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ANALYSIS OF HYDROLOGICAL FACTORS
INFLUENCING THE OPERATION
OF THE 100-N EMERGENCY WASTE
DISPOSAL CRIB

D. B. Cearlock and R. D. Mudd

November 1970

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D. B. Cearlock and R. D. Mudd

Water and Land Resources Department
Environmental and Life Sciences Division

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ANALYSIS OF HYDROLOGICAL FACTORS INFLUENCING
THE OPERATION OF THE 100-N EMERGENCY WASTE DISPOSAL CRIB

D. B. Cearlock and R. D. Mudd

INTRODUCTION

In the present conceptual waste management plan for the N-Reactor, liquid radioactive waste from a nuclear reactor incident will be discharged to an emergency waste disposal crib (EWD Crib). At this time, it is not known whether the crib will be reserved exclusively for liquid waste generated from a nuclear incident or for wastes from both nuclear incidents and fuel element ruptures. In part, nuclear safety and economic considerations will influence the decision as to what function the crib will serve in conjunction with the 1301-N Crib. By analyzing the transport of the radionuclides through the soils, we can evaluate the safety considerations (the controlling factor) for alternative uses of the two cribs. Once we know the alternatives that satisfy nuclear safety criteria, we can then compare them on an economic basis and decide the optimum use of the EWD and 1301-N Cribs. This report presents an analysis of the hydrological factors influencing the operation of the emergency waste disposal crib in order to help determine the most beneficial liquid waste management concept.

SUMMARY AND CONCLUSIONS

We evaluated the hydrological factors influencing the operation of the proposed Emergency Waste Disposal (EWD) Crib with the existing 1301-N Crib inactivated and with the 1301-N Crib receiving uncontaminated river water. This evaluation showed a significant advantage in operating the EWD Crib in conjunction with the 1301-N Crib. The EWD Crib with the 1301-N Crib in operation showed a 99.8% and 94% reduction in maximum total iodine and tritium, respectively, entering the Columbia River over that obtained through use of the 1301-N Crib. The EWD Crib with 1301-N Crib deactivated showed a 55% and 6% reduction in maximum total iodine and tritium, respectively, entering the Columbia River over that obtained through use of the 1301-N Crib. The higher reduction in iodine occurs because both decay and flow geometry affect the quantity of waste entering the river. In other words, only flow geometry

reduces the quantity of tritium entering the river because the travel times, 5 to 12 days, are too short to cause any appreciable reduction due to decay. This reduction occurs because the flow from the 1301-N Crib acts as a barrier to flow originating at the EWD Crib, thus diverting that flow into paths that have longer travel times to the river.

Changes in groundwater patterns were relatively small except directly beneath the cribs. For the discharge rates considered, flooding of the sanitary tile field will not occur. However, in the event of the construction of the Ben Franklin Dam, the possibility of flooding would be present.

Minimum travel times of 13 and 11 days were computed for flow from the EWD Crib to the Columbia River with the 1301-N Crib in operation and with 1301-N Crib deactivated, respectively. The travel times and the amount of reduction in the maximum quantity of waste entering the river are directly tied to the field estimated 5 day minimum travel time for flow from the 1301-N Crib to the Columbia River. If this travel time proves to be too short, the advantages of the EWD Crib over the 1301-N Crib would be even greater than they now appear.

As a result of this study, we believe that a 12 to 13 day travel time is more realistic than the present field estimate of 5 days. If the current field measured travel time from the 1301-N Crib to Well 299-N-8 is in error, the water arrival curves and relative mass flux curves could easily be corrected without additional calculations by changing the effective porosity to a more realistic value. The predicted groundwater surfaces and flow paths would remain unchanged. However, if the transmissibility distribution is in error, which would be determined by the pump tests currently being conducted near the crib sites, the entire analysis might have to be redone, depending on the magnitude of the error.

If the EWD Crib is intended to be reserved for liquid waste generated during a nuclear incident, the partially-saturated, transient model now under development should be applied in order to conduct a more realistic analysis. The information in this report could be used to evaluate the use of the crib in this manner, but the results would be limited because this analysis was based on continuous discharges.

We did not determine the discharge rate to the 1301-N Crib that would provide the maximum reduction of wastes entering the river from discharges to the EWD Crib. However, we believe that a very significant advantage would be gained by operating the 1301-N Crib in conjunction with the EWD Crib.

MATHEMATICAL SIMULATION MODEL

Analysis of the hydrological factors influencing operation of the EWD Crib required a simulation model that would reliably predict the groundwater flow system resulting from changes in the operational modes of the two cribs. To develop this model, we selected a mathematical analysis describing two-dimension flow in the horizontal plane as the best available method for solving the problem. Because of the lack of field data, a three-dimensional analysis would provide little more information and would not warrant the increased cost and difficulty of the study. Also, a two-dimensional analysis in the vertical plane, similar to that conducted in previous investigations on the 1301-N Crib,^(1,2) was not chosen because: 1) past theoretical and field investigations^(1,2,3) showed that vertical differences in travel times were exceedingly small when compared to horizontal differences, and 2) a two-dimensional analysis in the vertical plane is inadequate when handling more than one source (for example, discharge to the groundwater via the cribs) as in the present investigation.

The previously developed computer routine "STEADY" solves the equation:

$$\frac{\partial \left(T \frac{\partial \phi}{\partial x} \right)}{\partial x} + \frac{\partial \left(T \frac{\partial \phi}{\partial y} \right)}{\partial y} + Q = 0 \quad (1)$$

where T = transmissibility

Q = quantity of flow discharges to the crib

ϕ = hydraulic potential

$x+y$ = space coordinates.

The limitations of the two-dimensional analysis are: 1) the vertical component of flow is neglected, 2) inflow and outflow surfaces are assumed to penetrate the entire flow system, 3) aquifer thicknesses are assumed constant, and 4) it is assumed the permeability is constant with respect to depth.

The effect of the vertical component of flow and the effect of fully penetrating inflow and outflow surfaces are small except in the near vicinity of these surfaces. The overall influence on the travel times, flow paths, and changes in hydraulic potential is small. Because of the close proximity of the two cribs to the Columbia River and to the quantities of liquid being discharged to the cribs, the changes in aquifer thickness in the predicted cases should be small and can therefore be realistically assumed constant for this study. The results of this study bear out this fact. Geological information on the 100-N Area^(3,4,5) and examination of the sediments saturated or to be saturated by the groundwater indicate that the permeability is constant with respect to depth and therefore satisfies the assumption of the model that the permeabilities be constant with depth. The main limitation of this analysis is the assumption of continuous discharge. If the crib is to be reserved for waste generated from a nuclear incident, this analysis is not very realistic.

To use the predictive model described by Equation (1), we had to determine the transmissibility of the soil in the region covered by the model. Previous work^(5,6,7) has shown that the spatial variation in transmissibility on the Hanford project is considerable and cannot be considered homogeneous. A computer routine was developed in FY 1969 for calculating the transmissibility distributions from point measurements made at existing wells.^(8,9) In the calculation of the transmissibility by this method, we assume that the flow system is steady and two-dimensional. Testing of the routine showed it to be more than adequate for analysis of the groundwater flow system in the vicinity of the 100-N Area.

Figure 1 shows the portion of the Hanford groundwater flow system covered by the simulation model. Periodic measurements of the groundwater potentials for this region were made during January and February 1969. Analysis of the data showed insignificant changes in the groundwater potential during this period. Diurnal fluctuations of the potential in Well 199-N-8 located on the bank of the river were also small. We believed that the flow system had reached a steady condition during this period and, therefore, transmissibility calculations could be made.

HANFORD PROJECT

FIGURE 1. Portion of the Hanford Groundwater Flow System Covered by the Simulation Model

Wells 699-77-54, 699-71-52, and 199-K-10 were the only wells in this portion of the Hanford flow system where transmissibility measurements had been made. Measurements at wells near 100-N Area were delayed because of a budget freeze on capital facilities. This caused a lack of transmissibility measurements between 100-N and 100-D and around the 1301-N Crib—the areas of greatest concern. The transmissibility at 100-D was estimated from the field measured travel time. Tests conducted at 100-D firmly established the travel time from the D-Trench to the river.⁽⁸⁾ Knowing the travel time, flow path, and gradients, we can calculate the transmissibility from the following equation:

$$T = \frac{fLD}{it} \quad (2)$$

where f = porosity
 L = distance from the trench to the river
 i = groundwater gradient
 D = depth of the aquifer
 t = travel time.

All of the quantities in Equation (2) are measurable except the porosity (f).

With these measurements, we calculated the transmissibility distribution for the modeled area. Figure 2 shows the resulting transmissibility map. Although there were inconsistencies between interpreted groundwater potentials and transmissibility measurements, lack of time precluded the elimination of these inconsistencies.

VERIFICATION OF THE SIMULATION MODEL

The model can be verified by several methods and parametric relationships. One procedure is the calculation of the flow leaving the crib by using the calculated transmissibility distribution and the measured groundwater potential. Table 1 is a compilation of the quantity of water flowing between streamlines that encompass the entire flow leaving the crib. The estimated quantity of water being discharged to the crib is between 2300 and 2500 gal/min;⁽⁹⁾ the calculated quantity leaving the crib is 2400 gal/min, an excellent agreement.

FIGURE 2. Calculated Transmissibility Distribution Used in the Mathematical Simulation Model

TABLE 1. Calculated Flow Rates Between
Streamlines Shown in Figure 4
for the 1301-N Crib

<u>Streamline Numbers</u>	<u>Flow Rates, ft³/day</u>
A-1 to A-2	1.1 x 10 ⁴
A-2 to A-3	4.6 x 10 ⁴
A-3 to A-4	5.0 x 10 ⁴
A-4 to A-5	4.4 x 10 ⁴
A-5 to A-6	1.0 x 10 ⁴
A-6 to A-7	2.1 x 10 ⁴
A-7 to A-8	2.3 x 10 ⁴
A-8 to A-9	3.6 x 10 ⁴
A-9 to A-10	2.7 x 10 ⁴
A-10 to A-11	1.2 x 10 ⁴
A-11 to A-12	2.3 x 10 ⁴
A-12 to A-13	10.6 x 10 ⁴
A-13 to A-14	1.4 x 10 ⁴
A-14 to A-15	0.6 x 10 ⁴
A-15 to A-16	1.1 x 10 ⁴
A-16 to A-17	1.4 x 10 ⁴
A-17 to A-18	1.2 x 10 ⁴
Total Flow	46.6 x 10 ⁴

Another check is the comparison of the calculated travel time with the measured travel time. To calculate the travel times, we used the transmissibility distribution, the measured gradients, and an estimate of the effective porosity. An effective porosity of 12% was used which gave a minimum travel time (from the 1301-N Crib to Well 299-N-8) of 30 days. However, Chitwood and Renberger⁽¹²⁾ and recently conducted field tests indicate a minimum travel time of around 5 days. To make the computed travel time match the field measured travel time, we reduced the effective porosity from 12% to 2%. According to Bierschenk, effective porosities have been estimated to vary from 4.8% to 11% for the regions near 200-W and 200-E groundwater mounds.⁽¹³⁾ Using direct and indirect methods of calculations, Bierschenk also estimated the effective porosity of the Hanford aquifer average at about 9%. On the basis of this information, the effective porosity of 5% would appear to be the lowest practicable limit. This means that the minimum travel time from the crib to Well 299-N-8 should be on the order of 12 to 13 days. All of the field tests for measurement of travel times conducted at the 1301-N Crib have been inconclusive. Analysis of the data collected in these tests indicates that several different travel times show good agreement with the collected data. Also, the close agreement between calculated and estimated flow rates to the crib implies that the average transmissibility in the vicinity of the crib is very good. All of this information indicates that the travel time from the crib to the well is greater than the presently estimated 5 days.

One possible explanation for the disagreement between the travel times and calculated transmissibilities is that transmissibility distribution around the crib could vary considerably more than the calculated one and still result in the same average transmissibility. However, at the time of study no transmissibility measurements were available in the vicinity of the 100-N Crib for comparisons.

Because a 5 day travel time would be a conservative estimate, we used it as a basis for establishing the effective porosity of 2%; that is, the 5 day travel time represents the worst possible conditions based on available information. It should be noted that the effective porosities only affect

travel time calculations and that the choice of the porosity does not influence the predicted changes in potential or flow paths.

The third verification procedure involves a comparison of the calculated groundwater surface and the measured ground surface. In this study, the comparison showed good agreement. Over the simulated region, the average difference between the two surfaces was less than 0.5 ft. However, differences between the two surfaces as large as 2 ft occurred near the predicted stagnation point, created by the interaction of the 100-K Trench and 1301-N Crib. The stagnation point was predicted to occur farther eastward than the measured one. Shifting of the stagnation point was a result of boundary conditions chosen along the Columbia River near the 100-N Area. Not well defined by field measurements, these boundary conditions were estimated from Columbia River stage measurements and spring elevations. In the time available, the best possible adjustments were made.

ANALYSIS OF ALTERNATIVE CRIB OPERATIONAL MODES

Using the previously discussed mathematical model, we evaluated the hydrological factors influencing the operation of the EWD Crib under two conditions: 1) with the 1301-N Crib inactivated, and 2) with the 1301-N Crib receiving uncontaminated river water. We used a discharge rate of 2500 gal/min to the EWD Crib for both cases. When used in conjunction with the EWD Crib, the 1301-N Crib received the same rate.

Because of the short time allowed for the study, we investigated only the anticipated worst conditions: low flow of the Columbia River and steady state analysis. A steady state analysis also represents the worst condition with respect to radiological safety considerations. When the Columbia River is at low flow, the groundwater gradients (velocities) are much greater than at high river stages since less aquifer thickness is available at lower stages for transporting the same quantities of water (assuming constant discharge to the crib). The construction of Ben Franklin Dam should increase travel times owing to increased aquifer thickness and, therefore, any contamination would be less severe than low Columbia River stage conditions. However, an evaluation of the effects of Ben Franklin Dam on the management of the cribs should be conducted at a later time.

Figure 3 shows contours of the present groundwater table surface in the vicinity of the 100-N Area. This surface, resulting from a discharge of approximately 2500 gal/min of water to the 1301-N Crib, appears to have approached a quasi-steady state condition with the low flow condition of the Columbia River and the rest of the Hanford groundwater flow system. Figure 4 shows flow paths from the 1301-N Crib to the Columbia River with equal travel time lines superimposed. Using the field estimated travel time of 5 days between the 1301-N Crib and Well 299-N-8 as a reference, we calculated the shortest travel time from the crib to the river to be approximately 4 days. Table 1 gives the calculated flow between each of the streamlines shown in Figure 4. Figure A-1, in the appendix, shows the water arrival curve (the scaled accumulative flux, which originated from discharges to the 1301-N Crib, entering the Columbia River) for the 1301-N Crib. We used this curve to predict the total quantities of waste, resulting from ruptures or other discharges to the crib, entering the river as a function of time. The curve is used later in the comparison of the two alternative operational modes associated with the use of the EWD Crib. Table A-1 contains travel times for each of the streamlines shown in Figure 3.

Figure 5 shows the contours of the steady state groundwater surface resulting from a discharge of 2500 gal/min to the EWD Crib. This groundwater system evidences little change from the present system (Figure 3). However, directly beneath the EWD Crib the groundwater surface will be approximately 19 ft higher than the present surface.

Figure 6 shows the flow paths from the EWD Crib to the Columbia River, with equal travel time lines superimposed. The shortest predicted travel time from the crib to the river is 11 days, almost three times as long as the shortest time associated with the 1301-N Crib. The longer distance between the EWD Crib and the Columbia River accounts for the difference, because the travel time is proportional to the square of the distance. The different transmissibilities associated with the location of the EWD Crib will also cause variations in travel times.

FIGURE 3. Contours of the Present Groundwater Flow System
in the Vicinity of 100-N Area

FIGURE 4. Calculated Flow Paths Originating from the 1301-N Crib with Superimposed Equal Travel Time Lines

FIGURE 5. Contours of the Predicted Groundwater Flow System Resulting from Continuous Discharge to the EDW Crib

FIGURE 6. Predicted Flow Paths Originating from the EWD Crib with Superimposed Equal Travel Time Lines

Table 2 lists the flow rates between the flow paths shown in Figure 6 for the EWD Crib. Figure A-2 shows the water arrival curve for the EWD Crib and Table A-2 shows the travel times for each of the streamlines.

TABLE 2. Calculated Flow Rates Between Streamlines
Shown in Figure 6 for the EWD Crib

<u>Streamline Numbers</u>	<u>Flow Rates, ft³/day</u>
B-1 to B-2	3.6×10^4
B-2 to B-3	11.2×10^4
B-3 to B-4	9.1×10^4
B-4 to B-5	3.2×10^4
B-5 to B-6	1.7×10^4
B-6 to B-7	5.0×10^4
B-7 to B-8	2.8×10^4
B-8 to B-9	2.7×10^4
B-9 to B-10	2.7×10^4
B-10 to B-11	4.2×10^4
Total Flow	46.2×10^4

Figure 7 shows the contours of the steady state groundwater surface resulting from a discharge of 2500 gal/min to both the EWD and the 1301-N Crib. A comparison of this groundwater surface with the present surface (Figure 3) shows in general only a few feet rise in the predicted surface over the present surface. However, directly beneath the EWD Crib the model predicted a rise of 27 ft in the groundwater table. Figure 8 shows the flow paths from the EWD Crib to the Columbia River, with superimposed equal travel time lines. The calculated minimum travel time was approximately 13 days. The 1301-N Crib acts like a dam and diverts flow from the EWD Crib to longer flow paths and subsequently longer travel times. For this alternative, we calculated the shortest travel time from the 1301-N Crib to the river to be 2.5 days. From a hazard analysis point of view, this travel time is unimportant because uncontaminated water would be discharged to the 1301-N Crib.

The appendix contains the travel times for each flow path shown in Figure 8 and a water arrival curve.

FIGURE 7. Contours of the Predicted Groundwater Flow System Resulting from Continuous Discharges to the EWD and 1301-N Cribs

FIGURE 8. Predicted Flow Paths Originating from the EWD Crib with Superimposed Equal Travel Time Lines (Discharges to both EWD and 1301-N Cribs)

Table 3 lists the flow rates between the flow paths shown in Figure 8 for the EWD Crib. Figure A-3, in the appendix, shows the water arrival curve for the EWD Crib in operation with the 1301-N Crib and Table A-3 lists the travel times for each flow path.

TABLE 3. Calculated Flow Rates Between Streamlines Shown in Figure 8 for the EWD Crib

<u>Streamlines Numbers</u>	<u>Flow Rates, ft³/day</u>
C-1 to C-2	2.1 x 10 ⁴
C-2 to C-3	9.3 x 10 ⁴
C-3 to C-4	15.3 x 10 ⁴
C-4 to C-5	12.2 x 10 ⁴
C-6 to C-7	3.2 x 10 ⁴
C-7 to C-8	2.4 x 10 ⁴
C-8 to C-9	1.1 x 10 ⁴
Total Flow Rate	45.6 x 10 ⁴

Because of the location of the sanitary tile field between the two cribs, rising groundwater could flood the tile field. The lowest point in the sanitary tile field is 436.16 ft above mean sea level. The model predicted a groundwater surface elevation of approximately 422 ft for both cribs in operation and 413 ft when just the EWD Crib was in operation, at the southeast corner of the sanitary tile field. Because of the short duration, a high Columbia River stage causes only small changes in the groundwater surface beneath the tile field. Since the predicted groundwater surface is approximately 13 ft below the lowest point of the drain field when the discharge rate to both cribs is 2500 gal/min, the fluctuations due to high river stages will not interfere with the operation of the sanitary tile field irrespective of which alternative operational mode is chosen for the EWD Crib. However, the construction of Ben Franklin Dam could make the flooding of the sanitary tile field highly possible. This possibility should be investigated.

Table 4 shows a summary of field measured and predicted groundwater surface elevations beneath the 1301-N Crib, the EWD Crib, and the southeast corner of the sanitary tile field for the alternatives considered in the investigation.

TABLE 4. Summary of Groundwater Elevations
at Pertinent Locations

	<u>Crib(s) in Operation</u>		
	<u>1301-N Crib (field measured)</u>	<u>EWD Crib (predicted)</u>	<u>EWD & 1301-N Crib (predicted)</u>
Beneath the 1301-N Crib	409	399	416
Beneath the EWD Crib	401	420	428
Beneath the S.E. Corner of the Sanitary Tile Field	401	413	422

To make a realistic safety or hazard analysis, we must know the total quantity of waste entering the river as a function of time. The three phenomena that tend to reduce the quantity of waste entering the river are: 1) decay, 2) sorption, and 3) flow geometry. The effects of decay and sorption are well known, but the effects of flow geometry are sometimes misinterpreted. Flow geometry results from the variation in travel times from the crib to the river for the different flow paths. In other words, when a slug of waste is discharged to the crib, the peak of the slug of waste will reach the river first along the path with the shortest travel time. When the peak of the slug reaches the river on intermediate flow paths, the peak has already passed into the river for the shortest ones but has not reached the river on the longest ones. Therefore, the portion of the total slug of waste entering the river at any one time would be inversely proportional to the variation in travel times. This fact is borne out from the analysis of the water arrival curves.

Figure 9 shows a comparison of the three water arrival curves (for the 1301-N Crib, EWD Crib, and EWD Crib with 1301-N Crib in operation). The less the slope of the curves, the greater the variation in travel times and the greater the influence of flow geometry will be in reducing the peak discharge into the river. If the waste is discharged continuously to the crib, no reduction in peak discharge to the river would occur after the time of discharge exceeded the longest travel time. This is because all flow paths would be discharging contaminated water into the river simultaneously.

FIGURE 9. Comparison of the Three Water Arrival Curves of the 1301-N Crib, the EWD Crib, and the EWD Crib with the 1301-N Crib in Operation

According to Nelson,⁽¹⁾ the maximum rupture diversion time for the 1301-N Crib is 0.694 days. Since the maximum discharge time would result in less reduction due to flow geometry, we selected it as a more severe condition than average discharge time.

For the three cases under consideration, Figure 10 shows the relative mass flux of tritium entering the river (because of a rupture) as a function of time with a diversion time of 0.694 days. Integration of the curves shown in Figure 10 for any time period will give the relative activity

$$A/A^{\circ} = \frac{1}{t_D} \int_{t_1}^{t_2} n/n^{\circ} dt \quad (3)$$

entering the river during that time period.

where n = mass flux entering the river (curies/day)
 n° = mass flux discharged to the crib (curies/day)
 t = time (days)
 A° = total activity discharged to the crib (curies)
 A = activity entering the river (curies)
 t_D = diversion time (days).

To obtain the activity entering the river for the period of time chosen, we multiply Equation (3) by A° which is given by

$$A^{\circ} = CQt_D \quad (4)$$

where C = concentration of waste being discharged to the crib (curies/ft³)
 Q = discharge rate to the crib (ft³/day)

The maximum mass fluxes of tritium entering the river are 0.066, 0.055, and 0.0045 of the mass flux being discharged to the cribs for the 1301-N, EWD, and the EWD with the 1301-N Crib in operation, respectively. This means that, with respect to the maximum tritium activity discharged to the river, the EWD Crib has approximately a 6% reduction advantage over the 1301-N Crib. Used together, the EWD and 1301-N Cribs, with the waste being discharged to

FIGURE 10. Relative Mass Flux of Tritium Entering the Columbia River Because of a Rupture and Diverted to the 1301-N Crib, EWD Crib, and EWD Crib with 1301-N Crib in Operation, Respectively (Diversion Time = 0.694 Days)

the EWD Crib, reduce tritium activity by approximately 94%. Therefore, the operation of the EWD Crib with 1301-N Crib acting as a dam provides for the greatest reduction in maximum tritium activity entering the river as a result of a rupture. Even for the 1301-N Crib the maximum activity of tritium entering the river is approximately 93% less than that discharged to the crib. Flow geometry is the main factor for the various reductions in maximum activities. The travel times, 5 to 12 days, associated with this study are too short to cause appreciable decay of tritium.

Figure 11 shows the relative mass flux curves for iodine. The maximum mass fluxes of iodine entering the river are 0.044, 0.020, and 0.0012 for the 1301-N, EWD, and EWD with the 1301-N Crib in operation, respectively. Compared to the 1301-N Crib, the EWD Crib shows a 55% reduction in maximum iodine activity discharged to the river. The reason for the definite advantage of the EWD Crib over the 1301-N Crib in iodine reduction and not in tritium is because the longer travel times associated with the EWD Crib provide much more decay for iodine. On the other hand, the travel times of 5 to 12 days will not appreciably cause any decay in tritium. Compared to the 1301-N Crib, the EWD Crib in operation with the 1301-N Crib shows a 99.8% reduction in maximum iodine activity entering the river.

Using laboratory research with soil samples from the 1301-N Crib site, Hajek^(14,15) predicted the movement rate of other radionuclides. He determined migration rates of 1/100 and 1/1000 the rate of groundwater movement for ⁹⁰Sr and ¹³⁷Cs, respectively. These nuclides can be analyzed in the same manner as tritium and iodine by drawing new water arrival curves based on their rate of movement (relative to the movement of the groundwater) and then constructing relative mass flux curves. There was no formal analysis for these nuclides in this investigation.

FIGURE 11. Relative Mass Flux of Iodine Entering the Columbia River Because of a Rupture and Diverted to the 1301-N Crib, EWD Crib, and EWD Crib with 1301-N Crib in Operation, Respectively (Diversion Time = 0.694 Days)

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APPENDIX

WATER ARRIVAL CURVES
AND TRAVEL TIME DATA

FIGURE A-1. Water Arrival Curve for the 1301-N Crib

FIGURE A-2. Water Arrival Curve for the EWD Crib

FIGURE A-3. Water Arrival Curve for the EWD Crib in Operation with the 1301-N Crib

TABLE A-1. Travel Times for the Flow Paths from the 1301-N Crib to the Columbia River Shown in Figure 4

<u>Flow Path No.</u>	<u>Travel Time, Days</u>
A-1	4717
A-2	1320
A-3	352
A-4	177
A-5	55
A-6	24
A-7	13
A-8	9
A-9	7
A-10	4.5
A-11	4
A-12	5
A-13	9
A-14	26
A-15	27
A-16	76
A-17	102
A-18	161

TABLE A-2. Travel Times for the Flow Paths from the EWD Crib to the Columbia River Shown in Figure 6

<u>Flow Path No.</u>	<u>Travel Time, Days</u>
B-1	3096
B-2	614
B-3	254
B-4	132
B-5	50
B-6	20
B-7	13
B-8	11
B-9	15
B-10	28
B-11	132

TABLE A-3. Travel Times for the Flow Paths from the EWD Crib to the Columbia River Shown in Figure 8

<u>Flow Path No.</u>	<u>Travel Time, Days</u>
C-1	6039
C-2	3501
C-3	1491
C-4	241
C-5	113
C-6	13.3
C-7	28
C-8	62
C-9	334

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