APPENDIX B

CALCULATIONS IN SUPPORT OF PANEL GAS PRESSURIZATION DUE TO CREEP CLOSURE

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B.1.0 Introduction

This appendix presents the closure mechanisms and supporting calculations for panel volumetric closure for the analysis of gas pressurization within a closed panel at the Waste Isolation Pilot Plant (WIPP). The volume reduction is due to the panel volume change from viscoplastic creep closure of the walls, roof, and floor. As the walls, roof, and floor of the excavations converge, the total volume of the panel decreases. The volumetric closure of a panel is the result of several different mechanisms working in tandem. These mechanisms include:

- Viscoplastic creep of the salt toward the excavation
- Fracturing in the roof and floor caused by the deviatoric stresses around the excavation
- Bed separation at the clay seams in the roof and the floor.

The combination of these three mechanisms causes the observed convergence rates in Panel 1. Of these mechanisms, only creep of the salt reduces the total volume of the panel and pore space in the surrounding disturbed rock zone (DRZ). Fracturing in the roof and floor and bed separation transfer the void volume within the excavation to the DRZ. This void volume within the DRZ is assumed to be interconnected with the open excavation. Therefore the total reduction in volume within the panel, based simply on room closure, overestimates the effective reduction in void volume. However, quantifying the amount of interconnected void space within the DRZ would require a much more detailed analysis. The total volume change calculated from the room closure measurements is therefore considered conservative.

Other assumptions made in this calculation are:

- The volumetric closure rates are constant after panel closure.
- The waste in the panel provides no significant resistance to creep closure during the initial 35 years.

- The air volume is the total volume of the excavations minus the solid volume of the waste in drums or other waste packages. This is estimated to equal 138,000 ft^3 (3,908 m^3).

- The closure rate of each room in the panel equals the closure rate at the midpoint of the room.

- The length of each room or drift is constant; to simplify the calculations, only the width and height change with creep closure.

- The panel is comprised of seven rooms and two panel access drifts.

B.2.0 Panel Volume Change Calculation

The panel volume change calculation is performed by first calculating the initial panel volume, then calculating the room and drift closure rates, and finally calculating the panel volumetric closure rate. Following is a detailed description of each part of the calculation.

B.2.1 Initial Panel Volume

The initial panel volume is determined immediately after completion of excavation. The total volume is calculated by summing the individual room and drift volumes within the panel. These volumes are based on the as-built dimensions of the excavated rooms and drifts in Panel 1 (DOE, 1993). Table B-1 presents the room and drift dimensions and the calculated volume of each room and drift. The volume of the air-intake and air-exhaust drifts is not included. The total initial volume of Panel 1 is 1,669,434 ft^3 (47,273 m^3).

The total solid volume of the waste in a filled panel is 138,000 ft^3 (3,908 m^3) (DOE, 1994; Butcher, et al., 1991). Subtracting the waste volume from the total panel volume gives the total initial air volume (1,531,434 ft^3 [43,365 m^3]) in the panel.

B.2.2 Closure Rates

Using convergence data from Panel 1 the average closure rates of the rooms and drifts are determined (DOE, 1993). Closure rates within the rooms and drifts are higher in the first five years after excavation. The roof-to-floor and wall-to-wall closure rates for each of the rooms and drifts are presented in Table B-2.

Because all of the excavations in Panel 1 are approximately 13 x 33 ft (4 x 10 m), the closure rates for each room or drift are the same.

Table B-1
Initial Room and Drift Dimensions and Volume of Panel 1

Room or Drift	Initial Width (ft)	Initial Height (ft)	Initial Length (ft)	Initial Volume (ft^3)
Room 1	33	13	300	128,700
Room 2	33	13	300	128,700
Room 3	33	13	300	128,700
Room 4	33	13	300	128,700
Room 5	33	13	300	128,700
Room 6	33	13	300	128,700
Room 7	33	14	300	138,600
South 1950 panel access drift	33	14	848	391,776
South 1600 from Room 1 to Room 5	33	13	573	245,817
South 1600 from Room 5 to Room 7	33	14	262	121,044
Total Initial Panel Volume				1,669,437

B.2.3 Volumetric Panel Closure Rate

Using the closure rates from Table B-2, the dimensions of the rooms and drifts in Panel 1 can be calculated at the end of each progressive year or for subsequent years using the following equations.

For 0 to 5 years after excavation:

$$V_t = (w_i - R_H t) \times (h_i - R_{Vo} t) \times l_i$$

Table B-2
Room and Drift Closure Rates
(DOE, 1993)

Room or Drift	Vertical Closure Rate		Horizontal Closure Rate	
	0 to 5 Years (ft/yr)	> 5 Years (ft/yr)	0 to 5 Years (ft/yr)	> 5 Years (ft/yr)
Room 1	0.3194	0.2109	0.2234	0.1160
Room 2	0.3194	0.2109	0.2234	0.1160
Room 3	0.3194	0.2109	0.2234	0.1160
Room 4	0.3194	0.2109	0.2234	0.1160
Room 5	0.3194	0.2109	0.2234	0.1160
Room 6	0.3194	0.2109	0.2234	0.1160
Room 7	0.3194	0.2109	0.2234	0.1160
South 1950 panel access drift	0.3194	0.2109	0.2234	0.1160
South 1600 from Room 1 to Room 5	0.3194	0.2109	0.2234	0.1160
South 1600 from Room 5 to Room 7	0.3194	0.2109	0.2234	0.1160

For greater than 5 years after excavation:

$$V_t = (w_i - R_H t) \times (h_i - R_{V5}(t-5) - R_{V0}5) \times l_i$$

where

V_t = Volume of the room at time t
t = Time (in years)
w_i = Initial room width
h_i = Initial room height
l_i = Initial room length
R_H = Horizontal closure rate (ft/year)
R_{V0} = Vertical closure rate for first 5 years (ft/year)
R_{V5} = Vertical closure rate after 5 years (ft/year).

We obtain the incremental change in volume:

$$\Delta V = V_1 - V_2$$

where

V_1 = Volume of room at time t_1 (ft^3)
V_2 = Volume of room at time t_2 (ft^3)
ΔV = Change in volume of room between time t_1 and t_2 (ft^3)
t_1, t_2 = Years after excavation

The volume of all the rooms within the panel is calculated at the time of four years after excavation, when the waste is assumed to have been emplaced the amount of time required for waste emplacement (Table B-3). The total volume of the panel after four years is 1,469,112 ft^3 (41,601 m^3). The volume of the panel is then calculated at five years after excavation or one year after panel closure (Table B-3). This volume is 1,420,312 ft^3 (40,219 m^3), and the volume reduction in that year is 48,800 ft^3 (1,382 m^3).

The initial volume in a closed panel after approximately four years is obtained from the total volume at four years (1,469,112 ft^3 [41,601 m^3]) minus the solids volume (138,000 ft^3 [3,908 m^3]), or 1,331,112 ft^3 (37,693 m^3). This volume is used as the initial volume for the restricted air-flow model calculations.

The rate of change for panel volume is assumed to be constant for the first five years after excavation, because the vertical and horizontal closure rates are constant during this period. (Actually, rate of volume change over time decreases slightly with each year due to "corner effects," but this error is less than 2 percent and is considered insignificant.) Table B-3 also shows the panel volumes at 15 and 16 years after excavation and the change in volume between those years. The volumetric panel closure rate is 28,673 ft^3 per year (812 m^3 per year). This is the rate in volume change per year in the panel from five to approximately 35 years after excavation.

At approximately 16 years after excavation, the roof comes in contact with the waste stack. Only 35 years after excavation does the waste stack begin to provide significant resistance to creep (approximately 2 MPa). This resistance is expected to slow the vertical convergence rate by some amount.

Table B-3
Panel Volume at Various Times

Room or Drift	Volume of Room (ft^3)			
	At 4 Years	At 5 Years	At 15 Years	At 16 Years
Room 1	112,914	109,069	85,662	83,401
Room 2	112,914	109,069	85,662	83,401
Room 3	112,914	109,069	85,662	83,401
Room 4	112,914	109,069	85,662	83,401
Room 5	112,914	109,069	85,662	83,401
Room 6	112,914	109,069	85,662	83,401
Room 7	122,545	118,633	94,879	92,583
South 1950 panel access drift	346,395	335,337	268,191	261,702
South 1600 from Room 1 to Room 5	215,665	208,321	163,614	159,296
South 1600 from Room 5 to Room 7	107,023	103,607	82,861	80,856
Total Volume of Panel 1	1,469,112	1,420,312	1,123,529	1,094,856
Change in Volume		48,800		28,673

B.3.0 References

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