NTS-865

SANDIA REPORT SAND82-0170 • Unlimited Release • UC-70
Printed October 1982

WM RECORD COPY

Thermal Analyses for a Nuclear Waste Repository in Tuff Using USW-G1 Borehole Data

Roy L. Johnson

Prepared by
Sandia National Laboratories
Albuquerque, New Mexico 87185 and Livermore, California 94550
for the United States Department of Energy
under Contract DE-AC04-76DP00789

HYDROLOGY DOCUMENT NUMBER 178

SF 2900-Q(6-82)

Issued by Sandia National Laboratories, operated for the United States Department of Energy by Sandia Corporation.
NOTICE: This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government, any agency thereof or any of their contractors or subcontractors. The views and opinions expressed herein do not necessarily state or reflect those of the United States Government, any agency thereof or any of their contractors or subcontractors.

Printed in the United States of America
Available from
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161

NTIS price codes
Printed copy: A04
Microfiche copy: A01

SAND 82-0170

THERMAL ANALYSES FOR A NUCLEAR WASTE REPOSITORY IN TUFF USING USW-G1 BOREHOLE DATA

by

Roy L. Johnson
Applied Mechanics Division 1522
Sandia National Laboratories
Albuquerque, NM 87185

ABSTRACT

Thermal calculations using properties of tuffs obtained from the USW-G1 borehole, located near the SW margin of the Nevada Test Site (NTS), have been completed for a nuclear waste repository sited in welded tuff below the water table. The analyses considered two wasteforms, high level waste and spent fuel, emplaced at two different, gross thermal loadings, 50 and 75 kW/Acre (20.24 and 30.36 kW/ha). Calculations were made assuming that no boiling of the groundwater occurs; i.e., that the hydrostatic head potential was reestablished soon after waste emplacement.

ACKNOWLEDGEMENT

The author expresses his appreciation to K. W. Schuler, Applied Mechanics Division II, and A. R. Lappin, NNWSI Geotechnical Projects Division, for their helpful comments during review of this report. Also acknowledged is the considerate advice and assistance provided by R. K. Thomas, Applied Mechanics Division I throughout the course of this study.

CONTENTS

INTRODUCTION 6

PROBLEM SPECIFICATIONS 8
General. 8
Room and Pillar Geometry 8
USW-G1 Stratigraphy. 9

FINITE ELEMENT ANALYSIS. 11
Finite Element Mesh. 11
Radiation and Convection Approximation 11
Equivalent Volumetric Heat Source. 12
Thermal Properties of the Waste. 12

DISCUSSION OF RESULTS. 14
General. 14
High Level Waste and Spent fuel at a GTL of 75 kW/Acre 17
Spent Fuel at a GTL of 50 kW/Acre. 19
Effects of Stratification. 20

SUMMARY AND CONCLUSIONS. 21

REFERENCES 23

APPENDIX 24

FIGURES. 29-52

INTRODUCTION

Results of thermal calculations for a nuclear waste repository below the water table in tuff, made using the thermal properties appropriate to the stratigraphy of the USW-G1 hole, are summarized in this report. Three calculations were done, considering the waste form to be either high-level waste or UO_2 spent fuel. Calculations for high-level waste were done for a gross thermal loading (GTL) of 75 kW/Acre, spent fuel with GTL's of 50 and 75 kW/Acre. No boiling of the groundwater is considered. This assumption results in a greater temperature rise in the repository than if boiling is allowed. Assumed, in effect, is that the hydrostatic head potential is reestablished very quickly after waste emplacement and is great enough to prohibit boiling. While this assumption does lead to maximum temperatures in most locations, it minimizes uncertainties due to water vaporization and multiphase transport. Calculations covered the time period up to 200 to 300 years after emplacement.

Two concerns were addressed by the study: 1) Temperature rise in the vicinity of the waste-emplacement room; and 2) absolute temperatures at the stratigraphic interfaces between the emplacement horizon and those lying above and below it. The second concern was raised as the result of geologic studies, which showed the zeolite-free emplacement horizon to be bounded both above and below by zeolitic tuffs; these tuffs have a lower thermal conductivity than the repository or emplacement horizon.

Calculations were performed using the 1978 version of the computer code ADINAT[1]. The computational results for a layered stratigraphy are compared with those previously reported for a homogeneous stratigraphy [2, 3, 4].

PROBLEM SPECIFICATIONS

General

Material thermal properties and problem descriptions for these calculations were specified in Work Package YME-1, a copy of which is included in the APPENDIX. Initial temperature was taken as 36°C as specified in the Work Package. The design geometry and relative heat generation decay properties of the waste forms were specified by the MIDES Working Group.[5] These specifications are summarized in this section of the report. Relative heat generation decay properties for high level waste and spent fuel are given in Table 1.

Room and Pillar Geometry

Figures 1 and 2 show plan views of a repository layout and cross sections of a typical emplacement room for High Level Waste (HLW) and Spent Fuel (SF), respectively. Canister pitch is a function of gross thermal loading (GTL).

The problem of heat transfer in this geometry is three-dimensional. The calculations presented here were done by approximating the geometry as planar, with a cross-sectional plane oriented perpendicular to the length of the emplacement room, and the canister extended to infinity in the out-of-plane dimension. The heat source is thus assigned the dimensions of the canister hole in the plane but is continuous in the out-of-plane dimension. The heat source is transformed into an "equivalent heat source," as described in a later paragraph.

USW-G1 Stratigraphy

Thermal properties were identified for ten stratigraphic zones by A. R. Lappin, 9763. His results are shown in Tables A1 and A2 and are summarized in Figure 3. Table A2 is a correlation of functional stratigraphy with stratigraphic units. The vertical scale in Figure 3 is measured in meters from the floor level of the room. The waste canister is centered on zone 6, the zone identified in Figure 3 as the BULLFROG with canister centerline at an elevation of 579 m. The upper and lower stratigraphic contacts are at approximately +33 m and -30 m, respectively.

Thermal conductivities and heat capacities corresponding to saturated conditions were used in these calculations, since no boiling of the groundwater was assumed to occur.

TABLE 1

RELATIVE HEAT-GENERATION DECAY PROPERTIES[a]

Year After Emplacement[b]	HLW	SF
0	1.0	1.0
1	.95	.956
2	.907	.919
3	.871	.889
4	.851	.861
5	.810	.838
6	.783	.819
7	.769	.799
8	.734	.782
9	.714	.763
10	.692	.750
15	.600	.681
20	.529	.622
30	.402	.525
40	.313	.449
50	.246	.387
70	.157	.301
100	.0864	.238
190	.0296	.137
290	.0215	.108
390	.0163	.0919
490	.0145	.0806
590	.0127	.0711
690	.0113	.0633
790	.0100	.0569
890	.00897	.0514
990	.00810	.0466
1990	.00404	.0247
5990	.00230	.0148
9990	.00175	.0114

[a]See Y/OWI/TM-34, "Nuclear Waste Projections and Source Term Data for FY 1977." The HLW decay rates correspond to waste arising from fuel which is a 3:1 mix of fresh UO_2 and MOX fuels.

[b]Assumes waste is 10 years old at emplacement.

FINITE ELEMENT ANALYSIS

Finite Element Mesh

Figures 4 and 5 show plots of the complete finite element meshes, for HLW and SF, respectively, with portions blown-up in the regions of the room defined by points A-E. A total number of 596 nodal points and 530 four-node-quadrilateral elements were used for the HLW calculation and 582 nodes and 518 elements for the SF calculation. The meshes for both HLW and SF extended 250 m above and below the floor of the room. This distance was sufficient to maintain the isothermal boundary condition at the upper and lower boundaries of the mesh for the time period of the calculations (200 to 300 years after emplacement).

Radiation and Convection Approximation

The effects of radiation and convection within the emplacement room, which was assumed air-filled and unventilated, were approximated by defining solid, conduction elements with appropriate properties. O. L. George in Reference [3] showed the importance of thermal radiation in determining temperatures around the periphery of an air-filled room and that this radiation could be satisfactorily approximated by a thermal conduction model with a large diffusivity. In accordance with his recommendations, the following conduction properties were used here for modeling room elements:

$$K = 7.88 \times 10^8 \ J/yr\text{-}m\text{-}^\circ C$$

$$\rho C_p = 1000 \ J/m^3\text{-}^\circ C$$

Equivalent Volumetric Heat Source

The initial heat outputs, Q_o, used in these calculations are summarized in Table 2. These generation rates were

TABLE 2

Equivalent Volumetric Heat Sources

GTL kw/Acre	Q_o $J/Yr\text{-}m^3 \times 10^9$	
	HLW	SF
50	8.7753	4.8690
75	13.1630	7.3035

calculated on the basis of an equivalent volume having the dimensions of the canister hole in the plane but extending continuously in the out-of-plane dimension. This equivalent heat source, expressed as heat output per unit of volume, is a function of GTL or canister power, canister hole dimensions and canister pitch.

Thermal Properties of the Waste

The thermal properties of the elements representing the HLW canister were assumed constant over the temperature range considered, as follows:

$$K = 3.82 \times 10^7 \text{ J/yr-m-°C}$$

$$\rho C_p = 2.51 \times 10^6 \text{ J/m}^3\text{-°C}$$

Thermal properties of the elements representing the SF canister were assumed temperature dependent. Equivalent SF canister properties as presented by RE/SPEC in their letter memorandum dated February 4, 1980 were used to describe these properties. They are:

$$K = 0.211 \left(\frac{T + 273}{100}\right)^{1.197} \qquad \text{w/m-°C}$$

$$C_p = 690.2 + 13.38\left(\frac{T}{100}\right) \qquad \text{J/kg-°C}$$

where T is measured in Kelvin.

The variation of K and ρc_p with temperature used in these calculations is shown in Table 3.

TABLE 3

Equivalent Thermal Properties

of a Spent Fuel Canister

T °C	K J/yr-m-°C x 10^7	ρC_p J/m^3 - °C x 10^6
0.	4.563	2.895
100.	8.300	2.951
200.	13.084	3.007
500.	33.550	3.175

DISCUSSION OF RESULTS

General

Results of the calculations are presented graphically in two ways: 1) as temperature contours or isotherms, plotted with a contour interval of 5°C; and 2) as temperature-time histories for various points around the room, through the pillar, and at the upper and lower stratigraphic interfaces. The temperature at the upper and lower mesh boundaries is also plotted versus time in order to monitor the validity of the assumed isothermal boundary conditions.

Peak temperatures and time of occurrence at specific locations (points A-H of Figures 4 and 5) are listed in Table 4. In Table 5, temperature differences, that is temperature rises above initial temperature, are listed for these same locations. The temperature differences listed in Table 5 for USW-G1 data are calculated using temperatures shown in Table 4. Those listed for uniform stratigraphy come from temperatures reported elsewhere [2, 3, 4] and are for a uniform rock mass with slightly different thermal conductivity.

A post-processor POSADT2 was used to interface the output from ADINAT with existing computer plotting codes CNTR[6] and TPLOT2[7] to produce the graphs of data shown in Figures 6 through 8 and 9 through 23, respectively.

Table 4

PEAK TEMPERATURES
AT VARIOUS LOCATIONS

Temperatures in °C and Time of Occurrence in Years after Emplacement
Based on an initial Temperature of 36° C*

LOCATION (Point) (See Figures 4 and 5)	HIGH LEVEL WASTE		SPENT FUEL			
	75 kW/Acre		75 kW/Acre		50 kW/Acre	
	Temp	Time	Temp	Time	Temp	Time
Centerline Room Floor (A)	95	40	114	150	88	150
Lower Corner of Room (B)	95	40	114	150	88	150
Midheight Room Rib (C)	94	40	113	150	88	150
Upper Corner of Room (D)	93	45	112	150	87	150
Centerline Room Roof (E)	93	45	112	150	87	150
Quarter Pillar (F)	91	50	111	165	86	165
Centerline Pillar (G)	90	50	108	165	85	170
Upper Stratigraphic Boundary	71	125	93**	200	76**	300
Lower Stratigraphic Boundary	72	120	96**	200	77**	300

* All calculations based on conditions of no boiling of the groundwater

** Temperatures calculated at the end of the indicated time period. At these times temperatures have not yet peaked

Table 5

TEMPERATURE DIFFERENCES ABOVE INSITU AMBIENT
AT VARIOUS LOCATIONS FOR TWO DIFFERENT STRATIGRAPHIES

Temperatures in °C and Time of Occurrence in Years after Emplacement
Based on a Gross Thermal Loading of 75 kW/Acre and No Boiling of Groundwater

LOCATION (Point) (See Figures 4 and 5)	HIGH LEVEL WASTE				SPENT FUEL			
	Uniform Stratigraphy		USW-G1 Stratigraphy		Uniform Stratigraphy		USW-G1 Stratigraphy	
	ΔT[1]	Time	ΔT[2]	Time	ΔT[1]	Time	ΔT[2]	Time[3]
Centerline Room Floor (A)	52	40	59	40	67	100	77	100
Lower Corner of Room (B)	52	40	59	40	67	100	77	100
Midheight Room Rib (C)	51	40	58	40	66	100	76	100
Upper Corner of Room (D)	51	40	57	45	65	100	76	100
Centerline Room Roof (E)	51	40	57	45	65	100	76	100
Quarter Pillar (F)	50	50	55	50	63	100	72	100
Centerline Pillar (G)	49	50	54	50	62	100	70	100
Upper Stratigraphic Boundary	30	100	35	100	41	100	46	100
Lower Stratigraphic Boundary	32	100	36	100	46	100	51	100

[1] Temperature difference computed from a reference temperature of 55 °C at time of peak temperature

[2] Temperature difference computed from a reference temperature of 36 °C at time of peak temperature

[3] Temperature difference computed from a reference temperature of 36 °C at 100 years after emplacement

High Level Waste and Spent fuel at a GTL of 75 kW/Acre

Figures 6 and 7 show isotherms at times of 1, 5, 10, 50 and 100 years after emplacement of HLW and SF at a GTL of 75 kW/Acre. Temperature histories to 200 years after emplacement for various points in the room and pillar region are shown in Figures 9 through 18.

The results of the calculations using thermal properties based on USW-G1 hole data were compared with those obtained using properties of a uniform rock mass. The gross thermal loading of 75 kW/Acre was used as a basis of comparison of the two stratigraphies, since the GTL of 50 kW/Acre was not calculated previously using uniform properties. No direct comparison of peak absolute temperatures is possible for the two stratigraphies, since different initial temperatures were used in the calculations. The most meaningful comparison, that of temperature differences, was made and these are listed in Table 5.

It can be seen from the temperature differences shown in Table 5 that those calculated using the layered (USW-G1) properties are approximately 5-7 degrees higher for HLW and 8-10 degrees higher for SF than those calculated using uniform properties. This is apparently due to both a lower thermal conductivity of the BULLFROG (zone 6) and to the presence of the upper and lower bounding horizons. The properties used in the latter calculations were:

$K = 7.57 \times 10^7$ J/yr-m-°C (vs. 5.68×10^7 J/yr-m-°C for Zone 6 in G1)

$\rho C_p = 3.64 \times 10^6$ J/m^3-°C (vs. 3.81×10^6 J/m^3-°C for Zone 6 in G1)

For HLW, temperatures peak in less than 100 years for points around the room and in the pillar, generally at 40-50 years after emplacement. Peak temperatures at the upper and lower stratigraphic interfaces are reached at times greater than 100 years after emplacement, at near 125 years after emplacement. Temperatures at these interfaces peaked at approximately 72 degrees, thus causing no concern about dehydration of the zeolitic tuffs, regardless of the in situ fluid pressure. Since stratigraphic effects appeared minimal at 75 kW/Acre, calculations were not made for HLW emplaced at a GTL of 50 kW/Acre.

For SF, emplaced at 75 kW/Acre, temperatures around the room and in the pillar peaked approximately 150 years after emplacement. Temperatures at the stratigraphic interfaces were still increasing at 200 years, the longest time to which these calculations were extended. Moreover, at 200 years, the absolute temperatures at these interfaces had exceeded 85°C, the assumed transition temperature at which the zeolitic tuffs begin to dehydrate at atmospheric fluid pressure. For this reason, and because the condition of isothermal upper and lower

boundaries might be violated, the time period for these calculations was not extended beyond 200 years.

Spent Fuel at a GTL of 50 kW/Acre

Isotherms to 100 years after waste emplacement are shown in Figure 8. Temperature histories to 300 years for various points are plotted in Figures 19 through 23.

Overall, the temperature rises for GTL at 50 kW/Acre are lower than those at 75 kW/Acre, as one might expect. However, the absolute temperatures at the stratigraphic interfaces are higher for SF at 50 kW/Acre than for HLW at 75 kW/Acre. At the interfaces, the absolute temperatures for SF at a GTL of 50 kW/Acre are approximately 5 degrees higher than they are for HLW at the higher GTL (77°C vs 72°C). This may be explained by comparing the shape of the temperature-time curves for the two wasteforms. High-level waste produces temperatures which generally peak in less than 100 years. Due to the rapid decay in power output the temperatures then cool down as evidenced by the slope of the curves. Spent fuel, on the other hand, produces temperatures which peak later than 100 years, and cool down at a slower rate; in fact, they remain relatively constant from 180 to 300 years. This is also true near the heat source, where temperatures exhibit the same kind of behavior. The differences are apparently the result of the difference in relative heat generation decay properties between HLW and SF at the later times.

For SF at a GTL of 50 kW/Acre, temperatures at the stratigraphic interfaces are still increasing at 300 years. The absolute temperatures at this time are approximately 77°C; the slope of the temperature-time curves, however, indicates that the peak temperatures probably do not exceed 80°C.

Effects of Stratification

The increases in temperature differences reflected in the values shown in Table 4 can be attributed to lower thermal conductivities of the strata for the USW-G1 hole, and abrupt changes in thermal properties due to geologic stratification. An examination of Figures 6, 7 and 8 reveals that the isotherms near the interfaces of the BULLFROG with the upper and lower horizons are essentially parallel to those interfaces. This implies that steady state heat conduction across these interfaces is essentially one-dimensional and a temperature change across any horizon is inversely proportional to a change of conductivity of that horizon. Apparently, the heat source is sufficiently distant from each interface so that effects of stratification are negligible. If the heat source had been closer to one or more of the interfaces or if the interfaces have been inclined as with dipping horizons then the effects of layering may have been significant. This conclusion is supported by the findings reported in Reference [8].

SUMMARY AND CONCLUSIONS

Calculations were completed to study the effects of thermal properties of tuffs obtained from Hole USW-G1. The object of the study was twofold: 1) To determine calculated temperature rises in the vicinity of the emplacement room, using thermal conductivities slightly lower than those used in previous calculations. In addition, these calculations reflect the use of a layered stratigraphy. 2) To determine maximum gross thermal loadings (GTL) possible without exceeding an absolute temperature of 85°C at the interfaces of the BULLFROG horizon with the upper and lower bounding horizons of zeolitized tuffs. This temperature limit was selected on the basis of the assumption that the zeolitized tuffs would dewater at this temperature under ambient fluid pressures and that this contraction would lead to loss of mechanical integrity.

The study considered two wasteforms: high-level waste (HLW) and UO_2 spent fuel (SF). No boiling of the groundwater was considered.

It was found that with a gross thermal loading of 75 kW/Acre temperature rises above an initial temperature of 36°C were approximately 5 to 7 degrees higher for HLW and 8 to 10 degrees higher for SF than previous calculations using uniform and slightly lower thermal conductivity throughout the depth interval.

Waste emplacement was sufficiently distant from stratigraphic interfaces that the effects of layering were found to be negligible.

High-level waste at a GTL of 75 kW/Acre produced interface temperatures which were well below the 85°C temperature limit specified for these interfaces. It was necessary to reduce the GTL for spent fuel to 50 kW/Acre in order to satisfy the same condition.

REFERENCES

1. Bathe, Klaus-Jurgen, "ADINAT: A Finite Element Program for Automatic Dynamic Incremental Nonlinear Analysis of Temperatures," Report 82448-5, Massachusetts Institute of Technology, May 1977 (Rev. Dec. 1978).

2. Gartling, David K., Eaton, Roger R., and Thomas, Robert K., "Preliminary Thermal Analysis for a Nuclear Waste Repository in Tuff," SAND80-2813, April, 1981.

3. Johnson, Roy L., "Thermo-Mechanical Scoping Calculations for a High Level Nuclear Waste Repository in Tuff," SAND81-0629, June 1981.

4. Langkopf, Brenda S., "Thermal Analyses of Nuclear Waste Emplacement in Welded Tuff," SAND80-2639, December 1981.

5. Mine Design Working Group - Activity Work Package, December 4-5, 1979.

6. Beisinger, Zelma E., and Benzley, Steven E., "Structural Mechanics Computer Plotting Handbook," SAND75-0038, September 1975.

7. Beisinger, Zelma E., and Stone, Charles M., "TPLOT2: A Flexible X-Y Plotting Program for Use with Finite Element Software," SAND80-2508, February 1981.

8. Bulmer, Bruce M., and Lappin, Allen R., "Preliminary One-Dimensional Thermal Analysis of Waste Emplacement in Tuffs," SAND70-1265, April 1980.

APPENDIX

TABLE 1

Thermal and Thermomechanical Stratigraphic Zones for Hole USW-G1, NRDA
(Not to be used for analysis of emplacement in Topopah Springs Member, Paintbrush Tuff)

Zone	Depth (Feet)	Elevation (Meters)	Bulk Density (Mg/m^3)	Grain Density (Mg/m^3)	Porosity	Thermal Conductivity: Fully Saturated (W/mK)	Thermal Conductivity: Dehydrated (W/mK)	ρC_p (1) (kJ/m^3K) x 10^3	Heat of Vaporization Due to Water Content (kJ/m^3) (3)
1	0-293	1236.3-1325.6	1.97	2.38	0.30	1.00	—	3.640	—
2	293-1287	933.3-1236.3	2.14	2.54	0.20	1.50	—	3.222	—
3	1287-1867	756.5-933.3	1.95	2.33	0.30	1.25	—	3.598	—
4	1867-1987	720.0-756.5	2.10	2.57	0.30	1.50	—	3.849	—
5	1987-2340	612.3-720.0	1.93	2.39	0.33	1.35	0.90	3.724 0.900(2)	0.716×10^6
6	2340-2547	549.3-612.3	2.17	2.62	0.28	1.80	1.10	3.807 1.138(2)	0.607×10^6
7	2547-2780	478.3-549.3	2.00	2.45	0.31	1.35	1.00	3.766 0.975(2)	0.672×10^6
8	2780-3020	405-478.3	2.24	2.63	0.24	2.10	1.50	3.640 1.272(2)	0.521×10^6
9	3020-3155	363.9-405	2.14	2.56	0.27	1.50	—	3.766	—
10	3155-3510	255.7-363.9	2.32	2.65	0.20	1.75	—	3.515	—

(1) Unless otherwise specified, ρC_p is saturated state
(2) Dry state
(3) Calculated assuming T boil = 100°C

TABLE 2

Correlation of Functional Stratigraphy with named Stratigraphic Units, Hole USW-G1, NRDA

Zone 1: Alluvium, Tiva Canyon, Pah Canyon, Yucca Mountain and upper vitric portion of Topopah Springs Member of Paintbrush Tuff (Tpt).

Zone 2: Devitrified portion of Tpt, including lithophysal zones, all lumped into one zone.

Zone 3: Lower vitric portion of Tpt, all of Bedded Tuff of Calico Hills (Tcb), upper nonwelded portion of Prow Pass Member of Crater Flat Tuff (Tcfp).

Zone 4: Devitrified welded portion of Tcfp.

Zone 5: Lower nonwelded portion of Tcfp, upper nonwelded portion of Bullfrog Member of Crater Flat Tuff (Tcfb).

Zone 6: Devitrified welded portion of Tcfb.

Zone 7: Lower nonwelded Tcfb, upper zeolitized portion of Tram Member of Crater Flat Tuff (Tcft).

Zone 8: Devitrified welded portion of Tcft.

Zone 9: Heavily zeolitized portion of Tcft.

Zone 10: Welded, partially zeolitized Tcft.

WORK PACKAGE YME-1

Responsible Organization - 1521

Subject

Thermal room-and-pillar calculations for waste emplacement in the Bullfrog Member of the Crater Flat Tuff, based on material properties from Hole USW-G1.

Stratigraphy

See attached Table 1 for stratigraphic and thermal property definition.

Emplacement Depth

Assume waste centerline is at depth of 2450 feet (elevation of 579 m)

Emplacement Geometry

As per previous calculations. Specifically, these calculations are not to include any waste package other than the canister itself. Both HLW and SF (UO_2) need to be considered.

Initial Temperature

36°C

THERMAL CALCULATIONS

1. Objectives:

   A. To examine the thermal effects of the fact that the disposal horizon is no longer treated as a semi-infinite plate.

   B. To estimate maximum thermal loads feasible without heating the upper and/or lower boundary of the emplacement zone above about 85°C.

2. Waste Forms:

   Conventional HLW and UO_2 spent fuel, with power-decay properties as assumed for the most recent set of calculations.

3. Gross Thermal Loadings

75,50, and only possibly 25 kW/ac. NOTE: 75 kW/ac is representative of conditions assumed for the Reference Repository Conditions Committee. 50 kW/ac is approximately that loading derived from assumption of a 42" emplacement hole with engineered waste package and hole-hole spacing of 3 1/2 times hole diameter. Calculations would need to be done for 25 kW/ac only if calculations at 50 kW/ac indicated that the upper and/or lower stratigraphic contact of emplacement zone reached a temperature of 85°C or greater.

4. Backfill

In all cases except 75 kW/ac SF, assume no backfill. For this case only, assume that saturated backfill is emplaced at fifty years after initial waste emplacement. The reference properties of this backfill are K(sat.) = 1.0 W/mK, K(dry) = 0.5 W/mK, porosity = 0.30, grain density = 2.55 g/cm^3.

5. Calculation time

Runs should be extended to 100 years.

6. Calculation Type

2-D, as required for later coupling for jointed-rock mass thermomechanical calculations.

Summary

Total of five (possibly 7) cases: HLW 75,50, (25)kW/ac; SF 75 (with and without backfill at 50 years), 50, (25)kW/ac. All runs except 75 kW/ac SF assume no backfill. All runs assume no waste package.

Contact - A. R. Lappin

Figures 1 - 23

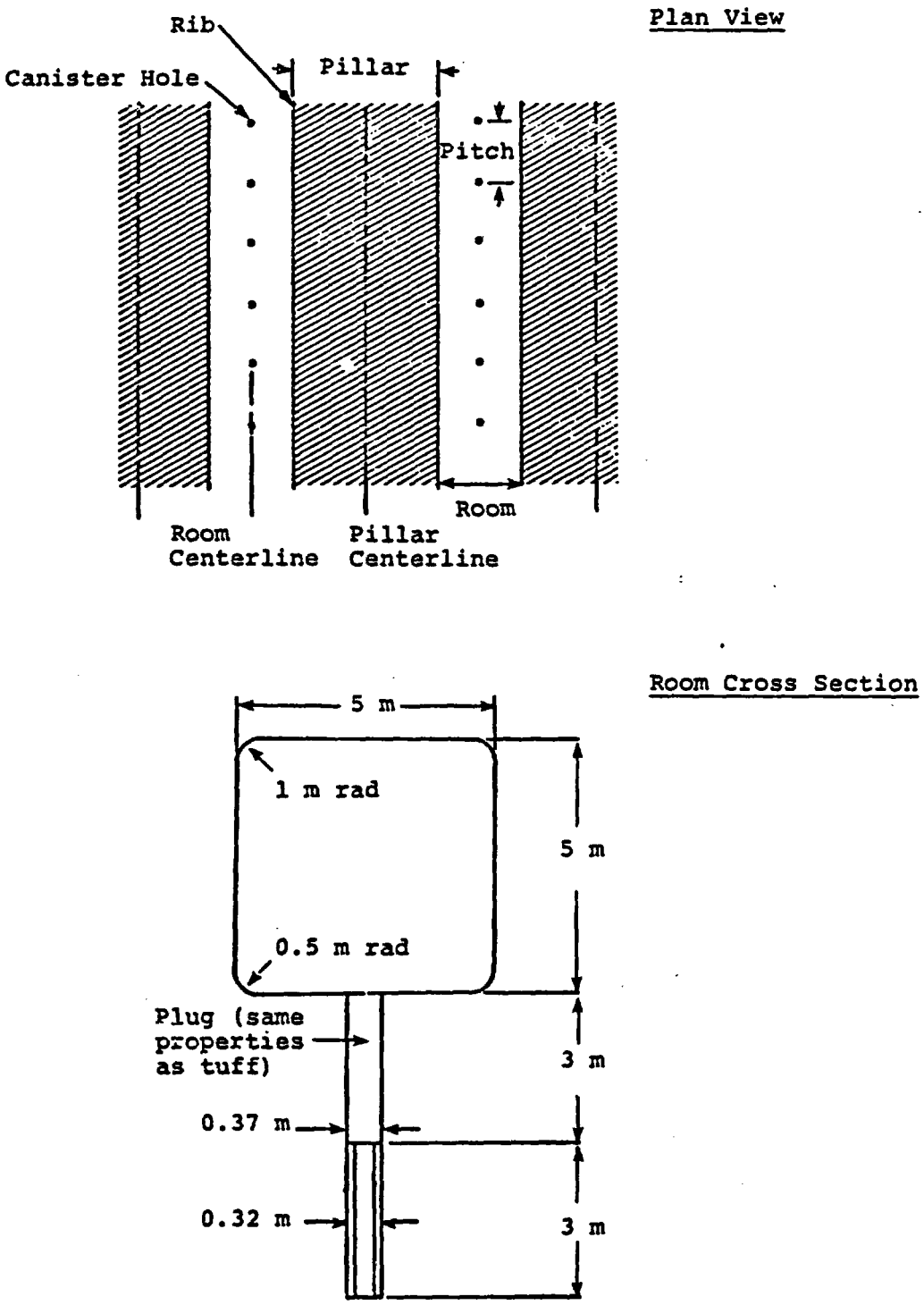


Figure 1. Initial Room Design for HLW Repository in Welded Tuff

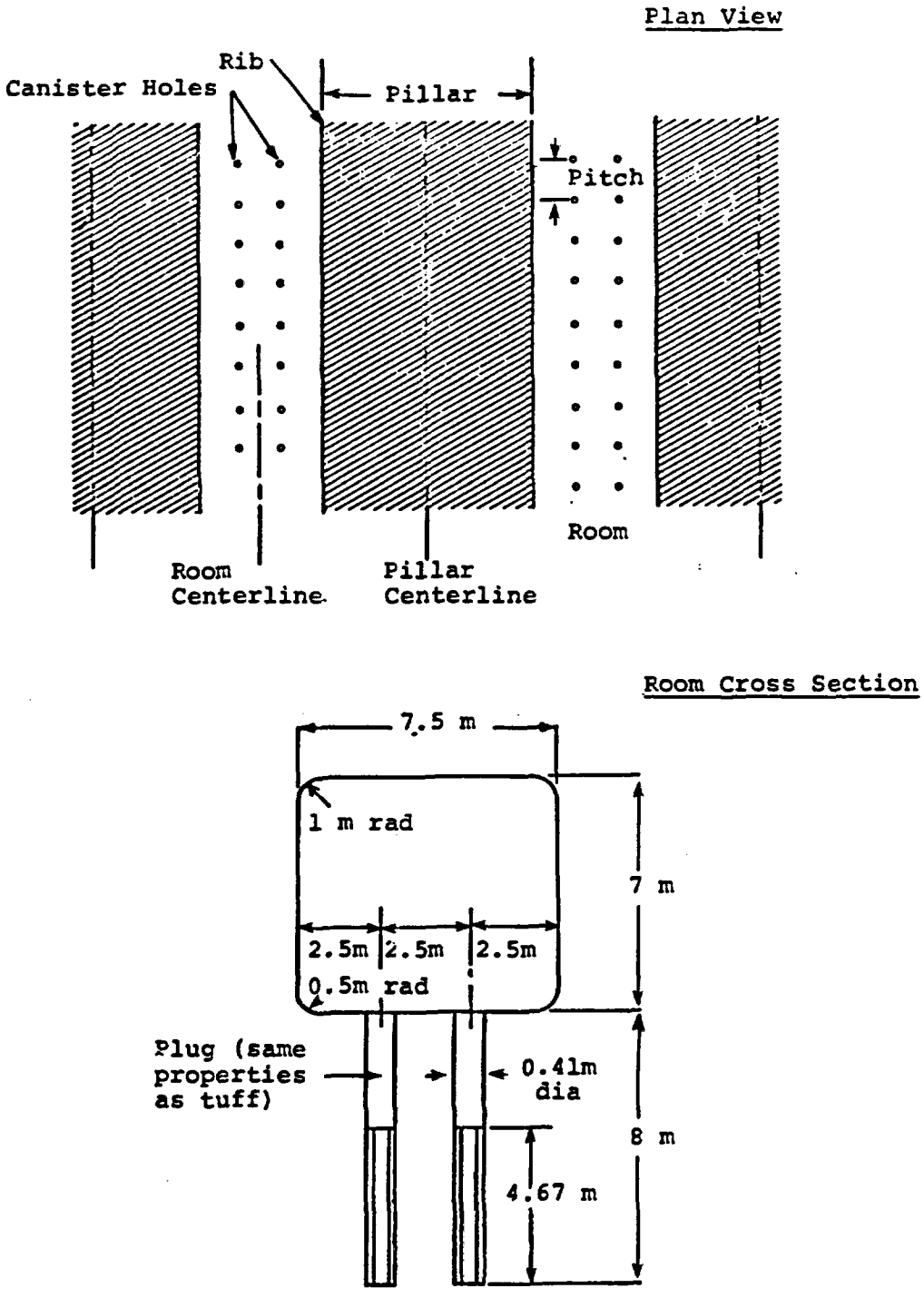
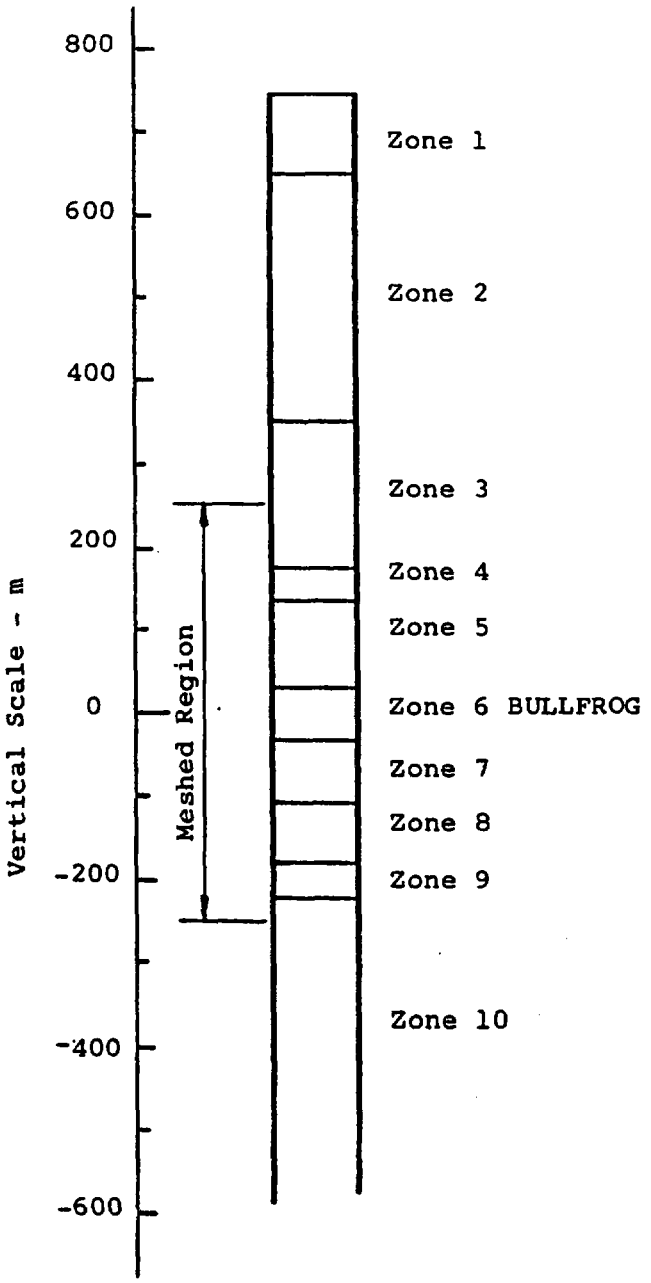
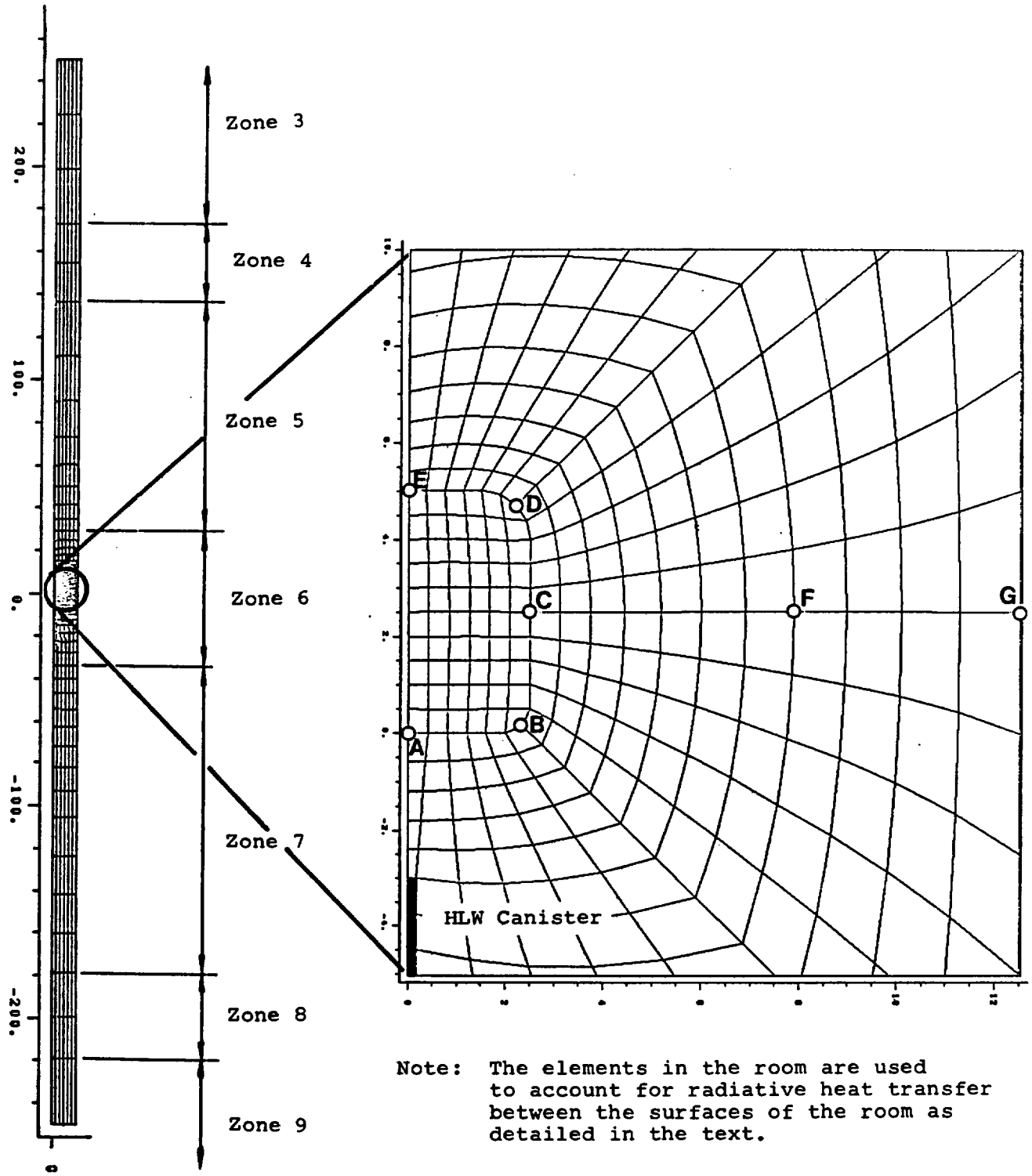


Figure 2. Initial Room Design for SF Repository in Welded Tuff



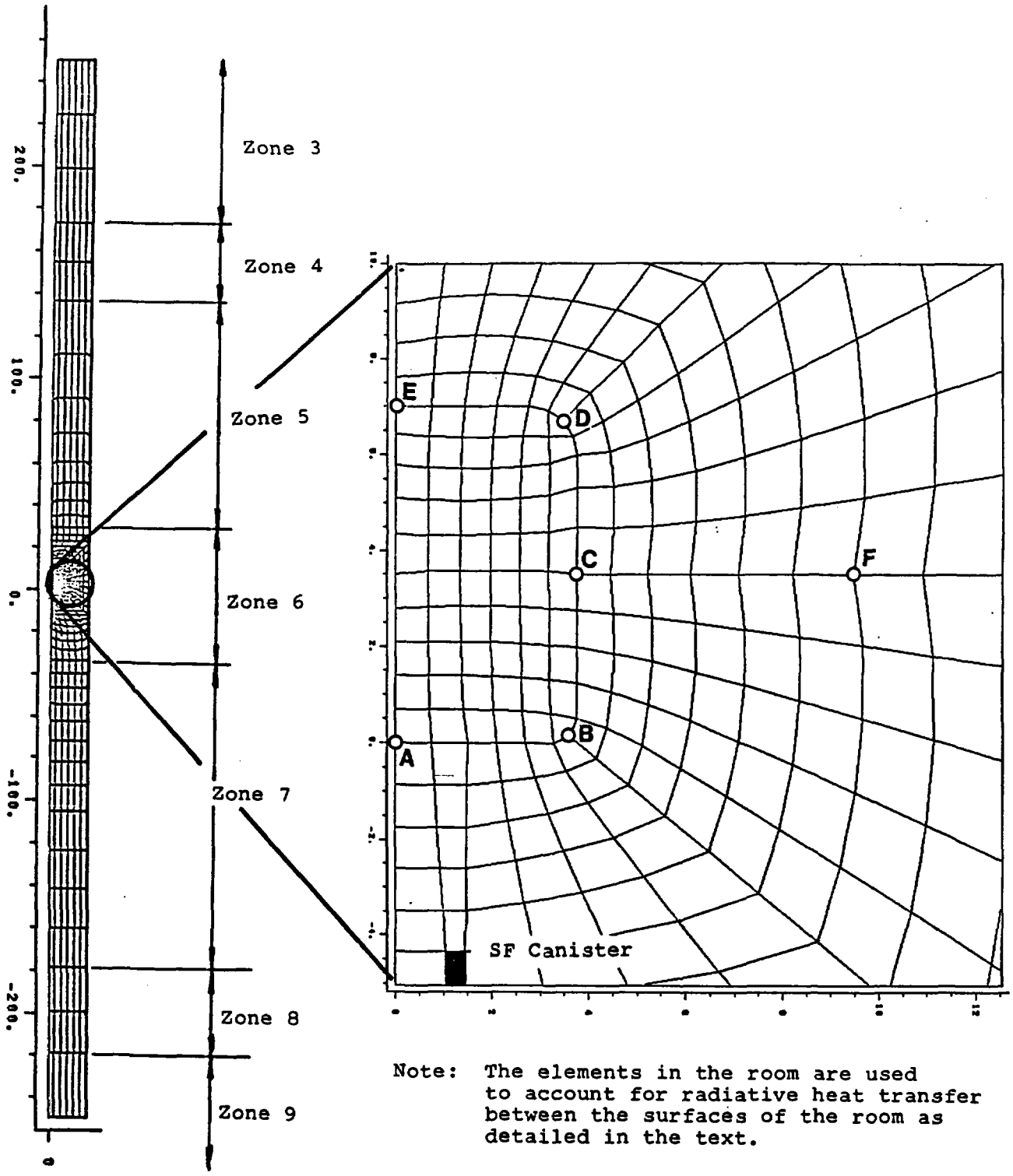
	THERMAL PROPERTIES	
	CONDUCTIVITY $J/m\text{-}^{o}C\text{-}Yr \times 10^{7}$	HEAT CAPACITY $J/m^{3}\text{-}^{o}C \times 10^{6}$
Zone 1		
Zone 2		
Zone 3	3.94	3.60
Zone 4	4.73	3.85
Zone 5	4.26	3.72
Zone 6 BULLFROG	5.68	3.81
Zone 7	4.26	3.77
Zone 8	6.62	3.64
Zone 9	4.73	3.77
Zone 10	5.52	3.52

Figure 3. Stratigraphic Column of the USW-G1 Borehole



Note: The elements in the room are used to account for radiative heat transfer between the surfaces of the room as detailed in the text.

Figure 4. Finite Element Mesh Used in the High Level Waste Thermal Calculations



Note: The elements in the room are used to account for radiative heat transfer between the surfaces of the room as detailed in the text.

Figure 5. Finite Element Mesh Used in the Spent Fuel Thermal Calculations

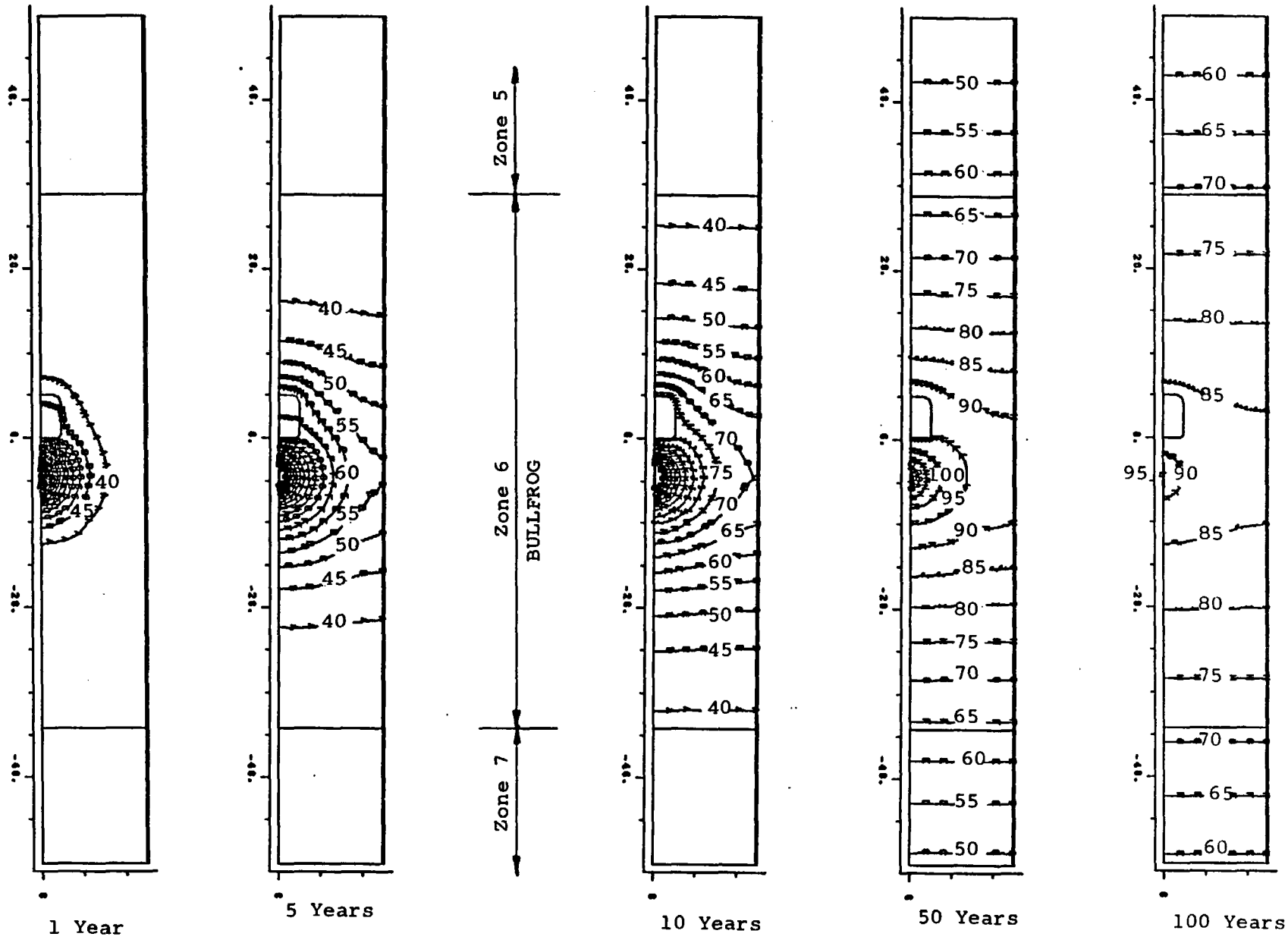


Figure 6. Isotherms at Various Times After Emplacement for High Level Waste, GTL = 75 kw/Acre

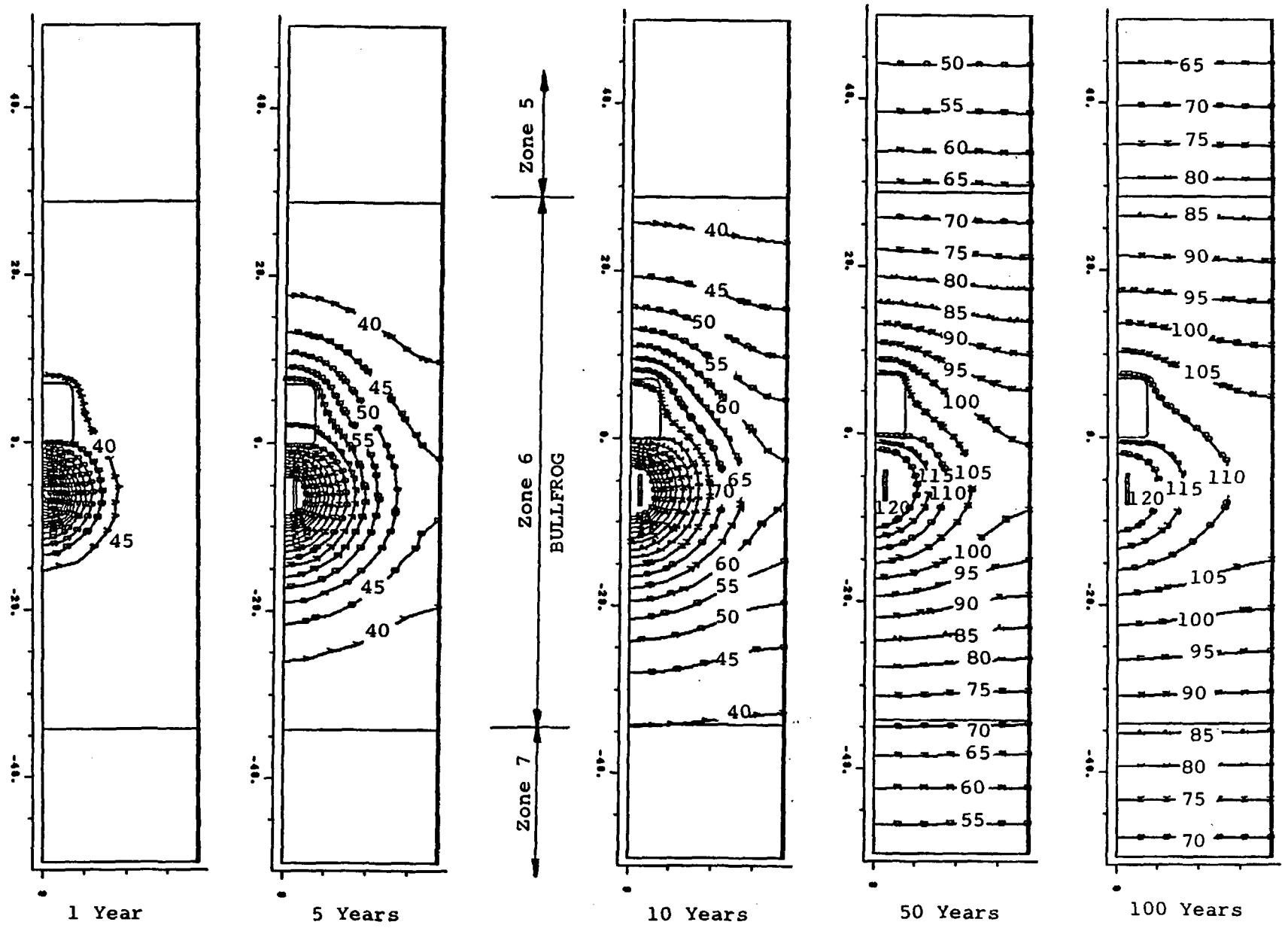


Figure 7. Isotherms at Various Times After Emplacement for Spent Fuel, GTL = 75 kw/Acre

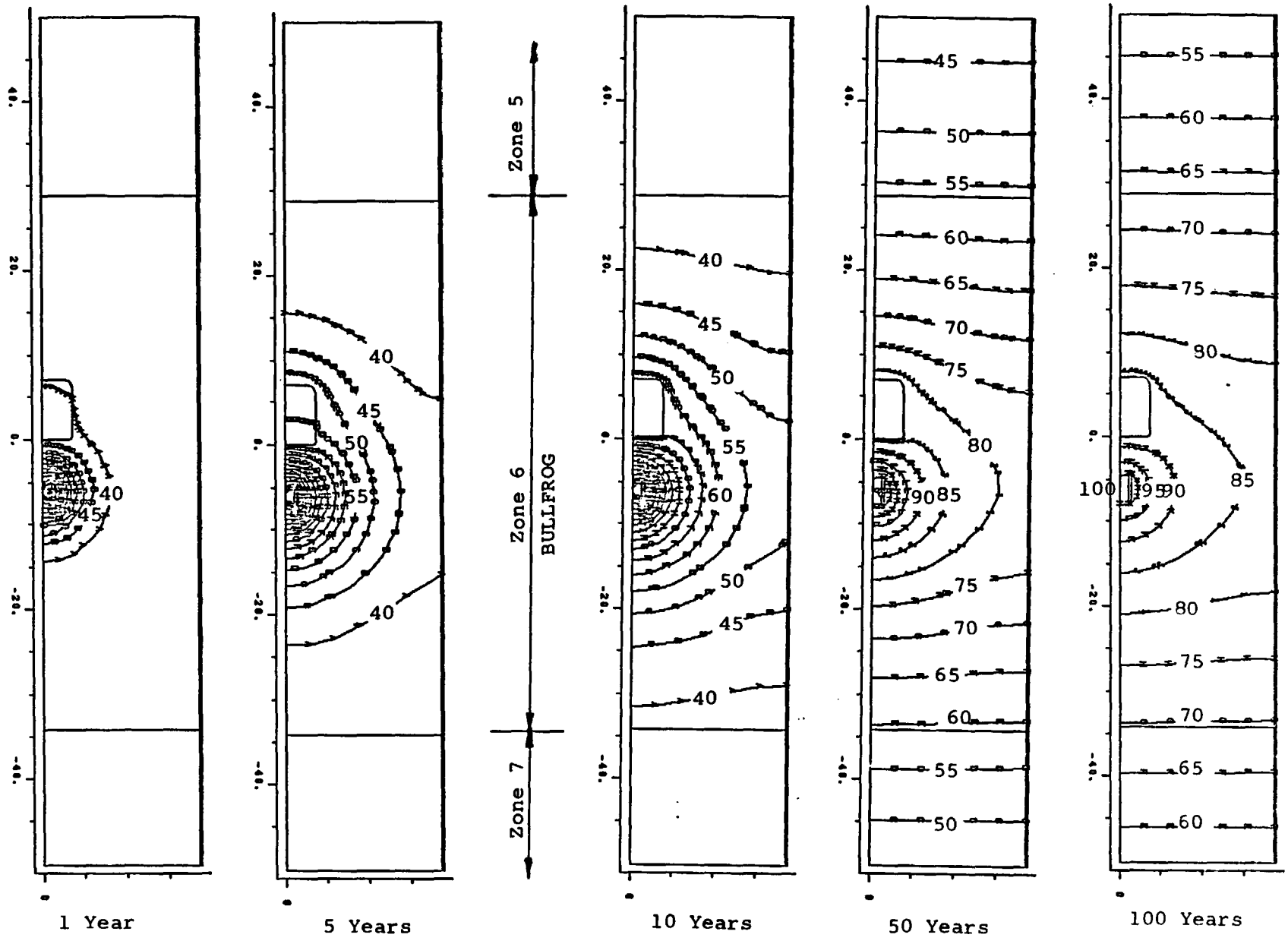


Figure 8. Isotherms at Various Times After Emplacement for Spent Fuel, GTL = 50 kw/Acre

GTL = 75 kw/Acre

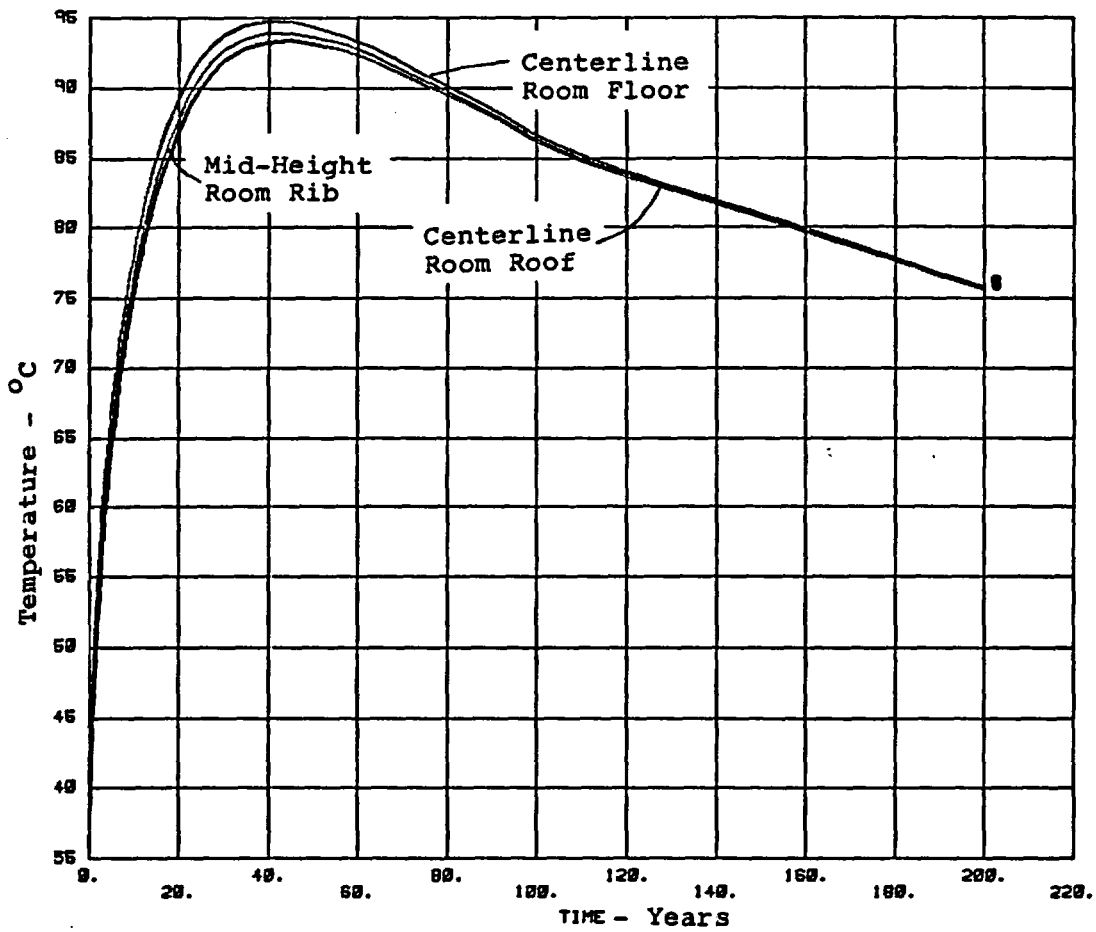


Figure 9. Temperature Histories at Various Points Around the Room for High Level Waste, GTL = 75 kw/Acre

GTL = 75 kw/Acre

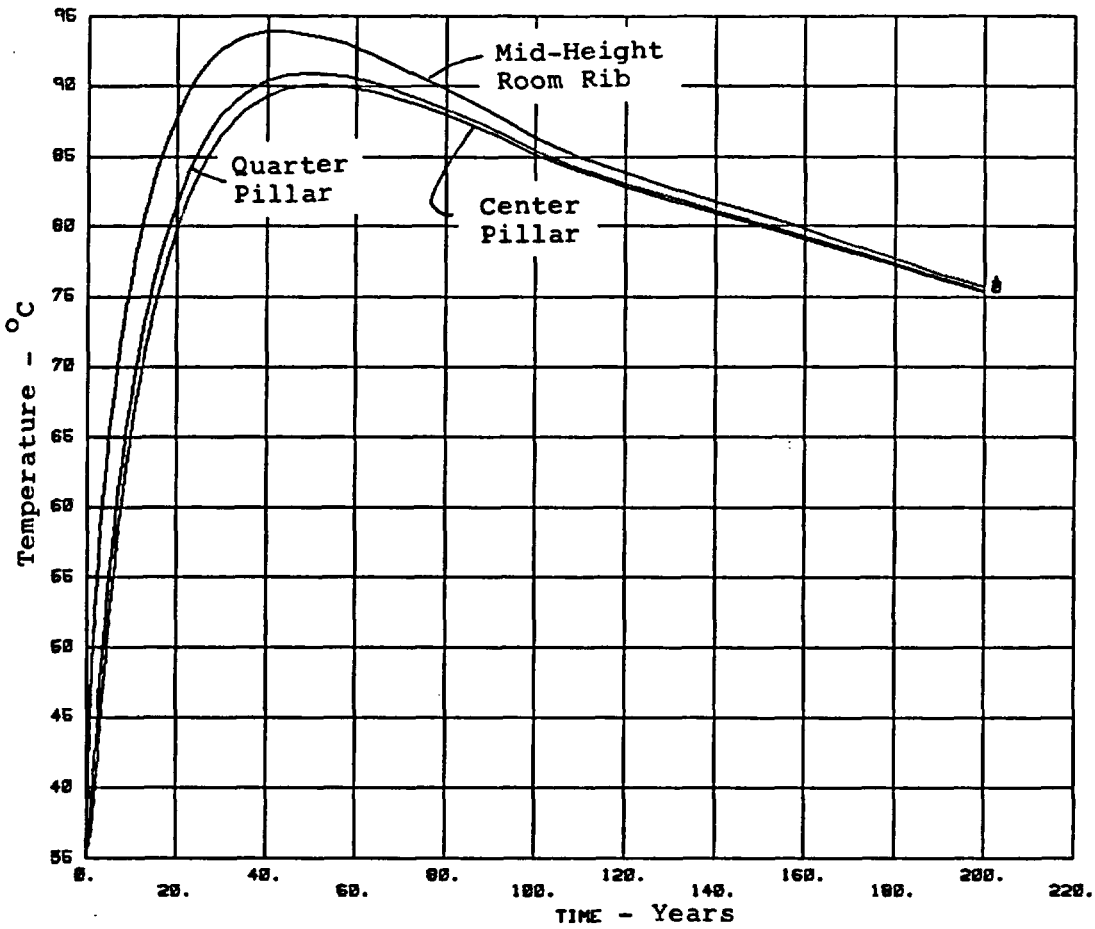


Figure 10. Temperature Histories at Various Points Through the Pillar for High Level Waste, GTL = 75 kw/Acre

GTL = 75 kw/Acre

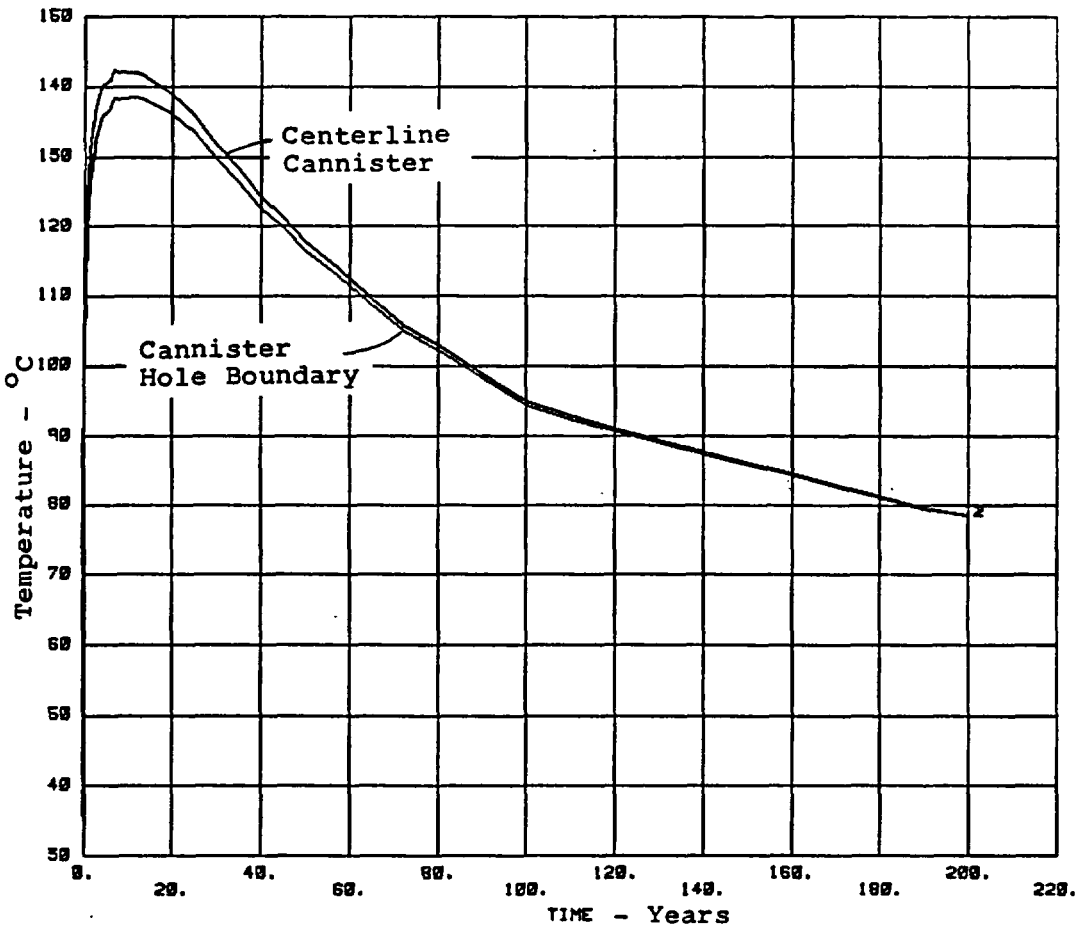


Figure 11. Temperature Histories at the Cannister for High Level Waste, GTL = 75 kw/Acre

GTL = 75 kw/Acre

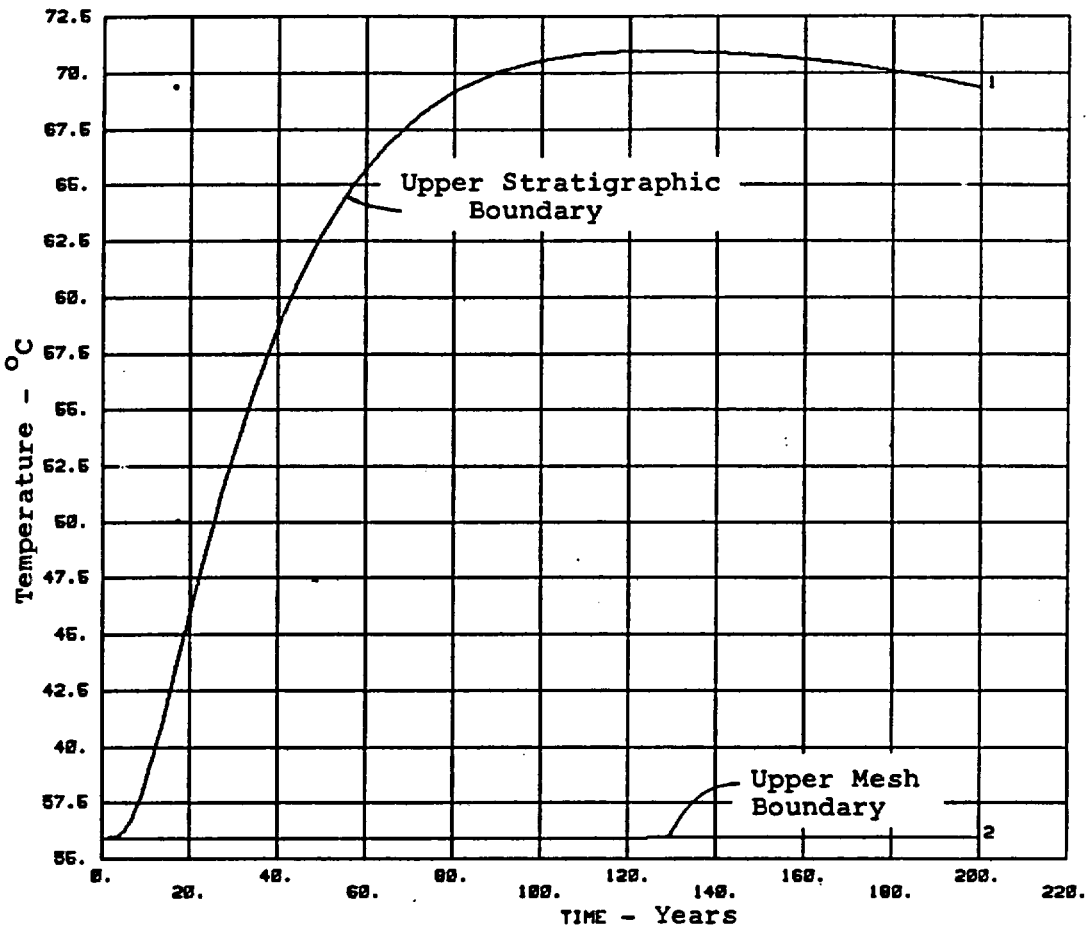


Figure 12. Temperature Histories at the Upper Stratigraphic Boundary and at the Upper Mesh Boundary for High Level Waste, GTL = 75 kw/Acre

GTL = 75 kw/Acre

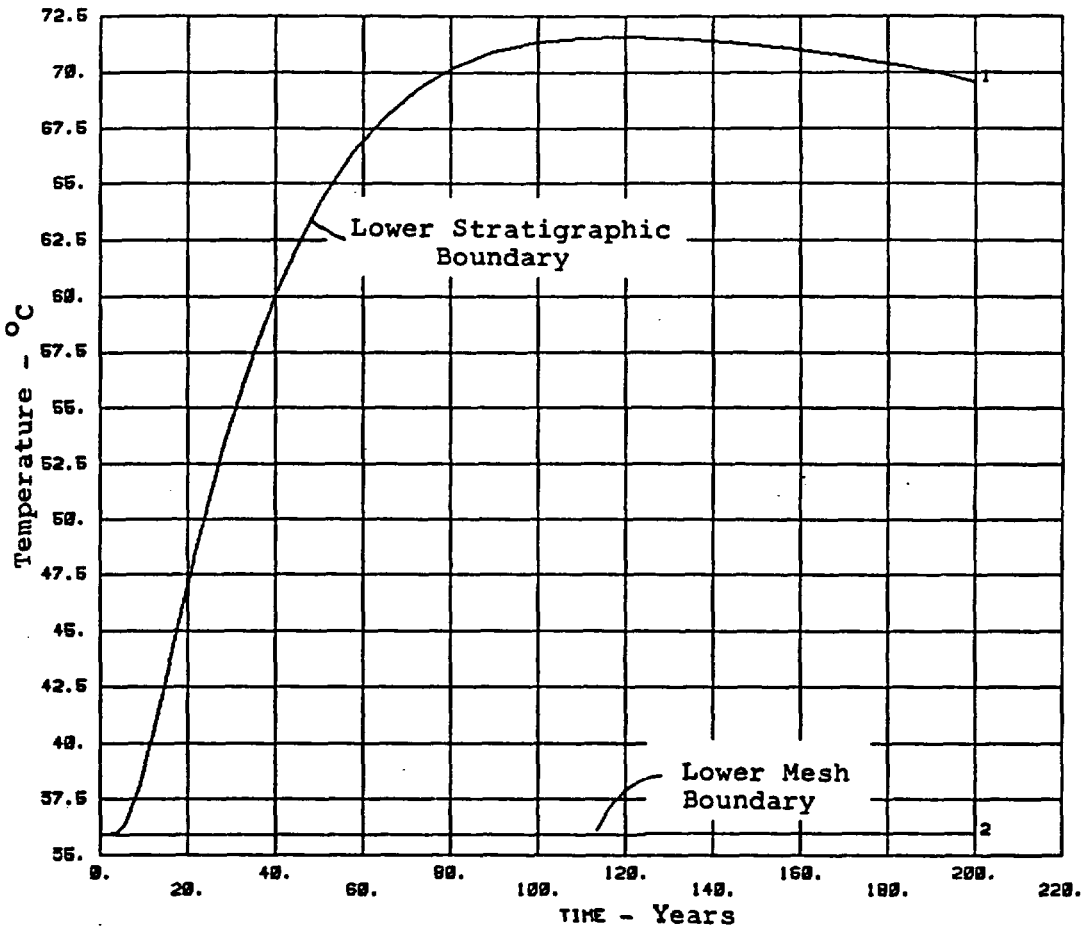


Figure 13. Temperature Histories at the Lower Stratigraphic Boundary and at the Lower Mesh Boundary for High Level Waste, GTL = 75 kw/Acre

GTL = 75 kw/Acre

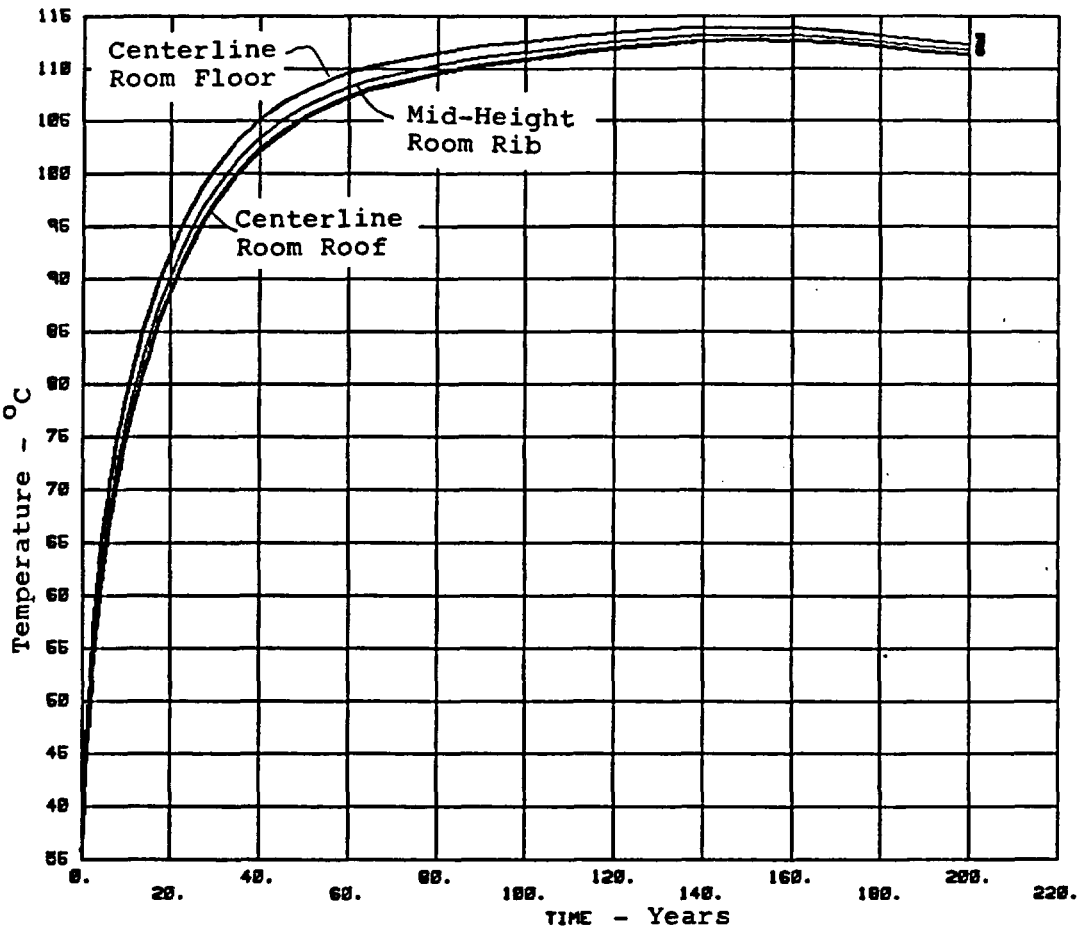


Figure 14. Temperature Histories at Various Points Around the Room for Spent Fuel, GTL = 75 kw/Acre

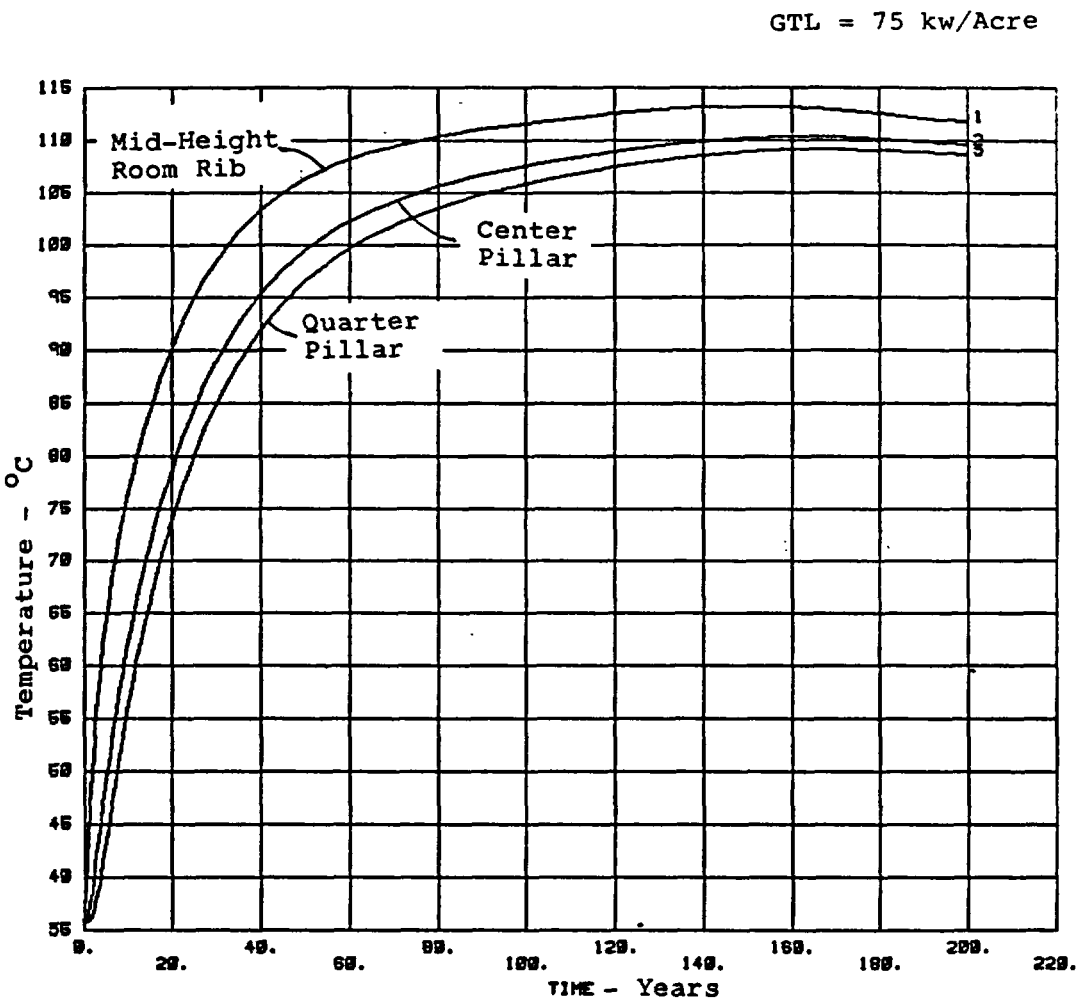


Figure 15. Temperature Histories at Various Points Through the Pillar for Spent Fuel, GTL = 75 kw/Acre

GTL = 75 kw/Acre

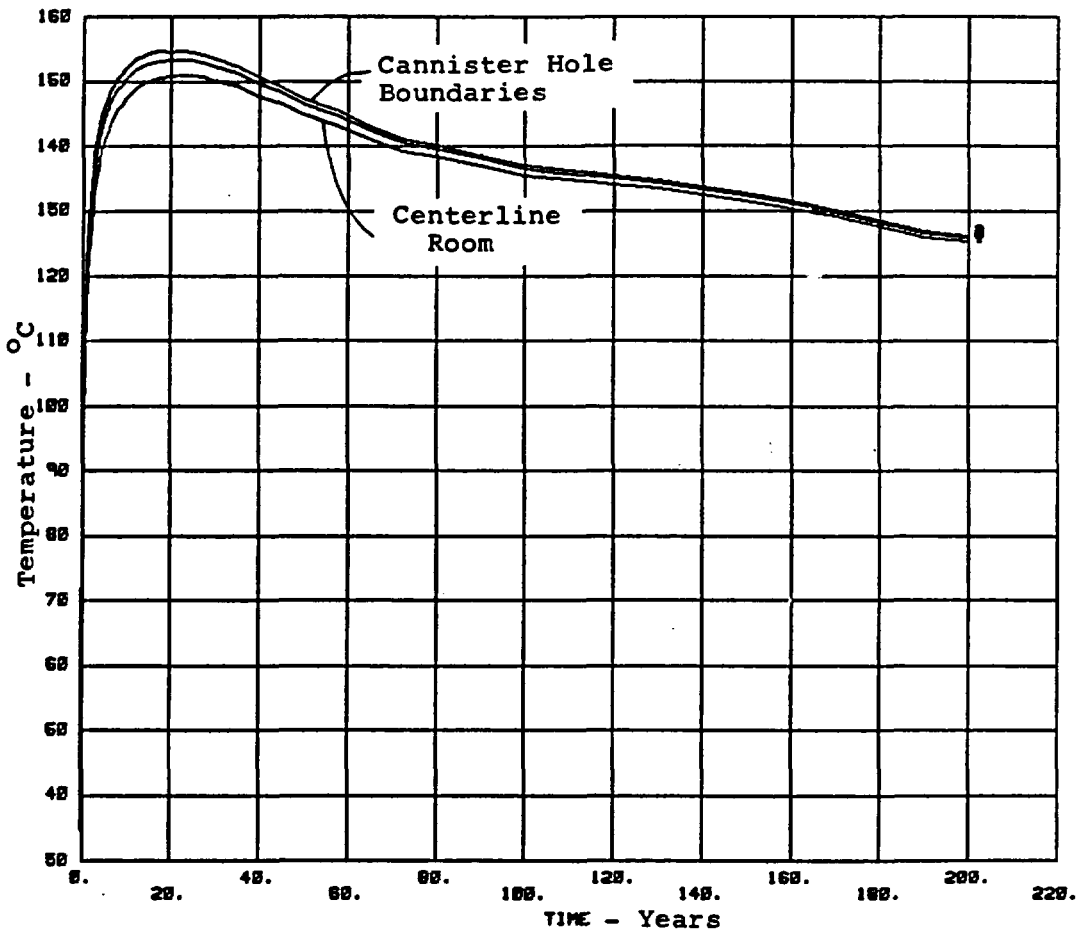


Figure 16. Temperature Histories at the Cannister for Spent Fuel, GTL = 75 kw/Acre

GTL = 75 kw/Acre

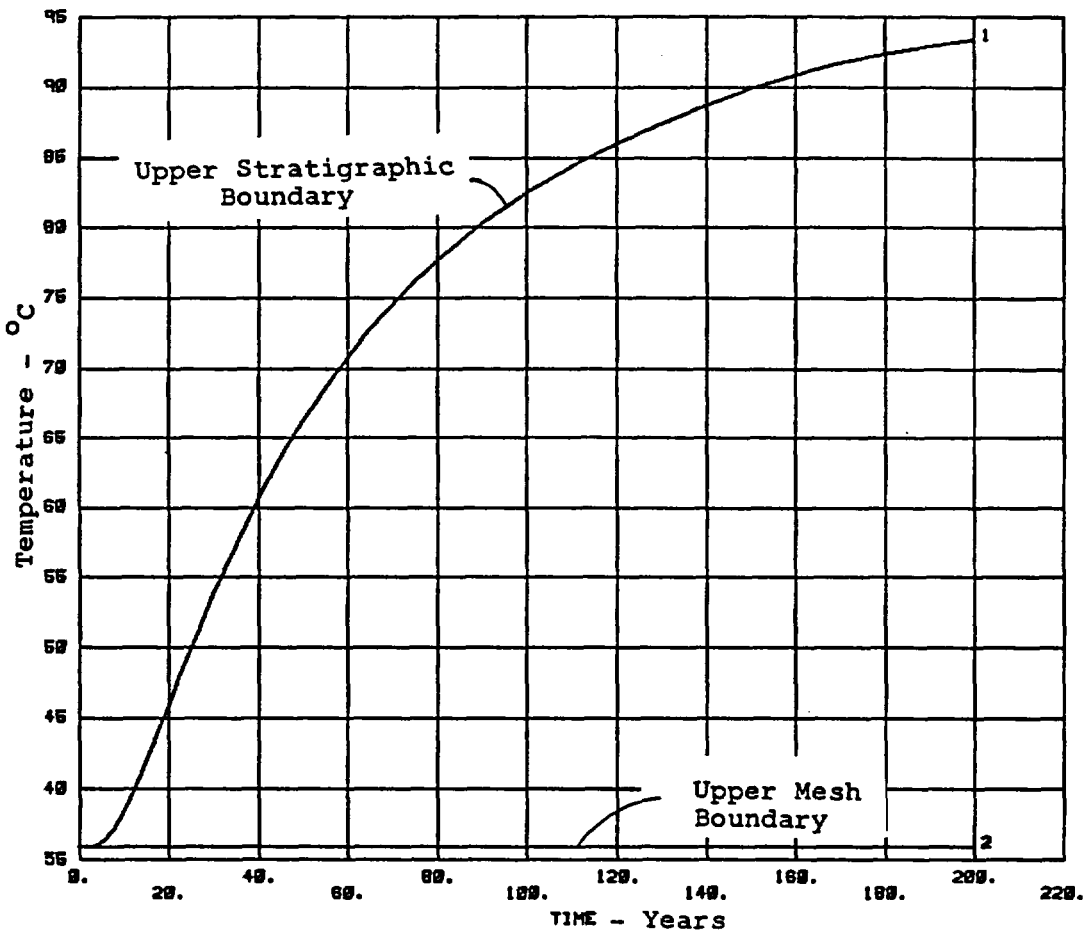


Figure 17. Temperature Histories at the Upper Stratigraphic Boundary and at the Upper Mesh Boundary for Spent Fuel, GTL = 75 kw/Acre

GTL = 75 kw/Acre

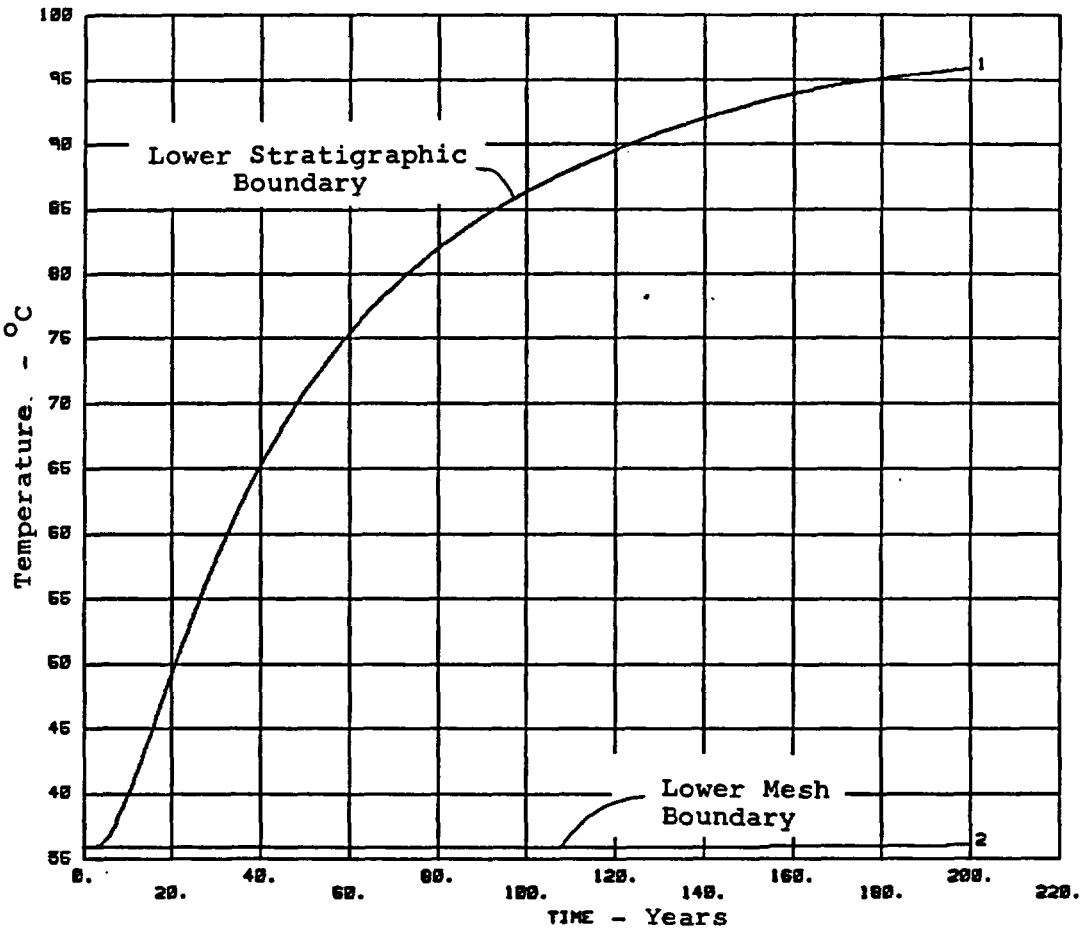


Figure 18. Temperature Histories at the Lower Stratigraphic Boundary and at the Lower Mesh Boundary for Spent Fuel, GTL = 75 kw/Acre

GTL = 50 kw/Acre

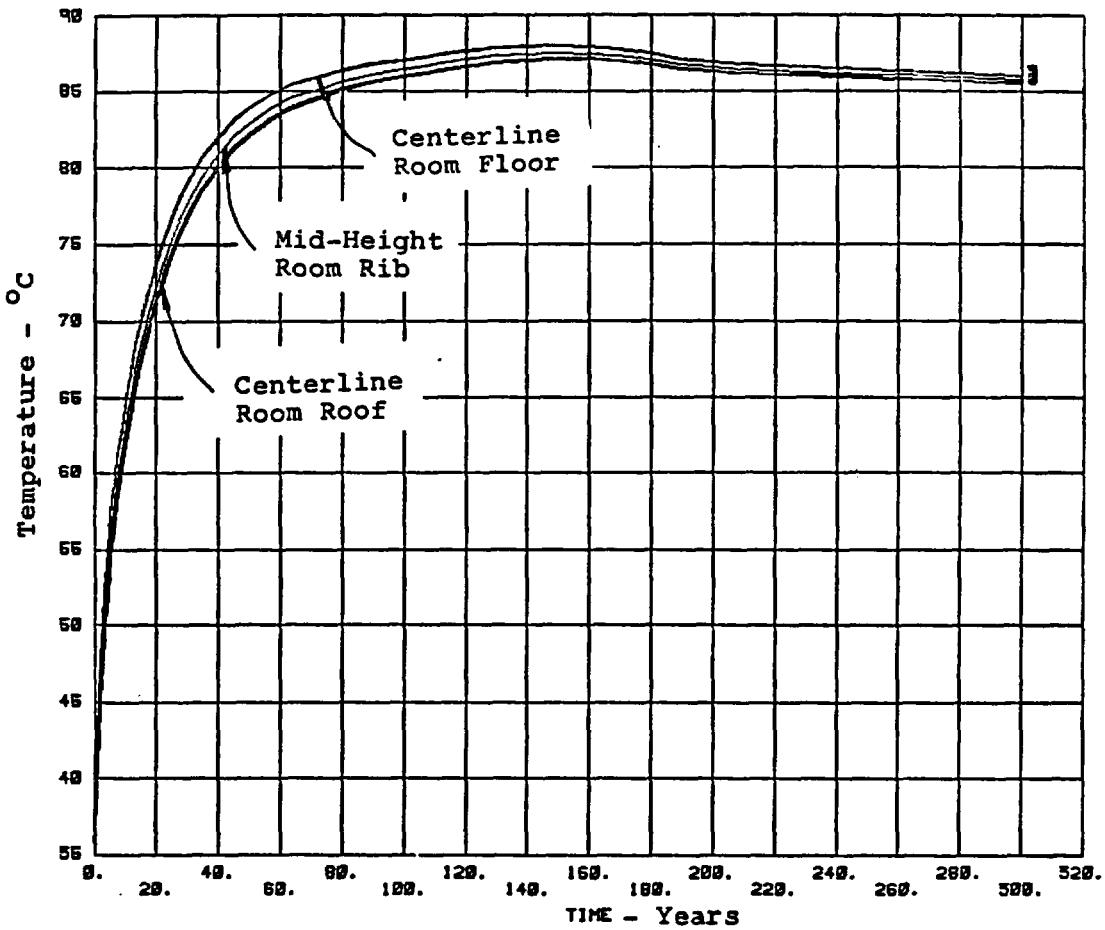


Figure 19. Temperature Histories at Various Points Around the Room for Spent Fuel, GTL = 50 kw/Acre

GTL = 50 kw/Acre

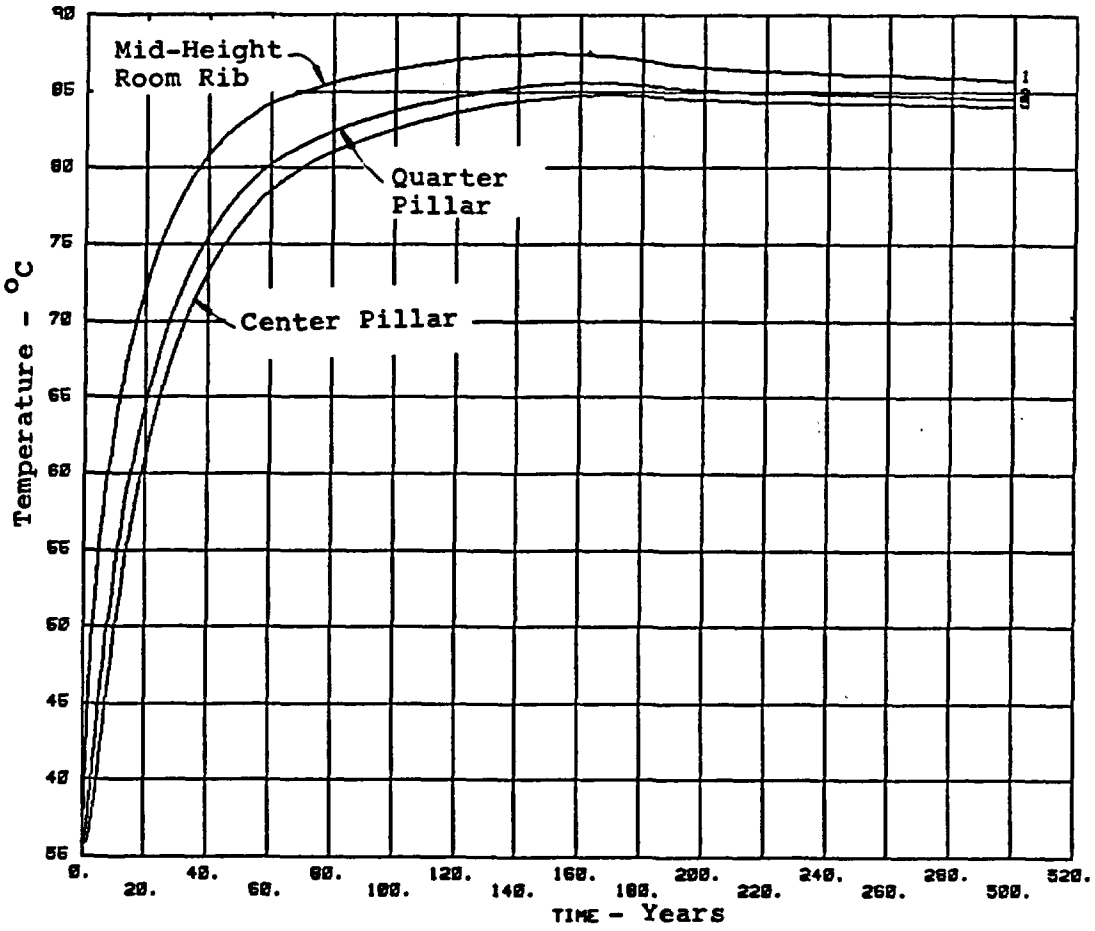


Figure 20. Temperature Histories at Various Points Through the Pillar for Spent Fuel. GTL = 50 kw/Acre

GTL = 50 kw/Acre

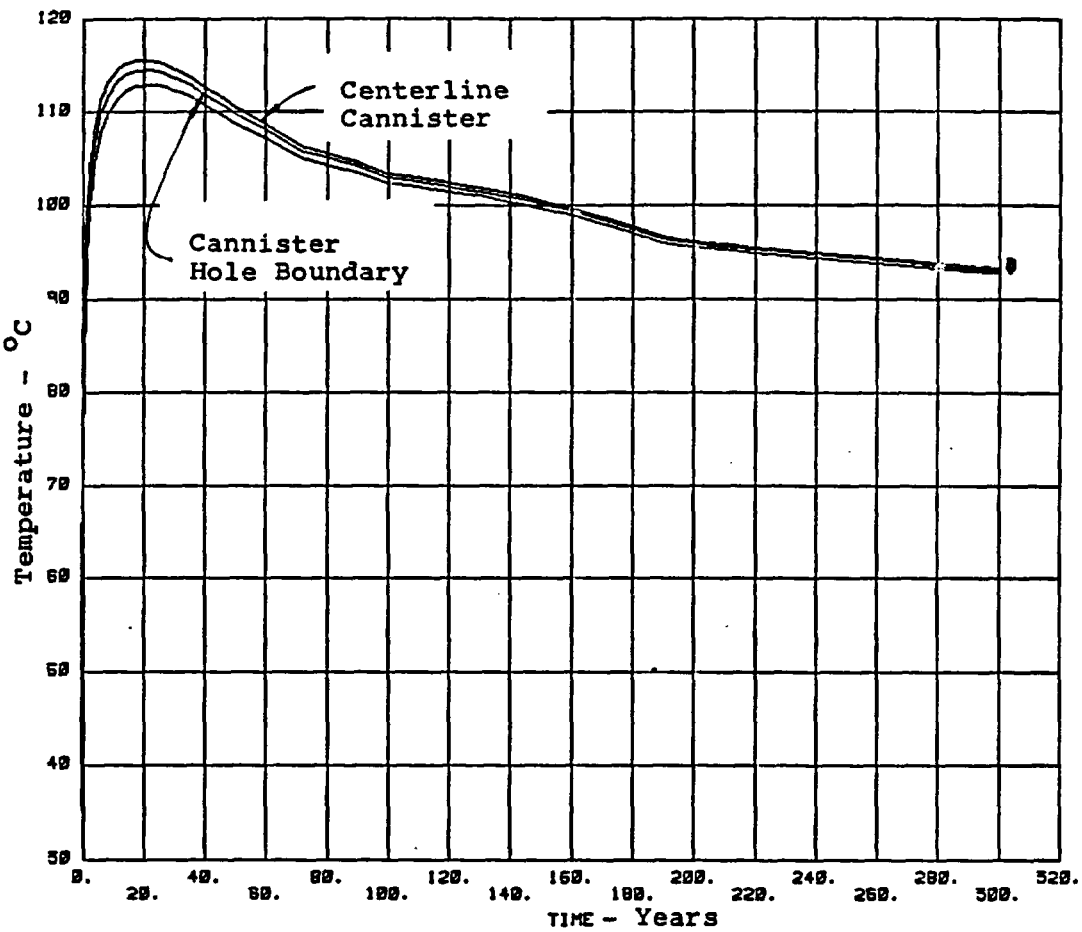


Figure 21. Temperature Histories at the Cannister for Spent Fuel, GTL = 50 kw/Acre

GTL = 50 kw/Acre

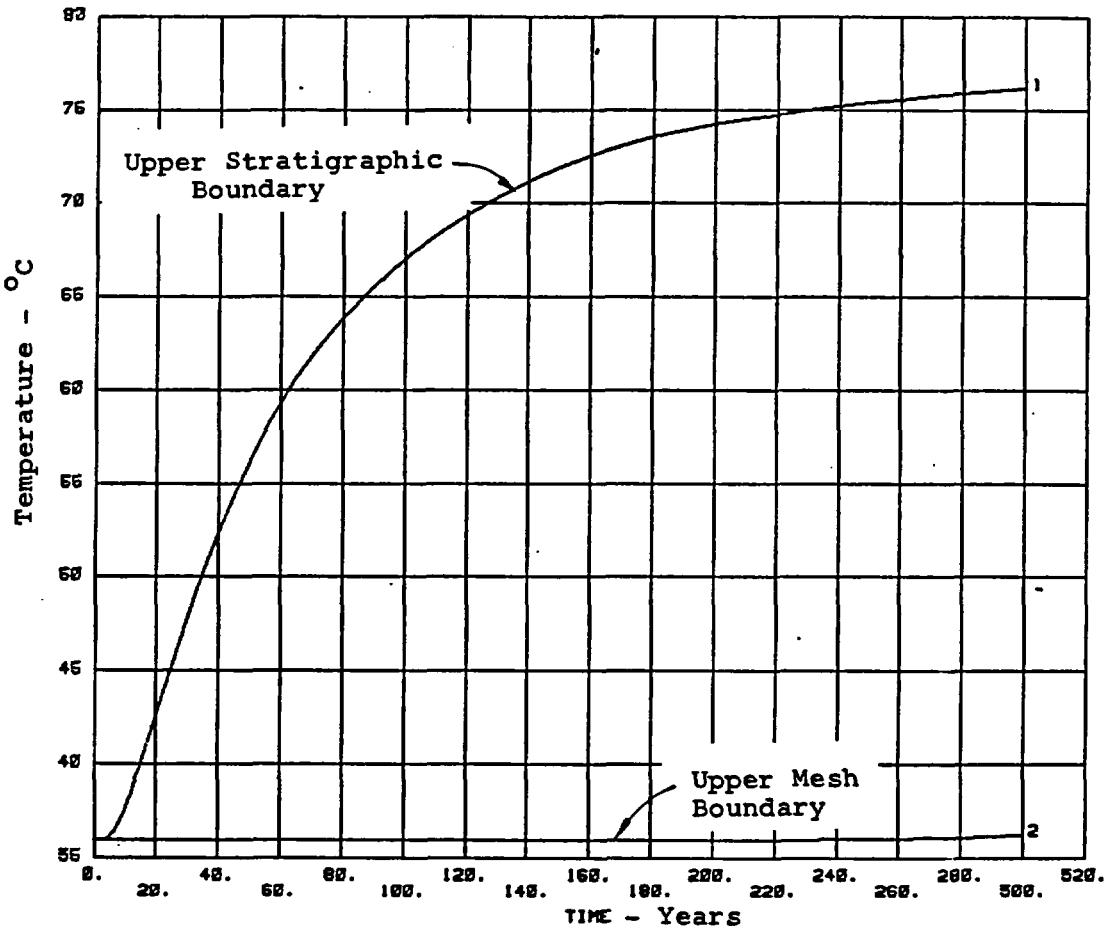


Figure 22. Temperature Histories at the Upper Stratigraphic Boundary and at the Upper Mesh Boundary for Spent Fuel, GTL = 50 kw/Acre

GTL = 50 kw/Acre

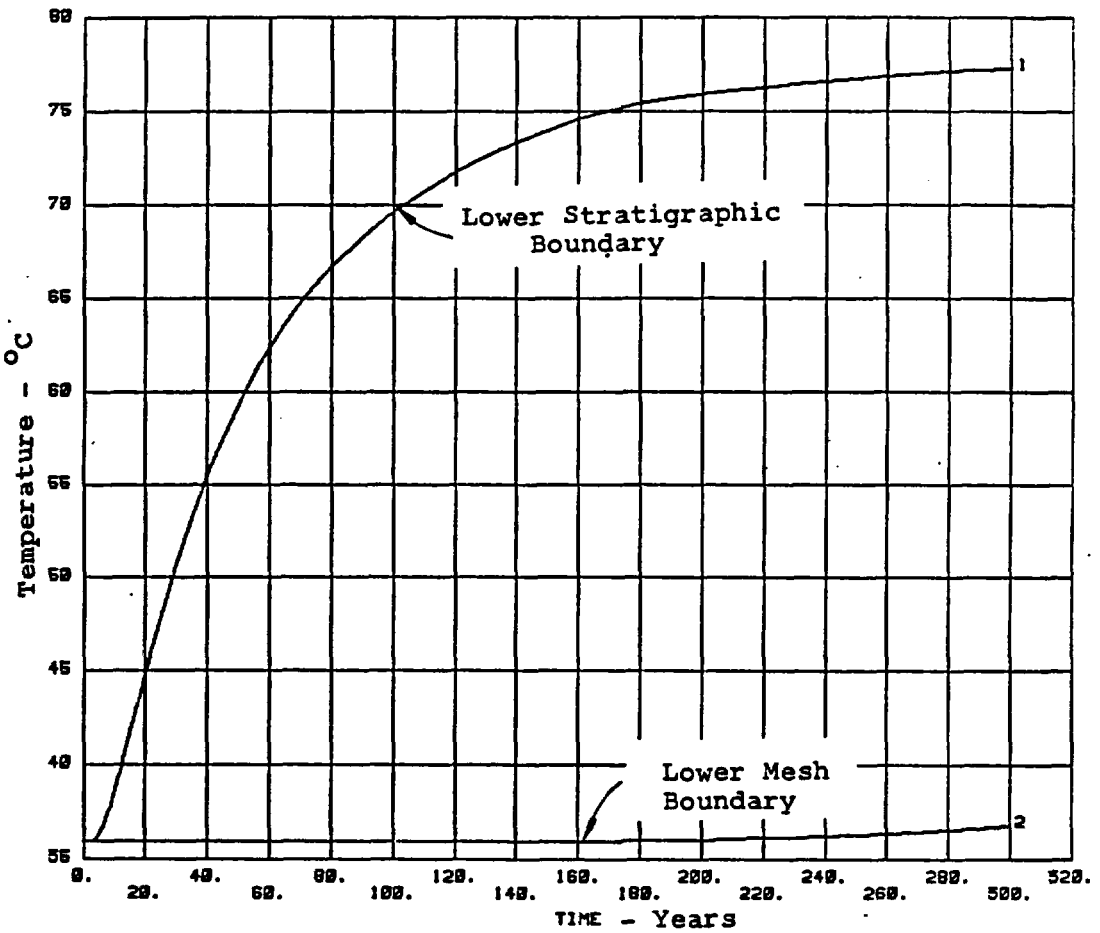


Figure 23. Temperature Histories at the Lower Stratigraphic Boundary and at the Lower Mesh Boundary for Spent Fuel, GTL = 50 kw/Acre

Distribution:

C. R. Cooley, Team Leader
Technology Development Team
Office of Waste Isolation
U. S. Department of Energy
NE-330
Germantown, MD 20767

R. Stein, Team Leader
Repository Projects Team
U. S. Department of Energy
Room B-220, NE-330
Germantown, MD 20767

W. W. Ballard, Jr., Director
Office of Waste Isolation
U. S. Dept. of Energy
Room B-207, NE 330
Germantown, MD 20767

L. D. Ramspott
Technical Project Officer
Lawrence Livermore Nat. Lab.
University of California
P.O. Box 808
Mail Stop L-204
Livermore, CA 94550

A. R. Hakl, Site Manager
Westinghouse - AESD
P. O. Box 708
Mail Stop 703
Mercury, NV 89023

J. H. Anttonen, Asst. Mgr.
U. S. Dept. of Energy
Richland Operations Office
P. O. Box 550
Richland, WA 99352

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

B. W. Church, Director
Health Physics Division
P. O. Box 14100
Las Vegas, NV 89114

G. L. Dixon
Technical Project Officer
U. S. Geological Survey
Post Office Box 25046
Mail Stop 954
Federal Center
Denver, CO 80225

W. E. Wilson
P. O. Box 25046
Mail Stop 416
Denver, CO 80225

W. S. Twenhofel
820 Estes Street
Lakewood, CO 80215

B. R. Erdal
Technical Project Officer
Los Alamos National Lab.
University of California
P. O. Box 1663
Mail Stop 514
Los Alamos, NM 87545

C. R. Cooley, Team Leader
Technology Dev. Team
Office of Waste Isolation
U. S. Dept. of Energy
Room B-214, NE-330
Germantown, MD 20767

R. Deju
Rockwell International
Atomics Intnl. Div.
Rockwell Hanford Operations
Richland, WA 99352

D. L. Vieth, Director (3)
Waste Management Proj. Office
U. S. Dept. of Energy
P. O. Box 14100
Las Vegas, NV 89114

R. H. Marks
U. S. Dept. of Energy
CP-1, M/S 210
P. O. Box 14100
Las Vegas, NV 89114

F. E. Coffman, Deputy Asst.
Sec. for Nuclear Waste
Mgmt. 7 Fuel Cycle Programs
U. S. Dept. of Energy
NE-30
Germantown, MD 20767

K. Street, Jr.
Lawrence Livermore Nat. Lab.
Univ. of California
Mail Stop L-209
P. O. Box 808
Livermore, CA 94550

W. A. Carbiener
Battelle
Office of NWTS Integration
Isolation
505 King Avenue
Columbus, OH 43201

S. Goldsmith
Battelle
Office of Nuc. Waste Isolation
505 King Avenue
Columbus, OH 43201

R. M. Hill
State Planning Coordinator
Governor's Office of
Planning Coordination
Capitol Complex
Carson City, NV 89023

H. D. Cunningham
Reynolds Elec. & Engr. Co. Inc.
Mail Stop 555
P. O. Box 14400
Las Vegas, NV 89114

J. A. Cross
Fenix Scisson, Inc.
P. O. Box 15408
Las Vegas, NV 89114

A. J. Rothman (2)
LLNL, MS L-204
University of California
P. O. Box 808
Livermore, CA 94550

A. E. Gurrola
Holmes & Narver, Inc.
P. O. Box 14340
Las Vegas, NV 89114

D. C. Hoffman
Los Alamos National Lab.
Mail Stop 760
P. O. Box 1663
Los Alamos, NM 87545

N. E. Carter
Battelle
Office of Nuc. Waste
Isolation
505 King Avenue
Columbus, OH 43201

ONWI Library (5)
Battelle
Office of Nuclear Waste
Isolation
505 King Avenue
Columbus, OH 43201

S. A. Robinson
Department of Energy
State of Nevada
Capitol Complex
Carson City, NV 89710

J. P. Colton
U. S. Nuclear Regulatory
Agency
Mail Stop 396-SS
Washington, DC 20555

A. M. Friedman
Argonne National Laboratory
9700 S. Cass Avenue
Argonne, IL 60439

S. M. Coplan (2)
High-Level Waste Mgmt. Dev.
Branch
Division of Waste Mgmt.
USNRC
Washington, DC 20555

P. A. Nowack (7)
U. S. Dept. of Energy
P. O. Box 14100
Las Vegas, NV 89114

1500	W. Herrmann
1510	D. B. Hayes
1511	J. W. Nunziato
1511	D. K. Gartling
1520	T. B. Lane
1521	N. E. Gilbertsen
1521	C. M. Stone
1521	R. K. Thomas
1522	T. G. Priddy
1522	R. L. Johnson (5)
1524	T. B. Lane (Actg.)
1530	L. W. Davison
1531	M. L. Blanford
1532	B. M. Butcher
1532	W. A. Olsson
1540	W. C. Luth
3141	L. J. Erickson (5)
3151	W. L. Garner (3)
3154-3	C. H. Dalin (25) (For DOE/TIC)
7417	F. W. Muller
9760	R. W. Lynch
9761	L. W. Scully
9762	L. D. Tyler
9763	J. R. Tillerson
9763	B. S. Langkopf
9763	A. R. Lappin
9763	R. M. Zimmerman
9763	R. Shaw
9764	R. C. Lincoln
9764	A. E. Stephenson
8214	M. A. Pound

Sandia National Laboratories