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INTERIM REPORT ON NUCLEAR WASTE DEPOSITORY THERMAL ANALYSIS

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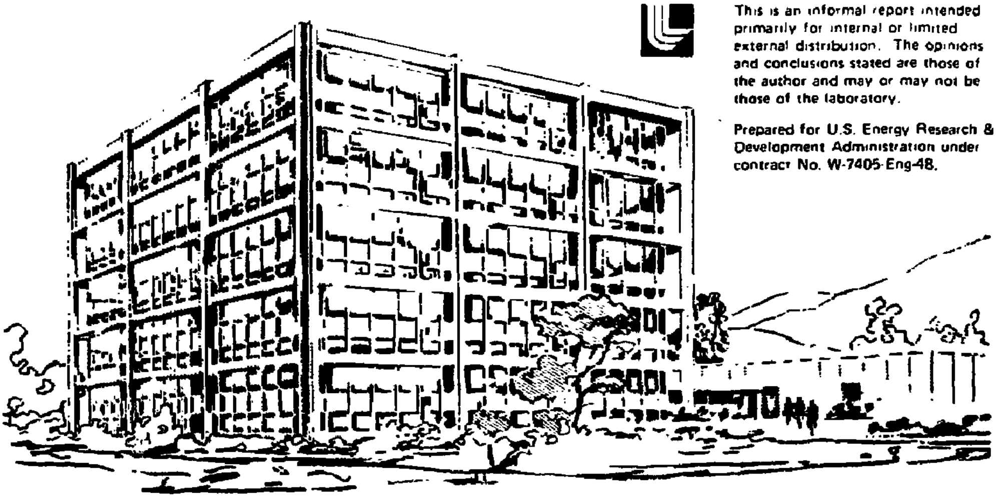

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INTERIM REPORT ON NUCLEAR WASTE
DEPOSITORY THERMAL ANALYSIS*

by

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ABSTRACT

A thermal analysis of a deep geologic depository for spent nuclear fuel is being conducted at LLL as part of the NRC Nuclear Waste Management Program. The TRUMP finite difference heat transfer code is used to analyze a 3-dimensional model of the depository. The model uses a unit cell consisting of one spent fuel canister buried in salt beneath a ventilated room in the depository. A base case was studied along with several parametric variations. It is concluded that this method is appropriate for analyzing the thermal response of the system, and that the most important parameter in determining the maximum temperatures is the canister heat generation rate. The effects of room ventilation and different depository media are secondary. Future work will extend this analysis and improve upon some of the simplifications used.

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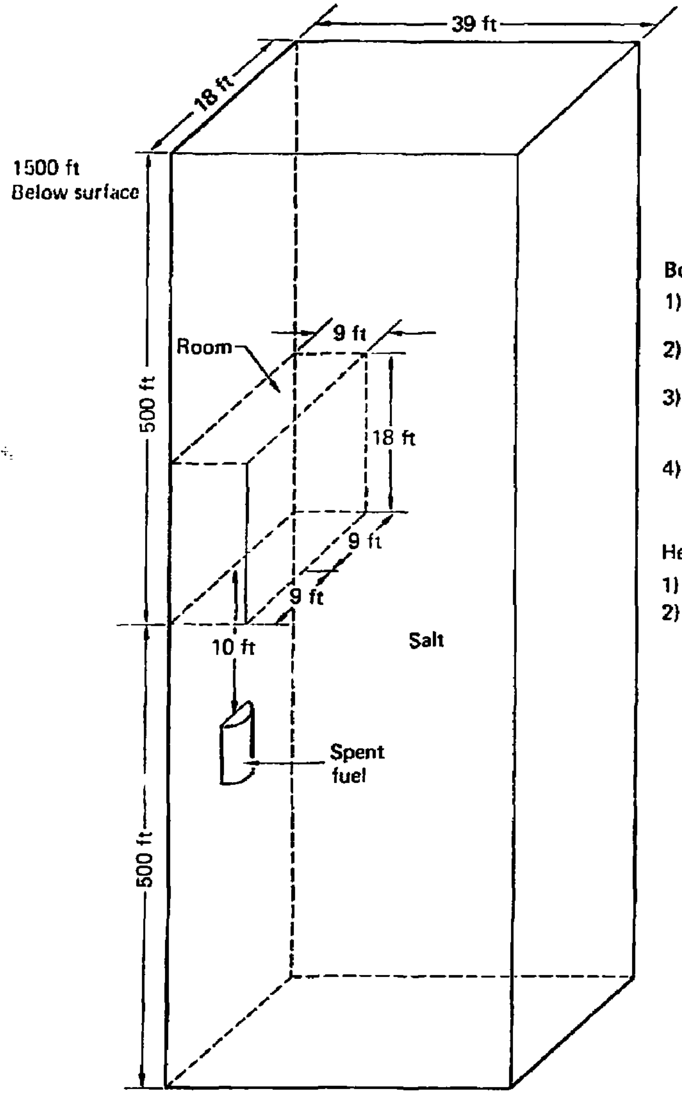
INTRODUCTION

Methods for the storage of spent nuclear reactor fuel are being studied as part of the NRC Waste Management Program at LLL. One method being considered is storage in deep underground depositories such as salt formations. The designing of a repository to isolate the spent fuel for either long term ultimate disposal or for the short term with subsequent retrieval requires knowledge of the thermal environment in the depository so that the conditions of the buried spent fuel and surrounding geologic media may be predicted. Therefore, a thermal analysis of a depository is being undertaken. The analysis employs a three dimensional computer model of the depository by means of the TRUMP heat transfer code (Ref. 2). This report presents the 3-D model used, as well as preliminary results from a base case and several parametric studies. Then it outlines the scope of future refinements in the analysis.

UNIT CELL MODEL

The geologic depository consists of many long parallel rooms of 18' x 18' cross section. The rooms are mined horizontally, with the floor located 2000 ft. below the surface. A solid salt pillar of 60 ft. width separates the rooms. The spent fuel canisters are buried 10 ft. below the floor in a single file along the centerline of the room.

The 3-D model is based on a unit cell within the depository. The unit cell consists of a single waste canister, the surrounding salt, and a section of the room. The dimensions of the unit cell (Fig. 1) are 39' x 18' x 1000', the same as those used in Reference 1 in a thermal analysis of a high level waste depository.



3-D unit cell for trump model of deep salt depository

Boundaries and conditions

1) Left side: Axis of symmetry for room – adiabatic
2) Right side: Center of salt pillar – adiabatic
3) Front & rear sides: Plane of symmetry between waste canisters – adiabatic
4) Top & bottom sides: Effective infinite distance from waste – constant geologic temperature

Heat transfer mechanisms

1) Conduction from waste to salt
2) Convection from salt to room air (simulated ventilation)

The room is split in half along its axis for one boundary of the unit cell. Since the canister is positioned beneath the center of the room, it too is split in half by the unit cell. The width of the cell extends 39 ft. out to the center of the salt pillar between rooms. The canisters are spaced 18 ft. apart along the room axis, and therefore the cell length is also 18 ft. The cell height of 1000 ft. is chosen so that the interior heat generation will have little effect on the top and bottom cell temperatures during the time periods of interest.

BOUNDARY CONDITIONS

Boundary conditions for the unit cell are as follows. Again refer to Figure 1.

1) Left Side - This is an axis of symmetry. For a room in the center of a depository filled with equal strength sources, this plane is adiabatic.
2) Right Side - This is the center of the salt pillar between rooms. Therefore, for central rooms, this is also an adiabatic plane.
3) Front and Rear Sides - These are symmetry planes between adjoining canisters in the room and again are adiabatic.
4) Top and Bottom Sides - For the short times under consideration in this problem these sides are not affected by the presence of the heat source and are therefore fixed at a constant geologic temperature.

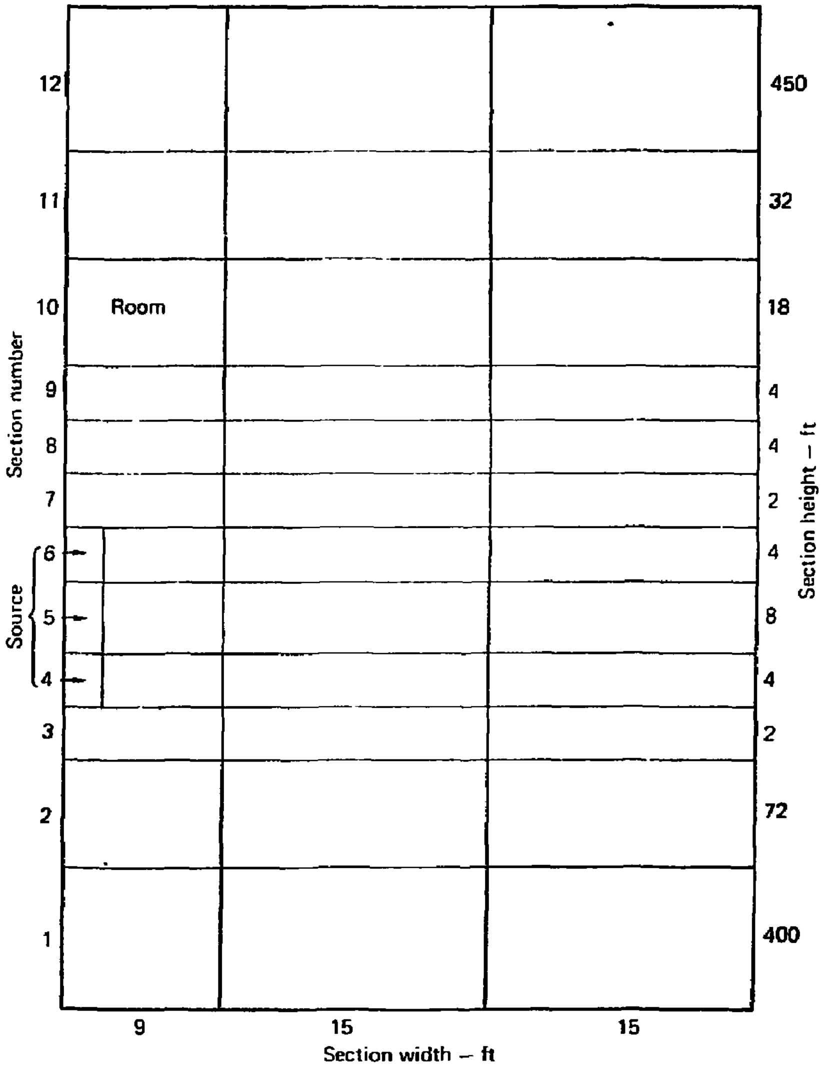
NODE GEOMETRY

A complex nodal system is used to provide an accurate representation of the thermal gradient in the regions close the the canister without compromising on the source geometry. Previous techniques have modeled the cylindrical canister as a rectangular solid of equivalent heat generation in order to maintain simple rectangular geometry throughout the unit cell. This introduces error into the temperature field near the canister/salt boundary. This model maintains cylindrical geometry both within the canister and outside of it to a distance of 9 feet from the canister centerline. Thus, more accurate temperatures are obtained near the canister. This information is essential for future studies of brine migration, canister corrosion, and thermal stress analysis.

Figure 2 is a side view of the cell showing its division into 12 axial sections of various heights. Each section is then divided into a two-dimensional pattern. The sections near the canister (3-9) contain 70 nodes each, while sections 1, 2, 11, 12 contain 18 nodes each. The room interior (section 4) is described by 1 node, therefore section 4 contains 13 nodes. Figures 3, 4, and 5 show the 3 nodal patterns used for the 12 sections.

MATERIALS AND PROPERTIES

Three materials are used in the TRUMP model. The canister is composed of UO_2, and the size set at 16 feet in length and 1 foot in diameter. The heat generation rate for the canister is based on a contents of 650 PWR fuel rods. This corresponds approximately to the maximum density packing achievable while leaving the individual rods intact. For the purposes of this study, the thermal properties of the canister are chosen to be those of a solid cylinder of UO_2. The decay heat rate and the UO_2 properties used are listed in Table 1.



Not to scale

Figure 2. A side view of the unit cell showing the dimensions of the 12 section.

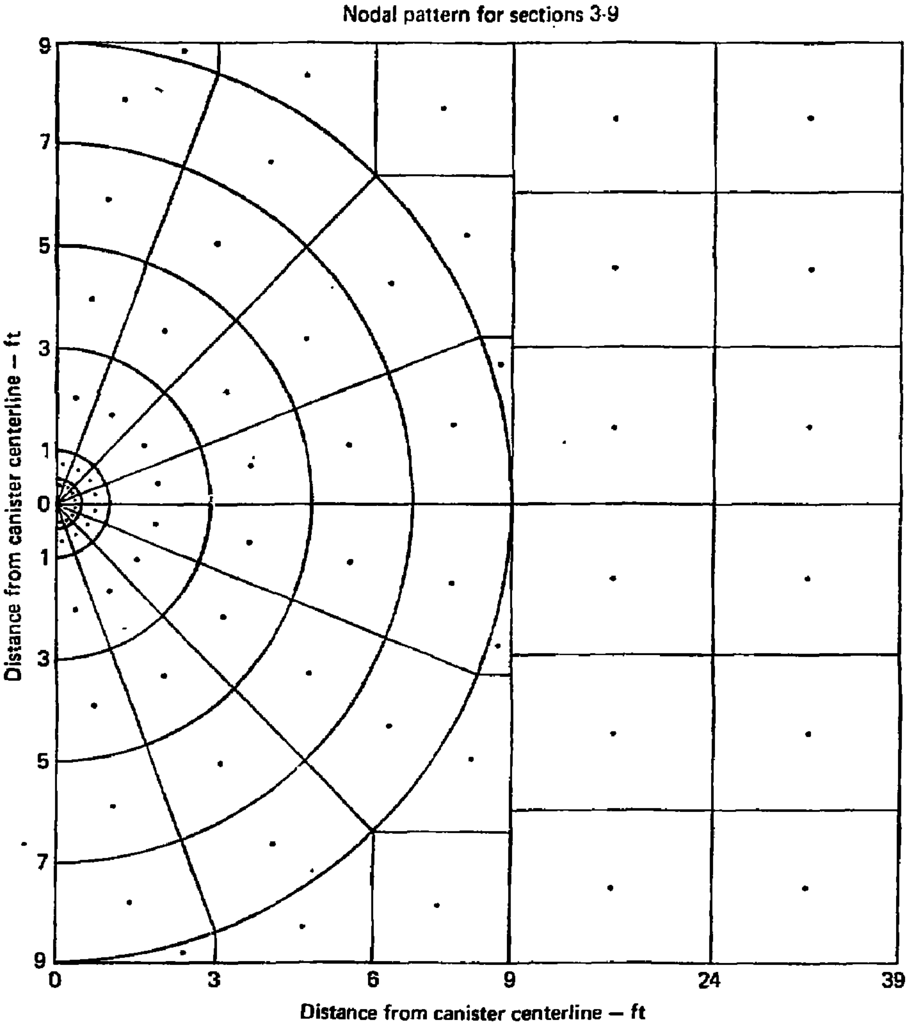


Figure 3. The 70 node geometry.

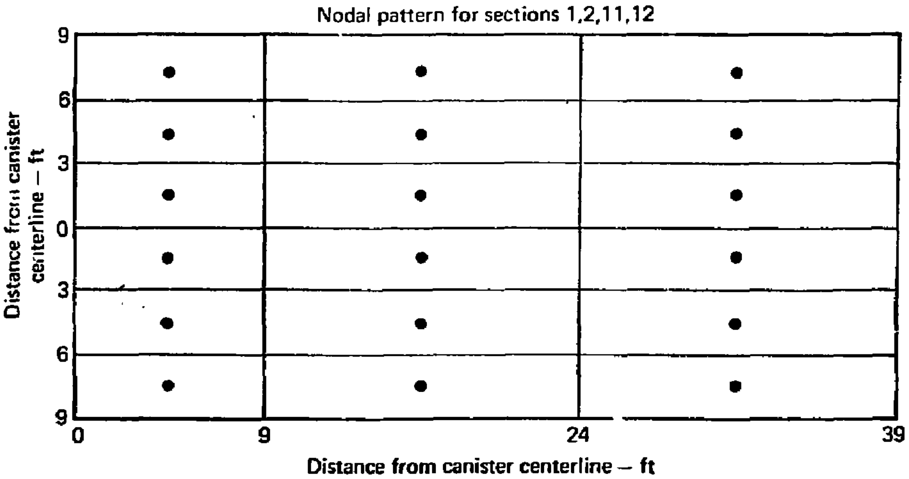


Figure 4. The 18 node geometry.

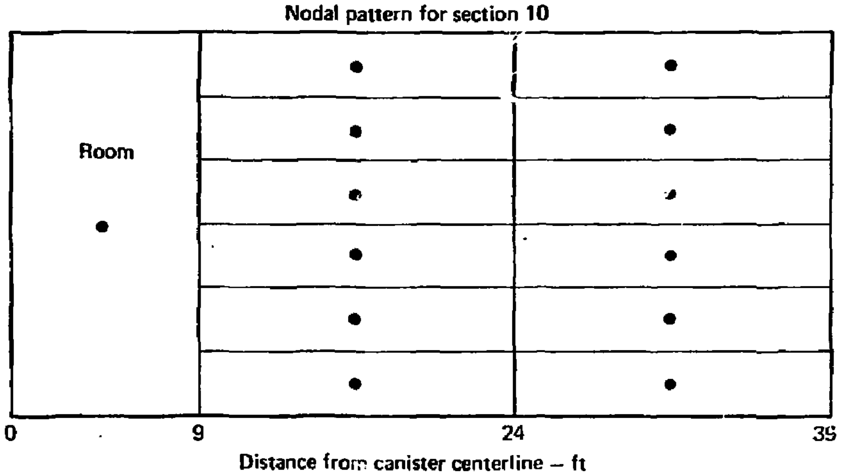


Figure 5. The 13 node geometry including the room.

TABLE 1

HEAT GENERATION RATE FOR SPENT FUEL

TIME (YR)	KW/CANISTER
0*	28.8**
1	11.6
3	4.61
5	2.81
10	1.81
30	1.13
100	0.40

* Initial time is 160 days after reactor shutdown.

** Based on a contents of 650 PWR fuel rods per canister.

THERMAL PROPERTIES OF UO_2 +

Conductivity-----------------4.62 BTU/hr.ft.°F

Density----------------------655 lb/ft^3

Specific Heat-----------------.059 BTU/Lb.°F

\+ Properties are constant with temperature.

The depository material is salt. The properties of salt used in the analysis including temperature dependent conductivity, are given in Table 2.1 and 2.2 of Ref. 1. The well known properties of the third material, air, are used for the node within the room.

BASE CASE

The base case for the TRUMP heat transfer model consists of a UO_2 cylindrical heat source surrounded by a salt heat sink. Heat is conducted through the salt to the cell boundaries and is convected to the room from the adjacent nodes. Room ventilation is modeled by maintaining the room node at constant temperature of 74°F. Initially, the heat source is set at a temperature of 200°F, while the salt is set to the natural geologic temperature corresponding to its depth below the surface. The convection coefficient chosen for the base case is 0.4 BTU/ft^{2}hr°F. The source strength is set at 4.6 Kw, which corresponds to 3 year old spent fuel.

The results of the base case analysis are shown in Figures 6-9. In Figure 6, the radial temperature profile is plotted for 8 nodes from the canister to the pillar. The time of the plot, 216 days after emplacement, corresponds to the time of maximum canister temperature. The profile shown is for section 5, the hottest of the 12 sections.

Figure 7 shows the peak axial temperature profile for 6 nodes extending from the center of the canister vertically through 10 feet of salt and into the room. Figures 8 and 9 are plots of temperature histories for the middle canister node and the adjacent salt node respectively.

The base case and all parametric calculations are performed over a time interval extending from the time of emplacement until the peak temperature was reached in the salt pillar. These times range from about 100 to 750 days. Long term calculations which can be used to predict

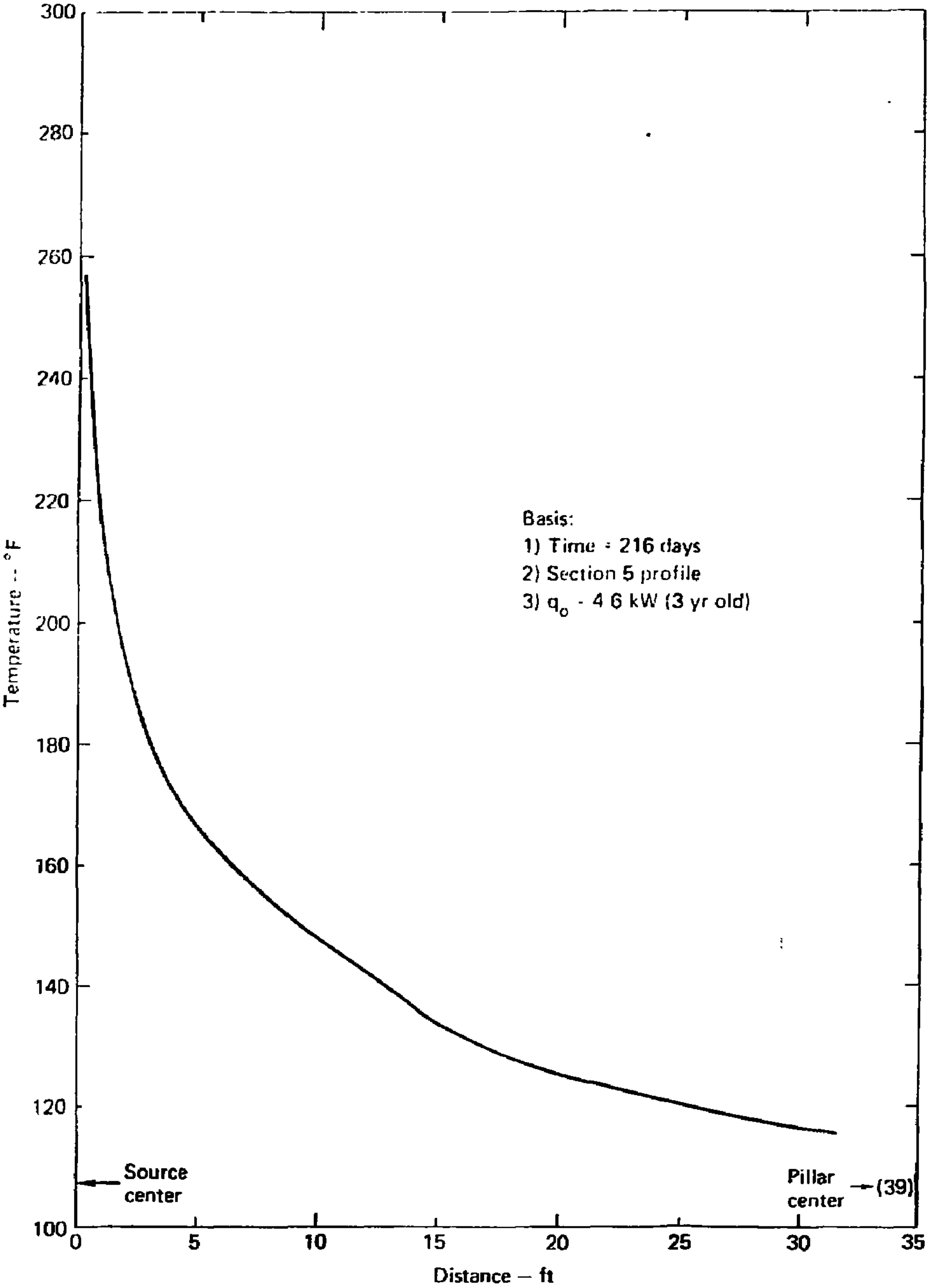


Figure 6. The peak radial temperature profile for the base case.

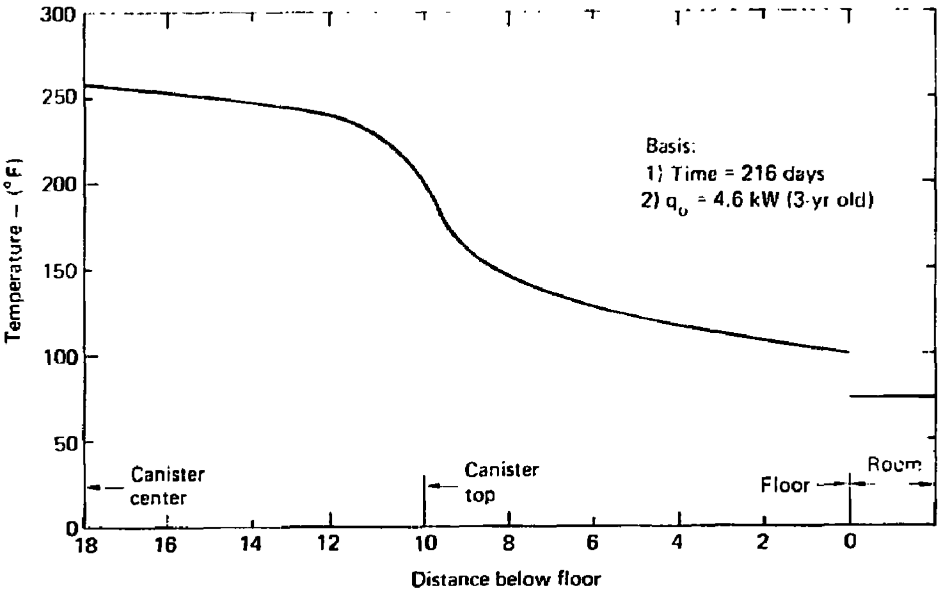


Figure 7. The peak axial temperature profile extending from the canister center to the room for the base case.

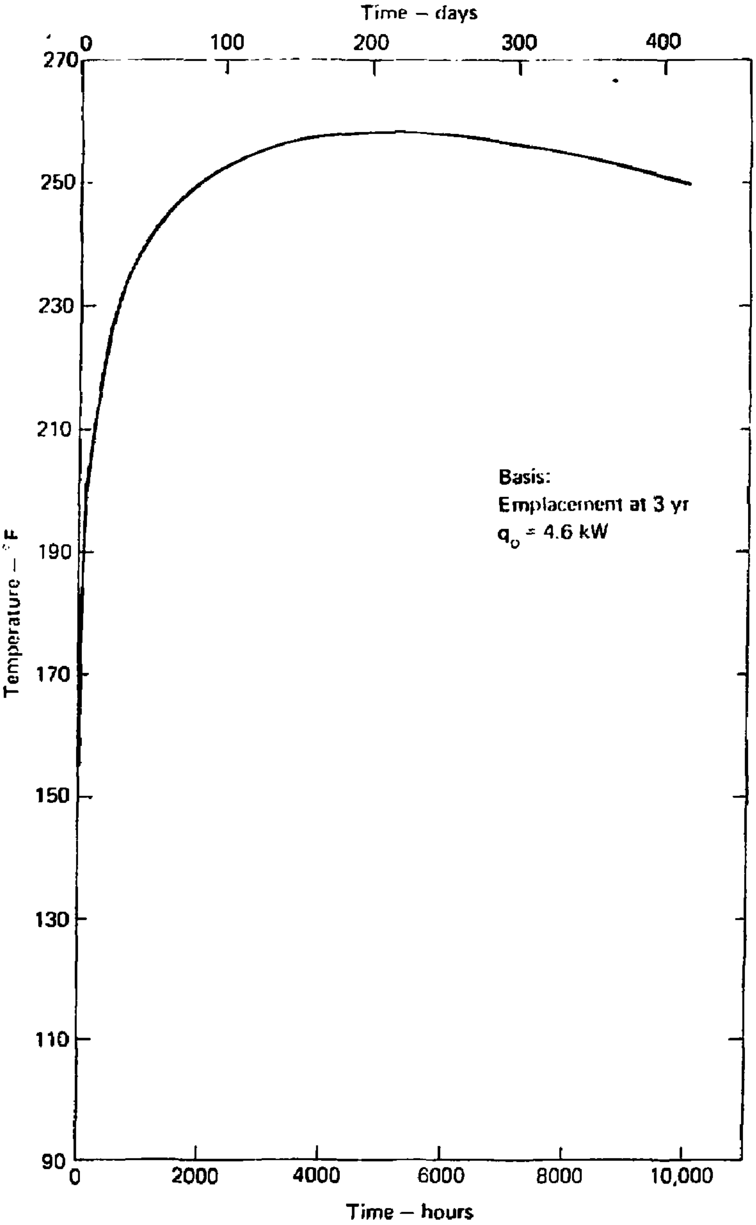


Figure 8. The peak source temperature history for the base case. The plot is for the canister at section 5. The initial temperature is 200°F.

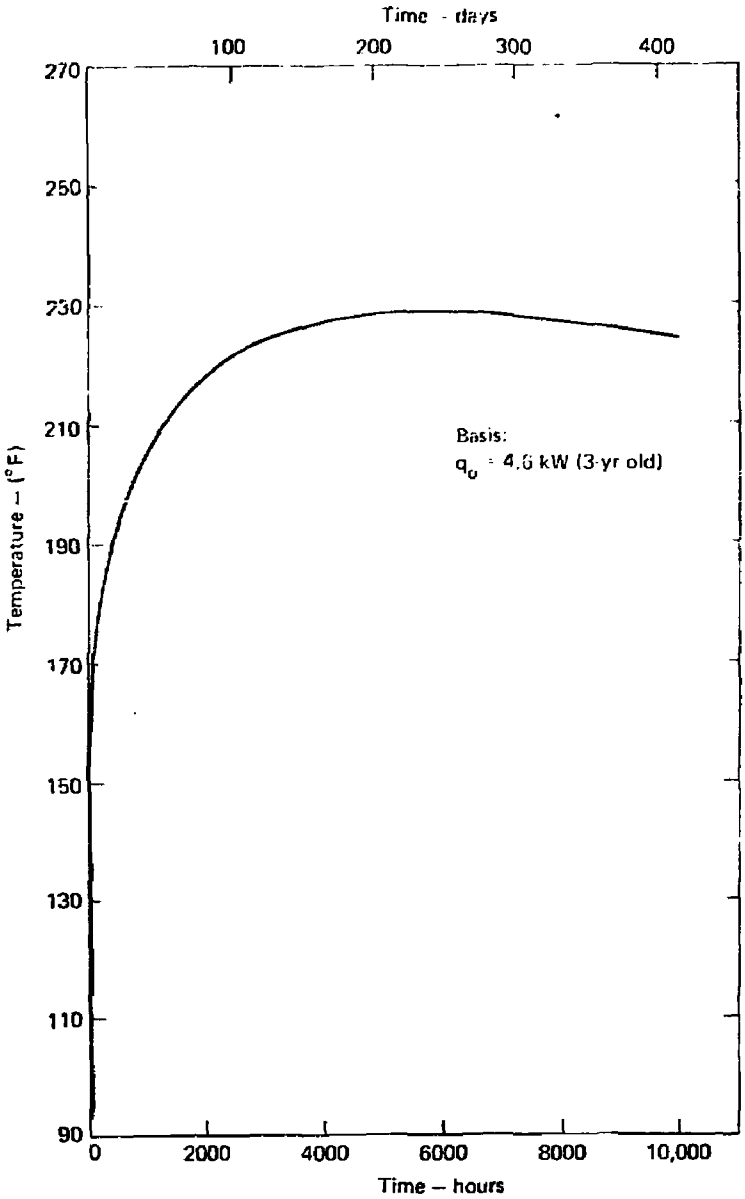


Figure 9. The peak salt temperature history for the base case. The plot is for the salt node nearest the canister at section 5.

surface thermal effects at the repository site will be addressed in future work.

PARAMETRIC STUDIES

Eight variations of the base case were run in order to study the effects of several parameters. The parameters of interest are the spent fuel heat generation rate, the convection coefficient for room ventilation, the room air temperature, and the depository thermal diffusivity.

For runs 2-4, the canister heat generation rate was varied from the base case (4.16 Kw) to 28.8 Kw, 11.6 Kw, and 2.8 Kw, corresponding to spent fuel of age 0, 1, and 5 years respectively. The peak canister and salt temperatrues for these cases are plotted in Figure 10. It is clear that the age and the packing density of the spent fuel at the time of emplacement is a very important factor for determining maximum temperatures.

The effect of the convection heat transfer coefficient for ventilation can be seen in Figure 11. There the peak radial temperature profile is plotted for the base case value of 0.4 BTU/hr ft^2°F and for values of 0.2 and 0.6 , which represent a range similar to that studied in Reference 1. A similar plot illustrating the effects of the room ventilation temperature appears in Figure 12, for the nominal value of 74°F and for 84°F. The effects of both the ventilation coefficient and the room temperature are quite small on the peak radial profile.

Run 8 replaces the salt in the depository with granite. The properties used are typical for western granite and are listed in Table 2. The thermal diffusivity of western granite is considerably smaller than that of salt over the temperature range of interest. For example, at 212°F, the thermal diffusivitites are 0.031 and 0.082 ft^2/hr for granite and salt respectively. The effects are shown in Fig. 13, which plots the peak radial profile for these two cases.

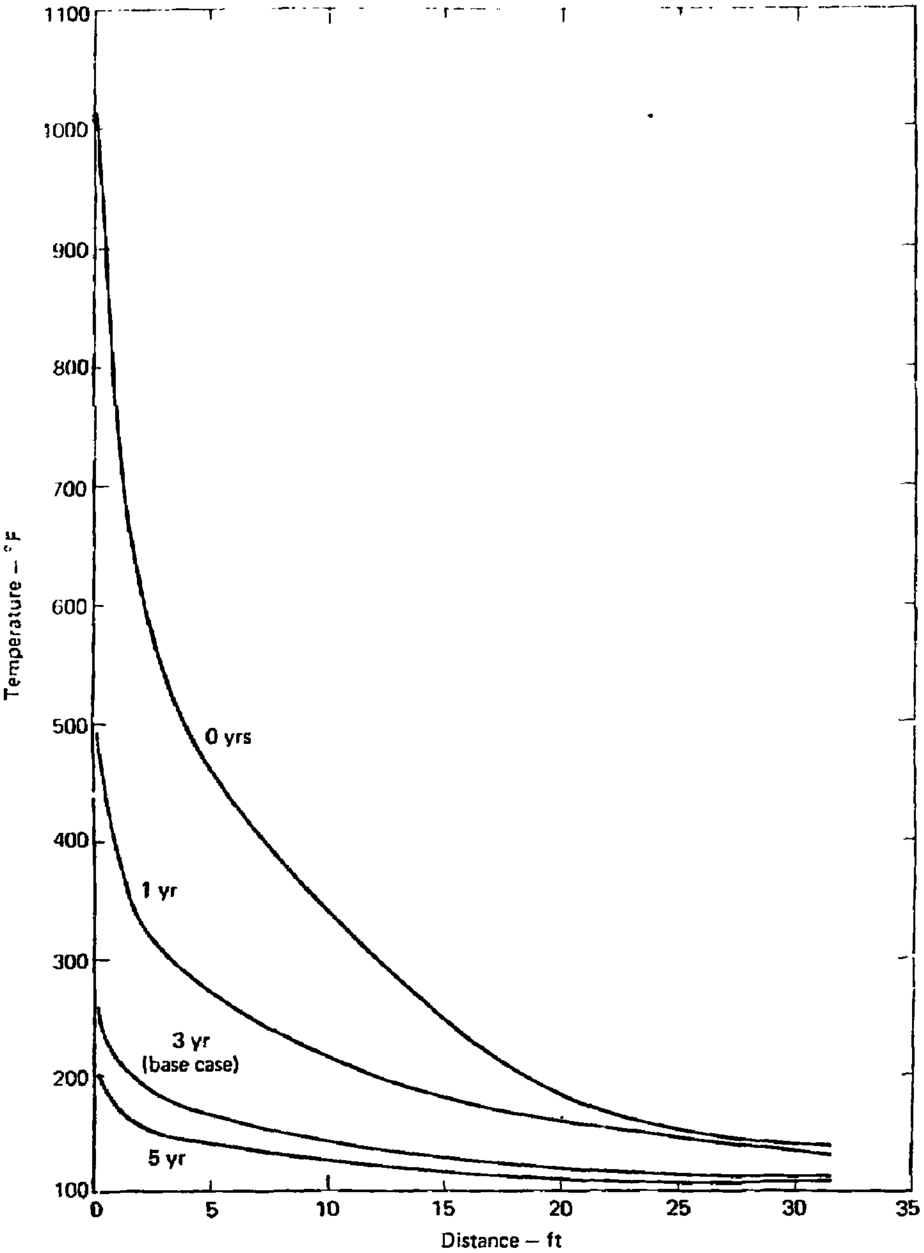


Figure 10. The peak radial temperature profile for various emplacement times. The 0-yrs curve corresponds to emplacement 160 days after reactor shutdown.

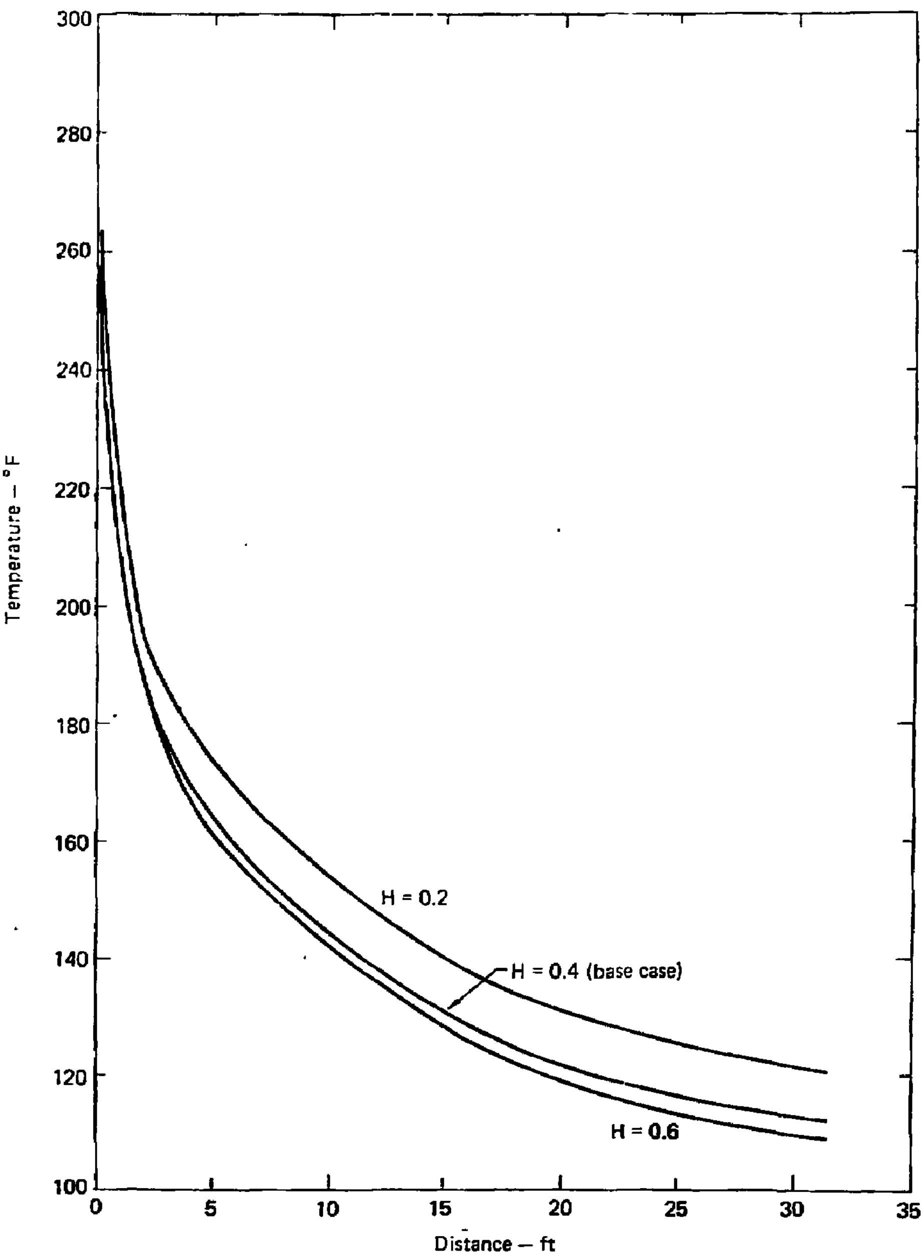


Figure 11. The peak radial temperature profiles using various room convection coefficients.

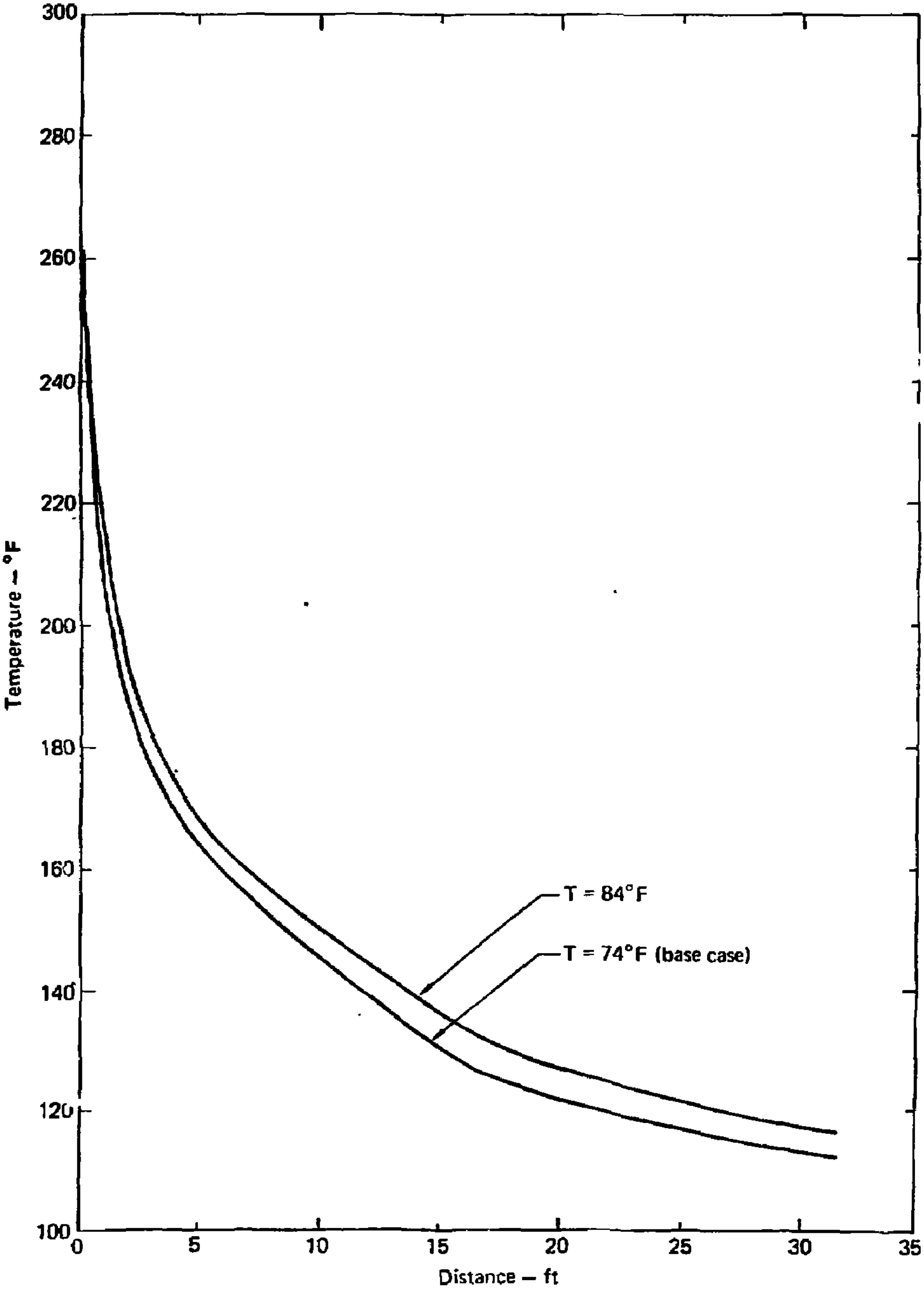


Figure 12. The peak radial temperature profiles using room temperatures of 74 and 84°F.

TABLE 2

THERMAL PROPERTIES OF WESTERN GRANITE

TEMPERATURE (°F)	CONDUCTIVITY (BTU/hr.ft.°F)
32	1.40
122	1.34
212	1.31
302	1.27
392	1.23

DENSITY--------------------------------171 Lb/ft^3

SPECIFIC HEAT--------------------------0.25 BTU/Lb.°F

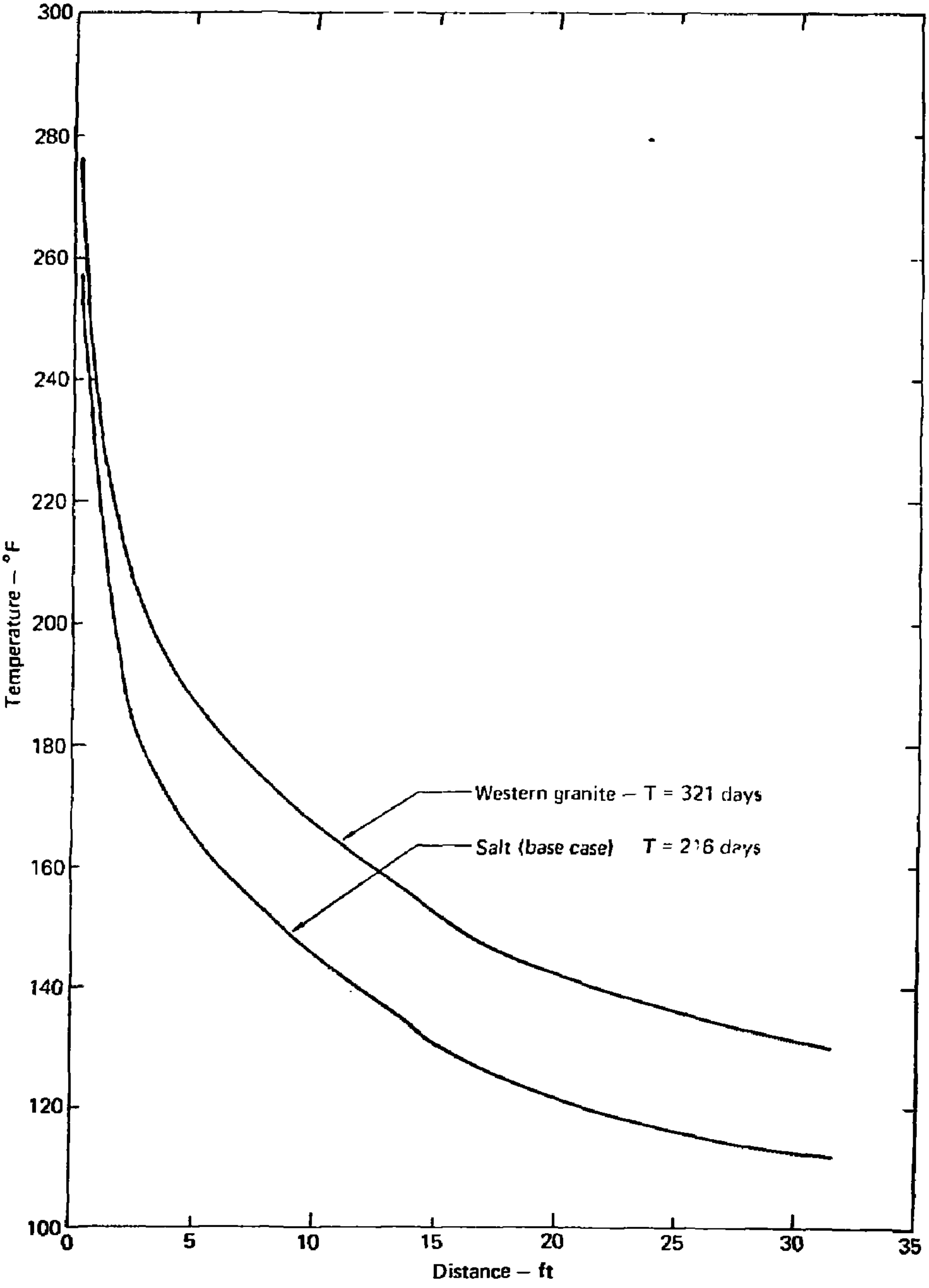


Figure 13. The peak radial temperature profiles using salt and granite depositories. Note the curves are for different times after emplacement.

All the 3-D TRUMP runs are summarized in Tables 3 and 4. Table 3 lists the important input parameters for the runs, while Table 4 presents the radial temperature profiles at the time of maximum source temperature. The nodes away from the source reach their maximum temperatures later than the source nodes. The final row in Table 4 lists the ultimate maximum temperature of the pillar for each case.

CONCLUSIONS AND FUTURE WORK

A thermal analysis using a 3-D model to be run with the TRUMP heat transfer code has been outlined. It is concluded from this analysis that the most important parameter affecting the maximum temperatures within the deep geologic depository is the heat generation rate within the unit cell. This rate is dependent upon the age of the spent fuel, the amount of fuel per canister, and the canister spacing. The thermal effects of room ventilation and different depository media are of secondary importance.

The model used is simplified through several assumptions which will be improved upon in future work. First of all, as the canister and its contents become more precisely described, the canister material itself will be included. The properties of the contents will be adjusted to represent more accurately the rod bundles and air gaps. Similarly, the assumption of perfect thermal contact between the canister and the salt will be relaxed.

The ventilation model will be improved through the addition of more nodes in the room. Mass flow of air will then be modeled, along with thermal radiation from the room surfaces. The convection heat transfer coefficient will be determined based on temperature and flow rate. Cases with no ventilation and with the room backfilled with salt will also be considered.

TABLE 3

TRUMP PARAMETER DESCRIPTION

RUN NUMBER	1	2	3	4	5	6	7	8
MAIN FEATURE	base case	fresh source	1-year source	5-year source	low h	high h	high air temp	western granite
SOURCE AGE AT EMPLACEMENT (YR)	3	0	1	5	✓	✓	✓	✓
SOURCE STRENGTH AT EMPLACEMENT (BTU/hr.ft^3)	1.25×10^3	7.80×10^3	3.14×10^3	0.76×10^3	✓	✓	✓	✓
CONVECTION COEFFICIENT (BTU/hr.ft.^{3}°F)	0.4	✓	✓	✓	0.2	0.6	✓	✓
ROOM TEMPERATURE (°F)	74	✓	✓	✓	✓	✓	84	✓
DEPOSITORY MEDIUM	salt	✓	✓	✓	✓	✓	✓	granite
DEPOSITORY DIFFUSIVITY (ft^2/hr)	.082 @212°F	✓	✓	✓	✓	✓	✓	.031 @212°F

A ✓ indicates the same value as used in the base case

TABLE 4 - TRUMP RESULTS

RADIAL TEMPERATURE PROFILE AT THE TIME OF THE MAXIMUM SOURCE TEMPERATURE

Run Number / Radial Position (ft)	1	2	3	4	5	6	7	8
0.25	257	1016	496	200	263	255	261	276
0.75	228	842	424	181	235	225	232	248
2.0	190	618	332	157	198	187	195	213
4.0	171	501	284	145	179	168	176	194
6.0	160	432	256	138	168	156	164	183
8.0	152	385	237	133	161	149	157	175
16.5	127	225	173	118	136	124	132	148
31.5	112	139	134	109	120	109	116	130
Time of Peak Source Temperature (Days)	216	96	166	372	266	201	231	321
Peak Pillar Temperature*	124	241	183	113	137	122	134	153

*Initial Temperature - 98°F

Another significant improvement will be the addition of more nodes to the problem. It is anticipated that the number of nodes can be doubled, allowing for a much finer zoning in the critical area near the canister/salt interface. Finally, the time scale of the analysis will be broadened and the unit cell extended in order to study longer term thermal effects at the repository surface. With these improvements, the analytical model of the depository thermal environment will be greatly refined.

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1. Science Applications, Inc., "Thermal Operating Conditions in a National Waste Terminal Storage Facility". Y/OWI/SUB-76/47950 September, 1976.
2. Arthur L. Edwards, "TRUMP A Computer Program for Transient and Steady-State Temperature Distributions in Multidimensional Systems". Lawrence Livermore Laboratory Report UCRL-14754, Rev. 3., September 1, 1972.