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J. F. Honstead
J. F. Honstead

EFFLUENT PLUME TEMPERATURE DATA

by

J. P. Corley

Manager, Evaluations and Measurements Unit
Environmental Studies Section
ENVIRONMENTAL HEALTH DEPARTMENT

June 3, 1968

PLUME TEMPERATURE DATA				
ROUTE TO				DATE

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EFFLUENT PLUME TEMPERATURE DATA

A primary factor in assessing the impact on the biosphere of the discharge of heated reactor effluent to the Columbia River is the degree of initial dilution. Each of the reactor effluent lines discharges at the bottom of the river, approximately normal to the current, and near the main channel. As part of the Division of Production research and development program titled "The Effects of Reactor Effluent on the Quality of Columbia River Water", the temperature measurements recorded in this document were taken over a period of several years. Generally, the exact locations of the ends of the effluent lines could not be determined from the river. The intent therefore was to determine the initial degree of dilution at the point where the mixed effluent first reached the surface, the so-called "bubble", over a range of river flow-rates. A secondary goal was to determine the distance downstream (in quarter-mile increments) at which vertical mixing of the effluent streams could be considered complete.

The data reported here have been partially reported previously⁽¹⁾ and used in the development of a mathematical model of plume development⁽²⁾. The purpose of this document is to provide a record of the field data in more detail than has previously been available.

SECRET
BY J. W. Jordan 3-23-81
BY J. W. Jordan 3-23-81

CLASSIFICATION CANCELLED

Per DOC May '73
By M. J. Anderson
6/14/73

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- (1) BNWL-CC-807 (SECRET), "Inter-Reactor River Temperature Data", J. P. Corley, September 9, 1966
 - (2) BNWL-CC-1261 (Declassified with Deletions), "An Analysis of the Physical Factors Governing the Size and Temperature Gradients of the Hanford Effluent Plumes", R. T. Jaske, June 20, 1967

PROCEDURE

All temperature measurements were taken with a resistance thermometer, with sensors providing either an 8-second or 16-second time constant and a continuous signal to a millivolt recorder. The calibrated accuracy of this system is $\pm 0.2^{\circ}$ C. The sensor was attached to a vaned weight suspended from a boat winch to the calculated water depth, with allowance for deviation of the cable from the vertical.

Shore markers were placed at measured 400-yard distances from the on-shore end of the effluent lines. The B and C outfall lines, like the D and DR lines, are less than 400 yards apart. The 400 yard distances, therefore, were measured from the downstream line, C and DR respectively. The 100-yard distances were estimated with the assistance of shoreline landmarks and may be in error by as much as 25 yards. The distances along the streamline from the ends of the outfall lines to the surface appearances (the "bubbles") of the effluent varied from outfall to outfall and with river flow-rate. Although the ends of the outfall lines could not be accurately located from the boat, the distances from the outfall lines to the "bubbles" were estimated to be as little as 5 yards to as much as 50 yards. The "bubbles" were visible in practically all instances, and were always easily detectable with the temperature sensor.

The usual procedure included:

- a) locating the "bubble" visually and measuring the upstream temperature,
- b) maintaining station in the "bubble" for several minutes at several sensor depths while recording the temperature,
- c) drifting the boat slowly across the plume several times with the sensor at different depths for the 100-yard and 400-yard stations.

The reactor effluent temperatures were taken from Daily Operating Reports, with no adjustment for heat losses in the 107 Retention Basins. From a series of comparative measurements made across the basins from 1963 to 1965, the errors in the calculated dilution factors from neglecting such losses would be no greater than 10%. The river flow-rate was determined from the USGS records for the gauge station, adjusted for time of wave travel to the outfall. The accuracy of the basic record is better than $\pm 5\%$. At times of rapidly changing flow-rate, the error in the estimated flow-rate at the outfall may be as much as $\pm 10,000$ cubic feet per second, as indicated in the data tables by an approximation symbol.

Where the data was available, a dilution factor was calculated using the formula:

$$DF = \frac{T_e - T_r}{\Delta T}$$

where DF is the inverse of the fraction of effluent in the mixed water volume,
 T_e is the reported effluent temperature,
 T_r is the upstream river temperature,
and ΔT is the maximum measured temperature at the station minus the river temperature

Dilution factors were plotted versus river flow rate on log-log graph paper. For every set of three or more comparable points, a straight line was plotted by a least-squares procedure and extrapolated to the expected minimum flow rate of 36,000 cfs.

RESULTS

Tables I.1 to I.17 show the observed maximum temperatures at the stations and depths indicated, as taken from the recorder charts. Table II is a summary of the data from Table I, with only the maximum temperature at each station listed.

The calculated dilution factors, with extrapolated lines of best fit, are shown in Figures 1 to 3 for the reactors at B, K, and D Areas. Table III gives the intercept values of the lines at the expected minimum river flow rate of 36,000 cfs. It should be pointed out that these listed minimum factors should not be interpreted as being the minimum dilution that could exist between ends of the outfall lines and the point where the effluent plumes reach the river surface. At any river flow rate, it is probable that for some short distance just beyond the end of the outfall line no dilution has yet occurred, i.e. $DF = 1$. The smaller the dilution factor, of course, the smaller the fraction of the river cross-section affected.

In general, the data points show the expected internal relationships. A straight line fit on the log-log scale implies a power function relationship as diffusion theory would predict. However, a break in slope would be expected at a point where the initial three-dimensional diffusion changes to two-dimensional, or in other words where a uniform vertical concentration is reached. Such a break in slope could be read into the zero distance data for C and K reactors.

Several data points are obviously in error, e.g. the 71,000 cfs point, zero distance, for the K reactors. The most probable cause of such major anomalies is a failure to record the maximum plume temperature at the given distance.

TABLE I.1

REACTOR EFFLUENT PLUME TEMPERATURES

2-11-64

<u>Location and Depth</u>	<u>Upstream Temp. °C</u>	<u>Maximum Bubble Temp. °C</u>	<u>Maximum Temp. at 100 yds. °C</u>	<u>Maximum Temp. at 400 yds. °C</u>	<u>River Flow Rate - cfs</u>
<u>1904-B</u>					
1 ft.	4.6	8.5			128,000
<u>1904-C</u>					
1 ft.		8.25			127,000
5 ft.		9.1			
<u>1904-K</u> (1 reactor only)					
1 ft.		10.2			138,000
5 ft.		8.5			
15 ft.		9.0			
<u>1904-F</u>					
1 ft.		>15°C			125,000
5 ft.		19.5			
15 ft.		21.8			

TABLE I.2

REACTOR EFFLUENT PLUME TEMPERATURES

4-8-64

<u>Location and Depth</u>	<u>Upstream Temp. °C</u>	<u>Maximum Bubble Temp. °C</u>	<u>Maximum Temp. at 100 yds. °C</u>	<u>Maximum Temp. at 400 yds. °C</u>	<u>River Flow Rate - cfs</u>
<u>1904-B</u>					
1 ft.	6.45	15.5			54,000
10 ft.	6.45	15.75			
20 ft.	6.7	12.30			
<u>1904-C</u>					
1 ft.		15.65	8.8	9.45	54,000
10 ft.		14.75	10.6	9.0	
20 ft.		17.15	10.6	8.55	
<u>1904-K</u>					
1 ft.	7.3	19.4	10.15	9.4	71,000
10 ft.	7.45	22.2	(8') 8.7	(8') 8.2	
12 ft.	7.6	-	(5') 9.25	(4') 9.5	

TABLE I.3

REACTOR EFFLUENT PLUME TEMPERATURES

4-9-64

<u>Location and Depth</u>	<u>Upstream Temp. °C</u>	<u>Maximum Bubble Temp. °C</u>	<u>Maximum Temp. at 100 yds. °C</u>	<u>Maximum Temp. at 400 yds. °C</u>	<u>River Flow Rate - cfs</u>
<u>1904-F</u>					
1 ft.	8.4	20.3	15.15	11.4	42,000
10 ft.		21.1	13.8		
<u>1904-DR</u>					
1 ft.	9.1	28.4	13.7	12.5	77,000
10 ft.		24.7	11.5	11.05	
15 ft.		21.45	-	-	
20 ft.		-	-	11.05	

TABLE I.4

REACTOR EFFLUENT PLUME TEMPERATURES

5-14-64

<u>Location and Depth</u>	<u>Upstream Temp. °C</u>	<u>Maximum Bubble Temp. °C</u>	<u>Maximum Temp. at 100 yds. °C</u>	<u>Maximum Temp. at 400 yds. °C</u>	<u>River Flow Rate - cfs</u>
<u>1904-C</u>					
1 ft.	9.35	13.3	10.95		160,000
10 ft.		13.6	11.0		
20 ft.		12.95	10.95		
<u>1904-K (1 reactor only)</u>					
1 ft.	9.1	10.1	9.9		153,000
10 ft.		11.85	9.9		
20 ft.		-	9.9		

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TABLE I.5

REACTOR EFFLUENT PLUME TEMPERATURES

5-25-64

<u>Location and Depth</u>	<u>Upstream Temp. °C</u>	<u>Maximum Bubble Temp. °C</u>	<u>Maximum Temp. at 100 yds. °C</u>	<u>Maximum Temp. at 400 yds. °C</u>	<u>River Flow Rate - cfs</u>
<u>1904-DR</u>					
1 ft.	11.3	14.9	12.6	12.2	237,000
10 ft.		14.5	12.35	12.1	
20 ft.		14.5	12.4	12.0	
<u>1904-H</u>					
1 ft.	11.35	14.1	13.2	12.85	229,000
10 ft.		13.9	13.1	12.6	
20 ft.		13.5	12.85	12.7	

TABLE I.6

REACTOR EFFLUENT PLUME TEMPERATURES

5-26-64

<u>Location and Depth</u>	<u>Upstream Temp. °C</u>	<u>Maximum Bubble Temp. °C</u>	<u>Maximum Temp. at 100 yds. °C</u>	<u>Maximum Temp. at 400 yds. °C</u>	<u>River Flow Rate - cfs</u>
<u>1904-C</u>					
1 ft.	10.45	12.7	11.65	11.4	255,000
10 ft.		13.5	11.65	11.2	
20 ft.		14.0	11.6	11.35	
<u>1904-K</u>					
1 ft.	10.95	12.9	12.95-near side	12.0	241,000
10 ft.		13.45	12.8-near shore	12.0	
20 ft.		13.3	12.7	12.3	

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TABLE I.7

REACTOR EFFLUENT PLUME TEMPERATURES

6-10-64

<u>Location and Depth</u>	<u>Upstream Temp. °C</u>	<u>Maximum Bubble Temp. °C</u>	<u>Maximum Temp. at 100 yds. °C</u>	<u>Maximum Temp. at 400 yds. °C</u>	<u>River Flow Rate - cfs</u>
<u>1904-F</u>					
1 ft.	12.4	14.25	13.3	13.5	338,000
10 ft.		14.25	13.5	13.25	
20 ft.		15.15	13.7	13.25	

TABLE I.8

REACTOR EFFLUENT PLUME TEMPERATURES

8-3-64

<u>Location and Depth</u>	<u>Upstream Temp. °C</u>	<u>Maximum Bubble Temp. °C</u>	<u>Maximum Temp. at 100 yds. °C</u>	<u>Maximum Temp. at 400 yds. °C</u>	<u>River Flow Rate - cfs</u>
<u>1904-B</u>					
1 ft.	16.7	18.75	17.85		192,000
10 ft.		18.95	-		
15 ft.		18.75	17.65		
<u>1904-C</u>					
1 ft.		20.55	18.65	17.95	189,000
10 ft.		20.95	-	-	
15 ft.		19.90	18.4	17.85	
<u>1904-K</u>					
1 ft.	16.8	18.8			189,000
10 ft.		19.5			
15 ft.		20.75			

TABLE I.9

REACTOR EFFLUENT PLUME TEMPERATURES

11-18-64

<u>Location and Depth</u>	<u>Upstream Temp. °C</u>	<u>Maximum Bubble Temp. °C</u>	<u>Maximum Temp. at 100 yds. °C</u>	<u>Maximum Temp. at 400 yds. °C</u>	<u>River Flow Rate - cfs</u>
<u>1904-C</u>					
1 ft.	10.5	16.6	14.4	11.8	87,000
10 ft.		16.2	13.1	11.75	
<u>1904-K</u>					
1 ft.	10.6	22.0			

TABLE I.10

REACTOR EFFLUENT PLUME TEMPERATURES

1-20-65

<u>Location and Depth</u>	<u>Upstream Temp. °C</u>	<u>Maximum Bubble Temp. °C</u>	<u>Maximum Temp. at 100 yds. °C</u>	<u>Maximum Temp. at 400 yds. °C</u>	<u>River Flow Rate - cfs</u>
<u>1904-F</u>					
1 ft.	6.15	15.9	9.55	8.2	~ 105,000
4 ft.		-	-	8.8	
8 ft.		15.45	10.3		
15 ft.		13.65	9.0		

TABLE I.11
REACTOR EFFLUENT PLUME TEMPERATURES

1-21-65

<u>Location and Depth</u>	<u>Upstream Temp. °C</u>	<u>Maximum Bubble Temp. °C</u>	<u>Maximum Temp. at 100 yds. °C</u>	<u>Maximum Temp. at 400 yds. °C</u>	<u>River Flow Rate - cfs</u>
<u>1904-K</u>					
1 ft.	5.45	10.0	9.45	7.85	~80,000
5 ft.		-	8.10	7.00	
10 ft.		10.0	7.50	7.30	
20 ft.		9.95			
<u>1904-D</u>					
1 ft.	6.15	18.25	8.15	7.25	108,000
5 ft.		-	8.3	-	
8 ft.		16.75	8.25	-	
10 ft.				7.2	

TABLE I.12
REACTOR EFFLUENT PLUME TEMPERATURES

2-11-65

<u>Location and Depth</u>	<u>Upstream Temp. °C</u>	<u>Maximum Bubble Temp. °C</u>	<u>Maximum Temp. at 100 yds. °C</u>	<u>Maximum Temp. at 400 yds. °C</u>	<u>River Flow Rate - cfs</u>
<u>1904-N</u>					
1 ft.	3.55	9.05	6.7	5.95	~140,000
10 ft.		8.80	6.0	6.05	
15 ft.		8.0	-	-	
20 ft.		-	6.8	5.9	

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TABLE I.13

REACTOR EFFLUENT PLUME TEMPERATURES

3-26-65

<u>Location and Depth</u>	<u>Upstream Temp. °C</u>	<u>Maximum Bubble Temp. °C</u>	<u>Maximum Temp. at 100 yds. °C</u>	<u>Maximum Temp. at 400 yds. °C</u>	<u>River Flow Rate - cfs</u>
<u>1904-K</u>					
1 ft.	3.80	15.5	10.15	9.35	~45,000
10 ft.		14.95	9.00	8.50	
15 ft.		14.7	9.95		

TABLE I.14

REACTOR EFFLUENT PLUME TEMPERATURES

3-30-65

<u>Location and Depth</u>	<u>Upstream Temp. °C</u>	<u>Maximum Bubble Temp. °C</u>	<u>Maximum Temp. at 100 yds. °C</u>	<u>Maximum Temp. at 400 yds. °C</u>	<u>River Flow Rate - cfs</u>
<u>1904-B</u>					
1 ft.	4.05	14.85			41,000
8 ft.		13.75			
10 ft.		12.5			
on bottom		14.75			
<u>1904-C</u>					
1 ft.	7.15	18.5	11.1	7.65	41,000
7 ft.		-	9.75	7.55	
10 ft.		27.6	-	7.55	

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TABLE I.15
REACTOR EFFLUENT PLUME TEMPERATURES

2-14-66

<u>Location and Depth</u>	<u>Upstream Temp. °C</u>	<u>Maximum Bubble Temp. °C</u>	<u>Maximum Temp. at 100 yds. °C</u>	<u>Maximum Temp. at 400 yds. °C</u>	<u>River Flow Rate - cfs</u>
<u>1904-C</u>					
1 ft.	3.8	15.5	10.15	9.35	115,000

TABLE I.16
REACTOR EFFLUENT PLUME TEMPERATURES

3-31-66

<u>Location and Depth</u>	<u>Upstream Temp. °C</u>	<u>Maximum Bubble Temp. °C</u>	<u>Maximum Temp. at 100 yds. °C</u>	<u>Maximum Temp. at 400 yds. °C</u>	<u>River Flow Rate - cfs</u>
<u>1904-D</u>					
3 ft.	8.7	20.2	13.8	9.8	90,000
10 ft.			12.3		
17 ft.			10.5		

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TABLE I.17

REACTOR EFFLUENT PLUME TEMPERATURES

6-16-66

<u>Location and Depth</u>	<u>Upstream Temp. °C</u>	<u>Maximum Bubble Temp. °C</u>	<u>Maximum Temp. at 100 yds. °C</u>	<u>Maximum Temp. at 400 yds. °C</u>	<u>River Flow Rate - cfs</u>
<u>1904-D</u>					
1 ft.	13.2	18.7	-	14.05	~280,000
<u>1904-K</u>					
1 ft.	12.8	14.6	-	14.15	~280,000

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TABLE II

PLUME TEMPERATURE SUMMARY

<u>Date-Time</u>	<u>River Flow Rate - cfs</u>	<u>Reactor Effluent Temp. °C</u>	<u>Upstream River Temp. °C</u>	<u>Maximum Bubble Temp. °C</u>	<u>Maximum ΔT_0</u>	<u>DF₀</u>	<u>Maximum Temp. at 100yds. °C</u>	<u>Maximum ΔT_{100}</u>	<u>DF₁₀₀</u>	<u>Maximum Temp. at 400yds. °C</u>	<u>Maximum ΔT_{400}</u>	<u>DF₄₀₀</u>
<u>1904-B</u>												
2-11-64/1100	128,000	88.5	4.5	8.5 (1')	4.0	21.						
4-8-64/0930	54,000	94.1	6.45	15.75 (10')	9.3	9.3						
8-3-64/1300	193,000	90.6	16.7	18.95 (10')	2.25	33.						
3-30-65/0700	41,000	89.2	4.05	14.85 (1')	10.8	7.9						
<u>1904-C</u>												
2-11-64/1130	127,000	90.0		9.1 (5')								
4-8-64/1000	54,000	94.6		17.15 (20')	-	-	10.6 (10-20')	-	-	9.45 (1')	3.0	29.
5-14-64/1000	160,000	92.7	9.35	13.6 (10')	4.25	19.	10.95 (1-20')	1.6	52.			
5-26-64/0930	255,000	94.7	10.45	14.0 (20')	3.55	24.	11.65 (1-20')	1.15	72.	11.4 (1')	0.95	89.
8-3-64/1330	189,000	93.0		20.85	-	-	18.65 (1')	-	-	17.95 (1')	1.25	60.
11-18-64/1020	87,000	94.2	10.5	16.6 (1')	6.1	14.	14.4 (1')	2.6	31.	11.8 (1')	1.3	64.
3-30-65/0715	41,000	94.0	7.15	27.6 (10')	20.45	4.2	11.1 (1')	3.95	22.	7.65 (1')	3.6	25.
2-14-66/1215	115,000	89.3	4.6	9.7 (3')	5.1	17.	8.3 (3')	3.7	23.	6.4 (3')	1.8	47.

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TABLE II (Continued)

PLUME TEMPERATURE SUMMARY

Date-Time	River Flow Rate - cfs	Reactor Effluent Temp. °C	Upstream River Temp. °C	Maximum Bubble Temp. °C	Maximum ΔT_o	DF _o	Maximum Temp. at 100yds. °C	Maximum ΔT_{100}	DF ₁₀₀	Maximum Temp. at 400yds. °C	Maximum ΔT_{400}	DF ₄₀₀
<u>1904-K</u>												
4-8-64/1200	71,000	56.0/87.5	7.45	22.2 (10')	14.75	4.5	10.15 (1')	2.7	24.	9.5 (4')	2.05	32.
5-14-64/1300	153,000	90.6	9.1	11.85 (10')	2.75	30.	9.9 (1-20')	0.8	51.			
5-26-64/1230	241,000	92.2/90.9	10.95	13.45 (10')	2.5	32.	12.95 (1')	2.0	40.	12.3 (20')	1.35	60.
8-3-64/1430	189,000	94.9/94.5	16.8	20.75 (15')	3.85	20.						
1-21-65/1030	~80,000	86.1	5.45	10.0 (1-10')	4.55	18.	9.45 (1')	4.0	20.	7.85 (1')	2.40	34.
3-26-65/0700	~45,000	85.2/85.5	3.8	15.5 (1')	11.7	7.0	10.15 (1')	6.35	13.	9.35 (1')	4.70	17.
6-16-66/1300	~280,000	91.5	12.8	14.6 (1')	1.8	44.	-	-	-	14.15 (1')	1.35	58.
<u>1904-D</u>												
7-31-64/1200	140,000	94.5	17.3	27.75 (1')	10.45	7.4						
1-21-65/1300	108,000	81.7	6.15	18.25 (1')	12.1	6.2	8.3 (5')	2.15	35.	7.25 (1')	1.1	69.
3-31-66/1345	90,000	93.2	8.7	20.2 (3')	11.5	7.4	13.8 (3')	5.1	16.5	9.8 (3')	1.1	77.
6-16-66/1100	~280,000	94.7	13.2	18.7 (1')	5.5	15.	-	-	-	14.05 (1')	0.85	96.

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TABLE II (Continued)

PLUME TEMPERATURE SUMMARY

Date-Time	River Flow Rate - cfs	Reactor Effluent Temp. °C	Upstream River Temp. °C	Maximum Bubble Temp. °C	Maximum ΔT_0	DF ₀	Maximum Temp. at 100yds. °C	Maximum ΔT_{100}	DF ₁₀₀	Maximum Temp. at 400yds. °C	Maximum ΔT_{400}	DF ₄₀₀
<u>1904-DR</u>												
4-9-64/1230	77,000	93.8	9.1	28.4 (1')	19.3	4.3	13.7 (1')	4.6	18.	12.5 (1')	3.4	24.
5-25-64/1030	237,000	94.3	11.3	14.9 (1')	3.6	23.	12.6 (1')	1.3	64.	12.2 (1')	0.9	95.
7-31-64/1200	140,000	94.5	18.05	-	-	-	20.35 (1')	2.3	33.	19.90 (1')	1.85	42.
<u>1904-F</u>												
2-11-64/1400	125,000	88.7	-	21.8 (15')								
4-9-64/1000	42,000	89.3	8.4	21.1 (10')	12.7	6.4	15.15 (1')	6.75	12.	11.4 (1')	3.0	27.
6-10-64/1000	338,000	94.1	12.4	15.15 (20')	2.75	30.	13.7 (20')	1.3	63.	13.5 (1')	1.1	71.
1-20-65/1300	~105,000	93.3	6.15	15.9 (1')	9.75	8.9	10.3 (20')	4.15	21.	8.2 (1')	2.05	42.
<u>1904-H</u>												
5-25-64/	229,000	93.7	11.35	14.1 (1')	2.75	30.	13.2 (1')	1.85	44.	12.85 (1')	1.5	53.
<u>1904-N</u>												
2-11-65/1100	~140,000	36.6	3.55	9.05	5.5	6.0	6.8 (20')	3.25	10.	6.05 (10')	2.50	13.

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TABLE III

MINIMUM DILUTION FACTORS -
RIVER FLOWRATE OF 36,000 cfs

<u>Outfall Line</u>	<u>Distance-yds.</u>	<u>DF_{min.}</u>
B	0	7
C	0	5
C	100	17
C	400	37
B-C	400	23
2K	0	4
2K	100	13
2K	400	17
D, DR	0	2
D, DR	100	7
D, DR	400	25

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FIGURE 1
B-C Reactor Effluent River Flow Versus Dilution Factor

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FIGURE 2
KE-KW Reactor Effluent River Flow Versus Dilution Factor

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FIGURE 3
D-DR Reactor Effluent River Flow Versus Dilution Factor

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