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Radionuclide Transport through Penetrations in Nuclear Waste Containers

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RADIONUCLIDE TRANSPORT THROUGH PENETRATIONS IN NUCLEAR WASTE CONTAINERS

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In this paper we analyze radionuclide transport through penetrations in nuclear waste containers. Penetrations may result from corrosion or cracking and may be through the container material or through deposits of corrosion products. The analysis deals with the resultant radionuclide transport, but not with how these penetrations occur. We provide numerical illustrations for diffusive nuclide flux through these apertures from mathematical expressions derived by Chambre'[1].

The U. S. Nuclear Regulatory Commission's performance objective[2] for the waste package subsystem requires substantially complete containment within the waste package for 300 to 1,000 years. Mass transfer through container holes may affect attaining substantially complete containment, and may also affect compliance with the release rate requirement. Analysis of radionuclide transport through penetrations aids evaluation of individual barriers, such as Zircaloy cladding for spent fuel.

The mathematical expressions for time-dependent diffusion through a hole of arbitary geometry in a thin-wall container show that such mass transport is dependent on the shape of the hole. The diffusive mass flux can be calculated for various aperture shape, and results are given for ellipses and circles. Early-time and large-time approximations of the mass transport are developed.

The calculated steady-state concentration field in the vicinity of a circular hole is shown in Figure 1, assuming a constant concentration of the dissolved species at the surface of the hole.

The single-hole results can be applied to multiple apertures in a container surface if the holes are separated by 12 or more hole radii to avoid interference. The mass transfer from all the holes can be estimated by multiplying the mass transfer rate through individual holes by the number of holes. Figure 2 shows the ratio of mass transfer into water-filled porous rock through a very thin-walled surface with multiple holes to the mass transfer rate from a waste solid with no container, as a function of the fraction of the container surface that is penetrated by holes. Numerous small holes on a container can increase the mass transfer above that of a waste form not enclosed by a container, a consequence of the large concentration gradients and the resultant high diffusive fluxes at the hole edges. For example, if all holes are 1-mm radius and widely spaced, enough holes to cover 0.005 or one-half per cent of the area of a container would result in a mass transfer rate almost as intense as that from a bare waste solid. However, the analysis also predicts that as the thickness of the container increases, mass flux decreases.

As a result of its fabrication history, exposure during reactor irradiation, and corrosion and mechanical stresses in the repository, Zircaloy cladding may contain many small perforations. Our results suggest that the radionuclide release rate through small holes may be significant.

In summary, this paper presents an initial analysis of radionuclide transport through holes in nuclear waste containers. We plan to make extensions to this work, and we invite experimental verification of these predictive theories.

Acknowledgment

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References

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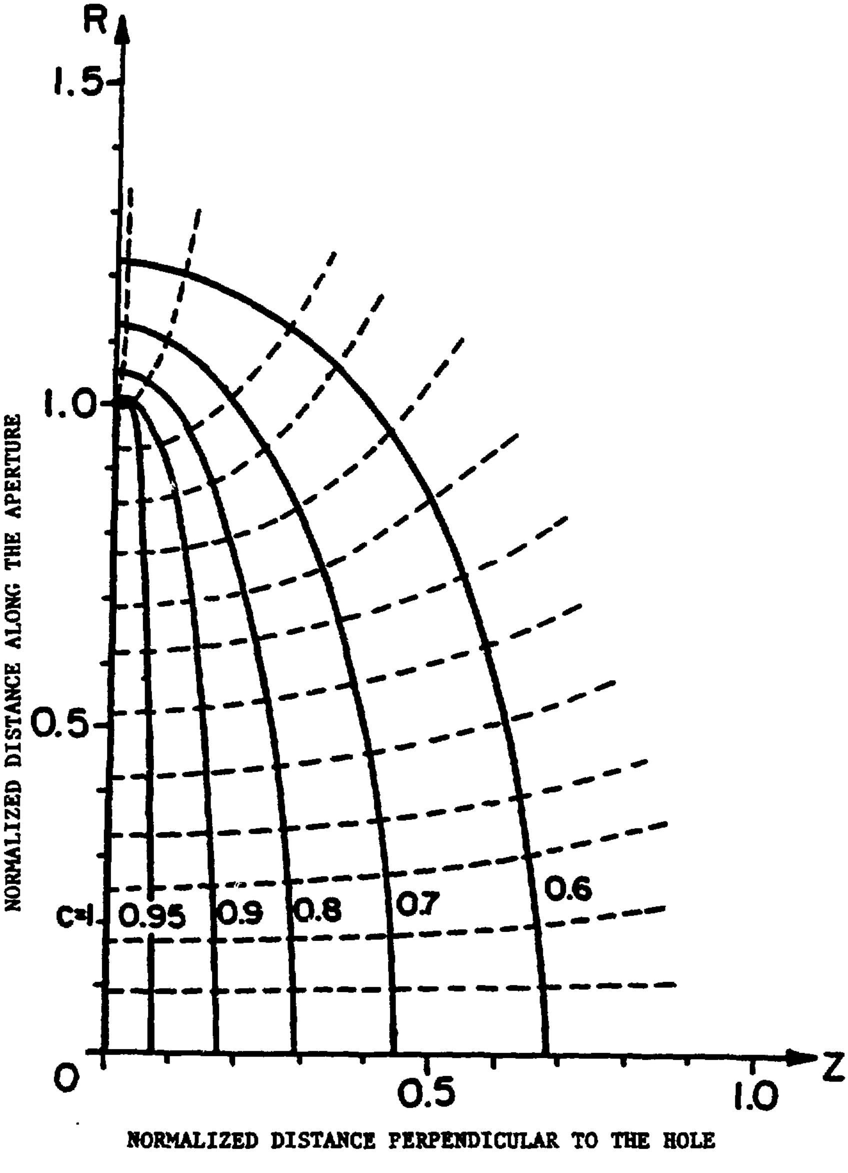

Figure 1. Surfaces of Non-dimensional Concentrations and Diffusion Paths Near the Aperture

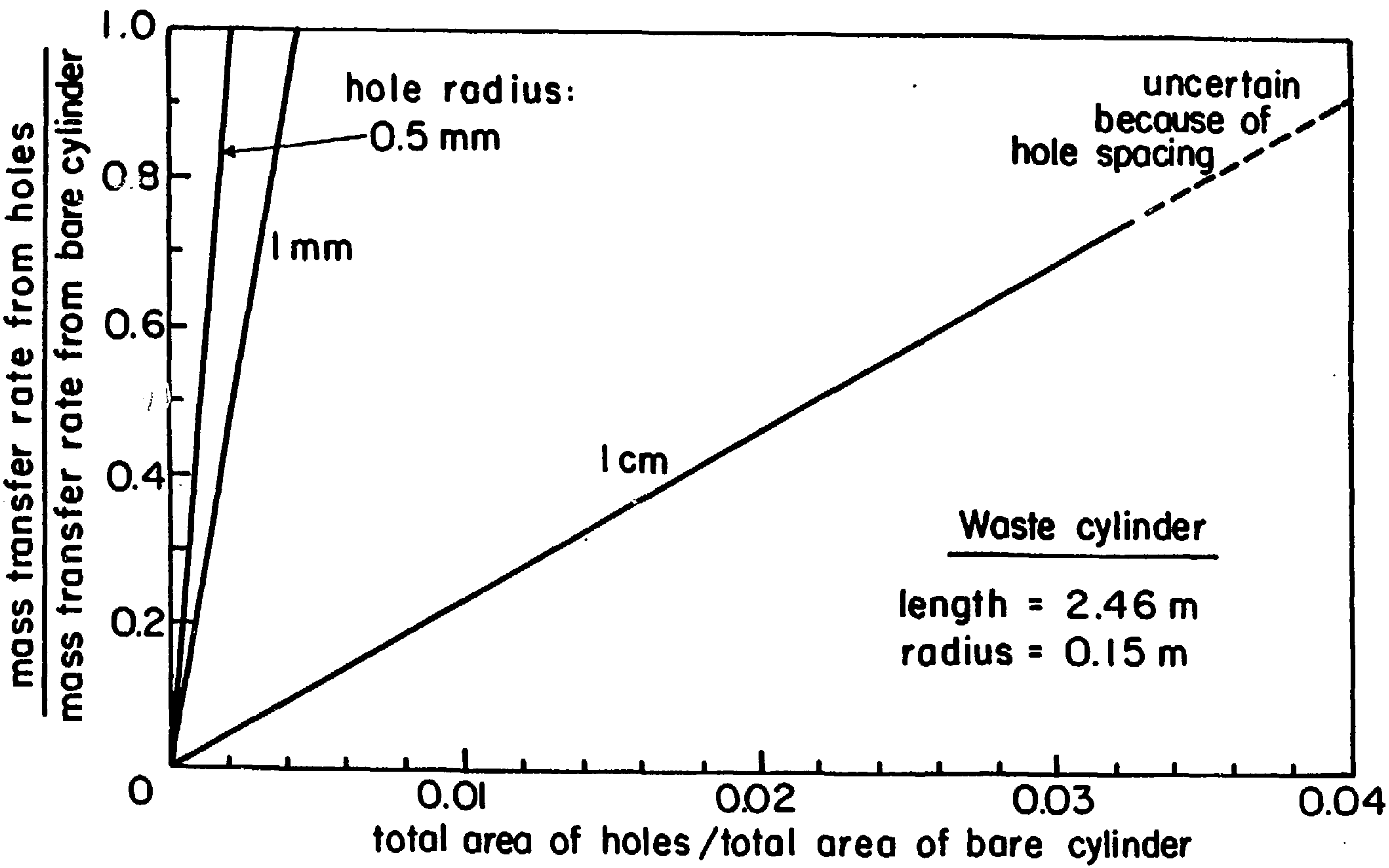

Figure 2. Radionuclide Fluxes from Multiple Holes and a Bare Waste Cylinder

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