Thermal Analyses of a Generic Salt Repository with High-Level Waste—10429

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ABSTRACT

Thermal analyses of disposal strategies for in a generic salt repository with high-level nuclear waste (HLW) have been completed. These studies were undertaken primarily to examine details of temperature distribution as a function of time for disposal concepts of wastes resulting from the recycling of spent nuclear fuel from a light water reactor. These analyses confirm that a conceptual salt repository for HLW appears feasible and worthy of more detailed evaluation. The analyses examined the temporal temperature distribution near a HLW package, as well as the far-field thermal response due to its transient heat pulse. The sensitivity of temperature distribution to several variations of primary features (e.g. the waste emplacement rate, waste configuration, etc.) was also determined.

The principal observations of the study include the following. The temperatures involved ensure sufficient time for waste emplacement within a panel and adequate time to mine adjacent panels without adverse consequences. The modeled concept of a single level repository is workable. Thermal loading is the primary driver of repository-wide (far-field relative to the waste canister) heat effects. Decay storage, decreasing the loading of the waste package and changing the waste configuration are viable methods for reducing the peak waste and salt temperatures. The results of the thermal analyses show that with application of informed heat management strategies, thermal front migration rates are slow enough that a feasible design of the repository can be implemented. Peak temperatures within the waste package can be controlled with modest engineering considerations.

INTRODUCTION

Disposal in salt was the original 1957 recommendation by the National Academy of Sciences for permanent isolation of heat-generating radioactive waste from the biosphere, and the concept is still a valid subject of research. There are many advantages for placing radioactive wastes in a geologic bedded-salt environment. One desirable mechanical characteristic of salt is that it flows plastically with time (“creeps”). The rate of salt creep is a strong function of temperature and stress differences. Higher temperatures and deviatoric stresses increase the creep rate. As the salt creeps, induced fractures are expected to close and heal, encapsulating the waste. With a backfill of crushed salt emplaced around the waste, the salt creep can cause the crushed salt to reconsolidate and heal to a state similar to intact salt, serving as an effective seal.

Thermal analyses have been completed of a generic salt repository for disposal of wastes generated by a conventional used nuclear fuel recycling facility recovering uranium and plutonium for reuse [1]. The facility is assumed to produce a vitrified high-level waste (HLW) cylinder containing the high-decay-heat radionuclides: americium, curium, cesium and strontium. The study was based on a high burn-up, short cooled fuel, which did not utilize decay storage (as is the commercial recycling practice worldwide) to reduce the thermal load on the repository. This was a very aggressive, potentially bounding, study basis. The results of these thermal analyses are summarized in this paper. For a more detailed discussion of the thermal analyses see Clayton and Gable [1].

APPROACH

The thermal analyses evaluated an efficient disposal strategy in which a series of panels are constructed underground. Each panel consists of individual rooms each containing many alcoves (see Fig. 1a). The disposal strategy assumes placement of one canister at the end of each alcove to be covered by crushed salt backfill for radiation shielding of personnel accessing adjacent alcoves (see Fig. 1b). The backfill effectively insulates the canister, increasing waste package and near-field temperatures. Mining operations are assumed to be performed on a “just-in-time” basis, so that the space is made available as it is needed for waste emplacement.

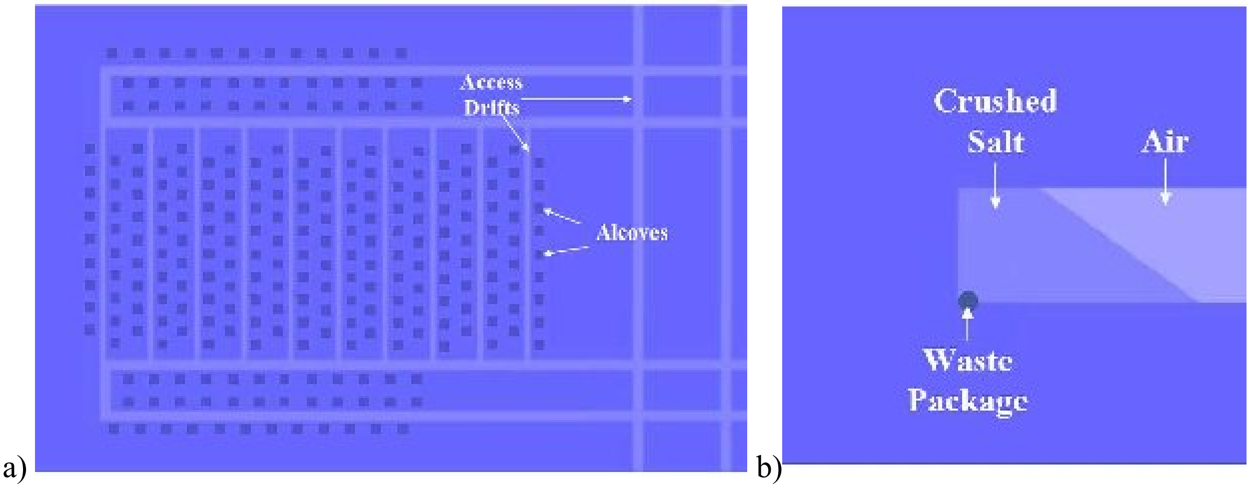

Fig. 1. a) Disposal panel layout and b) alcove configuration used in the generic salt repository study.

The HLW configuration used in these analyses consists of a cylinder 0.61 m (2 ft) in diameter, 2.7 m (9 ft) long. The HLW is assumed to have an initial heat load of 8.4 kW that decays with time (see Figure 3.1 in Clayton and Gable [1]). The thermal material properties assumed for the waste, intact salt and crushed salt are shown in Table I. The temperature dependent thermal conductivity of intact salt is based on the Munson et al. [2] relationship, as given in the following equation

$$\lambda_{salt}(T) = \lambda_{300}\left(\frac{300}{T}\right)^{\gamma} \qquad \text{(Eq. 1)}$$

where:

λ_{300} = material constant, 5.4 [W/m/K]

γ = material constant, 1.14

T = temperature [K].

Table I. Thermal properties of the materials used in the analyses.

Material	Thermal Conductivity (W/m/K)	Specific Heat (J/kg/K)	Density (kg/m^3)
Waste	1.0	840	2,220
Intact Salt	Eq. 1	931	2,190
Crushed Salt	Eq. 4	931	1,423

The thermal conductivity of the crushed salt is based on the results of the BAMBUS II study [3] where the thermal conductivity of crushed salt was determined from field experiments on drifts backfilled with crushed salt. From this study, a fourth-order polynomial was fit to the field data to describe crushed salt thermal conductivity as a function of porosity (ϕ):

$$k_{cs}(\phi) = -270\,\phi^4 + 370\,\phi^3 - 136\,\phi^2 + 1.5\,\phi + 5 \qquad \text{(Eq. 2)}$$

This representation is valid for porosities between zero and forty percent. When the porosity is zero, Equation 2 produces a thermal conductivity of 5.0 W/m/K. Therefore, Equation 2 is modified by a factor (*f*) to correspond with the salt, such that the thermal conductivity of 5.4 W/m/K is reproduced at zero porosity. Equation 2 is rewritten as:

$$k_{cs}(\phi) = \left(-270\,\phi^4 + 370\,\phi^3 - 136\,\phi^2 + 1.5\,\phi + 5\right) \cdot f \qquad \text{(Eq. 3)}$$

where *f* is simply (5.4/5.0 or 1.08). For this study, the initial porosity of the crushed salt is assumed to be 35 percent. The temperature-dependent nature of the crushed-salt thermal conductivity is assumed to be the same as for intact salt. Therefore, the crushed-salt thermal conductivity is given by:

$$\lambda_{c-salt}\left(T\right) = k_{cs}(\phi)\left(\frac{300}{T}\right)^{\gamma} \qquad \text{(Eq. 4)}$$

BASE CASE RESULTS

Investigations were conducted for what is referred to as the “Base Case”. The Base Case represents a 3-D assemblage in which all the alcoves and panel space are filled with the equivalent of intact salt. This configuration could represent a case when the drifts have closed completely, compressing the crushed salt backfill to its intact density. This provides an end member of the possible states of the underground. The other extreme case would include air and crushed salt backfill in the alcoves and panel space; this is looked at in the sensitivity cases. The maximum and average temperature of the waste package and surrounding salt, along with the lateral and vertical thermal front migration were determined as a function of time for the Base Case.

The temperature fields as a function of time for a slice through the Base Case at the alcove-scale are shown in Fig 2. The plane shown intersects the center of the waste package. The dark circles in Fig 2, located at the center of the figures, shows the position of the waste package, while the darker quadrilaterals indicate the backfill, which is modeled as intact salt. The lighter shaded areas show the access drift position.

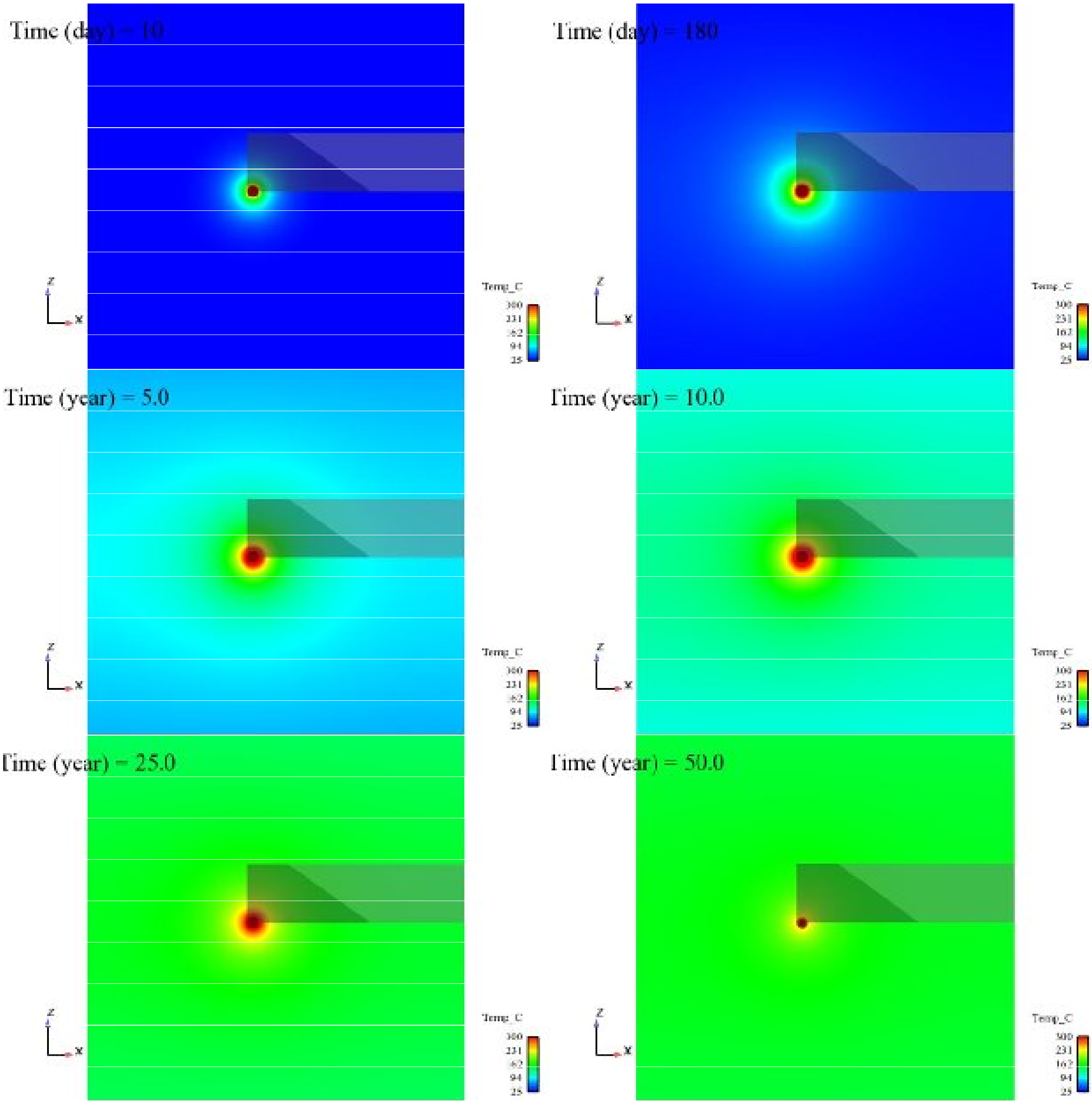

Fig. 2. Base Case temperature (ºC) fields at the alcove-scale at six simulation times for a vertical plane through the center of the waste package, along the center of the alcove.

As seen in Fig 2, the highest temperatures are within the waste package, with the temperature decreasing with increased distance from the waste. The temperature fields show the waste package heating up very quickly, while the surrounding salt heats up more slowly with time. Results at 25 and 50 years exhibit a decrease in the temperature near the waste package, while the surrounding temperature is not significantly changed. One of the important design considerations is the overall average temperature experienced by the salt formation. Given the assumptions of this study, the bulk temperature of the country rock is 150 ºC to 160 ºC, which remains after the HLW package decay heat decreases.

To further analyze the temperature field, the maximum and average temperature of the waste package and surrounding salt were calculated for comparison with other cases. Furthermore, the average temperature (calculated using 4 m of salt above and below the waste package) is useful in order to illustrate the general behavior compared with the maximum temperature which indicates the behavior at a single point. The maximum and average temperatures of the waste package and surrounding salt as a function of time are shown in Fig 3.

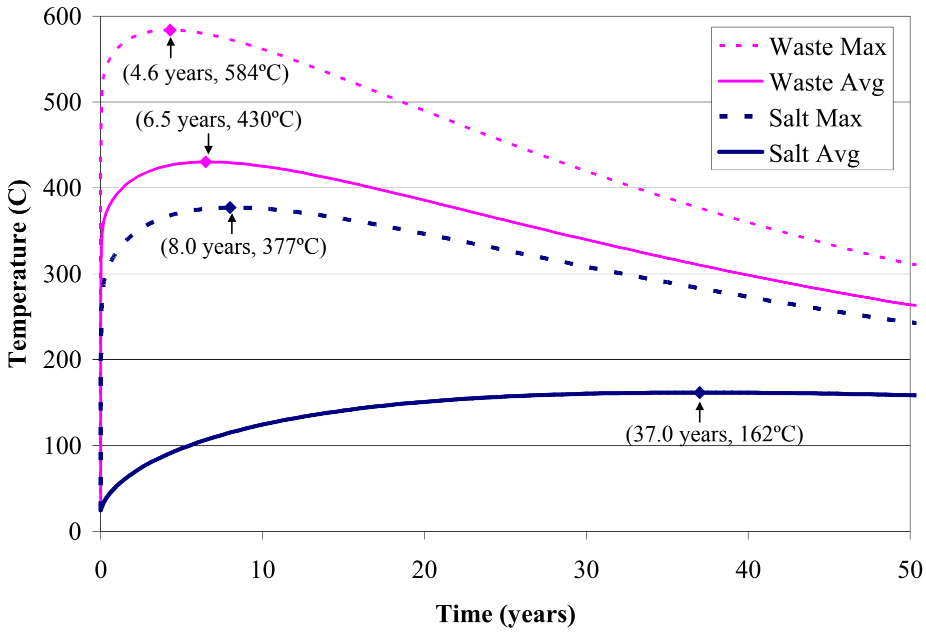

Fig. 3. Base Case maximum (Max) and average (Avg) waste and salt temperatures at the alcove-scale versus time.

Fig 3 shows both the maximum and average waste package temperatures rapidly increasing, reaching an overall maximum of 584ºC at 4.6 years. The average waste temperature peaks at 430ºC after 6.5 years and then steadily decreases as a result of the heat load decay. The maximum salt temperature (at the point of contact between the HLW canister and the salt) also rapidly increases and reaches an overall maximum of 377ºC at 8.0 years. The average salt temperature increases to 162ºC by 37 years and then begins to slowly decrease.

The Base Case overall maximum waste temperature (584ºC) is obtained before any neighboring alcoves could influence the temperature. Therefore, calculations that increase the spacing between alcoves would not moderate the peak temperature for this analysis; however, a greater dispersal of the heat load within the alcove could reduce the peak temperature. This calculation illustrates that implementing certain analysis assumptions (such as an 8.4 kW canister surrounded by salt) could challenge the temperature limit guidelines for glass stability. However, the severe calculation assumptions can be readily mitigated as discussed subsequently in the next section.

The maximum salt temperature (at the contact surface) for these calculations is 377ºC; however, these significantly higher temperatures affect only the immediate country rock. This particular measure of maximum salt temperature is coupled to the waste package temperature. A greater distribution of the heat load would greatly reduce this single point value. It may very well be possible that elevated temperatures would enhance plasticity proximal to the package and promote encapsulation. The Base Case calculations are illustrative only for a generic thermal response.

The increase in the average salt temperature is much slower and so is not a function of the heat load distribution, but rather the alcove spacing. Changing the heat load distribution should not affect the average salt temperature. Generally speaking, the average bulk temperature of the salt formation is a function of the average amount of heat put into the system. As long as the generic salt repository input assumption is 39 W/m^2, the average background bulk temperature of the salt will approach 150 ºC to 160 ºC. At these levels of temperature, salt creep would be greatly enhanced and room closure would occur rapidly as a consequence.

The Base Case results at the alcove-scale were used to investigate the lateral alcove-to-alcove thermal front migration. For purposes of discussion, a temperature isotherm of 38ºC (100ºF) was selected for profiling the computational results. This temperature was selected simply to aid the reader; it represents a relatively hot working environment especially considering the required personal protective equipment. It is not an unsafe condition.

For the Base Case, alcove-scale calculation, the 38ºC (100ºF) thermal front travels to 6.1 m (20 ft) (half the distance between alcoves) in ~75 days, including the effect of the neighboring waste package, while it would be ~150 days without. The travel times for the 38ºC (100ºF) thermal front with and without including the effect of the neighboring waste package are a lower and upper bound, respectively. The isotherm travel time for a specific waste package would depend on the number of neighboring alcoves that have been filled, their emplacement time, and location relative to the waste package. For the disposal concepts considered in these studies, these lag times provide a significant window for placing the waste and advancing beyond the reach of the thermal front. This result is quite important in terms of evaluating feasibility, as it would appear that even under the severe assumptions of these thermal analyses, ample time exists for safe disposal.

For the panel-scale Base Case calculation, the 8.4 kW waste packages were assumed to be emplaced in the alcoves, one per day, with a waste emplacement sequence that first, filled the middle section from the back towards the access drifts, and then filled the outer edges from the inside toward the outside. The Base Case results at the panel-scale were used to investigate the lateral panel-to-panel thermal front migration and the vertical thermal front migration. The lateral panel-to-panel migration is of interest, primarily for the operational safety and possible standup time. The vertical migration would be important if a multi-level repository concept is considered, with similar concerns of structural stability and operational safety. The progression of the thermal front was tracked by examining the 38ºC (100ºF) isotherm. Fig 4 shows the horizontal evolution of the 38ºC (100ºF) isotherm (colored purple) with the accompanying temperature field for the Base Case at the panel-scale.

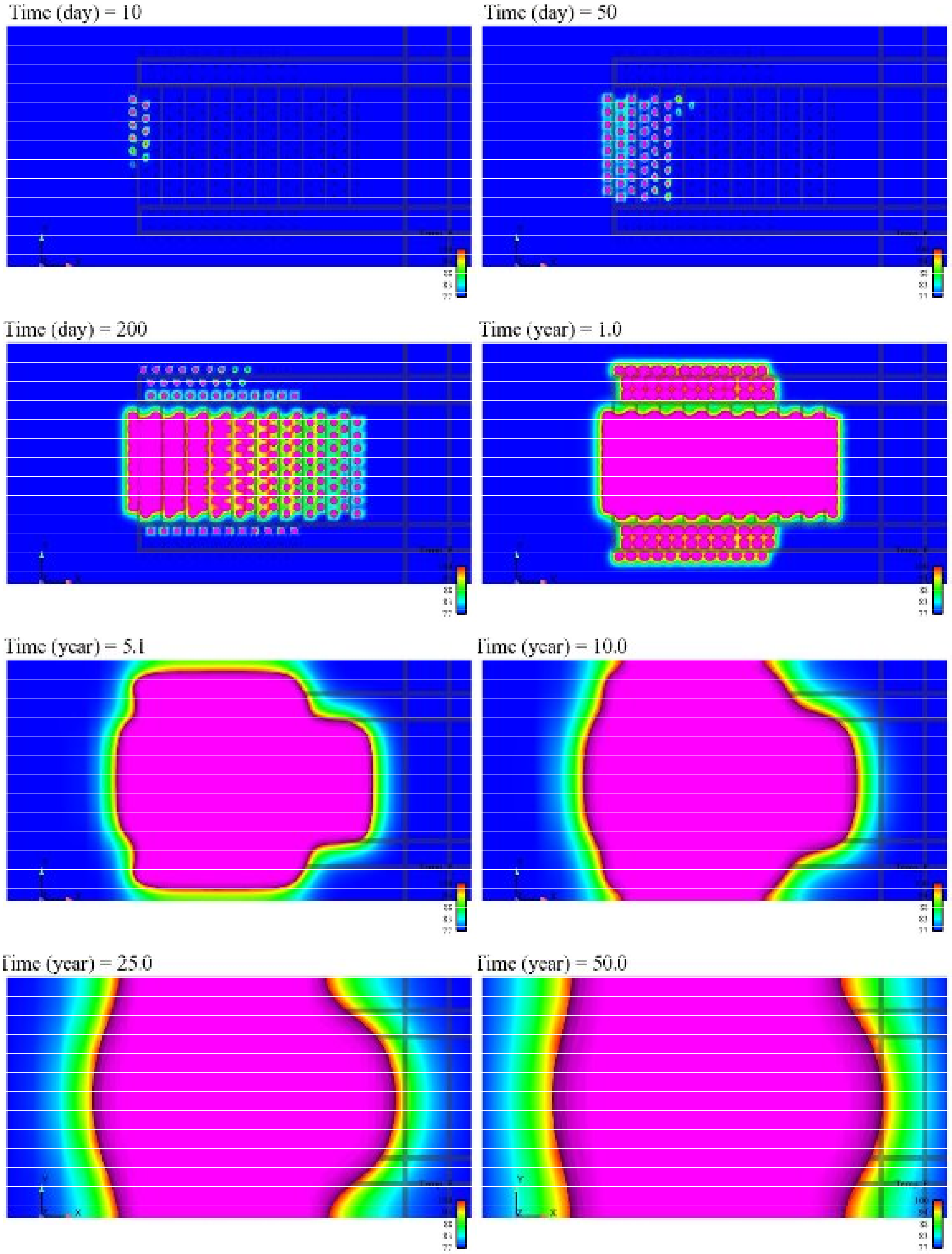

Fig. 4. Base Case 38ºC (100ºF) isotherm (purple) and temperature (ºF) fields at the panel-scale at eight simulation times for a horizontal plane through the center of the alcoves.

Examining the 10, 50 and 200 days simulation results in Fig 4 indicates that spherical shapes are produced at the alcove locations with waste emplaced. After approximately a year, the isotherms from the individual alcoves merge together and form one large isotherm, similar to the shape of the panel, which then continues to expand. Between 5 and 10 years, the influence of the neighboring panels becomes apparent, as evidenced by a significant increase in the thermal front migration which has merged with the thermal front from the neighboring panel.

The 38ºC (100ºF) thermal front travels 30.5 m (100 ft) (half the distance between panels) in ~7 years, including the effect of the neighboring panel, while it would be ~12 years without. The 38ºC (100ºF) thermal front slows down, traveling laterally to a total of ~61 m (200 ft) in 50 years. The 38ºC (100ºF) thermal front travels quicker vertically, reaching 30.5 m (100 ft) in ~5 years and realizing a total of ~117 m (385 ft) in 50 years. These calculated time frames show that a panel emplacement sequence could be designed such that the mining and emplacement of neighboring panels (laterally or vertically) occurs before the propagation of the 38ºC (100ºF) thermal front.

SENSITIVITY STUDIES

Sensitivity studies were conducted to evaluate the effects of various repository design factors on the near-field temperature distribution and the larger-scale thermal response in the repository. The sensitivity studies were performed to assess the effect of the following factors:

- Salt Creep and Reconsolidation
- Heat Load
- Emplacement Rate and Sequence
- Emplacement of Other Waste
- Waste Configuration
- Multiple Factors

A brief summary of the results of the sensitivity cases are presented in this paper. For a complete description and detailed results for the sensitivity cases, see Section 4.2 in Clayton and Gable [1].

Salt Creep and Reconsolidation

To investigate the influence of the crushed salt backfill, the extreme case where the air and crushed salt backfill in the alcove persist for the entire simulation was modeled. This is another end member of the possible states of the underground. By examining this case and comparing with the Base Case, the effect of the crushed salt backfill can be bracketed. In this hypothetical sensitivity case, the overall maximum temperature of the waste package is 929ºC at 2.7 years, while the peak average waste temperature is 659ºC at 3.9 years. The overall maximum salt temperature for this calculation is 899ºC at 2.7 years, with the peak average salt temperature of 162ºC at 37 years. The maximum salt temperature arises at the crushed salt-waste interface.

The peak temperatures for the crushed salt sensitivity case are higher and occur earlier than in the Base Case. The peak waste temperatures are reached before any neighboring alcoves influence the temperature. Therefore, increasing the spacing between alcoves would not lower the maximum waste temperature; however, a greater dispersal of the heat load within the alcove would readily moderate the maximum temperatures. The thermal front migration is minimally effected by the crushed salt backfill. The effect is on the order of several days and so is not significant when compared with the times needed to reach the larger distances.

The significant increase in maximum temperatures compared with the Base Case is due to the low thermal conductivity of the crushed salt. The maximum temperatures realized for this sensitivity calculation emphasizes the design consideration of heat dispersal to reduce the peak temperature. The average salt temperatures for the two cases are the same because the crushed salt has redistributed the heat, but hasn't changed the overall heat load. The insulating effect of the crushed salt backfill is a local phenomenon, the influence of which decreases with distance and time. For the thermal front migration, the key driver is the average salt temperature. Since the crushed salt backfill does not affect the average salt temperature, the thermal front migration is not influenced by salt creep and reconsolidation.

Heat Load

The effect of reducing the waste package heat load on the temperature and thermal front migration was determined by reducing the 8.4 kW per waste package to 7.0 kW, 4.2 kW and 2.4 kW and analyzing the results. This heat load reduction could result from a lower radionuclide loading in each package or from aging the waste to allow some of the heat to be lost due to radioactive decay. The 7.0 kW, 4.2 kW and 2.4 kW initial heat loads correspond to decayed heat storage times of 7 years, 27 years and 50 years, respectively. Maintaining the alcove-scale Base Case geometry while reducing the waste package heat load also reduces the areal thermal loading from the Base Case 39 W/m^2.

In order to disperse the local heat load and avoid hot spots, while maintaining the 39 W/m^2 areal thermal loading, a reduced spacing could be used. To investigate the option of reducing the local heat load while maintaining the areal thermal loading, three additional heat load sensitivity cases were completed which used a reduced spacing at the alcove-scale equal to the reduction in the heat load.

A comparison of the temperatures of the Base Case and heat load sensitivity cases is given in Table II and Table III. Table II and Table III indicate that decreasing the local heat load, either by aging or by reducing the radionuclide loading, decreases the peak temperatures. The heat load sensitivity cases with the Base Case areal thermal loading demonstrate the decreases in the peak waste temperatures that are possible with a greater dispersion of the heat load concentration within the alcove, while maintaining the 39 W/m^2 areal thermal loading, which maintains the average salt temperature.

These sensitivity cases demonstrate that temperature can be easily engineered and controlled. As the waste temperatures decrease, the maximum salt temperatures decrease. The sensitivity cases that maintain the Base Case areal thermal loading demonstrate the decreases in the peak temperatures that are possible with a greater dispersion of the local heat load concentration within the alcove. The average salt temperatures decrease with decreasing heat load and areal thermal loading, while the average salt temperatures are the same when the 39 W/m^2 areal thermal loading is preserved.

Table II. Comparison of waste temperatures for the Base Case and the six heat load sensitivity cases at the alcove-scale.

Package Heat Load (kW)	Areal Thermal Loading (W/m^2)	Waste Maximum		Waste Average	
		Temperature (C)	Time (years)	Temperature (C)	Time (years)
8.4	39	584	4.6	430	6.5
7.0	32.5	470	4.1	344	6.5
4.2	19.5	270	3.6	198	6.0
2.4	11.1	159	3.1	118	6.0
7.0	39	488	5.5	367	8.5
4.2	39	324	9.5	262	14.0
2.4	39	241	16.5	211	21.0

Table III. Comparison of salt temperatures for the Base Case and the six heat load sensitivity cases at the alcove-scale.

Package Heat Load (kW)	Areal Thermal Loading (W/m^2)	Salt Maximum		Salt Average	
		Temperature (C)	Time (years)	Temperature (C)	Time (years)
8.4	39	377	8.0	162	37.0
7.0	32.5	296	8.5	137	37.0
4.2	19.5	165	9.0	89	36.5
2.4	11.1	98	9.0	61	36.5
7.0	39	322	10.5	162	37.0
4.2	39	238	17.0	162	37.0
2.4	39	199	24.0	162	37.0

Lowering the heat load decreases the migration rate of the 38ºC (100ºF) thermal front. On the other hand, the thermal front migration rate increases when the alcove spacing decreases, as the effect of neighboring alcoves becomes more important. The change in the times needed for the 38ºC (100ºF) thermal front to reach the neighboring alcove are still sufficient to allow for the waste emplacement sequence within a panel to be designed.

Waste Emplacement and Sequence

The sensitivity cases also investigated the effect of the waste emplacement rate and the emplacement sequence within the panel. For the sensitivity cases, the waste emplacement rate was doubled and halved, while an alternative waste emplacement sequence was explored. Only minor differences between the waste emplacement and sequence sensitivity cases and the Base

Case were observed. Based on the results of the sensitivity cases, the waste emplacement rate and emplacement sequence within the panel would not have a significant impact on the overall temperature field, especially at longer times. The thermal front migration was not significantly affected by changing the emplacement rate or sequence.

Emplacement of Other Wastes

The purpose of this sensitivity study is to analyze the effect of the emplacement of other wastes, such as greater-than-class-C waste and low-level waste, in the access drifts on the temperature and thermal front migration. The sensitivity was determined using two bounding cases. For one case, the thermal properties of an insulating material (loose fill composed of blown glass fibers) were used in the analysis to represent the other waste. This is one bounding approximation for the thermal properties of other wastes. For the other case, the thermal properties of a conductive material (copper) were used in the analysis. This is another bounding approximation for the thermal properties of other wastes. These bounding cases were used to determine the effect of other waste emplacement in the access drifts on the temperature and thermal front migration.

A minor change in the peak temperatures of 6ºC or less is observed when including the effect of the emplacement of other wastes compared with the Base Case. The emplacement of other waste in the access drifts would not have a significant impact on the overall temperature field. The thermal front migration was not significantly affected by the emplacement of other waste in the access drifts. The minimal effect on the temperature translates to a minimal effect on the thermal front migration.

Waste Configuration

Several sensitivity cases were conducted to explore different waste configuration concepts that could reduce the peak waste and salt temperatures, while maintaining a constant areal thermal loading of 39 W/m^2. The concepts include reducing the waste cylinder volume in half and placing the two halves separately in the alcove or placing a copper plate on the alcove floor to enhance heat transfer. Each of the waste configuration sensitivity cases decreased the peak waste and salt temperatures from the corresponding value computed for the Base Case, but not as strongly as was observed for the heat load sensitivity cases. The average salt temperatures are all the same as the Base Case, because the principal factor controlling this temperature, the areal heat load, is the same. The minor effect on the temperature translates to a minor effect on the thermal front migration for the waste configuration sensitivity cases.

Multiple Factors

Due to the significant increase in the peak waste and salt temperature in the sensitivity case with no salt creep or reconsolidation, additional sensitivity cases were conducted to examine different emplacement strategies for the no-salt-reconsolidation end member. These additional sensitivity cases resulted from the combination of the sensitivity case with no salt creep or reconsolidation and other sensitivity cases with low peak waste and salt temperatures. These analyses were conducted to determine the possible reduction of the peak waste and salt temperatures under the assumption of no salt creep or reconsolidation.

The multiple-factor sensitivity cases are a combination of no crushed salt reconsolidation sensitivity case and the reduced heat load sensitivity cases; 4.2 kW, 39 W/m^2; 2.4 kW, 39 W/m^2 and 2.4 kW, 11.1 W/m^2, which incorporate various assumptions of lower heat loads per waste package and/or lower areal thermal loading. Table IV and Table V compare the peak and average temperatures of these multiple-factor sensitivity cases to the peak and average temperatures in the Base Case and the no crushed salt reconsolidation sensitivity case.

Table IV. Comparison of peak waste temperatures in the Base Case, no reconsolidation and multiple-factor sensitivity cases.

Case	Waste Maximum		Waste Average	
	Temperature (C)	Time (years)	Temperature (C)	Time (years)
Base Case	584	4.6	430	6.5
No Reconsolidation	929	2.7	659	3.9
No Reconsolidation + 4.2 kW, 39 W/m^2	442	6.5	341	9.5
No Reconsolidation + 2.4 kW, 39 W/m^2	299	11.5	251	15.5
No Reconsolidation + 2.4 kW, 11.1 W/m^2	214	1.8	156	3.1

Table V. Comparison of peak salt temperatures in the Base Case, no reconsolidation and multiple-factor sensitivity cases.

Case	Salt Maximum		Salt Average	
	Temperature (C)	Time (years)	Temperature (C)	Time (years)
Base Case	377	8.0	162	37.0
No Reconsolidation	899	2.7	162	37.0
No Reconsolidation + 4.2 kW, 39 W/m^2	422	7.0	162	37.0
No Reconsolidation + 2.4 kW, 39 W/m^2	286	12.5	162	37.0
No Reconsolidation + 2.4 kW, 11.1 W/m^2	194	2.3	61	36.5

A significant decrease in the peak waste temperature is observed for all the multiple factor sensitivity cases compared with the no crushed salt reconsolidation sensitivity case. The peak waste temperatures are below 500ºC. The peak salt temperature also decreased significantly for all the multiple factor sensitivity cases. The average salt temperature is the same for the multiple factor sensitivity cases with the same areal thermal loading. It is important to point out that higher local salt temperatures may not be detrimental at all. In fact, elevated temperatures proximal to the waste package are expected to accelerate creep deformation and enhance encapsulation.

SUMMARY AND CONCLUSIONS

The principal observations of the study include:

1. The temperatures involved with this scoping study of a generic alcove and panel layout are reasonable. The time required for the 38ºC (100ºF) thermal front to migrate to the midpoint between alcoves (6.1 m [20 ft]), ranges between 75 and 150 days, while it requires between 7 to 12 years to migrate to the midpoint between panels (30.5 m [100 ft]). These results ensure sufficient time for waste emplacement within a panel and adequate time to mine adjacent panels without adverse consequences. Although, the waste emplacement sequence within a panel and the panel construction sequence within the repository would need to be carefully selected over the life of the repository.

2. Thermal loading is the primary driver of repository-wide (far-field relative to the waste canister) heat effects. Minimal effects on the thermal front migration were observed when maintaining the areal thermal loading of 39 W/m^2. Reduction of the thermal loading reduced the thermal front migration.

3. Decay storage, decreasing the heat load of the waste package and changing the waste configuration are viable methods for reducing the peak waste and salt temperatures. Decay storage of the HLW prior to emplacement can result in acceptable near-field and far-field temperatures even when no reconsolidation of the backfill material is considered in the analyses. The sensitivity calculations investigated decay storage times of 7, 27 and 50 years (7.2 kW, 4.2 kW and 2.4 kW in each canister, respectively) and calculated a peak waste temperature of 442ºC after only 27 years of decay storage. Bulk temperatures of the salt are a function of the W/m^2 design basis. The greater the total heat, the greater the average salt temperature. However, with basic engineering considerations, the thermal distribution and resultant thermomechanical deformation can be controlled by design.

4. The modeling results confirm that inclusion of other non-HLW packages (low level or greater-than-class C) has minimal effects on peak waste and salt temperatures as well as the thermal front migration, and therefore can be emplaced in a generic salt repository with minimal change in the repository's thermal performance. Because the layout area is governed by the heat distribution, there is ample free volume for disposal of other waste materials.

The results of the 3-D thermal analyses show that with application of informed heat management strategies, thermal front migration rates are slow enough that a feasible design of the repository can be implemented. Peak temperatures within the waste package can be controlled with modest engineering considerations. The vast majority of the salt temperatures can be easily maintained below 200ºC. The high temperatures modeled in the salt may have certain advantages in terms of accelerating creep deformation around the waste and more rapid entombment.

ACKNOWLEDGEMENTS

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