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ANALYSIS OF WASTE RELEASED BY SEEPAGE TO THE COLUMBIA RIVER FROM THE 1301-N CRIB

By

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ANALYSIS OF WASTE RELEASED BY SEEPAGE TO THE COLUMBIA RIVER FROM THE 1301-N CRIB

By

R. William Nelson[1/]

INTRODUCTION

The 1301-N crib is designed to receive diverted primary coolant from the N-Reactor when a fuel element fails. Information on the rate of release of fission products and concentrations in the Columbia River is needed to evaluate the long-term public safety.

The purpose of this report is to present rational methods for predicting the arrival-time distribution of wastes to the river. These methods are specifically applied to provide estimates of the long-term maximum activities of I^{131} in the river as a result of the disposals to the 1301-N crib. Other radionuclide activities may be obtained through use of the basic flow system results.

SUMMARY

This report presents analysis of the effects that act to reduce the rate of contaminant entry to the Columbia River following diversion to the 1301-N crib. The methods, presented in detail, provide conservative predictions of river contamination levels after long-term operation.

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The boundary value problems used in making the predictions were purposely selected to provide a conservative analysis of travel time. For example, ultimate steady flow conditions were used, although in reality only after several years of crib use will these be approached. A constant low river stage of 380.5 feet was assumed for the detailed analysis, whereas such a level actually occurs only over a short period of time. Also, two-dimensional saturated flow systems with more short flow paths were used throughout the evaluation; these predict shorter travel times than occur in the actual three-dimensional flow system, which has more long flow paths. All considered, the resulting margins of safety in the calculated travel times probably lie between 5 and 10*. Therefore, a calculated travel time of 12 days, as found in this case, represents an actual travel time of 60 - 120 days. However, a hazards analysis based upon the "worst possible" philosophy should be used at present. After actual disposal experience is gained and field measurements of contamination in the ground water and at riverbank springs are available, then the present conservatism should be réevaluated.

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*The same methods used here were applied to evaluate seepage from the 100-H retention basin which has been in operation for many years. The calculated travel time in that case was 19.25 hours (0.80 day) as compared to 6.5 days measured using I^{131} ratios in water samples(1, 8).

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All the aspects of the ground water flow system vital to contamination analysis are brought together in the Basic Water Arrival-Time Distribution. This distribution is a continuous function interrelating the arrival time at the river with the cumulative relative flux of water leaving the crib. The function for the 1301-N crib has values of 11.78, 13.33 and 24.03 days for cumulative fluxes entering the river of 0.05, 50.0, and 95.0 percent respectively. The dependence of cumulative fluxes entering the river upon time, when combined with the rather short (less than 1 day) rupture discharge periods to the crib, results in a significant dilution of waste entering the river. For both rupture diversion periods assumed, 500 and 1000 minutes, the rupture frequency could be as often as once every 20 days and still nonsorbed isotopes from one diversion would have entered the river and moved downstream before radionuclides from the next rupture reach the river.

The decay of I^{131}, when combined with the dilution from flow geometry effects, gives the time variation of riverbank activity as a ratio to the activity entering the soil at the crib. These ratios are 0.072 and 0.117 for the average and maximum rupture diversion times, respectively.

GENERAL CONSIDERATIONS

The reactor effluents going to the crib will include a water purity bleed, a continuous coolant-monitoring bleed, and individual tube diversion during ruptures. The tube rupture diversion contributes the activity to the river through seepage from the crib. In the analysis to follow, not only peak activity

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to the crib but also the duration and frequency of rupture occurrence is important. Short infrequent rupture periods, even though of high activity, may yield rather low concentrations of contaminants in the river. However, ruptures involving much lower activity but occurring more frequently and for longer periods could produce higher river activities. Hence, the duration and frequency of ruptures are important.

The expected average time of diversion to the 1301-N crib during a fuel element failure is 500 minutes (0.347 day) with a frequency of once per month[10]. The maximum rupture diversion time is estimated at 1000 minutes (0.694 day). From these data will come the average and worst possible release rates of contamination to the river.

Crib Utility

Seepage from a crib is an effective and economical way to handle rather high but short-term activity peaks associated with fuel element failures. The beneficial reduction in river contamination is the result of three effects: 1) Travel time variations arising from ground water flow geometry, 2) decay time provided by slow ground water movement, and 3) decay time provided by any delay due to ion exchange.

Items 2 and 3 are well recognized. By contrast, item 1 is seldom considered, yet it is always present and provides a significant reduction in peak river concentrations. In fact it is the starting point for introducing both decay and, if present, ion exchange.

Item 1, the time variation due to flow geometry, results in a slow extended bleed of waste to the river. The slow bleed rate is a result of varying velocities

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along ground water flow paths of different lengths. In other words, the contamination following the shortest flow path enters and is swept downriver long before the waste following a longer path reaches the river. Depending upon the flow system, the net effect is three- to a hundredfold reduction in peak activity entering the river. Decay and ion exchange must be superimposed on this time variation from flow geometry.

ANALYSIS

The three independent effects (flow geometry, decay and sorption) diminish the peak activity entering the river from the crib. Each effect when present must be analyzed and then combined with the others to enable prediction of the activity distribution in the river. The analysis includes four general steps:

1. Describe the ground water flow system (1301-N crib) as a well posed boundary value problem, and solve that problem for the ground water potential and flow paths.
2. Carry out a macroscopic flow time analysis along paths of flow and appropriately introduce hydrodynamic dispersion to obtain the Basic Water Arrival Time Distribution.
3. Use the basic water arrival time distribution and the time of waste inflow to the crib to obtain the reduction in river contamination as a function of time*.
4. Introduce radioactive decay (I^{131} considered here) using the time and reduction distribution in Step 3 to determine the activity entering the river as a function of time.

*If ion exchange requires analysis, an additional step between Items 2 and 3 is needed.

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These steps will be considered consecutively in detail. At the same time usable results are provided for estimating I^{131} activities in the river from the 1301-N crib. Those interested primarily in conclusions may proceed directly to the Results section since the intervening topics describing the method can be omitted with a minimum loss in continuity.

1301-N CRIB FLOW SYSTEM

The 1301-N crib is located on the bank bluff some 60 feet above and 860 feet back from the Columbia River. Coolant effluent from the reactor overspills the crib entrance trough and spreads out into the three feet of bottom area (125 feet by 290 feet) filled with large stones. The water level in the crib will be maintained below the surface of the stones through pond seepage and occasional overflow into the crib extension trench. The time for movement along the crib length, into the trench, and then by seepage into the river is longer than by direct seepage from near the crib inlet to the river. Therefore, the first effluent to enter the river will move along a vertical plane extending perpendicularly back from the river, and passing through the crib near the entrance box. In this vertical plane, appropriate boundary value problems are considered.

Boundary Value Problems And Their Solution

Several boundary value problems were set up to describe the flow system in the vertical plane mentioned in the previous section. The boundary conditions and flow systems were purposely selected to provide conservative analyses of the

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travel time. For instance, ultimate steady-flow systems were used, although in reality only after several years of crib operation will these conditions be approached. Similarly, two-dimensional saturated flow systems, which are used throughout, predict shorter travel times than actually occur in the true three-dimensional flow system.

River fluctuations, which occur both seasonally and yearly, change the energy available for ground water flow and thereby alter the travel time distribution. Accordingly, three river boundary elevations, 400, 390, and 380.5 feet, were studied[9]. The lowest river stage boundary value problem gives the shortest minimum travel time, so it is the one considered in detail here.

In the solution of the crib flow system there are two boundary conditions that are particularly difficult to handle: the free surface (water table) and the surface of seepage (riverbank springs). Both of these boundaries arise from having a gravity component included in the ground water potential; hence the locations of the water table and riverbank springs are not known a priori, but must be obtained in the process of solution.

Classical conductance paper electrical analogs were used to solve the several boundary value problems[3]. The free surface and seepage surface were obtained by iteration until the required matching of potential and elevation conditions was satisfied. Once the water table and springs were correctly positioned, then equipotentials were measured and drawn on the conductance paper. Careful measurement of the current inflows and outflows on the conductance model enabled setting up the second boundary value problem to obtain the streamfunction.

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The streamfunction boundary value problem was then solved by a new conductance analog and the streamlines plotted. The traditional flow net for the system was obtained by tracing the streamlines and equipotentials on an overlay. The flow net (Figure 1) is the basis for the time analysis to follow.

USE OF FLOW GEOMETRY FOR THE ANALYSIS

Flow time is obtained from the flow system results by combining the velocity variations with the path length. Each flow path has a uniquely different flow time. Accordingly, the final time distribution sought is the aggregate of all individual flow times. This final distribution of time can be found from the flow net results through use of the appropriate expressions that follow.

Equations For Flow Time

The basic equations needed (from soil fluid mechanics) as a starting point are adequately discussed elsewhere[4,5], so they will only be noted here. The effective pore velocity is from Darcy's Law and the porosity:

$$\underline{V} = -\frac{K}{P} \text{ grad } \phi \qquad (1)$$

and the system of ordinary differential equations describing a streamline are:

$$\frac{dx}{\frac{\partial \phi}{\partial x}} = \frac{dy}{\frac{\partial \phi}{\partial y}} = \frac{dz}{\frac{\partial \phi}{\partial z}} \qquad (2)$$

Where: $\underline{V}$ is the effective macroscopic pore velocity vector,

K is the hydraulic conductivity of the soil,

P is the effective porosity,

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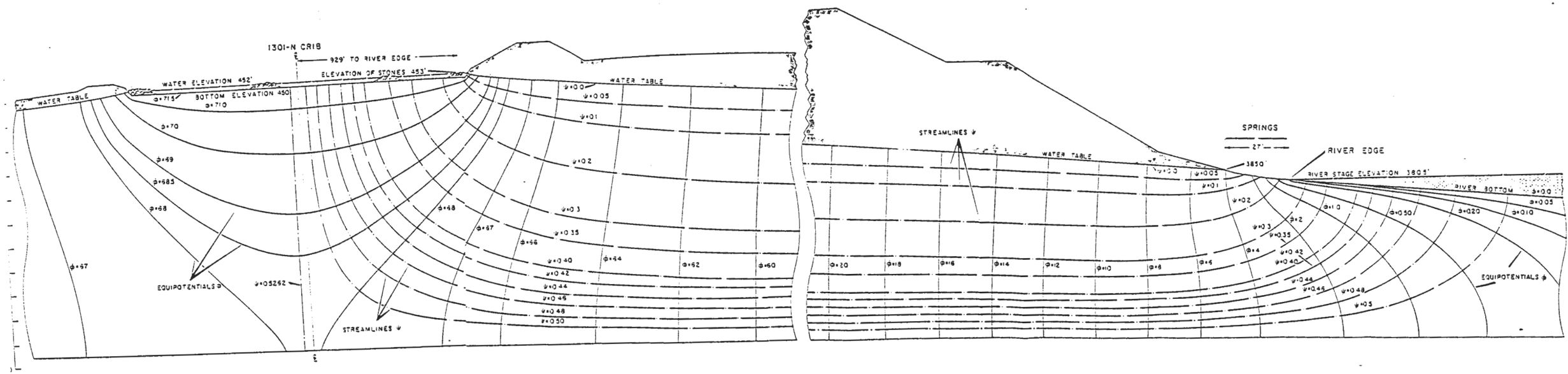
ELECTRICAL ANALOG RESULTS
1301-N CRIB TRAVEL TIME STUDY



$\phi = \frac{p}{\rho g} + z$ is the hydraulic head, potential or potential function,

x, y, z are the Cartesian coordinate directions with z oriented parallel with the earth's gravitational field,

p is the pressure,

ρ is the mass density, and

g is the gravitational scalar.

Let the differential length of flow path be ds; then, in terms of components,

$$(ds)^2 = (dx)^2 + (dy)^2 + (dz)^2 \qquad \text{or,}$$

$$ds = \pm\left(\sqrt{1 + \left(\frac{dy}{dx}\right)^2 + \left(\frac{dz}{dx}\right)^2}\right) dx \quad ; \tag{3}$$

but since ds is along a streamline defined by Equation (2), then upon rearranging the later equation and substituting into (3),

$$ds = \pm\sqrt{1 + \left\{\frac{\frac{\partial\phi}{\partial y}}{\frac{\partial\phi}{\partial x}}\right\}^2 + \left\{\frac{\frac{\partial\phi}{\partial z}}{\frac{\partial\phi}{\partial x}}\right\}^2}\; dx. \tag{4}$$

The definition of the absolute value of the velocity or speed, $|\underline{V}|$ is:

$$|\underline{V}| = \frac{ds}{d\tau} \tag{5}$$

where τ is time. Rearranging Equation (5) gives

$$d\tau = \frac{ds}{|\underline{V}|} \tag{6}$$

Equation (6) becomes, upon expanding Equation (1) and substituting in Equations

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(1) and (4):

$$d\tau = \pm \frac{P}{K}\sqrt{\frac{1 + \left(\frac{\frac{\partial\phi}{\partial y}}{\frac{\partial\phi}{\partial x}}\right)^2 + \left(\frac{\frac{\partial\phi}{\partial z}}{\frac{\partial\phi}{\partial x}}\right)^2}{\left(\frac{\partial\phi}{\partial x}\right)^2 + \left(\frac{\partial\phi}{\partial y}\right)^2 + \left(\frac{\partial\phi}{\partial z}\right)^2}}\, dx, \tag{7}$$

and upon integrating and rejecting negative terms, the expression for travel time, T, is

$$T = \int_{x_o}^{x_{max}} \frac{P}{K}\sqrt{\frac{1 + \frac{\frac{\partial\phi}{\partial y}^2}{\frac{\partial\phi}{\partial x}} \quad \frac{\frac{\partial\phi}{\partial z}^2}{\frac{\partial\phi}{\partial x}}}{\frac{\partial\phi}{\partial x}^2 + \frac{\partial\phi}{\partial y}^2 + \frac{\partial\phi}{\partial z}^2}}\, dx. \tag{8}$$

The evaluation of the integral must be carried out along a streamline. The parameter x_o is the value of x where the particular streamline leaves the crib, and x_{max} is the x coordinate of the point of emergence at the river.

Equation (8) is the precise definition of travel time requiring evaluation. However, in this case the potential distribution, $\phi(x,y,z)$, is not known as a function, but only as a flow net. Accordingly, a numerical summation with sufficient accuracy is needed to use in place of Equation (8). This is obtained by replacing dx with its approximate difference equivalent,

$$\lambda \doteq dx, \tag{9}$$

and by always orienting the coordinate system along the streamline such that

$$\frac{\partial\phi}{\partial y} \doteq 0, \tag{10}$$

and,

$$\frac{\partial\phi}{\partial x} \doteq 0. \tag{11}$$

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Further, let the difference approximation be

$$\frac{\partial \phi}{\partial x} \doteq \frac{\Delta \phi}{\lambda} \tag{12}$$

where $\Delta\phi$ is the potential difference along the streamline in the short distance λ. Then using Equations (9) through (12), and replacing the integral by the approximation sum:

$$T_m = \frac{P}{K} \sum_{i=1}^{i=N} \left(\frac{\lambda^2}{\Delta \phi} \right)_i \tag{13}$$

Equation (13) enables getting the travel time by dividing the streamline into many short increments, each λ long, and recording $\Delta\phi$ from the flow net; or for better accuracy by measuring $\Delta\phi$ electrically directly from the original analog.

Travel Time Analysis for the 1301-N Crib

The travel time along each streamline, T_m, (the m subscript designates which streamline) was calculated using Equation (13) and the analog results as in Figure 1. Table I contains the results for the low river stage of 380.5 feet.

TABLE I

SUMMARY OF CALCULATED GROUND WATER TRAVEL TIMES FROM 1301-N CRIB TO RIVER

Low river stage - 380.5 ft. - Hydraulic conductivity (K) = 270 ft/day
Porosity (P) - 0.3

Streamline Value ψ	Cumulative Relative Flux (q/Q_o)	$\sum_{i=1}^{N} \left(\frac{\lambda^2}{\Delta\phi}\right)_i$ (ft)	Travel Time (Days)	Streamline Length, L, (ft)
0	0.000	10,740	11.93	833
0.05	0.095	10,830	12.03	845
0.10	0.190	10,970	12.19	857
0.20	0.380	11,480	12.75	889
0.30	0.570	12,410	13.79	933
0.35	0.667	13,140	14.60	960
0.40	0.760	14,300	15.89	997
0.42	0.800	14,870	16.52	1011
0.44	0.836	15,690	17.43	1031
0.46	0.875	16,740	18.60	1052
0.48	0.912	18,450	20.49	1080
0.50	0.950	21,170	24.08	1114
0.526	1.000	------	-----	----

Estimate of Hydrodynamic Dispersion

Up to this point the analysis has considered only macroscopic or average flow conditions in porous media. The microscopic aspects of flow or distribution about the average (macroscopic) exert only small effects on river arrival time. These small effects (hydrodynamic dispersion) are nevertheless important enough to receive consideration here.

When two miscible fluids, originally separated by a sharp interface, move through porous media, the mechanisms of molecular diffusion and velocity variations in pores of irregular size and length tend to alter the shape of the interface. The magnitude of this effect (hydrodynamic dispersion), although not completely understood or described mathematically, can be estimated. This is possible by considering only the lateral component of dispersion as a deviation in arrival time, about the average or macroscopic arrival time obtained in the previous sections. Based on this assumption, and considering flow along the streamlines to be essentially the same as for a very long straight column of soil, then the equations of Banks and Jerosate[2], or Ogata[7] as written in earlier work[6] are applicable. Equation (24) in the earlier work[6], but converted to the notation used here, is:

$$\frac{t_m}{T_m} = 2\,M^2\left(\frac{\alpha}{L_m}\right) + 1 \pm \sqrt{\left[\left(2M^2\left(\frac{\alpha}{L_m}\right) + 1\right)^2 - 1\right]} \qquad (14)$$

where:

t_m is the arrival time of any relative concentration, C/C_o,

T_m is the macroscopic arrival time from the earlier analysis, corresponds to $C/C_o = 0.5$, and

α is the dispersity characteristic value for the soil, (α = 0.02 ft. was used),

L_m is the mth streamline length (see Table I),

$M = \text{erf}^{-1}\left(2\frac{C}{C_o} - 1\right)$ is the inverse error function of $\left(2\frac{C}{C_o} - 1\right)$,

C is the water concentration (best visualized as the concentration of a perfect water tracer) at any time, t_m, as the dispersed front reaches the river, and

C_o is the concentration of the hypothetical water tracer in the crib.

Using Equation (14) with the column lengths from Table I and an α of 0.02 foot, enables an estimate to be made of the hydrodynamic dispersion along each streamline. The estimate must be incorporated into earlier results to get the Basic Water Arrival-Time Distribution.

Figure 2 shows both the macroscopic and microscopic flow effects and is the basis for determining the resultant combination. The heavy center curve labeled $C/C_o = 0.5$ is a plot of the cumulative fractional flux, q/Q_o*, versus the arrival time, T_m, from Table I. The flow length (Table I) associated with each T_m was used with successive values of C/C_o** to obtain the family of curves on each side of the central curve in Figure 2. The family of curves, a result of hydrodynamic dispersion, incorporates the micro-aspects of flow in porous media.

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* The variable q/Q_o is utilized rather than ψ. Such use gives higher calculated peak activities in the river than will actually occur. This is the result of solving two-dimensional flow systems in the earlier section rather than the true three-dimensional flow cases.

** The concentration term, C/C_o, is used here to conveniently convey the idea that different fractions of the water arrive at different times due to hydrodynamic dispersion along a single streamline.

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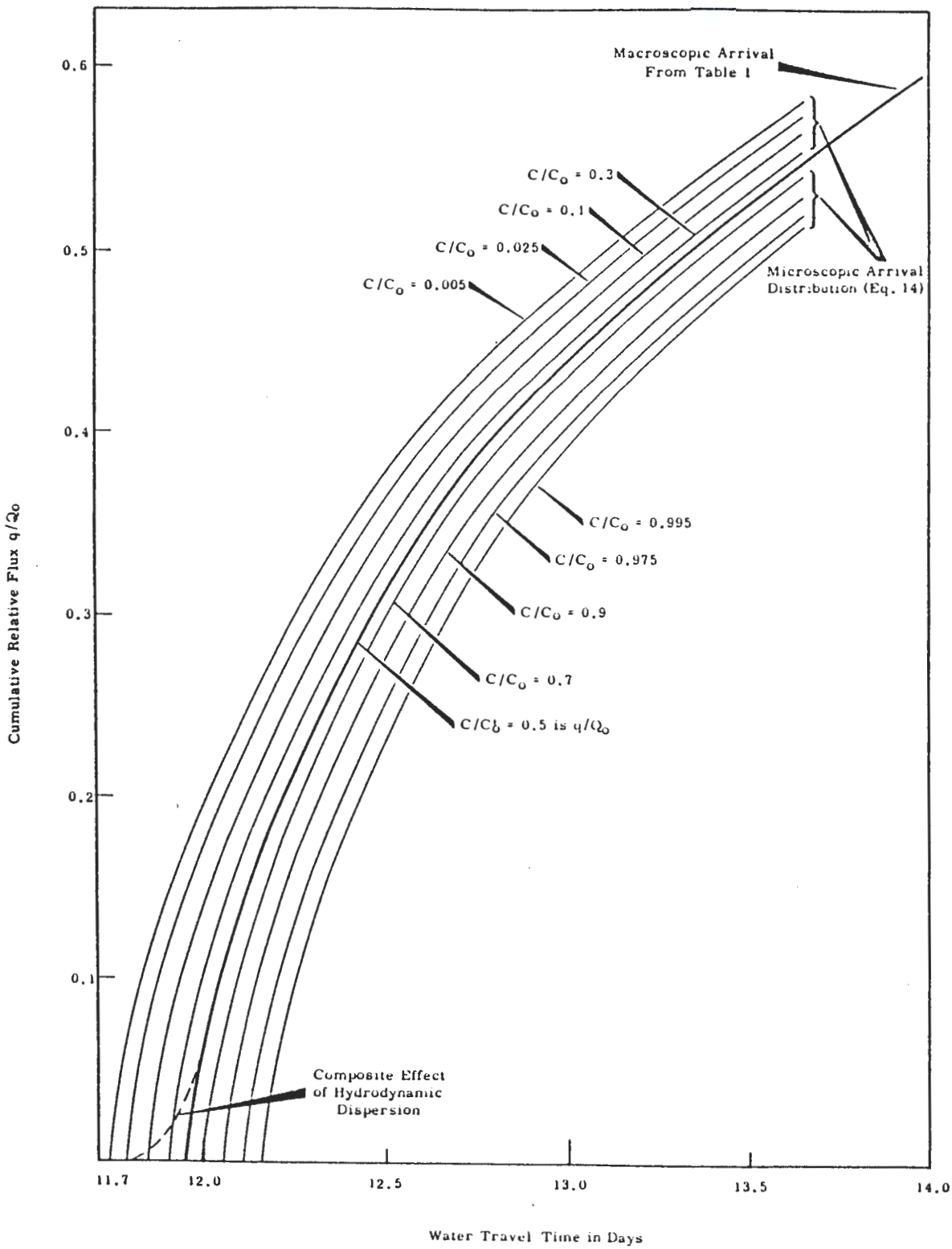

Figure 2. Macroscopic Arrival-Time Distribution and Hydrodynamic Dispersion.

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The microscopic and macroscopic effects in Figure 2 must be combined into a single distribution. This is accomplished by obtaining the variation in q/Q_o with concentration, C/C_o, at a single time. For example, a vertical line in Figure 2 representing 13.5 days intersects the $C/C_o = 0.995$ curve at a q/Q_o of 0.489. Similarly, the 13.5 days intersection for $C/C_o = 0.9$ gives a q/Q_o of 0.508. Other intersections are: $C/C_o = 0.5$, $q/Q_o = 0.527$; $C/C_o = 0.1$, $q/Q_o = 0.544$, etc. This distribution is shown in Figure 3 for a time equal to 13.5 days. The other curves shown in the latter figure were obtained similarly. The concentrations and cumulative flux rates in Figure 3 are normally distributed about q/Q_o, except for the shorter times where severe truncation occurs. It is only in the truncated region where the dispersion effects will be of significance.

The combined effects of hydrodynamic dispersion and flow geometry are obtained by evaluating the integral:

$$\left(\frac{Q}{Q_o}\right)_t = \int_o^{(C/C_o)_{max}} \left(\frac{q}{Q_o}\right)_t^d \left(\frac{C}{C_o}\right), \qquad (15)$$

where: $\left(\frac{Q}{Q_o}\right)_t$ is the cumulative relative flux of water arriving at the river at time t,

$\left(\frac{C}{C_o}\right)_{max}$ is the maximum concentration associated with $q/Q_o = 0$,

t is the river arrival time, and the other terms are as defined earlier.

Equation (15) defines the successive areas under the time curves in Figure 3; these areas were found by planimeter. The results are presented in Table II.

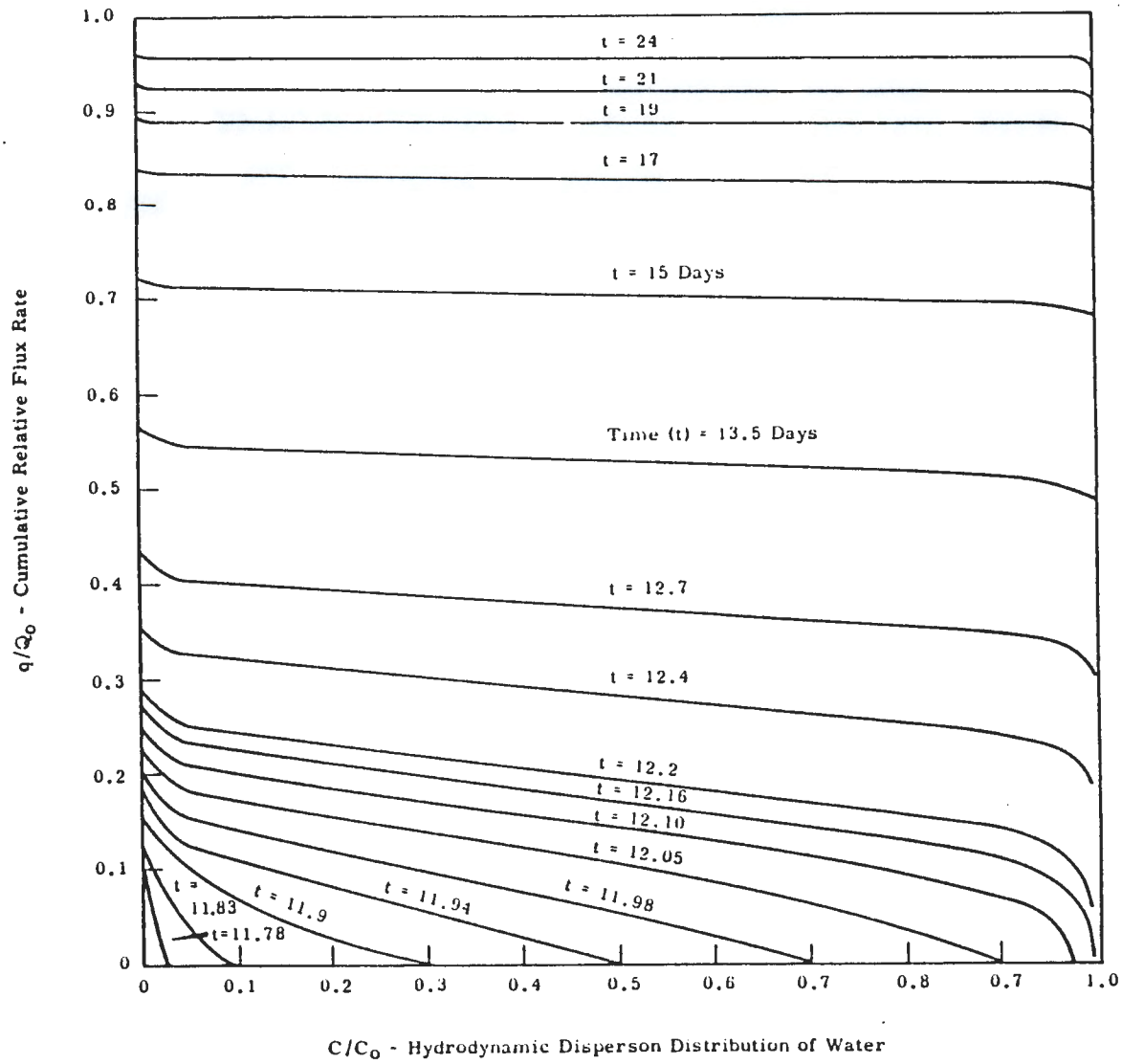

Figure 3. Variations of C/C_o with Cumulative Macroscopic Flux, q/Q_o, for Different Times.

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TABLE II

BASIC WATER ARRIVAL-TIME DISTRIBUTION

(Containing the combined effects of hydrodynamic dispersion and flow geometry for the 1301-N crib)

Time (t) (days)	Total Cumulative Relative Flux Rate $(Q/Q_o)_t$
11.76	------
11.78	0.0005
11.83	0.0050
11.90	0.016
11.94	0.035
11.98	0.061
12.05	0.100
12.10	0.139
12.16	0.170
12.20	0.193
12.30	0.240
12.40	0.300
12.75	0.380
13.79	0.570
14.60	0.665
15.89	0.760
16.52	0.798
17.43	0.836
18.60	0.874
20.49	0.912
24.08	0.950
-----	1.000

The results in Table II provide the basic water arrival-time distribution, which completely describes the time delay brought about by seepage from the crib.

USE OF THE BASIC WATER-TIME DISTRIBUTION

The basic water arrival-time distribution completely describes the effect of the flow system on contamination entering the river. The distribution predicts the arrival and recession curves for contaminated coolant diverted during a fuel element failure.

The basic arrival-time distribution for early times, shown in Figure 4 as the heavy curve labeled Curve 1, is a plot of results from Table II. This curve is the boundary between contaminated water due to rupture diversion and uncontaminated water which preceded the diversion. The region to the left of the curve represents clean water; whereas, the region to the right represents contaminated water. Curve 2 was drawn by adding 0.347 day (the average rupture diversion period) to all of the times in Table II. This curve represents the reappearance of uncontaminated water after the end of the diversion. Curve 2 also represents a contamination boundary; however, this time the region to the right is clean water, and that to the left is contaminated water. The composite result, as seen in Figure 4, is a band of waste lying only between Curves 1 and 2. In fact, the integral between the two curves is the total volume of contaminated liquid leaving the crib during the diversion time of 0.347 day. Since the ordinate in Figure 4 is the cumulative relative flux, then at any time, t, the fraction of the ground water flow rate into the river, which is contaminated, is the difference in ordinate values. Curve 3 of Figure 4 is the difference of cumulative flow rates, or the fraction of the steady flow rate (Q_o), which at that time is entering the river. Also, Q/Q_o is the effective dilution of contamination, caused by ground water flow geometry, from the crib to the river.

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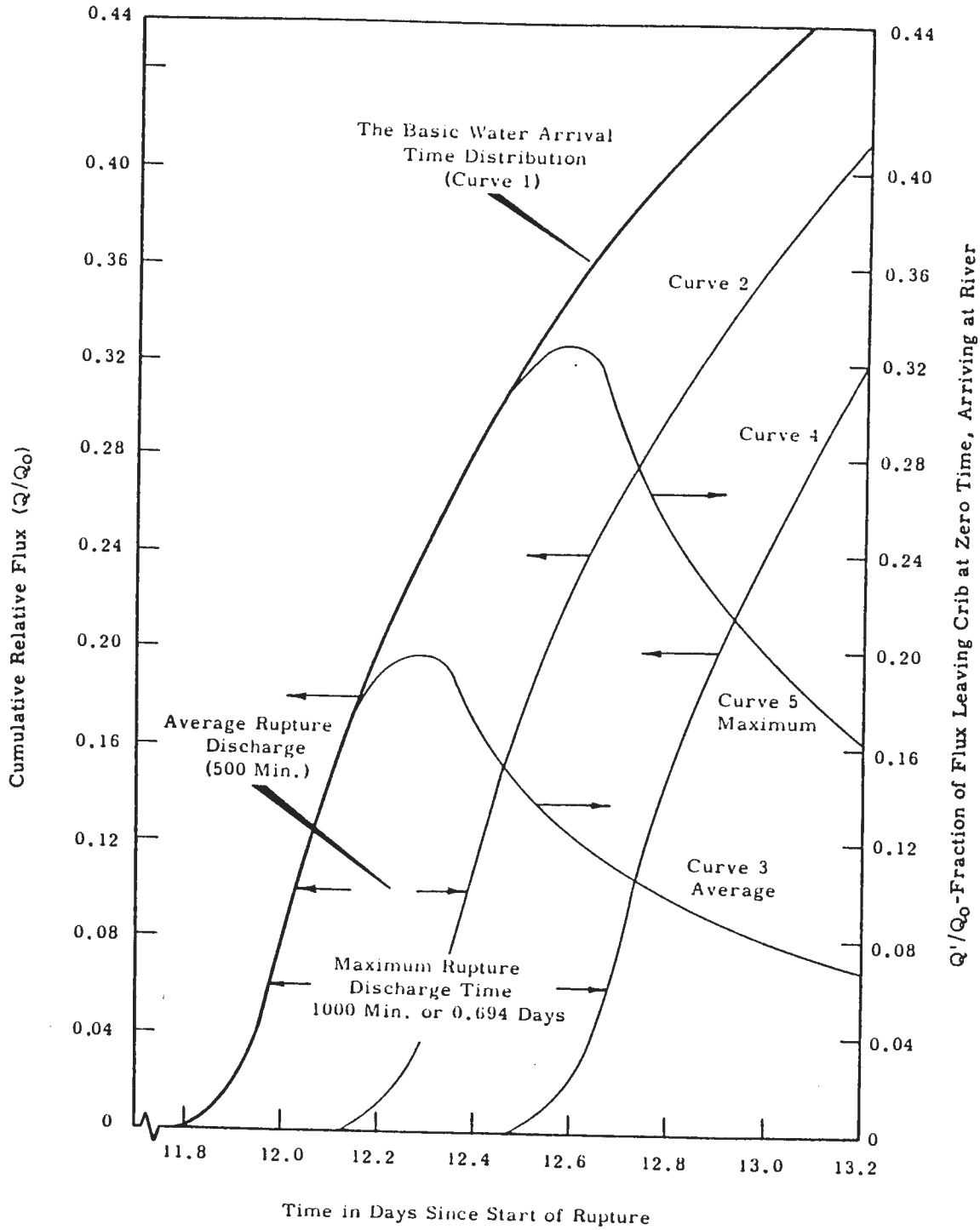

Figure 4. Time Variation of Contaminated Water Flux into the River for the Average and Maximum Rupture Discharge Period.

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Curve 4 in Figure 4 is a replot of the basic arrival-time distribution with the maximum rupture diversion time of 0.694 day added to each time shown in Table II. The relative release rate of contamination to the river as a function of time for the maximum diversion time is shown as Curve 5 in Figure 4. The numerical values of Q'/Q_o for Curves 3 and 4 are tabulated in Table III. There remains only to include decay for the I^{131} and to obtain the combined activity reduction from decay and flow geometry dilution.

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I^{131} ACTIVITY REDUCTION BY DECAY AND FLOW GEOMETRY DILUTION

Everything to this point has considered the water arrival-time distribution arising from flow geometry, which acts effectively as dilution of the waste. The effect of decay for any fission product, which is not sorbed, is easily included using the travel times from the flow system analysis*; I^{131} is considered in Table III. The fractional activity, A/A_o, is the product of the decay reduction and the dilution, Q'/Q_o, due to flow geometry. The fractional activity, when multiplied by the I^{131} activity leaving the crib, A_o, gives the instantaneous activity entering the river via crib seepage. The entire distribution is shown graphically in the Results section.

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*Soil sorption, for example strontium and cesium, can be introduced into the analysis much the same as hydrodynamic dispersion was incorporated previously, if the relationship between the water and ion travel-time distributions can be predicted. Cursory analysis indicates that very large reductions in activities may be expected when there is sorption.

TABLE III

FRACTION OF ACTIVITY LEAVING THE 1301-N CRIB WHICH REACHES THE RIVER AS A FUNCTION OF TIME. FOR THE AVERAGE AND MAXIMUM RUPTURE DIVERSION TIMES

River Arrival Time	Rupture Diversion Time					
	Average (0.347 day)			Maximum (0.694 day)		
(Days)	Decay Factor*	Q/Q_o	A/A_o**	Decay Factor***	Q/Q_o	A/A_o
11.80	0.3727	0.002	0.0007	0.3851	0.002	0.0008
11.90	0.3690	0.020	0.0074	0.3801	0.020	0.0076
11.95	0.3679	0.040	0.0147	0.3790	0.040	0.0152
12.00	0.3662	0.070	0.0256	0.3770	0.070	0.0264
12.05	0.3650	0.109	0.0398	0.3759	0.109	0.0410
12.10	0.3625	0.144	0.0522	0.3742	0.144	0.0539
12.15	0.3619	0.170	0.0615	0.3723	0.174	0.0648
12.20	0.3600	0.188	0.0677	0.3707	0.198	0.0738
12.25	0.3584	0.198	0.0710	0.3690	0.220	0.0812
12.30	0.3570	0.200	0.0714	0.3679	0.242	0.0890
12.35	0.3552	0.191	0.0678	0.3662	0.263	0.0963
12.40	0.3538	0.169	0.0596	0.3650	0.282	0.1031
12.50	0.3506	0.143	0.0501	0.3619	0.316	0.1144
12.70	0.3447	0.112	0.0386	0.3552	0.302	0.1073
13.00	0.3359	0.079	0.0265	0.3461	0.188	0.0651
13.50	0.3218	0.058	0.0187	0.3315	0.133	0.0441
14.00	0.3082	0.048	0.0149	0.3175	0.100	0.0318
15.00	0.2825	0.032	0.0090	0.2911	0.065	0.0189
16.00	0.2592	0.021	0.0054	0.2671	0.046	0.0123
18.00	0.2181	0.011	0.0024	0.2250	0.022	0.0050
20.00	0.1839	0.007	0.0013	0.1894	0.014	0.0027
22.00	0.1546	0.004	0.0006	0.1595	0.009	0.0014

*The zero time for I^{131} decay was taken as the end of the rupture diversion time of 0.347 day.

**The fraction of the initial activity reaching the river, A/A_o, is the product of the decay and dilution flux rates for the ground water, Q/Q_o.

***The zero time for decay calculations was taken as the end of the rupture diversion time of 0.694 day. If the actual distribution in time of activity entry into the soil from the crib were known, such results could be treated similar to the way hydrodynamic dispersion was introduced in the earlier section.

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RESULTS

The results of specific importance for the 1301-N crib evaluation include: direct ground water flow system data, the flow-geometry dilution effects on activity entry to the river, and the predicted reduction of I^{131} release to the river by combined ground water dilution and decay effects.

Direct Flow System Results

Three of the conservative two-dimensional boundary value problems were set up to study the effects of river stage on the travel time along the shortest flow path. The river elevations studied were 380.5, 390, and 400 feet above mean sea level. The results, presented in Figure 5, are the macroscopic minimum flow times. Also shown in Figure 5 are the extremes of measured and expected long-term river stages[9]. From these data the 380.5 foot river stage was selected as the flow system for the complete time analysis.

Questions have arisen on the effects of river bank springs on the travel time, and on how extensive spring development will become during long-term use of the crib. The locations of the surface of seepage were obtained in the process of analog solution of the boundary value problems. The effect of river stage on the maximum elevation of spring appearance above the water level in the river is shown in Figure 6. The results indicate that springs will develop in time; however, little concern is warranted since piping will not be a problem in the rocks and gravel along the riverbank by 100-N area.

Dilution Resulting From Flow Geometry.

The dilution of contaminants by the ground water flow system for the average diversion time to the crib is shown in Figure 7. The square wave of contamination

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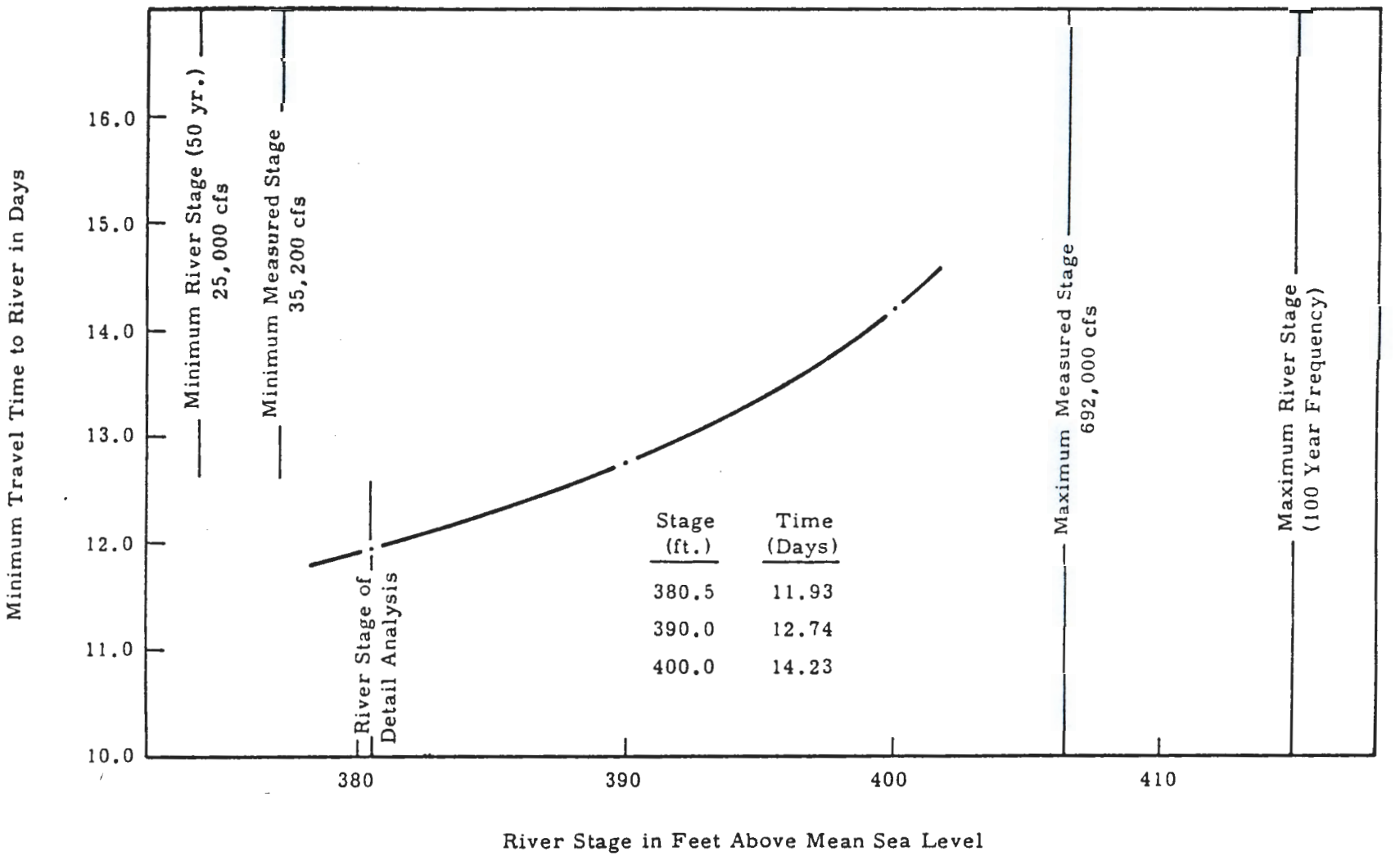

Figure 5. Predicted Minimum Macroscopic Travel Time Variation with River Stage for the 1301-N Crib.

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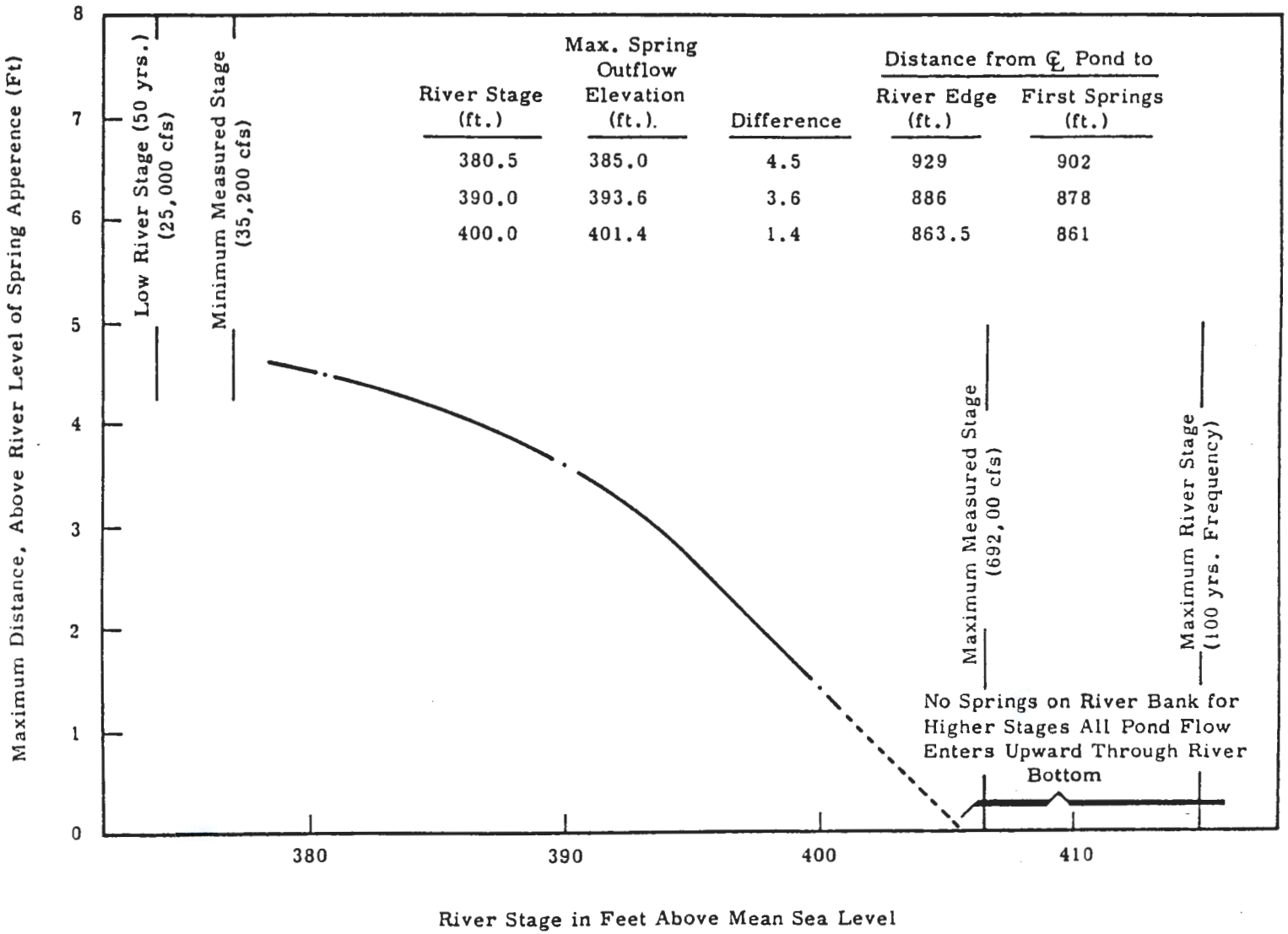

River Stage (ft.)	Max. Spring Outflow Elevation (ft.).	Difference	Distance from ℄ Pond to River Edge (ft.)	Distance from ℄ Pond to First Springs (ft.)
380.5	385.0	4.5	929	902
390.0	393.6	3.6	886	878
400.0	401.4	1.4	863.5	861

Figure 6. Predicted Maximum Elevation of Springs Above River Level at Different River Stages.

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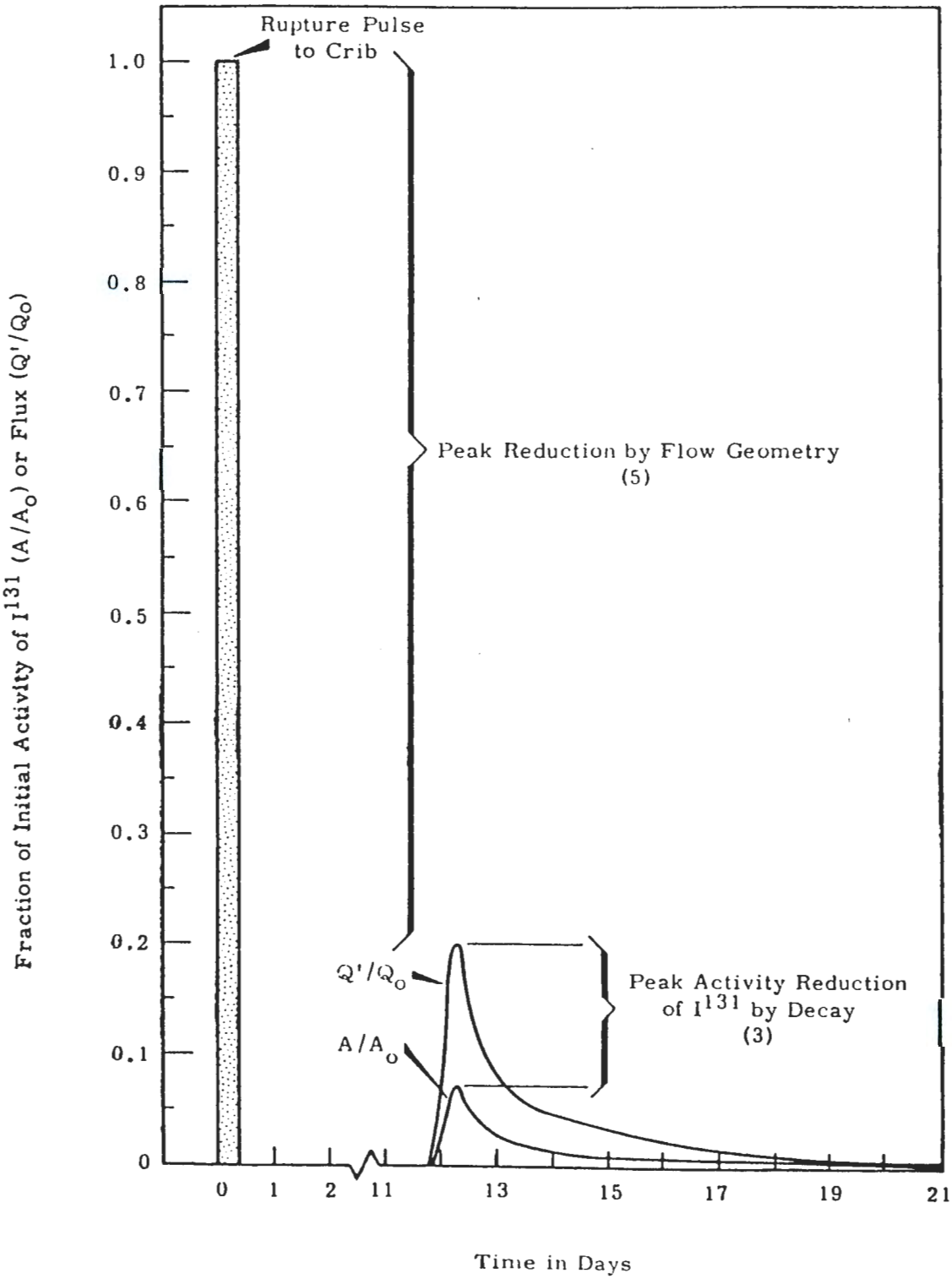

Figure 7. Reduction in River Activity by Seepage from the 1301-N Crib.

leaving the crib between t = 0 and t = 0.347 is reduced to the much lower concentration but longer bleed to the river commencing at just under 12 days. The reduction in peak river activity is fivefold as a result of flow geometry. This reduction is almost twice the reduction due to decay.

The release rate to the river 30 days after tube diversion is insignificant (Figure 7); therefore, there will be no long-term continuous addition of contaminants to the river, since the expected rupture frequency is one per month. The same statement is true for the maximum diversion time of 0.694 day. In fact, the rupture frequency could be in both cases as high as one every 20 days, and still the nonsorbed radionuclides from the first rupture would have entered the river and moved downstream prior to the radionuclides from the following rupture having reached the river.*

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Iodine-131 Release To The River

The decay of I^{131}, when combined with dilution from flow geometry, provides a predicted activity in the river as a ratio to the activity entering the soil at the crib. These results, as summarized in Table III, are shown in Figure 8 for the average and maximum rupture diversion times. The peak activities are reduced to 0.072 and 0.117 of the original values for the average and maximum diversion times, respectively.

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*This statement applies only to nonsorbed species. When ion exchange occurs, the frequency of rupture may have a significant effect due to the possibility of carry-over from one rupture to the next. Hence there may be a gradual build-up in river contamination with time. (See also footnote under previous topic, I^{131} Activity Reduction By Decay And Flow System Geometry).

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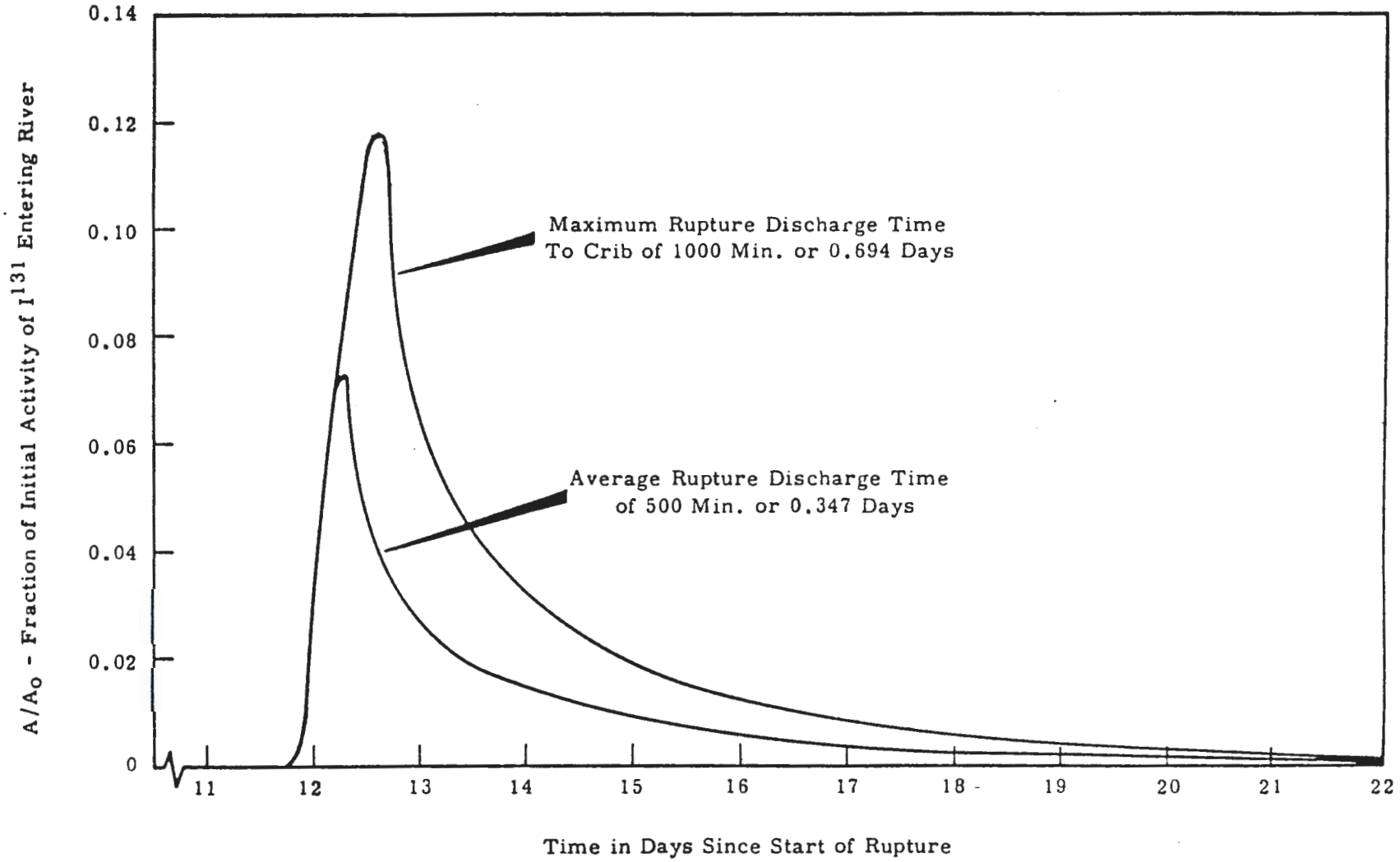

Figure 8. Fraction of I^{131} Activity Leaving the 1301-N Crib and Arriving at the River as a Function of the Time After Rupture Diversion.

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