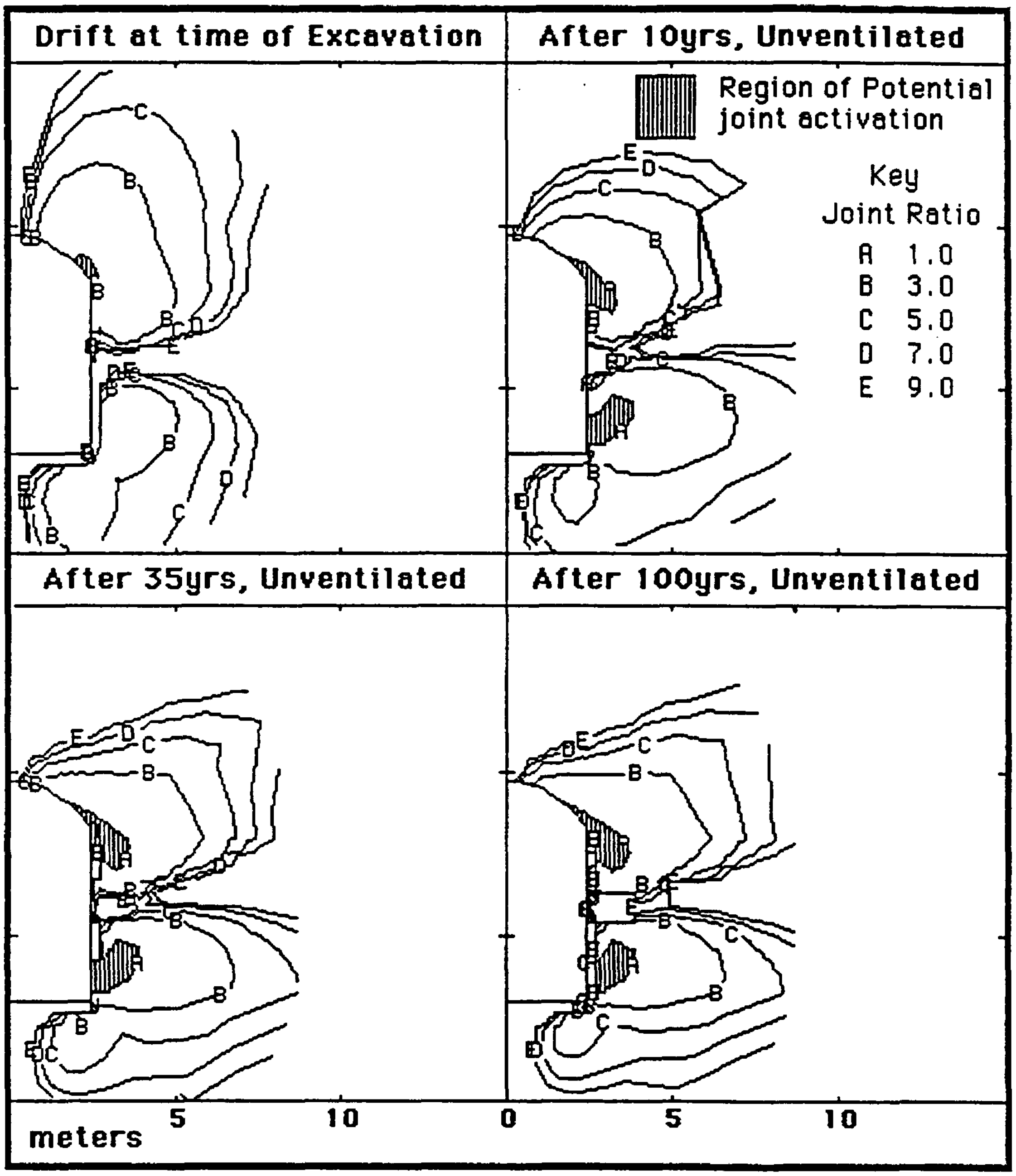


Figure A.4 Boundary-Element Predictions of the Ratio Between the Joint Strength and Stress Around the Vertical Emplacement Drift, at Times up to 100 Yr After Waste Emplacement - Unventilated Drift

APPENDIX B

FINITE-ELEMENT ANALYSES OF VERTICAL EMPLACEMENT

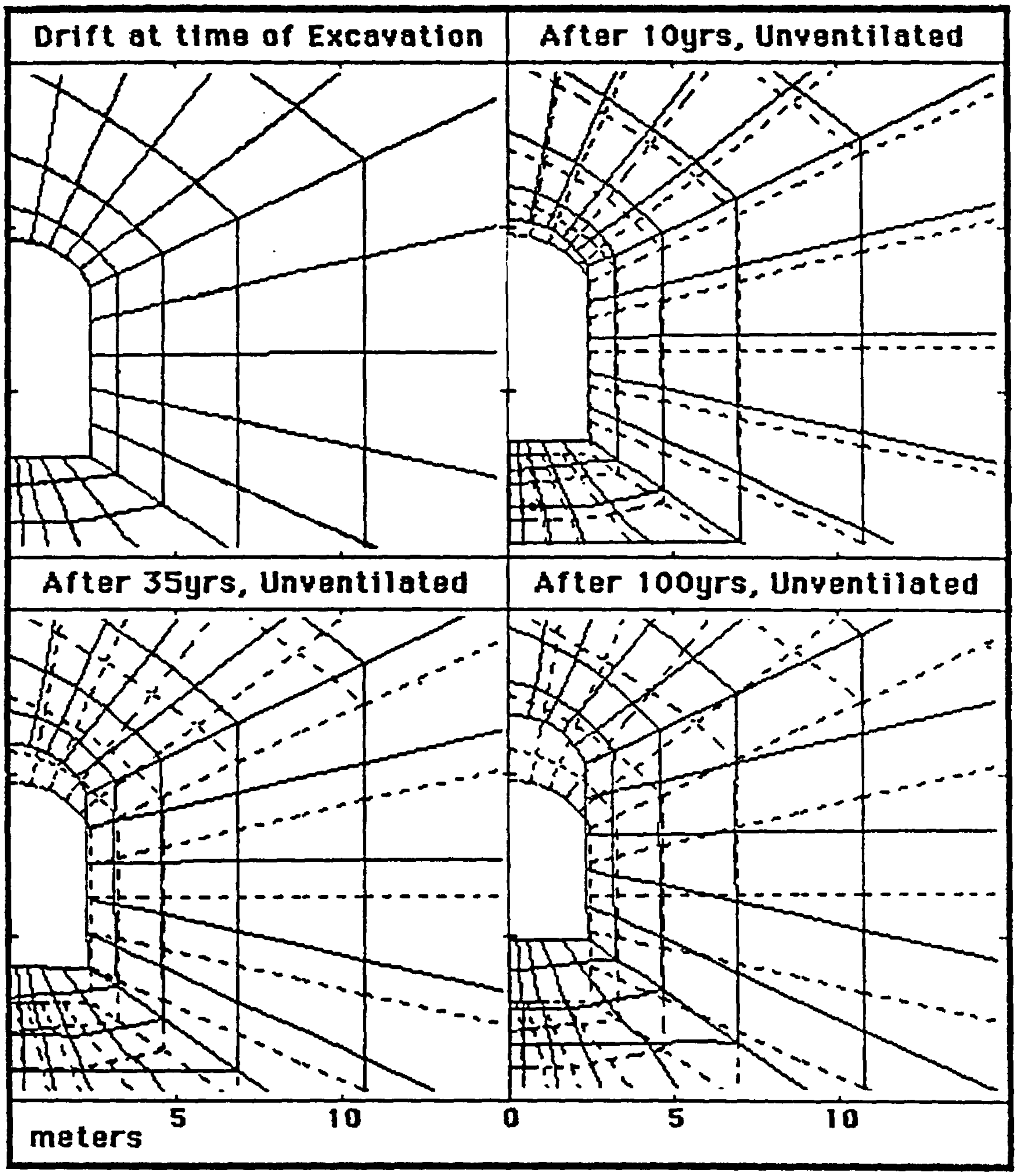


Figure B.1a Finite-Element Prediction of Deformations in the Vicinity of the Vertical Emplacement Drift, at Times up to 100 Yr After Waste Emplacement - Unventilated Case. (The displacement scale is magnified 20 times relative to the geometric scale. Deformed rock is shown with the solid lines. The deformations are measured relative to the pre-excavation state.)

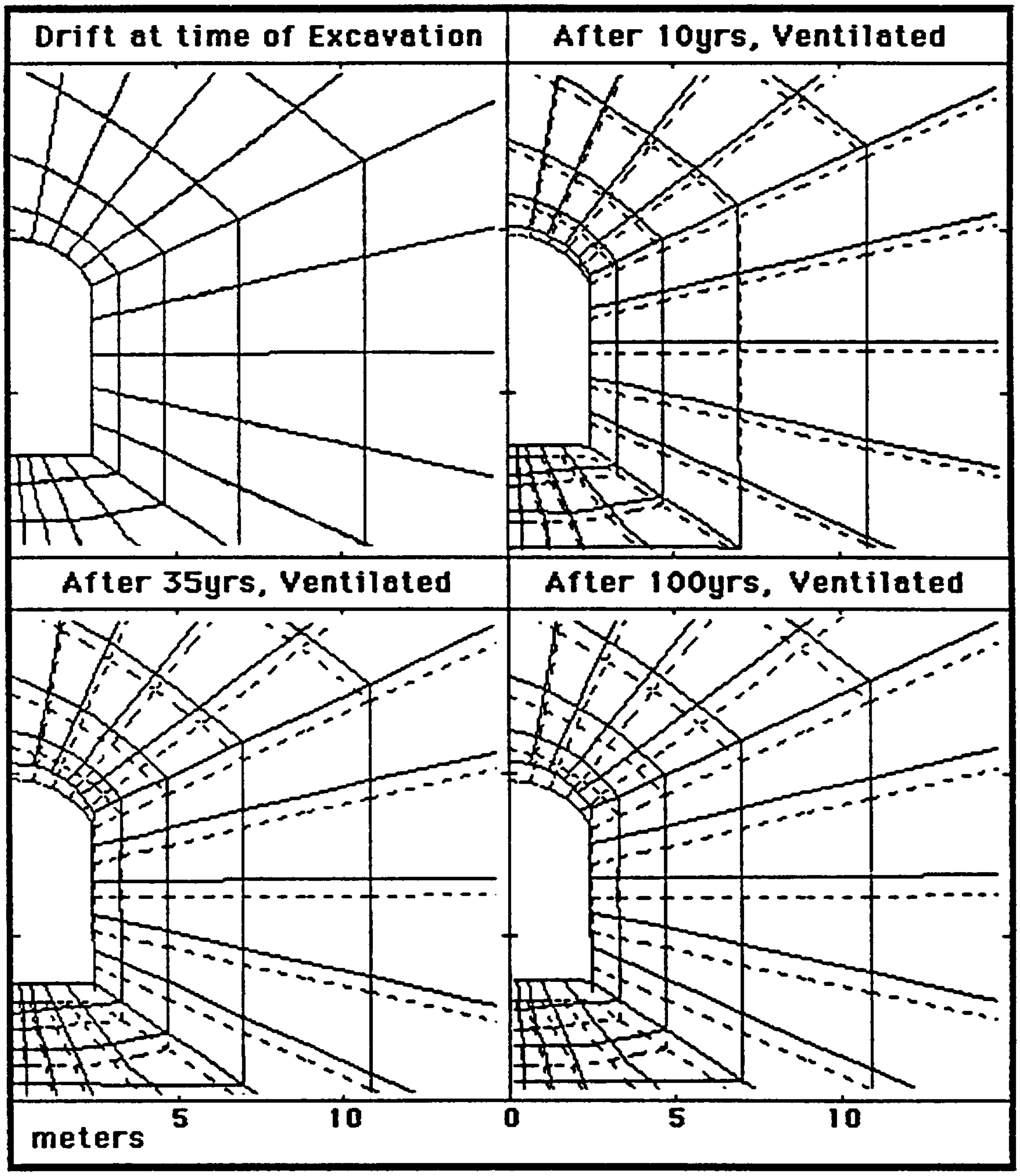


Figure B.1b Finite-Element Prediction of Deformations in the Vicinity of the Vertical Emplacement Drift, at Times up to 100 Yr After Waste Emplacement - Ventilated Case. (The displacement scale is magnified 20 times relative to the geometric scale. Deformed rock is shown with the solid lines. The deformations are measured relative to the pre-excavation state.)

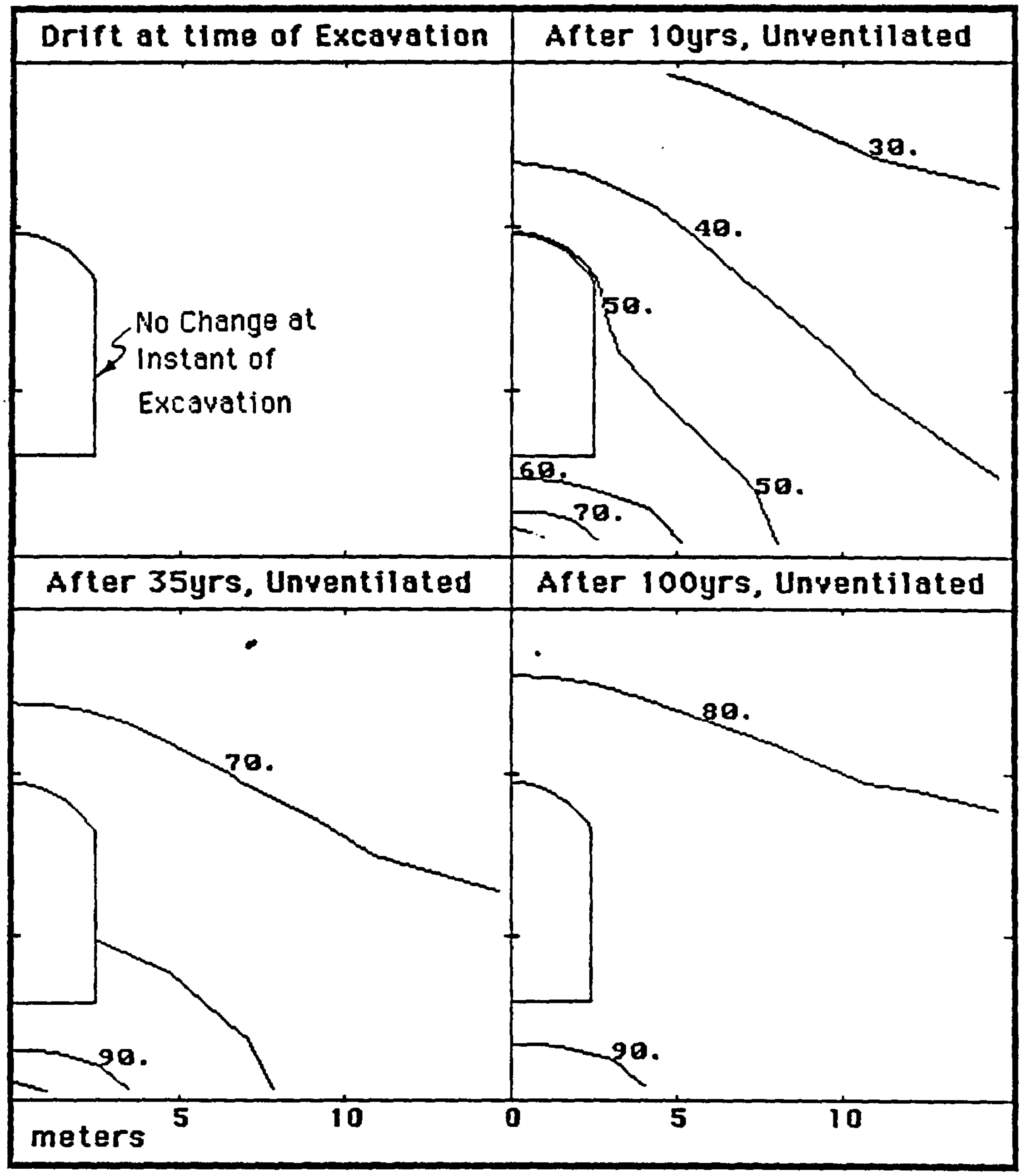


Figure B.2a Finite-Element Predictions of the Temperature Changes (°C) in the Vicinity of the Vertical Emplacement Drift, at Times up to 100 Yr After Waste Emplacement - Unventilated Case

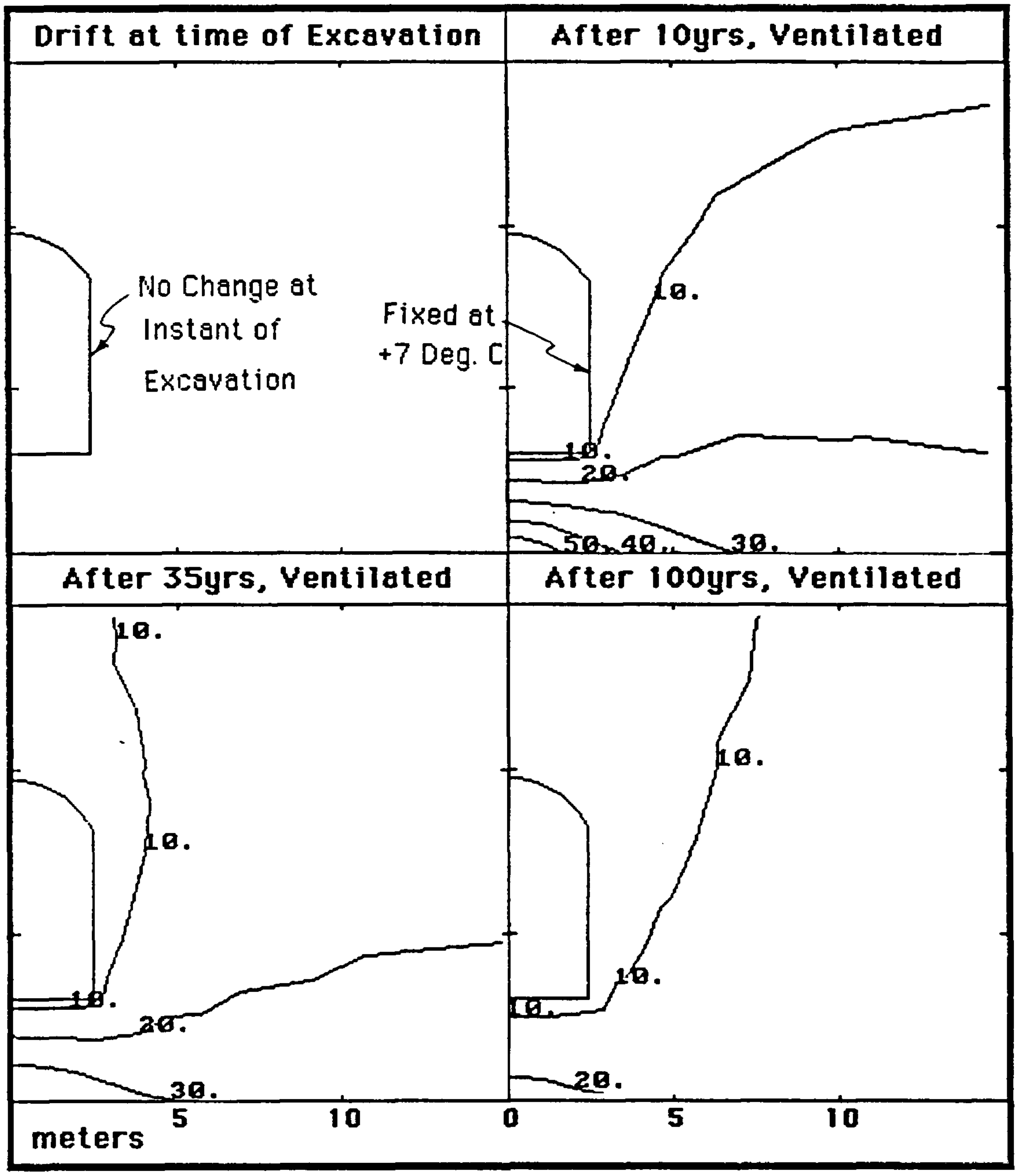


Figure B.2b Finite-Element Predictions of the Temperature Changes (°C) in the Vicinity of the Vertical Emplacement Drift, at Times up to 100 Yr After Waste Emplacement - Ventilated Case

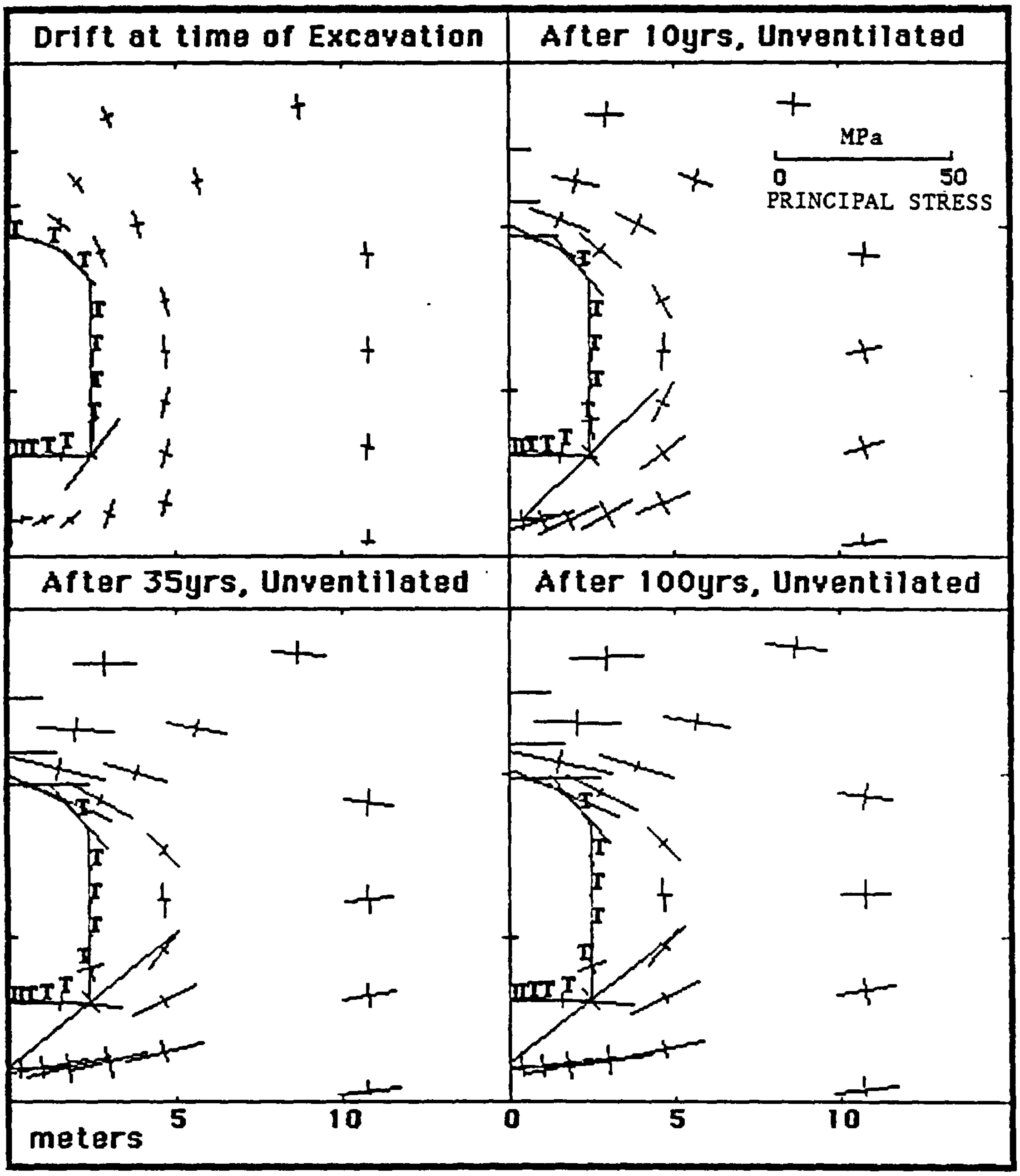


Figure B.3a Finite-Element Predictions of the Principal Stresses in the Vicinity of the Vertical Emplacement Drift, at Times up to 100 Yr After Waste Emplacement - Unventilated Case

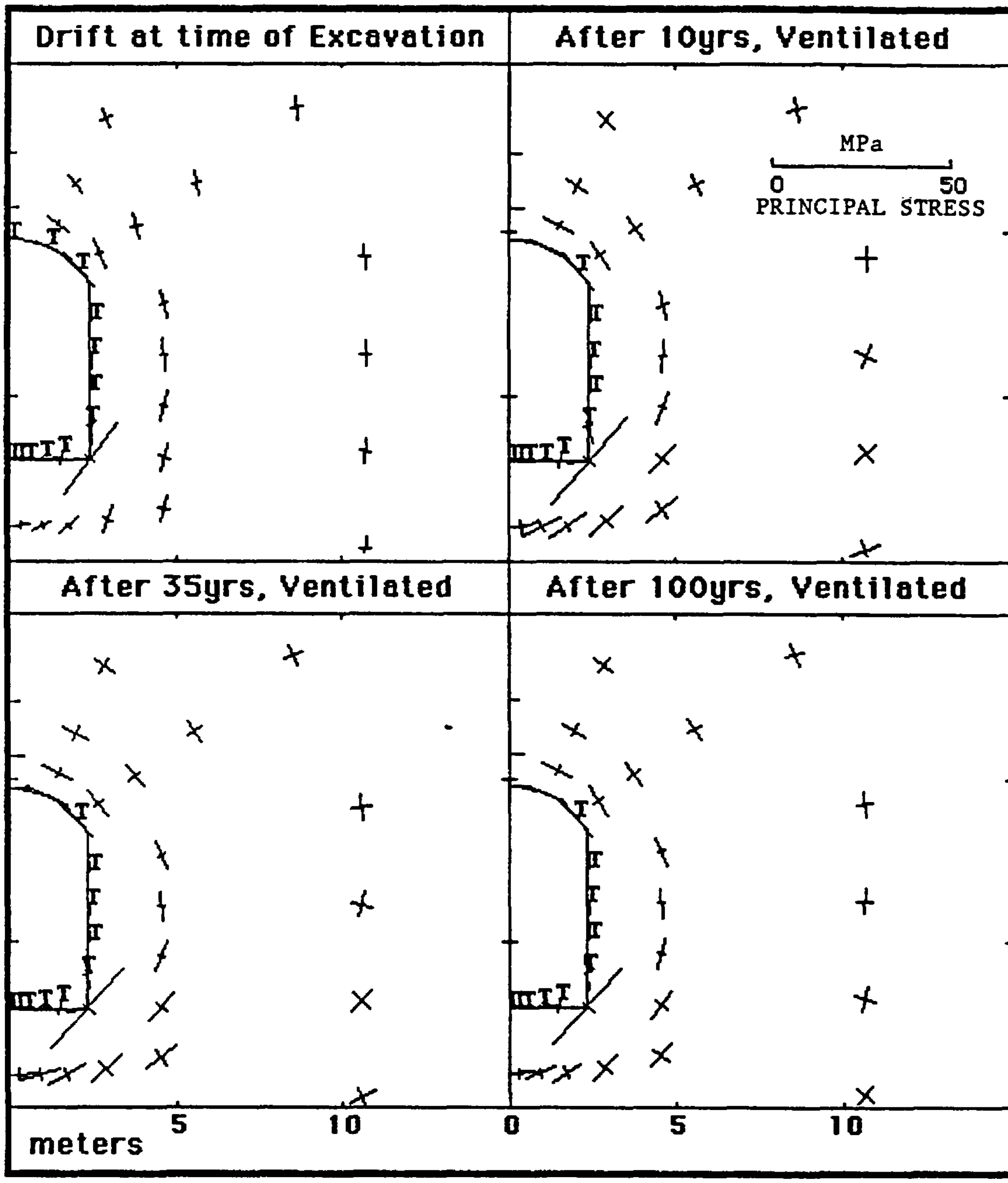


Figure B.3b Finite-Element Predictions of the Principal Stresses in the Vicinity of the Vertical Emplacement Drift, at Times up to 100 Yr After Waste Emplacement - Ventilated Case

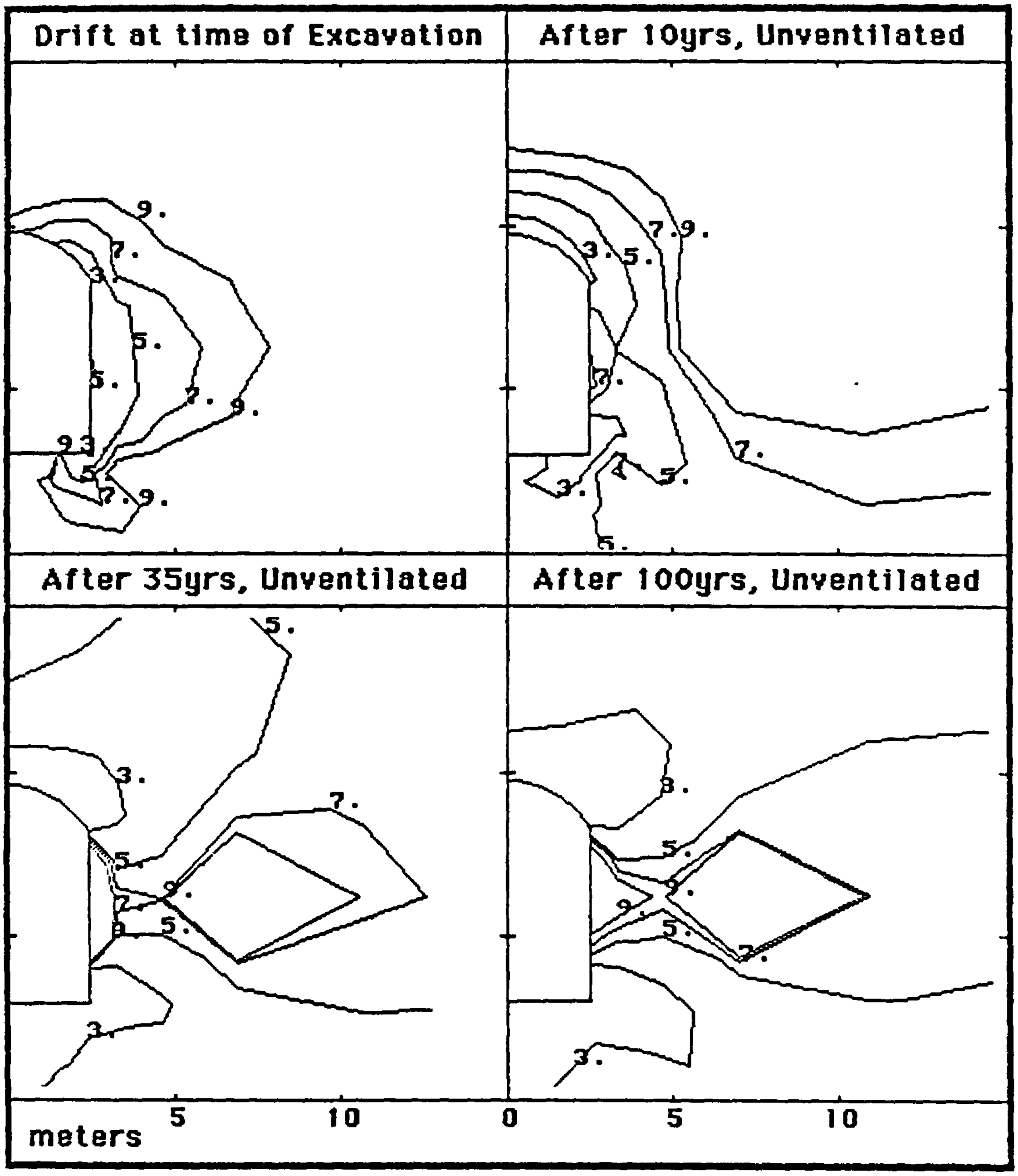


Figure B.4a Finite-Element Predictions of the Ratio Between Matrix Strength and Stress Around the Vertical Emplacement Drift, at Times up to 100 Yr After Waste Emplacement - Unventilated Case

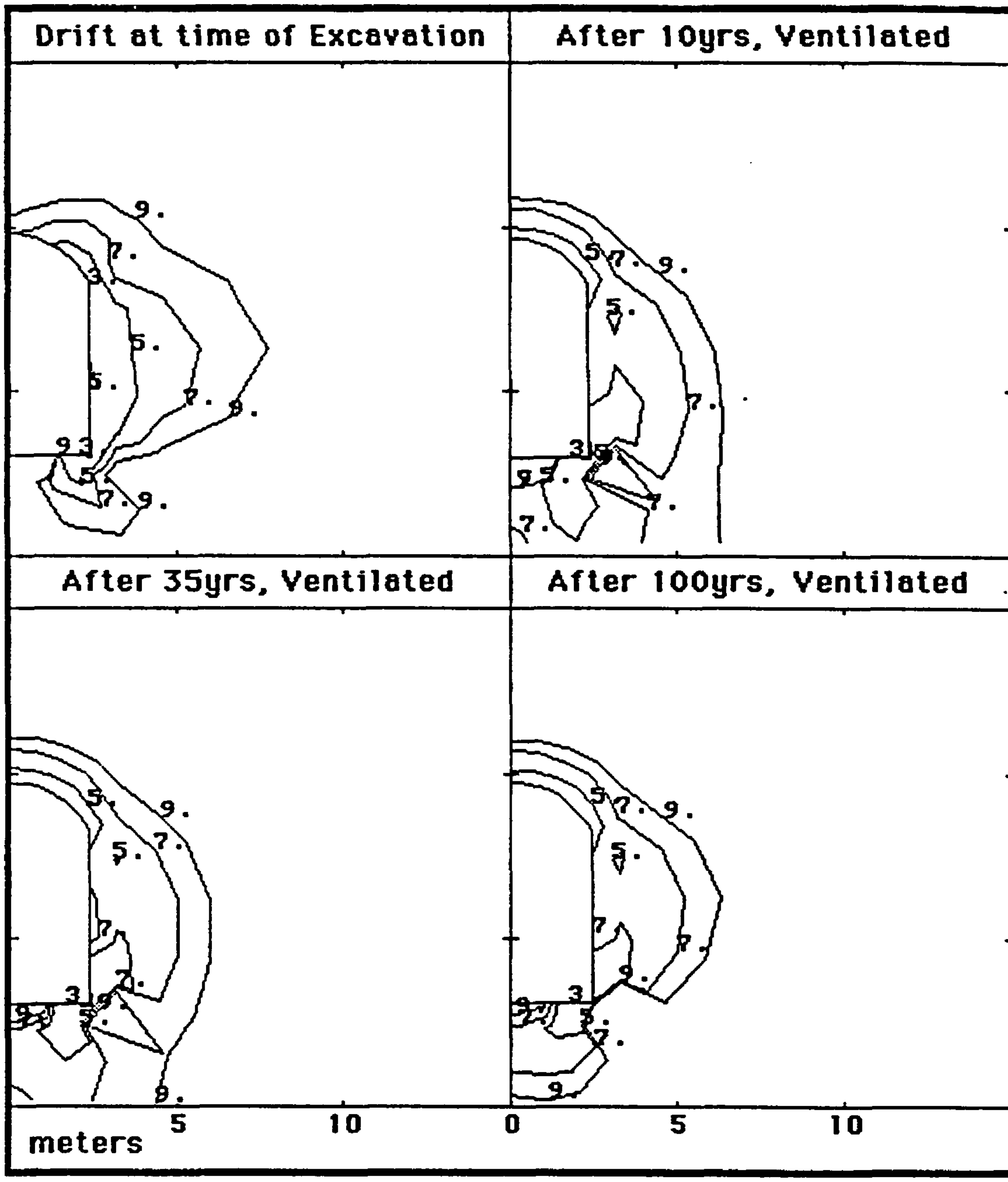


Figure B.4b Finite-Element Predictions of the Ratio Between Matrix Strength and Stress Around the Vertical Emplacement Drift, at Times up to 100 Yr After Waste Emplacement - Ventilated Case

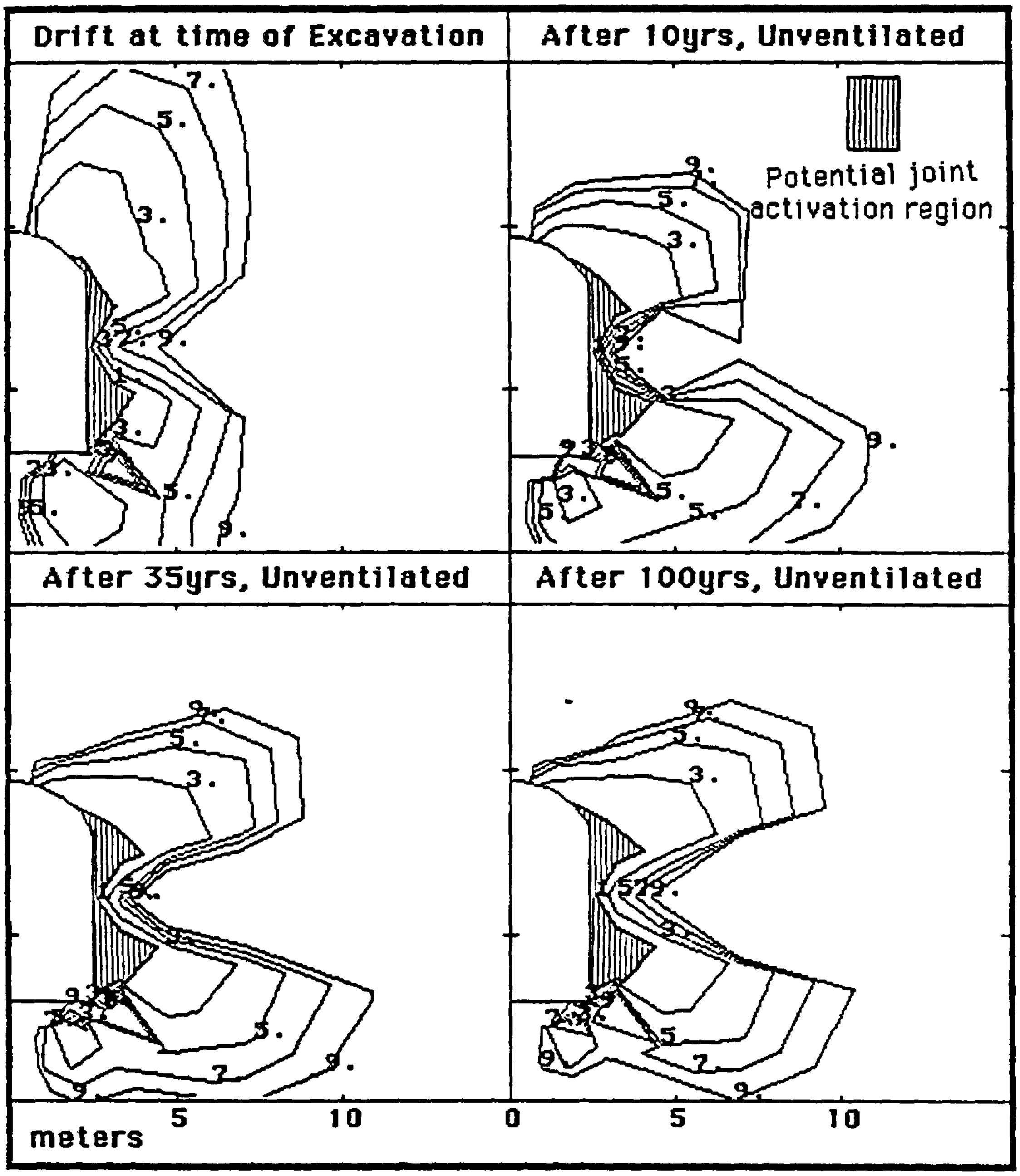


Figure B.5a Finite-Element Predictions of the Ratio Between Joint Strength and Stress Around the Vertical Emplacement Drift, at Times up to 100 Yr After Waste Emplacement - Unventilated Case

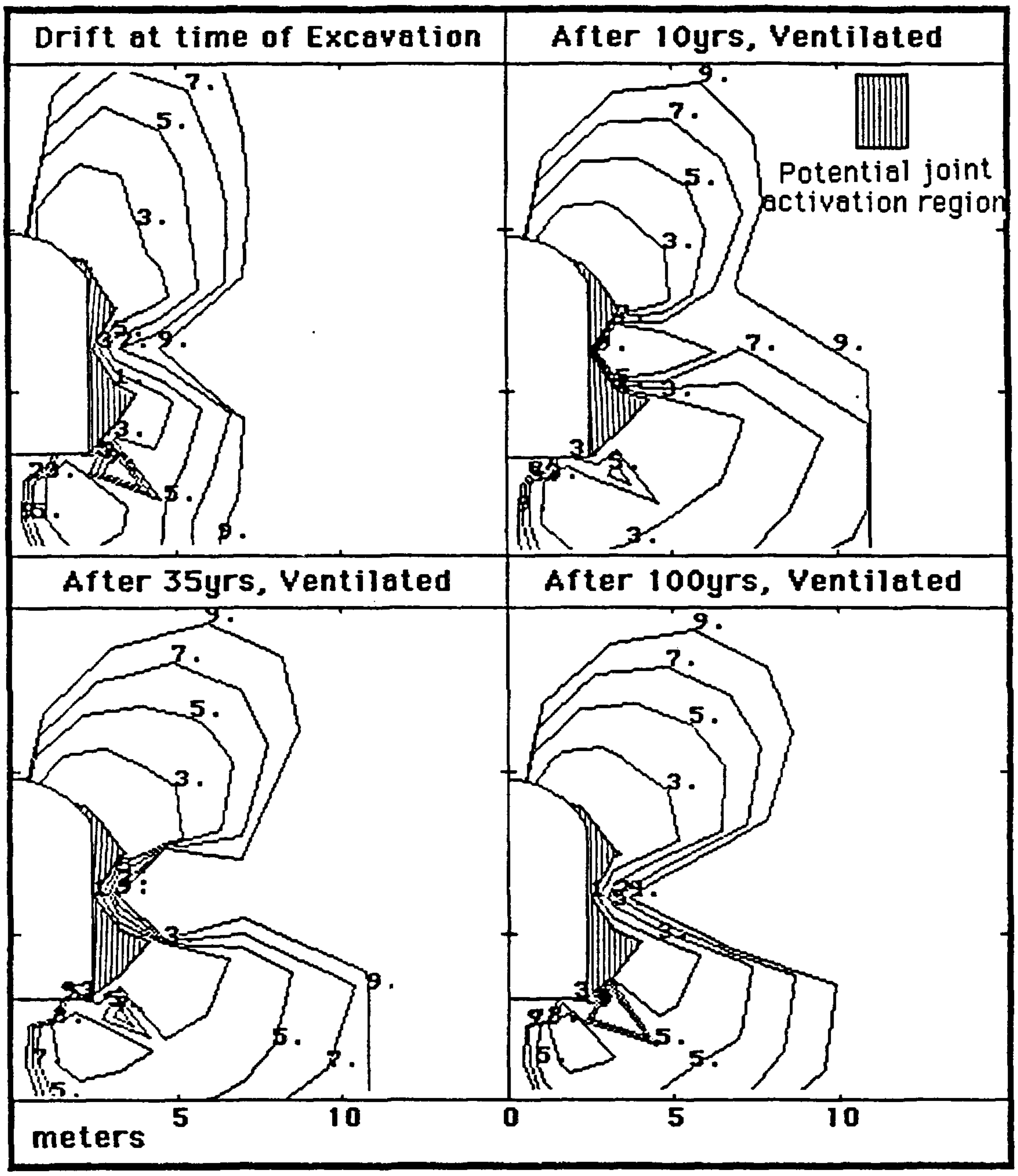


Figure B.5b Finite-Element Predictions of the Ratio Between Joint Strength and Stress Around the Vertical Emplacement Drift, at Times up to 100 Yr After Waste Emplacement - Ventilated Case

APPENDIX C

BOUNDARY-ELEMENT ANALYSES OF HORIZONTAL EMPLACEMENT

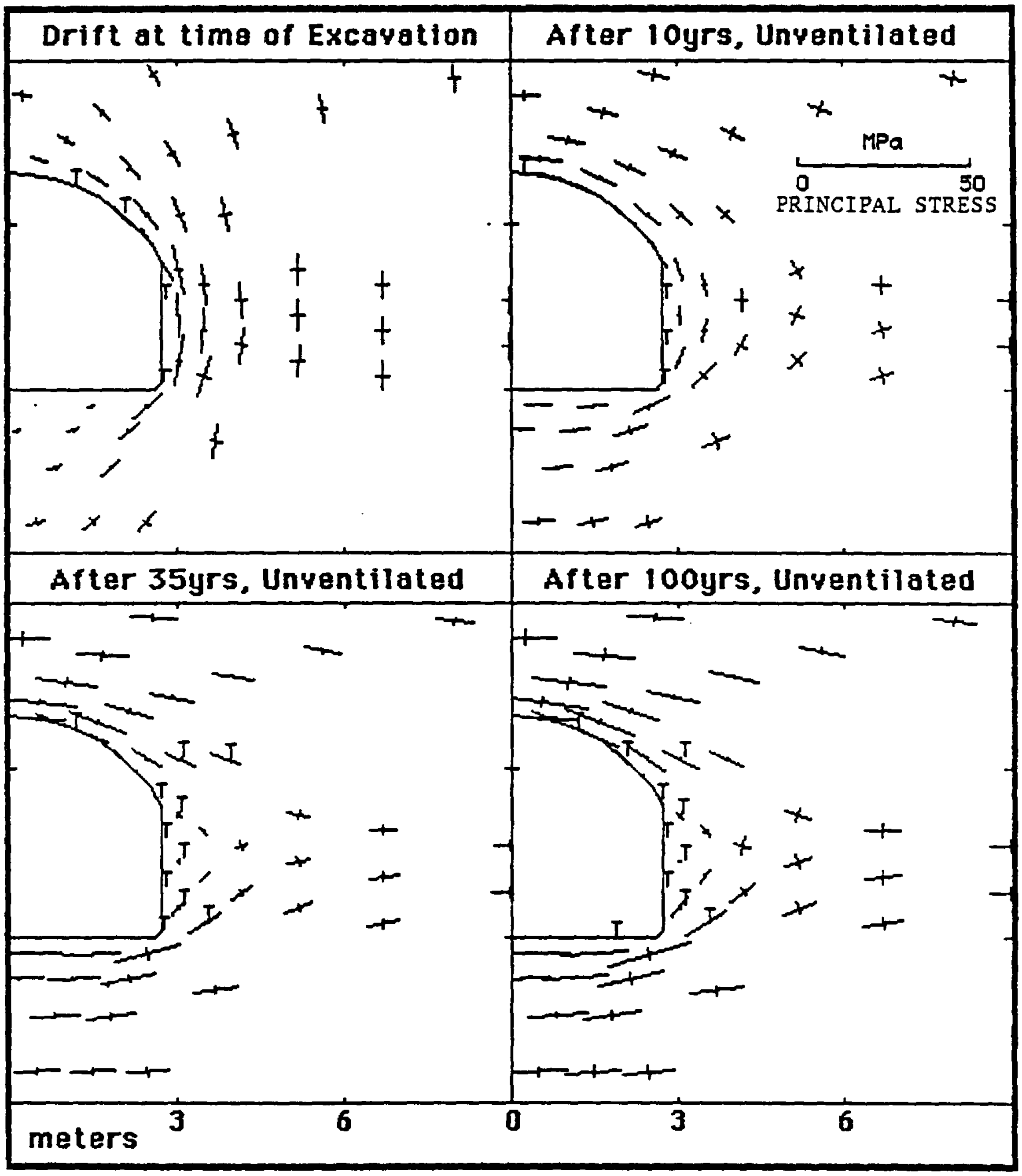


Figure C.1 Boundary-Element Predictions of Principal Stresses in the Vicinity of the Horizontal Emplacement Drift, at Times up to 100 Yr After Waste Emplacement - Unventilated Drift

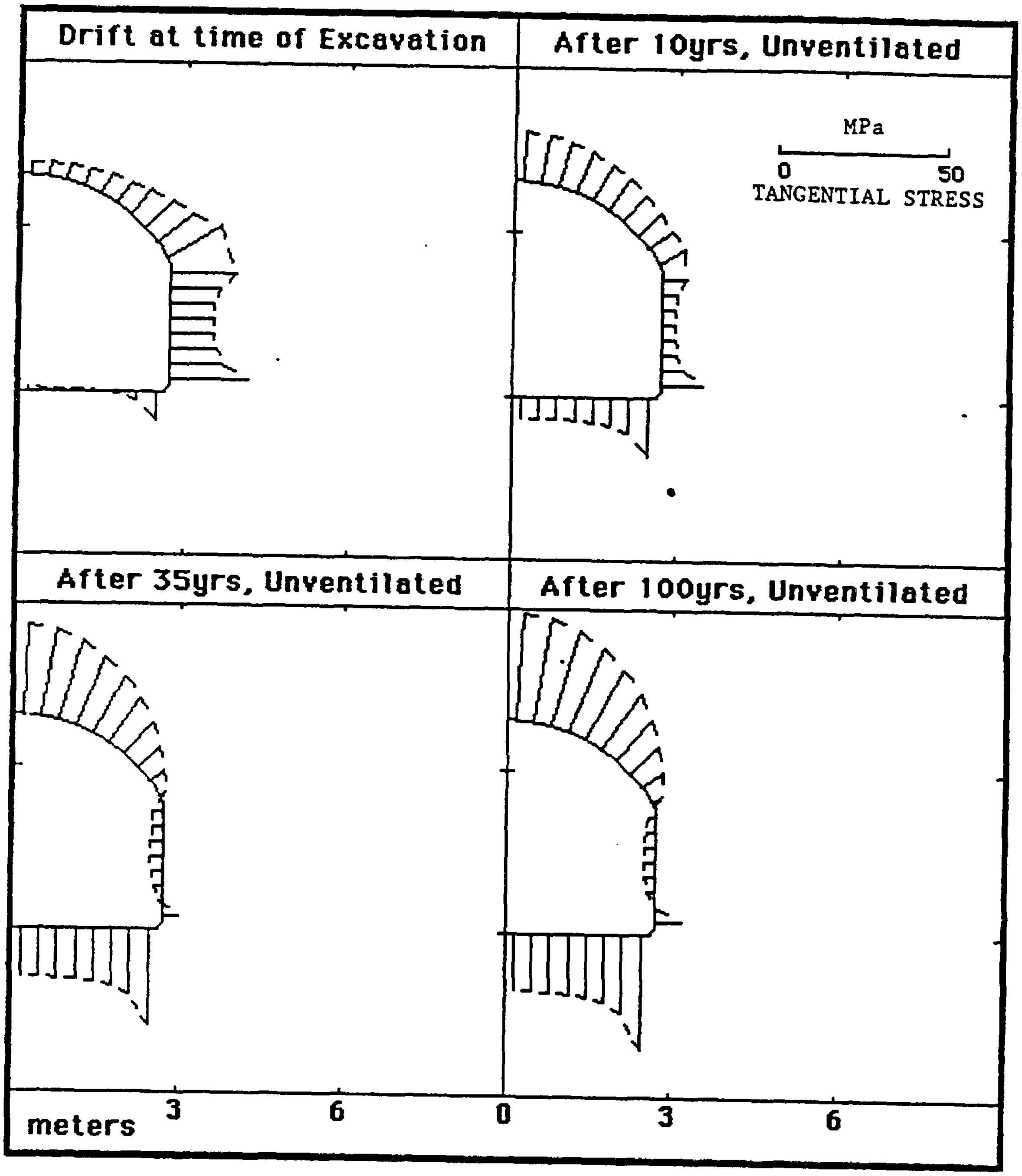


Figure C.2 Boundary-Element Predictions of Tangential Stress Distribution Around the Horizontal Emplacement Drift, at Times up to 100 Yr After Waste Emplacement - Unventilated Drift

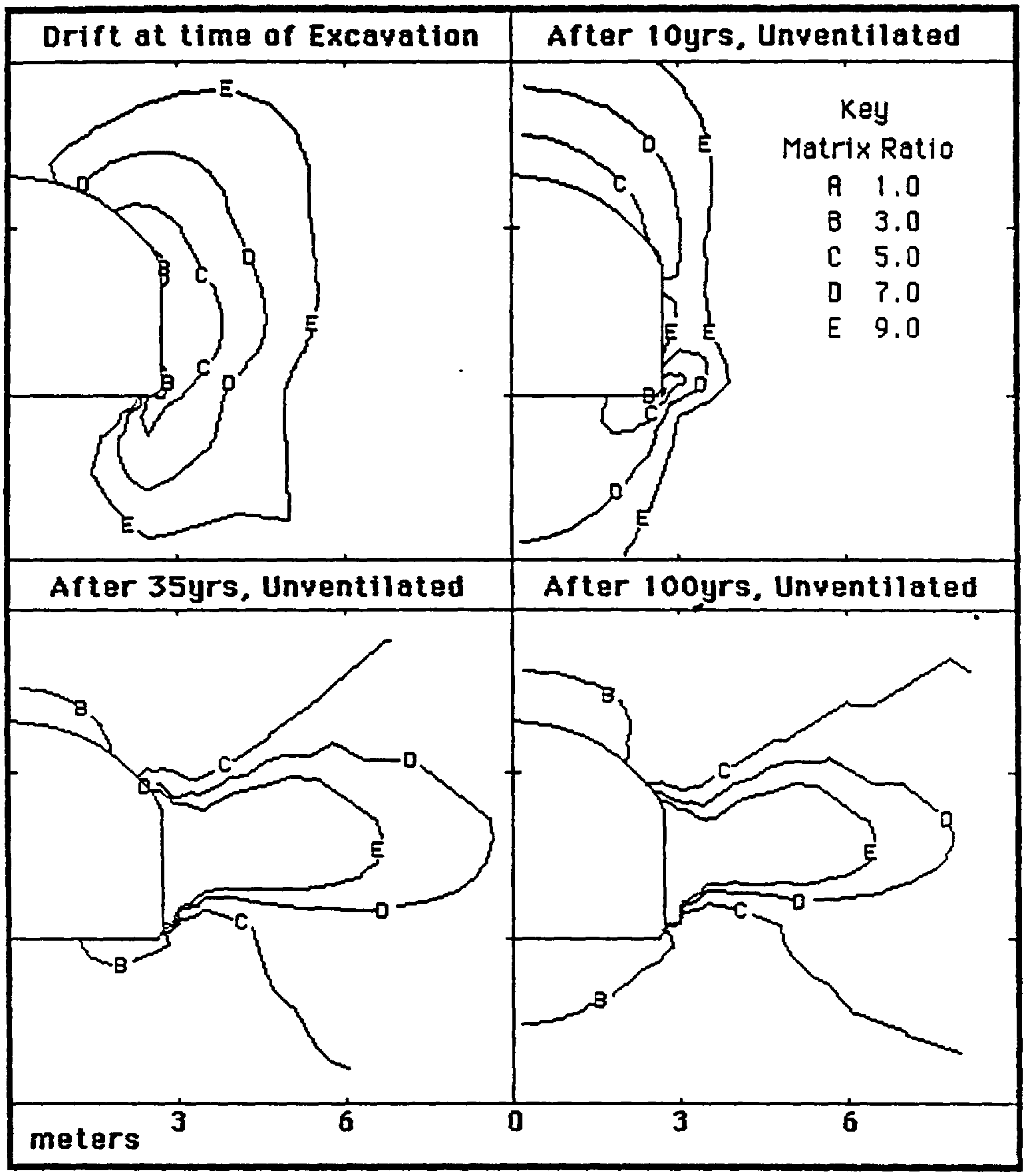


Figure C.3 Boundary-Element Predictions of the Ratio Between the Matrix Strength and Stress Around the Horizontal Emplacement Drift, at Times up to 100 Yr After Waste Emplacement - Unventilated Drift

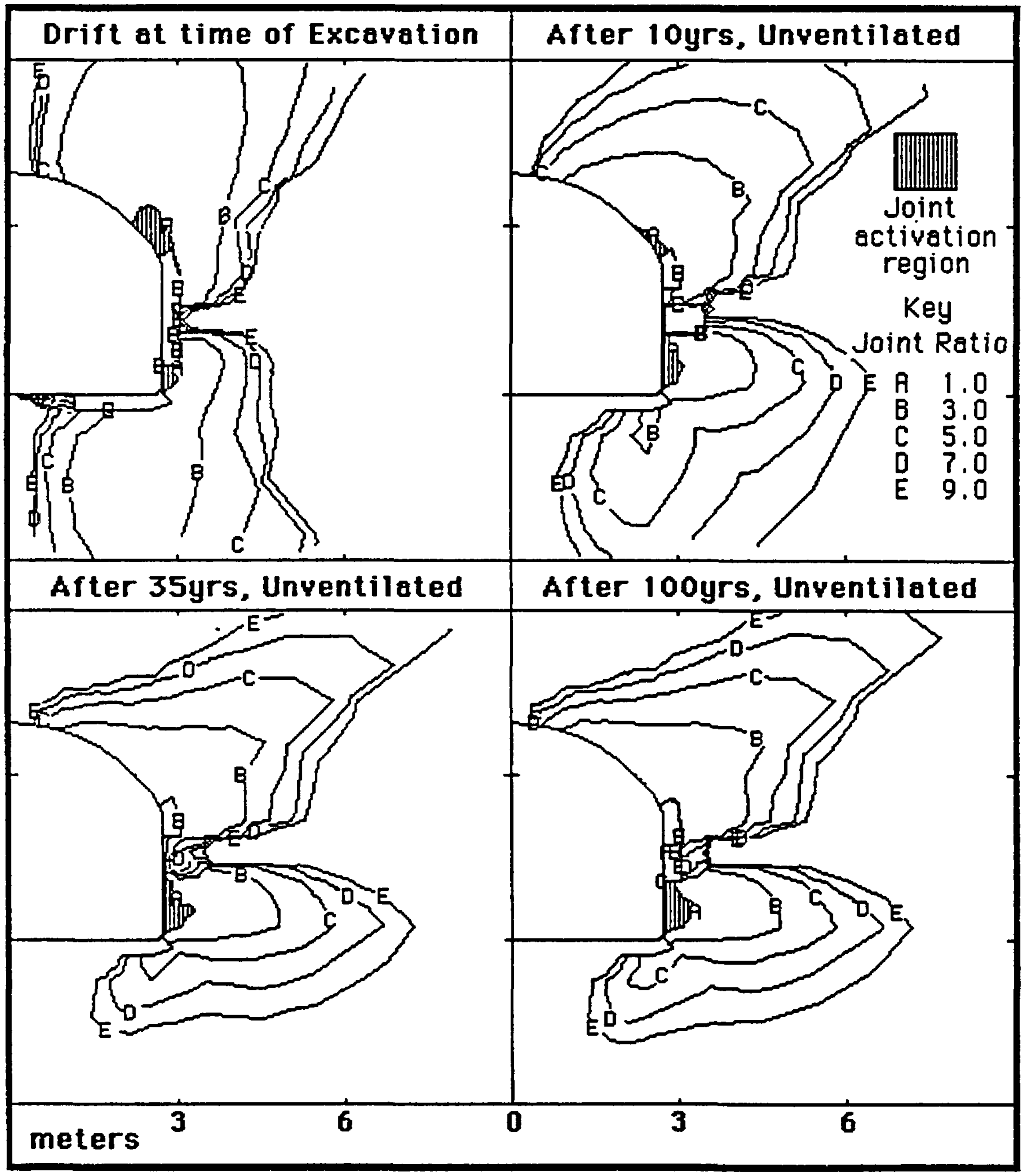


Figure C.4 Boundary-Element Predictions of the Ratio Between the Joint Strength and Stress Around the Horizontal Emplacement Drift, at Times up to 100 Yr After Waste Emplacement - Unventilated Drift

APPENDIX D

FINITE-ELEMENT ANALYSES OF HORIZONTAL EMPLACEMENT

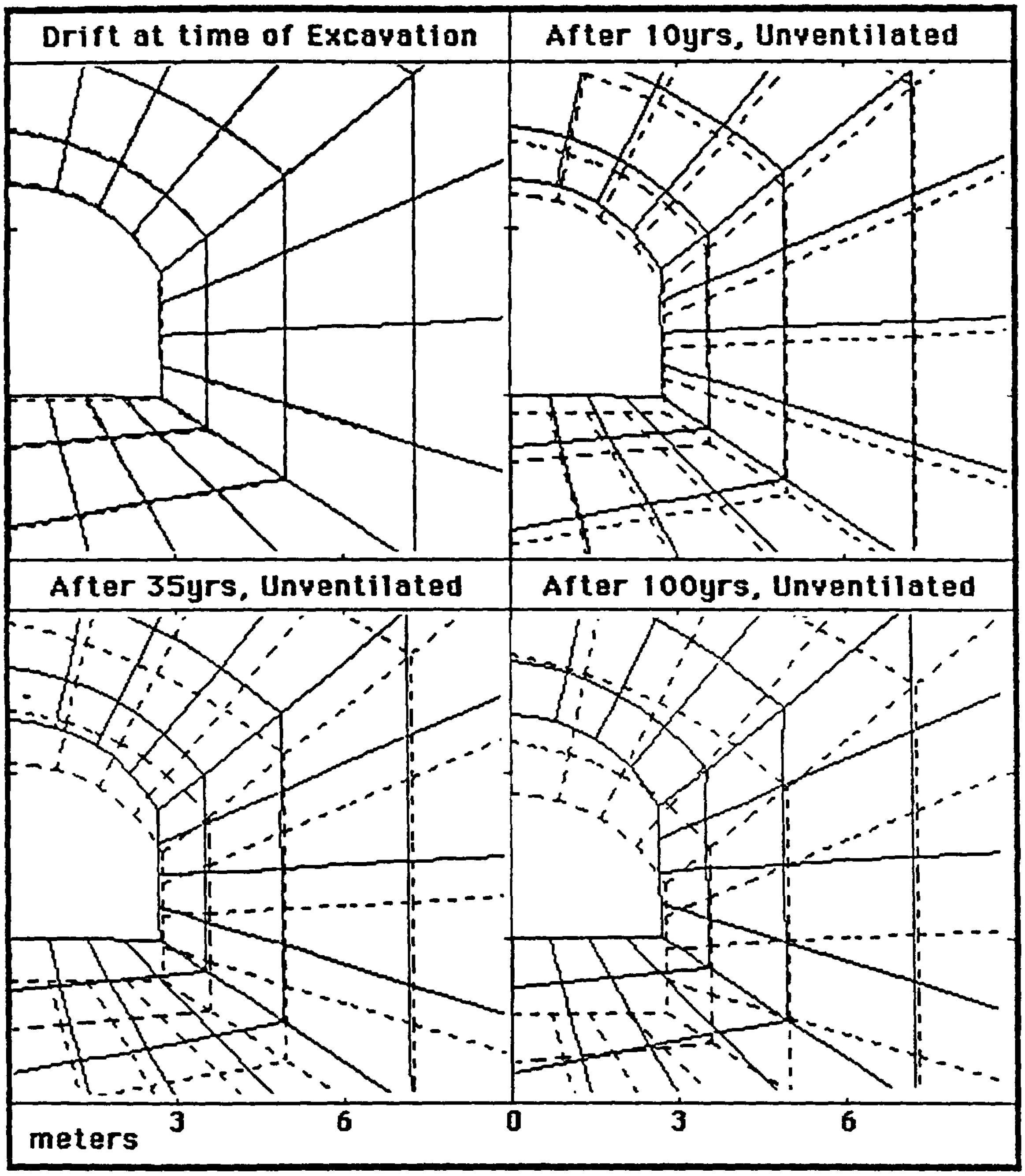


Figure D.1a Finite-Element Prediction of Deformations in the Vicinity of the Horizontal Emplacement Drift, at Times up to 100 Yr After Waste Emplacement - Unventilated Case. (The displacement scale is magnified 20 times relative to the geometric scale. Deformed rock is shown with the solid lines. The deformations are measured relative to the pre-excavation state.)

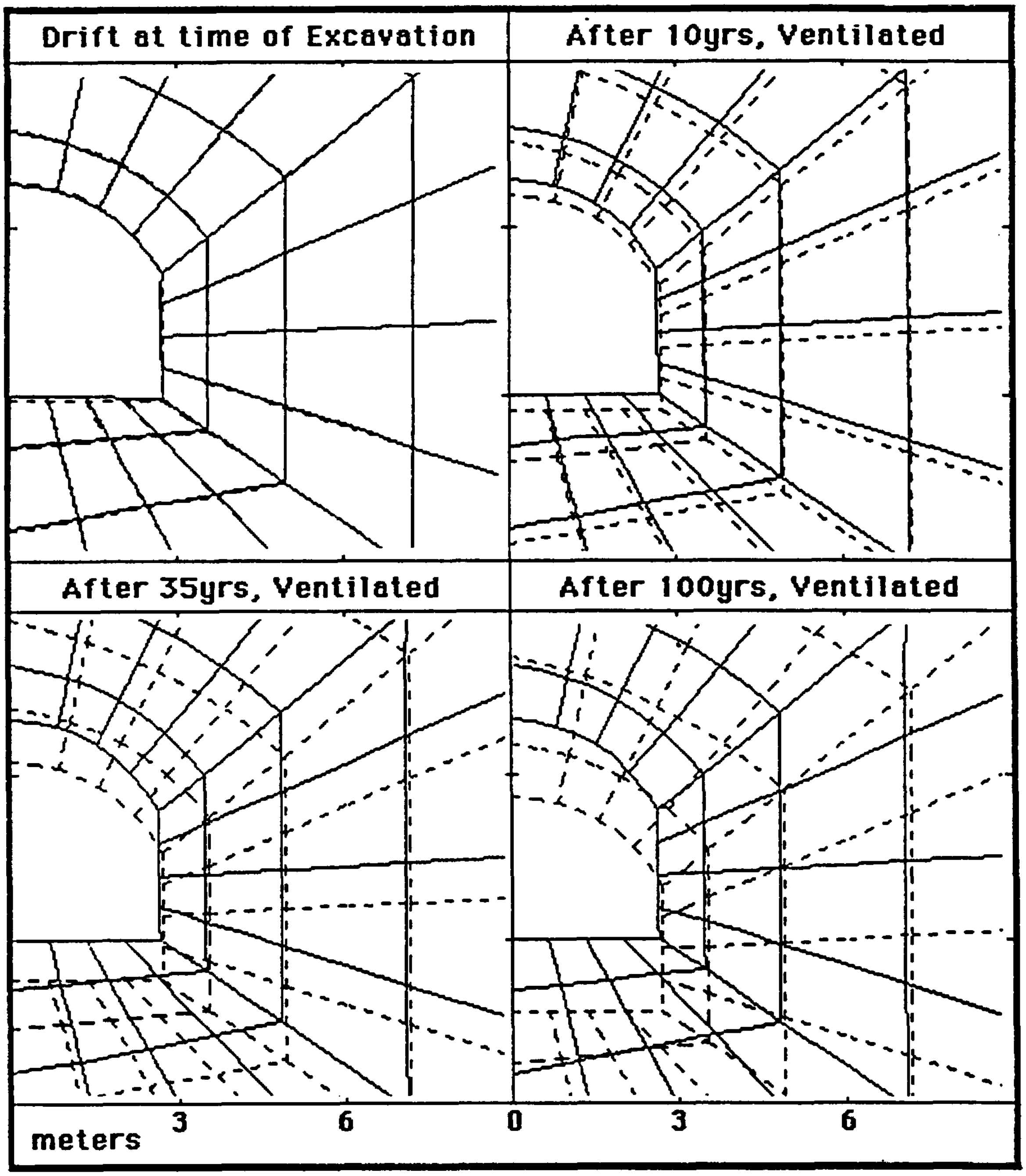


Figure D.1b Finite-Element Prediction of Deformations in the Vicinity of the Horizontal Emplacement Drift, at Times up to 100 Yr After Waste Emplacement - Ventilated Case. (The displacement scale is magnified 20 times relative to the geometric scale. Deformed rock is shown with the solid lines. The deformations are measured relative to the pre-excavation state.)

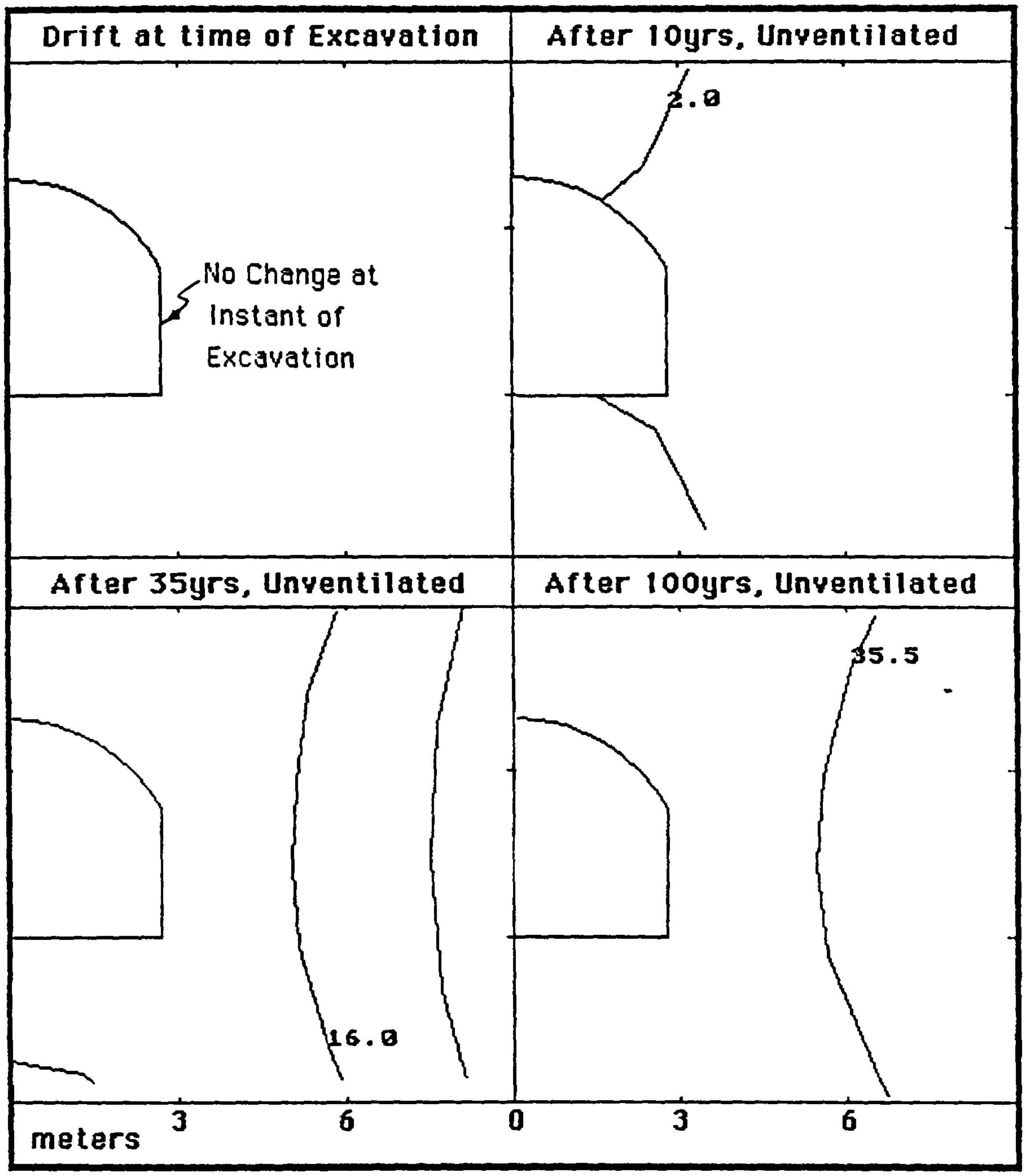


Figure D.2a Finite-Element Predictions of the Temperature Changes (°C) in the Vicinity of the Drift for the Horizontal Emplacement Drift, at Times up to 100 Yr After Waste Emplacement - Unventilated Case

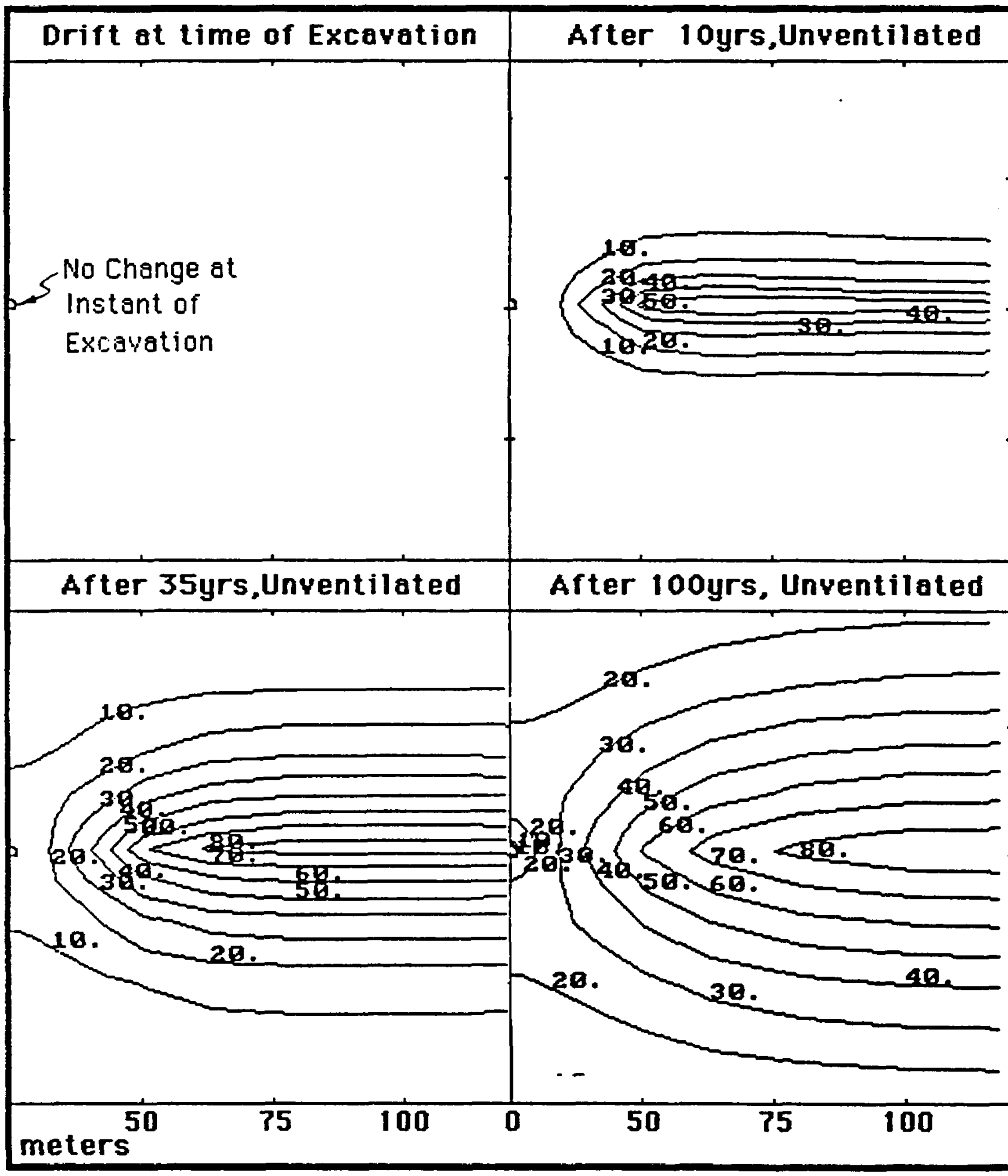


Figure D.2b Finite-Element Predictions of the Temperature Changes (°C) in the Far-Field of the Horizontal Emplacement Drift, at Times up to 100 Yr After Waste Emplacement - Unventilated Case

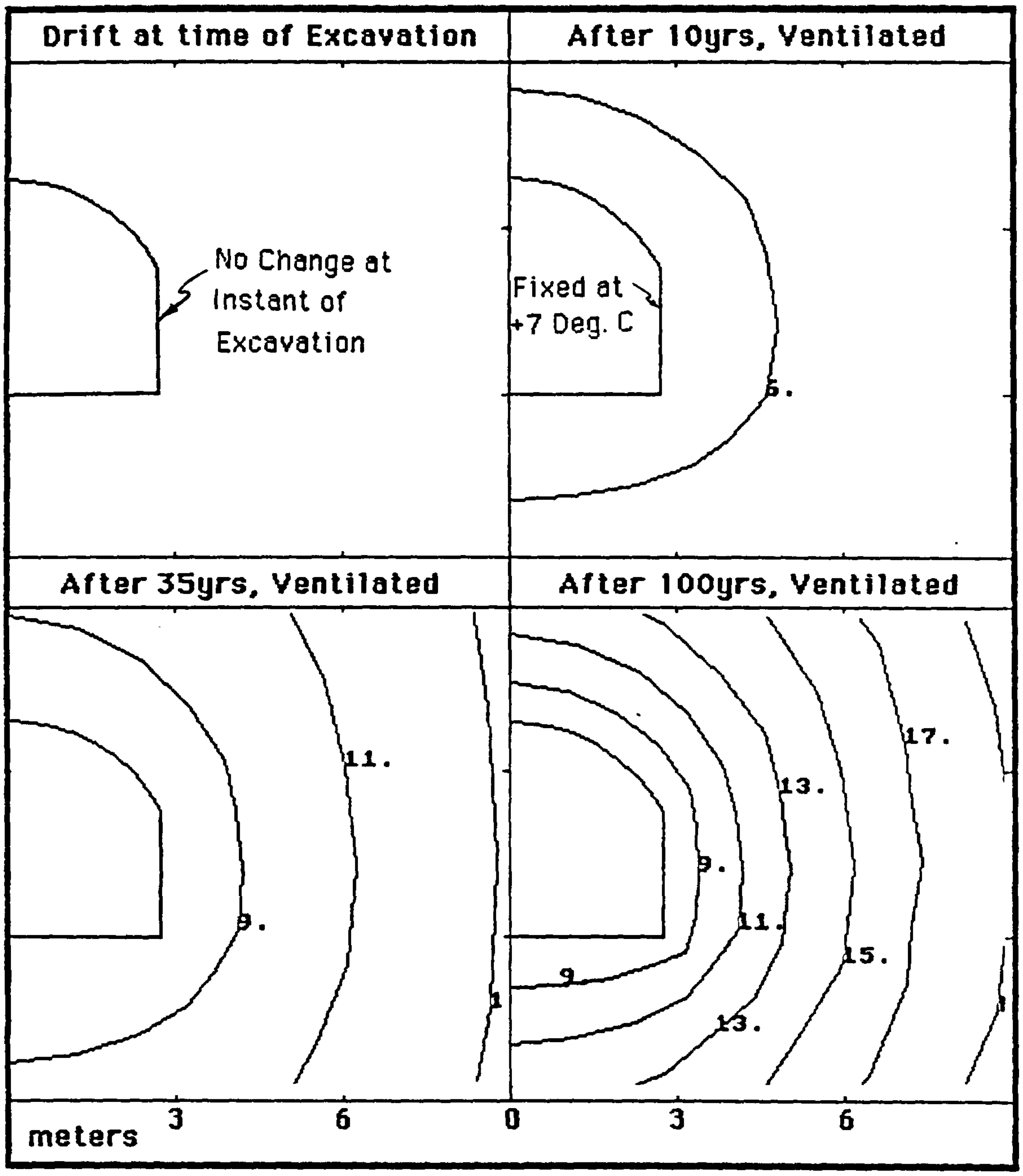


Figure D.2c Finite-Element Predictions of the Temperature Changes (°C) in the Vicinity of the Drift for the Horizontal Emplacement Drift, at Times up to 100 Yr After Waste Emplacement - Ventilated Case

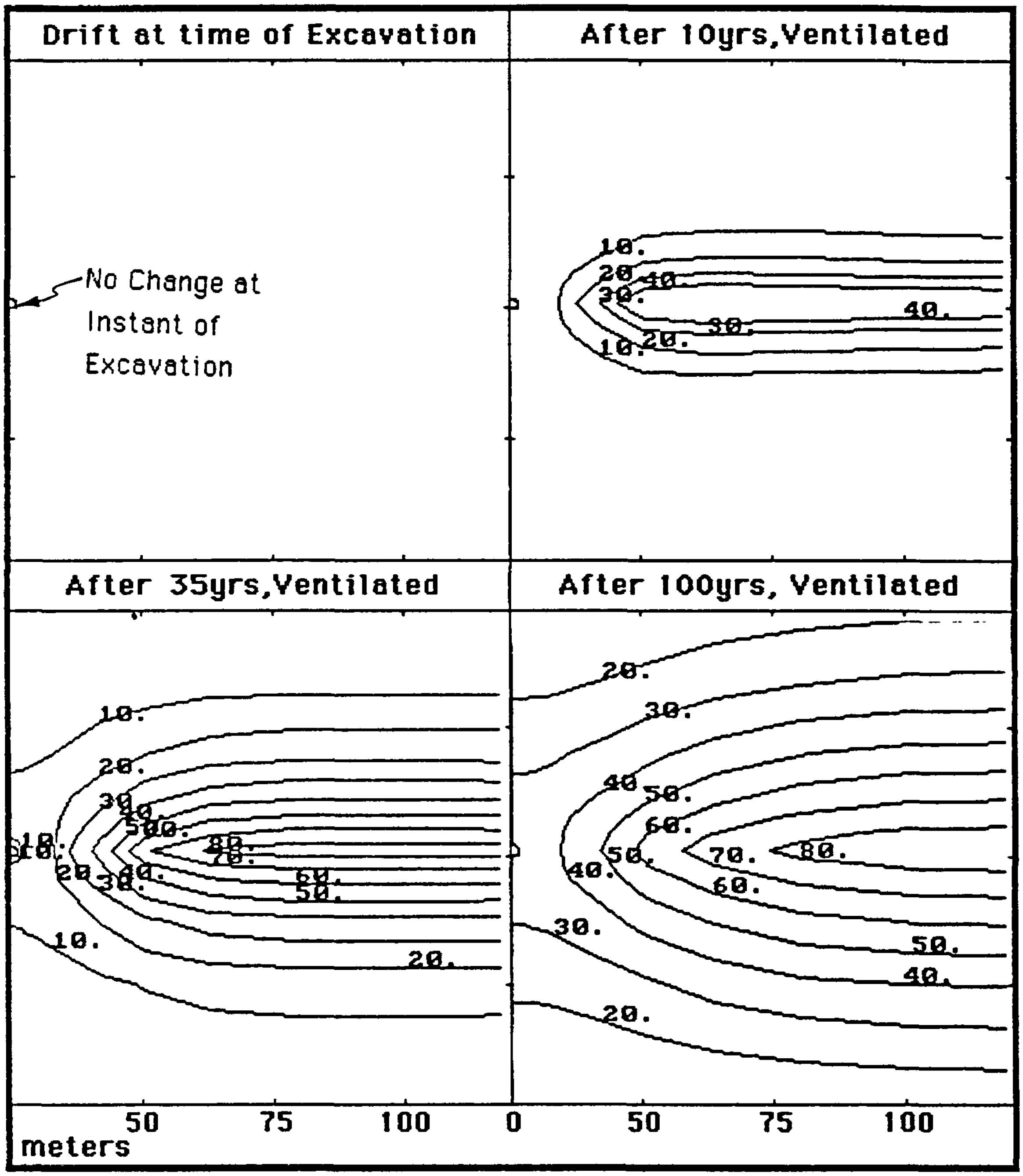


Figure D.2d Finite-Element Predictions of the Temperature Changes (°C) in the Far-Field of the Horizontal Emplacement Drift, at Times up to 100 Yr After Waste Emplacement - Ventilated Case

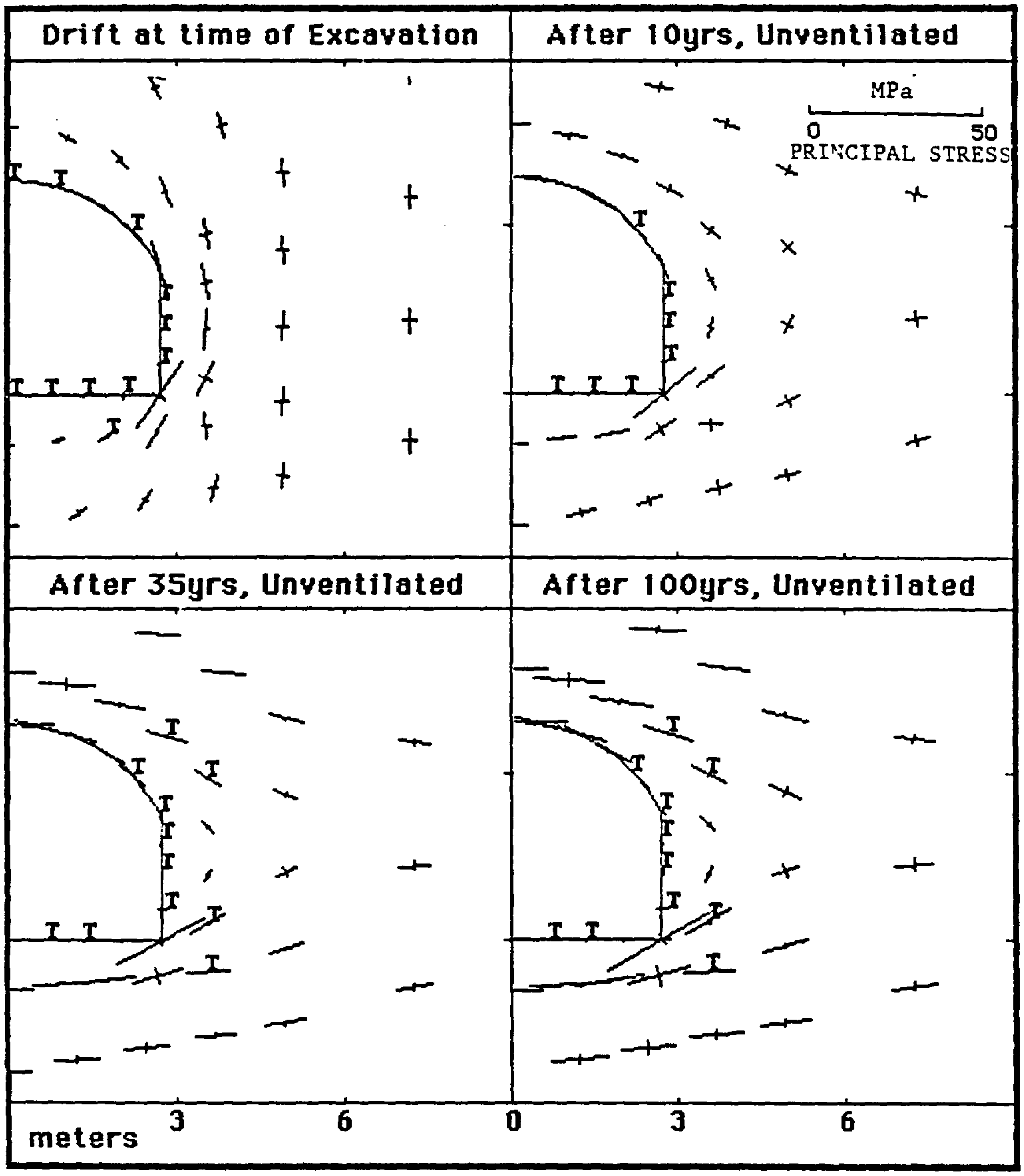


Figure D.3a Finite-Element Predictions of the Principal Stresses in the Vicinity of the Horizontal Emplacement Drift, at Times up to 100 Yr After Waste Emplacement - Unventilated Case

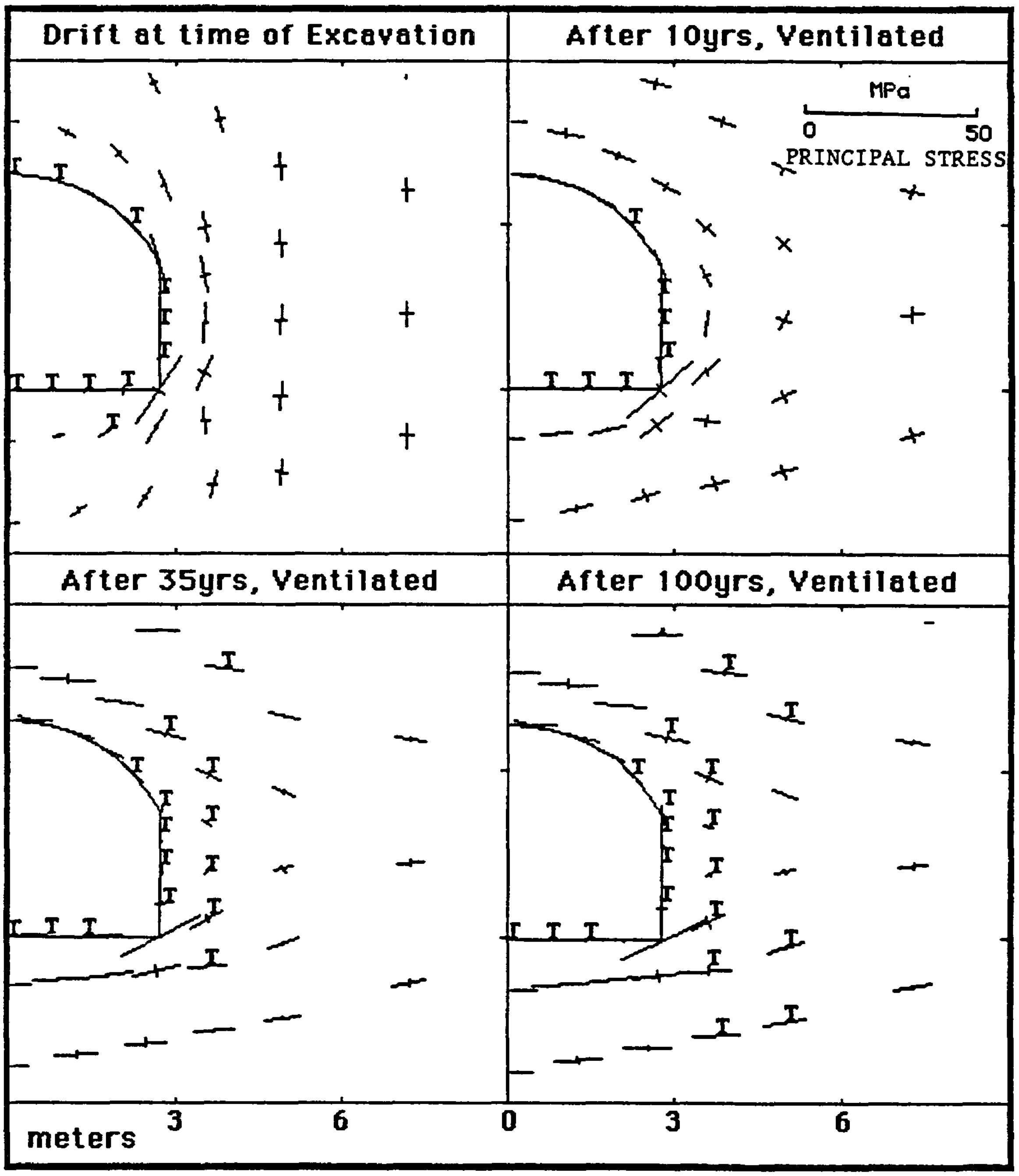


Figure D.3b Finite-Element Predictions of the Principal Stresses in the Vicinity of the Horizontal Emplacement Drift, at Times up to 100 Yr After Waste Emplacement - Ventilated Case

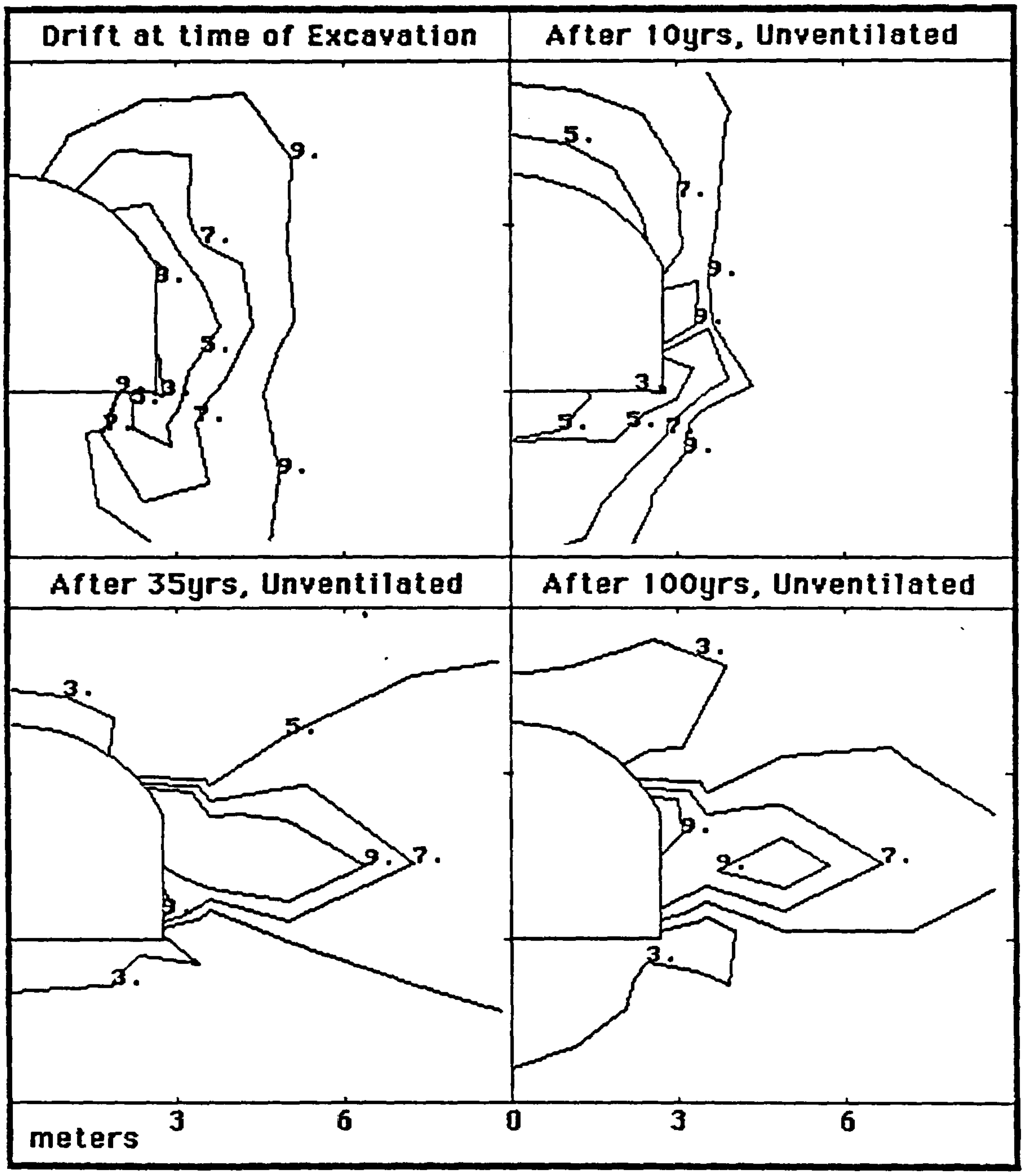


Figure D.4a Finite-Element Predictions of the Ratio Between Matrix Strength and Stress Around the Horizontal Emplacement Drift, at Times up to 100 Yr After Waste Emplacement - Unventilated Case

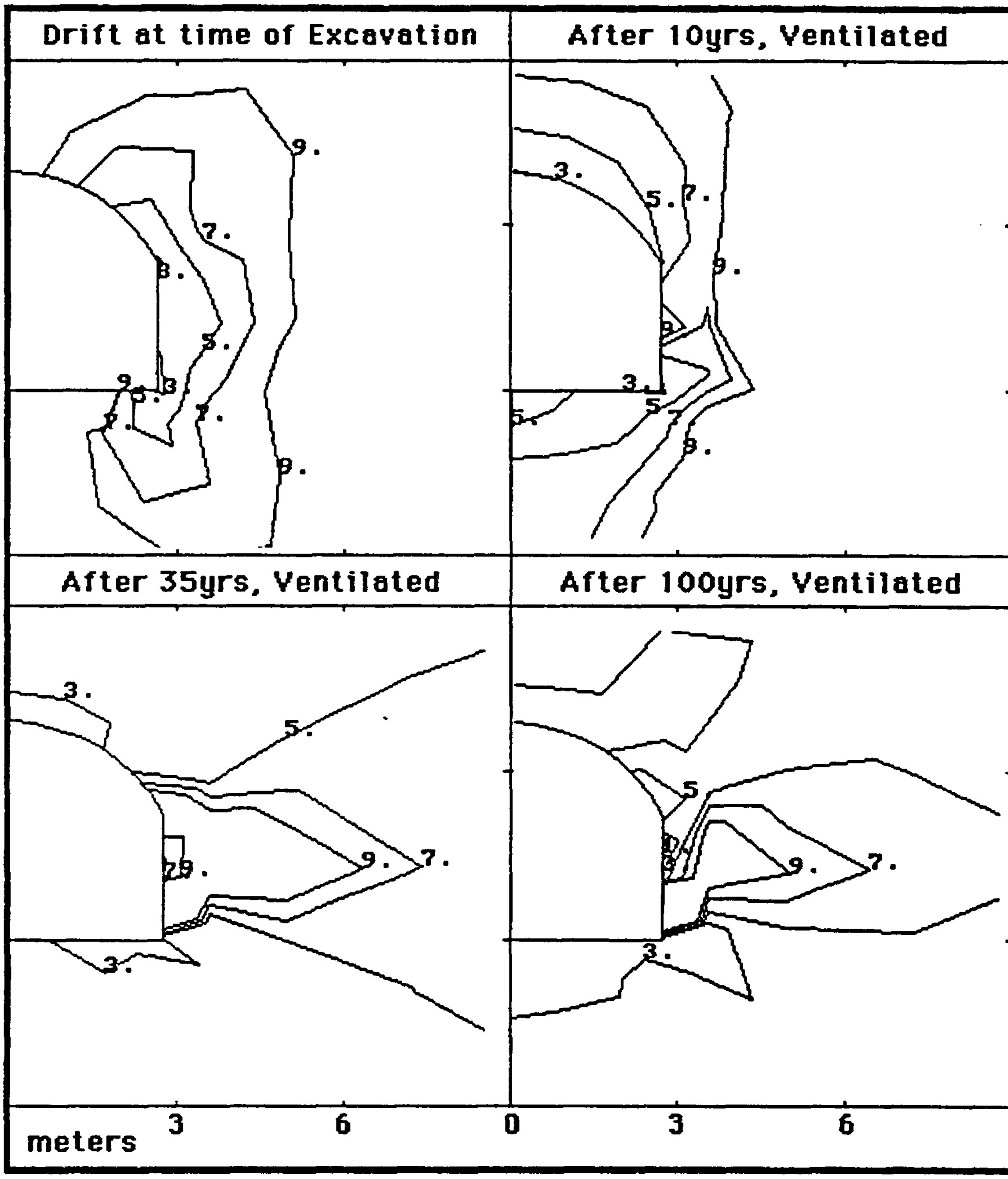


Figure D.4b Finite-Element Predictions of the Ratio Between Matrix Strength and Stress Around the Horizontal Emplacement Drift, at Times up to 100 Yr After Waste Emplacement - Ventilated Case

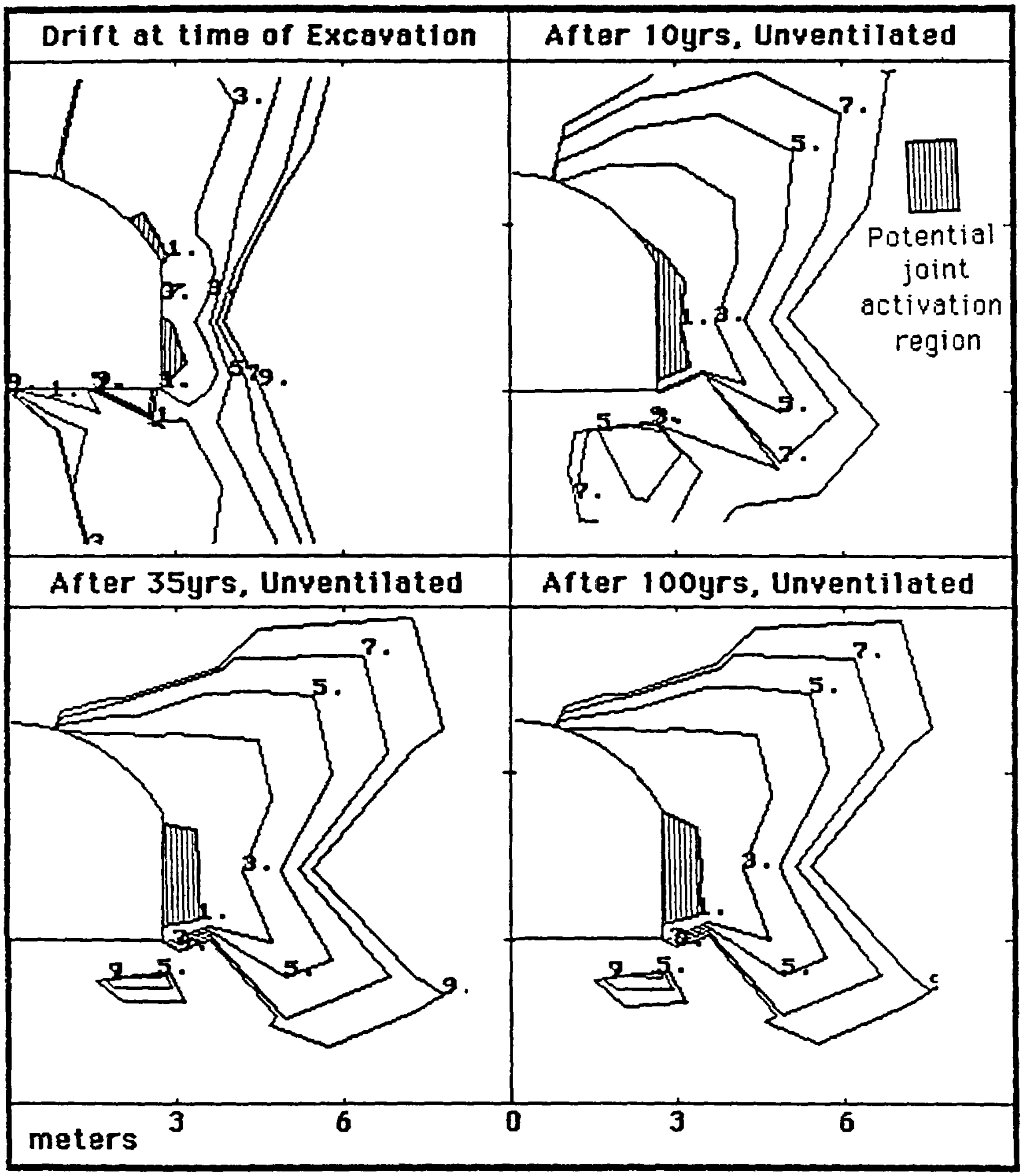


Figure D.5a Finite-Element Predictions of the Ratio Between Joint Strength and Stress Around the Horizontal Emplacement Drift, at Times up to 100 Yr After Waste Emplacement - Unventilated Case

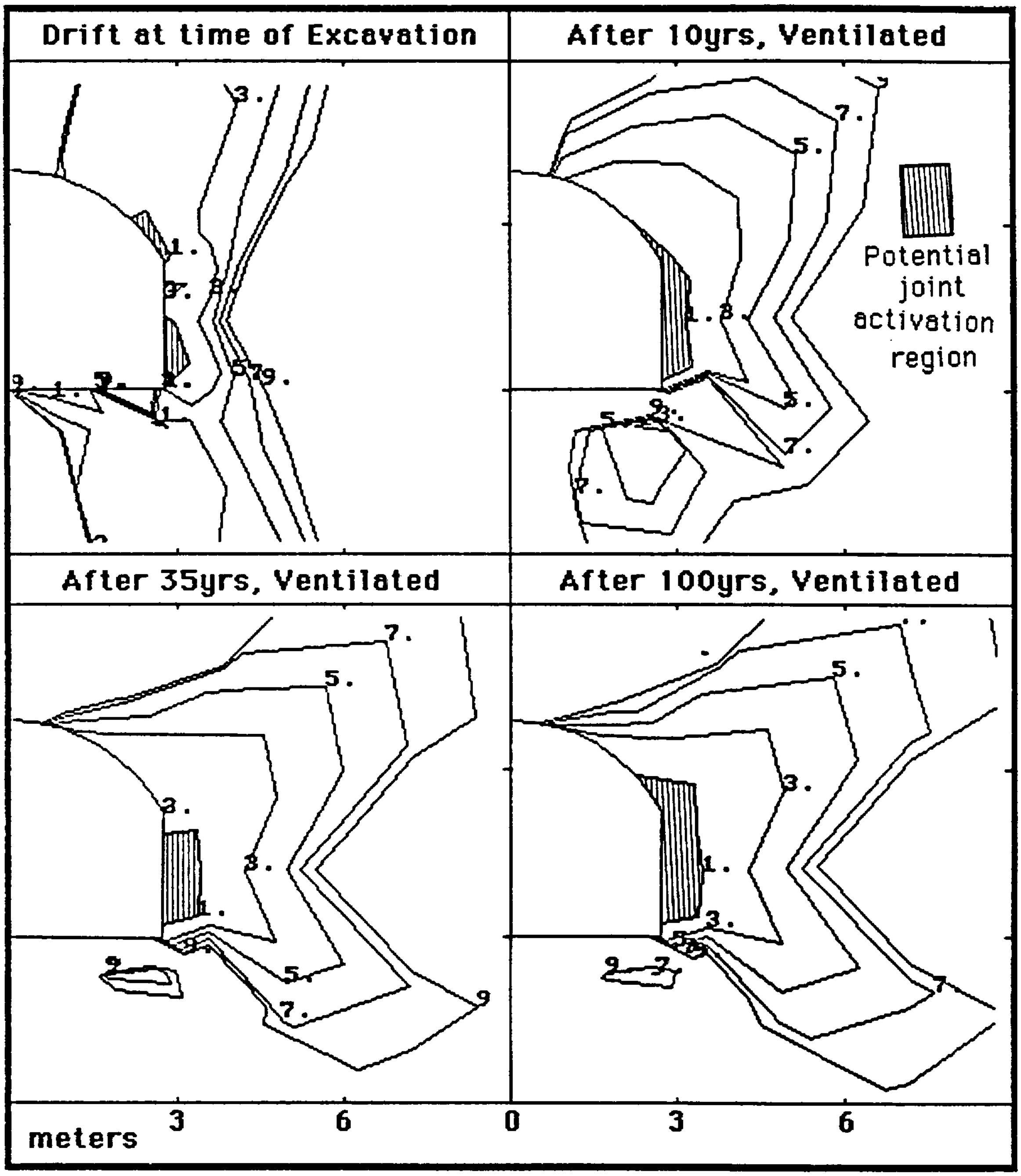


Figure D.5b Finite-Element Predictions of the Ratio Between Joint Strength and Stress Around the Horizontal Emplacement Drift, at Times up to 100 Yr After Waste Emplacement - Ventilated Case

APPENDIX E

MEMO: MANSURE, A.J.,

"ALLOWABLE THERMAL LOADING AS A FUNCTION OF WASTE AGE"

Sandia National Laboratories

Albuquerque, New Mexico 87185

date: 2/13/1985

to: Hill, 6311

from: A.J. Mansure, 6314 Arthur Mansure

subject: Allowable Thermal Loading as a Function of Waste Age

INTRODUCTION:

During the unit evaluation calculations were done to determine the allowable thermal loading and demonstrate that this loading did not have any adverse far-field effects (Johnstone, 1984). Based on that study 57 kW/acre has been used as a baseline for calculations and for design of the underground facility layout. The unit evaluation assumed 10 year out of the reactor spent fuel. Thermal decay curves used during the unit evaluation were taken from Kissner (1978).

The criteria used to determine the allowable thermal loading in the unit evaluation was that the drift floor temperature should not exceed 100oC for vertical emplacement. That criteria was not based upon any firm requirement for ventilation or retrieval. In addition the vertical emplacement floor temperature is dependent upon such things as drift thermal loading (kilowatts per meter of drift or the output of the canisters divided by the spacing between the boreholes) and upon the standoff between the canister and the drift floor. Further, the same allowable thermal load was used for horizontal and vertical emplacement although horizontal emplacement drift temperatures are expected to be much lower than vertical emplacement drift temperatures because of larger standoffs between the waste and the drift for horizontal emplacement. Thus the allowable thermal load is being reevaluated.

This memorandum considers the effect of waste age on allowable thermal loading. O'Brien and Shirley (1984) analyzed both constant initial areal power densities and "constant borehole spacings" for wastes of different ages. They found that "constant borehole spacing" gave nearly the same areal energy deposition for waste ages 5 to 30 years, where as, constant initial areal power density resulted in greatly different areal energy densities. They thus recommended emplacement at "constant borehole spacing". (Their recommendation is for fixed package size, ie. number of assemblies per package.)

BASIS FOR COMPARING THERMOMECHANICAL EFFECTS OF WASTE OF DIFFERENT AGES

It has been assumed that far-field thermomechanical effects are the determining factor for the allowable thermal load. Surface uplift can be used as an indicator of thermomechanical effects. Surface uplift peaks at about two thousand years (see Figure 1, Brandshaug, 1983). Thus for waste that is not 10 years out of the reactor to produce the same thermomechanical effects as ten year old SF, it should be emplaced at an initial areal power density that results in approximately the same accumulated areal energy deposition through 2000 years. The allowable initial power density as a function of waste age (for a given burnup) is thus determined by

$$Pa \int_{A}^{2,000} Na(t)dt = 57(kW/acre) \int_{10}^{2,000} N10(t)dt \qquad (1)$$

where Pa is the initial power density of waste of age A at emplacement, Na is the normalized power function for waste of age A, and N10 is the normalized power function for waste of age 10 years.

These integrals were evaluated numerically by fitting each pair of data points with an exponential so the normalized energy between any two times is given by

(N1-N2)*(T2-T1)/ln(N1/N2)

The accuracy of this approach for evaluating the integrals was assessed by comparing to a trapezoidal integration (which would systematically lead to an over estimation). The trapezoidal integration was 1.1% higher.

The assumption that the integrals should be evaluated through 2000 years was checked by also evaluating them through 1000 years. When the initial power density was calculated with that assumption, the allowable power density was 100.7% or less of the initial power density determined using 2000 years.

ALLOWABLE THERMAL LOADING

The data for determining the allowable initial power density was taken from the GR (DOE, 1984). That data is not the same as used in the unit evaluation which came from Kissner (1978). In general the data in the GR does not decay as fast as the data used in the unit evaluation (see Table 1). Therefore, the right hand side of equation 1 was evaluated using the data from Kissner (1978) to insure the amount of energy deposited in 2000 years was no more than that used in the unit evaluation.

Using the data in Table 1 the allowable initial power density Pa was calculated using equation 1. Values determined are summarized in Table 2 and Figure 2.

Most of the increased allowable thermal loading for younger waste in Figure 2 is due to the higher thermal output per MTU of younger waste. The point made by Figure 2 is not to emplace younger waste so as to deposit more energy per acre, but to compensate for the higher initial outputs of younger waste so as to achieve the same energy density. O'Brien and Shirley (1984) suggest that the way to achieve almost constant energy density is "constant borehole spacing". That of course assumes several other variables such as the number of assemblies per canister are constant. A better way to express that same concept is constant assemblies per acre rather than "constant borehole spacing."

The number of assemblies per acre can be determined from the allowable initial thermal loading according to

$$\text{ASSMB}*(\text{MTU/assmb})*P(A)\int_{A}^{2,000} Na(t)dt = (57\text{kW/acre})\int_{10}^{2,000} N10(t)dt$$

where ASSMB is the number of assemblies allowed per acre, (MTU/assmb) is the number of MTU per assembly (=.4614 for PWR and =.1833 for BWR, O'Brien, 1985), and P(A) is the power per MTU at age A.

Table 2 gives the number of assemblies per acre allowed for average age and burnup spent fuel (average burnups are 33,000 MWD/MTU for PWR and 27,5000 MWD/MTU for BWR, O'Brien, 1985). In contrast to allowable initial power density, the number of assemblies per acre is relatively constant and decreases with waste age at emplacement. This is because the younger waste over time produces more energy and so has to be spread out farther. This measure of allowable thermal loading may also be reasonable for high burnup fuel (Mansure, 1985).

Table 1. Data used to evaluate allowable initial power density

Year	Unit Evaluation *	GR data PWR **	PWR *	BWR **	BWR *
5		1798		1380	
6		1534		1193	
7		1375		1079	
8		1270		1004	
9		1196		951.5	
10	1	1140	1	911.3	1
16		949.2	.833	772.7	.848
18		907.6	.796	741.5	.814
20	.75	870.5	.764	713.5	.783
25	.681	790.7	.694	651.9	.715
30	.622	723.1	.634	598.9	.657
40	.525	612.2	.537	510.6	.56
50	.449	524.8	.46	440.1	.483
60	.387	454.8	.399	383.5	.421
70		398.5	.35	337.7	.371
80	.301	352.9	.31	300.5	.33
90		315.8	.277	270.2	.297
100		285.6	.251	245.5	.27
110	.238				
200	.137	160.1	.14	142.1	.156
300	.108	126.4	.111	113.5	.125
400	.0919	107.5	.0943	97.19	.107
500	.0806	93.79	.0823	85.03	.0933
600	.0711				
700	.0633				
800	.0569				
900	.0514				
1000	.0466	54.71	.048	49.9	.0547
2000	.0247	29.18	.025	26.81	.029

* Data normalized to 10 year old output.
** Watts/MTU

Table 2. ALLOWABLE LOADING

YEAR	-kW/acre- PWR	BWR	-assemblies/acre- PWR	BWR
5	84.6	73.8	102	291
6	72.8	64.3	103	294
7	65.8	58.5	104	296
8	61.2	54.8	104	298
9	58.0	52.3	105	300
10	55.6	50.3	106	301
11	53.6	48.7	106	303
12	52.1	47.5	107	304
13	50.9	46.4	108	306
14	49.8	45.6	108	308
15	48.9	44.8	109	309
16	48.0	44.1	110	311
17	47.2	43.4	110	313
18	46.5	42.8	111	314
19	45.8	42.2	111	316
20	45.1	41.6	112	317
21	44.4	41.0	113	319
22	43.8	40.5	113	320
23	43.2	39.9	114	322
24	42.5	39.4	114	323
25	41.9	38.8	115	324
26	41.3	38.3	115	326
27	40.7	37.8	115	327
28	40.1	37.3	116	328
29	39.5	36.7	116	329
30	39.0	36.2	117	330

References

Brandshaug, T., NNWSI Unit Evaluation at Yucca Mountain, Nevada Test Site: Far-Field Thermal/Rock Mechanics Analysis, RE/SPEC Inc., RSI-0209, 1984

Department of Energy, Generic Requirements for a Mined Geologic Disposal System, Appendix B, ORG/B-2, Sep. 1984.

Johnstone, J.K., R.R. Peters, and P.F. Gnirk, Unit Evaluation at Yucca Mountain, Nevada Test Site, Summary Report and Recommendations, SAND83-0372, 1894.

Kissner, Nuclear Waste Projections and Source Term Data for FY 1977, Y/OWI/TM-34 Office of Waste Isolation, Oak Ridge, TN, 1978.

Mansure, A.J., Effect of High Burnup Fuel on Underground Facility Design, Memo to R. Hill (6311) 2/13/1985b.

O'Brien, P.D. and C.S. Shirley, The Effect of Waste Age on the Design of a Geologic Repository, Waste Management '84, Vol. I, 1984.

O'Brien, P.D., Reference Nuclear Waste Descriptions for a Geologic Repository at Yucca Mountain, Nevada, SAND84-1848, in preparation, 1985.

Distribution:

6310 T.O. Hunter
6311 L.W. Scully
6312 F.W. Bingham
6314 J.R. Tillerson /File
6311 H.R. MacDougall
6311 P.D. O'Brien
6311 C.G. Shirley
6314 B. Ehgartner
6314 A.J. Mansure
6314 R.E. Stinebaugh
6330 NNWSICF

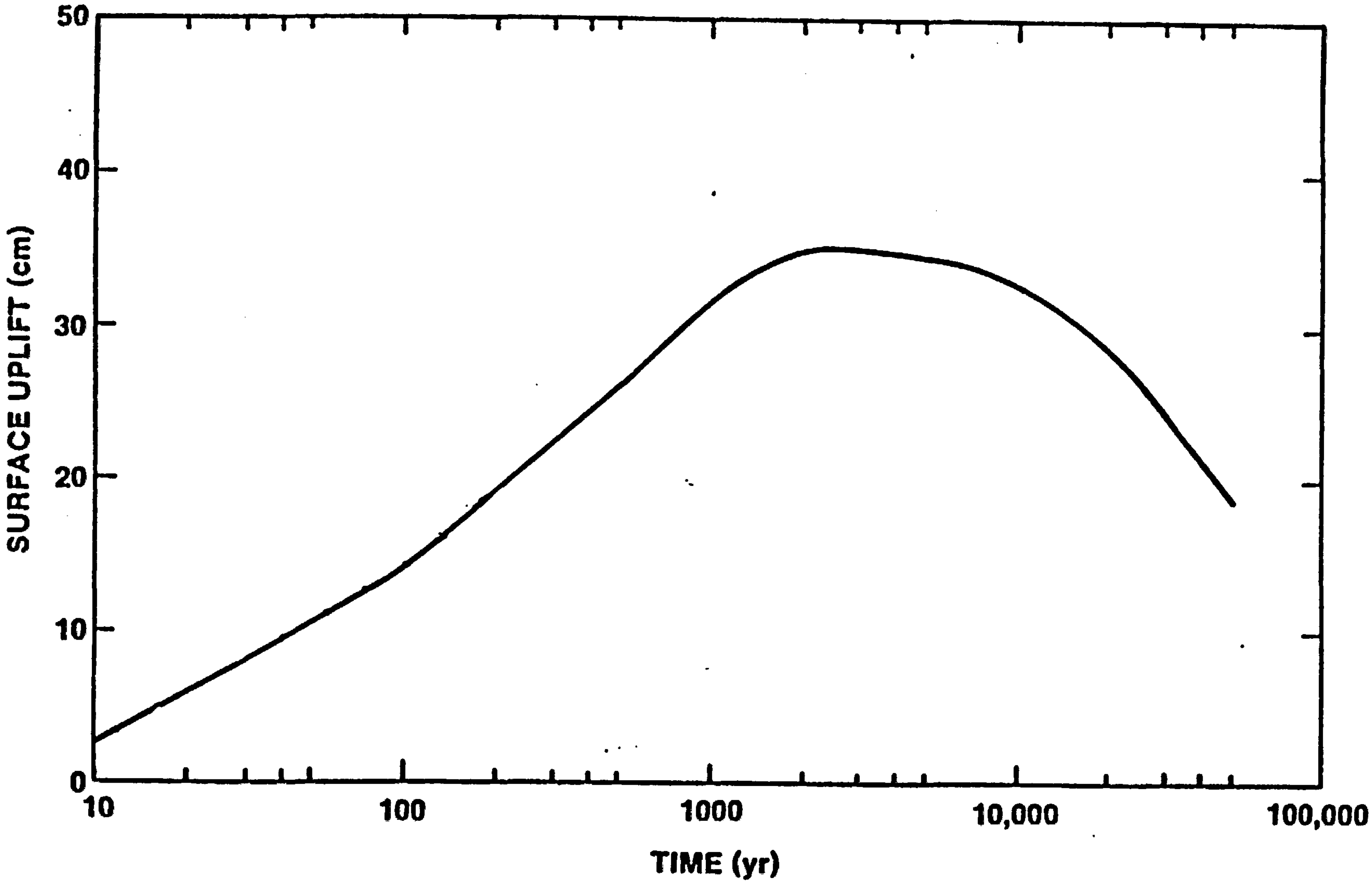


Figure 1. Surface Uplift for 10 Year Old SF Emplaced in the
Topopah Spring Member at 57 kW/acre (Brandshaug, 1983)

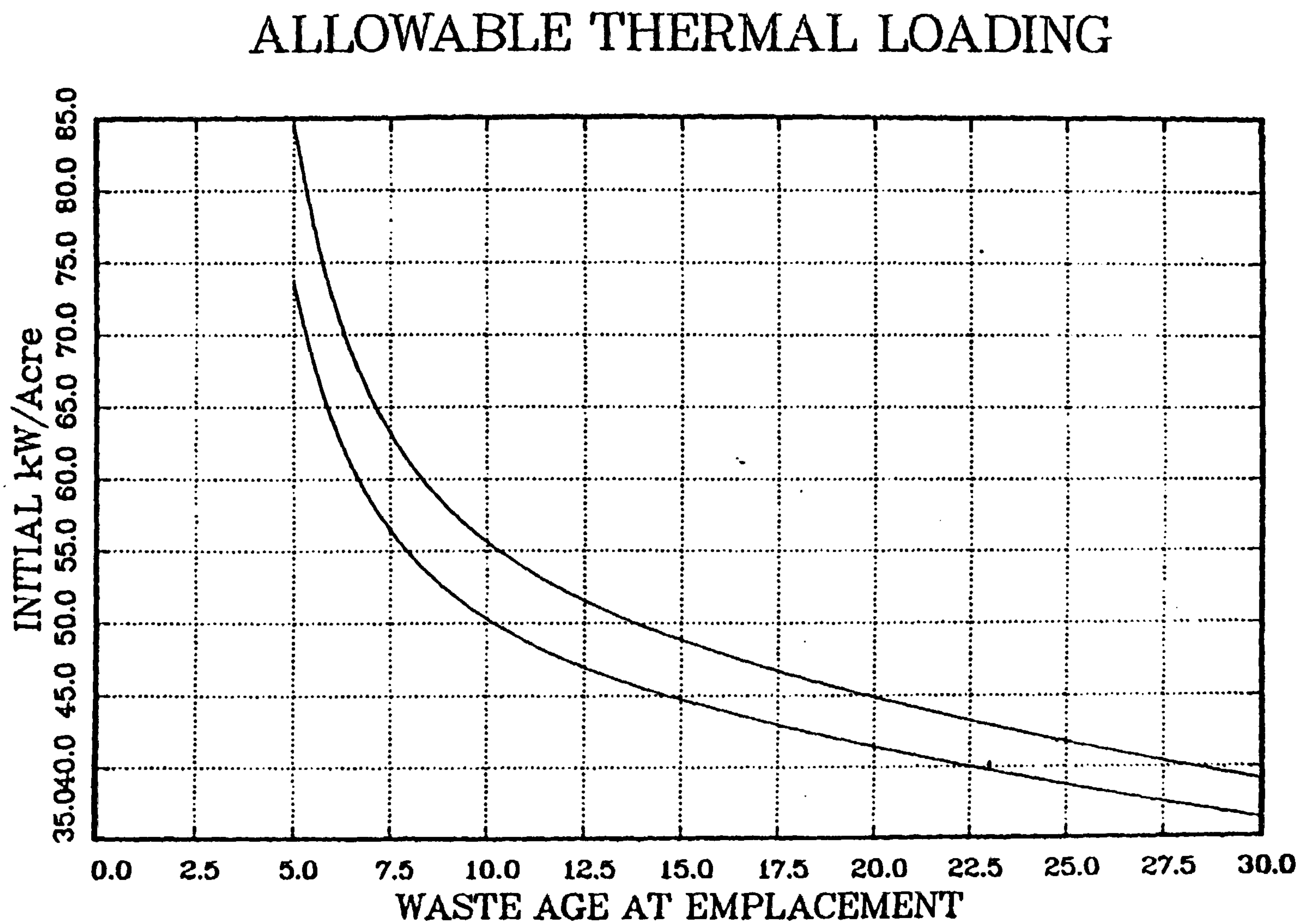


Figure 2. Allowable Initial Power Density

APPENDIX F

MEMO: MANSURE, A.J. AND R.E. STINEBAUGH, "MEMORANDUM OF RECORD OF INSTRUCTIONS FOR THERMAL DESIGN ANALYSIS AND PERFORMANCE ASSESSMENT LAYOUT."

DEC 11 1986

Sandia National Laboratories
P.O. Box 5800
Albuquerque, NM 87185

Date: 4/18/1985

To: R. Hill, 6311

From: A.J. Mansure and R.E. Stinebaugh, 6314 AJM RES

Subject: Memorandum of Record of Instructions for Thermal Design, Analysis, and Performance Assessment of Layout, Version I

This memo establishes reference design parameters to be used in thermal, thermomechanical, and hydrologic calculations. Such parameters include both underground facility design criteria parameters (canister diameter) and the results of the design process (drift dimensions).

Parameters that establish the reference design are presented in this memo in three sections:

1) section one contains underground facility design criteria parameters (this section will be superceded by the Functional Design Criteria when it is published). Many of the numbers in this section such as borehole diameter are important to calculations.

2) section two contains guidance to the underground facility design A&E. This section does not contain parameters that are to be used in calculations. It is included in this memo for completeness of documentation of the reference design.

3) section three contains layout dimensions established by Parsons Brinkerhoff. These dimensions constitute the current and reference design and should be used in calculations.

1. Design Criteria Parameters

The following criteria are to be used establishing borehole spacings and the layout of the underground facility to ensure thermal conditions are satisfactory.

1.1 Temperature:

- borehole wall temperature for spent fuel is not to exceed 220 deg. centigrade for all times
- temperature one meter from the borehole wall is not to exceed 200 deg. centigrade for all times
- horizontal emplacement drift rock wall temperature (long borehole case) is not to significantly exceed 50 deg. centigrade at 50 years for spent fuel
- vertical emplacement access drift rock wall temperature (panel access drift) is not to significantly exceed 50 deg. centigrade at 50 years for spent fuel

1.2 Waste Package, Equipment, and Facility Dimensions:

1.2.1 Spent Fuel
- canister diameter 26"
- canister length 15 ft.

1.2.1.1 horizontal borehole
- diameter 33"
- length approximately 682 ft
- liner id 31"
- liner thickness .5"
- dolly length 16.5 ft.
- unencumbered drift dimensions (dimensions dictated by equipment clearences are included) see attached Figure 1.
- minimum borehole spacing for emplacement 8 ft.

1.2.1.2 vertical borehole
- diameter 29" (counter bored above canister)
- counter bore diameter 34"
- depth 25 ft.
- bottom 14 ft. (not lined)
- unencumbered drift dimensions (dimensions dicated by equipment clearences are included) see attached Figure 2
- minimum borehole spacing for mining and emplacement 7.5 ft.

1.2.2 DHLW & WVHLW
- canister diameter 26"
- canister length 10 ft.

1.2.2.1 horizontal borehole
- diameter 33"
- maximum length approximately 682 ft.
- dolly length 11.5 ft.
- liner id 31"
- liner thickness .5"
- unencumbered drift dimensions (dimensions dictated by equipment clearences are included) see attached 3
- minimum borehole spacing for emplacement 8 ft.

1.2.2.2 vertical borehole
- diameter 29"
- depth 20 ft.
- unencumbered drift dimensions (dimensions dictated by equipment clearences are included) see attached Figure 4
- minimum borehole spacing for mining and emplacement 5 ft.

1.3 High burnup fuel emplaced at equivalent assemblies per acre as average burnup fuel (Mansure, 1985a).

1.4 Overall thermal loading (assemblies per acre or initial kilowatts per acre) for SF is to be equivalent to 57 kW/acre - 10 year old waste (Johnstone, 1984) as described in "Allowable Thermal Loading as a Function of Waste Age" (Mansure, 1985b). Overall thermal loading for DHLW ---TBD---?

1.5 SF thermal decay characteristics should be based on the decay functions given in "Thermal Decay Curves for PWR and BWR SF Waste" (Mansure, 1985c). DHLW thermal decay characteristics should be based on the decay functions given by Peters (1983).

1.6 Rock properties: project baseline rock properties are given in "Recommended Matrix and Rock-Mass Bulk, Mechanical, and Thermal Properties for Thermomechanical Stratigraphy of Yucca Mountain" (Nimick, et. al. 1984). Thermal conductivity and heat capacity used do not have to agree with values in that report but should be traceable to that document and a clear argument should be developed as to how properties used result in a conservative design.

1.7 SF canister initial thermal outputs, age, and number per year should be as given in O'Brien (1985) case II.

1.8 Unless otherwise justified pillar space between drifts that are not continuously maintained (access drifts, ie. P/B panel drifts) should be about four times the drift width.

1.9 Determination (calculation) of thermal loading should be based upon P/B module drawings (see attached Figures 5 & 6).

2. Underground Facility Design Guidance

The above criteria result in the following design guidance for spent fuel. Should these design guidance be inconsistent with the criteria and good design practice SNL should be advised.

2.1 For horizontal emplacement a 115' standoff will achieve the 50 deg. centigrade at 50 years objective for both PWR and BWR independent of canister output, is for all waste ages and borehole spacings, as long as allowable loadings (Mansure, 1985b) are adhered to. Standoff used for horizontal emplacement should be about this distance.

2.2 For horizontal emplacement the hottest borehole wall conditions result from 8.55 year old PWR canisters. This is the youngest aged for which PWR can have 6 assemblies per canister and still meet the 3.4 kW/canister loading limit presently being assumed for design of the canister (O'Brien, 1985). For this age PWR and canister output, the borehole wall and rock temperature at 1 meter calculated are 212 and 168 deg. centigrade. The borehole spacing used in this calculation is 36 meters. This borehole spacing is based upon the above criteria and the standoff in 2.1. Thus for horizontal emplacement the present criteria, especially the canister output and the dolly length, result in thermal conditions that automatically satisfy 1.1, borehole wall and 1 meter temperature, if 1.4, 1.9 and 2.1 are adhered to. Therefore adequate data and analysis exist to proceed with the horizontal layout using 1.9 to establish borehole spacing.

2.3 Vertical emplacement is much more complex thermally than horizontal emplacement. For vertical emplacement it is possible to violate borehole wall temperature. Adequate analysis have not been done to delineate how to establish vertical emplacement borehole and drift spacing.

2.4 Vertical emplacement drift temperature calculations have shown the following:

- For the same standoff between the waste and the panel access drifts, waste of varying age emplaced at the allowable thermal loading (Mansure, 1985b) results in essentially the same drift temperature at 50 years.
- For the same standoff between the waste and the panel access drifts, waste emplaced at the same loading but with different borehole and emplacement drift spacings results in essentially the same drift temperature at 50 years.

Based upon these two facts, it is reasonable to use the same standoff (actual standoff will vary slightly to keep number of boreholes an integer) for all waste ages and to determine this standoff prior to determining borehole spacing. This is convenient since borehole spacing is dependent upon drift spacing.

2.5 For Vertical emplacement, panel access drift temperature is dependent not only upon the standoff between the waste and the drift, but also the pillar between the drifts. If the pillar is very small, then the standoff must be bigger to compensate. The tradeoff is not one to one, but if the the sum of twice the standoff, twice the drift width and the width of the pillar is constant, then the temperature only varies a few degrees. Minimizing the pillar width does not necessarily result in the minimum mining. Recommended dimensions are about 23.75m for both the standoff and the pillar width. This makes the pillar about 4 times the drift width for a 6.25m drift and makes the pillar width equal to the standoff.

3. Reference Layout Dimensions

Current layout dimensions that result from the above criteria and guidance have been established by P/B. These are summarized below and should be used in design analysis and performance assessment.

3.1 Excavated dimensions for spent fuel

3.1.1 - horizontal emplacement

- standoff 102 ft.
- panel width 1400 ft.
- number of canisters per borehole 35
- emplacement drift width 18 ft.
- emplacement drift height 13 ft.
- alcove face to face distance 31 ft. (a equipment criteria number)

3.1.2 - vertical emplacement

- standoff 77.5 ft.
- barrier pillar width 63 ft.
- mid panel drift width 16 ft.
- mid panel drift height 22 ft..
- emplacement drift width 16 ft.
- emplacement drift height 22 ft.
- access drift width 21 ft.
- access drift height 14 ft.
- panel width 1400 ft.

3.2 Excavated dimensions for DHLW and WVHLW

3.2.1 - horizontal emplacement
- standoff -TBD- (10 to 102 ft.)
- module width varies (up to 700 ft.)
- number of canisters per borehole -TBD-
- emplacement drift width 26 ft. *
- emplacement drift height 13 ft.

3.2.2 - vertical emplacement
(double row of boreholes with 7' between rows and 5' between boreholes in a row)
- standoff -TBD-
- barrier pillar width 40 ft. *
- emplacement drift width 16 ft.
- emplacement drift height 18 ft.
- access drift width 21 ft.
- access drift height 13 ft.
- panel width varies (up to 700 ft.)

* Subject to thermostructural review.

References

Johnstone, J.K., R.R. Peters, and P.F. Gnirk, Unit Evaluation at Yucca Mountain Nevade Test Site: Summary Report and Recommendation, Sandia National Laboratory, SAND83-0372, 1984

Mansure, A.J., Effect of High Burnup Fuel on Underground Facility Design, memo to R. Hill, 2/13/1985a

Mansure, A.J., Allowable Thermal Loading as a Function of Waste Age, memo to R. Hill, 2/13/1985b

Mansure, A.J., Thermal Decay Curves for PWR and BWR SF Waste, memo to R. Hill, 2/13/1985c

Nimick, F.B., S.J. Bauer, and J.R. Tillerson, Recommended Matrix and Rock-Mass Bulk, Mechanical and Thermal Properties for Thermomechanical Stratigraphy of Yucca Mountain, Version I, SNLA Dept. 6310 Keystone Document Number 6310-85-1, 1984

O'Brien, P.D., Reference Nuclear Waste Descriptions for a Geologic Repository at Yucca Mountain, Nevada, SAND84-1818, in preparation, 1985.

Peters, R.R., Thermal Response to Emplacement of Nuclear Waste in Long, Horizontal Boreholes, SAND82-2497, 1983.

MINING REQUIREMENTS FOR HORIZONTAL EMPLACEMENT OF SPENT FUEL

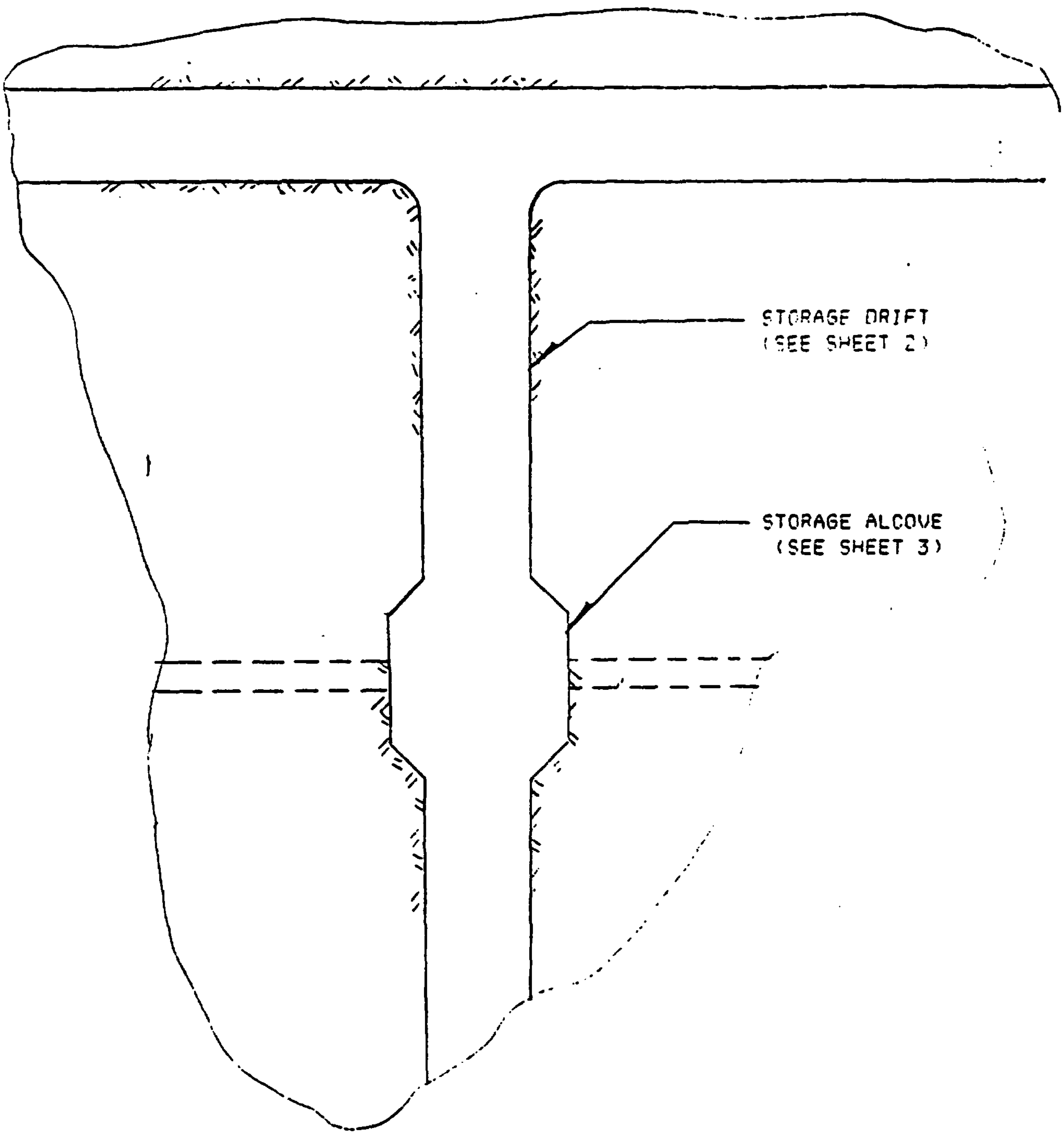


FIGURE 1
SHEET 1 OF 3

STORAGE DRIFT

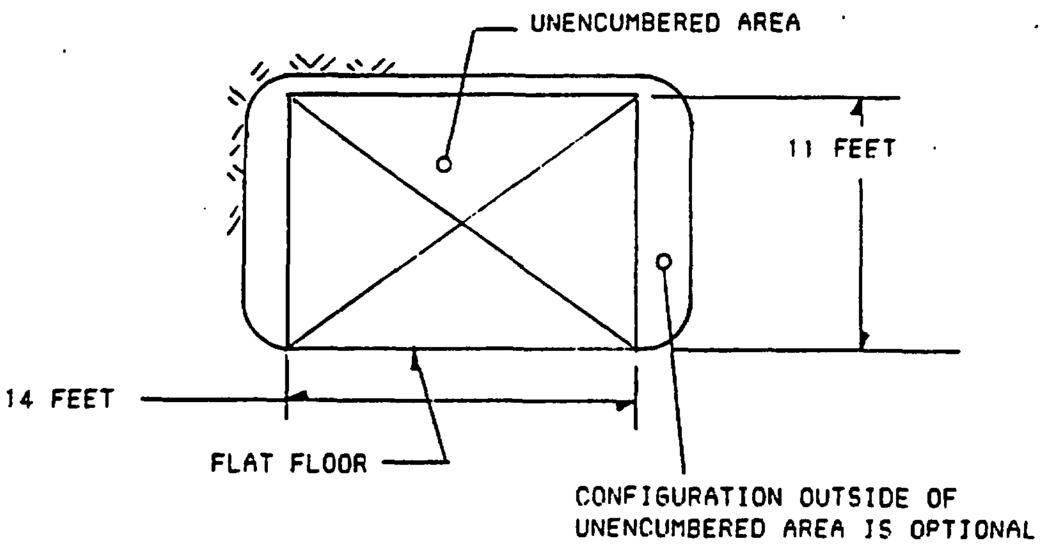


FIGURE 1
SHEET 2 OF 3

STORAGE ALCOVE

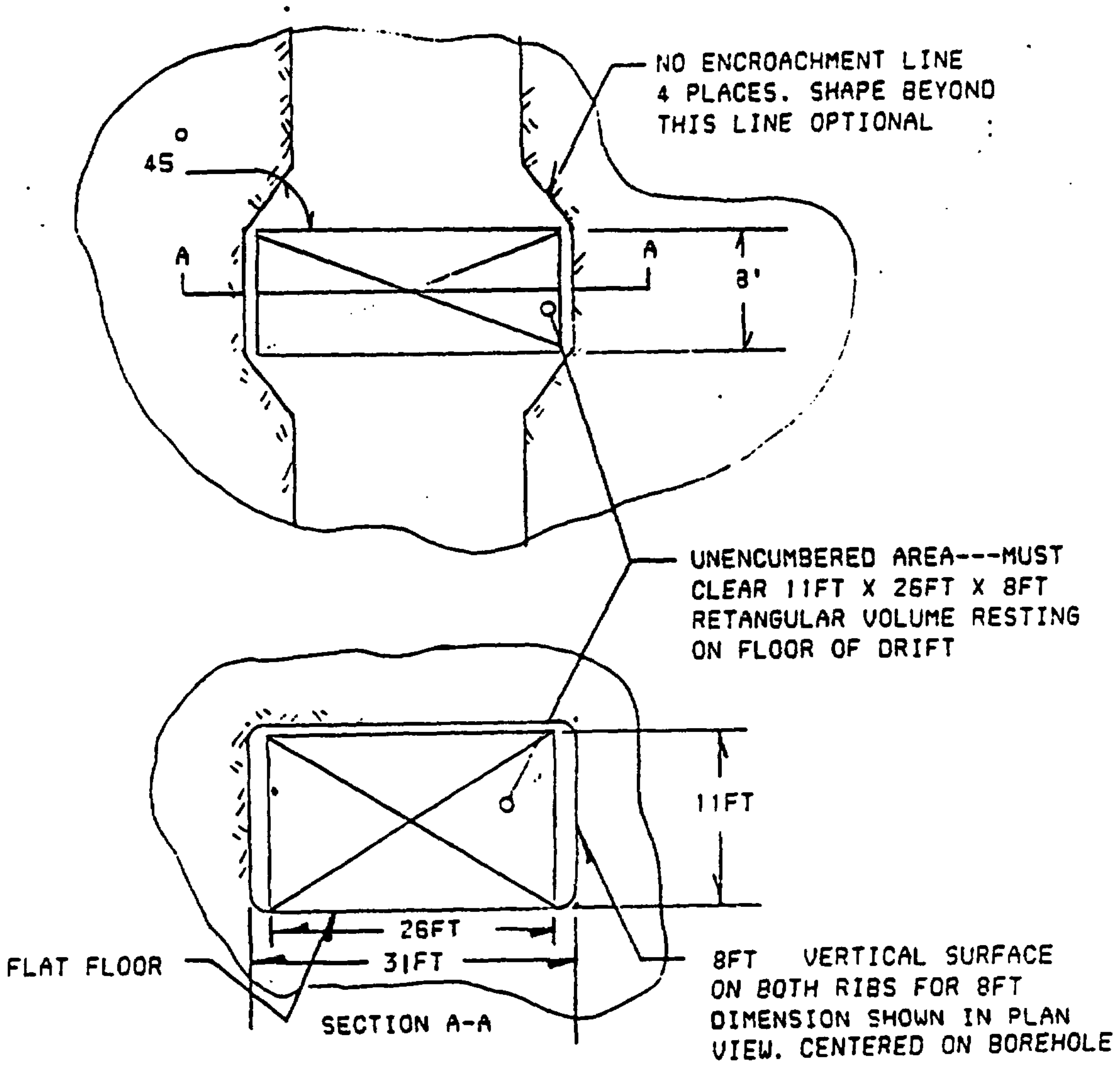
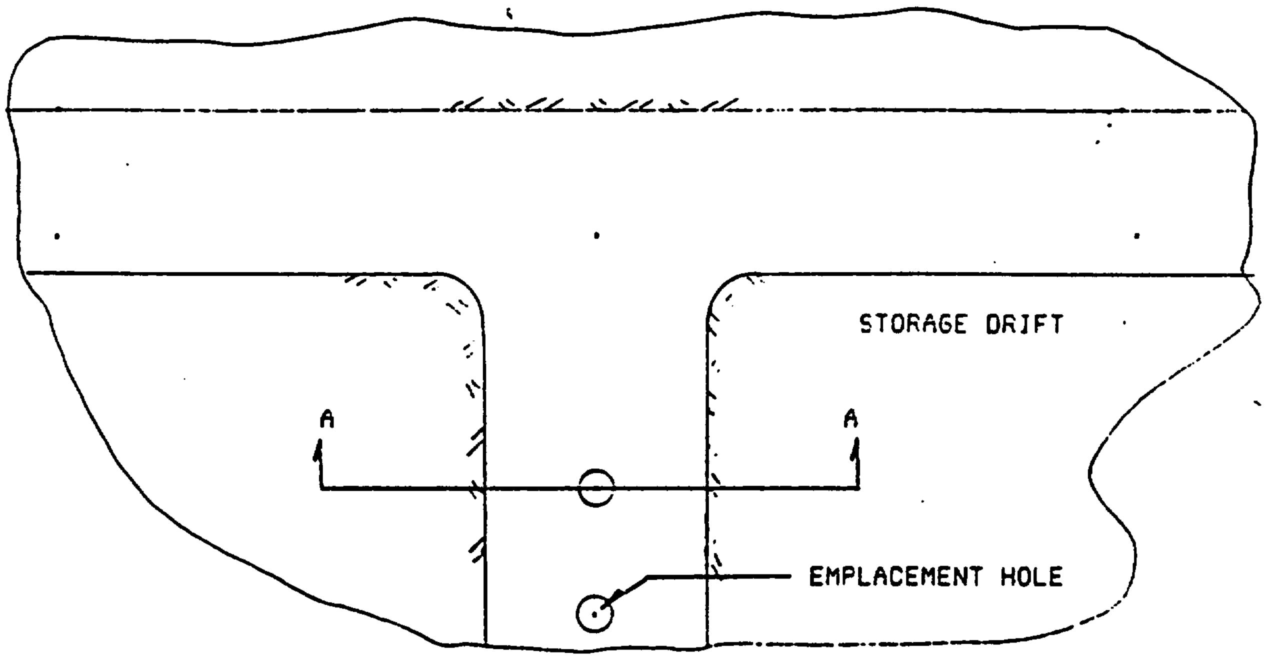
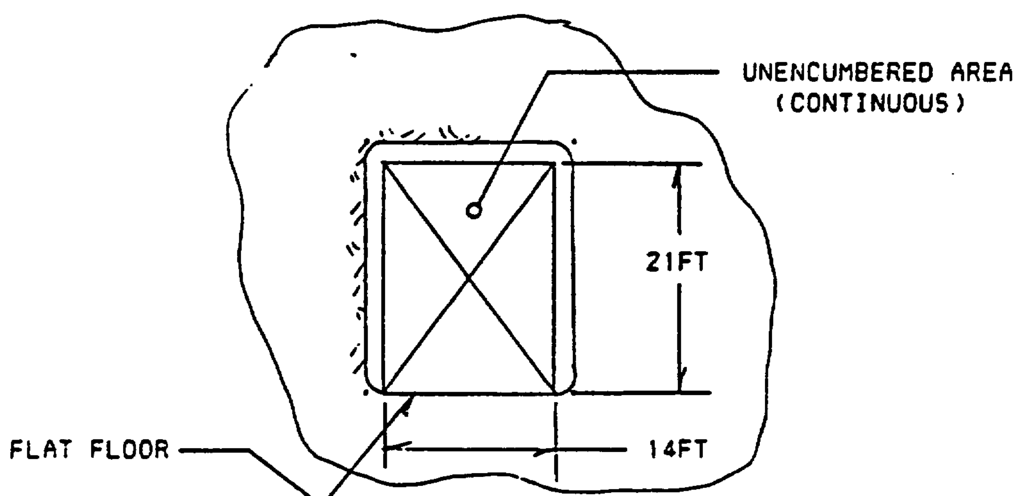


FIGURE 1
SHEET 3 OF 3

MINING REQUIREMENTS FOR VERTICAL EMPLACEMENT OF SPENT FUEL





SECTION A-A

FIGURE 2

MINING REQUIREMENTS FOR HORIZONTAL EMPLACEMENT OF <u>DHLW AND WVHLW</u>

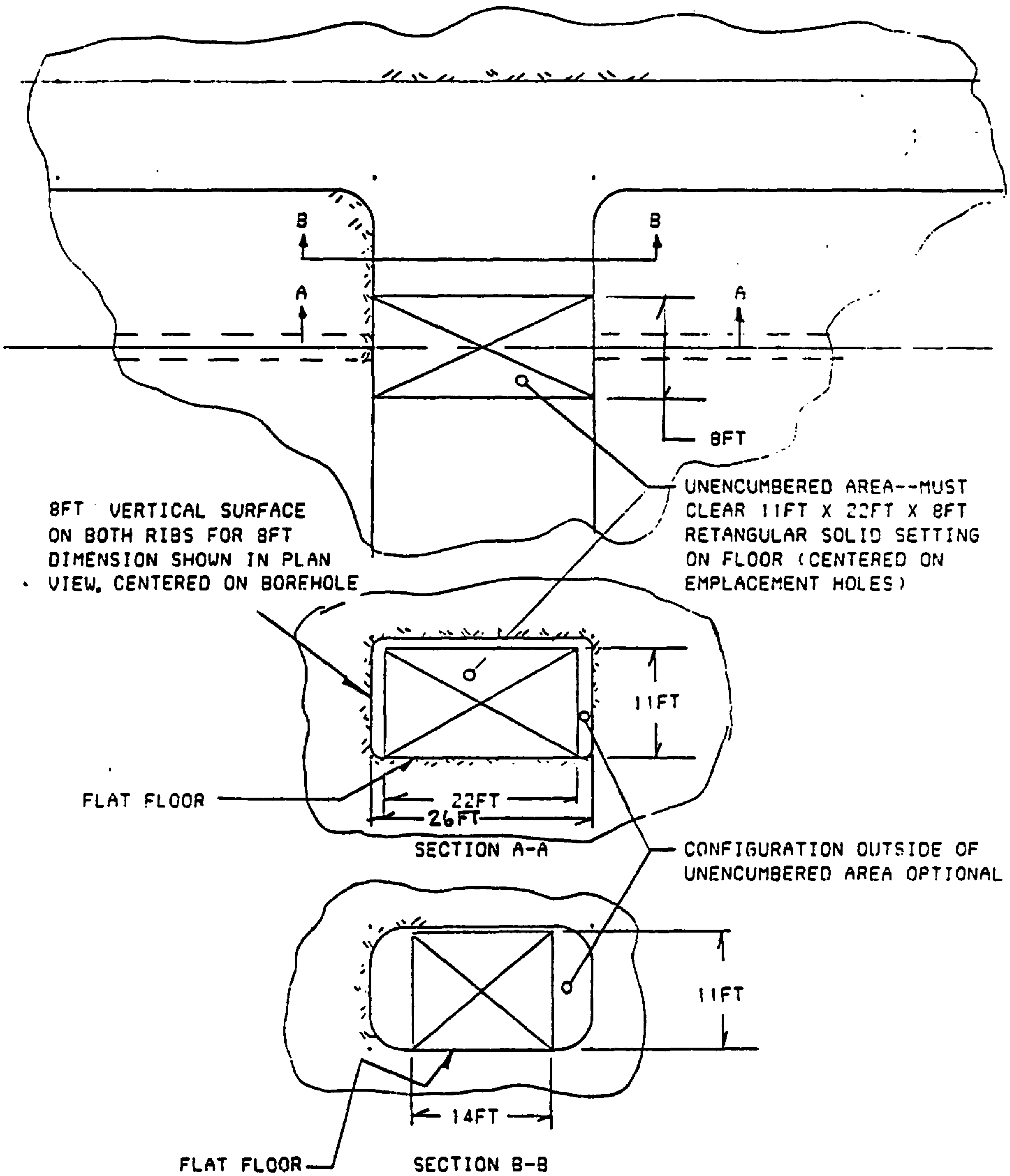


FIGURE 3

MINING REQUIREMENTS FOR VERTICAL EMPLACEMENT OF DHLW AND WVHLW

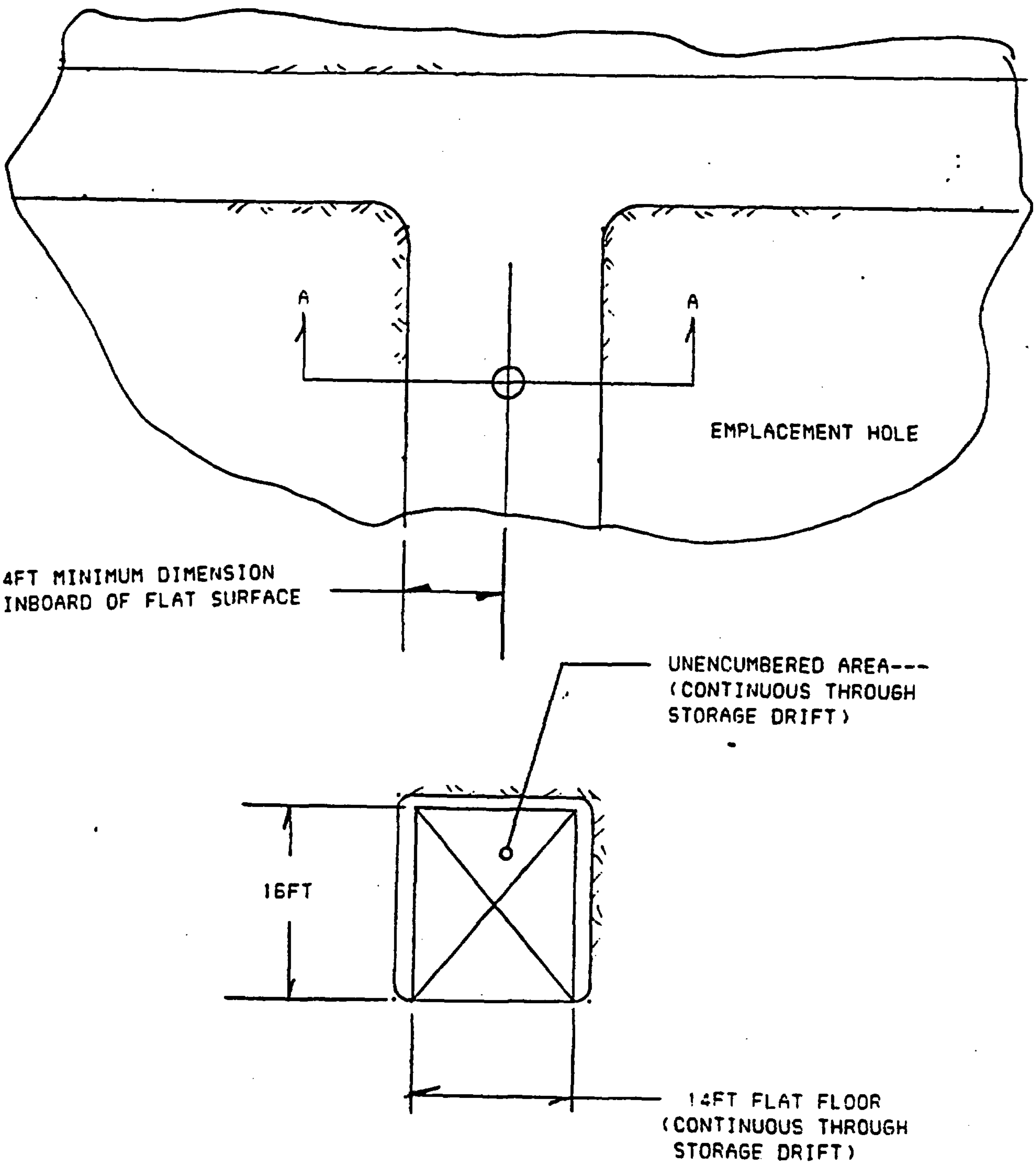
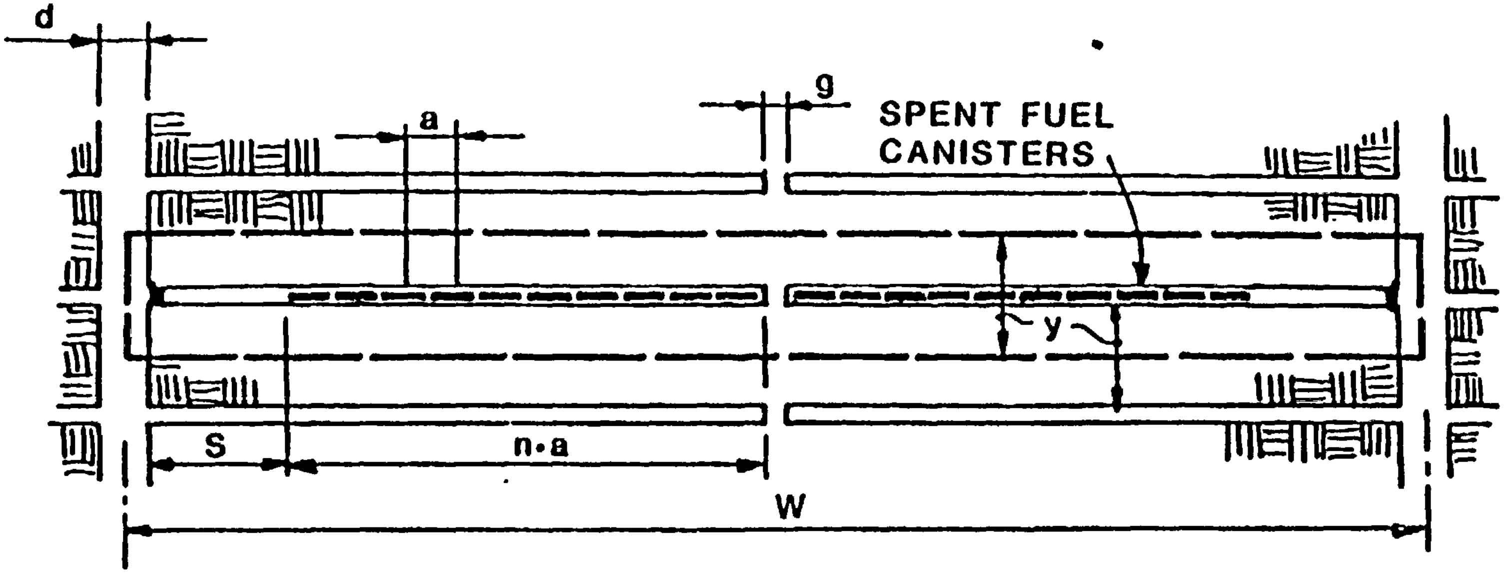


FIGURE 4



MODULE DESIGN UNIT

CHO - CANISTER HEAT OUTPUT
W - PANEL WIDTH
d - EMPLACEMENT DRIFT WIDTH
g - SEPARATION BETWEEN HOLE ENDS
k - 43,560 FT^2/ACRE
a - CANISTER LENGTH (INCLUDING DOLLY ASSEMBLY)

y - HOLE SPACING
n - NUMBER OF SPENT FUEL CANISTERS PER HOLE
S - STANDOFF TO EMPLACEMENT DRIFT

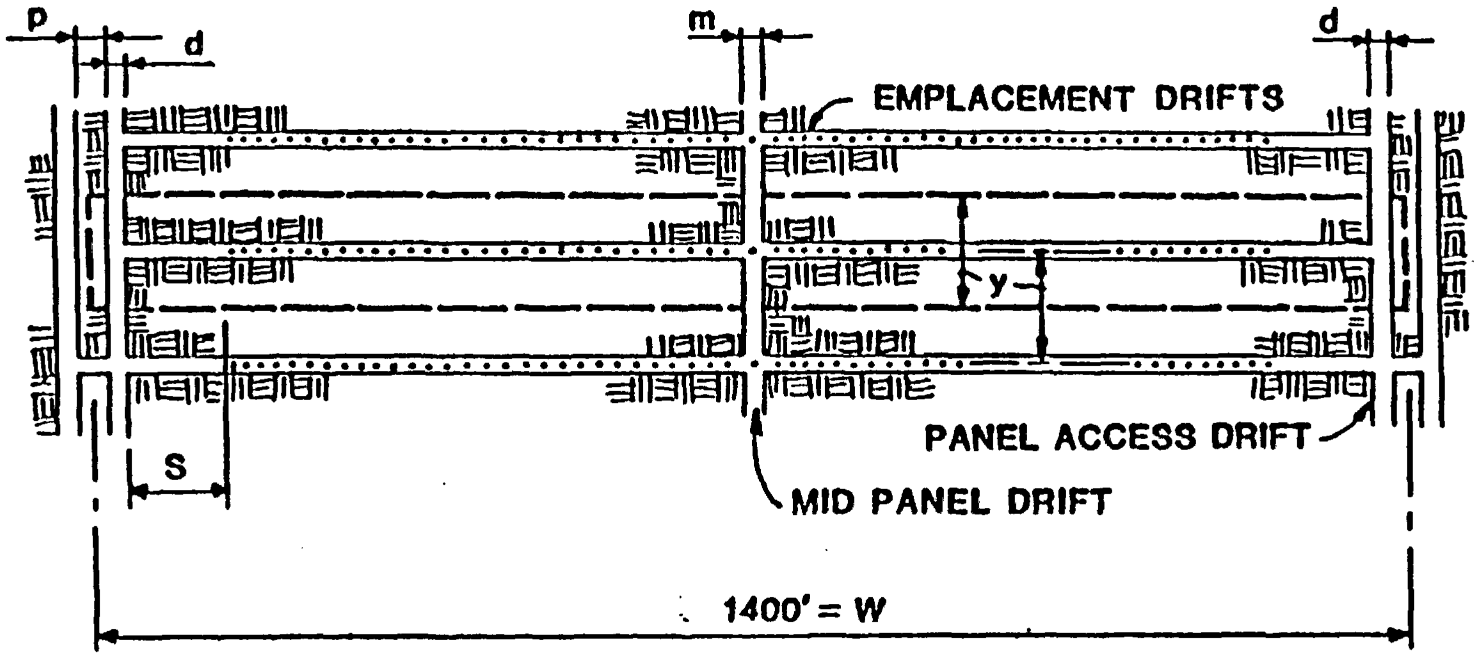
$$APD = \frac{CHO \cdot 2 \cdot n \cdot k}{y \cdot W}$$

$$W = d + g + 2(s + n \cdot a)$$

FIGURE 5 EMPLACEMENT DRIFT DETAIL:HORIZONTAL CONFIGURATION

FIGURE 6 EMPLACEMENT DRIFT DETAIL:VERTICAL CONFIGURATION

F-15/F-16



MODULE DESIGN UNIT

CHO	CANISTER HEAT OUTPUT
W	PANEL WIDTH
p	BARRIER PILLAR WIDTH
d	PANEL ACCESS DRIFT WIDTH
m	MID PANEL DRIFT WIDTH
k	43,560 FT^2/ACRE
a	HOLE SPACING
y	DRIFT SPACING
n	NUMBER OF SPENT FUEL CANISTERS PER MDU
S	STANDOFF TO PANEL ACCESS DRIFT

$$APD = \frac{CHO \cdot \quad n \cdot k}{y \cdot W}$$

1400

APPENDIX G

COMPARISON OF STUDY DATA WITH NNWSI REFERENCE INFORMATION BASE

FIGURE G.1

MATERIAL PROPERTY DATA

Material Property	Value Used	RIB Value[a]	RIB Reference
Density	2.34 g/cc	2.34 g/cc	1/2/1/5/1-3
Thermal Conductivity	2.07 W/mK	2.07 W/mk (25-100°C)	1/3/1/6/1-5
Heat Capacity	2.25 $J/cm^3 \cdot K$	2.25 $J/cm^3 \cdot K$ (25-100°C)	1/3/1/6/1-5
Coefficient of Thermal Expansion	$10.7*10^{-6}K^{-1}$	10.7 (25-200°C)	1/3/1/6/1-5
Elastic Modulus	15.1 GPa	15.1 GPa	1/3/1/7/1-6
Poisson's Ratio	0.2	0.2	1/3/1/78/1-6
Uniaxial Strength (Matrix)	75.4 MPa	75.4 MPa	1/3/1/7/1-6
Tensile Strength (Matrix)	-9.0 MPa	-9.0 MPa	1/3/1/7/1-6
Friction Angle (Matrix)	29.2°	29.2°	1/3/1/7/1-6
Cohesion (Joint)	1.0 MPa	1.0 MPa	1/3/1/8/1-2
Friction Coefficient (Joint)	0.8	0.8	1/3/1/8/1-2

Reference:
[a] Zeuch and Eatough, 1986 - TS2 Data, 80% Saturated.

FIGURE G.2a

GEOMETRIC DATA FOR VERTICAL EMPLACEMENT OPTION

Geometric Parameter	Value Used		RIB Value (ft)	RIB Reference
Drift Dimension				
Width	16.0[a]	(4.88m)	16.0[d]	2/2/1/1-17
Height	22.0[a]	(6.71m)	22.0[d]	2/2/1/1-17
Radius of Roof Arch	9.0[b]	(2.74m)	9.5[e]	----------
Container Borehole Dimensions				
Depth	25.00[a]	(7.62m)	25.00[d]	2/2/1/1-17
Diameter	2.42[a]	(0.74m)	2.42[d]	2/2/1/1-17
Panel Dimensions				
Waste Standoff from Access Drift Wall	77.5[a]	(23.62m)	77.5[d]	2/2/1/1-17
Access Drift Width	21.0[a]	(6.40m)	21.0[d]	2/2/1/1-17
Emplacement Drift Spacing	112.0[c]	(34.14m)	112.0[d]	2/2/1/1-17
Barrier Pillar Width	63.0[a]	(19.20m)	63.0[d]	2/2/1/1-17
Panel Width	1400.0[a]	(426.72m)	1400.0[d]	2/2/1/1-17

Source references:

[a]Mansure and Stinebaugh (1985).
[b]Parsons, Brinckerhoff, Quade and Douglas (1985).
[c]Mansure and Ortiz (1984).
[d]Mansure and Stinebaugh (1985).
[e]Parsons, Brinckerhoff, Quade and Douglas (1985).

FIGURE G.2b

GEOMETRIC DATA FOR VERTICAL EMPLACEMENT OPTION

Geometric Parameter	Value Used		RIB Value (ft)	RIB Reference
Emplacement Drift Dimension				
Width	18.0[a]	(5.49m)	18.0[d]	2/2/1/1-15
Height	13.0[a]	(3.96m)	13.0[d]	2/2/1/1-15
Radius of Roof Arch	10.2[b]	(3.11m)	9.5[e]	----------
Container Borehole Dimensions				
Waste Standoff From Emplacement Drift	117.50[a]	(35.81m)	117.50[d]	2/2/1/1-15
Length	682.00[a]	(207.87m))	682.00[d]	2/2/1/1-15
Diameter	2.75[a]	(0.84m)	2.75[d]	2/2/1/1-15
Panel Dimensions				
Panel Width	1400.00[a]	(426.72m)	1400.00[d]	2/2/1/1-15
Panel Depth	985.0[c]	(300.23m)	748.0[e]	----------

Source references:

[a]Mansure and Stinebaugh (1985).
[b]Parsons, Brinckerhoff, Quade and Douglas (1985).
[c]Mansure and Ortiz (1984).
[d]Mansure and Stinebaugh (1985).
[e]Parsons, Brinckerhoff, Quade and Douglas (1985).

APPENDIX H

DISTRIBUTION LIST

DISTRIBUTION LIST

Chief
Repository Projects Branch
Division of Waste Management
U.S. Nuclear Regulatory Commission
Washington, DC 20555

Document Control Center
Division of Waste Management
U.S. Nuclear Regulatory Commission
Washington, DC 20555

NTS Section Leader
Repository Project Branch
Division of Waste Management
U.S. Nuclear Regulatory Commission
Washington, DC 20555

SAIC-T&MSS Library (2)
Science Applications
International Corporation
101 Convention Center Drive
Suite 407
Las Vegas, NV 89109

ONWI Library
Battelle Columbus Laboratory
Office of Nuclear Waste Isolation
505 King Avenue
Columbus, OH 43201

Department of Comprehensive
Planning
Clark County
225 Bridger Avenue, 7th Floor
Las Vegas, NV 89155

Lincoln County Commission
Lincoln County
P.O. Box 90
Pioche, NV 89043

Community Planning and
Development
City of North Las Vegas
P.O. Box 4086
North Las Vegas, NV 89030

City Manager
City of Henderson
Henderson, NV 89015

Planning Department
Nye County
P.O. Box 153
Tonopah, NV 89049

Economic Development
Department
City of Las Vegas
400 East Stewart Avenue
Las Vegas, NV 89101

Director of Community Planning
City of Boulder City
P.O. Box 367
Boulder City, NV 89005

Technical Information Center
Roy F. Weston, Inc.
955 L'Enfant Plaza, Southwest
Suite 800
Washington, DC 20024

Commission of the
European Communities
200 Rue de la Loi
B-1049 Brussels
BELGIUM

D. H. Alexander (RW-232)
Office of Civilian Radioactive
Waste Management
U.S. Department of Energy
Forrestal Building
Washington, DC 20585

Eric Anderson
Mountain West Research-Southwest, Inc.
398 South Mill Avenue, Suite 300
Tempe, AZ 85281

J. H. Anttonen
Deputy Assistant Manager for
Commercial Nuclear Waste
Basalt Waste Isolation Project Office
U.S. Department of Energy
P.O. Box 550
Richland, WA 99352

Timothy G. Barbour
Science Applications
International Corporation
1626 Cole Boulevard, Suite 270
Golden, CO 80401

E. P. Binnall
Field Systems Group Leader
Building 50B/4235
Lawrence Berkeley Laboratory
Berkeley, CA 94720

R. J. Blaney (RW-22)
Office of Geologic Repositories
U.S. Department of Energy
Forrestal Building
Washington, DC 20585

P. M. Bodin (12)
Office of Public Affairs
U.S. Department of Energy
P.O. Box 14100
Las Vegas, NV 89114

E. S. Burton (RW-25)
Siting Division
Office of Geologic Repositories
U.S. Department of Energy
Forrestal Building
Washington, DC 20585

Flo Butler
Los Alamos Technical Associates
1650 Trinity Drive
Los Alamos, New Mexico 87544

V. J. Cassella (RW-222)
Office of Civilian Radioactive
Waste Management
U.S. Department of Energy
Forrestal Building
Washington, DC 20585

B. W. Church
Director
Health Physics Division
U.S. Department of Energy
P.O. Box 14100
Las Vegas, NV 89114

C. R. Cooley (RW-24)
Geosciences & Technology Division
Office of Geologic Repositories
U.S. Department of Energy
Forrestal Building
Washington, DC 20585

J. A. Cross
Manager
Las Vegas Branch
Fenix & Scisson, Inc.
P.O. Box 14308
Mail Stop 514
Las Vegas, NV 89114

H. D. Cunningham
General Manager
Reynolds Electrical &
Engineering Co., Inc.
P.O. Box 14400
Mail Stop 555
Las Vegas, NV 89114

Neal Duncan (RW-44)
Office of Policy, Integration, and
Outreach
U.S. Department of Energy
Forrestal Building
Washington, DC 20585

J. J. Fiore (RW-221)
Office of Civilian Radioactive
Waste Management
U.S. Department of Energy
Forrestal Building
Washington, DC 20585

John Fordham
Desert Research Institute
Water Resources Center
P.O. Box 60220
Reno, NV 89506

Judy Foremaster (5)
City of Caliente
P.O. Box 158
Caliente, NV 89008

D. L. Fraser
General Manager
Reynolds Electrical & Engineering
Co., Inc.
P.O. Box 14400
Mail Stop 555
Las Vegas, NV 89114-4400

M. W. Frei (RW-231)
Office of Civilian Radioactive
Waste Management
U.S. Department of Energy
Forrestal Building
Washington, DC 20585

B. G. Gale (RW-223)
Office of Civilian Radioactive
Waste Management
U.S. Department of Energy
Forrestal Building
Washington, DC 20585

R. W. Gale (RW-40)
Office of Civilian Radioactive
Waste Management
U.S. Department of Energy
Forrestal Building
Washington, DC 20585

V. M. Glanzman
U.S. Geological Survey
913 Federal Center
P.O. Box 25046
Denver, CO 80225

Vincent Gong
Technical Project Officer for NNWSI
Reynolds Electrical & Engineering
Co., Inc.
P.O. Box 14400
Mail Stop 615
Las Vegas, NV 89114-4400

A. E. Gurrola
General Manager
Energy Support Division
Holmes & Narver, Inc.
P.O. Box 14340
Mail Stop 580
Las Vegas, NV 89114

R. Harig
Parsons Brinkerhoff Quade &
Douglas, Inc.
1625 Van Ness Avenue
San Francisco, CA 94109-3678

Roger Hart
Itasca Consulting Group, Inc.
P.O. Box 14806
Minneapolis, Minnesota 55414

T. Hay
Executive Assistant
Office of the Governor
State of Nevada
Capitol Complex
Carson City, NV 89710

L. R. Hayes (3)
Technical Project Officer for NNWSI
U.S. Geological Survey
421 Federal Center
P.O. Box 25046
Denver, CO 80225

W. M. Hewitt
Program Manager
Roy F. Weston, Inc.
955 L'Enfant Plaza, Southwest
Suite 800
Washington, DC 20024

T. H. Isaacs (RW-22)
Office of Civilian Radioactive
Waste Management
U.S. Department of Energy
Forrestal Building
Washington, DC 20585

Allen Jelacic (RW-233)
Office of Civilian Radioactive
Waste Management
U.S. Department of Energy
Forrestal Building
Washington, DC 20585

C. H. Johnson
Technical Program Manager
Nuclear Waste Project Office
State of Nevada
Evergreen Center, Suite 252
1802 North Carson Street
Carson City, NV 89701

S. H. Kale (RW-20)
Office of Civilian Radioactive
Waste Management
U.S. Department of Energy
Forrestal Building
Washington, DC 20585

B. J. King (2)
Librarian
Basalt Waste Isolation Project
Library
Rockwell Hanford Operations
P.O. Box 800
Richland, WA 99352

Cy Klingsberg (RW-24)
Office of Geologic Repositories
Geosciences and Technology Division
U.S. Department of Energy
Forrestal Building
Washington, DC 20585

J. P. Knight (RW-24)
Office of Civilian Radioactive
Waste Management
U.S. Department of Energy
Forrestal Building
Washington, DC 20585

T. P. Longo (RW-25)
Office of Geologic Repositories
U.S. Department of Energy
Forrestal Building
Washington, DC 20585

R. R. Loux, Jr. (3)
Executive Director
Nuclear Waste Project Office
State of Nevada
Evergreen Center, Suite 252
1802 North Carson Street
Carson City, NV 89701

S. A. Mann
Manager
Crystalline Rock Project Office
U.S. Department of Energy
9800 South Cass Avenue
Argonne, IL 60439

Dr. Martin Mifflin
Desert Research Institute
Water Resources Center
2505 Chandler Avenue
Suite 1
Las Vegas, NV 89120

D. F. Miller
Director
Office of Public Affairs
U.S. Department of Energy
P.O. Box 14100
Las Vegas, NV 89114

R. Lindsay Mundell
U.S. Bureau of Mines
Denver Federal Center
P.O. Box 25086
Building 20
Denver, Colorado 80225

S. D. Murphy
Technical Project Officer for NNWSI
Fenix & Scisson, Inc.
P.O. Box 15408
Mail Stop 514
Las Vegas, NV 89114

J. O. Neff
Manager
Salt Repository Project Office
U.S. Department of Energy
505 King Avenue
Columbus, OH 43201

D. C. Newton (RW-23)
Engineering & Licensing Division
Office of Geologic Repositories
U.S. Department of Energy
Forrestal Building
Washington, DC 20585

N. A. Norman
Project Manager
Bechtel National Inc.
P.O. Box 3965
San Francisco, CA 94119

D. T. Oakley (4)
Technical Project Officer for NNWSI
Los Alamos National Laboratory
P.O. Box 1663
Mail Stop F-619
Los Alamos, NM 87545

O. L. Olson
Manager
Basalt Waste Isolation Project Office
Richland Operations Office
U.S. Department of Energy
P.O. Box 550
Richland, WA 99352

Gerald Parker (RW-241)
Office of Civilian Radioactive
Waste Management
U.S. Department of Energy
Forrestal Building
Washington, DC 20585

David K. Parrish
RE/SPEC Inc.
3815 Eubank, N.E.
Albuquerque, NM 87191

J. P. Pedalino
Technical Project Officer for NNWSI
Holmes & Narver, Inc.
P.O. Box 14340
Mail Stop 605
Las Vegas, NV 89114

P. T. Prestholt
NRC Site Representative
1050 East Flamingo Road
Suite 319
Las Vegas, NV 89109

W. J. Purcell (RW-20)
Associate Director
Office of Civilian Radioactive
Waste Management
U.S. Department of Energy
Forrestal Building
Washington, DC 20585

L. D. Ramspott (3)
Technical Project Officer for NNWSI
Lawrence Livermore National
Laboratory
P. O. Box 808
Mail Stop L-204
Livermore, CA 94550

J. R. Rollo
Deputy Assistant Director
for Engineering Geology
U.S. Geological Survey
106 National Center
12201 Sunrise Valley Drive
Reston, VA 22092

B. C. Rusche (RW-1)
Director
Office of Civilian Radioactive
Waste Management
U.S. Department of Energy
Forrestal Building
Washington, DC 20585

J. E. Shaheen (RW-44)
Outreach Programs
Office of Policy, Integration and
Outreach
U.S. Department of Energy
Forrestal Building
Washington, DC 20585

Dr. Madan M. Singh
President
Engineers International, Inc.
98 East Naperville Road
Westmont, IL 60559-1595

M. E. Spaeth
Technical Project Officer for NNWSI
Science Applications
International Corporation
101 Convention Center Drive
Suite 407
Las Vegas, NV 89109

Christopher M. St. John
J.F.T. Agapito Associates, Inc.
27520 Hawthorne Blvd., Suite 295
Rolling Hills Estates, CA 90274

Ralph Stein (RW-23)
Office of Civilian Radioactive
Waste Management
U.S. Department of Energy
Forrestal Building
Washington, DC 20585

K. Street, Jr.
Lawrence Livermore National
Laboratory
P. O. Box 808
Mail Stop L-209
Livermore, CA 94550

W. S. Twenhofel
Consultant
Science Applications
International Corp.
820 Estes Street
Lakewood, CO 89215

D. L. Vieth (4)
Director
Waste Management Project Office
U.S. Department of Energy
P.O. Box 14100
Las Vegas, NV 89114

J.S. Wright
Technical Project Officer for NNWSI
Waste Technology Services Division
Westinghouse Electric Corporation
Nevada Operations
P.O. Box 708
Mail Stop 703
Mercury, NV 89023

6300 R. W. Lynch
6310 T. O. Hunter
6310 NNWSICF
6310 71/12462/04/Q2
6311 L. W. Scully
6311 C. Mora
6311 V. Hinkel (2)
6312 F. W. Bingham
6313 T. E. Blejwas
6314 J. R. Tillerson
6314 B. L. Ehgartner
6314 A. J. Mansure
6315 S. Sinnock
6315 M. J. Eatough
6332 WMT Library (20)
6430 N. R. Ortiz
8024 P. W. Dean
3141 S. A. Landenberger (5)
3151 W. L. Garner (3)
3154-3 C. H. Dalin (28)
for DOE/OSTI