PROCESS- AND SYSTEMS-LEVEL SENSITIVITY ANALYSES—STATUS REPORT

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QUALITY OF DATA, ANALYSES, AND CODE DEVELOPMENT

DATA: CNWRA-generated original data that are contained in this report meet quality assurance requirements described in the CNWRA Quality Assurance Manual. Sources for other data should be consulted for determining the level of quality for those data.

ANALYSES AND CODES: Analyses in this report were performed using the codes MULTIFLO Version 1.2β and TPA Version 3.2 which are controlled under CNWRA Technical Operating Procedure 018, Development and Control of Scientific and Engineering Software.

1 INTRODUCTION

Numerical analyses at the process and systems levels were conducted to evaluate the importance of critical components of thermal effects on flow (TEF) on the predicted performance of the proposed high-level nuclear waste (HLW) repository at Yucca Mountain (YM), Nevada. Process-level analyses were conducted with a heat and mass transfer code to simulate thermally driven redistribution of moisture in the region near the emplacement drifts in response to recent repository design changes under consideration by the U.S. Department of Energy (DOE). Design changes addressed in these analyses include a thermal load created by disposal of spent nuclear fuel (SNF) equivalent to 60 metric tons of uranium (MTU)/acre and active ventilation of emplacement drifts for 50 yr after waste emplacement.

Systems-level analyses were conducted using the Nuclear Regulatory Commission (NRC) performance assessment code TPA Version 3.2 to ascertain which conditions could lead to TEF becoming an important factor to repository performance. Two categories of TPA analyses were conducted, both for four cases: (i) basecase, (ii) basecase modified to include the effects of dripping, (iii) basecase modified to include the effects of specific corrosion factors modified to account for occurrences of rapid corrosion at closure welds or other possible waste package (WP) material susceptibility, and (iv) basecase modified to include both the effects of dripping and the effects of modified corrosion parameters. The first category of systems-level analyses evaluated the importance of the TEF processes on the failure of the WP by corrosion. The second category of analyses evaluated the impact of refluxing, as represented in the REFLUX3 submodule of TPA Version 3.2, on radionuclide release from the WP after failure. Repository performance was reported in terms of annual individual dose predicted 20 km downgradient along the path of groundwater flow from the proposed repository and in terms of number of WP failures by corrosion. The annual individual dose is synonymous to the total effective dose equivalent as defined in 10 CFR Part 20.

In the first category of analyses, the threshold relative humidity (RH) value at which aqueous corrosion occurs was decreased to simulate corrosion from dripping into an otherwise low RH environment. The chloride concentration multiplication factor applied to water entering an emplacement drift to account for the concentrating effects of evaporation and the thickness of water present on WP surfaces during corrosion were also adjusted. In the second category of sensitivity analyses of repository performance, TPA Version 3.2 was used to evaluate the importance of the REFLUX3 submodule to repository performance. REFLUX3 is included in TPA Version 3.2 to incorporate the effects of water refluxing into the emplacement drifts on radionuclide transport from the WP.

2 DESCRIPTION OF ANALYSES

2.1 PROCESS LEVEL

Process-level analyses were conducted to provide in-depth evaluation of heat and mass transfer in the region near the waste emplacement drifts with respect to recent repository design modifications under consideration by the DOE. The specific set of repository design modifications recommended to DOE by their contractors are referred to as Enhanced Design Alternatives II (EDA II). The specific design alternatives evaluated in this analysis included a thermal heat load from 60 MTU/acre, reduced from the Total System Performance Assessment-Viability Assessment (TSPA-VA) (TRW Environmental Safety Systems, Inc., 1998) heat load from 85 MTU/acre, and ventilation of the emplacement drifts for the 50-yr period after waste emplacement, a feature not explicitly included in previous designs.

The thermal load imposed by the emplacement of HLW mostly is a function of the average ground surface area per WP. The thermal load per WP cannot be modified except by aging the HLW, a process in which the HLW is allowed to cool for extended periods of time prior to emplacement. Although the thermal output by the WPs will persist for thousands of years, aging HLW for several tens of years prior to emplacement dissipates a significant amount of heat during the period of greatest heat output from the WPs. Aside from aging HLW prior to emplacement or varying the number of or type of SNF bundles placed in each WP, the only explicit way to adjust the areal thermal load of a repository is to modify the distances separating WPs such that the average ground surface area per WP is either increased (to decrease thermal load) or decreased (to increase thermal load). Both the distance between emplacement drifts and the distance between WPs within a drift can be adjusted to achieve the desired areal thermal load.

A vertically oriented, two-dimensional, drift-scale numerical model was formulated for the process-level analyses. The model extended from the ground surface to a depth of 727.6 m, approximately 122 m below the water table, and extended from mid-drift to mid-pillar, a distance of 40.5 m. This geometry is consistent with the 60 MTU/acre repository loading designated in EDA II. The model had 10 elements in the lateral direction and 80 in the vertical direction. The model consisted of 20 thermo-hydrostratigraphic units, which included the Tiva Canyon, Paintbrush, Topopah Springs, Calico Hills, Prow Pass, and Bull Frog members. Thermophysical, hydraulic, and physical property values for both the matrix and fracture continua were taken from the TSPA-VA (TRW Environmental Safety Systems Inc., 1998) and are summarized in tables 2-1 through 2-3. The data sets are identified as DTN:LL980209004242.026 for the matrix and fracture properties and DTN:STN05071897001.002 for the thermophysical properties. Note that matrix permeabilities are isotropic but that fracture permeabilities are anisotropic. A second set of hydraulic properties is reported for the proposed repository horizon in the TSPA-VA (TRW Environmental Safety Systems Inc., 1998). Differences between the two data sets are the values assigned to the van Genuchten α parameter for two units (i.e., TSw36 and TSw37). TSw36 has an α value of 8.08e−7 and TSw37 has an α value of 5.30e−7 in the original TSPA-VA basecase data set. The second set of hydraulic properties is identified as DTN:LL980209004242.026. The second set was calculated during calibration exercises using results from the single-heater test. These data are presumed to be more representative of the actual rock properties and are used in these analyses.

Table 2-1. Matrix hydraulic properties [taken from TSPA-VA (TRW Environmental Safety Systems Inc., 1998)]

Unit	Porosity	Permeability (m^2)	α (Pa^{-1})	n
TCw11	0.066	5.40e-18	1.15e-6	1.30
TCw12	0.066	5.40e-18	2.01e-6	1.32
TCw13	0.140	5.69e-17	3.74e-6	1.83
PTn21	0.369	1.61e-14	3.98e-5	1.34
PTn22	0.234	3.30e-15	7.94e-6	1.97
PTn23	0.353	5.40e-14	5.44e-5	1.43
PTn24	0.469	8.80e-14	3.43e-5	1.63
PTn25	0.464	3.18e-13	1.81e-4	1.47
TSw31	0.042	7.76e-17	5.84e-5	1.30
TSw33	0.135	2.04e-17	6.21e-6	1.33
TSw35	0.115	2.22e-17	4.01e-6	1.25
TSw36	0.092	8.70e-18	2.27e-6	2.06
TSw37	0.020	8.39e-18	7.39e-6	1.59
CH1vc	0.265	1.60e-12	7.60e-5	1.19
CH2vc	0.321	5.50e-14	4.12e-5	1.30
CH3zc	0.240	2.50e-18	2.16e-5	1.27
CH4zc	0.169	5.49e-18	1.03e-6	1.76
PP3vp	0.274	1.91e-15	1.66e-5	1.46
PP2zp	0.197	1.75e-17	8.39e-6	1.55
BF3vb	0.274	1.91e-15	1.66e-5	1.46

Table 2-2. Fracture hydraulic properties [taken from TSPA-VA (TRW Environmental Safety Systems Inc., 1998)]

Unit	Porosity	Permeability x (m^2)	Permeability y (m^2)	Permeability z (m^2)	α (Pa^{-1})	n
TCw11	2.33e-4	2.59e-8	2.59e-8	9.83e-8	2.37e-3	3.00
TCw12	2.99e-4	2.02e-8	2.02e-8	4.62e-8	2.37e-3	3.02
TCw13	7.05e-5	3.40e-9	3.40e-9	4.00e-8	9.12e-4	3.02
PTn21	4.84e-5	1.08e-8	1.08e-8	1.08e-8	1.10e-3	3.02
PTn22	4.83e-5	4.04e-9	4.04e-9	4.04e-9	1.85e-3	3.02
PTn23	1.30e-4	1.98e-9	1.98e-9	1.98e-9	3.45e-3	3.00
PTn24	6.94e-5	8.89e-10	8.89e-10	8.89e-10	9.13e-4	3.00
PTn25	3.86e-5	2.01e-9	2.01e-9	2.01e-9	1.81e-4	1.47
TSw31	8.92e-5	1.12e-8	1.12e-8	1.20e-7	1.44e-4	2.30
TSw33	1.05e-4	8.49e-9	8.49e-9	2.50e-7	1.73e-3	3.00
TSw35	3.29e-4	2.77e-9	2.77e-9	1.16e-8	1.26e-3	3.00
TSw36	3.99e-4	3.01e-9	3.01e-9	3.01e-9	1.32e-3	3.00
TSw37	4.92e-4	2.44e-9	2.44e-9	2.44e-9	1.19e-3	2.93
CH1vc	7.14e-5	2.44e-9	2.44e-9	2.44e-9	1.18e-3	3.02
CH2vc	7.14e-5	4.03e-9	4.03e-9	4.03e-9	1.18e-3	3.00
CH3zc	1.10e-5	1.06e-9	1.06e-9	2.28e-9	1.12e-3	2.89
CH4zc	1.10e-5	1.41e-9	1.41e-9	2.28e-9	1.14e-3	3.00
PP3vp	7.14e-5	9.69e-9	9.69e-9	9.92e-9	1.42e-3	3.00
PP2zp	1.10e-5	5.87e-9	5.87e-9	2.28e-9	1.14e-3	3.00
BF3vb	7.14e-5	9.69e-9	9.69e-9	9.92e-9	1.42e-3	3.00

Table 2-3. Matrix thermal and physical properties [taken from TSPA-VA (TRW Environmental Safety Systems Inc., 1998)]

Unit	Thermal Conductivity-Wet (J/s/m-K)	Thermal Conductivity-Dry (J/s/m-K)	Rock Specific Heat (J/kg-K)	Rock Density (kg/m^3)
TCw11	1.76	1.02	847	2.51e+3
TCw12	1.88	1.28	837	2.51e+3
TCw13	0.98	0.54	857	2.47e+3
PTn21	0.50	0.35	1080	2.34e+3
PTn22	0.97	0.44	849	2.40e+3
PTn23	1.02	0.46	1020	2.37e+3
PTn24	0.82	0.35	1330	2.26e+3
PTn25	0.67	0.23	1220	2.37e+3
TSw31	1.00	0.37	834	2.51e+3
TSw33	1.80	0.71	883	2.51e+3
TSw35	2.02	1.20	900	2.54e+3
TSw36	1.84	1.42	865	2.56e+3
TSW37	2.08	1.69	984	2.36e+3
CH1zc	1.31	0.70	1060	2.31e+3
CH2zc	1.17	0.58	1200	2.24e+3
CH3zc	1.20	0.61	1150	2.35e+3
CH4zc	1.35	0.73	1170	2.44e+3
PP3vp	1.26	0.66	841	2.58e+3
PP2zp	1.35	0.74	644	2.51e+3
BF3vp	1.26	0.66	841	2.58e+3

The emplacement drift air space between the WP and rock was not incorporated into the model. The heat source was assigned to a single model element placed among elements with TSw35 properties. Radiation was not included as a heat transfer mechanism either in the drift or at the ground surface. Design features such as the drip shield and backfill specified in the EDA II were not explicitly included in these analyses. The effect of backfill or rockfall after emplacement is implicitly included by the omission of an air space around the WP, although the property values assigned to the backfill were the same as those assigned to the host rock. Specifying neither fluid nor heat flow at the vertical boundaries had the effect of placing the model at the center of the repository and neglecting repository edge effects. Constant gas pressure (93,361 Pa) was specified at the upper boundary. Analyses were conducted for two groundwater infiltration rates at the upper boundary, 1.0 mm/yr and 10.0 mm/yr. A constant pressure of 101,325 Pa was specified at the bottom boundary. A geothermal gradient of 1.37e−2 K/m was specified from the top to bottom of the model domain. The thermal load was imposed on a single element of the model at a depth of 385 m. The thermal load decay data from DOE (1997, table 1C.7) for a thermal load of the 3,000 Mwd/MTU are given in table 2-4.

The combined effects of explicitly omitting radiation and convective heat transfer in the drift air, changing heat and mass transfer by the inclusion of backfill material and a dry shield, and repository edge effects are complex and not fully understood. Nonetheless, the resulting analysis results are believed to give a sense of magnitude and direction of changes brought about by changes in thermal load and ventilation. Insufficient evidence and understanding are available to assess if the analyses are conservative.

Process-level analyses were also conducted to evaluate the potential cooling and drying impact of ventilation emplacement drift on repository performance. Because the ventilation mechanism is not explicitly incorporated in MULTIFLO, the effects of ventilation were indirectly included by reducing the thermal load for the 50-yr period after emplacement, as specified in the EDA II design. Two additional simulations were conducted to evaluate the potential effect of ventilation. The thermal load specified in table 2-4 was modified by directly reducing the thermal load by 20 percent and by 50 percent for the first 50 yr of the simulation.

All process-level numerical analyses were performed using METRA, the flow component to MULTIFLO Version 1.2β, a multiphase, multidimensional, nonisothermal heat and mass transfer simulator (Lichtner and Seth, 1998). A dual continuum conceptual model (DCM) was used to represent the medium. The DCM formulation is similar to the dual permeability continuum formulation used in recent DOE numerical simulations (TRW Environmental Safety Systems, 1998). The DCM conceptualization provides a separate continuum for heat and mass transfer through both the matrix and the fractures. The two continua are joined throughout the model domain by transfer functions to effect the heat and mass transfer between the two continua.

The transfer of fluid between continua is analogous to Darcy's law in which the rate and direction of fluid transfer are a function of the pressure difference between the two continua, the surface area interfacing the two continua, and the harmonic mean of the matrix and fracture intrinsic permeabilities. This fracture-matrix coupling can be expressed as stated in Eq. (2-1).

$$Q_t = \frac{A\,A_{\mathrm{mod}}\,\rho g}{\mu} k_{\mathrm{harmonic}}\, k_r \frac{P_f - P_m}{d} \qquad (2\text{-}1)$$

where g is gravity, μ is viscosity, k_r is the upstream weighted relative permeability, P is pressure, and d is the distance over which the fracture-matrix pressure drop occurs. The variable A is a composite measure of the fracture volume and matrix block size and A_{mod} is a modifier used to characterize the connectivity between the fracture and matrix continua. Reducing A_{mod} has the effect of reducing the coupling of the two continua. Equation (2-2) defines the harmonic mean of intrinsic permeability at the fracture/matrix interface as

Table 2-4. Thermal load decay rate [taken from U.S. Department of Energy (1997) table 1C.7]

Time (yr)	Thermal Load (W/MTU)
0	1,020.0
0.6	949.0
0.8	813.0
1.0	780.0
1.5	709.0
2.0	649.0
3.0	550.0
4.0	471.0
5.0	408.0
6.0	358.0
7.0	317.0
8.0	283.0
9.0	256.0
20	144.0
30	114.0
40	97.80
50	85.60
100	50.40
200	27.30
300	21.50
500	17.80
1,000	12.90

$$k_{\text{harmonic}} = \frac{k_f k_m}{k_f + k_m} \tag{2-2}$$

An analogous form of Fourier's law is used to define the rate of transfer of heat between the matrix and fracture continua. The values assigned to the terms A and A_{mod} are listed in table 2-5.

Table 2-5. Values for A and A_{mod} [modified from TSPA-VA (TRW Environmental Safety Systems Inc. 1998)]. Note that A is volf and A_{mod} is areamodf in MULTIFLO.

Unit	A	A_{mod}
TCw11	2.33e−4	5.00e−4
TCw12	2.99e−4	5.00e−4
TCW13	7.05e−5	5.00e−4
PTn21	4.84e−5	5.00e−1
PTn22	4.83e−5	5.00e−1
PTn23	1.30e−4	5.00e−1
PTn24	6.94e−5	5.00e−1
PTn25	3.86e−5	5.00e−1
TSw31	8.92e−5	5.00e−1
TSw33	1.05e−4	5.00e−4
TSw35	3.29e−4	5.00e−4
TSw36	3.99e−4	5.00e−4
TSw37	4.92e−4	5.00e−4
CH1vc	7.14e−5	5.00e−1
CH2vc	7.14e−5	5.00e−1
CH3zc	1.10e−5	5.00e−1
CH4zc	1.10e−5	5.00e−1
PP3vp	7.14e−5	5.00e−4
PP2zp	1.10e−5	5.00e−1
BF3vb	7.14e−5	5.00e−4

2.2 SYSTEMS LEVEL

TPA Version 3.2 (Mohanty and McCartin, 1998) was used to evaluate the potential importance of TEF to repository performance at the systems level. Two categories of analyses were conducted at the systems level. The first category evaluated the effects of dripping and WP material weaknesses on WP failure by corrosion. The second category of systems-level analyses evaluated the impact of water refluxing, as represented in the REFLUX3 submodule of TPA Version 3.2, on radionuclide release from the WP after WP failure. The first category of analyses addressed the importance of water moving into an emplacement drift on a WP exhibiting properties more vulnerable to corrosion than alloy C-22, the candidate inner-layer WP material in TSPA-VA (TRW Environmental Safety Systems, 1998). The dripping mechanism was considered sufficiently important to warrant independent evaluation in terms of total performance assessment because dripping is potentially the dominant mechanism to expose the WPs to water. Corrosion by exposure to water is considered to be the dominant mechanism that could lead to WP failure. Dripping is not explicitly included in the WP failure module EBSFAIL in TPA Version 3.2, hence modification of key parameters in EBSFAIL to simulate the effects of dripping. Dripping is explicitly included in the TPA Version 3.2 sub-module REFLUX3 in the radionuclide release module EBSREL is required. The effects of dripping on WP corrosion were investigated in the first category of analyses. The effects of dripping on radionuclide release from the WP were investigated in the second category of analyses. There are four sets of analyses in each category. Descriptions of the systems-level TPA analyses sets are summarized in table 2-6.

2.2.1 Dripping and Corrosion Sensitivity Analyses

The four sets of analyses conducted to evaluate dripping and related corrosion mechanisms were conducted using TPA Version 3.2 to assess total system performance. Set A: basecase property values were used. The basecase incorporates the DOE VA design (TRW Environmental Safety Systems, Inc., 1998). Set B: the same basecase property values as in Set A were used but with the effects of dripping included. The corrosion processes were modified in an attempt to incorporate the salient effects of dripping on WPs although the actual dripping mechanisms were not included in the analysis. Set C: the corrosion processes were modified to include the effects of dripping and several WP material properties were modified to allow assessment of WP failure due to canister weakness at closure welds or other possible WP material deficiencies. These material deficiencies are considered different and separate from those that contribute to juvenile failures. Set D: the effects of dripping were not included but with modifications to the material properties. Using TPA Version 3.2, 250 realizations were simulated for each set of the stochastic analyses. Simulations using Sets A, B, C, and D calculate annual dose at a distance of 20 km versus time and time to WP failure by corrosion.

Set A of the TPA systems level analyses was conducted using basecase values for the input parameters as specified in TPA Version 3.2. This set of analyses was performed to provide a standard against which subsequent analyses could be compared.

Set B of the TPA systems-level analyses was conducted to evaluate the importance of dripping on WPs with material properties specified in the DOE VA design. Because the TPA Version 3.2 corrosion model does not explicitly include the physical mechanisms that lead to dripping into an emplacement drift, parameters specific to the environment controlling WP failure were modified to replicate the perceived effects of dripping. The specific parameters modified to replicate dripping are found in the EBSFAIL module and are summarized in table 2-7: CriticalRelativeHumidityHumidAirCorrosion, ThicknessOfWaterFilm[m], CriticalRelativeHumidityAqueousCorrosion, and ChlorideMultFactor. Of these parameters, three have a potentially substantial effect on WP corrosion: CriticalRelativeHumidityAqueousCorrosion, ThicknessOfWaterFilm[m], and ChlorideMultFactor. Humid air corrosion does not contribute to WP degradation at a significant level; therefore, CriticalRelativeHumidityHumidAirCorrosion was not explicitly evaluated in the analyses.

Table 2-6. Descriptions of the systems-level TPA analyses for categories 1 and 2 TPA analyses

Analysis Set	Initial Data Set	Data Set Modification
Category 1		
Set A	*tpa.inp*	None–basecase
Set B	*tpa.inp*	Effects of dripping included
Set C	*tpa.inp*	Dripping included and alloy C-22 replaced with alloy 625
Set D	*tpa.inp*	Alloy C-22 replaced with alloy 625, no dripping
Category 2		
Set E	*tpa.inp.meanvalues*	None–basecase
Set F	*tpa.inp.meanvalues*	Effects of dripping included
Set G	*tpa.inp.meanvalues*	Dripping included and Alloy C-22 replaced with alloy 625
Set H	*tpa.inp.meanvalues*	Alloy C-22 replaced with alloy 625, no dripping

Table 2-7. EBSFAIL module parameter values modified to incorporate the effects of dripping (included are basecase and modified values)

Parameter and Distribution	Basecase Value	Modified Value
CriticalRelativeHumidityHumidAirCorrosion constant	0.55	0.10
CriticalRelativeHumidityAqueousCorrosion uniform	[0.75, 0.85]	[0.15, 0.25]
ThicknessOfWaterFilm[m] uniform	[0.001, 0.003]	[0.00001, 0.00003]
ChlorideMultFactor uniform	[1.0, 30.0]	[29.0, 30.0]

The input factor CriticalRelativeHumidityAqueousCorrosion defines the threshold RH above which aqueous corrosion will occur. The basecase value for CriticalRelativeHumidityAqueousCorrosion is a uniform distribution for RH over the range [0.75 to 0.85]. The input value for RH was decreased in this analysis to a uniform distribution over the range [0.15 to 0.25] to replicate occurrences of dripping into an emplacement drift at times when the emplacement drift RH is low. This range of RH values is consistent with the possible condition where water drips into a drift where the air temperature is slightly above boiling. Because humid air corrosion does not contribute to WP degradation at a significant level, the range assigned CriticalRelativeHumidityHumidAirCorrosion was simply adjusted to be consistent with (i.e., lower than) the range assigned to CriticalRelativeHumidityAqueousCorrosion, the more important process in terms of corrosion of the WPs. For example, CriticalRelativeHumidityHumidAirCorrosion was assigned a value of 0.10 for a uniform distribution over 0.15 to 0.25 for CriticalRelativeHumidityAqueousCorrosion.

ChlorideMultFactor is a multiplication factor applied to the chloride concentration of water that interacts with the WP surface. The value for ChlorideMultFactor was predicted using a MULTIFLO Version 1.2β reactive path simulation of water flow through a fracture in welded tuff. ChlorideMultFactor was input as a uniform distribution and was increased to a range of [29.0–30.0], an increase over the basecase range of [1.0, 30.0]. The restriction of the allowable range of ChlorideMultFactor to the upper end of the range of possible values was incorporated to fully account for evaporation processes which may elevate solute concentrations of water flowing down fractures toward the elevated temperatures of the WPs. The increase in chloride concentration is justified in light of recent chloride concentrations measured for water sampled from a borehole at the drift-scale heater test at the Experimental Shaft Facility at YM. The chloride concentration of water sampled from borehole 59-4, located above the heater drift, was measured to be 1,130–1,250 mg/l (Civilian Radioactive Waste Management System Management and Operating Contractor, 1999) which, although less than the maximum chloride concentration considered in these analyses, suggests that elevated chloride concentration in water located above the emplacement drifts can be expected. There is some question regarding the representativeness of these measured chloride concentrations; nevertheless, the measured concentrations are consistent with the hypothesis that elevated chloride concentrations of water dripping into emplacement drifts are feasible.

ThicknessOfWaterFilm[m] is the thickness of water on the corrosion surface. Reducing this thickness allowed for more rapid corrosion since oxygen diffuses from air through the water to the WP surface. ThicknessOfWaterFilm[m] was reduced from the basecase uniform distribution range of [0.001, 0.003] to [0.00001, 0.00003] to account for a thinner layer of water on the WP surface during periods of drying between drips.

Sets C and D of the TPA systems-level analyses were conducted to evaluate the importance of dripping on WPs with container material weaknesses at closure welds or at locations with other possible container material susceptibilities. Set C evaluated the effect of WP with material weaknesses without the effects of dripping and Set D evaluated the modified WP properties with the effects of dripping included. Three WP material properties in EBSFAIL vary when the WP outer container material is modified from alloy C-22 to alloy 625: InnerOverpackErpIntercept, InnerOverpackErpSlope, and CritChloideConcForSecondLayer[moL/L]. The first variable is the repassivation potential intercept of the inner overpack in mV relative to a hydrogen electrode. The second variable is the repassivation potential slope of the inner overpack in mV. The third variable denotes the critical chloride concentration for localized corrosion of the outer overpack. The InnerOverpackErpIntercept value was modified from the alloy C-22 uniform distribution range of [1,040.0, 1,240.0] to the alloy 625 range of [48.5, 148.5]. InnerOverpackErpSlope was modified from the alloy C-22 value of 0.0 to the alloy 625 value of −160.8. CritChloideConcForSecondLayer[moL/L] was modified from the alloy C-22 value of 1.0 moL/L to the alloy 625 value of 3.0e−2 moL/L. Basecase and modified property values for these parameters are summarized in table 2-8.

Table 2-8. EBSFAIL module parameter values modified to incorporate the effects of WPs with container material weaknesses at closure welds or other possible container material weakness (included are basecase and modified ranges or values)

Parameter and Distribution	Basecase Value	Modified Value
InnerOverpackErpIntercept[mV] uniform	[1040.0, 1240.0]	[48.5, 148.5]
InnerOverpackErpSlope constant	0.0	-160.8
CritChloideConcForSecondLayer[moL/L] constant	1.0	3.0e-2

2.2.2 REFLUX3 Sensitivity Analyses

The second category of the TPA systems-level analyses evaluated the effect of water refluxing on radionuclide release from the WP. Three reflux submodules (REFLUX1, REFLUX2, and REFLUX3) are contained in the near-field environment module NFENV of TPA Version 3.2. The reflux submodules determine the quantity of water, q_{drip}, that eventually flows to the emplacement drift. The quantity q_{drip} is used by NFENV to calculate q_{perc}, the percolation flux from the condensate zone. The effects of only one of the reflux submodules (i.e., REFLUX3) were evaluated in this sensitivity study. Following is a description of REFLUX3.

REFLUX3 incorporates a procedure to estimate the amount of water flowing downward through fractures located below the boiling isotherm. Input information required to exercise REFLUX3 includes time varying thickness of the dry-out zone, temperature gradient at the boiling isotherm above the emplacement drift, and flow from the condensate zone above the boiling isotherm. Given this information, REFLUX3 estimates the depth that water will penetrate the boiling isotherm as a function of dry-out zone thickness and the volume of water flowing from the condensate zone. Refluxing water originates from two sources, infiltration from the ground surface, and water vaporized from the dry-out zone surrounding WPs. The amount of water available for refluxing by infiltration is determined by the TPA Version 3.2 module UZFLOW outside of the REFLUX3 submodule. The time-varying dry-out thickness is read from a table calculated using a process-level thermohydrological code such as MULTIFLO. Equation (2-3) converts the dry-out thickness to an equivalent depth of water, D, using

$$\mathbf{D} = (\mathbf{T})(\mathbf{n})(\mathbf{S} - \mathbf{S_n}) \tag{2-3}$$

where T is the thickness of the dry-out zone, n is rock porosity, S is liquid saturation, and S_n is residual saturation. The volume of water in the condensate zone is the sum of water from the dry-out zone and infiltration. REFLUX3 calculates the volume of water above a single WP. This time-varying volume of water is available to flow to the WPs.

Water flowing down a fracture will penetrate below the boiling isotherm before it is completely vaporized. If the penetration distance is greater than the thickness of the dry-out zone above the drifts, refluxing water will reach the drifts and be available to contact the WPs. The penetration distance, L, is calculated with an expression developed by Phillips (1994, 1996).

$$\mathbf{L} = \left[\frac{\mathbf{Q h} \rho_{\mathrm{w}}}{\kappa \, \nabla \mathbf{T}} \right]^{\frac{1}{2}} \tag{2-4}$$

where ρ_w is the density of boiling water, Q is flow from the condensate zone, h is enthalpy of phase change for water, κ is thermal conductivity, and ∇T is the temperature gradient at the boiling isotherm. The variables ρ_w, h, κ, and ∇T are specified as input into TPA Version 3.2.

All of the flow down fractures vaporizes and is returned to the condensate zone when the penetration distance is less than the thickness of the dry-out zone. Some portion of the flow reaches the emplacement drift when the penetration distance is greater than the thickness. The remainder of the flow vaporizes and returns to the condensation zone. The fraction of flow vaporized is assumed proportional to the ratio of the dry-out zone thickness to the penetration distance. For example, if the ratio of the dry-out zone thickness to the penetration distance is 0.8, 80 percent of the flow down the fractures is vaporized and 20 percent reaches the drift.

REFLUX3 uses several additional variables specified in *tpa.inp*: the fraction of water that flows from the condensate zone toward the drifts is FractionOfCondensateRemoved, the fraction of water in the condensate zone permanently removed from the system by some unspecified mechanism (e.g., shed along edges of the repository) is FractionOfCondensatRemoved, and the fraction of water flowing from the condensate zone toward the drift that is removed by an unspecified mechanism (e.g., flowpaths that bypass drifts) is FractionOfCondensateTowardRepositoryRemoved. Refluxing occurs only while WP temperatures are above boiling. The output of REFLUX3 is the amount of water that reaches the drift. The amount of water that actually contacts the WPs is determined in the module EBSREL.

REFLUX3 was evaluated using TPA Version 3.2 with all nonREFLUX3 variables kept constant and assigned average or mean values. [Note: Input file *tpa.inp.meanvalues* was used in these analyses.] In this manner, the effect of only REFLUX3 on repository performance can be assessed. Four sets of analyses were performed. Set E contains basecase mean values for all input parameters with the exception of the REFLUX3 parameters summarized in table 2-9. The four REFLUX3 input parameters not typically considered constant were set to the distribution types and ranges specified in the *tpa.inp* basecase data set. These four parameters are: FractionOfCondensateRemoved[1/yr], FractionOfCondensateTowardRepository[1/yr], FractionOfCondensateTowardRepositoryRemoved[1/yr], and TemperatureGradientInVicinityOfBoilingIsotherm[K/m]. The four REFLUX3 parameters defined by distributions were allowed to vary in this set of analyses. Three of the REFLUX3 input parameters are considered constant with minimal uncertainty and were not varied in the sensitivity analyses. These are WPUnitCellWidth[m], DensityOfWaterAtBoiling[kg/m^3], and EnthalpyOfPhaseChangeForWater[J/kg]. Set F differs from Set E in that dripping is represented in the analyses by modifying the same variables modified in Set B: CriticalRelativeHumidityHumidAirCorrosion, ThicknessOfWaterFilm[m], CriticalRelativeHumidityAqueousCorrosion, and ChlorideMultFactor. Similar to Set C, Set G includes both the effects of dripping and potentially vulnerable WP materials such as might be experienced at closure welds. WP material properties were representative of alloy 625 compared to the alloy C-22 specified in the DOE VA. These parameters include InnerOverpackErpIntercept, InnerOverpackErpSlope, and CritChloideConcForSecondLayer[moL/L]. Set H is modified with parameters of alloy C-22 replaced by alloy 625 as in Set G; however, the effects of dripping are not included. Similar to the earlier sets of analyses,

Table 2-9. Submodule REFLUX3 input parameters and assigned basecase values

Parameter and Distribution	Basecase Value
WPUnitCellWidth[m] constant	22.5
FractionOfCondensateRemoved[1/yr] loguniform	[1.0e−8, 1.0]
FractionOfCondensateTowardRepository[1/yr] uniform	[0.0, 1.0]
FractionOfCondensateTowardRepositoryRemoved[1/yr] loguniform	[1.0e−8, 1.0]
DensityOfWaterAtBoiling[kg/m^3] constant	960.5
EnthalpyOfPhaseChangeForWater[J/kg] constant	2.4e6
TemperatureGradientInVicinityOfBoilingIsotherm[K/m] uniform	[1.0, 100.0]

250 realizations were run for Sets E, F, G, and H. Results are presented in terms of dose at a distance of 20 km from the proposed repository and in terms of WP failure versus time. Parameters specific to the REFLUX3 submodule are listed in table 2-9. The basecase values for the input parameters are listed with the variables. The time varying thickness of the dry-out zone is calculated using MULTIFLO and provided in tabular form to the REFLUX3 submodule.

3 RESULTS OF ANALYSES

3.1 PROCESS LEVEL

Results from the process-level analyses are presented in this section. Two sets of analyses are presented, one for an infiltration rate of 1 mm/yr and one for 10 mm/yr. For each set, there were three analyses: (i) basecase–full thermal load for emplacement of 60 MTU/acre, (ii) ventilation with 20 percent heat removal, and (iii) ventilation with 50 percent heat removal. Following is a description of the graphical illustrations:

(a) Contour of temperature at the time of maximum lateral extent of the boiling isotherm
(b) Dry-out zone thickness versus time
(c) Horizontal extent of dry-out zone versus time

Temperature contours for the vertical cross-section simulation are illustrated for specified times in figures 3-1 through 3-3 for an infiltration rate of 1 mm/yr and in figures 3-4 through 3-6 for an infiltration rate of 10 mm/yr. The MULTIFLO simulations indicate that there is no coalescence of the boiling isotherms of adjoining emplacement drifts for any of the simulations, including the basecase that contains no heat removal due to ventilation. The horizontal extent of the boiling isotherm was 29.06 m for the basecase, 18.20 m for 50 yr of heat removal at 20 percent, and 10.42 m for 50 yr of heat removal at 50 percent (figure 3-7) for an infiltration rate of 1 mm/yr and, similarly, 26.88, 17.06, and 9.99 m for an infiltration rate of 10 mm/yr (figure 3-8). The distance was measured from the center of the heater element to the 96 °C isotherm. The temperature of boiling at the repository horizon was approximately 96 °C. Similarly, the maximum vertical extent of the boiling isotherm above the drift is 23.46, 17.69, and 10.90 m (figure 3-9) at a 1 mm/yr infiltration rate and 23.79, 17.68, and 10.75 m for an infiltration of 10 mm/yr (figure 3-10). All maximum vertical thicknesses and horizontal extents occurred at about 150 yr after the onset of heating. The thickness of the dry-out zone was measured as the distance from the center of the heater element (located at a depth of 385.28 m below ground surface) to the 96 °C isotherm above the heater. The offsets in horizontal extent of the dryout zone observed after 50 yr, figures 3-7 and 3-8, are due to the termination of ventilation at 50 yr.

3.2 SYSTEMS LEVEL

Results from systems-level analyses performed using TPA Version 3.2 were plotted to evaluate the potential importance of TEF on repository performance for the period of time up to 10,000 yr. These results were plotted in terms of WP failure by corrosion versus time and in terms of dose versus time. WP failure by corrosion is graphically illustrated for TPA analysis Sets A–D in figure 3-11 and for Sets E–H in figure 3-12. In each set, the cumulative number of WP failures by corrosion is plotted versus time. Total potential dose at a receptor group located 20 km downgradient along the path of groundwater flow from the proposed YM repository is plotted versus time for Sets A–D in figure 3-13 and for Sets E–H in figure 3-14. The first four sets (A–D) are sensitivity analyses conducted to evaluate TEF mechanisms associated with WP failure by corrosion. Sets E–H are sensitivity analyses conducted to evaluate the submodule REFLUX3, which incorporates TEF mechanisms into calculations of radionuclide release from the WPs.

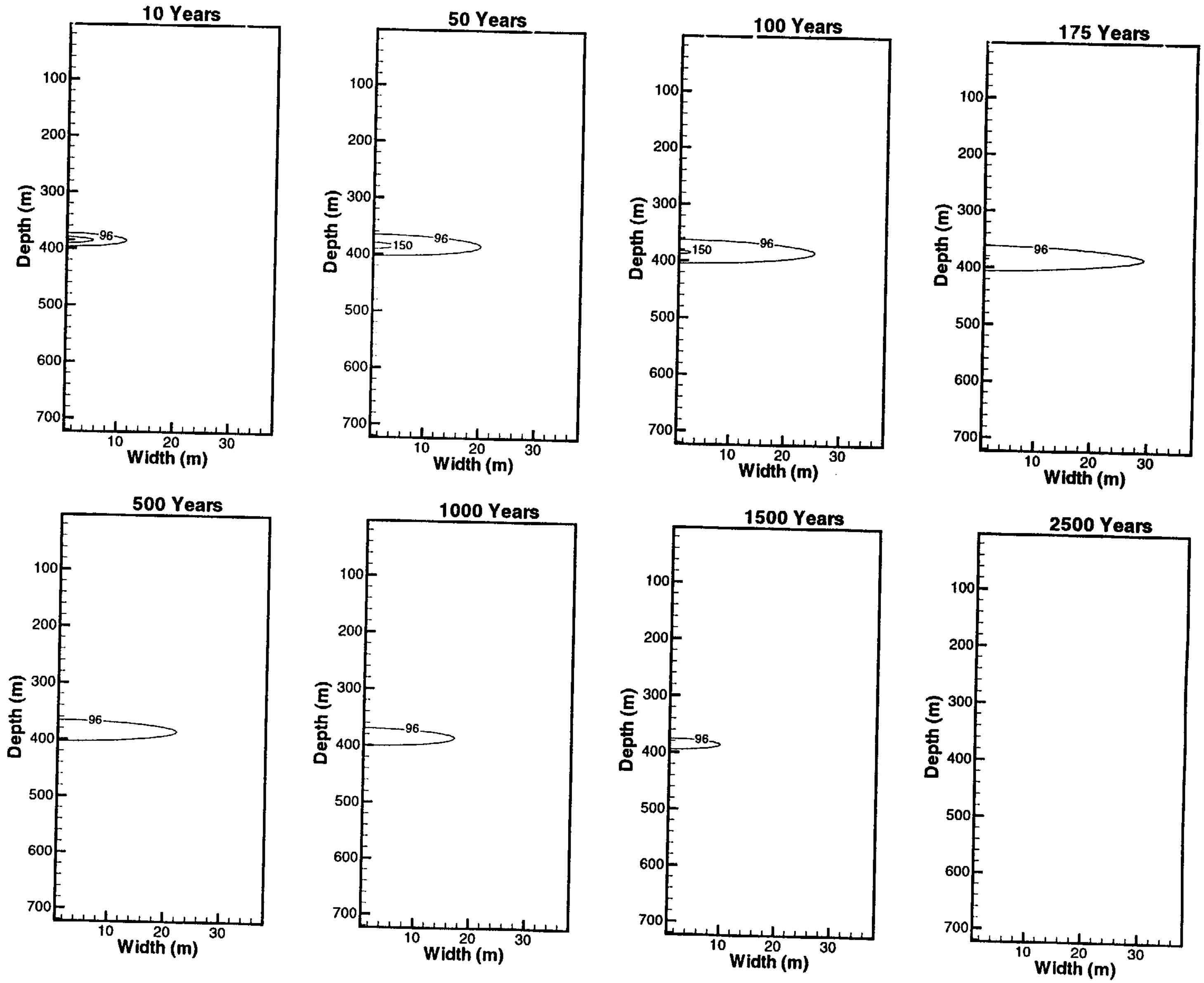

Figure 3-1. Temperature contours (°C) after 10, 50, 100, 175, 500, 1,000, 1,500, and 2,500 yr of heating predicted using MULTIFLO for a thermal load from 60 MTU/acre, an infiltration rate of 1 mm/yr, and no heat loss due to ventilation

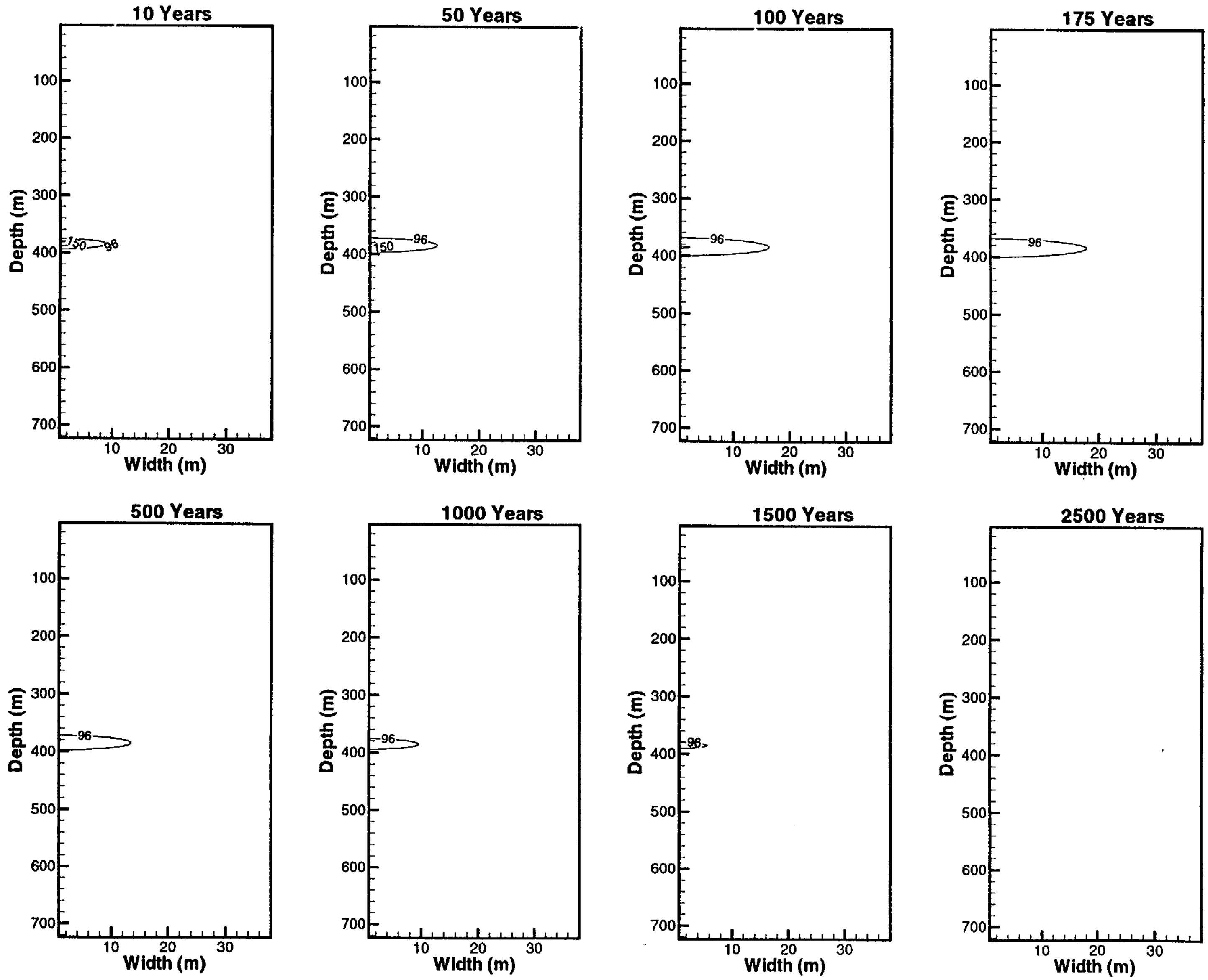

Figure 3-2. Temperature contours (°C) after 10, 50, 100, 175, 500, 1,000, 1,500, and 2,500 yr of heating predicted using MULTIFLO for a thermal load from 60 MTU/acre, an infiltration rate of 1 mm/yr, and 20-percent heat loss for 50 yr after waste emplacement due to ventilation

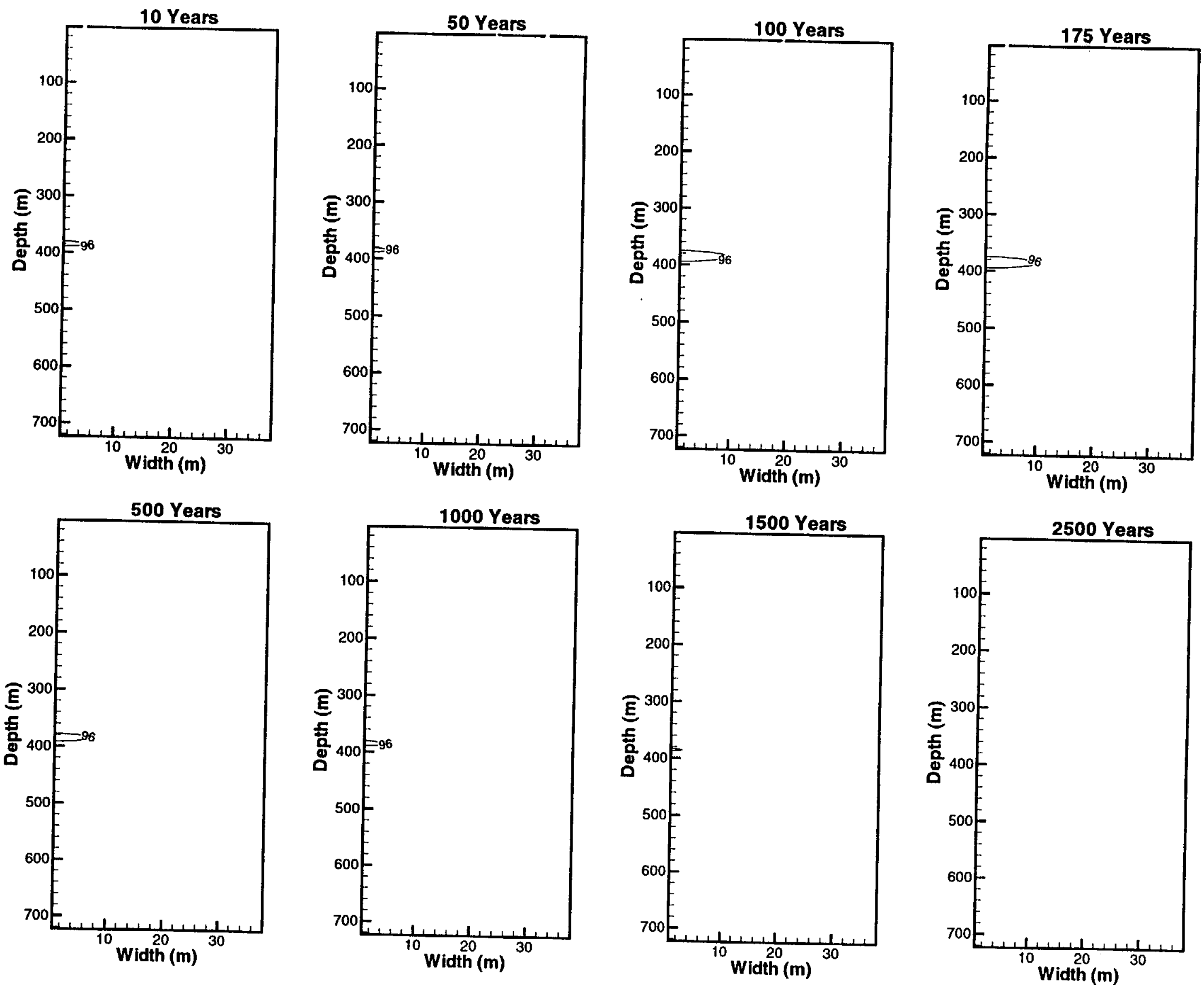

Figure 3-3. Temperature contours (°C) after 10, 50, 100, 175, 500, 1,000, 1,500, and 2,500 yr, of heating predicted using MULTIFLO for a thermal load from 60 MTU/acre, an infiltration rate of 1 mm/yr, and 50-percent heat loss for 50 yr after waste emplacement due to ventilation

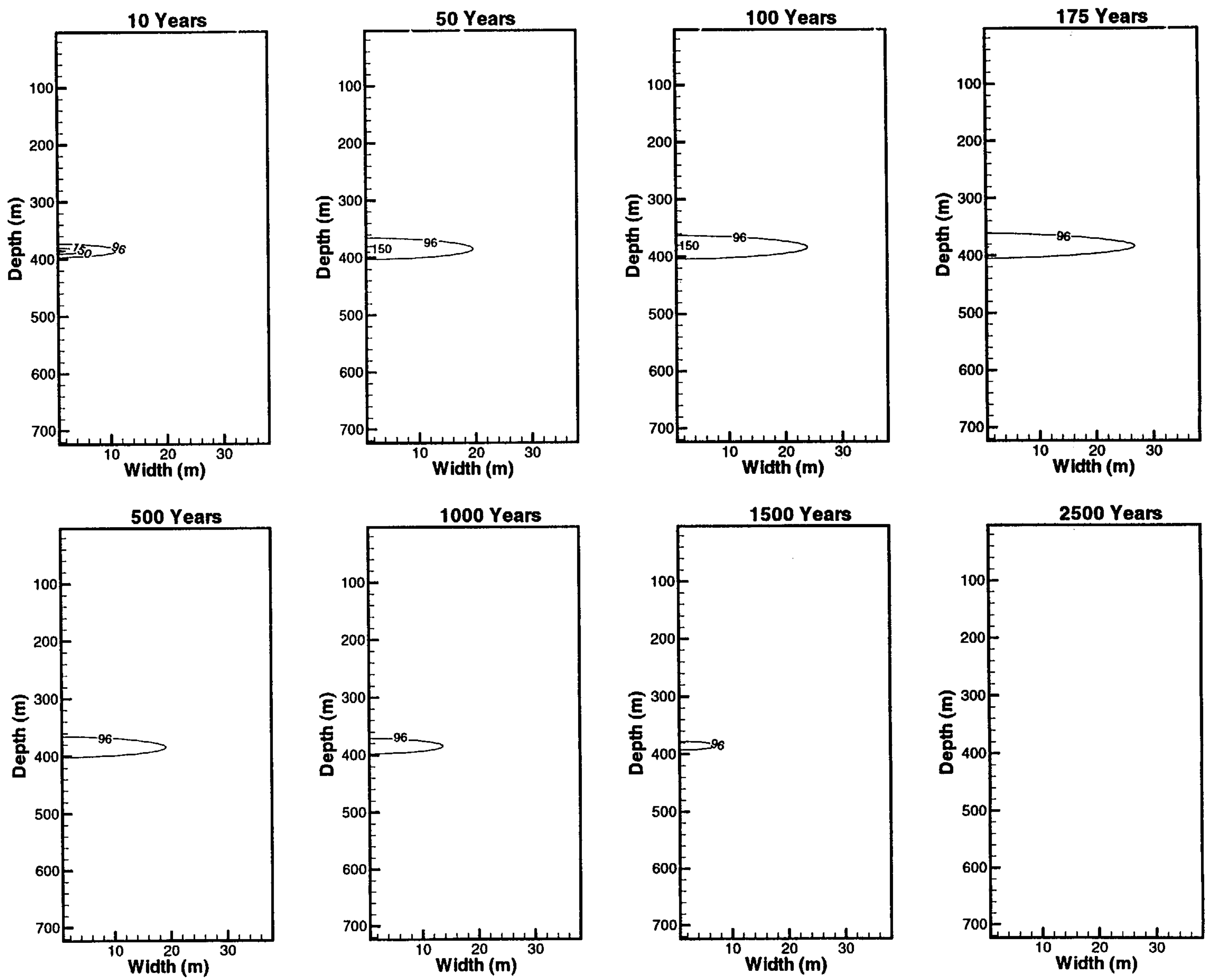

Figure 3-4. Temperature contours (°C) after 10, 50, 100, 175, 500, 1,000, 1,500, and 2,500 yr of heating predicted using MULTIFLO for a thermal load from 60 MTU/acre, an infiltration rate of 10 mm/yr, and no heat loss due to ventilation

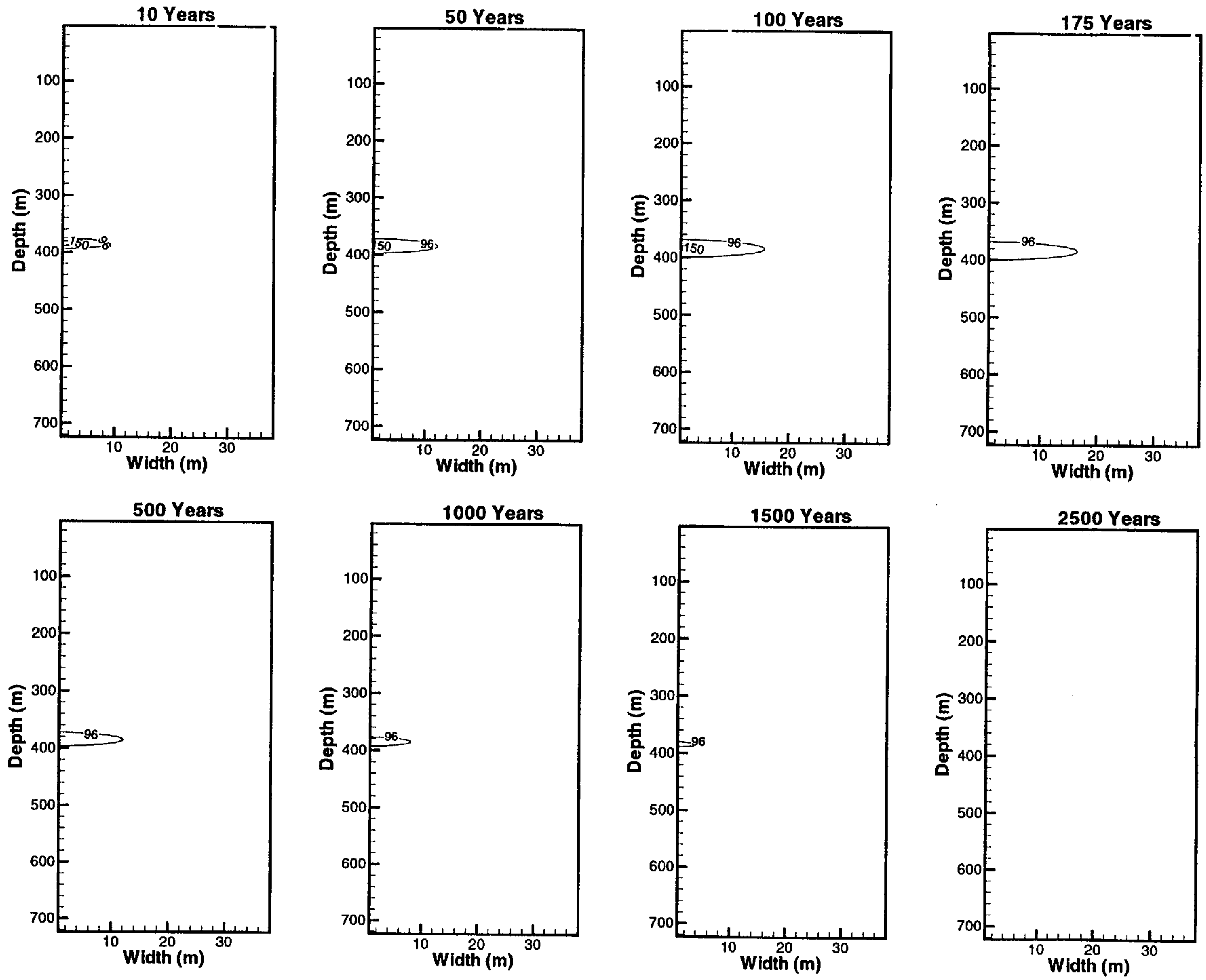

Figure 3-5. Temperature contours (°C) after 10, 50, 100, 175, 500, 1,000, 1,500, and 2,500 yr of heating predicted using MULTIFLO for a thermal load from 60 MTU/acre, an infiltration rate of 10 mm/yr, and 20-percent heat loss for 50 yr after waste emplacement due to ventilation

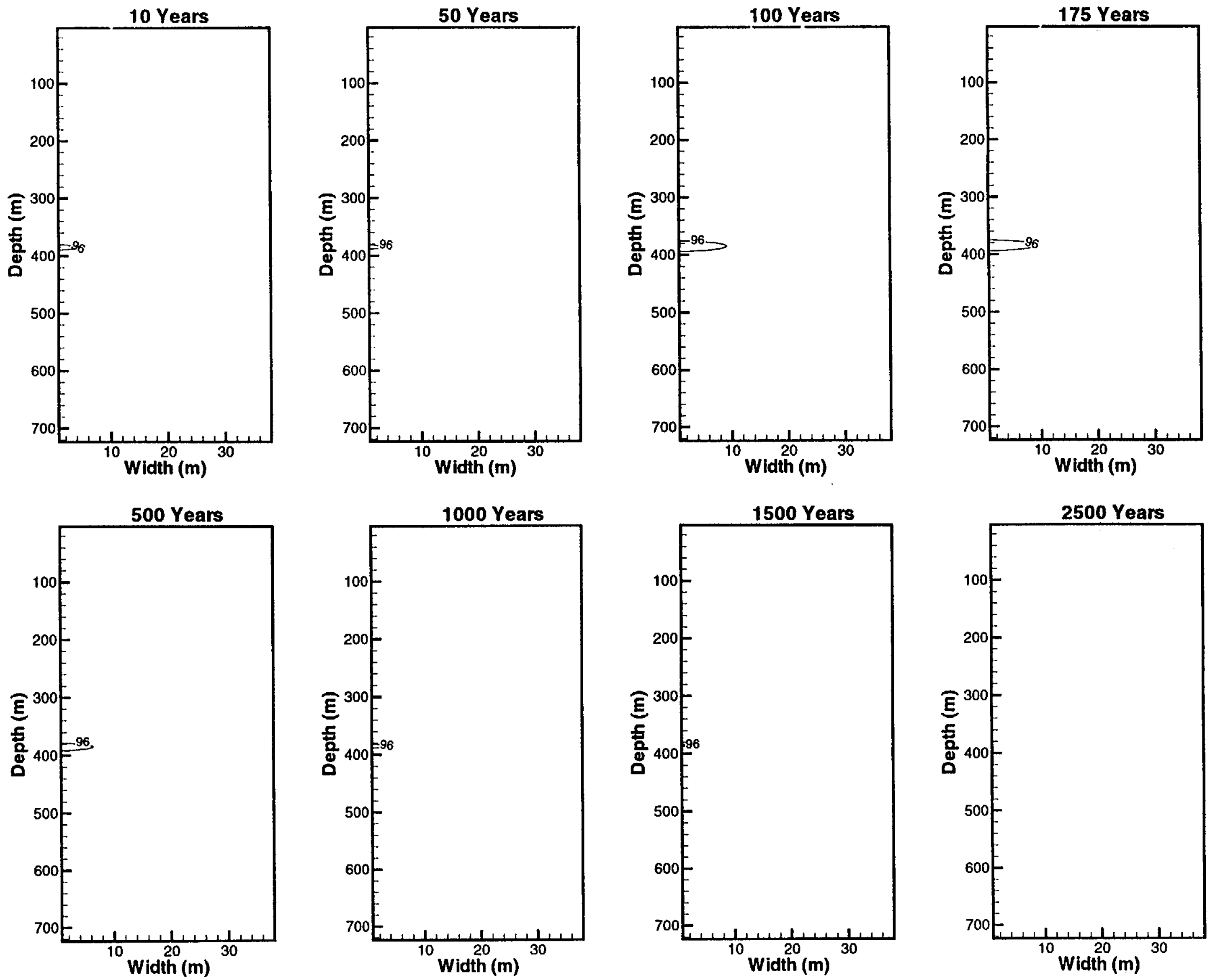

Figure 3-6. Temperature contours (°C) after 10, 50, 100, 175, 500, 1,000, 1,500, and 2,500 yr of heating predicted using MULTIFLO for a thermal load from 60 MTU/acre, an infiltration rate of 10 mm/yr and 50-percent heat loss for 50 yr after waste emplacement due to ventilation

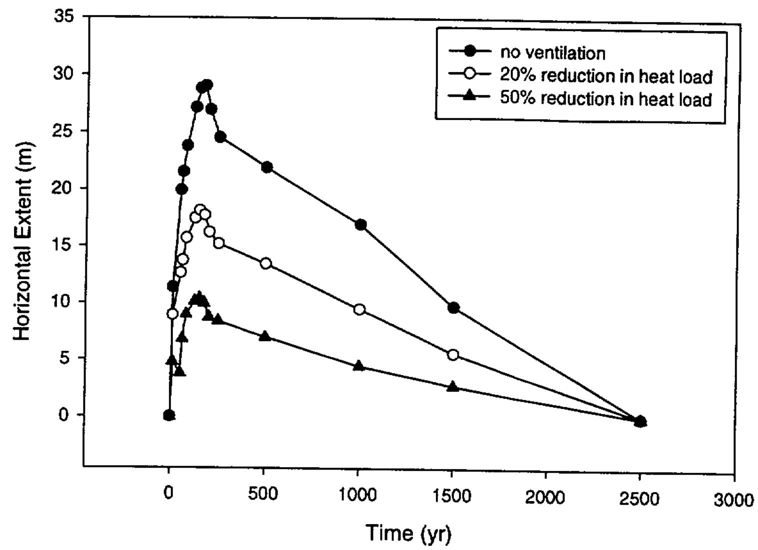

Figure 3-7. Horizontal extent of boiling isotherm (m) from center of heat source at an infiltration rate of 1 mm/yr versus time for a 60 MTU/acre thermal load for (a) no ventilation–solid circles, (b) ventilation with 20 percent heat loss–open circles, and (c) ventilation with 50 percent heat loss for 50 yr–triangles

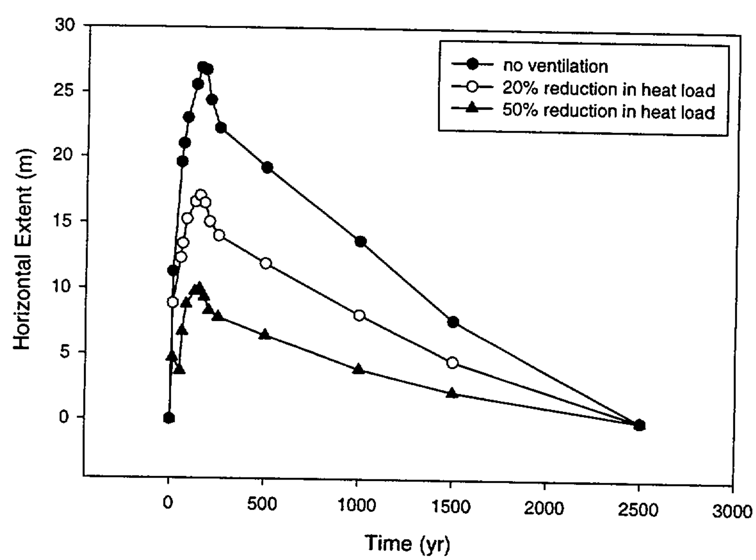

Figure 3-8. Horizontal extent of boiling isotherm (m) from center of heat source at an infiltration rate of 10 mm/yr versus time for a 60 MTU/acre thermal load for (a) no ventilation–solid circles, (b) ventilation with 20 percent heat loss–open circles, and (c) ventilation with 50 percent heat loss for 50 yr–triangles

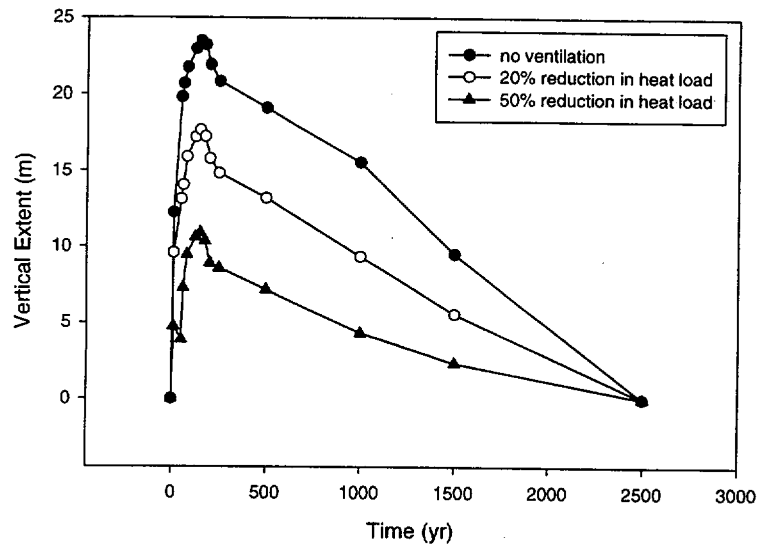

Figure 3-9. Vertical thickness of boiling isotherm (m) above center of heat source at an infiltration rate of 1 mm/yr versus time for a 60 MTU/acre thermal load for (a) no ventilation–solid circles, (b) ventilation with 20 percent heat loss–open circles, and (c) ventilation with 50 percent heat loss for 50 yr–triangles

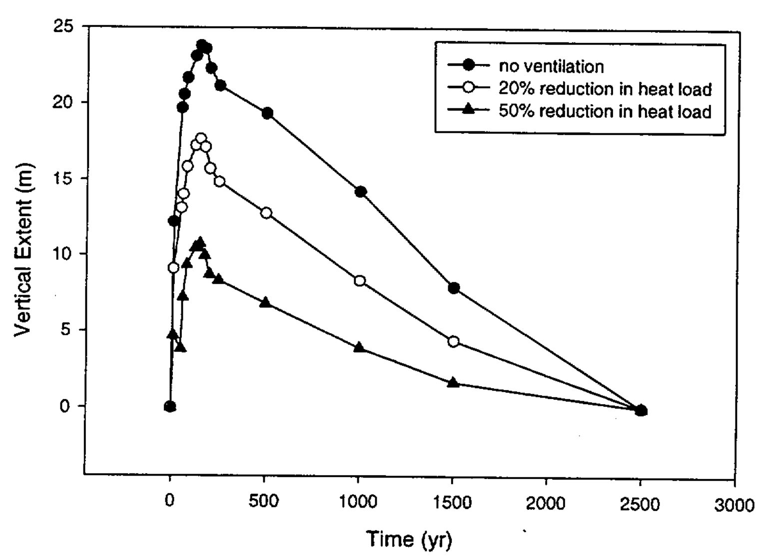

Figure 3-10. Vertical thickness of boiling isotherm (m) above center of heat source at an infiltration rate of 10 mm/yr versus time for a 60 MTU/acre thermal load for (a) no ventilation–solid circles, (b) ventilation with 20 percent heat loss–open circles, and (c) ventilation with 50 percent heat loss for 50 yr–triangles

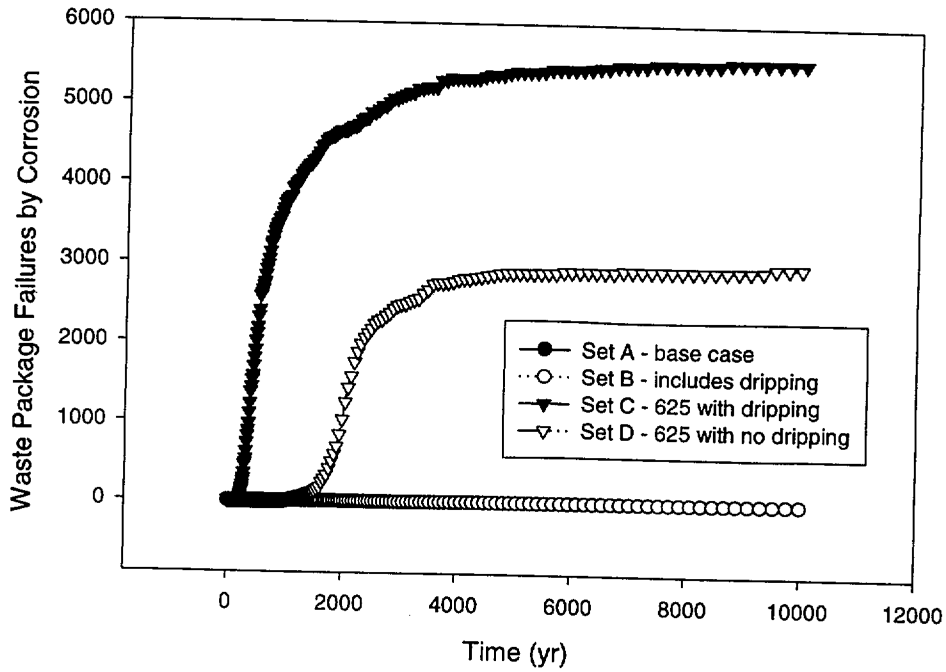

Figure 3-11. TPA Version 3.2 sensitivity analysis results expressed as predicted waste package failure by corrosion versus time for data sets A–D. Set A: basecase; Set B: effects of dripping included; Set C: alloy C-22 replaced with alloy 625, effects of dripping included; Set D: alloy C-22 replaced with alloy 625 and no dripping. Note that Sets A and B are the same.

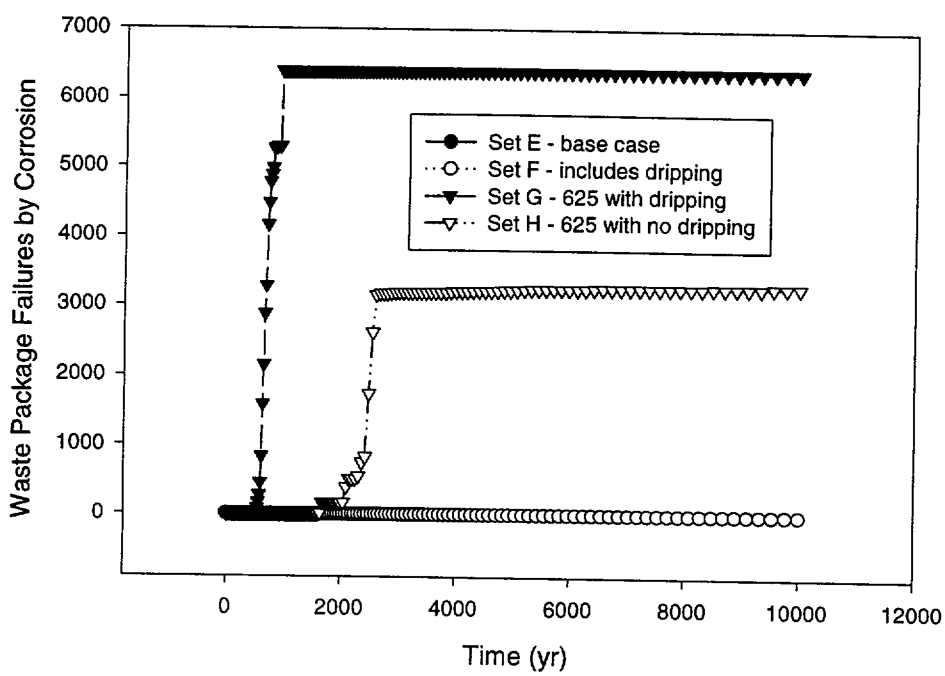

Figure 3-12. TPA Version 3.2 REFLUX3 sensitivity analysis results expressed as predicted waste package failure by corrosion versus time for data sets E–H. Set E: basecase; Set F: effects of dripping included; Set G: alloy C-22 replaced with alloy 625, effects of dripping included; Set H: alloy C-22 replaced with alloy 625 and no dripping. Note that Sets E and F are the same.

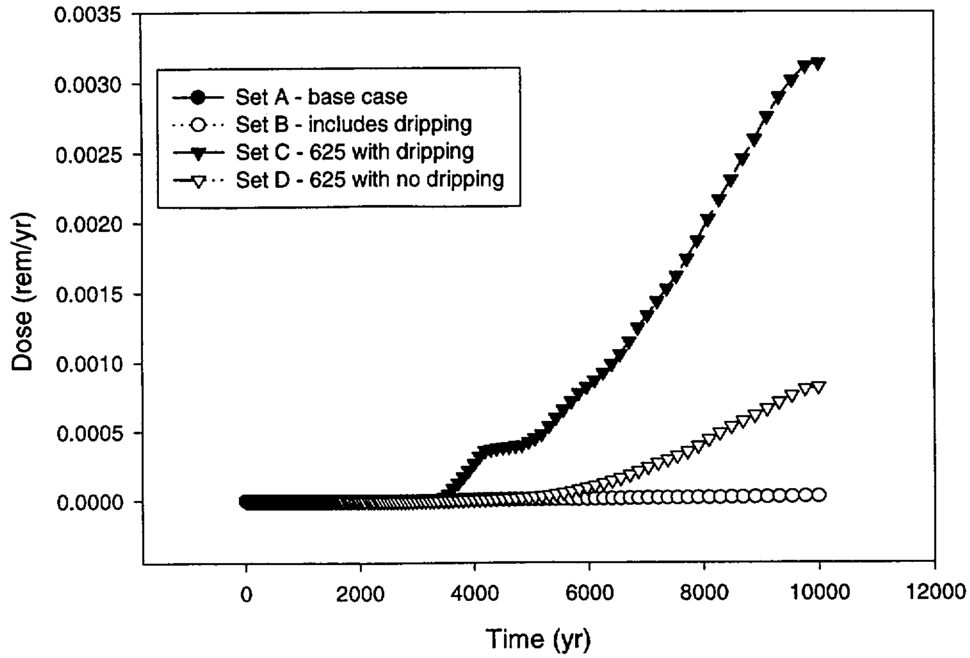

Figure 3-13. TPA Version 3.2 sensitivity analysis results expressed as simulated cumulative dose 20 km downgradient from the repository versus time for data sets A–D. Set A: basecase; Set B: effects of dripping included; Set C: alloy C-22 replaced with alloy 625, effects of dripping included; Set D: alloy C-22 replaced with alloy 625 and no dripping. Note that Sets A and B are the same.

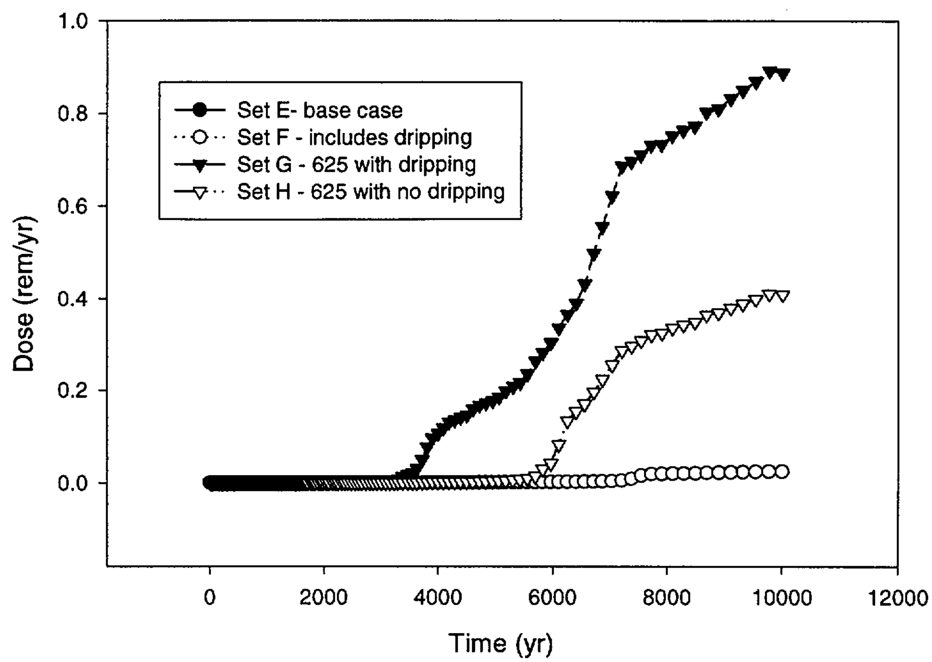

Figure 3-14. TPA Version 3.2 REFLUX3 sensitivity analysis results expressed as simulated cumulative dose 20 km downgradient from the repository versus time for data sets E–H. Set E: basecase; Set F: effects of dripping included; Set G: alloy C-22 replaced with alloy 625, effects of dripping included; Set H: alloy C-22 replaced with alloy 625 and no dripping. Note that Sets E and F are the same.

In the first four sets of analyses, WP failure by corrosion was only observed when WP material properties were modified from alloy C-22 to alloy 625. There were no WP failures by corrosion for the analyses of alloy C-22 WP material (Sets A and B). The number of WP failures by corrosion was greater and the time to WP failure was shorter, however, when the effects of dripping were included with the alloy 625 (i.e., Set C–with dripping versus Set D–without dripping). The number of total failures observed at 10,000 yr for alloy 625 with dripping was 5,547 compared to a total of 2,987 failures observed for alloy 625 without dripping. The time to failure for alloy 625 with dripping was significantly less than alloy 625 without dripping. For example, 3,803 WPs failed at 1,000 yr, when the effects of dripping were included compared to less that 10 WPs failed by 1,000 yr without dripping. Dose predictions at 20 km were consistent with WP failure calculations. At 10,000 yr, about 0.0030 rem/yr dose was predicted to occur at the 20-km point for the case of alloy 625 WP material with the effects of dripping included (Set C) compared to about 0.0007 rem/yr for alloy 625 without dripping (Set D).

The second category of analyses (Sets E–H) was conducted to evaluate the effect of refluxing water on radionuclide release from failed WPs. Time periods extending to 10,000 yr were evaluated. Only REFLUX3 parameters, dripping parameters (when included), and alloy 625 parameters (when included) were varied. All other variables were maintained at their mean values. Results from this category of analyses were consistent with the first category of analyses. WP failures by corrosion were only observed if alloy C-22 was replaced with alloy 625. There was no WP failure by corrosion for the analyses of alloy C-22 (Sets E and F). Similar to the first category of tests, the number of alloy C-22 WP failures was greater in the presence of dripping (Set G) than without dripping (Set H). Dose was consistent with the WP failure predictions, however, the dose predictions in the REFLUX3 analyses were considerably greater than predicted in Sets A–D of the analyses. The dose at 10,000 yr was about 0.9 rem/yr for Set G (alloy 625 with dripping) and about 0.4 rem/yr for Set H (alloy 625 without dripping).

4 SUMMARY

4.1 PROCESS LEVEL

Drift-scale numerical simulations of thermohydrological processes for the proposed repository with a thermal load from 60 MTU/acre were conducted for a range of modeled conditions. Modeled conditions included (i) a basecase with no heat loss by ventilation, (ii) heat loss by ventilation equivalent to 20 percent reduction in heat load for the first 50 yr after waste emplacement, and (iii) heat loss by ventilation equivalent to 50 percent reduction in heat load for the first 50 yr after waste emplacement. These analyses were conducted at infiltration rates of 1 mm/yr and 10 mm/yr. Based on these process-level analyses, it appears that the boiling isotherms of adjoining emplacement drifts (i.e., 96 °C at the repository horizon) will not coalesce either with or without ventilation of the emplacement drifts and at either rate of infiltration. Lack of coalescence of the boiling isotherm between drifts allows for greater propensity of shedding of condensate and infiltration water that might otherwise seep into an emplacement drift. Coalescence of the boiling isotherm, as indicated for higher repository thermal loads (i.e., 85 MTU/acre as in the VA design), could conceivably prevent the downward flow of condensate and infiltration waters, thereby increasing the potential for focused flow down individual fractures, some of which might intersect emplacement drifts leading to premature and potentially excessive wetting of WPs. Although the magnitude of heat loss by ventilation was not directly calculated in these analyses and is not known, the removal of heat by ventilation at either 20 or 50 percent of the total thermal load for the first 50 yr after emplacement resulted in smaller dry-out zones that persisted for shorter durations when compared to calculations with no effects from ventilation included.

4.2 SYSTEMS LEVEL

Systems-level TPA analyses were conducted to evaluate the potential importance of dripping and WP material deficiencies on WP failure by corrosion. The impact of refluxing as represented in the REFLUX3 submodule on radionuclide release from a failed WP was also evaluated. Systems-level analyses results were plotted in terms of WP failure by corrosion versus time and in terms of total potential dose at 20 km downgradient along the flow of groundwater from the proposed repository versus time extending to 10,000 yr. Systems-level TPA analysis of the basecase indicated no WP failure by corrosion for the VA design (Sets A and E). The TSPA-VA design specifies alloy C-22 as the inner-layer WP material. Additionally, no WP failure by corrosion is predicted when only the effects of dripping were included (Set B). The effects of dripping were incorporated into the analyses by: (i) reducing the threshold RH for aqueous corrosion from a uniform distribution of [0.75, 0.85] to [0.15, 0.25]; (ii) reducing the threshold RH for humid-air corrosion from 0.55 to 0.10; (iii) reducing the thickness of water film on the WP surface through which oxygen must diffuse from a uniform distribution of [0.001, 0.003] to [0.00001, 0.00003]; and (iv) increasing the chloride concentration multiplication factor from a uniform distribution of [1.0, 30.0] to [29.0, 30.0]. This lack of WP failure by corrosion due to dripping indicates that either dripping on a WP does not affect WP performance if the WP material performs according to the properties assigned alloy C-22 in the TSPA-VA, or TPA does not effectively incorporate WP failure by corrosion, at least in the manner in which dripping was represented in these sets of analyses.

Significant WP failure by corrosion was encountered when the material properties of the WP were modified to reflect material deficiencies derived from closure welds or any other material defect, nonuniformity, or inadequacy not considered in juvenile WP failure. The material modifications were incorporated by replacing alloy C-22 specific property values with those of alloy 625. Three WP material properties in EBSFAIL varied when the WP inner container material was modified from alloy C-22 to alloy 625: (i) the repassivation potential intercept of the inner overpack, (ii) the repassivation potential slope of the inner overpack, and (iii) the critical chloride concentration for localized corrosion of the outer overpack. The repassivation potential intercept value was modified from the alloy C-22 uniform distribution range of [1,040.0, 1,240.0] to the alloy 625 range of [48.5, 148.5]. The repassivation potential slope of the inner overpack was modified from the alloy C-22 value of 0.0 to the alloy 625 value of −160.8. Critical chloride concentration for localized corrosion of the outer overpack was modified from the alloy C-22 value of 1.0 moL/L to the alloy 625 value of 3.0e−2 moL/L. The result of the material property modifications was that a significant number of WPs failed by corrosion during the compliance period. In fact, the first WPs failed starting at year 188 and 1,000 WPs failed by year 365 when the WP material was represented as alloy 625 and the effects of dripping were included. If the effects of dripping are not included, the initial WP failure is delayed until about 950 yr and 1,000 WPs do not fail until almost 1,000 yr. At 10,000 yr, a dose of about 0.0030 rem/yr was calculated at the 20-km point for the case of alloy 625 WP material with the effects of dripping included (Set C) compared to about 0.0007 rem/yr for alloy 625 without dripping (Set D).

The second category of analyses was conducted to evaluate the effect of refluxing water, as represented in the REFLUX3 submodule, on radionuclide release from failed WPs. Only REFLUX3 input parameters, dripping parameters (when included), and alloy 625 parameters (when included) were varied. All other variables were maintained at their mean values. Results from this category of analyses were consistent with the first category of analyses. No WP failures by corrosion were predicted for alloy C-22 for the period extending to 10,000 yr (Sets E and F). WP failures by corrosion were only observed if alloy C-22 parameters were replaced with alloy 625. The number of WP failures was greater in the presence of dripping (Set G) than without dripping (Set H). Annual dose was consistent with the WP failure predictions, however, the annual dose predictions in the REFLUX3 analyses (Sets E–H) were considerably greater than predicted in the first four sets (A–D) of analyses. The dose at 10,000 yr was about 0.9 rem/yr for WP material alloy 625 with dripping and about 0.4 rem/yr for alloy 625 without dripping, which is about three orders of magnitude greater than the predictions for Sets A–D. The magnitude of this difference is attributed to the combination of mean values assigned to the remaining input parameters and the values assigned to the specific parameters investigated in this analysis.

These analyses indicate repository performance is high (in terms of low annual dose) if the WPs perform in accordance with the alloy C-22 property values specified in TSPA-VA. However, if the WP material has reduced performance due to closure welds or any other material deficiency not considered in juvenile failures, WP failure by corrosion can become significant. The number of WP failures by corrosion can be increased, the time to WP failure by corrosion can be reduced, and the annual potential dose at 20 km from the proposed repository can be increased if the effects of dripping are included with WP material deficiencies. Although total replacement of WP material alloy C-22 by alloy 625 in this analysis is a bounding assumption, the results indicate the potential importance of WP material corrosion susceptibility and the effects of dripping on WP materials performance.

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U.S. Nuclear Regulatory Commission
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Subject: Thermal Effects on Flow (TEF) KTI Intermediate Milestone No. 1402-661-930: Process-Level Sensitivity Analysis (REFLUX3/MULTIFLO)—Status Report

Dear Mr. Pohle:

Attached is the Center for Nuclear Waste Regulatory Analyses (CNWRA) document entitled "Process- and Systems-Level Sensitivity Analyses—Status Report." To better reflect in these analyses recent U.S. Department of Energy repository design changes, the delivery date for this milestone has been rescheduled from July 30, 1999 to September 10, 1999 through the CNWRA Program Manager's Periodic Report for Period 10–FY1999. This technical document fulfills the requirements for the subject milestone.

If you have any questions on this report, please contact me at (210) 522-5151 or Ronald T. Green at (210) 522-5305.

Sincerely,

Asadul H. Chowdhury, Manager
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