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GAS FLOW IN AND OUT OF A NUCLEAR WASTE CONTAINER

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We analyze the flow of gases out of and into a high-level-waste container in the unsaturated tuff of Yucca Mountain. Containers are expected to fail eventually by localized cracks and penetrations. Even though the penetrations may be small, argon gas initially in the hot container can leak out. As the waste package cools, the pressure inside the container can become less than atmospheric, and air can leak in. ^{14}C released from the hot fuel-cladding surface can leak out of penetrations, and air inleakage can mobilize additional ^{14}C and other volatile radioactive species as it oxidizes the fuel cladding and the spent fuel. In an earlier paper[1] we studied the gas flow through container penetrations occurring at the time of emplacement. Here we analyze the flow of gas for various penetration sizes occurring at 300 years.

According to the Yucca Mountain Site Characterization Plan (SCP),[2] a waste container will have failed if the product of gas pressure and volumetric leakage rate exceeds 10^{-4} atm-cm^3/s.[3] This value divided by RT, where R is the gas constant and T the absolute temperature, gives the allowable molar leak rate, above which the container would be considered failed.

Assuming first penetrations at 300 years with no prior leakage, viscous flow through penetrations equivalent to a single hole of radius 5 or 10 μm, or larger, and using the time variation of the average waste-package temperature given in the SCP,[2] we calculate the time-dependent inventory of gas within the waste container as a function of time after emplacement, shown in Figure 1. Curves are for a fill pressure of one atmosphere and fill temperatures of 298 K or 558 K, the maximum internal gas temperature predicted to occur after emplacement. The magnitude of the leak rate is shown as a function of these parameters in Figure 2, together with the SCP-limit leak rate. The container gas volume is 1 m^3, and wall thickness is 1 cm.

Figure 1 shows that for a 5-μm hole and a fill temperature of 298 K, argon slowly leaks out until well over 1000 years, after which repository cooling causes the internal pressure to fall below atmospheric, and air leaks in. For a 10-μm hole or larger, the internal pressure rapidly falls to atmospheric, as early as 1 year for a 30-μm hole. The rate of subsequent air inleakage is determined by the cooling rate and is not affected by larger holes. Figure 2 shows that the leak-rate limit is not exceeded by a 5-μm hole, and it is exceeded only briefly by larger holes at this fill temperature.

For a 558 K fill temperature, penetration results only in inleakage of air. If intended to apply to inleakage as well, the leak-rate limit is exceeded only briefly for 10-μm and larger holes.

These data provide the means of estimating release rates of gaseous radionuclides. Assuming that early heating of the waste package volatilizes 1 percent of the ^{14}C inventory from the cladding surfaces, a 5-μm hole and 298 K fill temperature result in an initial argon leak rate of 0.03 mole/yr, and a ^{14}C fractional leak rate of 7×10^{-6}/yr. For a 10-μm hole, the release rate would be 16-fold larger.

If the time and temperature of container penetration during repository cooling are known, initial filling at that temperature and one atmosphere will result in no outleakage. For an equivalent hole of 10 μm or larger, the rate of subsequent inleakage will then be controlled by cooling rate and will be independent of hole size. For such penetrations the inleakage rate will not exceed the SCP limit. For a given temperature history, initial fill conditions and an initial penetration can be selected to eliminate outleakage and to control inflow through subsequent penetrations of any size, provided subsequent penetrations occur after the temperature maximum.

References

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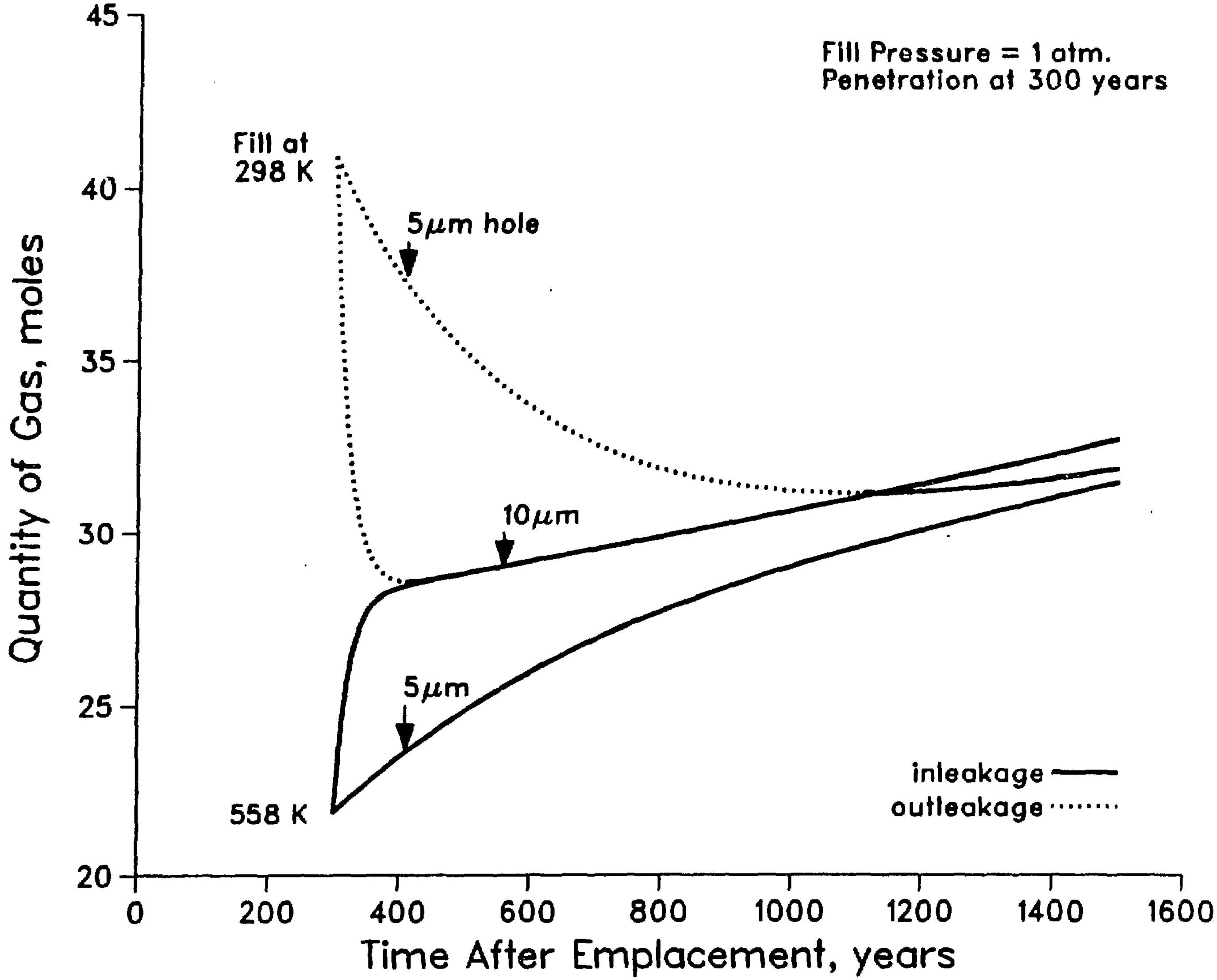

Figure 1: Quantity of Gas in a Container as a Function of Time

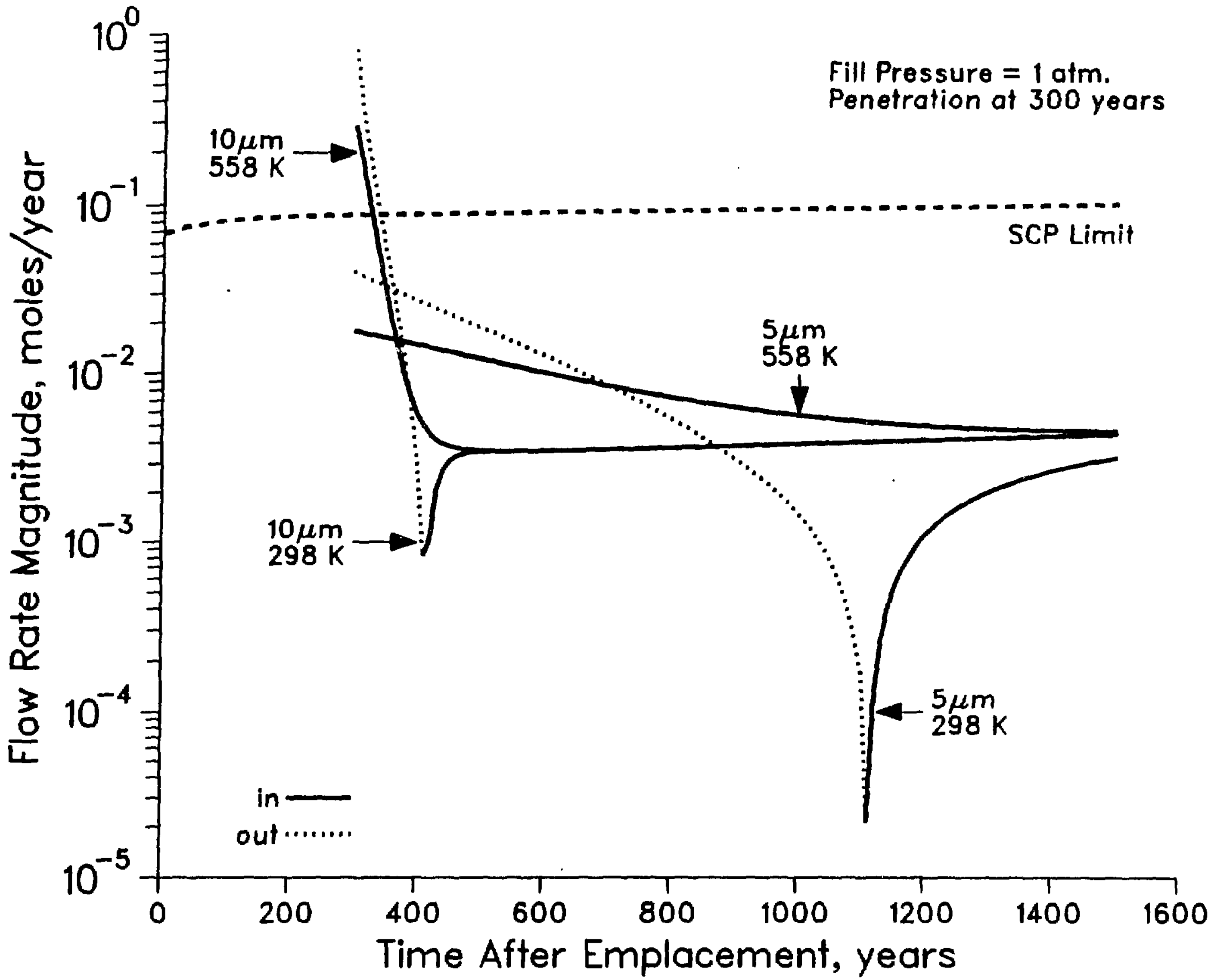

Figure 2: Magnitude of Flow Rate Through a Container Penetration as a Function of Time For Various Apertures and Fill Conditions