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subject: Effectiveness of Mixing Processes in the Waste Isolation Pilot Plant Repository

MgO backfill is being used in the Waste Isolation Pilot Plant (WIPP) as a chemical control agent to mitigate the effect of microbial CO_2 generation on actinide mobility in a post-closure repository environment. MgO is emplaced as super-sacks on the top of waste container stacks and as mini-sacks between and around waste containers. To enhance worker safety, the Department of Energy (DOE) proposes to eliminate the emplacement of MgO mini-sacks. This memorandum supports the DOE's assessment that the elimination of MgO mini-sacks will not impact MgO/brine accessibility in the WIPP and therefore the functionality of MgO as a chemical control will remain effective as stated in the Compliance Certification Application (CCA). Using a bounding calculation, the memo demonstrates that molecular diffusion alone will be sufficient to mix brines with MgO backfill in the repository without the presence of MgO mini-sacks.

In the following bounding calculation, only molecular diffusion is considered. The diffusion of a chemical species in a porous medium can be described by Fick's equation (e.g., Richardson and McSween, 1989, p.132):

$$\frac{\partial C}{\partial t} = \frac{\partial}{\partial X}\left(D_{eff} \frac{\partial C}{\partial X} \right) \qquad (1)$$

where C is the concentration of the diffusing chemical species; t is the time; X is the distance; and D_{eff} is the effective diffusivity of the chemical species in a given porous medium. D_{eff} is related to the porosity (ϕ) of the medium by (e.g., Oelkers, 1996):

$$D_{eff} = \phi^2 D \qquad (2)$$

where D is the diffusivity of the species in pure solution. The D values for most aqueous species at room temperatures fall into a narrow range, and 10^{-5} cm^2/sec is a good approximation (e.g., Richardson and McSween, 1989, p.138). From the CCA calculations (Bean et al., 1996, p.7-29; WIPP PA Department, 1993, equation B-8), the porosity in the WIPP waste panels after room closure is calculated to be 0.4 to 0.7. From Equation (2), the effective diffusivity D_{eff} in the waste is estimated to be $2 \sim 5 \times 10^{-6}$ cm^2/sec ($= 6 \sim 16 \times 10^{-3}$ m^2/year).

Given a time scale of T, the typical diffusion penetration distance (L) can be determined by scaling Equation (1):

$$L = \sqrt{D_{eff} T} \,. \qquad (3)$$

Using Equation (3), the diffusion penetration distance in the WIPP can be calculated as a function of diffusion time, as shown in Figure 1.

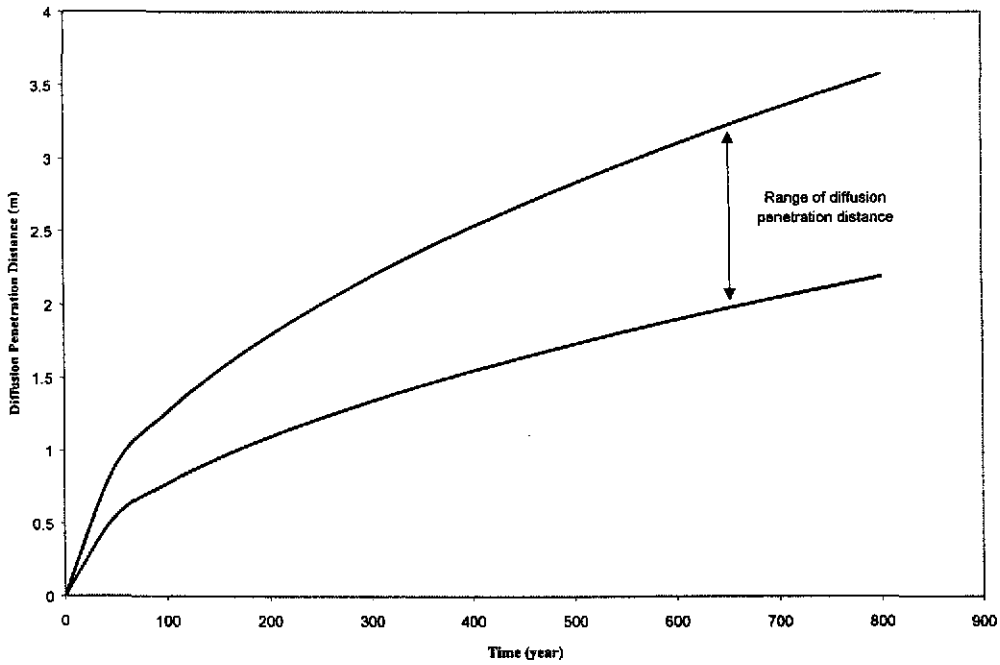

Figure 1. Diffusion penetration distance in the WIPP as a function of diffusion time

The average time for a brine pocket to remain in a waste panel after it enters the repository is characterized by a so-called mean residence time ($T_{residence}$), which can be calculated by:

$$T_{residence} = \frac{V_\phi}{F} \qquad (4)$$

where V_ϕ is the pore volume in a waste panel; and F is the rate of brine flow up to the Culebra formation through a borehole. From the CCA calculations, the pore volume in a waste panel after room closure ranges from 2,500 to 7,000 m^3 (Helton et al., 1998, p.8-50), and the maximum flow rate is 5.5 m^3/year (Helton et al., 1998, p.8-69). Using these values, $T_{residence}$ is estimated to be > 450 years. Over this time scale, according to Equation (3) and Figure 1, molecular diffusion alone can mix brine composition effectively at least over a distance of 1.6 m.

The height of waste stacks in the repository after room closure (h) can be calculated by:

$$h = \frac{h_0(1-\phi_0)}{1-\phi} \qquad (5)$$

where h_0 and ϕ_0 are the initial height of waste stacks and the initial porosity of wastes, which are assumed to be 4 m and 0.88, respectively, in the CCA. For ϕ = 0.4 - 0.7, h is estimated to be 0.8 to 1.4 m, which is less than the calculated diffusion penetration distance. Since MgO super-sacks are directly placed on the top of waste stacks in the current waste emplacement configuration, it can be concluded that molecular diffusion alone can effectively mix brines with super-sack MgO (in a vertical direction) without the presence MgO mini-sacks. In other words, the elimination of MgO mini-sacks will not affect MgO accessibility by brine in the WIPP.

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