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Transient Diffusion from a Waste Solid into Fractured Porous Rock

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Previous analytical studies of the advective transport of dissolved contaminants through fractured rock have emphasized the effect of molecular diffusion in the rock matrix in affecting the space-time-dependent concentration of the contaminant as it moves along the fracture^{1,2,3,4}. Matrix diffusion only in the direction normal to the fracture surface was assumed. Contaminant sources were constant-concentration surfaces of width equal to the fracture aperture and of finite or infinite extent in the transverse direction, as shown in Figure 1(a). Such studies illustrate the far-field transport features of fractured media. To predict the time-dependent mass transfer from a long waste cylinder surrounded by porous rock and intersected by a fracture, the present study includes diffusion from the waste surface directly into porous rock, as well as the more realistic geometry shown in Figure 1(b). Here we present numerical results from Chambré's analytical solution for the time-dependent mass transfer from the cylinder, for the low-flow conditions wherein near-field mass transfer is expected to be controlled by molecular diffusion⁵.

The governing equations describe three-dimensional diffusion in the rock matrix and two-dimensional diffusion in the fracture, assuming local sorption equilibrium and uniform concentration across the fracture width. A constant concentration N^* of low-solubility dissolved species is prescribed at the waste surface. No waste container is present. The solution applies to an infinitely long cylinder of constant radius and is a good approximation for a long cylinder with negligible end effects. A non-zero steady-state solution exists for species with radioactive decay. The results are illustrated in Figure 2, which shows instantaneous concentration isopleths, mass flux across the fracture surface, and mass fluxes from the waste into the fracture and into the rock matrix. The diffusion coefficient D is conservatively chosen as that for a liquid continuum. Concentrations are normalized to the quantity j_0 defined in Figure 2. The mass flux into the fracture is calculated to be about two orders of magnitude greater than that into the rock matrix, because of the assumed hundred-fold greater porosity in the fracture.

Figure 3 presents release rates as a function of time after beginning of dissolution, calculated by integrating the time-dependent mass flux over the waste surface. The mass release rates are normalized to the quantity $4\pi aDN^*$, where a is the cylinder radius. Even though the mass flux from the waste into the rock matrix is low relative to that into the fracture, the larger waste surface exposed to the matrix

and the greater assumed matrix sorption result in greater release rate to the matrix than to the fracture. This indicates that, for the parameters assumed here, the earlier mass-transfer theories³ for a waste solid completely surrounded by porous unfractured rock can adequately predict release rates in low-flow conditions in fractured media. If tortuosity significantly reduces the diffusion coefficient in the rock matrix and not in the fracture, mass-transfer directly from the waste to the fracture becomes more important.

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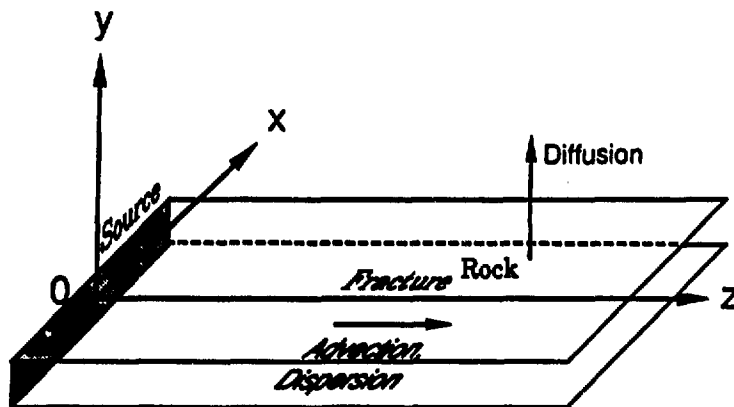


Figure 1(a)

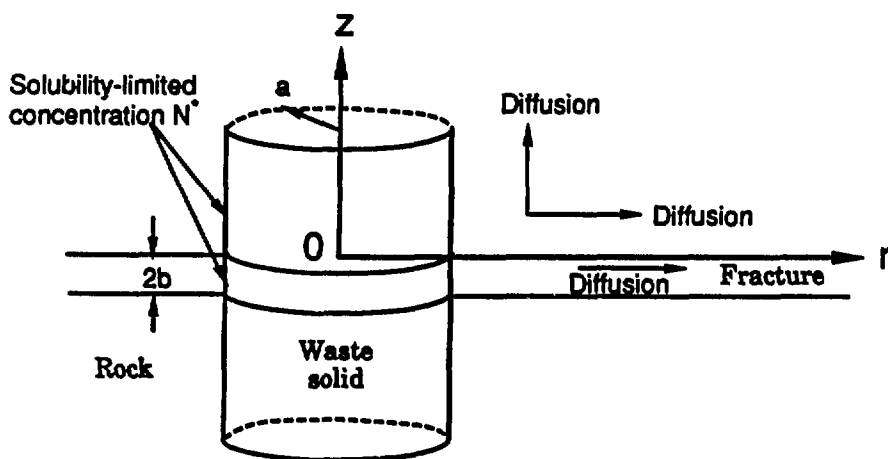


Figure 1(b)

Figure 1 Comparison of (a) planar geometry, used in other studies, and (b) cylindrical geometry, used in this study.

^{239}Pu (Half life : 24,400 yr)

Cylinder radius, $a = 25$ cm

Fracture width, $2b = 1$ cm

Porosity of fracture, $\epsilon_1 = 1$

Porosity of rock, $\epsilon_2 = 0.01$

Retardation factor in fracture, $K_1 = 1$

Retardation factor in rock, $K_2 = 500$

Diffusion coefficient, $D_1 = D_2 = D$
 $= 500 \text{ cm}^2/\text{yr}$

Solubility-limited concentration, N^*

$$l_0 = \frac{D N^*}{a}$$

At 625 year

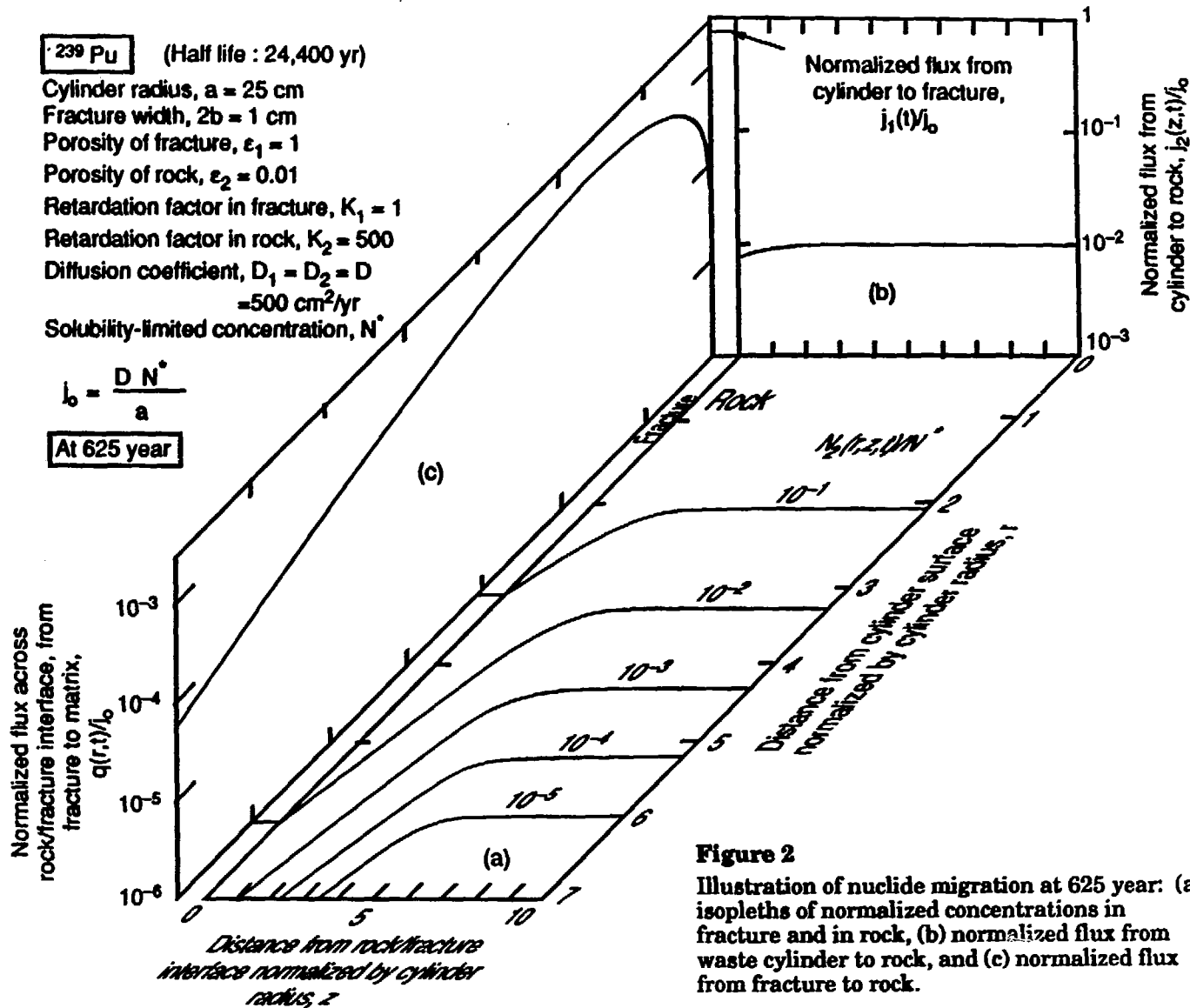


Figure 2

Illustration of nuclide migration at 625 year: (a) isopleths of normalized concentrations in fracture and in rock, (b) normalized flux from waste cylinder to rock, and (c) normalized flux from fracture to rock.

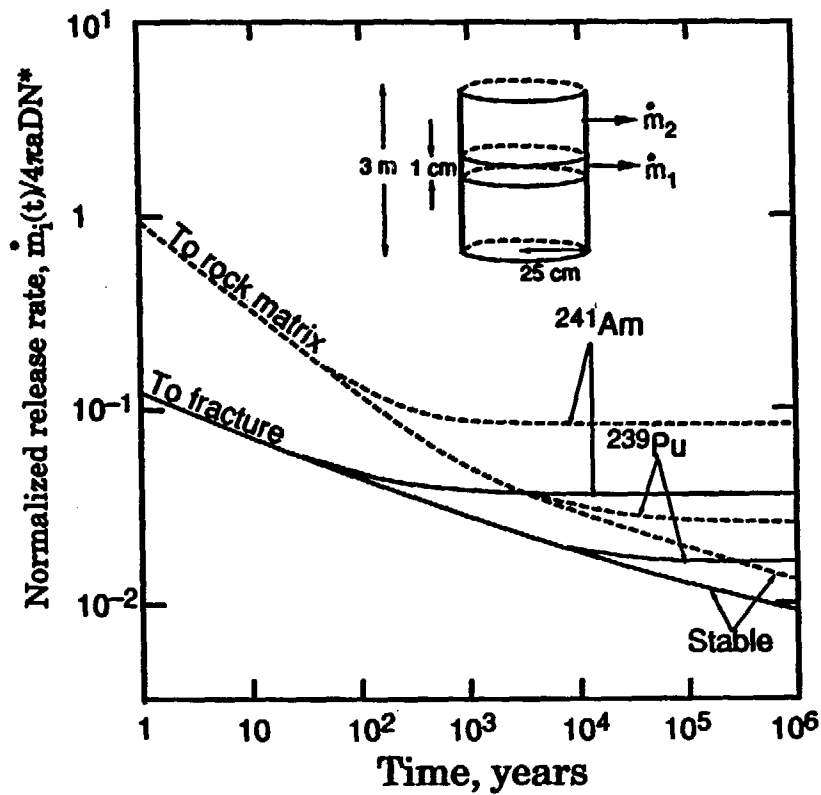


Figure 3

Normalized release rates of nuclides from a 3 m-high waste cylinder. Parameters from Figure 2 apply.