Department of Energy
Washington, DC 20585

QA: N/A
DOCKET NUMBER 63-001

December 2, 2009

ATTN: Document Control Desk
Christian Jacobs, Senior Project Manager
Project Management Branch Section B
Division of High-Level Waste Repository Safety
Office of Nuclear Material Safety and Safeguards
U.S. Nuclear Regulatory Commission
EBB-2B2
11545 Rockville Pike
Rockville, MD 20852-2738

YUCCA MOUNTAIN – SUPPLEMENTAL RESPONSE – REQUEST FOR ADDITIONAL INFORMATION (RAI) –VOLUME 2, CHAPTER 2.1.1.4, SET 3 (DEPARTMENT OF ENERGY'S SAFETY ANALYSIS REPORT SECTION 1.7) – Identification of Event Sequences

References:
1. Ltr, Jacobs to Williams, dtd 6/03/09, "Yucca Mountain - Request for Additional Information – Volume 2, Chapter 2.1.1.4, Set 2 and Set 3 (Department of Energy's Safety Analysis Report Section 1.7)"
2. Ltr, Williams to Jacobs dtd 7/07/09, "Yucca Mountain - Request For Additional Information (RAI) –Volume 2, Chapter 2.1.1.4, Set 3 (Department of Energy's Safety Analysis Report Section 1.7)" – Identification of Event Sequences

The purpose of this letter is to transmit the U.S. Department of Energy's (DOE) supplemental response to one (1) Request for Additional Information (RAI). Supplemental RAI number 1 (Question #6) is provided as a separate enclosure. The original response to that RAI was provided on July 7, 2009, by Reference 2.

Four DOE references, not previously submitted to the U.S. Nuclear Regulatory Commission (NRC), are provided on optical storage media (OSM) as Enclosure 2. Additionally, Enclosure 3, on OSM, contains electronic attachments associated with two of the references. The electronic attachments are data files provided in their native file format, consistent with Sections 2.2 and 2.17 of the NRC guidance on electronic submissions. They are required by NRC staff in their native format to evaluate DOE's responses. The electronic attachments are not intended to be placed on or accessed through ADAMS, and will be made available to the public upon request. DOE expects to submit the remaining supplemental responses on or before December 21, 2009.

There are no commitments made in the enclosed supplemental response. If you have any questions regarding this letter, please contact me at (202) 586-9620, or by email to jeff.williams@rw.doe.gov.

Jeffrey R. Williams
Jeffrey R. Williams, Supervisor
Licensing Interactions Branch
Regulatory Affairs Division
Office of Technical Management

OTM:SAB-0142

NMSS25

Enclosures (3):

1. Supplemental Response to RAI Volume 2, Chapter 2.1.1.4, Set 3, Number 1 (Question #6)
2. Optical Storage Media – DVD containing four references
3. Optical Storage Media – DVD containing electronic reference attachments

cc w/enclosure 1:
J. C. Chen, NRC, Rockville, MD
J. R. Cuadrado, NRC, Rockville, MD
J. R. Davis, NRC, Rockville, MD
R. K. Johnson, NRC, Rockville, MD
A. S. Mohseni, NRC, Rockville, MD
N. K. Stablein, NRC, Rockville, MD
D. B. Spitzberg, NRC, Arlington, TX
J. D. Parrott, NRC, Las Vegas, NV
L. M. Willoughby, NRC, Las Vegas, NV
Jack Sulima, NRC, Rockville, MD
Christian Jacobs, NRC, Rockville, MD
Lola Gomez, NRC, Rockville, MD
W. C. Patrick, CNWRA, San Antonio, TX
Budhi Sagar, CNWRA, San Antonio, TX
Bob Brient, CNWRA, San Antonio, TX
Rod McCullum, NEI, Washington, DC
B. J. Garrick, NWTRB, Arlington, VA
Bruce Breslow, State of Nevada, Carson City, NV
Alan Kalt, Churchill County, Fallon, NV
Irene Navis, Clark County, Las Vegas, NV
Ed Mueller, Esmeralda County, Goldfield, NV
Ron Damele, Eureka County, Eureka, NV
Alisa Lembke, Inyo County, Independence, CA
Chuck Chapin, Lander County, Battle Mountain, NV
Connie Simkins, Lincoln County, Pioche, NV
Linda Mathias, Mineral County, Hawthorne, NV
Darrell Lacy, Nye County, Pahrump, NV
Jeff VanNeil, Nye County, Pahrump, NV
Joe Kennedy, Timbisha Shoshone Tribe, Death Valley, CA
Mike Simon, White Pine County, Ely, NV
K. W. Bell, California Energy Commission, Sacramento, CA
Barbara Byron, California Energy Commission, Sacramento, CA
Susan Durbin, California Attorney General's Office, Sacramento, CA
Charles Fitzpatrick, Egan, Fitzpatrick, Malsch, PLLC

<u>EIE Document Components</u>:

[102529]_BABEAF000-01717-0200-00002.pdf	2,594 kB
[185082]_860-K0C-SSD0-00100-000-00B_1.pdf	41,225 kB
[185082]_860-K0C-SSD0-00100-000-00B_2.pdf	32,405 kB
[186510]_800-30R-SSP0-00100-000-00A.pdf	13,948 kB
[186512]_810-KVC-VUE0-00100-000-00A.pdf	4,270 kB

RAI Volume 2, Chapter 2.1.1.4, Third Set, Number 1, Supplemental Question 6:

Clarify the basis for using plain concrete as ground support for ventilation exhaust shafts that could be subject to thermal stresses due to heating from exhaust air (SAR 1.3.3.3.1).

1. RESPONSE

The selection of plain concrete as the ground support for the repository shafts is based on analysis of its performance under the operational conditions anticipated for the exhaust shafts, for a service life of 100 years and is subject to the applicable requirements and criteria described in SAR Sections 1.3.2 and 1.3.3.3. The use of a concrete liner has been analyzed for representative shafts for the anticipated construction, *in situ*, thermal, and seismic loads during the preclosure period. The subsurface ground support design information is presented in SAR Section 1.3.3.3.1, with SAR Section 1.3.3.3.1.5 being specific to the shaft ground support design. This response includes submittal of the *Shaft Liner Design* calculation (BSC 2008a) referenced in SAR Section 1.3.3, which evaluated the shaft stability, the shaft ground control and reinforcement, and the parameters of the shaft liner required to maintain the long term shaft operation. The *Shaft Liner Design* calculation demonstrated unreinforced (plain) concrete to be adequate as a shaft liner (BSC 2008a, Section 7.1). The *Evaluation of Potential Impacts of Off-Normal Temperatures on Inaccessible Nonemplacement Openings* (BSC 2007) is also submitted with this response as it specifically evaluated potential impacts of the maximum off-normal temperatures on inaccessible nonemplacement repository openings. The shaft liner calculation examines thermal stresses on the shaft structure resulting from heating of the rock mass, while the off-normal temperatures document examines the impact of heated exhaust air in the exhaust mains and exhaust shafts.

As illustrated in SAR Figure 1.3.4-16, the emplacement drift exhaust air temperature peaks shortly after emplacement of the waste packages and decreases steadily thereafter. Outlet air temperatures for typical 600 m and 800 m long emplacement drifts peak at approximately 83°C and 100°C, respectively (BSC 2008b[1], Tables 7 and 9). Throughout the preclosure period, the shafts will experience lower air temperatures than the calculated maximum exhaust air temperatures reported in Figure 1.3.4-16 because of the phased emplacement of the waste over time, such that the heated air stream exhausting out of multiple emplacement drifts toward a single shaft will be a mix of different air temperatures, and the exhaust shaft concrete would not experience the maximum possible air temperatures from each drift. Also, as documented in the *Temperature Change in Exhaust Airflow* calculation (BSC 2008c), a computational fluid dynamics-based simulation of the airflow heat transfer process (using the computational code FLUENT), the heated air from the emplacement drift cools as the air moves through the exhaust main (by heat convection to the ambient rock) and up the exhaust shaft (by adiabatic cooling) to the surface. Figure 1 illustrates time history results from the FLUENT evaluations of the shaft airflow temperatures.

---

[1] BSC 2008b is being submitted as an attachment to RAI 2.2.1.1.4-3-001 response (RTN 00409-06-00).

1.1 PROPERTIES AND CODES FOR THE SHAFT LINER

Mechanical properties and applicable American Concrete Institute (ACI) codes for the concrete liner for the repository shafts are listed in SAR Table 1.3.3-4. The concrete liner is based on a typical concrete compressive strength of 6,000 psi, and the design utilizes structural concrete codes ACI 318-02/318R-02, *Building Code Requirements for Structural Concrete*, and ACI 506R-05, *Guide to Shotcrete*.

A temperature of 177°C (350°F) is considered as the short-term limit under which concrete, when used for ground support, can function during off-normal operations (ACI 349-01) (BSC 2007, Sections 2 and 6.2).

1.2 SHAFT LINER DESIGN CALCULATION

The *Shaft Liner Design* calculation (BSC 2008a) provides a shaft stability analysis based on the thermal inputs derived from thermal line loads of 1.45 kW/m and 2.0 kW/m. The 1.45 kW/m evaluation considers a 100 year preclosure period with 50 years of forced ventilation followed by 50 years of natural ventilation. A 100-year forced ventilation heating period is considered for the 2.0 kW/m evaluation (BSC 2008a, Section 1). The *Shaft Liner Design* calculation uses FLAC3D, a three-dimensional finite difference program, to model the three-dimensional rock structures and perform coupled mechanical and thermomechanical analyses (BSC 2008a, Section 4.2.1).

Consistent with project thermal designs, the *Shaft Liner Design* calculation results are based on waste package heat generation from instantaneous waste emplacement over the entire repository, and the phased emplacement of waste packages over time was conservatively not considered (BSC 2008a, Section 3.2.1). The rock strata response evaluations considered a range of rock material properties and loading cases (BSC 2008a, Sections 1 and 6.2.1). The analysis also did not take credit for the initial ground support, typically consisting of rock bolts and wire mesh (BSC 2008a, Section 6.5.4.1).

1.2.1 Shaft Liner Design Methodology

Typically, shaft analyses include calculations of shaft deformations resulting from the *in situ* stresses present at a particular shaft depth. These deformations depend on rock properties and shaft diameter, as well as the type of shaft liner and other ground support used to maintain stability of the shaft excavation. Considering that the shaft liner is installed after most of the rock deformation due to shaft excavation has already occurred, the liner will not be subject to any significant ground pressure due to *in situ* stress relaxation. Therefore, thermally induced stresses are the only stresses carried by the liner under the static loading conditions (BSC 2008a, Section 6.5.3.1.2).

The calculation first evaluates the performance of a shaft excavation without ground support, and then the support liner is added. The unsupported shaft case is used as a benchmark of shaft performance to which the performance of the shaft with the liner installed is compared. The analyses are performed utilizing geotechnical data characterizing the behavior of distinct stratigraphic units of five rock mass categories which bound the variability of rock properties. As noted above, the calculation analyzes and compares the shaft structural analysis results of the original 1.45 kW/m thermal loading to the 2.0 kW/m thermal loading conditions in order to evaluate the shaft structural results for the higher thermal loading (BSC 2008a, Sections 1 and 4.3).

A generic shaft, which contained the simplified stratigraphy representative of other shafts, was modeled. A generic depth of 400 m (1,312 ft) was selected to represent the repository average shaft depth of 346 m (1,135 ft), adding some conservatism to the analysis (BSC 2008a, Section 3.2.2). The generic shaft is considered to represent an average case and no distinction is made for this shaft to be either the intake or an exhaust-type shaft for the unsupported shaft case (BSC 2008a, Section 6.3). Static and dynamic analyses of the unlined shaft indicate the shaft and shaft/shaft station intersections remain stable (BSC 2008a, Section 7.1).

The *Shaft Liner Design* calculation's thermal methodology identifies and describes the two approaches utilized to evaluate the effect of thermal loads using temperature fields after 100 years of heating. The first approach involved FLAC3D computer modeling for a detailed assessment of the thermally induced liner hoop stresses within a 1.25 m thick slab of each thermal mechanical unit. The second approach involved FLAC3D computer modeling for a large regional model which considered the thermally-induced stresses on the repository scale. These stresses develop as a result of heating the entire repository block rock mass, and are different in the middle section of the repository block from those around the periphery (BSC 2008a, Section 4.3.1.2.2).

Although the *Shaft Liner Design* calculation's details are not repeated in this response, the following calculation content guide is provided (BSC 2008a):

- Section 6.5.1—Documentation of the baseline case and the unlined shaft evaluation
- Section 6.5.2—Description of the modeling for a lined shaft
- Section 6.5.3—Description of the shaft performance, and
- Section 6.6—Discussion of uncertainty evaluations for the calculation's inputs, properties, and loading conditions.

1.2.2 Modeling of the Shaft Liner

The plain, unreinforced concrete was selected as a construction material for the shaft liner based on the following considerations. First, the use of concrete in shafts is a common and proven technology that adds to the confidence regarding construction quality and predictability of results. Second, the concrete-lined shaft is smooth and durable, providing minimum resistance to airflow. Third, at closure of the repository, the unreinforced concrete can be removed, per repository closure plans described in SAR Section 1.3.6 (BSC 2008a, Section 6.5.5.1).

For the generic shaft, results of modeling indicate that, for the ground conditions considered, shaft excavations are expected to be stable along their entire depths. The expected shaft closure is relatively small and the rock mass deformations are generally elastic. Plastic deformations around shafts might occur in the poor quality rock mass (e.g., Category 1 of PTn and TSw1 lithophysal units); however, their extent is limited (BSC 2008a, Section 6.5.1.2, p. 71).

A 0.3 m (12 in.) and 0.25 m (10 in.) concrete liner for shafts with an 8 m (26 ft) excavated diameter, and 0.25 m (10 in.) thick shaft liner for shafts with a 5 m (16 ft) excavated diameter were analyzed. The thermal evaluation considers the generic shaft configuration at the periphery of the repository and shafts in the middle of the repository, which will experience different stresses. The differences in deformation and thermally induced stresses depend on the location of the shaft in the layout, specifically, the distance between the shaft and the center of the heated area. As such, two shafts were modeled as representative of thermal conditions existing in the middle of the repository, and two shafts were modeled as representative of thermal conditions existing along the periphery of the emplacement area. One intake and one exhaust shaft were modeled in each of these two thermal conditions. The largest stress changes in the horizontal plane due to thermal loading and the maximum vertical displacements, the result of thermal strain, occur at shafts located in the middle of the repository (BSC 2008a, Section 6.5.2.1).

1.2.3 Summary of Shaft Liner Evaluations

Conditions After 100 Years of Heating—After 100 years of heating, stresses in the shaft liners analyzed for both the 1.45 kW/m and 2.0 kW/m thermal loads (34.47 MPa and 23.45 MPa tangential stress; 20.10 MPa and 13.67 MPa axial stress respectively (BSC 2008a, Table 6-39)) will not exceed the concrete compressive strength of 40 MPa, but tangential stresses in the TSw1 lithophysal and TSw2 nonlithophysal units will exceed the allowable stress of 26.0 MPa. This will result in some rock degradation (fracturing) around the liner. The allowable stress is determined by applying a 0.65 reduction factor to the compressive value (as recommended by ACI 318-02), which indicates the potential for tensile cracking of the concrete liner. The overall shaft stability is preserved since the compressive strength is not exceeded. Otherwise, the thermal loading cases analyzed in the 2.0 kW/m thermal load analysis indicate that the liner stresses do not exceed the allowable liner stresses (BSC 2008a, Section 6.5.2.3.1). The analysis approach uses thermal parameters that are considered conservative to establish a bound of the shaft liner stress, and the calculated thermal stresses are judged to be higher than those expected under field conditions (BSC 2008a, Section 6.5.4).

Final Ground Support—A 0.3 m (12 in.) thick concrete liner for an 8 m (26 ft) shaft excavated diameter and a 0.25 m (10 in.) thick shaft liner for a 5 m (16 ft) shaft excavated diameter were analyzed. Results of analyses indicate that overall shaft stability is preserved and satisfies the design requirements. The analysis of shaft performance under thermal and seismic loads has shown that the concrete liner stress in shafts located near the center of the repository, and at the deeper shaft sections, exceeds the allowable limit; however, the shaft liner stress level is well below the uniaxial compressive strength of concrete. Under thermal and seismic loads, shaft fracturing (tensile cracking) may occur at some locations in the form of subhorizontal cracks in the shaft liner. As described above, the overall shaft stability is preserved since the compressive strength is not exceeded. These lateral cracks are common in typical mine shaft structures and experience has shown that such cracks do not pose any safety and/or operational difficulties (BSC 2008a, Section 6.5.4).

It should be noted that the thermal parameters used in the analyses are considered conservative; the thermally induced stresses are judged to be higher than those expected under actual field conditions, and the overall shaft performance under thermal and seismic loads is considered acceptable (BSC 2008a, Sections 6.5 and 7.1).

As noted in Section 6.5.4.1 of *Shaft Liner Design* (BSC 2008a), though not analyzed in the calculation, the option of including steel fibers in the concrete mix would increase the tensile strength of the liner and could be reviewed during the detailed design phase.

1.2.4 Related Support Information

Drift Scale Test—The Drift Scale Test was an integral part of the Yucca Mountain site characterization program: a full-scale *in situ* thermal test with the purpose of developing a better understanding of thermal, mechanical, hydrological, and chemical processes, as well as the interaction between those processes taking place in the rock mass. An important aspect of the test covered the performance of the two tunnel sections, one equipped with the concrete liner and the other supported with a ground support system of wire mesh and friction-type rockbolts. The heated test drift concrete liner has a nominal 0.2 m thickness and contains sections of both unreinforced plain concrete and steel fiber reinforced concrete (CRWMS M&O 1997, Section 8.2). The unreinforced lining configuration is similar to the design shaft concrete liner.

After approximately five years of heating the drift to a test temperature on the order of 200°C (392°F), the heaters were turned off (January 2002). After four years of ambient cooling, a reentry into the drift for inspection was done (April 2006). Observations of the tunnel section equipped with the cast-in-place concrete liner ground support revealed no major structural instabilities and no evidence of the liner deteriorating due to the elevated temperature. The tunnel invert remained free of concrete fragments that would indicate concrete liner damage. The concrete shrinkage cracks commonly observed in concrete during the curing stage were identified before the start of the heating cycle. These cracks have shown no signs of deterioration or relative movement.

Because the overall effects of thermal load in the current calculation are not expected to produce excessively large stresses at the maximum temperature, which is about one half of that temperature introduced in the Drift Scale Test, which produced no visible evidence of damage, the effects on shaft liner due to the heat from the ventilation air is expected to be relatively minor (BSC 2008a, Section 6.6.3).

Potential Impacts of Off-Normal Temperatures—A study also submitted with this response, *Evaluation of Potential Impacts of Off-Normal Temperatures on Inaccessible Nonemplacement Openings* (BSC 2007), assessed potential impacts of the expected maximum temperature that the shafts' concrete liners would be exposed to during a short-duration off-normal event. That maximum temperature has been defined as 177°C (350°F) for the exhaust mains, intersections formed by exhaust mains and emplacement drifts, and the exhaust shafts. Off-normal temperature profiles are based on temperatures due to loss of ventilation during the preclosure period (BSC 2007, Section 5.4). Although the study determined that it was an unlikely scenario for the exhaust-side openings to experience a temperature approaching 177°C (350°F) when the maximum drift wall temperature for the emplacement drifts is below 200°C (392°F) (BSC 2007, Section 9), the results indicated that the cementitious materials in the exhaust mains, intersections formed by exhaust mains and emplacement drifts, and exhaust shafts will not be detrimentally affected or impacted when subjected to an off-normal temperature pulse up to 177°C (350°F).

Inspections—*Ground Support Maintenance Plan* (BSC 2008d) specifies activities associated with maintaining safe and continuous operation of all subsurface openings. Exhaust shafts are inaccessible for human entry under normal operating conditions due to high temperatures and will be inspected by a specialized device equipped with cameras and laser measuring systems. Conceptually, the device will be similar to those used in industry for the inspection of the inside of wastewater pipes. The inspection interval will be determined during detailed design and modified as observations are taken. Inspections will also be conducted following seismic events (BSC 2008d, Section 6.2.1).

2. COMMITMENTS TO NRC

None.

3. DESCRIPTION OF PROPOSED LA CHANGE

None.

4. REFERENCES

ACI 318-02/318R-02. 2002. *Building Code Requirements for Structural Concrete (ACI 318-02) and Commentary (ACI 318R-02).* Farmington Hills, Michigan: American Concrete Institute. TIC: 252731.

ACI 349-01. 2001. *Code Requirements for Nuclear Safety Related Concrete Structures.* Farmington Hills, Michigan: American Concrete Institute. TIC: 252732.

ACI 506R-05. 2005. *Guide to Shotcrete.* Farmington Hills, Michigan: American Concrete Institute. TIC: 258596.

BSC (Bechtel SAIC Company) 2007. *Evaluation of Potential Impacts of Off-Normal Temperatures on Inaccessible Nonemplacement Openings*; 800-30R-SSP0-00100-000-00A. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20070329.0011.

BSC 2008a. *Shaft Liner Design.* 860-K0C-SSD0-00100-000-00B. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20080215.0003.

BSC 2008b. *Preclosure Emplacement Drift Temperature Calculation for the 2.0 kW/m Thermal Load.* 800-KVC-VUE0-00700-000-00A. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20080110.0001.

BSC 2008c. *Temperature Change in Exhaust Airflow*. 810-KVC-VUE0-00100-000-00A. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20081120.0002.

BSC 2008d. *Ground Support Maintenance Plan*. 800-30R-SSD0-00100-000-00C. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20080215.0001.

CRWMS M&O 1997. *Heated Drift Cast-in-Place Concrete Lining Test Configuration Requirements Analysis*. BABEAF000-01717-0200-00002 REV 01. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19970718.0074.

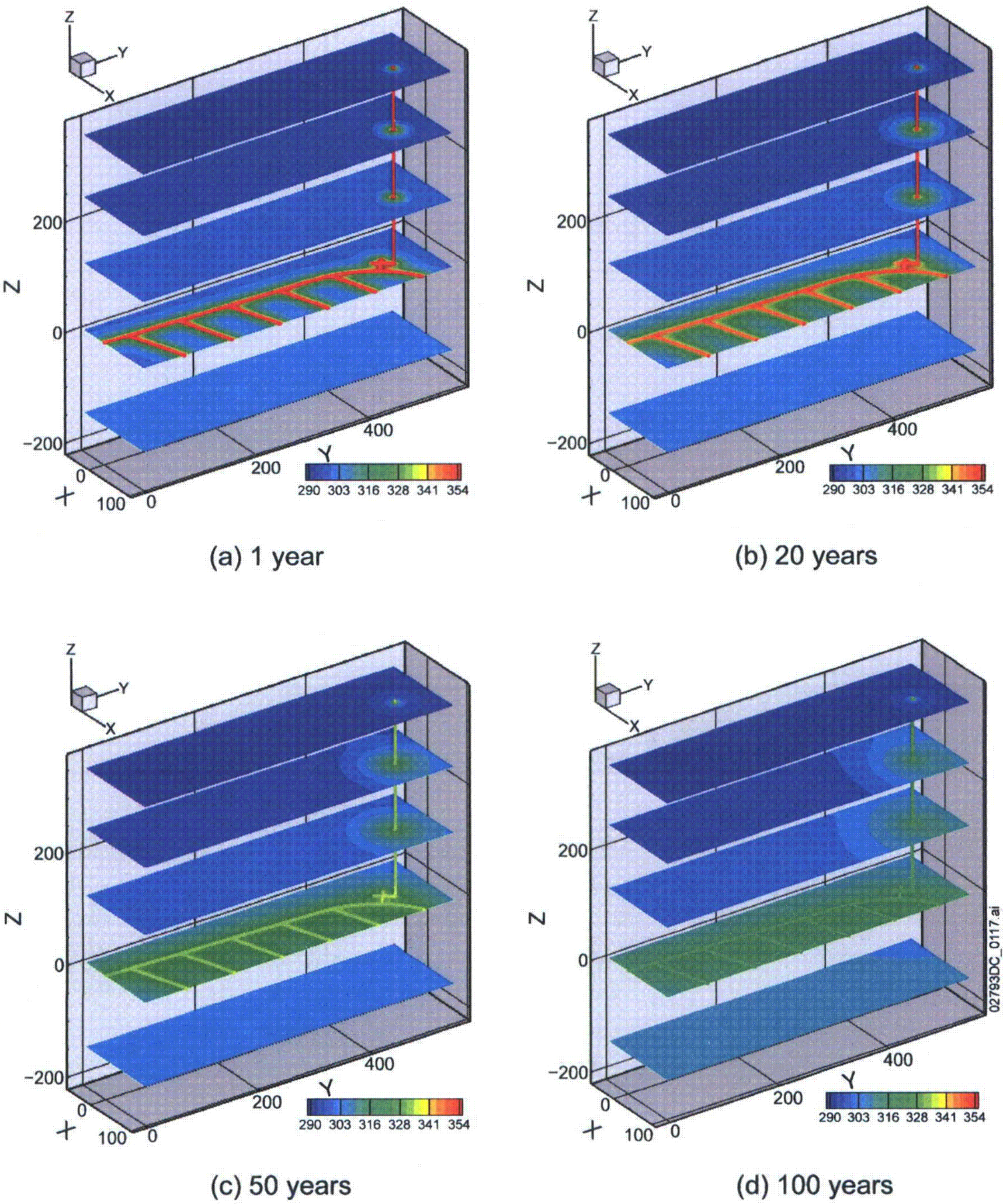

Figure 1. Slice View of Rock Mass Temperature (K) Distribution for Selected Time Intervals with Instantaneous Emplacement of Waste

NOTE: Temperature scale in degrees Kelvin (K = °C + 273.15). Axis dimensions in the x, y, and z directions are in meters.

Source: BSC 2008c, Figure 4.