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Civilian Radioactive Waste Management System
Management and Operating Contractor

SITE CHARACTERIZATION PLAN THERMAL GOALS

REEVALUATION

B00000000-01717-5705-00005, Rev. 00

September 8, 1993

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APPROVED BY:

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1028

Civilian Radioactive Waste Management System
Management and Operating Contractor

SITE CHARACTERIZATION PLAN THERMAL GOALS REEVALUATION

B00000000-01717-5705-00005, Rev. 00

September 8, 1993

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Executive Overview

To obtain a license to emplace nuclear waste, a potential repository must comply with certain performance standards for both postclosure and preclosure, and meet the performance objectives established in the regulations. However, early in the design stages it is difficult, if not impossible, to assess the complete performance of the system due to lack of mature ("validated") predictive models and adequate data. Additionally, because performance standards are not established for the Yucca Mountain Site, (the EPA standards have been remanded) it is necessary to define surrogate or derived criteria. It is believed that meeting those criteria should result in adequate performance of the potential repository and the natural and engineered barrier systems, and that the criteria could be used to evaluate and rank thermal loading options.

The Site Characterization Plan (SCP) (DOE, 1988) attempted to define surrogate criteria that could be used to establish potential repository performance. These criteria or SCP thermal goals were developed from knowledge existing at the time and, as a reference case, emphasized performance for waste emplacement in a vertical borehole. Since that time, new knowledge has become available and some additional analyses of thermal loading have been performed. Additionally, other emplacement modes such as in-drift emplacement are being considered to accommodate larger waste packages. New concepts such as "extended hot" are also being considered as possible methods to achieve improved waste isolation. Thus it became clear that the thermal goals established in the SCP should be reevaluated. This is consistent with a phased design approach that incorporates maturing design concepts.

The DOE Yucca Mountain Site Characterization Project Office (YMPO) therefore authorized a two month effort to be undertaken to reevaluate the SCP thermal goals. The objectives of the effort were to: (1) provide thermal criteria that would support the Fiscal Year (FY) 1993 Thermal Loading Systems Study; (2) help focus planned testing and analysis efforts; and (3) acquire information that potentially could be used to initiate a change to the project technical baseline. To achieve the objectives, an expert Working Group was established and tasked to address the following questions:

1. What was the technical rationale for establishing the goal?

2. Is the rationale still applicable and valid for more than just vertical borehole emplacement? If the goal is not completely adequate should it be deleted or changed?

3. Are there any other goals that are needed or would be appropriate to add?

4. If uncertainties exist in the waste isolation performance of the potential repository under a specific goal, what tests and/or analyses should be recommended to reduce or eliminate the uncertainty?

Fifteen thermal goals identified in various sections of the SCP were evaluated by the Working Group. It is our recommendation that two goals be deleted: (1) to keep borehole wall temperature <275 degrees C and (2) keep the mid-drift temperature <100 degrees C. We recommend adding one goal to establish a thermal loading that would not degrade the Upper Paintbrush Tuff Formation (Lowermost Tiva Canyon; Yucca Mountain; Pah Canyon; and Uppermost Topopah Spring Members) (Vitric nonwelded) (PTn) barrier. Two other thermal goals and a process statement were reworded to afford compatibility with any emplacement mode, not just the vertical borehole. A recommendation was made to increase the conservatism of a goal to limit potential impact on the surface environment by limiting temperature rise to < 2 degrees C rather than <6 degrees C. Additionally, and probably more important, is the fact that based on the evaluation, additional tests and analyses were recommended to reduce the uncertainty associated with some of these goals.

It is recommended that this revised set of goals be used in the ongoing Thermal Loading Study as the criteria against which the performance should be "graded." It is also recommended that certain work be done to enable a better evaluation which would establish a more definitive basis for the thermal goals. Finally, once the recommended analysis is done and the data taken the thermal goals should again be evaluated.

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THERMAL GOALS REEVALUATION

Background

To obtain a license to emplace nuclear waste, a potential repository must comply with certain performance standards for both postclosure and preclosure, and meet the performance goals established in the regulations. To demonstrate compliance with regulations it must be shown with "a reasonable assurance . . . that the objectives and criteria will be met" based on "accelerated tests and predictive models that are supported by such measures as field and laboratory tests, monitoring data and natural analog studies." (10 CFR 60.101(a)(2)-NRC,1988) Performance measures are the parameters used to determine whether the potential repository system meets regulatory criteria and objectives. Thus, these performance measures should be used in the selection of system options. However, early in the design stages it is difficult, if not impossible, to predict the complete performance of the system due to lack of mature ("validated") predictive models and adequate test data. Additionally, performance standards are not established for the Yucca Mountain site since the EPA standards in 40 CFR 191 have been remanded, are being reviewed, and must be repromulgated. Therefore it is necessary, for the present, to define surrogate or derived criteria which if met, it is believed, should result in adequate performance of the potential repository and the natural and engineered barrier systems, and which could be used to evaluate and rank thermal loading options.

The SCP (DOE, 1988) attempted to define surrogate criteria that could be used to establish performance of the potential repository. The SCP started from the regulations and defined four steps which were: (1) functions; (2) processes; (3) performance measures; and (4) performance goals and confidence. The functions step comprised four functions, derived from 10 CFR 60.133, which it was believed would provide compliance with the regulations. The fourth function focuses on postclosure performance and was the primary basis for developing a set of thermal goals for the potential repository. This function is stated as:

> "Design thermal loading taking into account performance objectives and thermomechanical response of host rock." (10 CFR 60.133 (i), 10 CFR 60.133 (e) (2), and 10 CFR 60.133 (h)) (DOE, 1988)

Based on this function, process steps were identified describing how the function will be accomplished. Performance measures were developed which identify a parameter or measurement (temperature, for example) that will be used to determine how well the process is being performed. Finally, based on the performance measures, a goal was developed which provides a performance measure value allowing the process to be favorably resolved.

The SCP thermal goals established in 1988 were developed from knowledge existing at the time and, as a reference case, emphasized performance for waste emplacement in a vertical borehole. Since that time, new knowledge (data and theories) has become available and additional analyses of thermal loading have been performed. Additionally, other emplacement modes such as in-drift emplacement are being considered to accommodate larger waste packages. New concepts such as "extended hot" are also being considered as possible methods to achieve improved waste isolation. The thermal goals established in the SCP were reevaluated to address these matters.

The DOE Yucca Mountain Site Characterization Project Office (YMPO), therefore authorized a two-month effort to be undertaken to reevaluate the SCP thermal goals. This effort, conducted between March 24, 1993 and May 31, 1993, established a Working Group of experts that would utilize existing information and perform limited analyses as necessary to reevaluate the thermal goals. The objectives of the effort were to: (1) provide thermal criteria that would support the FY 1993 Thermal Loading Systems Study; (2) help focus planned testing and analysis efforts; and (3) acquire information that potentially could be used to initiate a change to the project technical baseline.

SCP Thermal Goals

To meet the regulations, the effects of thermal loading on the engineered and natural barriers and their ability to contain nuclear waste must be considered. To do this, a set of performance measures and corresponding performance goals were selected and identified in the 1988 SCP. A group of experts used existing information and professional judgment to establish the associated performance goals during meetings held in 1986 in Albuquerque, New Mexico (DOE, 1988). The SCP goals cover a variety of issues from the waste package performance and temperatures of natural barriers to environmental constraints. These performance goals are relied upon to provide additional or backup assurance that the potential repository and its engineered components meet the preclosure and postclosure performance objectives. These goals, however, emphasize just one emplacement mode, a vertical borehole; and the goals apply principally to the postclosure performance at a thermal loading of 57 kW/acre.

The thermal goals evaluated by this Working Group were taken from the SCP (DOE, 1988) and are shown in Table 1 along with the associated processes these goals affect and the performance measures used to determine whether the objective is met. Most of the goals identified in Table 1 were taken from Table 8.3.2.2-4 of the SCP. However, five goals were extracted from other parts of the SCP, including the waste package postclosure characteristics (Issue 1.10).

Table 1
SCP Thermal Goals

	Process	Performance Measure	Thermal Goal
1	Limit temperature changes in selected barriers	Temperature	4-O[a] Limit temperature of CHn to <115° C
2			4-P Limit temperature of TSw3 to <115° C
3	Limit deleterious rock movement or preferred pathways	Rock displacement	4-Q Relative motion < 1 m at the top of TSw1 - no intact rock failure - no continuous joint slip
4	Limit impact on surface environment	Temperature	4-R Rise in surface temperature <6° C
5		Surface uplift	4-S Surface uplift <0.5 cm/year
6	Vary borehole and drift spacing to control thermal loading and container temperature	Thermal loading	4-T Design basis thermal loading less than allowable thermal loading
7		Borehole wall temperature	4-U Temperature <275° C
8		Rock mass temperature	4-V Temperature at 1m from borehole <200° C
9	Limit potential for borehole collapse	Stress, deformation, factor of safety and potential rock fall	4-W Boreholes that do not load container beyond limits imposed under Issue 1.10
10	Limit corrosiveness of container environment	Time container is above boiling temperature of water	4-X Majority of borehole walls above boiling temperature of water for >300 years

[a]4-O indicates function 4 (thermal loading) and goal O. Table 8.3.2.2-4 went only to 4-X; the remainder of the goals from other areas of the SCP such as 1.10 were assigned a designator (e.g., 4-Z) consistent with the numbering system.

Table 1
SCP Thermal Goals (Continued)

	Process	Performance Measure	Thermal Goal
11 12	Limit degradation of fuel matrix or cladding	Temperature	4-Y Fuel cladding temperature <350° C 4-Z High level waste glass temperature <500° C
13	Limit access drift temperature (Vertical Borehole)	Temperature	4-AA Wall temperature in access drift <50° C for first 50 years
14	Provide for hydrologic drainage	Temperature	4-AB Rock temperatures midway between emplacement drifts <100° C
15	Limit emplacement drift temperature (Horizontal Emplacement)	Temperature	4-AC Wall temperatures in emplacement drift <50° C for first 50 years

The Working Group was asked to answer the following questions in its evaluation of the thermal goals:

1. What was the technical rationale for establishing the goal?

2. Is the rationale still applicable and is it valid for more than just vertical borehole emplacement? If the goal is not still completely adequate should it be deleted or changed?

3. Are there any other goals that are needed or would be appropriate to add?

4. If uncertainties exist as to the waste isolation performance of the potential repository under a specific goal, what tests and/or analyses should be recommended to reduce or eliminate the uncertainty?

To answer these questions, the Working Group was organized into five teams that would examine processes important to waste isolation. The teams were oriented along the disciplines of thermal-hydrological (TH), thermal-geochemical (TG), thermal-mechanical (TM), engineered barrier system (EBS), and operations and safety (OS). Additionally, Licensing and Regulatory and Performance Assessment personnel were involved. The teams and team members are listed in Table 2. Periodic meetings were held where each team's progress was reported so that the team leaders could evaluate and comment on the work to ensure that a goal was not being changed in a way that would adversely impact other disciplines.

Table 2
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Team	Team Member
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Assessment of Goals

The working group performed an assessment of the SCP thermal goals to determine, as discussed above, the rationale for each goal, whether or not the goal was still valid, if there were other goals that should be added, and what uncertainties needed to be resolved. Each team evaluated one or more goals which fell in its area of concern (e.g. thermal, hydrological, engineered barrier system, etc.) and its assessment was reviewed and commented on in open panel discussions by the other teams. The results of this assessment are provided in this section.

SCP Thermal Goal 1: Limit temperatures in the Calico Hills nonwelded (CHn) unit to less than 115 degrees C (4-O).

Rationale: The principal SCP rationale for setting upper limits on temperature in these units is the concern that mineralogic changes could occur due to dehydration induced by potential repository heating and that these may cause "chemical and physical effects that could be detrimental to waste isolation."

Discussion: Both the Calico Hills (CHn) and Lower Topopah Spring (TSw3) members are considered essential for waste isolation. These items have been identified as important to waste isolation and are on the Q-List based on findings of the AP-6.17Q Assessment Team at a January 19-21, 1993 workshop and follow-up evaluations by the Assessment Team. The CHn unit consists of variably zeolitized bedded, nonwelded, and partially welded tuffs extending vertically downward to the water table from the basal vitrophyre in the overlying TSw unit. As defined, the CHn natural barrier includes the Crater Flat tuff where it is present above the water table. The CHn natural barrier is regarded principally as a geochemical barrier; however, the marked contrast between the hydrologic properties of the basal vitrophyre in the TSw unit anent groundwater travel times in the unsaturated zone. This implies that hydrologic properties and the adjacent CHn unit could contribute significantly to the generation of long pre-waste emplacement may transform to analcime at elevated temperatures. The significance of thermal effects on these properties could be as important as the geochemical aspects.

Establishment of this goal was prompted by the belief that zeolitic Calico Hills tuffs, particularly those rich in clinoptilolite, may transform to analcime at elevated temperatures. The significance of this goal increased after Smyth (1982) examined mineral stability constraints on radioactive waste isolation in zeolite-bearing volcanic rocks. Smyth concluded that increased temperatures will cause breakdown of the zeolites in the tuffs, with consequent release of water and reduction in volume. He recommended keeping the clinoptilolite-rich tuffs saturated with water and below about 85 degrees C. The choice of this temperature was based on an assumption that the recrystalization of clinoptilolite to analcime is a function of temperature and sodium ion content of the pore water: the higher the sodium content of the water, the lower the temperature of recrystalization. Smyth calculated that the reaction should begin at about 105 degrees C for rock in contact with water of J-13 composition, but evaporation of water due to potential repository heating could result in higher sodium concentrations. For an assumed 1000-ppm upper limit on sodium content, the reaction could begin at about 95 degrees C. Allowance for a 10 percent margin of error produced the 85 degrees C temperature limit.

The rationale for the choice of the higher 115 degrees C limit for the CHn is contained in SCP section 8.3.5.12.5. This section states that the performance goal was set to limit mineral alteration and dehydration but does not identify any technical basis for the temperature selection. The temperature probably was derived from preliminary performance calculations and represents about the lowest temperature at which the potential repository could meet minimum waste storage requirements and also satisfy ground-water travel time requirements. This temperature is supposed to limit the magnitudes of expected changes in CHn hydrologic properties to no greater than those used as a performance goal for the Topopah Spring welded unit: less than an order of magnitude increase in permeability and less than a factor of two decrease in effective porosity.

Bowers and Burns (1990) developed activity diagrams for clinoptilolite to investigate the susceptibility of this zeolite to further diagenetic reactions. They also felt that prolonged interactions of clinoptilolite with groundwater depleted in Al but enriched in Na or Ca and heated by the thermal effects of a potential repository may eliminate calcic clinoptilolite in the rocks underlying the potential host rock. Although increased temperatures will cause primarily reversible (or partially reversible) dehydration and collapse, large-scale mineralogic transformations to another zeolite such as analcime almost certainly require saturated conditions (Bowers and Burns, 1990). However, preliminary data presented by Flint (1993) suggest that the reversible changes in zeolite volume cause irreversible changes in bulk-rock permeability, possibly due to dehydration-induced volume reductions and associated microcracking.

Mineralogic data from Yucca Mountain suggest that clinoptilolite and mordenite transition to higher-temperature phases at about 100 and 130 degrees C respectively (Bish and Aronson, 1993), although these reaction temperatures were obtained for a saturated system with a long reaction period ($>10^5$ yrs). Thus elevated temperature in the potential repository gives rise to increased uncertainty in mineral stability. Also the state of saturation becomes an important variable as to which mineral transitions will occur.

Recommendation: This goal appears to be still relevant and at this time should be retained as written. If anything, consideration should be given to reducing the temperature in CHn to the boiling point since, if zeolitic tuffs experience increased saturation due to shedding of water, they may indeed react at temperatures below 115 degrees C. The effects of increased temperatures on the zeolitic portions of the CHn will depend strongly on the state of saturation, i.e., whether the rocks are in a steam environment or are saturated. To investigate the geologic processes affecting attainment of the goal and reduce the uncertainties associated with it, the dehydration/rehydration and thermal expansion/contraction behavior of clinoptilolite and mordenite should be mapped in temperature-water vapor pressure $P(H_2O)$ space. In addition, the amounts of heat energy associated with the dehydration and rehydration of clinoptilolite and mordenite should be measured. Because water molecules are strongly held within the zeolite structures, considerably more energy is required to dehydrate a zeolite than to boil physically bound water in pores. The enthalpy of vaporization of the least-strongly held water in zeolites is ~20 percent greater than the enthalpy of vaporization of water, and more strongly held water in zeolites can have enthalpies of vaporization up to twice that of water. These differences will significantly affect heat budget in a heated block of zeolitic tuff, both during heat-up and cool-down periods, and these energy differences must be considered in any thermal models of potential repository behavior. The energetics of

dehydration of a variety of compositions of clinoptilolite and mordenite will be measured using differential scanning calorimetry, and dehydration enthalpies will be determined on a per-gram-zeolite basis and on a per-gram-water basis.

SCP Thermal Goal 2: Limit temperatures in the Topopah Spring basal vitrophyre (TSw3) unit to less than 115 degrees C (4-P).

Rationale: The rationale for limiting the temperature in the lower vitrophyre of the Topopah Spring Member is exactly the same as for the CHn unit: to limit mineral alteration and dehydration. As for the CHn, the 115 degrees C thermal goal is a default value related to hydrologic property changes and ground-water travel time. Because the TSw3 is much thinner than the CHn and represents less ground-water pathway, mineralogic and resultant hydrologic changes in the unit have less effect on travel times. For this reason, the choice of thermal goal for the TSw3 may be less critical as an independent goal and more meaningful with regard to effects on the CHn.

Discussion: The changes in porosity and mechanical properties of TSw3 vitrophyre exposed to unsaturated-zone conditions under a confining stress at 180 degrees C have been measured by Blacic and others (1982). They found a 22 percent relative decrease in the already very low porosity of 1.7 percent. Vaniman, Bish, and Chipera (1993) have found that the rate at which the most readily removable water in vitrophyre glass (several weight percent) is lost during heating is a function of temperature up to at least 400 degrees C. Even at lower temperatures, significant water loss occurred within a few years.

One implication of these studies is that loss and migration of several weight percent of water probably will be unavoidable at 115 degrees C or even lower temperatures, and that this amount of water could substantially change the hydrologic conditions in a rock with such low porosity. However, the existence of such low bulk porosity raises questions about the relative roles of the bulk porosity, probably represented by the perlitic fracture network, and localized fracture zones in fluid evolution and transport.

Under saturated conditions, including locally saturated conditions, there may also be glass dissolution and secondary-mineral sealing (Levy, 1984). In addition, there is a zeolite-smectite zone concentrated at the TSw2-TSw3 transition, although this potential barrier is so close to the potential repository horizon that it is likely to be compromised under *any* waste-loading scenario. Furthermore, placing a temperature goal on this unit identical to that proposed for the underlying CHn unit would ensure that the goal of keeping the CHn layer less than 115 degrees C is met since it is farther from the potential repository. This may imply some inconsistency in this goal that should be investigated.

To understand the hydrologic changes in the TSw3 unit as a result of heating, some laboratory experiments are warranted to determine if, and to what extent, the hydrologic properties of the vitrophyre may be altered by strong heating and cooling. Effects on both bulk hydrologic properties and local fracture zones should be investigated. Natural-analog field studies of fracture zones in TSw may help address this issue. Additionally, performance assessment calculations will be needed to determine the extent to which any thermally altered hydrologic properties will degrade the performance of the natural barrier.

Recommendation: This goal should be retained at this time but, similar to the goal for CHn, certain tests will be required to ensure that the goal is adequate. The hydrologic implications of this goal should probably be emphasized and reconsidered. The laboratory experiments discussed above for the CHn thermal goal to identify the hydrologic properties under heating conditions and the performance assessment calculations should be undertaken for this layer also.

SCP Thermal Goals 3 and 5: Limit surface uplift to less than 0.5 cm/year (4-S) and relative motion of top of TSw1 to less than 1 m with no intact rock failure and no continuous joint slip (4-Q).

Rationale: These goals should be treated together as far-field thermomechanical goals. Their purpose was to ensure that far-field thermal effects would not produce preferential pathways for fluid flow.

Discussion: As the potential repository heats up and expands, the potential repository remains confined by the surrounding, relatively undisturbed rocks. If the expansion is sufficient, this can result in large horizontal stresses developing in the far-field and an uplift in the potential repository region. If this uplift is large enough, it could cause the rocks above the potential repository, especially the non-welded Upper Paintbrush Tuff Formation (lowermost Tiva Canyon; Yucca Mountain's Pah Canyon; and uppermost Topopah Spring Members) (vitric nonwelded) (PTn) units, to extend, resulting in fracturing of the units. This would damage the principal natural barrier above the potential repository and could result in the opening of preferential pathways for water infiltration, or pathways for gas migration.

These thermal goals for limiting the amount of uplift were established to preserve natural barriers. Little additional analysis has been performed since these SCP goals were established. Three-dimensional thermal-structural analyses are needed to address this issue. YMPO is planning a series of these analyses during FY 1994.

Recommendation: The thermal goals should remain as stated until the analyses discussed above have been completed. At that time the goals should be reassessed. As far-field goals, both are adequate for any of the emplacement modes under consideration.

SCP Thermal Goal 4: Limit the rise in surface temperature to less than 6 degrees C (4-R).

Rationale: This goal is understood to have originated as an environmental requirement to limit surface temperature changes to levels which would not result in significant changes in the near-surface biological environment.

Discussion: There is some uncertainty as to whether this goal has a regulatory basis, originates from calculations of thermal loading effects, or has some other basis. A possible basis for the magnitude of the goal is the average seasonal change in ground surface temperature or studies of the effects of surface temperature changes on vegetation. A draft July 1981 DOE report, NWTS-25 (DOE, 1981), recommended a constraint of the maximum temperature increase within 3 meters of the surface of less than 4 degrees C based on expert judgment, heat transfer calculations, and natural analogs. A DOE report, NWTS-30 (December 1982), based on the NWTS-25 report, suggests that the higher value of 6 degrees C be the maximum allowable surface temperature increase. Individuals involved in the original SCP work recall that the 6 degree C value was determined by application of a 50 percent design factor of safety to the original 4 degrees C value. However, it appears that the conservatism was applied inappropriately; 2 degrees C would have been the more conservative value. More recent work by Dr. Ostler (1991) indicates that a temperature increase of less than 2 degrees C is expected to have minimal impact on biological resources and is similar to observed natural variability.

Recommendation: A limit of the surface temperature increase of less than 2 degrees C due to the potential repository thermal loading is recommended as a revised goal.

SCP Thermal Goal 6: A thermal goal to design for a thermal loading less than the allowable thermal loading was established in the SCP (4-T).

Rationale: This goal was very generic so that the potential repository would be designed to accommodate borehole and drift spacing which would provide the flexibility necessary to achieve the thermal loading in the potential repository.

Discussion: This is a common sense goal that should be maintained and updated when an emplacement mode is selected. Additionally, it is possible that future studies could conclude that a fairly narrow range of thermal loading is optimal for waste isolation. In that case, the goal would need to be rewritten to ensure that the design allows a thermal loading only in that desired range.

Recommendation: The wording of the process should be changed to: "Vary the details of the potential repository configuration and waste package spacing to control thermal loading and waste package container temperature."

SCP Thermal Goal 7: Keep the borehole wall temperature less than 275 degrees C (4-U).

Rationale: This goal was originally established for the specific vertical borehole emplacement in the SCP as a limit that would ensure that the waste package did not exceed the 350 degrees C limit.

Discussion: This goal is applicable only to the specific design used in the SCP. For a large waste package emplaced in a drift it may be that the waste package temperature could exceed 350 degrees C and yet the drift wall temperature could still be significantly less than 275 degrees C. This goal is unnecessary if the goals to keep the waste package centerline temperature <350 degrees C (4-Y) and the 1-m rock temperature <200 degrees C (4-V) are met.

Recommendation: It is recommended that this goal be eliminated.

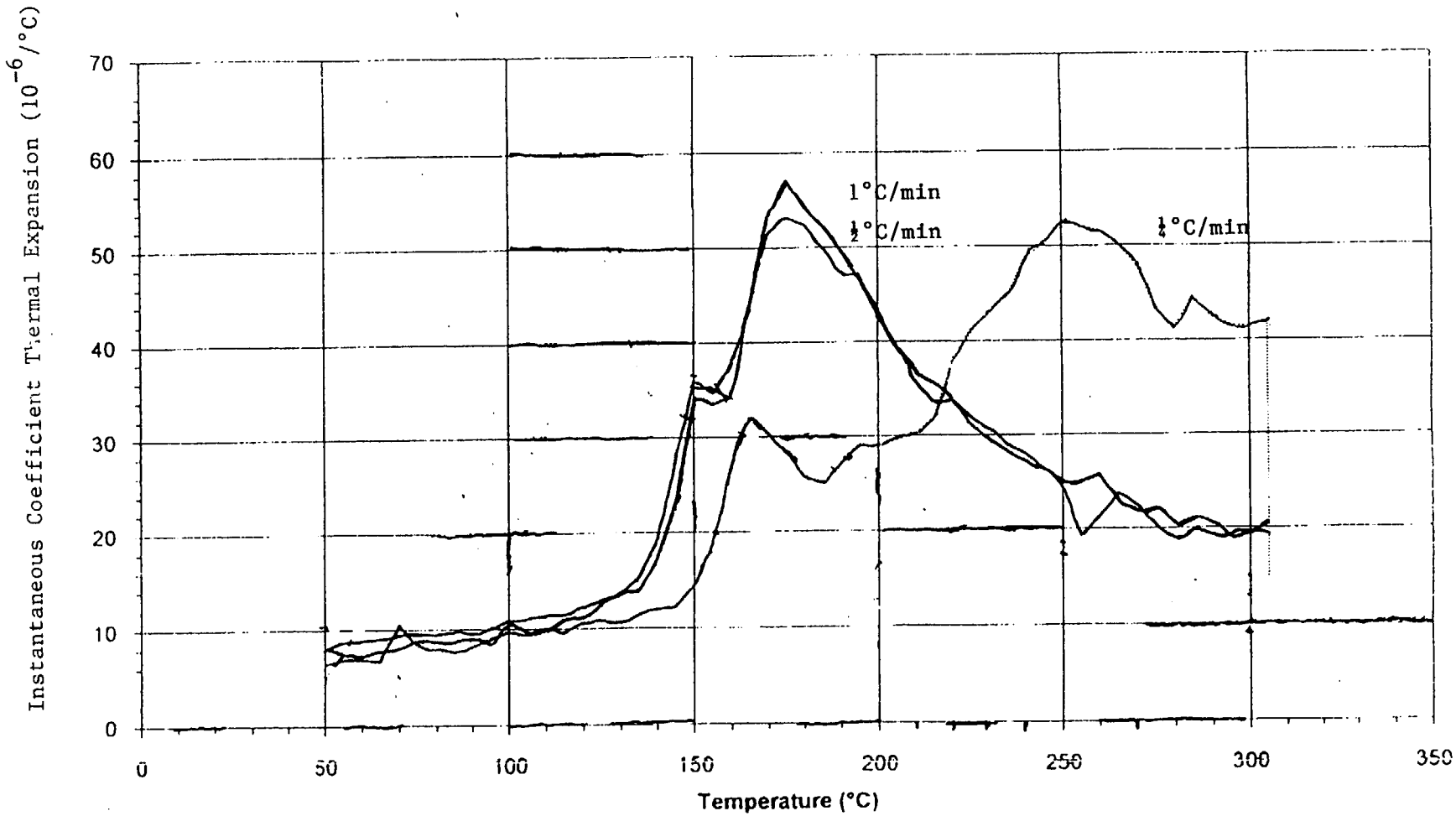
SCP Thermal Goal 8: Limit the rock mass temperature at 1 meter from the borehole to less than 200 degrees C (4-V).

Rationale: This goal was established to minimize adverse stresses in the rock around the borehole that may cause closure of the borehole and local rock failures resulting in damage to the container (pre-and postclosure concern) and/or prevent retrieval of the container (preclosure concern).

Discussion: Phase transitions of silica polymorphs (tridymite and cristobalite) were believed to occur at temperatures between 230 and 250 degrees C, based on work done by Oversby on the importance of α-β cristobalite transition (1993). Mechanics experiments identify a significant change in macroscopic thermal expansion at 250 degrees C where the thermal expansion coefficient goes from 2.5 to 5.3×10^{-6}/°C. The potential host rock for the potential repository contains significant amounts of cristobalite, so the α-β cristobalite transition may be a valid concern. Thus, if a large volume of rock were allowed to exceed these temperatures, substantial closure of the borehole could occur that might crush the container or cause local rock failure that would damage the container and prevent potential retrieval. Thus, a conservative goal of less than 200 degrees C was established. Although this temperature limit is somewhat conservative and the distance of 1 meter is arbitrary, stress calculations indicate that if these limits are not exceeded the stresses in the rock should not be large enough to result in significant spallation.

Because borehole emplacement is the baseline case to which all new design work will be compared until a new baseline is established, the goal is still relevant. Some recent thermal expansion data determined by SNL is shown in Figure 1. The expansion data indicate changes in the coefficient of thermal expansion of as much as a factor of 5 which may occur around 180 to 250 degrees C. A series of simple thermal and structural calculations were performed to determine the ramifications of this change in expansion coefficient. These calculations are summarized in Appendix A. The results indicate that it is primarily the temperature gradient that is responsible for causing structural instabilities. It can be concluded that the temperature gradient can be kept below a level where large-scale failure would develop if the drift wall temperature can be kept below 200 degrees C. This is discussed further in the following paragraphs. Also, SNL has determined that cooling may cause even larger fluctuations than heating. This could have serious implications for blast cooling of emplacement drifts used as part of some retrieval scenarios.

Figure 1. Thermal Expansion of Gl-388.8-1-SNL-A



Additional analysis should be performed to assess the impact of thermal expansion on near-field rock stresses in light of current information on expected rock-mass quality in the potential repository horizon. New data on intact rock strength from the laboratory tests currently underway on core samples from NRG-6 need to be factored into this analysis. Additionally, the effect of blast cooling on these rocks and the consequences of the resulting stresses imposed need to be ascertained.

A question of whether this goal would be applicable to in-drift emplacement also needs to be addressed. If one considers the intent of the goal to prevent damage to the containers from near-field rock motion that would cause premature releases or prevent retrieval, then a similar goal should be established to guide design for in-drift emplacement. In-drift emplacement involves several concerns: (1) rock stresses in large openings may result in failure of the ground support and damage to the waste packages from rock falls; (2) large thermal expansion could cause warping of the drifts (floor heave) that could be extensive enough to prevent retrieval of large, heavy casks; and (3) the drifts must be stable and safe to allow maintenance during the preclosure period.

To form a basis for recommending a tentative goal for in-drift emplacement, a series of simple thermal and structural calculations was performed as indicated above. The analyses are not comprehensive and make many assumptions that may prove to be wrong once data from the site are obtained. However, it was the intent of this assessment to provide a conservative or "worst case" estimate of the near-field conditions to establish reasonable bounds for the design effort. Many additional analyses are expected to be performed in FY 1994 that will help establish more firmly a set of goals for in-drift emplacement. This initial effort addresses only concerns (1) and (3) above. Concern (2) will require more detailed analysis. The results of these calculations are presented in Appendix A.

Summarizing the work presented in Appendix A, it can be concluded that even though large volumes of rock are above 150 degrees C, any failure of the rock, were it to occur, would be restricted to a small region around the drift. The results seem relatively insensitive to the magnitude of the thermal expansions around 150 degrees C because of the relatively low thermal gradients in the rock walls. At higher heating rates where an ideal, conservative case with no thermal decay is used, steep thermal gradients can develop above 200 degrees C. These gradients result in large stresses which conceivably could result in rock failure. Keeping the temperatures below 200 degrees C would prevent thermal gradients of a magnitude that could cause large-scale failure to develop.

Based on the results of the calculations it can be concluded that it is primarily the temperature gradient rather than the actual temperature that will give rise to stresses. For the typical fuel characteristics expected, however, it appears that restricting the wall temperature to 200 degrees C will limit temperature gradients to levels low enough so that failure of the drift walls will be unlikely. Therefore it appears that this temperature limit is valid for in-drift emplacement as well.

<u>Recommendation</u>: This goal is still valid but it should be reevaluated in FY 1994 after more thermal expansion data (principally from NRG-6 samples) are available. The goal to establish a limit of 200 degrees C for the emplacement borehole wall temperature at a depth of 1 meter should be retained. However, it is realized that the 1-meter depth is somewhat arbitrary.

The analysis summarized above and presented in Appendix A indicated that a similar goal could be recommended for the in-drift emplacement mode. The analysis indicated that large stresses would be unlikely to form if the wall temperature of the rock in the in-drift emplacement mode could be kept less than 200 degrees C.

Rock stress resulting from blast cooling should also be considered. This analysis should be done in FY 1994 and factored into the next analysis.

SCP Thermal Goal 9: Boreholes should not load the waste container beyond the limits imposed under Issue 1.10 (4-W).

Rationale: This goal was established so that waste package integrity would not be compromised due to borehole loading.

Discussion: This goal appears appropriate and consistent with the other goals for borehole emplacement.

Recommendation: Retain the goal for borehole emplacement.

SCP Thermal Goal 10: A goal was established to maximize the time that the majority of the borehole walls remain above boiling for longer than 300 years (4-X).

Rationale: This goal was linked to nuclear containment in 10 CFR 60 and the belief that the waste package lifetime could be extended by keeping the drift walls above boiling as long as possible.

Discussion: Waste package material, temperature, and environment, not strictly borehole or drift temperatures, ultimately will govern the waste package lifetime. More work is currently planned to evaluate waste package candidate material lifetimes over a range of temperature conditions and environments and to evaluate this using a systems analysis approach. There are plans to establish corrosion curves for various waste package candidate materials over a range of temperatures. This work needs to be done before an adequate evaluation can be made as to whether this goal is appropriate. Thus, there remains a significant level of uncertainty about how this goal needs to be stated, which must wait to be resolved.

Recommendation: The Working Group consensus is that the goal is desirable and therefore will be retained. Adherence to the goal is not required for evaluation of various thermal loadings. We recommend that the goal be restated slightly so that it will be compatible with whatever thermal loading strategy is chosen. It is suggested that the goal be rewritten to state: "maximize the time the waste package container stays above the local boiling point of water consistent with the thermal loading strategy developed." This goal needs to be carefully evaluated as better definition of the EBS such as backfill options and thermal loading strategy are developed.

SCP Thermal Goal 11: Limit the fuel cladding temperature to less than 350 degrees C (4-Y).

Rationale: The thermal goal to limit the fuel cladding temperature was originally established based on studies performed at Pacific Northwest Laboratories. In those studies, if the temperature of the fuel rods exceeded about 380 degrees C, the Zircaloy fuel cladding would likely fail due to creep. Thus, to ensure that the cladding would not undergo creep failure a conservative "not to exceed" goal of 350 degrees C was established.

Discussion: Zircaloy cladding failure by creep is rate-limited and is really a function of both time and temperature. Phase change of the UO_2 to U_3O_8, should it occur, results in an increase in volume which can stress the Zircaloy cladding and possibly cause creep failure. Failure can occur under some conditions at lower temperatures but over a longer period of time. However, phase change in the pellets generally will not occur unless the cladding has already failed and oxygen has entered. Thus, creep will not likely be expected from this mechanism but mainly from internal pressure due to fission gas release and temperature. The integrity of the cladding received from the reactors also depends on several factors in addition to temperature, including the internal pressure, the inert or atmospheric gases to which the fuel rod is exposed during reactor operation, and the length of time the rod has previously been exposed to these conditions. To establish a goal that would allow waste package designers to quantify the performance allocation that can be expected from the fuel cladding will require that some experimental data be taken and analysis done to examine Zircaloy cladding failure resulting from creep. The fuel material properties also need to be examined to better determine the performance for long-term storage under these conditions. Once this is done the goal can be better evaluated.

Recommendations: Until the experimental analysis of Zircaloy cladding failure is performed, the goal of <350 degrees C should be retained as a guide to various studies underway and for conceptual design efforts. Emphasis should be placed on ensuring that the appropriate studies are done to determine the performance of Zircaloy cladding.

SCP Thermal Goal 12: A goal was established to keep the temperature of the high level waste (HLW) glass less than 500 degrees C (4-Z).

Rationale: It was believed that temperatures above this value could result in devitrification of the borosilicate glass waste form.

Discussion: Discussions with Savannah River personnel (Plodinec, 1993) indicated that this goal was still applicable and should be retained. They have an ongoing program to characterize the glass and study its devitrification. These discussions are reproduced in Appendix B in the form of a message from M. J. Plodinec to R. D. McCright.

Recommendation: The goal should be retained and any new information produced by Savannah River should be factored into future thermal goal update efforts.

SCP Thermal Goal 13: A goal was established to limit the wall temperature in the access drifts to less than 50 degrees C for the first 50 years (4-AA).

Rationale: The rationale for this goal is to establish an environment during the emplacement period that could be modified to allow access by thermally unprotected workers, and in closed areas, could be cooled within eight weeks to allow such access. This goal was established for the vertical borehole emplacement mode.

Discussion: This is a key thermal goal from an operational and safety perspective, particularly with respect to considerations of retrieval (Issue 2.4) and other preclosure activities. The goal derives from the need to provide an appropriate environment during preclosure operations.

Several considerations went into establishing this goal. First, it was noted that for workers, an operational environment of 50 degrees C is appropriate only under certain humidity conditions. Extremely humid environments may require lower operating temperatures. For example, a dry-bulb temperature of 49 degrees C at 30 percent relative humidity would exceed permissible heat exposure threshold limits if the globe temperature (a measure of radiant heat load) exceeds 17 degrees C. Some variation in this limit may be possible, but for the purposes of this work, a goal of 50 degrees C is reasonable for worker environmental temperature. The human exposure factors associated with the safety limits are described in more detail in Appendix C. Second, the temperature limit of 50 degrees C is important as a mechanical operations limit. For example, diesel engines, such as may be used for a transporter, have an upper operational temperature limit slightly higher than 50 degrees C. Third, higher temperatures may require establishing special instrumentation and cabling specifications to withstand the thermal environment.

Recommendation: The goal to keep access drift wall temperatures to less than 50 degrees C in the first 50 years of emplacement should be retained but should be restated to apply to any emplacement mode.

SCP Thermal Goal 14: Maintain rock temperature less than 100 degrees C midway between emplacement drifts (4-AB).

Rationale: Ostensibly, the intent of this goal is to promote free ground water or condensate drainage through and away from the potential repository horizon.

Discussion: No specific reference to the origin of this goal was found although it was believed to be a condition that would improve waste package lifetime. This goal would be attainable only for a potential repository that had waste emplaced at a density no greater than about 37 to 42 kW/acre. Above these values the heat is sufficient to elevate the average potential repository temperature above boiling. Above-boiling temperatures produce conditions where water above the potential repository can be removed by only one of three methods: (1) vapor-phase transport; (2) liquid transport around the boiling region across long lateral distances, perhaps hundreds to thousands of meters; or (3) superheated or pressurized liquid movement through the potential repository horizon. These conditions may be difficult to maintain uniformly throughout the potential repository and may be hard to test. The MGDS Thermal Loading Study is evaluating the advantages of hotter and cooler (below boiling) repositories from the standpoint of performance.

Recommendation: No technical justification for this goal was determined, nor was a statement of this goal found in the SCP. Therefore it was recommended that this goal should be eliminated at this time. However, it needs to be reevaluated once the results of the thermal loading study are completed.

SCP Thermal Goal 15: Maintain wall temperatures in emplacement drifts <50 degrees C for the first 50 years for horizontal borehole emplacement (4-AC).

Rationale: This goal, found on page 8.3.5.2-10 (item #2) in Section 8.3.5.2 (Waste Retrievability), is similar to the goal for the vertical borehole case. What may be confusing is that the words "emplacement drift" are used. However, the horizontal borehole emplacement drift is similar to the vertical borehole access drift. This is clearly shown in Figure 6-64 on page 6-151 of the SCP (DOE, 1988). Hence, the rationale for this goal is similar to that for Goal 13.

Recommendation: The goal to keep the emplacement drifts for horizontal boreholes to <50 degrees C for the first 50 years after emplacement should be retained, but should be evaluated again on completion of ventilation studies and radiation calculations.

Additional Discussions

The group discussed several other issues important to waste isolation. It was suggested that a goal be established to keep the Paintbrush nonwelded member (PTn) below boiling to prevent ^{14}C release or conditions that might enhance water percolation. The PTn unit exists between the Tiva Canyon (TCw) and Topopah Spring (TSw) welded units and is recognized as potentially important for controlling the rate and spatial distribution of water entering the deep unsaturated zone as net land-surface infiltration. The presence of thin vitrophyres in the basal TCw and upper TSw and the relatively high hydraulic conductivity and storage capacity of the nonwelded and bedded tuffs of the intervening PTn unit combine to divert ground water laterally down-dip and away from the potential repository. Although the effectiveness of this potential barrier remains to be evaluated fully, the PTn may be capable of limiting the amount of infiltrating water that could readily percolate to the potential repository horizon under present day arid as well as possible future wetter climatic conditions. It is speculated that the PTn may also provide a barrier against release of ^{14}C if a waste package is breached.

As part of this examination into the natural barriers, it is important to examine the impact of temperature changes on the various chemical species, not only in the PTn layer but in the other natural barrier layers as well. Recently, available information on the chemical and mineral species present in the rock at Yucca Mountain has highlighted the need for further studies. Specifically, thermo-chemical changes need to be examined and dissolution and movement of these species due to changes in the thermal-hydrologic properties of the barriers also need to be investigated.

The group initially proposed establishing a thermal goal of not exceeding the boiling point of water in the potential repository at the PTn unit even though additional analyses and data are needed to confirm this determination. Rock data of the PTn unit should be obtained and evaluated in light of the above concerns. Instead of a boiling point limit, the Working Group decided that based on present knowledge, only a more general goal should be established at this time.

As a corollary of the discussions about access drift temperatures, the Working Group was concerned about the possible need for manned operations in the emplacement drifts. In the emplacement drifts, the closed drifts' surface temperatures would likely be considerably higher (probably above boiling) than access drifts. Ventilation may not be able to produce the requisite cooling to achieve a temperature of 50 degrees C in a reasonable amount of time. Furthermore, forced cooling may induce a temperature gradient sufficient to initiate rock falls, which would further complicate the ability to ventilate these emplacement drifts and hamper operations. Thus, a careful evaluation should be made of the ability to ventilate emplacement drifts for retrieval and the stress that rapid cooling may impose on the rock surfaces.

Summary and Recommendations

A Working Group was formed to reassess the SCP thermal goals to determine whether each goal was still valid, if there were goals that needed to be added, and what if any effort was needed to reduce the uncertainty associated with a particular goal. The objectives of the effort were to: (1) provide thermal goals that would support the FY 1993 Thermal Loading Systems Study; (2) help focus the planned testing and analysis efforts; and (3) acquire data that potentially could be used to initiate a change to the project technical baseline. Sixteen thermal goals were evaluated; fifteen were from various sections of the SCP; one goal was added, and another was split into two to include in-drift emplacement. A summary of the group's findings and recommendations follows:

1. Goal 4-O to limit temperature in CHn: No change at this time but some laboratory work and measurements are recommended to establish the properties and enthalpies of the zeolites under elevated temperature conditions.

2. Goal 4-P to limit temperature in TSw3: No change at this time. Similar work as above is recommended, which would also include establishing the hydrologic properties of this layer under heating.

3. Goal 4-Q to limit relative motion to <1m at the top of TSw1: No change at this time but it should be reassessed after the planned three-dimensional thermal structural analyses are completed.

4. Goal 4-S to limit surface uplift to <0.5 cm/yr: No change at this time but it should be evaluated after analyses mentioned under 4-Q are performed.

5. Goal 4-R to limit the rise in surface temperature to <6 degrees C: This goal should be changed to <2 degrees C.

6. Goal 4-T to design the thermal loading for less than that allowable: The process was reworded to apply to all emplacement modes, not just the vertical borehole.

7. Goal 4-U to limit borehole wall temperature to <275 degrees C: This goal, considered redundant, should be eliminated.

8. Goal 4-V to limit the 1 m temperature in the borehole to <200 degrees C: This goal should be retained and an ancillary goal be included which would provide a similar limit for the in-drift wall temperature. Data from NRG-6 should be evaluated and factored into the next assessment. Additionally, the resultant stresses on the rocks from blast cooling should be examined.

9. Goal 4-W not to load the waste container beyond certain limits: This goal was unchanged.

10. Goal 4-X to keep borehole wall temperatures above boiling: This goal was changed to read: "maximize the time the waste package stays above boiling consistent with the thermal strategy." Research on waste package lifetimes and engineered barriers in a two-phase environment should be conducted and data on corrosion rates of materials incorporated.

11. Goal 4-Y to limit fuel cladding temperature to <350 degrees C: This goal was retained but it is recommended that Zircaloy cladding failure and fuel properties be examined.

12. Goal 4-Z to limit high level waste glass temperature to <500 degrees C: This goal was retained but should be reevaluated once Savannah River completes their analysis of borosilicate glass.

13. Goal 4-AA to limit access drift wall temperature to <50 degrees C for the first 50 years: Retain this goal but perform a thorough evaluation of ventilation capabilities and effects.

14. Goal 4-AB to limit mid-drift rock temperatures to 100 degrees C: This goal should be deleted. The systems studies will evaluate the required performance and determine the thermal loading range that will provide this performance.

15. Goal 4-AC to limit emplacement drift wall temperatures to <50 degrees C for first 50 years for horizontal boreholes: This goal should be retained, but carefully evaluated once ventilation studies and radiation calculations have been performed.

16. Goal 4-AD to protect the PTn layer: This goal should be added. Work needs to be done to acquire data on this layer and its performance under elevated temperatures so that a quantifiable performance measure can be developed.

The above goals and the revisions based on the Working Group's recommendations are summarized in Table 3. The revised goals are noted with an *. Additionally, some discussion was raised about geochemistry issues; some effort should be expended looking at sulfur chemistry and sources in the mountain. Possibly a small experiment could be configured and included in the heated block tests.

The revised thermal goals should be reevaluated at various stages in the site characterization activities being done for the potential repository. It is recommended that the tasks suggested above be refined into actual experiments and analyses to be performed next year. Results should then be factored into a reassessment of the thermal goals. The revised goals listed in Table 3 will be used in the MGDS Thermal Loading Study being conducted during FY 1993 and the results of that study should also be available for Working Group use in the next assessment.

Table 3
Revised SCP Thermal Goals

	Process	Performance Measure	Thermal Goal
1 2 16**	Limit temperature changes in selected barriers	Temperature	4-O[a] Limit temperature of CHn to <115°C 4-P Limit temperature of TSw3 to <115°C 4-AD Establish a thermal loading which would not degrade PTn barrier*
3	Limit deleterious rock movement or preferred pathways	Rock displacement	4-Q Relative motion <1m at the top of TSw1 - no intact rock failure - no continuous joint slip
4 5	Limited impact on surface environment	Temperature Surface Uplift	4-R Rise in surface temperature <2° 4-S Surface uplift <0.5 cm/year
6 7 8 8[1]	Vary the details of the potential repositoryconfiguration and waste package spacing to control thermal loading and waste package container temperature*	Thermal loading Borehole wall temperature Rock mass temperature	4-T Design basis thermal loading less than allowable thermal loading 4-U Deleted* 4-V Keep the rock mass temperature at 1-m from vertical borehole <200°C Keep in-drift wall temperatures <200°C*
9	Limit potential for borehole collapse	Stress, deformation, factor of safety, and potential rock fall	4-W Boreholes that do not load container beyond limits imposed under Issue 1.10.

Table 3 (Continued)
Revised SCP Thermal Goals

	Process	Performance Measure	Thermal Goal
10	Limit corrosiveness of container environment	Time container is above boiling temperature of water	4-X Maximize the time the waste package container stays above boiling consistent with the thermal strategy developed*
11	Limit degradation of fuel matrix or cladding	Temperature	4-Y Fuel cladding temperature <350°C
12		Temperature	4-Z High level waste glass temperature <500°C
13	Limit access drift temperature	Temperature	4-AA Temperature in access drift <50°C for first 50 years, any emplacement mode*
14	Provide for hydrologic drainage	Temperature	4-AB Delete*
15	Limit Emplacement drift temperature (horizontal borehole)	Temperature	4-AC Emplacement drift wall temperature <50°C for first 50 years for horizontal borehole

[a]4-O indicates function 4 (thermal loading) and goal O. Table 8.3.2.2-4 went only to 4-X; the remainder of the goals from other areas of the SCP such as 1.10 were assigned a designator (e.g., 4-Z) consistent with the numbering system. *Revised from SCP Goal.

*Revised from SCP Goal

**Added Goal

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APPENDIX A

THERMAL MECHANICAL CALCULATIONS FOR IN-DRIFT EMPLACEMENT

As part of a Total System Performance Assessment 1 study, a number of thermal analyses aimed at estimating the near-field temperatures for in-drift emplacement were performed. For the analyses presented here, temperature history from the previous study was used to perform a series of structural calculations to assess the near-field rock stresses and potential failure modes. The temperature history was that generated for an in-drift emplacement at 100kW/acre for 30 year old spent fuel. The emplacement drifts were assumed to be 7.9 m diameter on 30.5 m centers. The thermal calculations for an open, unventilated drift were carried out to 75 years at which time the drift was assumed to be backfilled. One additional calculation was performed without the backfill to evaluate any difference if the drift was left open for 200 years. The structural calculations were performed using elastic rock-mass properties for each unit. The results were post-processed to see what volume of the rock mass, if any, exceeded the rock-mass strength given in the Reference Information Base (RIB) (DOE, 1993). For comparison, a calculation using the same initial heat load but not allowing for decay of the heat source was performed. This would provide some evidence of what sort of thermal load and stress conditions it takes to fail the rock mass around the drift.

In the analyses, it was assumed that the thermal expansion of the rock mass increased by a factor of five (an extreme case) between 150 and 175 degrees C. These results were compared to similar calculations where the thermal expansion was constant until 250 degrees C (the usual assumption). The results are given in Figures A-1 through A-10.

From Figures A-1 through A-6 it can be concluded that even though large volumes of rock are above 150 degrees C, failure is restricted to a small region around the drift. This may still be a problem because failure of the floor may prevent retrieval; but, it will take more detailed analysis to resolve this issue. The results seem to be relatively insensitive to the magnitude of the thermal expansion above 150 degrees C. This is because the decaying heat source and the nominal power output allows heating with relatively low thermal gradients.

Figures A-7 through A-10 show what happens at higher heating rates. With no power decay of the heat source, steep thermal gradients develop, which result in large stresses and more significant failure. For this size opening, it appears that failure could be controlled by restricting the drift wall temperature to 200 degrees C. This would prevent thermal gradients of a magnitude that can cause large-scale failure.

The principal concerns then, are: (1) rock stresses in large openings may result in failure of the ground support and damage to the waste packages from rock falls; (2) large thermal expansion could cause warping of the drifts (floor heave) that could be extensive enough to prevent retrieval of large, heavy casks; and (3) the drifts must be stable and safe to allow drift maintenance during the preclosure period.

The conclusion from this initial analysis is that for in-drift emplacement, an initial temperature limit of no greater than 200 degrees C should be placed on the emplacement driftwalls. This temperature limit is likely very conservative for addressing concerns (1) and (3). It may be less conservative for concern (2). In addition, the analyses have not addressed other important factors such as drift size. The conditions of emplacement in the drift are also very important for concern (2). Results for packages that are set on a crushed tuff floor will be considerably different from those set directly on the intact rock. These issues will be dealt with in the coming months as more systems studies calculations are completed.

Figure A-1. Temperature Distribution Around Drift Just before Backfilling

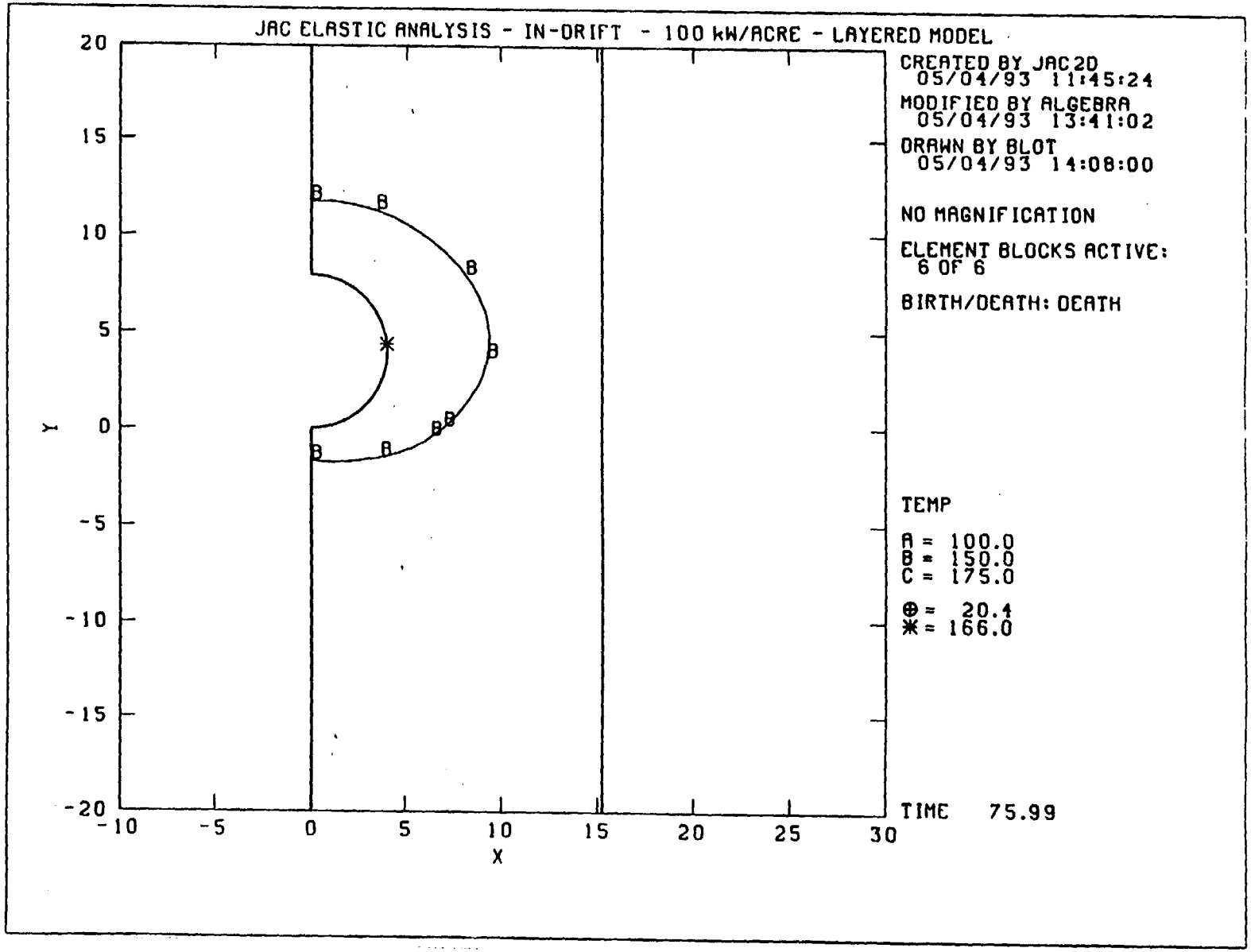


Figure A-2. Zones of Failed Rock at Same Conditions as Figure A-1, Using Large Thermal Expansion (Figure 1)

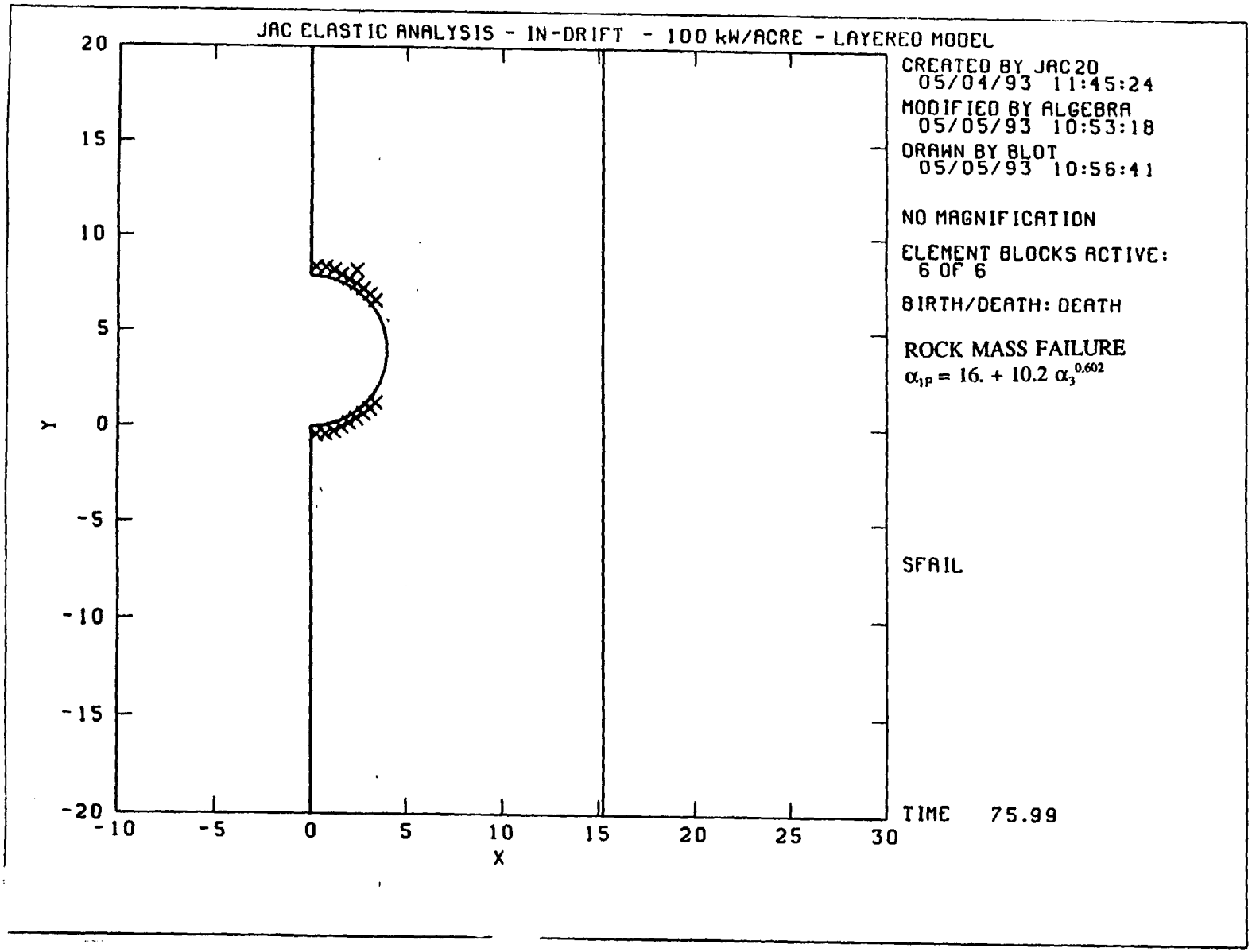


Figure A-3. Temperature Distribution Around Drift at 200 yr (125 yr after Backfilling)

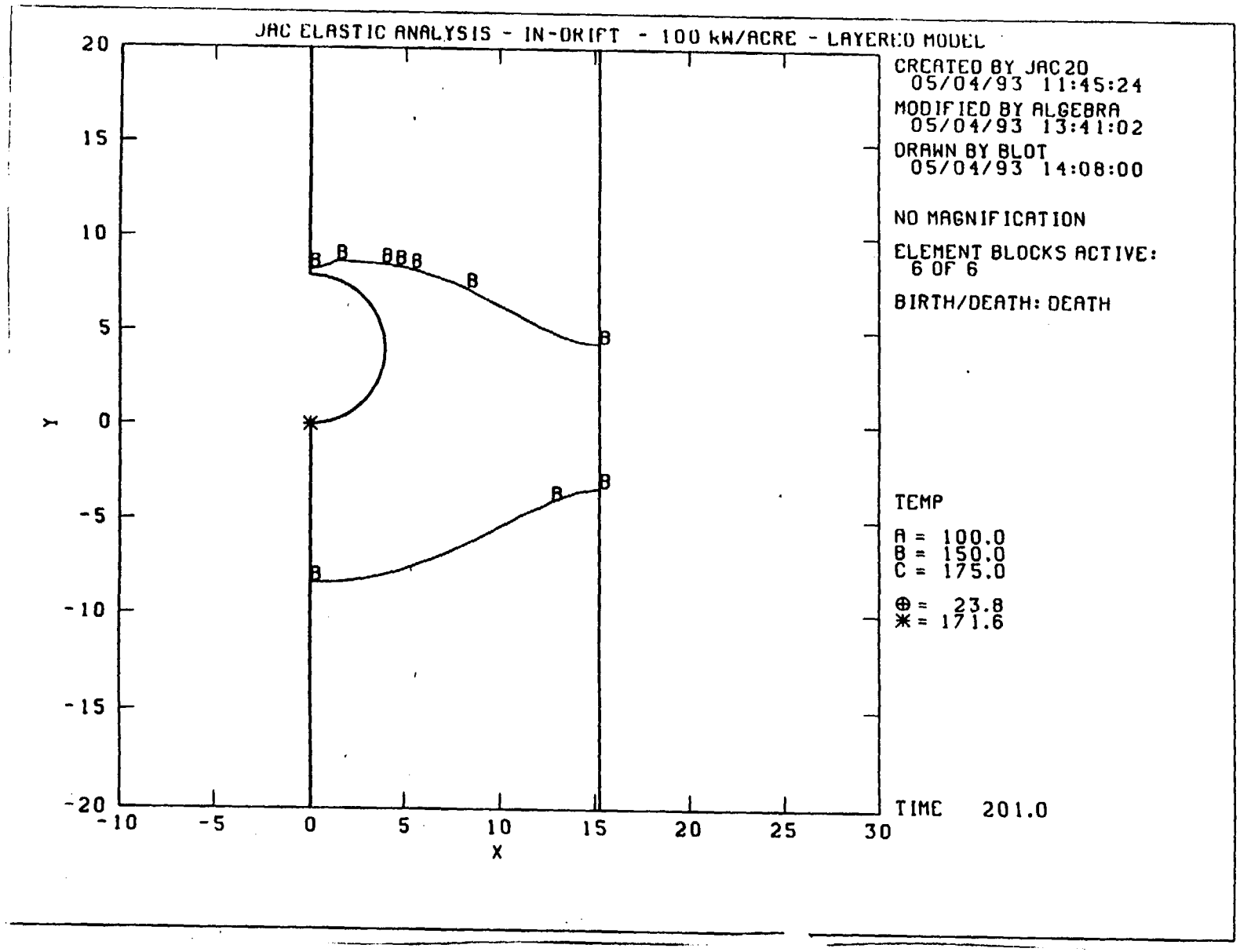


Figure A-4. Zones of Failed Rock at Same Condition as Figure A-3, Using Large Thermal Expansion (Figure 1)

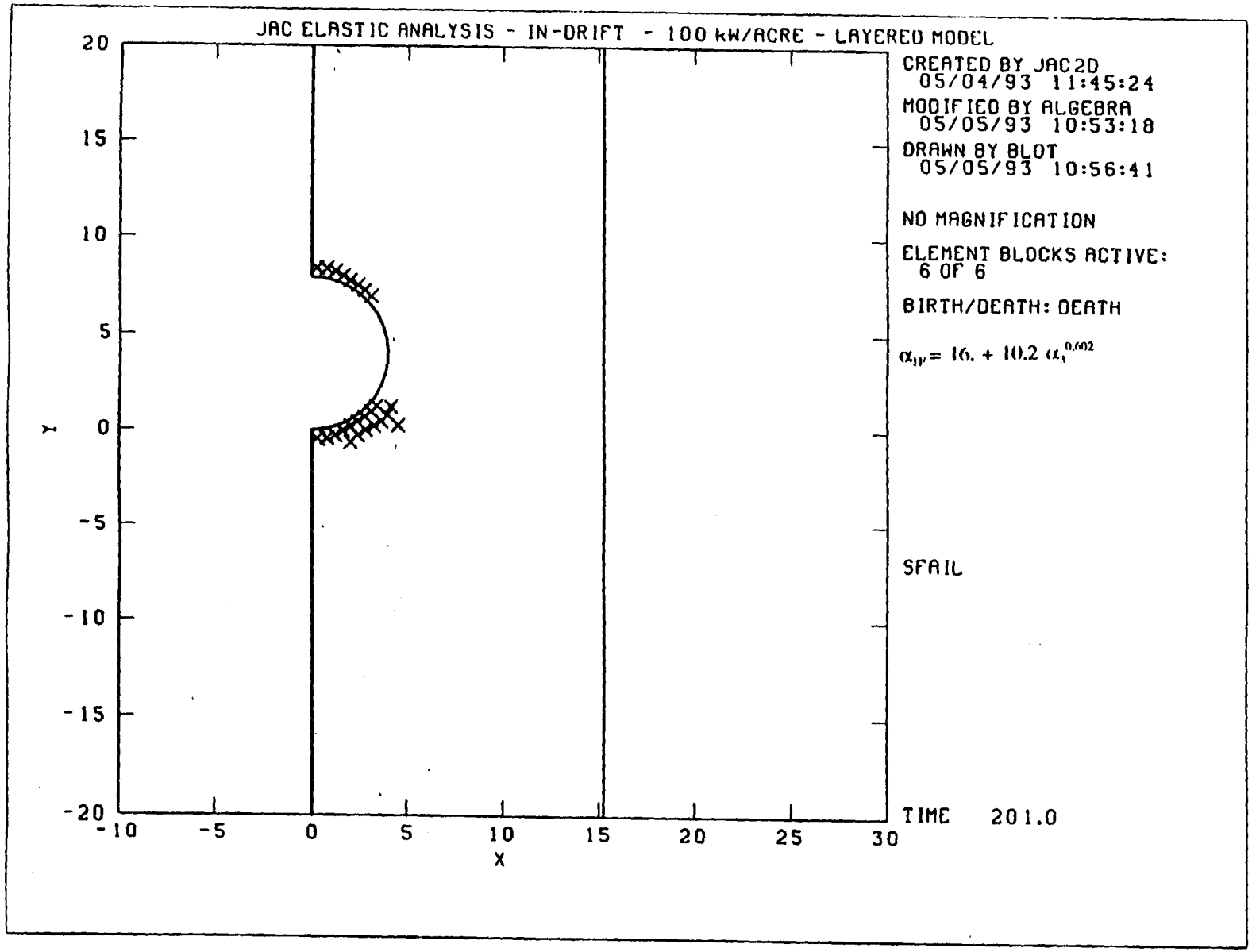


Figure A-5. Zones of Failed Rock at 200 yr for Unbackfilled Drift, Using Large Thermal Expansion (Figure 1)

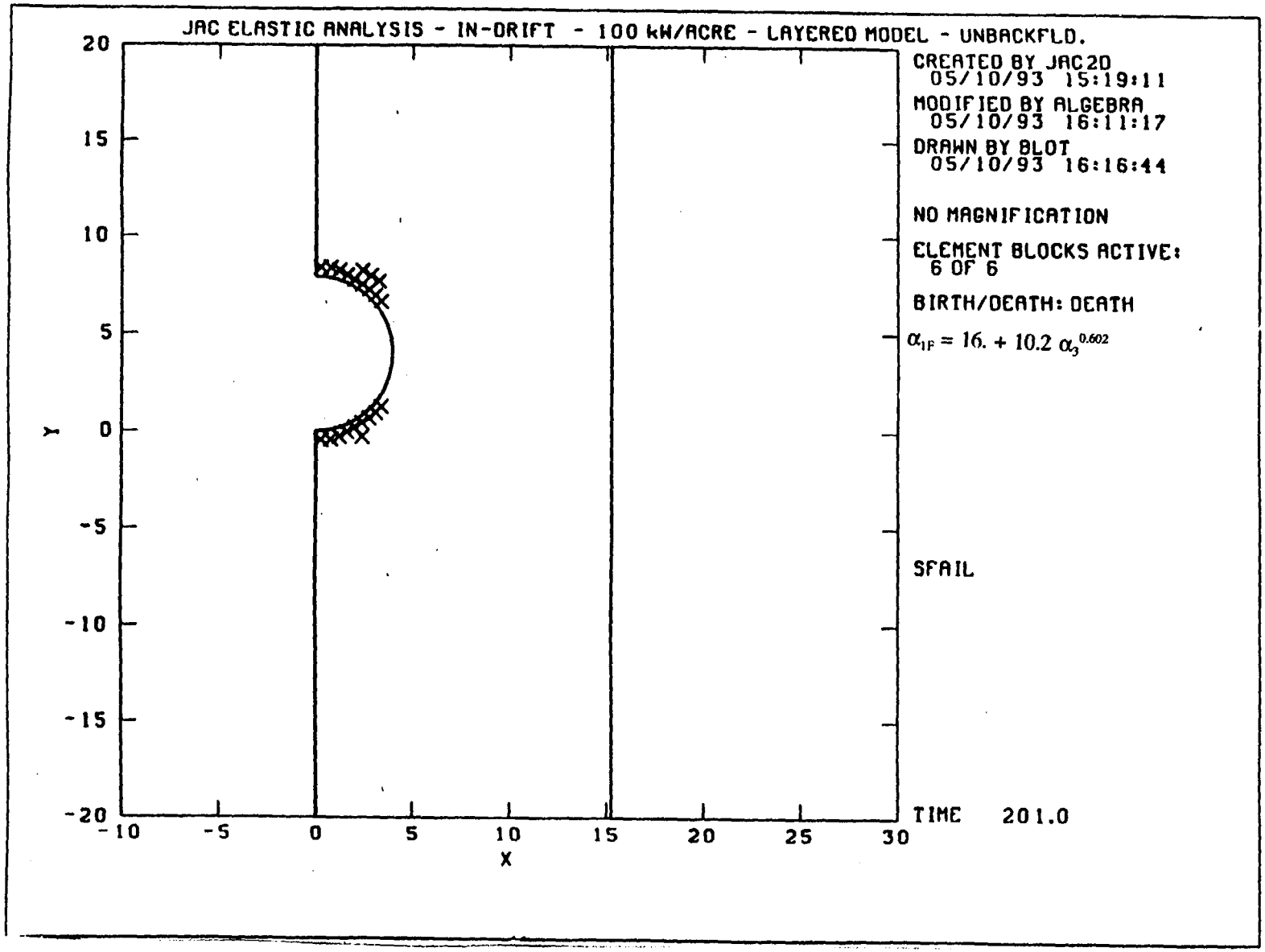


Figure A-6. Zones of Failed Rock at 75 yr Using Nominal Thermal Expansion (10 x 10^{-6}/° C)

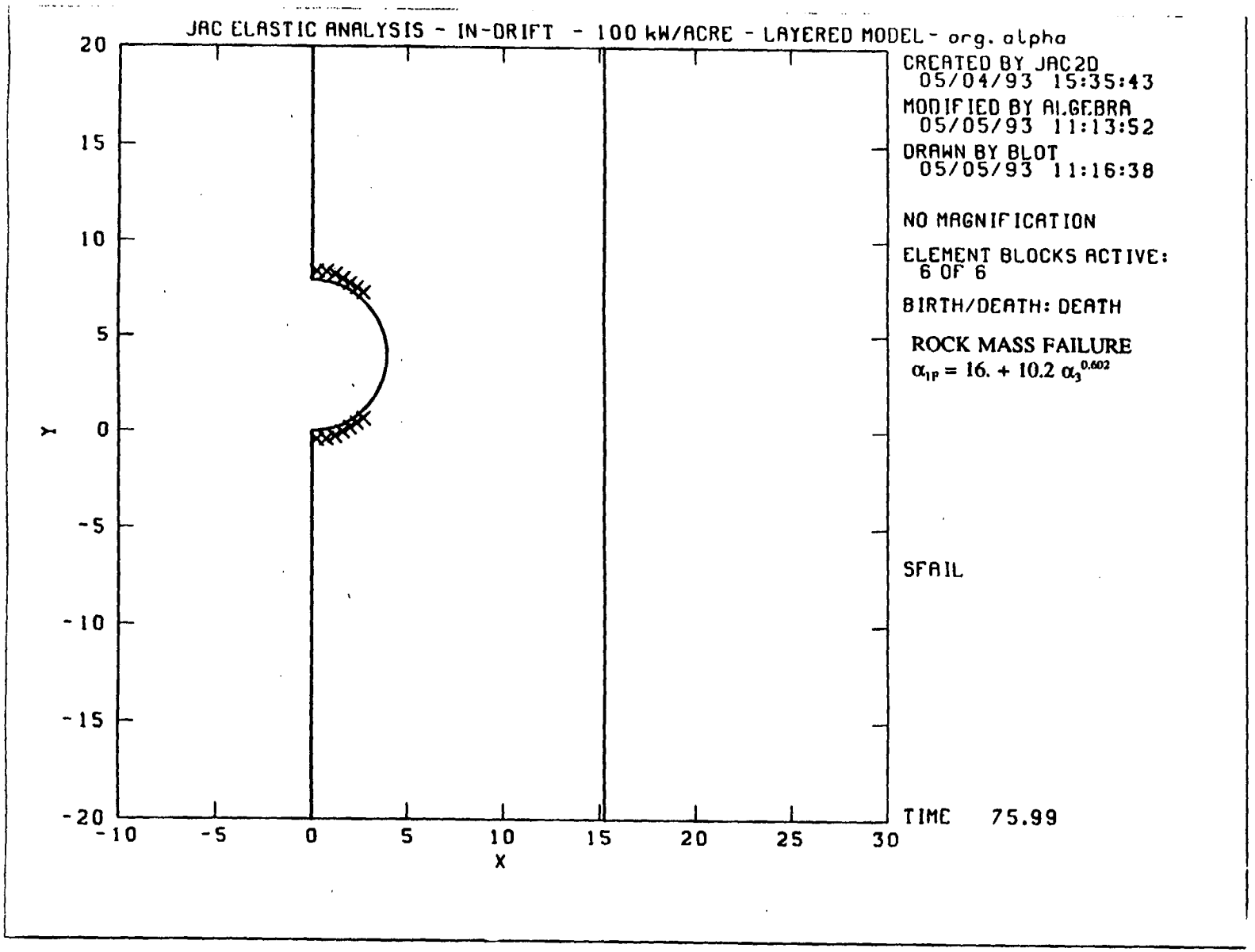


Figure A-7. Temperature Distribution Around Drift at 26 yr for a 100 kW/Acre Constant Thermal Output (No Decay in Thermal Output).

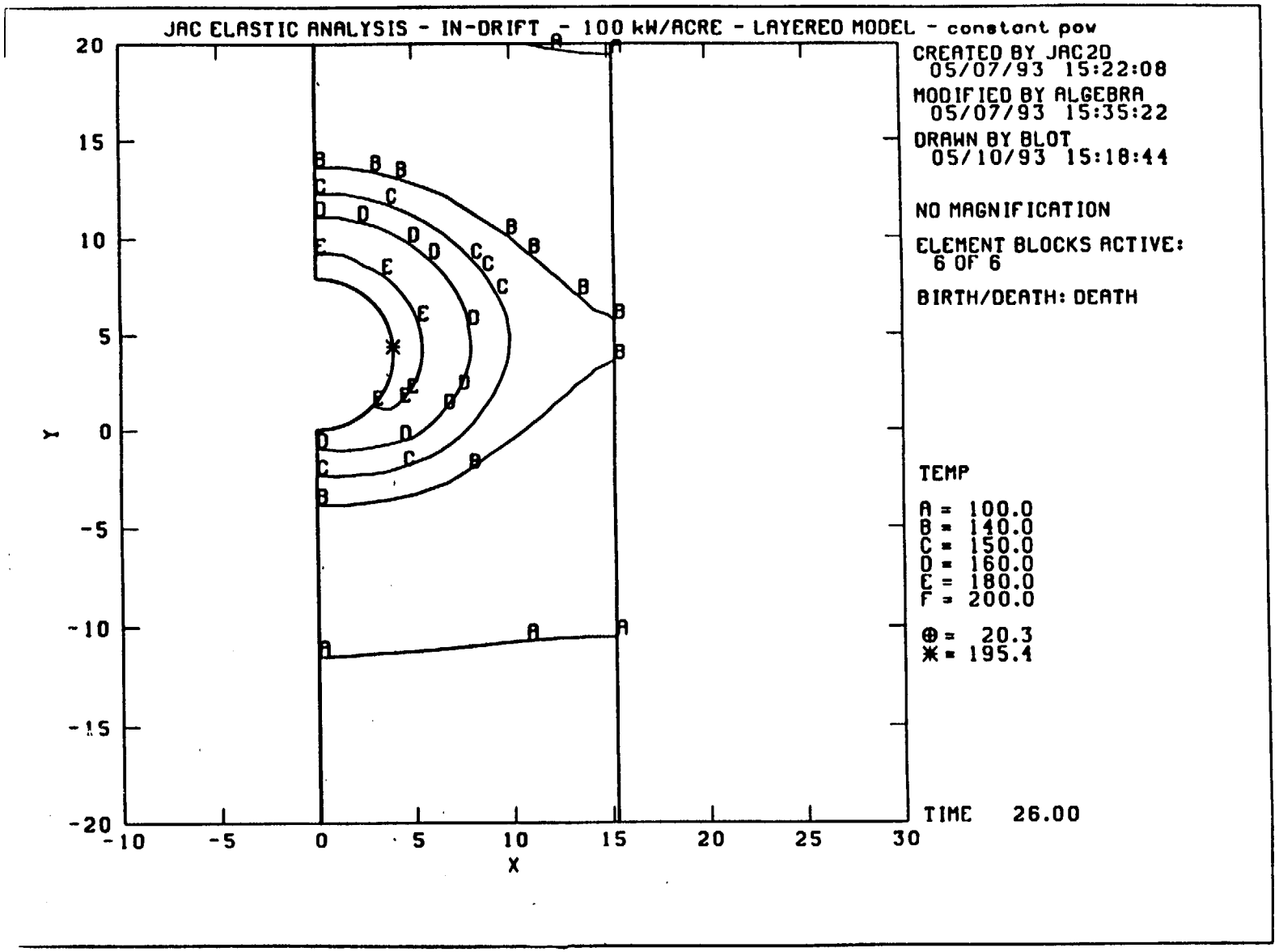


Figure A-8. Zones of Failed Rock at Same Conditions as in Figure A-7, A-8, Using Large Thermal Expansion (Figure 1)

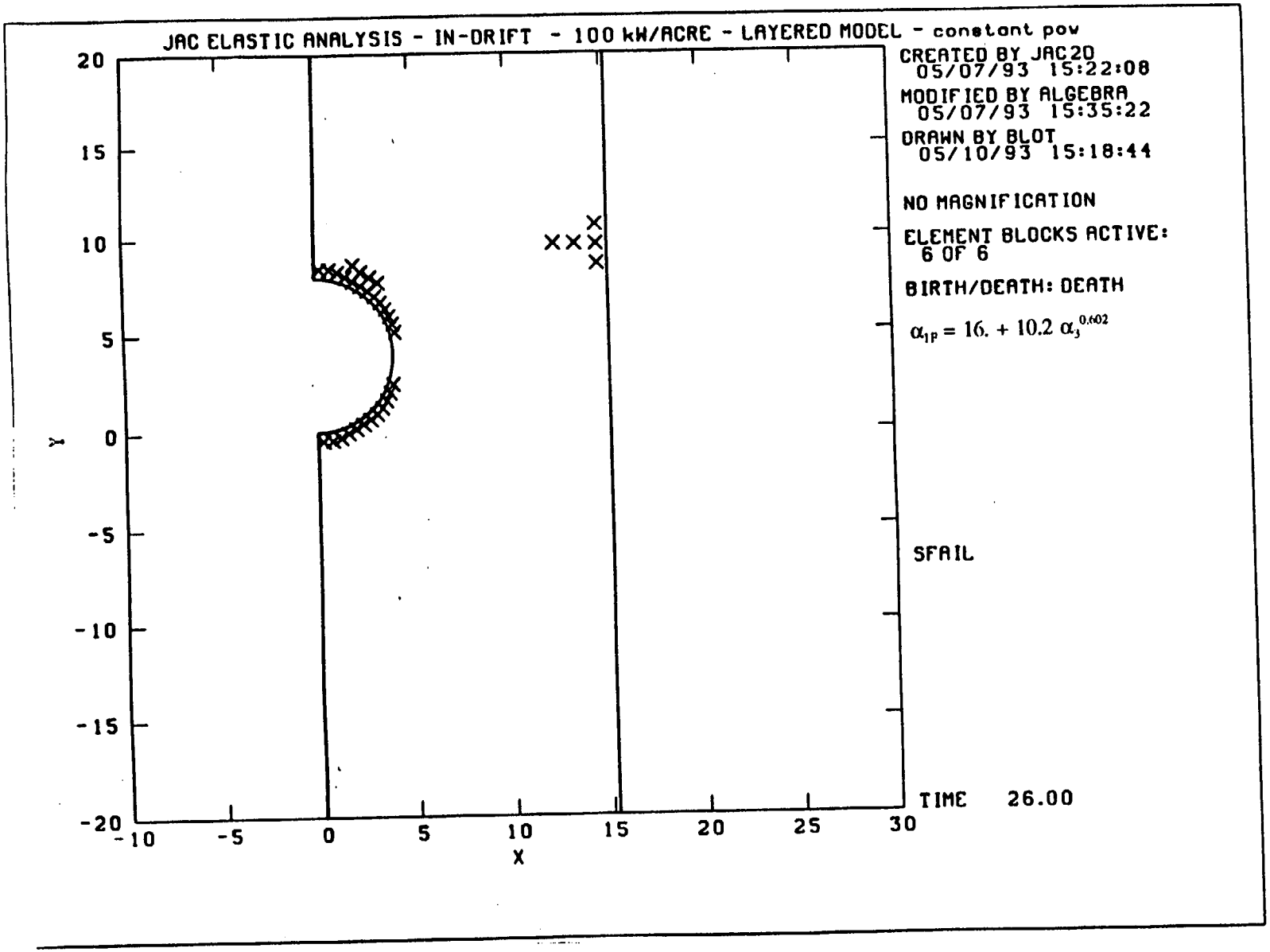


Figure A-9. Temperature Distribution Around Drift at 28 yr for a 100 kW/Acre Constant Thermal Output (No Decay in Thermal Output)

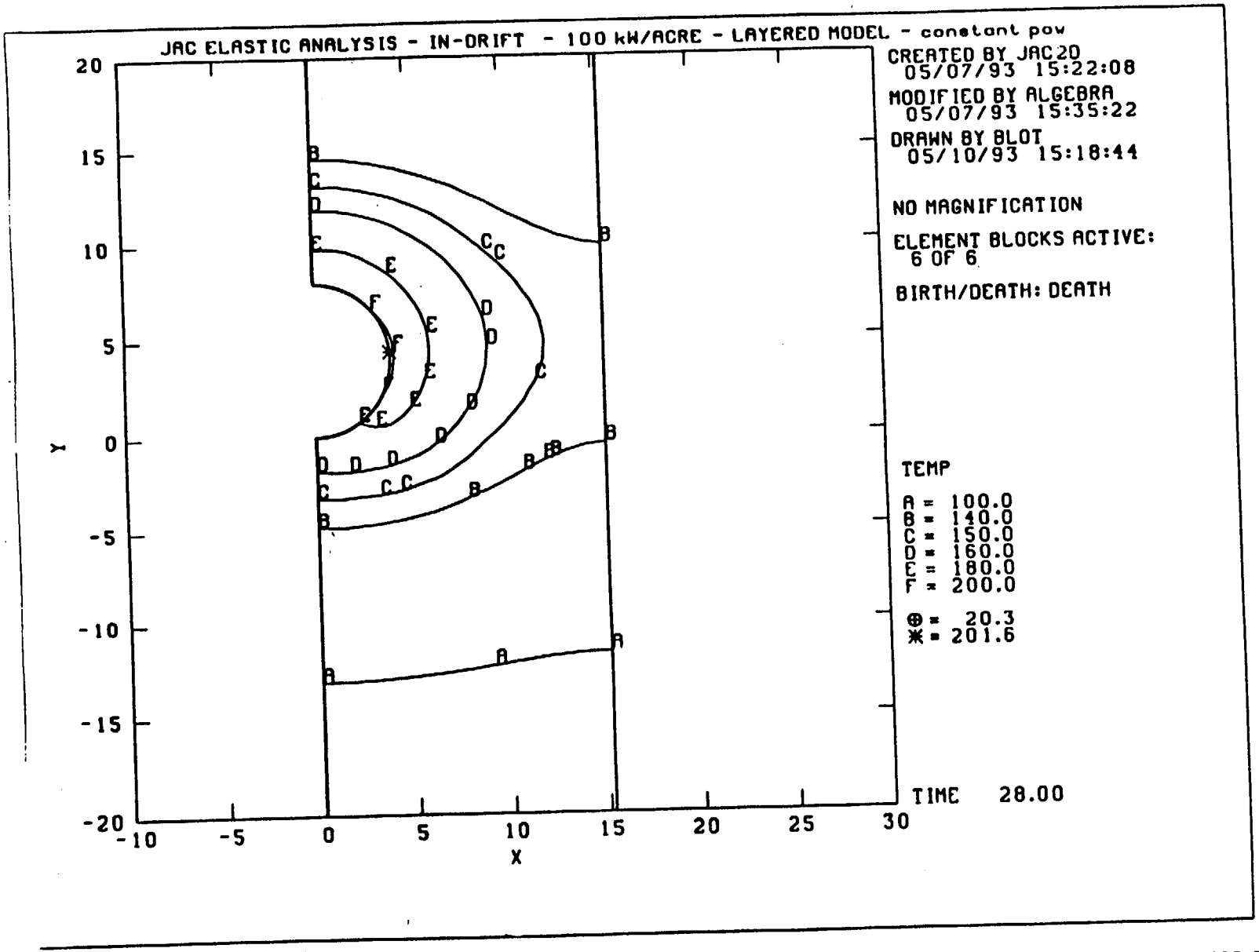
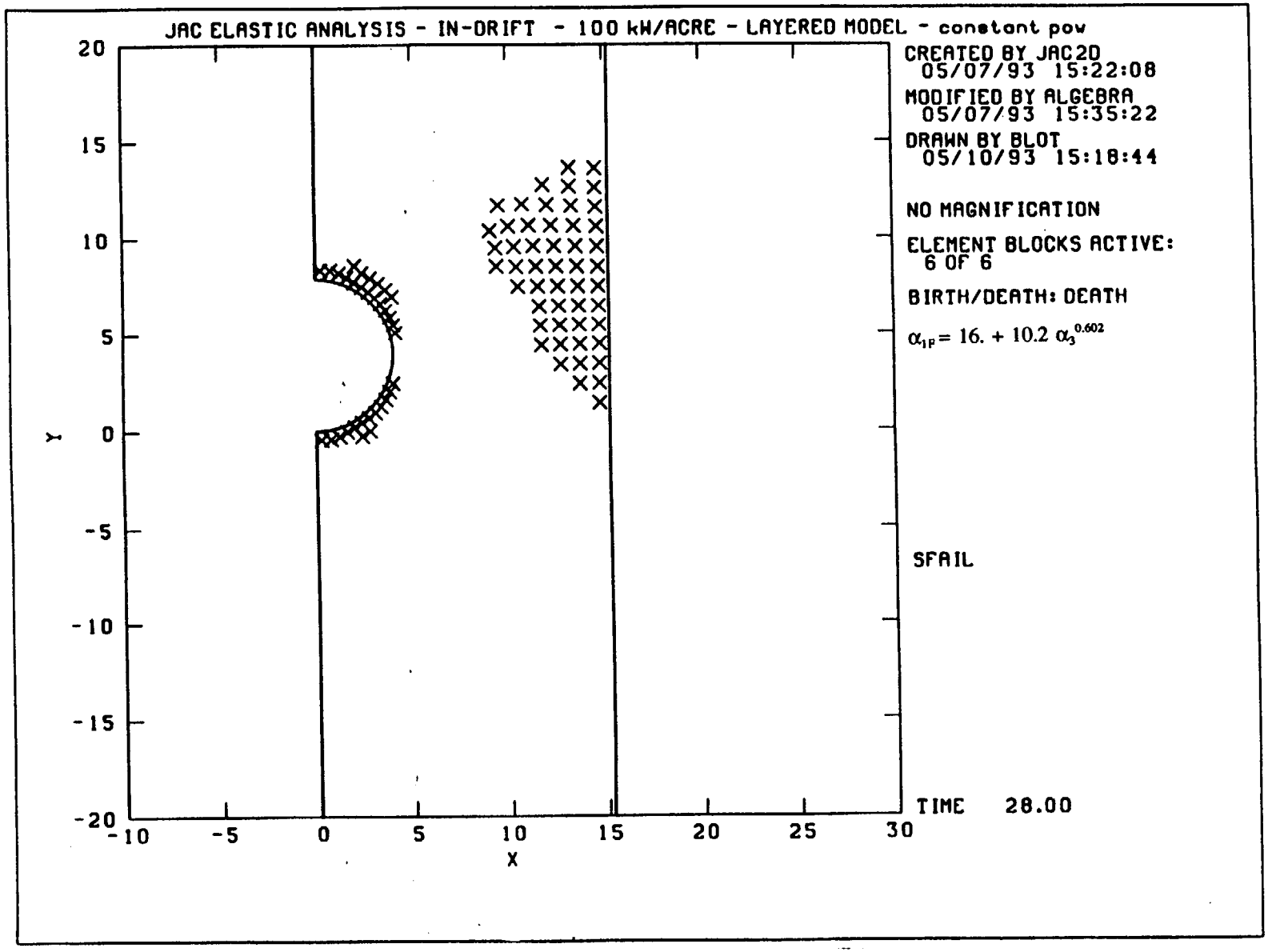


Figure A-10. Zones of Failed Rock at Same Conditions as in Figure A-9, Using Large Thermal Expansion (Figure 1)



APPENDIX B

HIGH LEVEL WASTE GLASS

TO: R. D. McCRIGHT
FROM: M. J. PLODINEC. 5-2170 DATE: 4/22/93
SUBJECT: THERMAL GOALS

I believe retention of the present thermal goal is the right thing to do, based on the following reasoning:

- It is unlikely that even "impervium" could pass all of the licensing hurdles necessary to certify a package as preventing ingress of water for 100,000 years. Thus, it is inevitable that waste form performance eventually will become part of the potential repository license.

- Keeping the potential repository dry as long as possible means that when the inevitable interaction between water and glass begins, it occurs at the lowest possible temperature. Thus, the rate of release of radioactivity is minimized. This implies that it is desirable to make the maximum temperature as high as possible.

- Conversely, the maximum temperature should be low enough that the properties of the glass are not adversely affected (compared to the same properties of unaltered glass).

- For "reasonable" waste glasses, the lowest temperature at which crystal formation is observed is 500-550°C. Thus, the thermal goal should not exceed 500°C.

Thus, I conclude that maintaining the present 500°C goal does not unduly restrict waste form producers, and may have positive benefits in licensing the potential repository. It must be noted, however, that I am ignoring thermal effects on the waste package materials, particularly our canister. This is appropriate for the DWPF, because YMP is taking no credit for our canister. However, depending on the material of the overpack, this may be a significant factor in the decision.

APPENDIX C

HEAT EXPOSURE THRESHOLDS

The following discussion of guidelines for permissible heat exposure thresholds was taken from a May 24, 1993, letter from Ricky Carr of Morrison Knudsen to Paul McKie of the M&O. It describes heat stress and heat exposure times for individuals working in mining environments.

(MK Letterhead)

DATE: May 24, 1993

TO: Paul Mc Kie

FROM: Ricky Carr

LOCATION: MK/Las Vegas

LOCATION: MK/Denver

SUBJECT: Heat Stress

The American Conference of Governmental Industrial Hygienists (ACGIH) has specified Threshold Limit Values (TLVs) for heat stress conditions under which it is believed that nearly all workers may be repeatedly exposed without adverse health effects. These TLVs are based on the assumption that nearly all acclimatized, fully clothed (e.g. lightweight pants and shirt) workers with adequate water and salt intake should be able to function effectively under the given working conditions without exceeding a deep body temperature of 38° C.

The TLV for heat stress is expressed as the Wet Bulb Globe Temperature Index (WBGT) and is a function of the work load, work-rest regimen, type of clothing worn, and acclimatization and fitness of the workers. The WBGT is calculated by the following equation (assuming no solar load):

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

where:
NWB=Natural Wet-Bulb Temperature
GT = Globe Temperature

The Natural Wet Bulb Temperature takes into account the relative humidity and the evaporative cooling from air movement (e.g. wind or ventilation). Globe Temperature accounts for radiant heat load.

Table 1. Examples of Permissible Heat Exposure Threshold Limit Values from the 1992-1993 Threshold Limit Values for Chemical Substances and Physical Agents is reproduced below:

	Work Load		
Work-Rest Regimen	Light	Moderate	Heavy
Continuous work	30.0	26.7	25.0
75% Work- 25% Rest, each hour	30.6	28.0	25.9
50% Work 50% Rest, each hour	31.4	29.4	27.9
25% Work- 75% Rest, each hour	32.2	31.1	30.0

Values are given in °C WBGT.

The TLVs specified in the above table are based on the assumption that the WBGT value of the resting place is the same or very close to that of the workplace. Where the WBGT of the workplace is different from that of the rest area, a time-weighted average value should be used for both environmental and metabolic heat. The TLVs for continuous work are applicable where there is a work-rest regimen of a 5-day work week and an 8 hour work day with a short morning and afternoon break of approximately 15 minutes and a longer lunch break of approximately 30 minutes. The permissible heat exposures TLVs are valid for light summer clothing. If special clothing is required for performing a particular job and this clothing is heavier or impedes sweat evaporation or has higher insulation value, then a correction factor to the TLV WBGT should be applied. Cotton coveralls should reduce the TLV WBGT by 2 °C.

Acclimatization to heat stress generally takes one to two weeks for healthy, well conditioned workers. Some loss of acclimatization may occur if exposure to heat stress does not occur for periods greater than two days, with substantial loss of acclimatization occurring if exposures do not occur for periods exceeding two weeks.

Based upon limited information regarding expected working conditions at the SEAM project it is anticipated that heat stress will be an occupational hazard for underground workers. Dry-bulb temperatures may reach 120° F (49° C); using the Psychrometric Chart and Vapor Pressure Nomograph (Figure 31-3, The Industrial Environment- Its Evaluation and Control, NIOSH, 1973) and assuming the relative humidity to be approximately 30%, this corresponds to a wet-bulb temperature of approximately 88 °F (31° C). It can be seen that if the above assumptions are correct that if the Globe Temperature exceeds 17° C then the WBGT TLV is likely to be exceeded.

Controls that could be considered to reduce the heat stress load that workers may experience include increased ventilation to reduce the Wet-Bulb temperature, the use of cooling vests to reduce the workers deep core temperatures, allowing or requiring more frequent breaks, and/or taking breaks in air-conditioned locations.

Metrosonics, Inc. (Box 23075, Rochester, NY 14692) manufactures a heat stress monitor capable of measuring WBGT and provide an 'instantaneous' readout. Imaging & Sensing Technology (465 Dobbie Dr., Cambridge, Ontario N1R 5X9) also makes a similar instrument.

FIGURE CAPTIONS - THIS PAGE NOT PART OF TEXT

ROCK MASS FAILURE
$\alpha_{1F} = 16. + 10.2\ \alpha_3^{0.602}$

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