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Authors
Zwahlen, E.D.
Lee, W.W.-L.
Pigford, T.H.
et al.

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E.D. Zwahlen, W.W.-L. Lee, T.H. Pigford,
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E. D. Zwahlen, W. W.-L. Lee, T. H. Pigford, and P. L. Chambré

Department of Nuclear Engineering
University of California

and

Earth Sciences Division
Lawrence Berkeley Laboratory
University of California
Berkeley, California 94720

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A GAS-PHASE SOURCE TERM FOR YUCCA MOUNTAIN

E. D. Zwahlen, W. W.-L. Lee, T. H. Pigford, P. L. Chambré
Department of Nuclear Engineering, University of California
and
Lawrence Berkeley Laboratory
University of California
Berkeley, CA 94720

We previously presented analyses of gas flow into and out of a partly failed nuclear waste container for various assumed hole sizes and failure times.[1,2] We also estimated the release rate of ^{14}C by advection and counter-diffusion from the failed container. Here we present an estimate of ^{14}C release rate and cumulative release for hole sizes of one to 300-μm and failure at emplacement and 300 years. A more detailed discussion of the theory and illustrations is given in Zwahlen *et al.*[1,2]

Gas flow is described by the viscous flow law

$$Q = \frac{\pi r^4 (P^2 - P_0^2)}{16 \mu \ell R T} \tag{1}$$

Here Q is the moles of gas flowing per unit time, P and P_0 are the gas pressure inside and outside the container, and μ is the gas viscosity. In a waste container of volume V containing n moles of gas, the equation can be transformed into a differential equation for n,

$$\frac{dn(t)}{dt} = -\frac{\pi r^4 [(nR\bar{T}/V)^2 - P_0^2]}{16 \mu \ell R T_w} \tag{2}$$

with the initial quantity of gas given by the ideal gas law

$$n(0) = \frac{P(0)V}{RT(0)} \tag{3}$$

Here, $\bar{T}$, the average internal temperature, and T_w, the wall temperature are known functions of time, and μ is an empirical function of T_w.

When air flows into the container, ^{14}C can be released by counter-diffusion. The counter-diffusion is described by

$$\bar{v}\frac{dc}{dz} = D\frac{d^2 c}{dz^2}, \qquad 0 \le z \le \ell \tag{4}$$

with boundary conditions $c(0) = c_0$ and $c(\ell) = 0$. Also $\bar{v}$ is the slug flow velocity of air, where $\bar{v}$ is negative for counter-diffusion. The release rate $\dot{m}$ is

$$\dot{m} = \begin{cases} \pi r^2 \bar{v} c_0 \dfrac{e^\alpha}{e^\alpha - 1}, & \bar{v} <> 0; \\ \pi r^2 c_0 D/\ell, & \bar{v} = 0 \end{cases} \tag{5}$$

where $\alpha = \bar{v}\ell/D$.

For the calculations, the following data is used

Container gas volume, $V = 1.22$ m^3

Wall thickness, $\ell = 0.01$ m
External gas pressure, $P_0 = 0.1$ MPa
Internal gas fill pressure, $P = 0.1$ MPa
Internal gas fill temperature, 298 K
Internal gas temperature-time data from *Site Characterization Plan*[3] [p. 7-41]
Initial ^{14}C inventory 3.1 Ci (1.1×10^{11} Bq) per package
Volatile ^{14}C fraction = 10% (assumed)
Diffusion coefficient = 0.27×10^{-4} m^2/s [Source: Ref. 4]

Figures 1 and 2 show the ^{14}C release rate and and Figures 3 and 4 show the cumulative releases for holes of one to 300-μm and the hole occurring at emplacement and 300 years. We describe the curves for the hole occurring at emplacement, and then suggest a source term.

For a 1-μm hole, argon flows out for all time and carries with it $^{14}CO_2$. The initial release rate is 10^{-6} Ci/year (3.7×10^4 Bq/a) and decreases as the argon flow decreases.

For a 5-μm hole, the initial $^{14}CO_2$ release rate is 5×10^{-4} Ci/year (1.9×10^7 Bq/a) and the release is mainly by advection. At about 900 years, air begins to flow into the container, and the release decreases sharply due to the counter-diffusion resistance of the air flow.

For a 10-μm hole, the initial release rate is almost 10^{-2} Ci/year (3.7×10^8 Bq/a). At about 70 years, air begins to flow into the container, and the release rate decreases sharply. As the cooling rate slows down, the air inflow rate decreases and the counter-diffusion resistance decreases. Then the ^{14}C release rate reaches a near constant rate.

For holes 20-μm or larger, the pressure inside the container falls rapidly to near atmospheric when the hole occurs. About 50% of the argon and $^{14}CO_2$ is released immediately, after which air begins to flow into the container. The air inflow rate is independent of the hole size and is determined solely by the cooling rate. However, the air velocity (and thus the resistance to diffusion) does depend on hole size.

Thus, for all holes bigger than 20-μm, 0.144 Ci (5.3×10^9 Bq) of ^{14}C is released at penetration.

For the 20-μm and 30-μm holes, the air inflow is a resistance to diffusion and the initial release rate is low. As the air inflow rate decreases, the $^{14}CO_2$ release rate increases.

For the 100-μm, 200-μm, and 300-μm holes the air inflow velocity is so small that there is little, if any, resistance to the outward diffusion of $^{14}CO_2$. The slight increase in the release rate for the 100-μm hole is due to the decrease in the air inflow rate. The later decrease in the release rate for these three hole sizes is due to depletion of the $^{14}CO_2$ in the container.

The cumulative release graph is easily understood. For holes of 20-μm to 300-μm, the cumulative releases start at 0.144 Ci (5.3×10^9 Bq), the initial amount released, and then increase. For the 300-μm hole, all of the ^{14}C is released in under 200 years. For the 20-μm and 30-μm holes, the initial release accounts for nearly all of the release.

For holes occurring at 300 years, the major difference is that for the larger holes only about 30% of the argon and $^{14}CO_2$ is released at penetration time because the waste container is cooler and the internal gas pressure is less than that emplacement. Thus the initial release pulse is 0.097 Ci (3.6×10^9 Bq) of ^{14}C.

This is our recommended source term. Assume an initial release of 0.144 Ci/package (5.3×10^9 Bq/package) for a hole occurring at emplacement and 0.097 Ci/package (3.6×10^9 Bq/package) for a hole occurring at 300 years. From the curves presented here, an upper bound for the time-dependent release rate of ^{14}C can be obtained by using the maximum release rate at each time. Clearly this will give a cumulative release greater than the assumed volatile fraction of ^{14}C, but this gives a conservative estimate.

References

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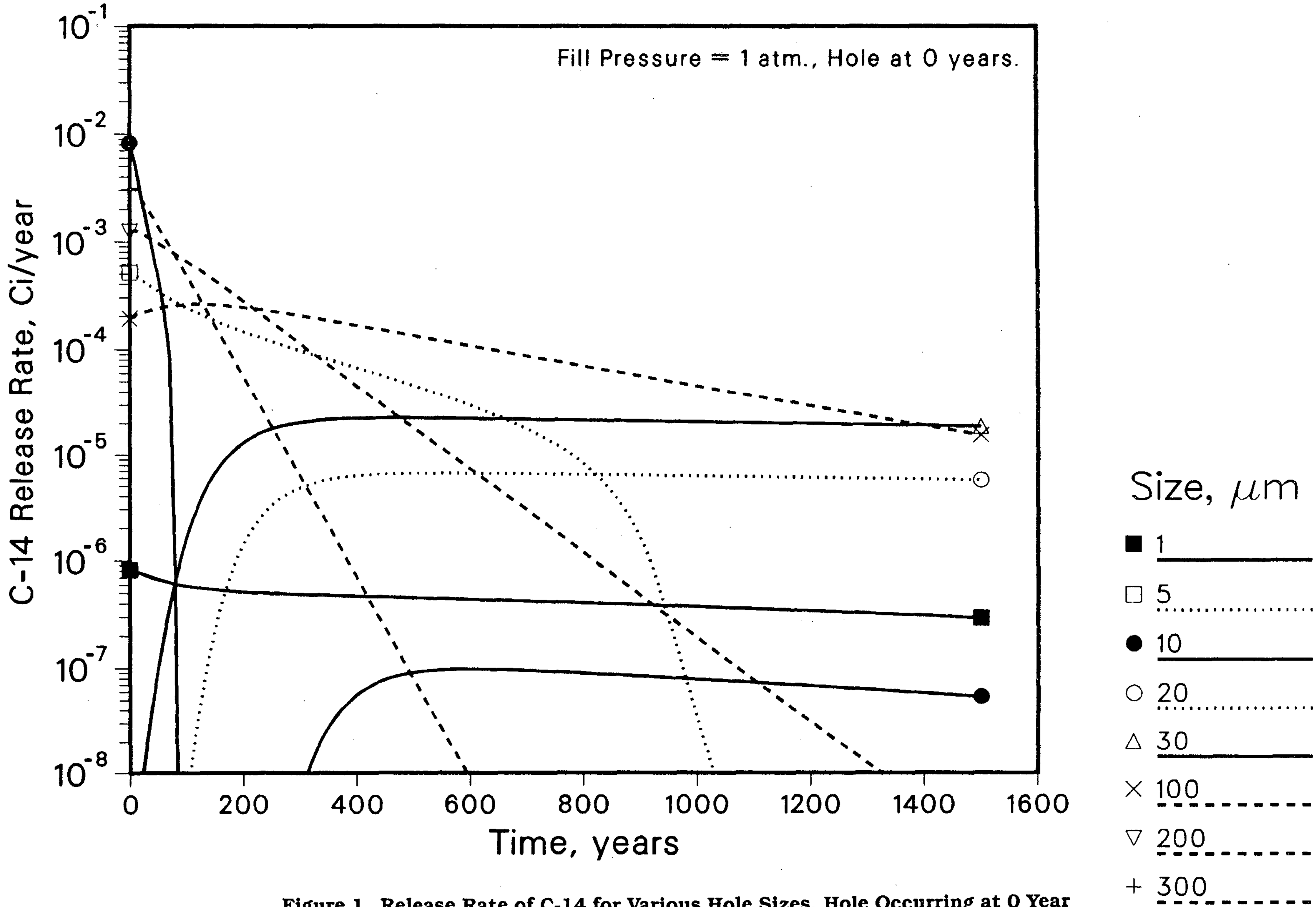

Figure 1. Release Rate of C-14 for Various Hole Sizes, Hole Occurring at 0 Year

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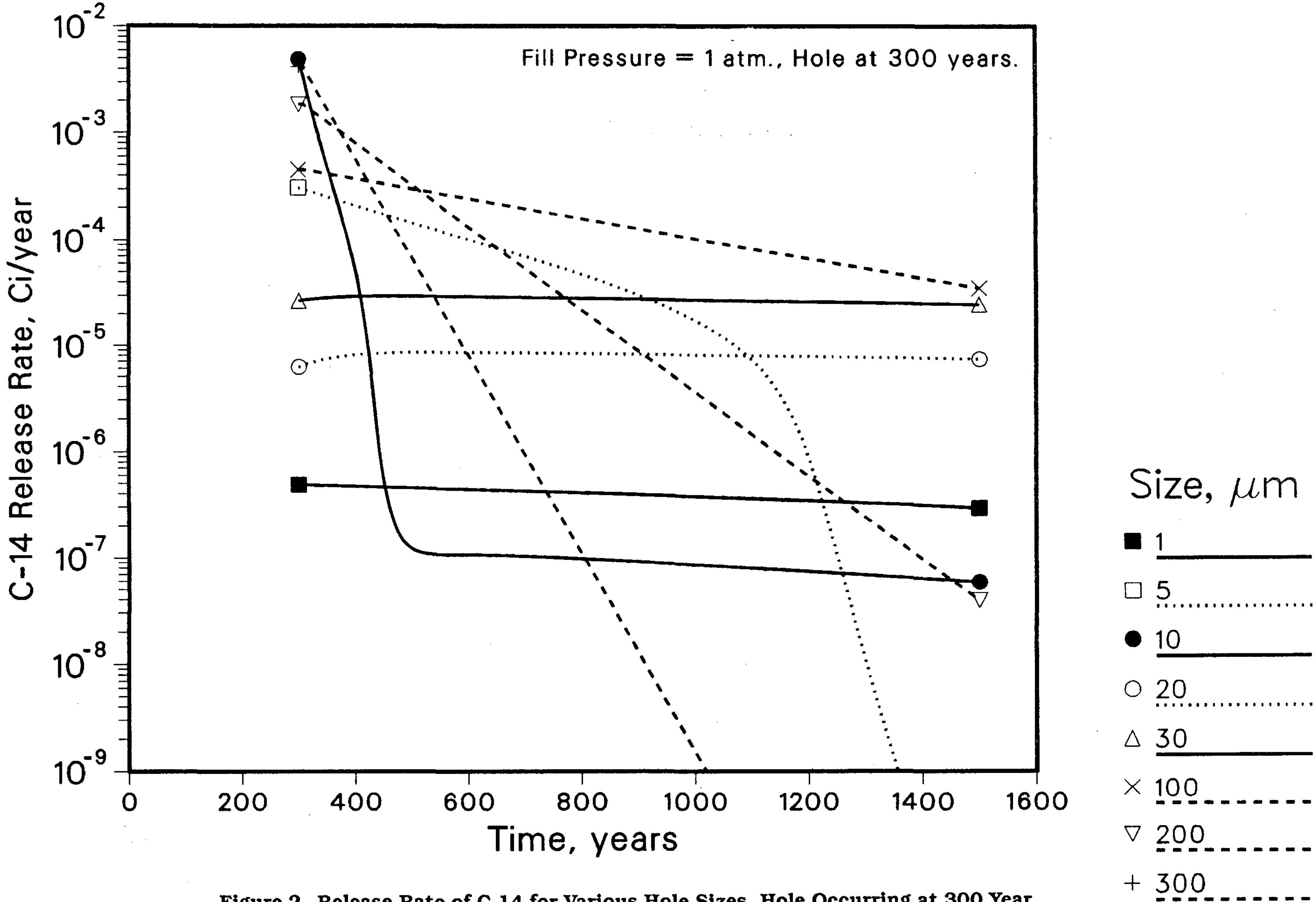

Figure 2. Release Rate of C-14 for Various Hole Sizes, Hole Occurring at 300 Year

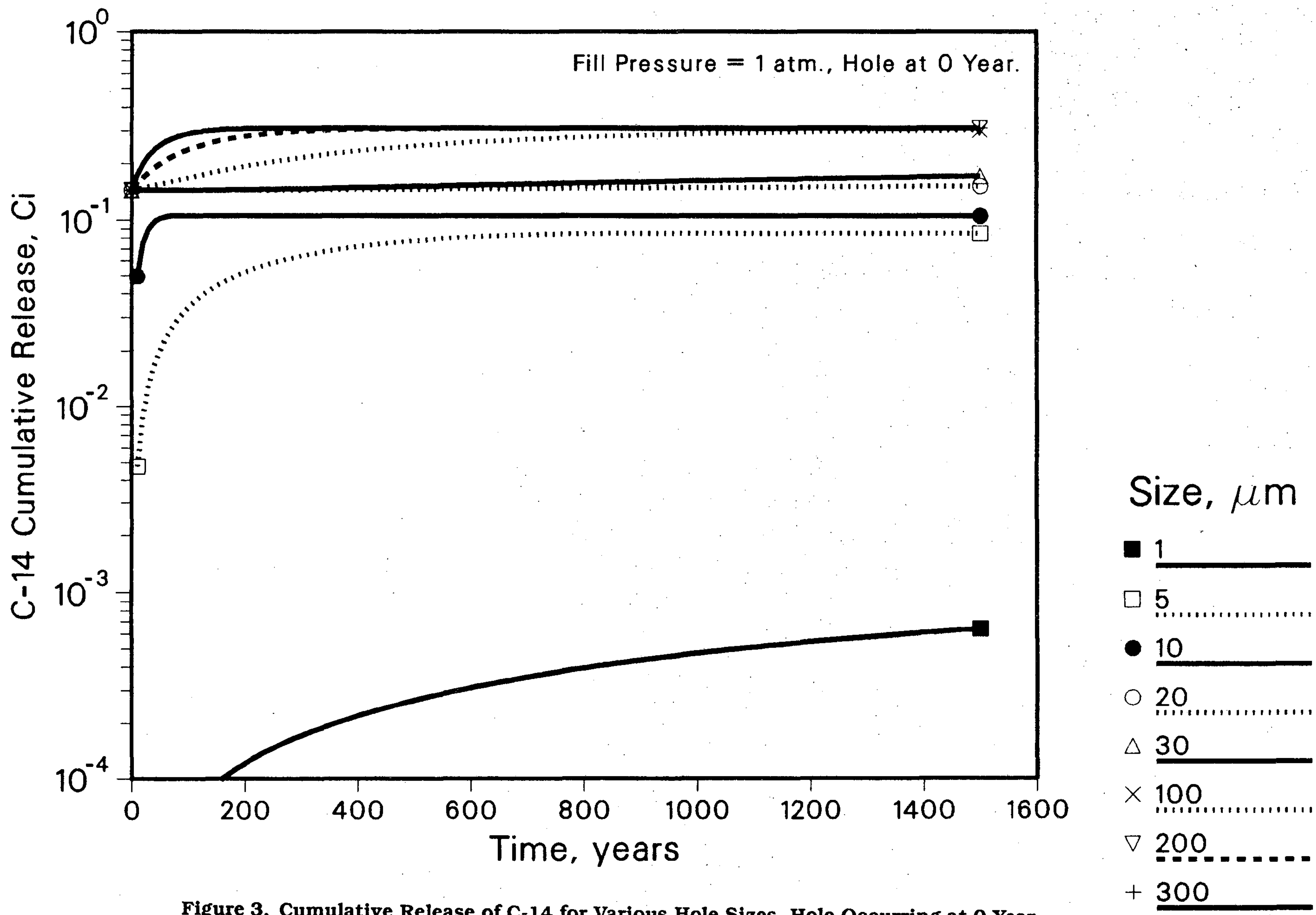

Figure 3. Cumulative Release of C-14 for Various Hole Sizes, Hole Occurring at 0 Year

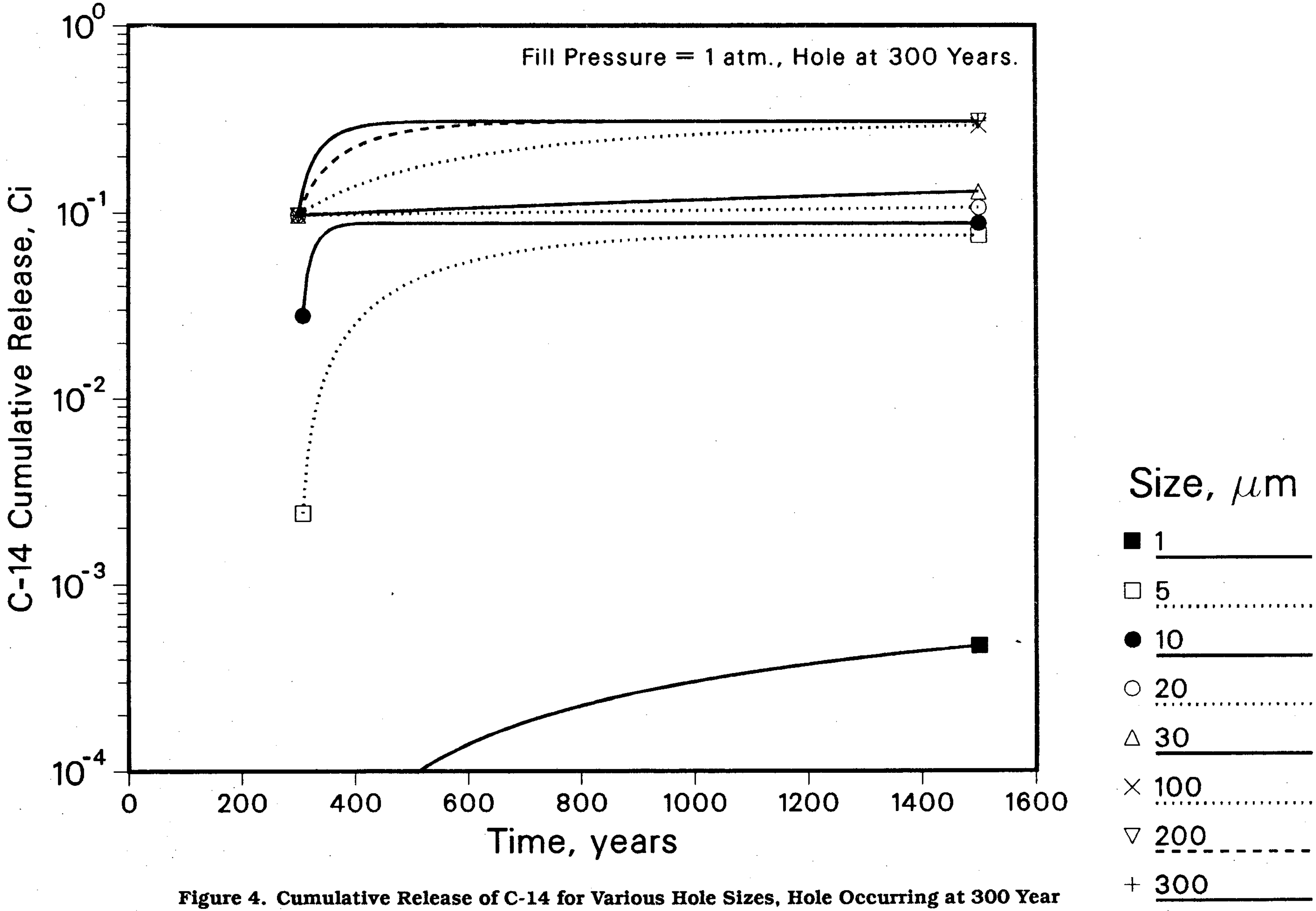

Figure 4. Cumulative Release of C-14 for Various Hole Sizes, Hole Occurring at 300 Year

LAWRENCE BERKELEY LABORATORY
UNIVERSITY OF CALIFORNIA
INFORMATION RESOURCES DEPARTMENT
BERKELEY, CALIFORNIA 94720