A PARAMETRIC THERMAL ANALYSIS OF THE WIPP/DHLW EXPERIMENTAL AREA

W. L. Lundberg
WESTINGHOUSE ELECTRIC CORPORATION
Waste Technology Services Division
Madison, Pennsylvania 15663-0286

ABSTRACT

Results of a thermal analysis of the WIPP DHLW experimental area are presented. The work was done parametrically to show the effect of canister heat load and emplacement period on the thermal environment in the area. The focus of the work was on facility operational concerns. Removal of the DHLW canisters from the facility will be required upon completion of a 25-year experiment period. Thus, room temperatures to be encountered by workers re-entering the DHLW area, and salt temperatures to which canister removal equipment will be exposed, must be known. In addition, the analysis also examined the room and canister cooling effectiveness of forced ventilation, and calculations at various air velocities were performed.

INTRODUCTION

The Waste Isolation Pilot Plant (WIPP) near Carlsbad, NM will be the site for the permanent disposal of both contact-handled transuranic (CH-TRU) and remote-handled transuranic (RH-TRU) wastes. In addition, plans have also been developed for the vertical borehole emplacement at WIPP of canisters containing defense high level waste (DHLW). These would be used in tests to investigate the thermal, mechanical and corrosion interaction between the DHLW canisters and the geology.

While the transuranic wastes will generate no appreciable heat, this would not be true of the DHLW. This waste material would generate significant heat, most likely in the range of 300 to 500 W per canister at emplacement time. Consequently, the geology around the DHLW packages and emplacement rooms would experience a transient temperature condition beginning at that time.

If DHLW canisters are emplaced at the WIPP facility, their removal will be required upon completion of a 25-year experiment period. Aside from the effects that elevated temperatures may have on the canisters themselves, the fact that the canisters must be retrieved after 25 years gives rise to questions regarding worker comfort during retrieval operations and salt temperatures that the retrieval equipment will encounter. To address these issues, an analysis has been performed to predict temperatures in the WIPP DHLW experiment area. This was done parametrically so the effects of key variables such as emplacement time period and canister heat load could be determined. In addition, analyses of various forced ventilation (blast cooling) scenarios were made to determine the air flow rates required to effectively prepare the emplacement rooms for worker access. It is the purpose of this paper to present the results of this analytical work.

It is possible that DHLW canisters could be emplaced at the WIPP facility in a borehole configuration other than the one considered in this analysis. However, it is expected that certain results reported herein could still be useful in that event, at least to provide guidance in the early planning for the experiments. In particular, predictions of room surface temperature and blast cooling effectiveness should be applicable regardless of the borehole configuration since they are expected to depend more upon the areal heat load than upon borehole physical detail.

ANALYSIS OBJECTIVE

The objective of this analysis was to define the thermal environment that will exist around the DHLW canisters and in the DHLW rooms during the canister emplacement period, and to predict the effectiveness of blast cooling in preparing the rooms for canister retrieval. As indicated above, this information is required in the retrieval equipment design effort and in planning for worker operations during the retrieval process. This analysis was not concerned with DHLW experiment assessment or with DHLW pre-test predictions.

FACILITY PHYSICAL DESCRIPTION

The WIPP repository will be mined approximately 650 m below ground level. Figure 1 depicts the repository room arrangement and identifies the location of the DHLW experimental area. The presence

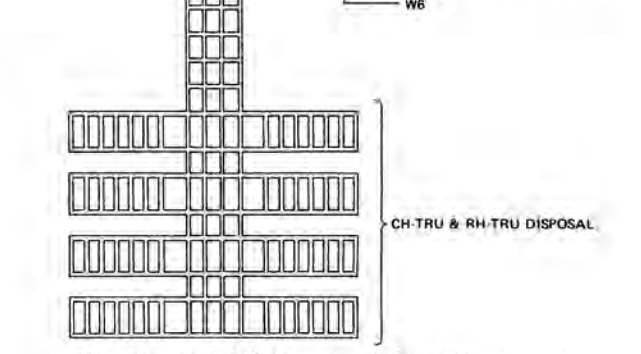

Fig. 1. WIPP Underground Facility Layout.

of six DHLW rooms is indicated. However, when the analysis was performed, it was understood that only three inboard rooms (W2, W3, and W4) would actually contain DHLW canisters. The rooms were assumed to be square in cross-section, 6.1 m on each side, 100 m in length, and spaced at center-to-center distances of 24 m. The effects of creep on room dimensions were neglected.

It was assumed that the canisters (metallic, cylindrical) containing DHLW were placed in vertical boreholes and that the boreholes, in turn, were arranged in a square-pitch pattern as shown in Fig. 2. The borehole depth was assumed to be 5.5 m and the hole diameter was selected sufficient to provide a 15 cm radial gap between the canister and the hole. After emplacement in its borehole, each canister was assumed to be covered with crushed salt to room floor level.

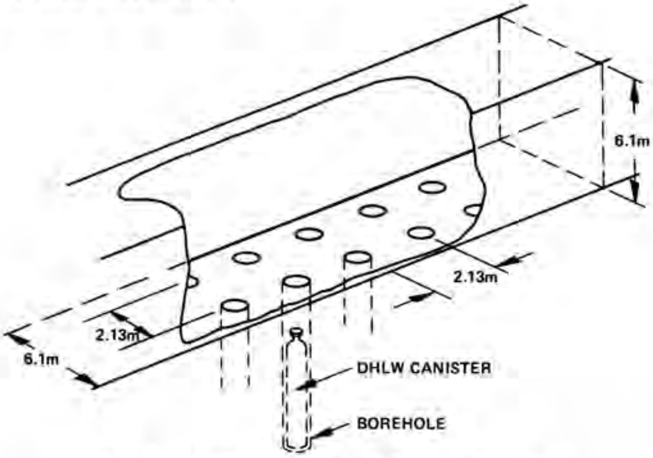

Fig. 2. WIPP DHLW Borehole Arrangement.

Calculations were performed for three emplacement-time heat loads -- 300, 700, and 1000 W per canister, corresponding to local areal heat loads of 12, 27, and 39 W/m^2, respectively. In the 300 and 700 W cases, the canister outside diameter was assumed to be 61 cm. For 1000 W, a different waste mix would be applied requiring a canister diameter of 41 cm.

In each canister, the radioactive waste material is immobilized in borosilicate glass, and the mixture, regardless of the canister heat load, was assumed to fill the canister to a height of 230 cm.

ADDITIONAL ANALYSIS ASSUMPTIONS

The geology in the heat-effected zone surrounding the DHLW experimental area was assumed to be halite. The following property values for this material were taken from Ref. 1:

Density - 2.3 g/cm^3
Specific Heat Capacity - 0.86 j/g-C
Thermal Conductivity - 5.0(300/T)$^{1.14}$,
W/m-C, where T is in degrees kelvin.

The ambient salt temperature and the temperature of inlet ventilation air at the repository horizon were assumed to be 29°C. The reference relative humidity was 25%.

The decay heat curves for the 300, 700 and 1000 W canisters are identified in Fig. 3. Curve A applies to the 700 W canister but it was also used to obtain the decay characteristics for 300 W DHLW. This approach assumes, therefore, that the waste compositions in the 300 and 700 W cases were initially identical but that the material in the 300 W canisters was older at emplacement time by approximately 30 years.

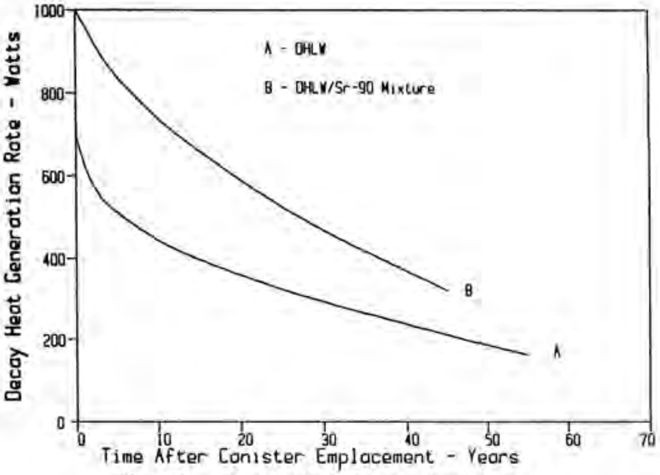

Fig. 3. Decay Heat Characteristics.

In the 1000 W case, Fig. 3, Curve B, it was assumed that the waste would be a two-component material. One component would have the same decay heat characteristics as the waste in the 700 W canister, and the second was assumed to be equilibrium strontium-90.

ANALYSIS METHODOLOGY

Unit Cell Repository Model

The calculations to determine peak canister/salt temperature and room surface temperatures were done with a finite-element computer program employing a "Unit Cell" thermal model of the repository. Figure 4 shows a localized view of the DHLW experimental area and identifies the side boundaries of the unit cell model. The boundaries are positioned at the half-way points between adjacent boreholes and each one represents an adiabatic surface. In the vertical direction, the boundaries extend upward and downward from the repository horizon to arbitrary distances where the temperature will not vary during the simulation time period.

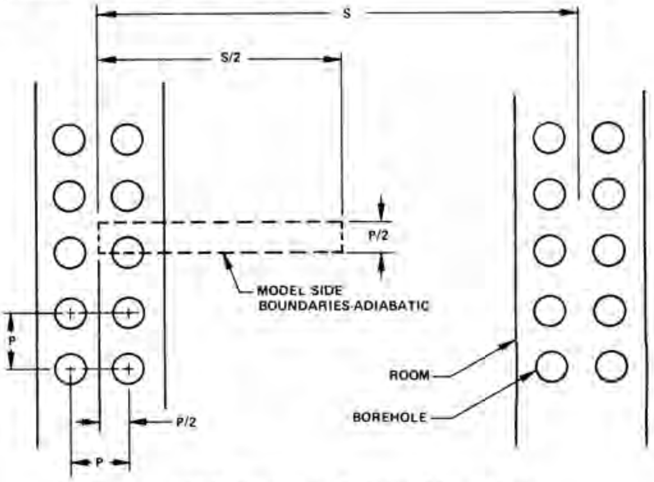

Fig. 4. WIPP DHLW Local Area Plan View.

The unit cell modeling method will provide an accurate repository representation when it is applied to a large repository consisting of a uniform array of parallel rooms. Further, the model assumes, in effect, that all boreholes are *loaded simultaneously*. These conditions would not, of course, be characteristics of the WIPP DHLW experimental area. It will be small in size, such that end and side effects will impact central room and canister temperatures, and the boreholes will be loaded and unloaded sequentially. These are real effects that would tend to suppress those temperatures. It was determined, however, that the reference calculations should apply the unit cell method assuming that predictions involving large-repository effects were desired and that measures (e.g., guard heater installation) could possibly be taken in the DHLW experimental area to simulate large-repository conditions.

Unit Cell Application

The unit cell model was employed in two stages to predict the thermal response of the DHLW area to canister emplacement. The first covered the actual emplacement period, and the second, the room cooldown in preparation for canister retrieval. During the emplacement period, the room was assumed to be filled with stagnant air. The only room heat transfer process was thermal radiation from the floor to back (ceiling).

In the second stage, room cooldown times of up to six months were analyzed. During this period the room was assumed to be cooled by forced air ventilation. Calculations were done with air velocities of 0.3, 0.7, and 1.0 m/s.

Physiological Effects Modeling

To evaluate worker comfort in a warm working environment, the method employed in a similar study,[2] was adopted. For this initial study of the WIPP DHLW area thermal environment, and of conditions workers may encounter upon re-entering the area to retrieve canisters, it was believed to provide a reasonable starting point. In further, more detailed work for WIPP/DHLW, however, this topic should receive some additional attention to verify that all applicable worker comfort requirements have been identified.

Worker comfort was evaluated using a parameter called the wet bulb globe temperature, WBGT. It is defined as

$$WBGT = 0.7\ WBT + 0.3\ GT$$

where WBT is the wet bulb temperature and GT is the globe temperature. Globe temperature is the equilibrium temperature reached by a high absorptivity body which is exposed to thermal radiation and is air-cooled. Therefore, the WBGT is a comfort index that considers the combined effects of air dry bulb temperature, relative humidity, room wall temperature, and cooling air velocity.

The National Institute for Occupational Safety and Health defines hot environmental conditions as occurring whenever any combination of air speed, air temperature, humidity, and enclosure temperature results in a WBGT value that is greater than 26°C [3]. This definition was adhered to in this analysis and combinations of canister heat load, blast cooling air velocity, and cooling time were sought for which the WBGT would be less than 26°C.

Finite-Repository Thermal Modeling

As indicated above, the unit cell method is best suited for large-repository simulation or for calculations on small repositories which will implement some method of achieving a large-repository boundary condition. Since the WIPP DHLW experimental area currently falls in neither category, it was determined that calculations should be performed to indicate the sensitivity of room and borehole temperatures to variations in repository size. To that end, two additional finite-element thermal models were prepared which considered finite-repository effects and predicted transient repository temperatures.

Analysis with the first, termed the parallel room model, was intended to show the effect of the number of parallel heated rooms on temperatures in the central room. It is a two-dimensional model that includes a large expanse of unheated geology adjacent to the outboard rooms. Then, to examine the room length effect, the second model considered the repository to consist of an infinite number of parallel heated rooms that were finite in length and bounded on each end by heat-absorbing geology. With this model, the heated length model, the analyst can vary that length and determine the sensitivity of room centerpoint temperatures and the lengthwise temperature distribution to those variations. Calculations with finite-repository models such as these can be very useful in establishing the necessary size of experimental repository panels.

DISCUSSION OF RESULTS

Thermal Environment in the WIPP DHLW Area During the Emplacement Period

From unit cell simulations, Figs. 5 and 6 present peak room temperature and peak canister temperature as functions of time during the canister emplacement period. Three curves are shown in each figure, each applying to a different canister heat load. The room temperature values were taken from a point on the floor centerline between two adjacent boreholes, and the peak canister temperatures occur on the canister side surface near its mid-plane.

Room temperatures will be sufficiently high during the DHLW emplacement period to create an uncomfortable environment for any workers in the area. This is apparent from Fig. 5 where room surface temperatures are shown to exceed 50°C even in the 300 W canister case (for emplacement periods beyond five years). Thus, measures will be required to cool the DHLW rooms before re-entry.

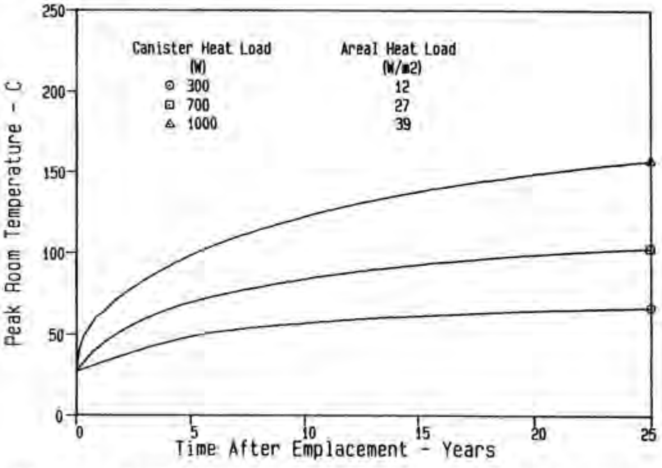

Fig. 5. Room Temperature During Canister Emplacement.

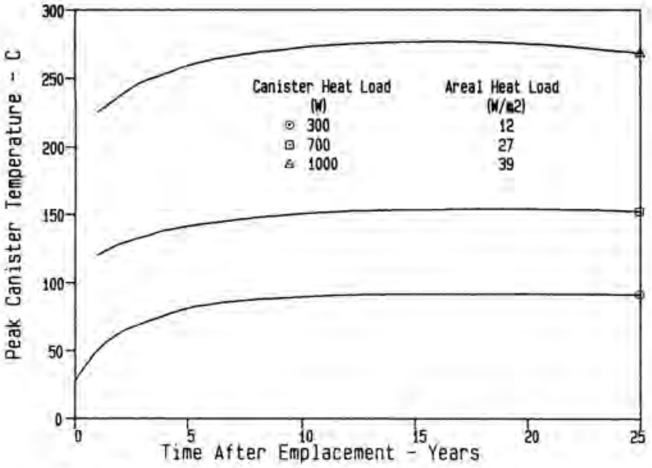

Fig. 6. Canister Temperature During Canister Emplacement.

A maximum salt temperature of 150°C has been identified for use in the design of canister retrieval equipment. Figure 6 shows that borehole temperatures will be below this value by a comfortable margin in the 300 W canister case, and that it will be exceeded by only several degrees centigrade in the 700 W case. Therefore, retrieval equipment for at least these two cases can be designed to this temperature specification without depending upon auxiliary cooling. The 1000 W canister case, however, is much more severe thermally, and cooling will have to occur by some method before and/or during the canister retrieval operation.

Thermal Environment in the WIPP DHLW Area During Blast Cooling

Figure 7 illustrates room temperature response to blast cooling initiated after a canister emplacement period of 25 years. The response to forced air flow is fairly quick, evidence that blast cooling, in the air velocity range considered, could be effective in preparing a DHLW room for re-entry and canister retrieval.

Canister temperature (Fig. 8), however, responds relatively slowly to blast cooling due to salt heat capacity effects. Thus, if a significant drop in canister temperature were required, blast cooling would apparently not be the way to achieve it.

Sample transient WBGT predictions, assuming 25% relative humidity, are presented in Fig. 9. With even the lowest air velocity, 0.3 m/s, blast cooling would apparently be effective in reducing the WBGT to 26°C. This is a very favorable finding since 0.3 m/s corresponds to the normal WIPP facility ventilation air velocity.

Results of all WBGT calculations are cross-plotted in Fig. 10 to show room re-entry time (time to reach WBGT of 26°C) as a function of air velocity and canister heat load. The figure clearly indicates that re-entry time depends strongly upon both parameters.

Through its dependency upon wet bulb temperatures, WBGT is also a function of relative humidity. Increasing the relative humidity to 60%, the maximum WIPP design value, would add approximately 5°C to the WBGT values, and render the 0.3 m/s air flow *ineffective even* in the 300 W canister case.

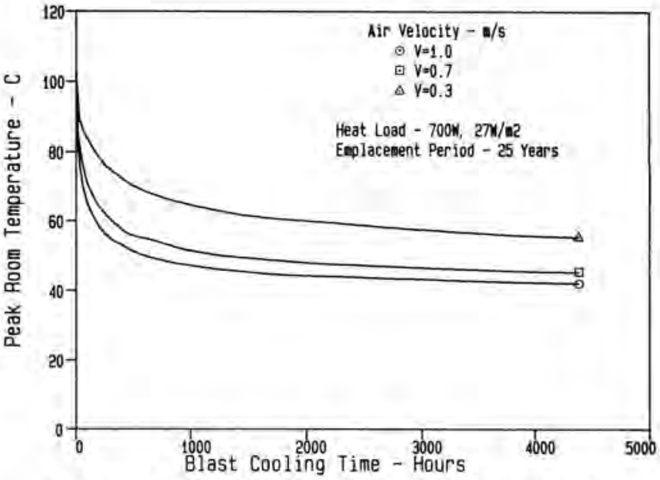

Fig. 7. Room Temperature During Blast Cooling.

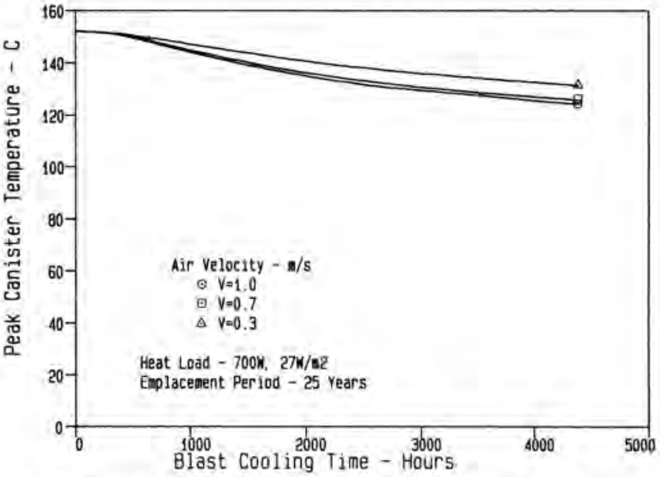

Fig. 8. Canister Temperature During Blast Cooling.

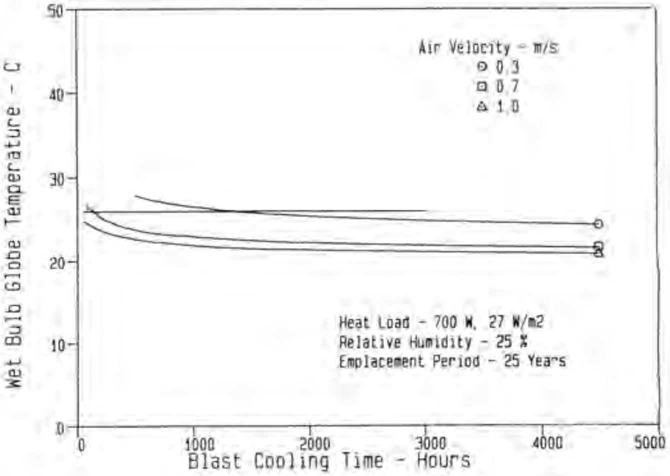

Fig. 9. WBGT During Blast Cooling.

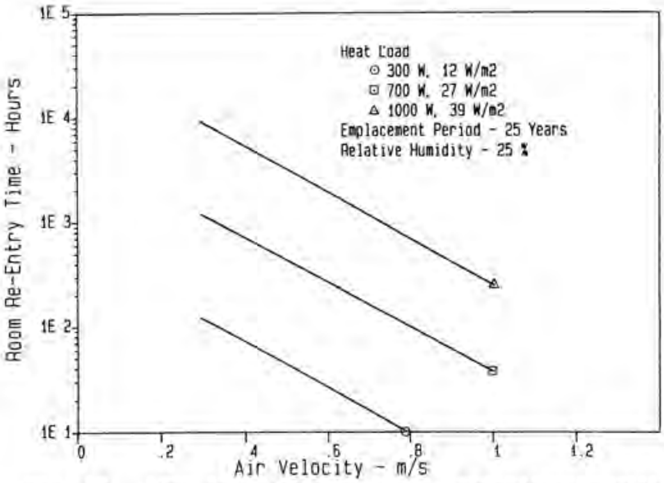

Fig. 10. Time to Reach 26°C WBGT - Relationship With Air Velocity and Heat Load.

Finite-Repository Temperature Predictions - Number of Rooms Effect

As the number of rooms containing DHLW canisters in boreholes increases, temperatures in the central room will increase and approach infinite-repository values. This effect is demonstrated in Fig. 11 where central room wall temperature is displayed as a function of time for several finite repositories and an infinite repository. The figure, applying to 700 W canisters, indicates that the central room temperature is a strong function of the number of rooms. It also indicates that at least seven heated parallel rooms are required to effectively isolate the central room from the unheated geology that bounds the finite repository on its sides.

The effect of the number of rooms on repository transverse temperature distribution is indicated in Fig. 12. The temperature point plotted at each room location is the outboard wall temperature after a twenty-five year emplacement period. The figure shows that the outer rooms will tend to exhibit temperatures that are significantly less than the unit cell temperatures, and that their main function will be to buffer the inner rooms and to drive their temperatures toward the unit cell values.

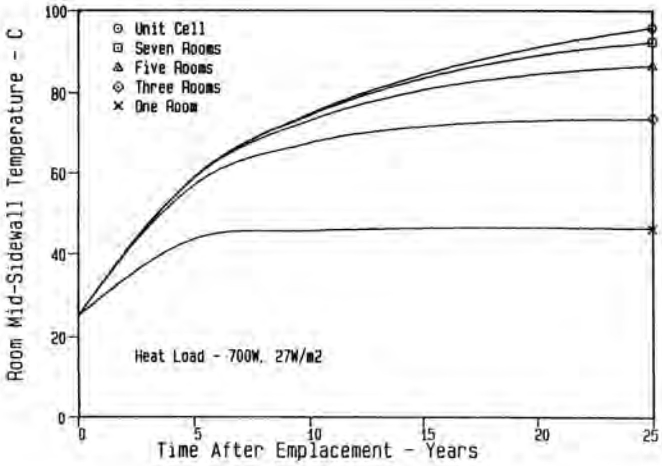

Fig. 11. Number-of-Heated Rooms Effect on Central Room Temperature.

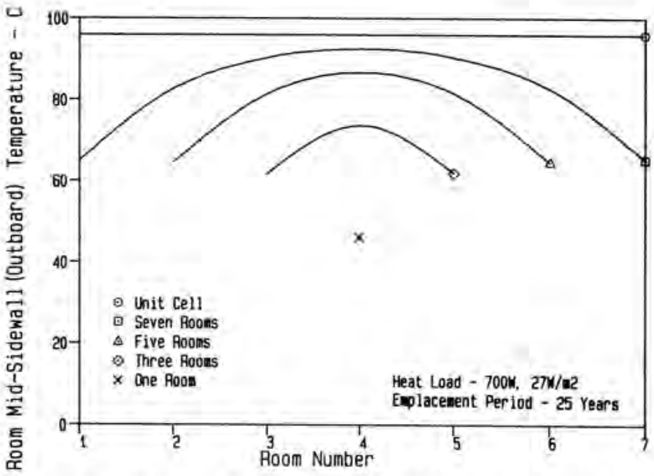

Fig. 12. Number-of-Heated Rooms Effect on Repository Transverse Temperature Distribution.

Finite-Repository Temperature Predictions - Room Heated Length Effect

The effect of room heated length on room and canister temperatures will also be significant. Using the heated length model, several calculations were performed in which the heated length was varied from 15 to 90 m and the predicted room temperatures were compared with unit cell values. In Fig. 13, room wall temperature at the heated length centerpoint is plotted as a function of time for several values of length. The canister heat load at emplacement time was 700 W. As in the number-of-rooms study, it was found that the heat absorption effect produced by the solid geology surrounding a finite repository will produce a very significant effect upon room temperatures. Only with heated lengths greater than 90 m would temperatures at the centerpoint closely approach unit cell values.

Room lengthwise temperature distributions are plotted in Fig. 14 for several values of room heated length. They apply to 700 W canisters after a 25-year emplacement time. In the short room cases particularly, the temperatures, as already indicated in Fig. 13, are considerably less than the unit cell values, and the temperature variations in the length direction are also significant.

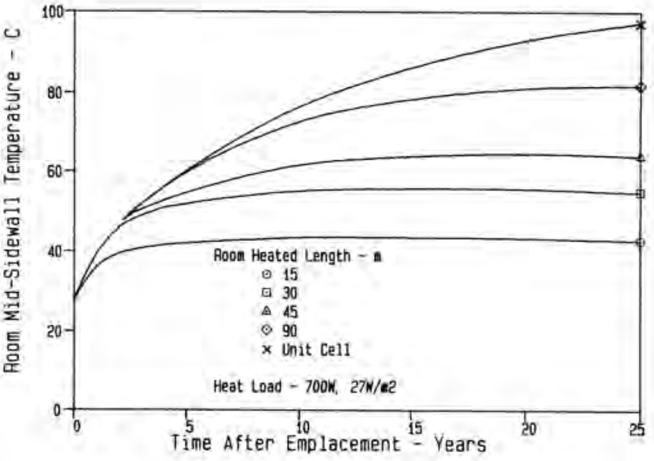

Fig. 13. Room-Heated-Length Effect on Room Centerpoint Temperature.

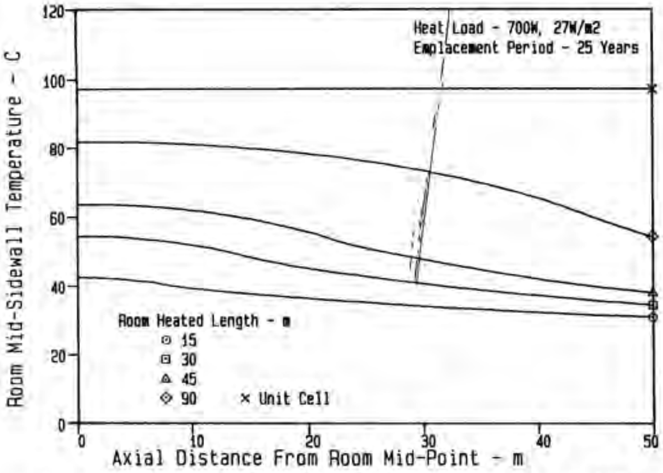

Fig. 14. Room-Heated-Length Effect on Room Axial Temperature Distribution.

CONCLUSIONS

Based upon the analysis with the unit cell thermal model, the following conclusions were drawn regarding the operational aspects of the WIPP DHLW experimental area.

- With 25% relative humidity, and canister heat loads of 700 W or less, blast cooling velocities in the 0.3 - 1.0 m/s range could be selected which would permit timely room re-entry upon completion of a 25-year emplacement period. The finding that the DHLW area could be cooled with 0.3 m/s air flow is significant since 0.3 m/s is the baseline ventilation air velocity for the WIPP facility.
- With 1000 W canisters, the minimum practical blast cooling velocity would be approximately 0.7 m/s.
- Blast cooling will not be effective in canister cooling if a significant temperature reduction (e.g., 50°C or more) is required.
- When finite-repository effects are included in the analysis, predicted repository temperatures are reduced significantly. This is due to the absorption of heat by the large expanse of geology that surrounds a finite repository on all sides. Thus, predictions of test area thermal environment based upon a unit cell thermal model can be misleading unless measures such as the installation of guard heaters or sacrificial heated rooms are to be taken.

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ACKNOWLEDGMENT

R. R. Ondeck, formerly with Westinghouse, prepared the computer models and performed most of the calculations reported herein.