Title 40 CFR Part 191 Compliance Certification Application for the Waste Isolation Pilot Plant

MASS Attachment 7-1

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MEMORANDUM

To: M.G. Marietta

From: T.W. Thompson, F.D. Hansen FDH

Date: August 2, 1996

Subject: Long-term Performance of Panel Closures

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1. INTRODUCTION

After waste has been emplaced in a panel, closures will be built to restrict flow from the panel during the remainder of the operational phase. These closures will include a length of concrete placed in the panel entries. Although it is not the intent of these closures to restrict flow over the regulatory period of 10,000 years, evaluation of their long-term performance characteristics are required to determine their contribution to overall system performance.

Flow of fluids into or out of the panels will be controlled by the conductance of the panel closure, and of the surrounding disturbed rock zone (DRZ). Performance Assessment (PA) calculations use a constant value for DRZ permeability of 10^{-15} m^2, a value which is substantiated in the records package for the waste rooms (FEP: S6). Consideration of the current panel closure designs indicates that they will maintain their structural integrity for the regulatory period. If this is the case, then the concrete element of the closure system will continue to provide resistance to inward deformation of the surrounding salt, and will prohibit growth of the DRZ from its initial state. Since the DRZ will not increase during the regulatory period, and may decrease, the assumption of a constant DRZ permeability is reasonable.

The panel closures have been designed to limit the flow of brine and gas out of the disposal regions during the operational phase, and current designs call for these operational closures to include concrete elements (Figure 1). Although these closures are designed for an operational use, it is expected that they will continue to provide fluid flow restriction during the post-closure phase. The remainder of this memorandum establishes the permeability expectations of the closures, with emphasis on the potential for concrete degradation and increase in permeability. For the purposes of these analyses the concrete elements are taken to have a length of nominally 26 ft (7.9 m) (USDOE, 1996a,b), and to be made of a material chosen so as to be compatible with the environment, such as Salado Mass Concrete (SMC: Sandia, 1996) or a similar mix. Degradation of the concrete may occur by interaction with brine flowing through the plug, or with brines flowing along the plug/salt interface or in the DRZ.

2. CONCRETE PROPERTIES

The initial permeability expected for the concrete panel closures are documented in the materials specification appendix of the Compliance Submittal Design Report (CSDR) (Sandia, 1996a) developed for the shaft seal system. In addition to conventional engineering properties, the SMC has well documented permeability characteristics, permeabilities having been determined from field tests (Knowles and Howard, 1996) and laboratory studies (Pfeifle et al., 1996). Figure 2, taken from the CSDR, summarizes the available data, and indicates a permeability for as-placed SMC of between $2x10^{-21}$ and $1.8x10^{-17}$ m^2. For calculations performed in this memorandum a value of 10^{-17} m^2 is used, this being at the high end of the values used by PA for the shaft concrete components, and consistent with other data. For example, data on generic portland cement pastes shows that the permeability of oil field concrete plugs is on the order of $1 x10^{-19}$ m^2, while data from the Bell Canyon Test indicate permeabilities for borehole concrete plugs of 5 x 10^{-17} m^2 (Petersen and Christensen, 1980; Christensen and Hunter, 1980).

For the purposes of calculating degradation of the concrete member an assumption of porosity is necessary. The expected value is 5 %, which is higher than the 2% estimated by Petersen and Christensen (1980) for the Bell Canyon Test plugs, but is generally consistent with practical experience of field emplaced concrete structures, and is the value for cast in-place SMC given in the CSDR (Sandia, 1996a). An upper limit for porosity is taken as 10%, which is an engineering estimate for concrete, and is used to add a level of conservatism to the calculations.

As noted in the introduction, the concrete closure member is expected to be structurally stable for the regulatory period, and to provide support for the surrounding rock and the DRZ. In this context it can be noted that the unconfined compressive strength of SMC is greater than 4500 psi (30 MPa), and that under the confined state of stress within the closure system the ultimate strength will be greater (Pfeifle et al, 1996). The compressive strength of SMC is sufficient to preclude structural failure of the concrete member in the panel entries.

3. DEGRADATION OF CONCRETE

The solid matrix that makes up concrete is composed almost entirely of amorphous to cryptocrystalline solid phases. These phases are thermodynamically unstable, and with time and exposure to water they alter into more stable and more crystalline assemblages. Thermodynamic calculations conducted by Alcorn et al (1992) have predicted the alteration phases of portland cement due to exposure to a variety of waters and brines as including tobermorite, quartz, gypsum, calcite, clays and zeolite, produced at the expense of soluble and unstable materials such as portlandite. The theoretical alteration assemblage occupies more volume than the original solids. These calculated results have been verified by subsequent experiments in which waters and cement were reacted (Onofrei et al., 1992), and are confirmed, at least partially, from observations made on recovered plugs originally placed decades ago in potash mineral exploratory holes in the Delaware Basin (Bonen, 1996), as well as from evaluations of salt-saturated concrete after six years in the WIPP (Wakeley et al., 1993).

At free surfaces concrete materials are not physically supported and can spall. Long term leaching experiments report that surface diffusion controlled alteration is dependent on the C_3A content of the cement and the Mg and $S0_4$ content of leachant (Walton et al., 1990). Creation of an alteration rind weakens the concrete and makes it subject to spalling (Wakeley et al., 1994). The mechanism for spalling is that the alteration phases occupy more volume than the original solids, volumetric expansion increases internal pore pressures until concrete tensile strengths are exceeded and spalling occurs. Short-term, empirical studies of ordinary concrete in brine report alteration rates in the range of 0.7 to 1 mm/year (Atkinson and Hearne, 1990) - These rates are likely to be overestimates because diffusion distance varies as the square root of time. Further details are given in Appendix C of Thompson et al., 1996.

4. DEGRADATION OF CONCRETE PANEL CLOSURES

The concrete elements of the panel closures may degrade in one of two ways, either by flow of brines through the mass of the concrete element, or by flow of brines along the interface.

4.1 Flow Through the Concrete Element

An estimate of the degradation of a concrete closure element may be made based on data on the progression of concrete chemical alteration reported by Berner (1990) for both fresh water and brine leachants (Figure 3). The progression is charted in terms of the volume of water flow, with degradation indicated by a decrease in Ca, increase in SO_4 and increase in SiO_2 in solution (corresponding to removal of silica and sulphate from the concrete) which occurrs at between 100 and 1000 water exchange cycles. This indicates that more than 100 pore volumes of leachants must pass through concrete before there is chemical evidence that the matrix is being significantly attacked. Based on these results, it has been assumed (conservatively) that the concrete closure elements will degrade significantly after 100 pore volumes of water have passed through them. A more detailed discussion of these results is given in Thompson et. al. (1996).

This volume can be converted to performance life by using Darcy's Law and considering the flow of fluids though the plug and the surrounding DRZ. If there is a pressure difference between the panel and the rest of the repository, flow will occur through the panel closure and the surrounding DRZ, with the two elements acting as flow resistors in parallel (Figure 4). If the pressure in the panel is P_1 (Pa) and in the rest of repository is P_2 (Pa), then under brine saturated conditions, the steady state flow rate out of the panels will be Q, where:

$$Q = A^*(k'/\mu)^*(P_1 - P_2)/L \;\; m^3/sec, \qquad (1)$$

where:
A is the total flow area of the panel closure plus DRZ (m^2)
L is the flow length (m)
μ is the fluid viscosity (Pa.s)
k' is the composite permeability of the panel closure plus DRZ (m^2).

The composite permeability, k', is given by:

$$k' = (k_d A_d + k_c A_c)/(A_d + A_c), \qquad (2)$$

where:
k_d, k_c are the permeabilities of the DRZ and plug closure respectively (m^2)
A_d, A_c are the flow cross-sectional areas of the DRZ and plug closure respectively (m^2).

The flow through the panel closure, q_c, will be:

$$q_c/Q = k_c A_c/(k_d A_d + k_c A_c). \tag{3}$$

The pore volume of the panel closure (V_p) is:

$$V_p = A_c L \phi \text{ m}^3,$$

where ϕ is the porosity. The number of pore volumes (N_p) flowing through the closure in unit time will be:

$$N_p = q_c/V_p \text{ pore volumes/sec},$$

and the time for 100 pore volumes to flow through the closure will be:

$$t_{100} = 100/(N_p{*}3.154\text{x}10^7) \text{ years}$$

The current design (USDOE, 1996a,b) calls for a length of 7.9 m (26 ft) for the concrete closure, and a cross-sectional area of 15.63 to 24.16 m^2 (4.27 to 6.10 m wide by 3.66 to 3.96 m high). As noted in Section 2 an undegraded concrete permeability of 10^{-17} m^2, and a porosity ranging from 5% to 10% may be assumed. The DRZ around the closure is assumed to have a permeability of 10^{-15} m^2. Based on the BRAGFLO grid (Sandia, 1996b) the DRZ may be assumed to have a height of 11.95 m above the closure and 2.23 m below. It is assumed that the salt DRZ in the pillars at either side of the closure heals due to creep closure onto the rigid concrete. The DRZ flow area may therefore be taken as between 60.55 and 86.50 m^2.

Given these values, the effective permeability of the closure and the DRZ, from equation (2), is between 7.84 and 7.97x10^{-16} m^2, with an effective flow area of 76.18 to 110.66 m^2. When brine flows between the panel and the rest of the repository, from equation (3), only between 0.26 and 0.28 % will flow through the closure, the remainder of the flow will be through the DRZ.

An analysis of calculations made with BRAGFLO (Sandia, 1996b) using a range of parameters, and assuming permeabilities for the closures and DRZ of 10^{-15} m^2, indicates that the maximum cumulative flow between the panel and the rest of the repository for any likely E1 or E2 scenario will be of the order of 10^4 m^3 (Figure 5). With these flows, and the split in flows indicated above, only 26 to 28 m^3 of brine will flow through the concrete closure in 10,000 years. For a porosity range of 5 % to 10 % the maximum cumulative flow through the concrete closure in 10,000 years will therefore be between about 0.6 and 1.2 pore volumes. The same point is made in Figure 6, which shows the cumulative flow with closure permeabilities of 10^{-15} to 10^{-17} m^2. Degradation will be minimal with these flow volumes.

4.2 Flow Along the Interface

Flow along the interface may be more rapid due to the higher permeabilities in the DRZ. A <u>maximum</u> effect of this flow might be estimated to be equivalent to the free surface spall rate of

0.5 to 1 mm/yr. Such a degradation rate is unrealistically high, since the degradation will be controlled by the rate of fluid flow, and total loss of material will not occur in a physically constrained region. However this rate of spall is much less than the expected closure rates (measured at the order of 0.1 to 0.2 ft/yr. or 30 to 60 mm/yr in Panel 1: USDOE, 1996b) so even such a rapid spall rate would be more than compensated for by creep of the salt on the closure. It is therefore concluded that the effect of flow along the interface will be minimal. At most it will lead to an insignificant increase in the DRZ flow area.

5. CONCLUSIONS

It is concluded that the potential flow through the concrete closure is nearly two orders of magnitude too small to cause any significant degradation. Degradation caused by flow in the DRZ adjacent to the concrete will be taken up by creep closure. It is therefore concluded that the panel closures will retain their initial permeability in the post-closure phase. If this permeability is 10^{-17} m^2, then the effective permeability of the DRZ and the closure together will be about 8×10^{-16} m^2. An assumption of a permeability of 10^{-15} m^2 for the closure and the DRZ is reasonable.

It is also concluded that since no significant degradation is expected for the concrete members, these will maintain their structural integrity and will provide a rigid support to prevent growth of the DRZ during the regulatory period.

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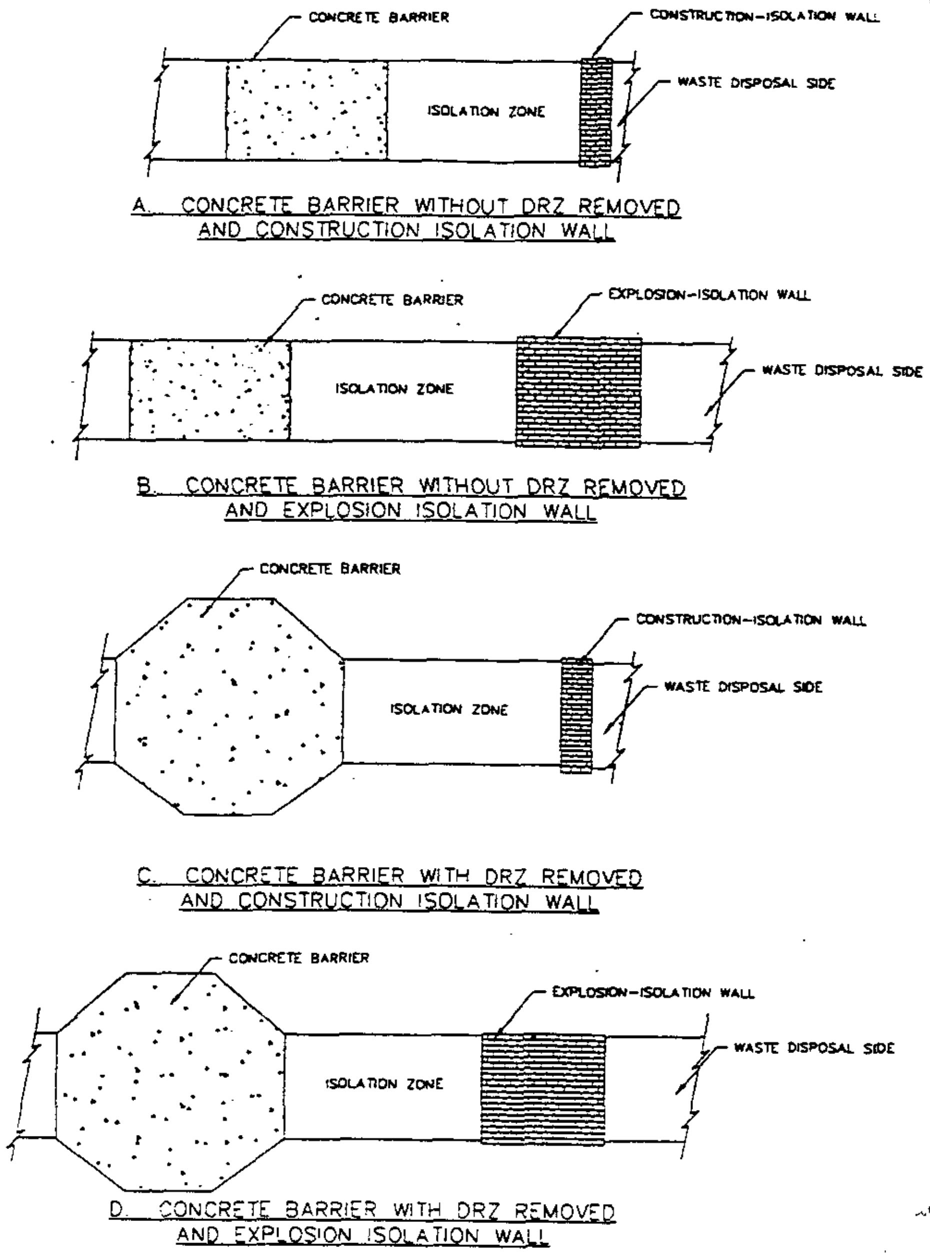

Figure 1: Panel Closure Designs (after USDOE, 1996a)

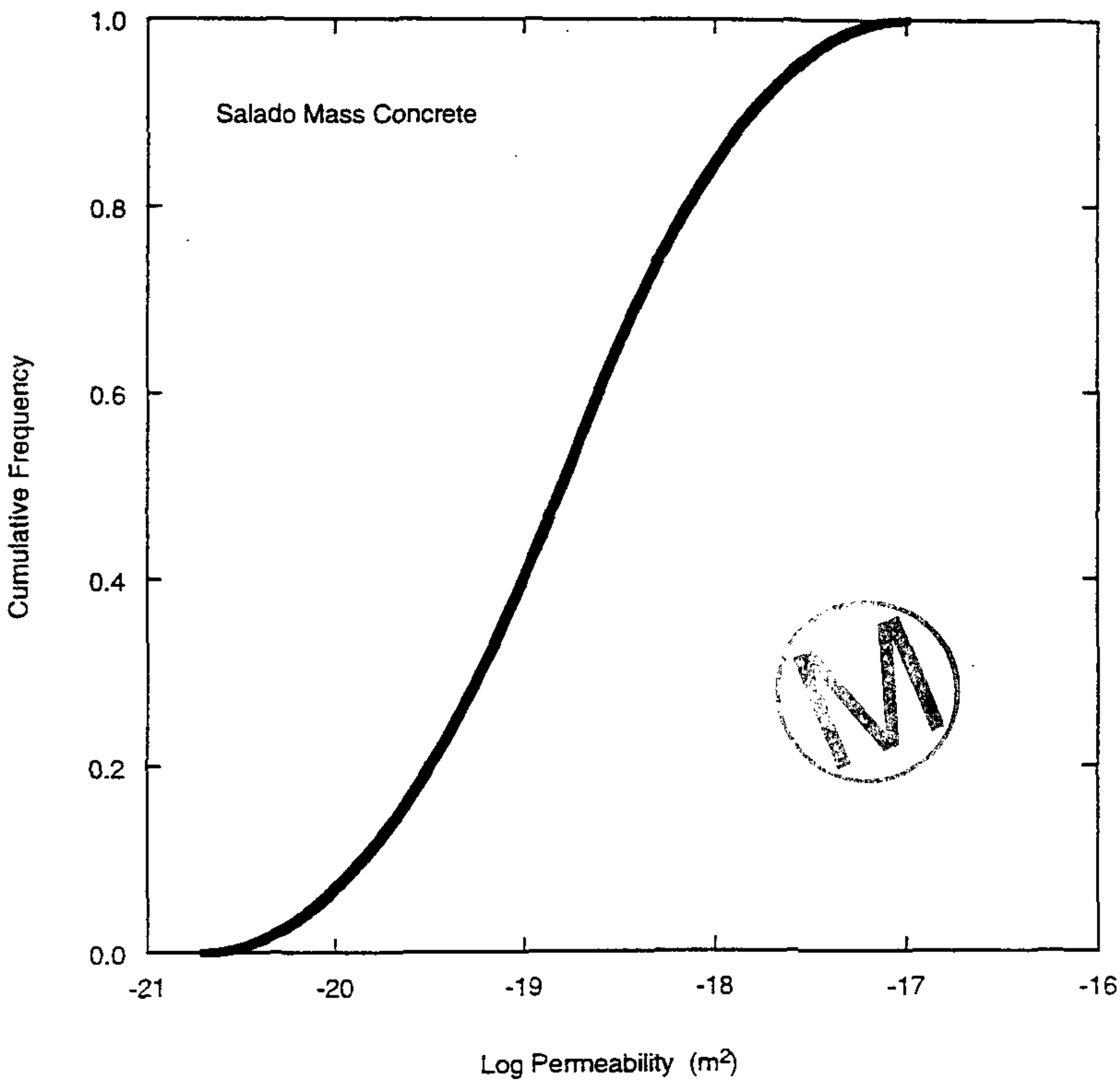

Figure 2: Cumulative Distribution Function for Permeability of SMC (after Sandia, 1996)

Figure c-3 Degradation of "HTS" in standard marl grundwater "MAR". After 6650 cycles calcite is the only solid phase present (T = 25 °C).

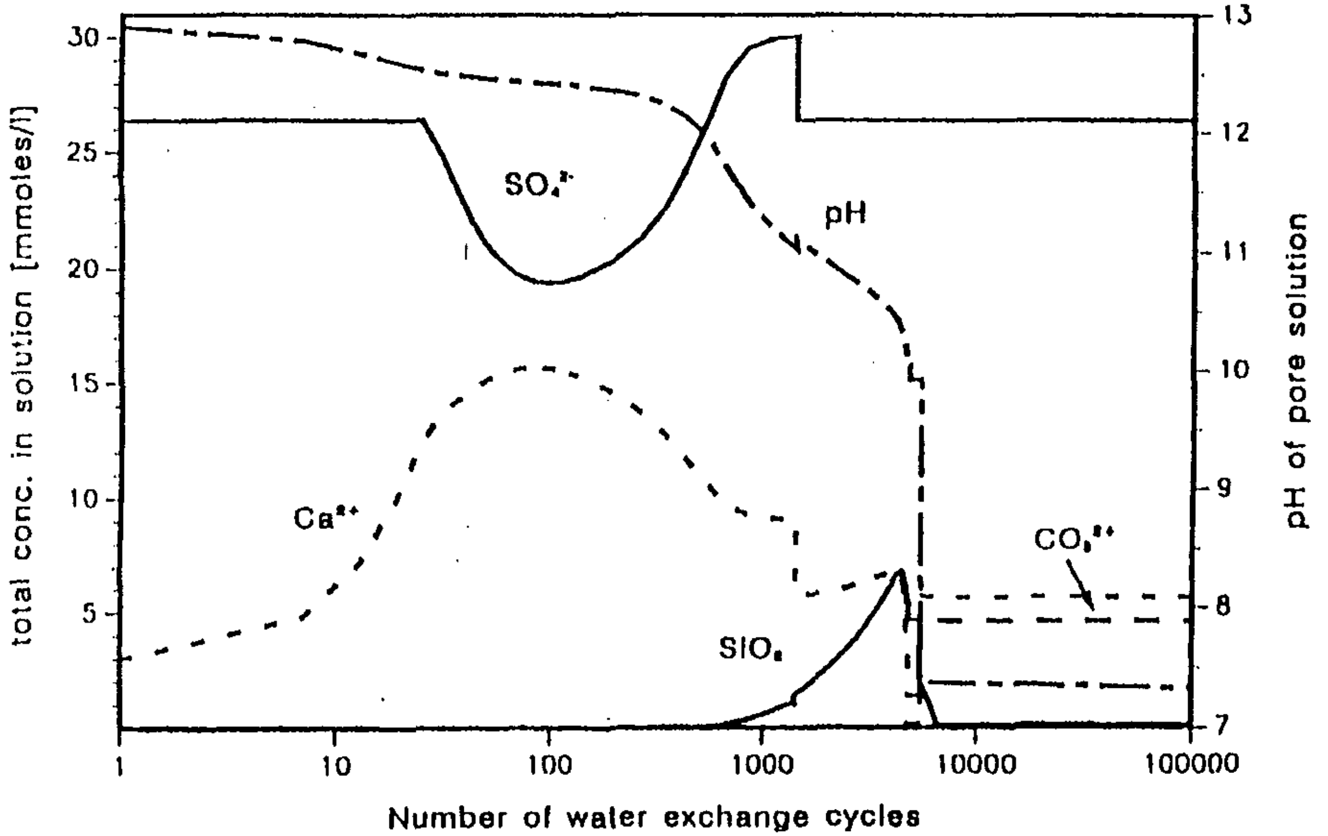

Figure 3: Degradation of Concrete in Brine (after Berner, 1990)

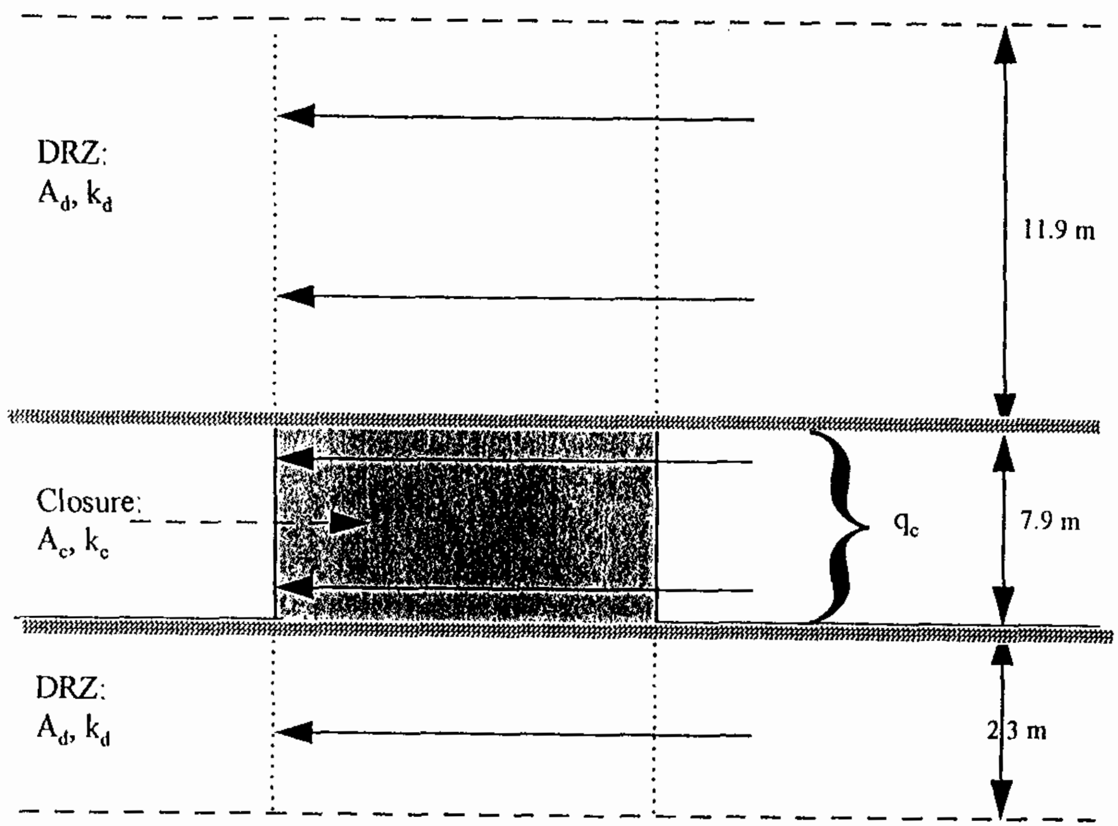

Figure 4: Parallel Flow through the Panel Closure and DRZ

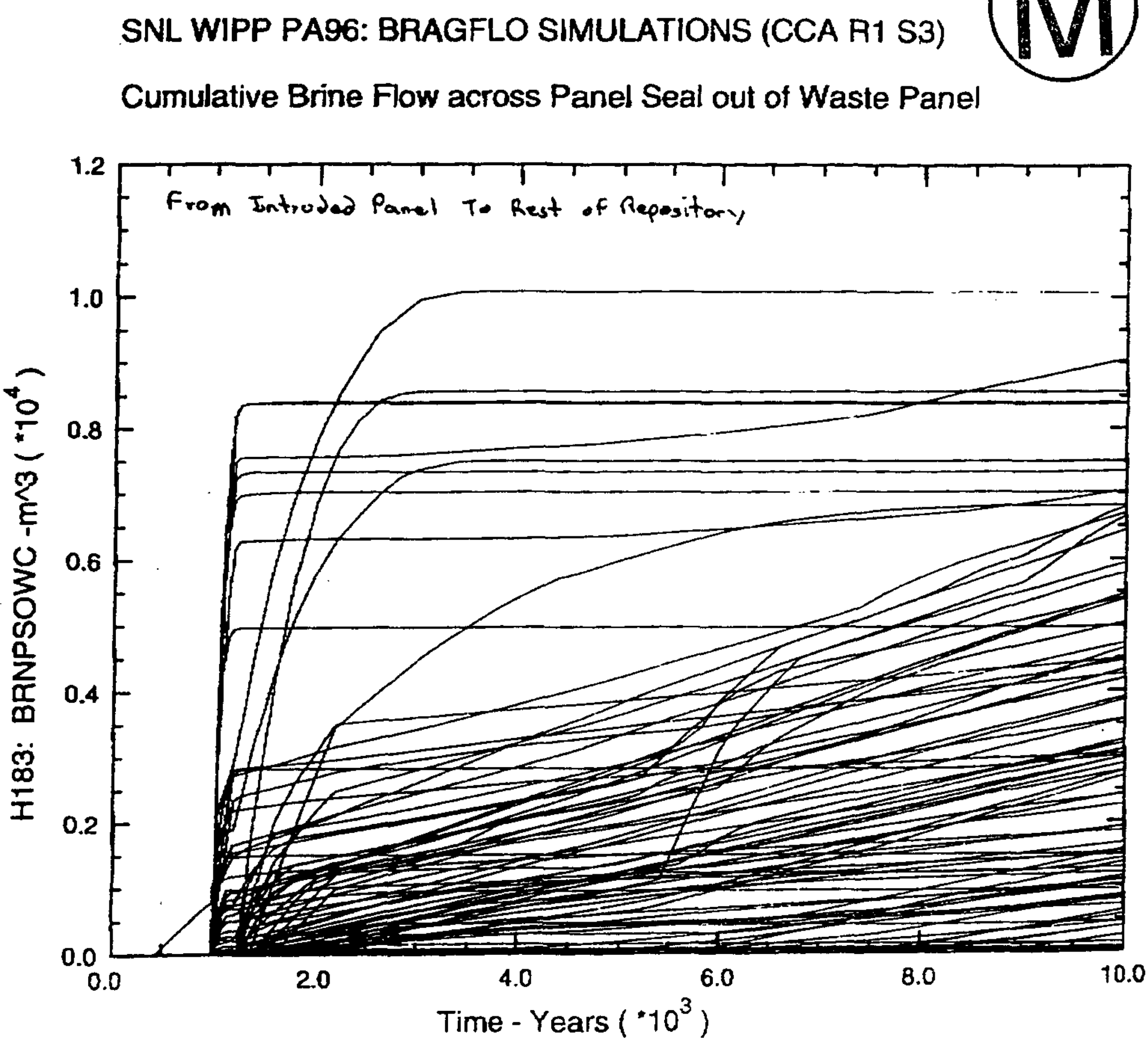

Figure 5: Cumulative flows between a panel and the rest of the repository for an E1 Intrusion at 1000 Years

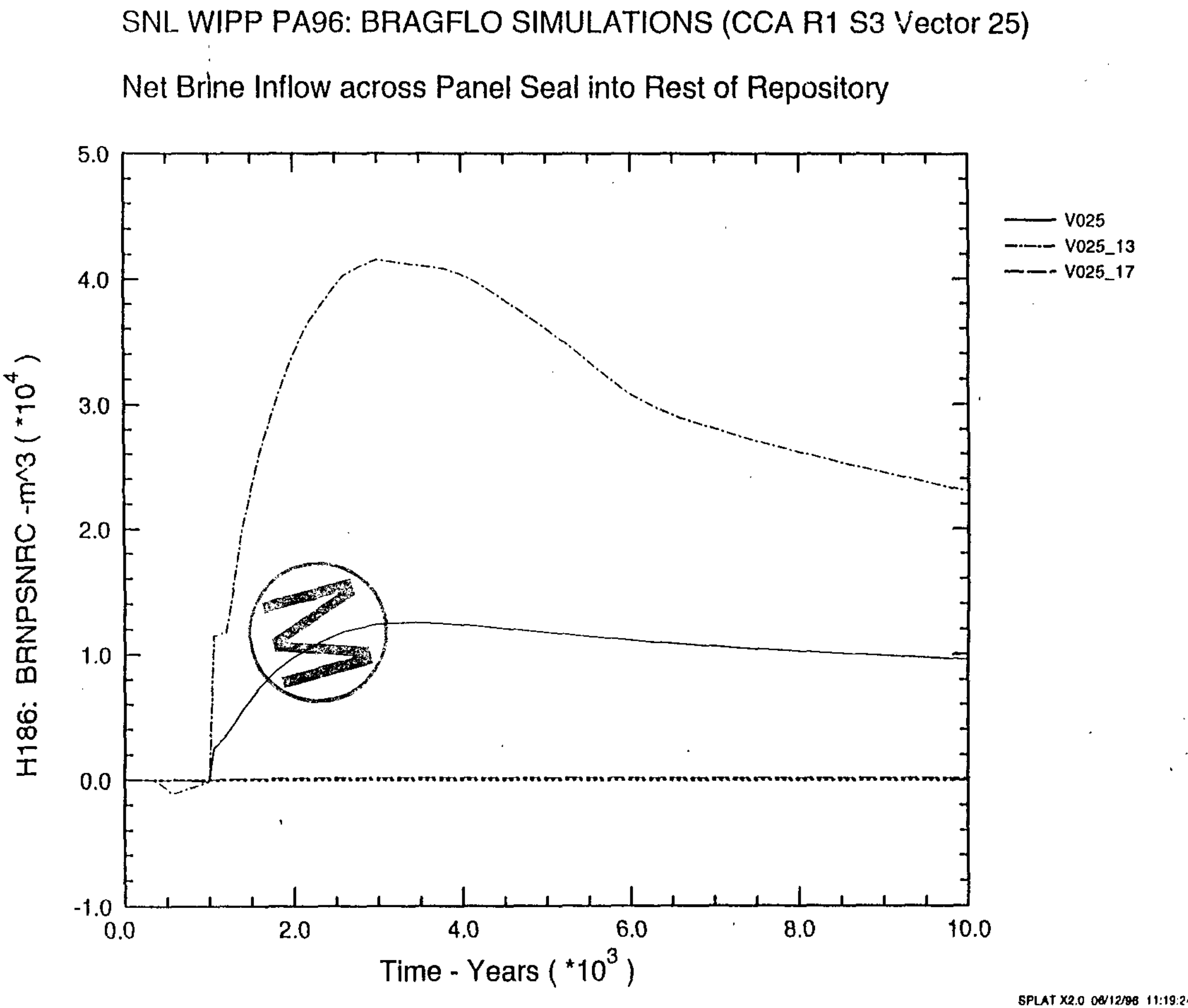

Figure 6: Cumulative flows through the Panel Closures for Permeabilities of 10^{-15} to 10^{-17} m^2. Results shown are for the Maximum Flow Case of Figure 5.