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TITLE
ENVIRONMENTAL EFFECTS OF A FUEL ELEMENT FAILURE

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ENVIRONMENTAL EFFECTS OF A FUEL ELEMENT FAILURE

by

R. B. Hall
Environmental Studies and Evaluation
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ENVIRONMENTAL EFFECTS OF A FUEL ELEMENT FAILURE

The failure of a fuel element in one of the process tubes at the KE Reactor on May 12, 1963 resulted in the largest single release of fission products to the river yet experienced at Hanford. The fuel element was zircalloy clad and of experimental design. It was felt that the cause and severity of failure were related to the unusual conditions of exposure of the element in the reactor and that recurrence could and would be avoided.(1) About a pound of uranium was missing when the fuel element was examined after discharge(2) and the measured transport of fission products by the river at the 300 Area support that estimate.

River Water Contamination

A listing of significant events is contained in Table 1. The arrival of the leading edge of the activity, as shown in Figure 1, was observed on the Columbia River Monitor at the 300 Area at 1200 May 12. This time of arrival was in good agreement with an estimate based on a release from KE Reactor beginning at 0120, a river flow rate of about 118,000 cfs (see Table 2), and Soldat's flow time calculations.(3) Soldat's calculations were used to predict the arrival of the leading edge of the activity at Pasco at about 2100 on May 12.

The fission product release was estimated by calculating the abundance of fission products in association with one pound uranium exposed in the neutron flux for the period that the fuel element had been in the reactor. These values, corrected for a decay period of 24 hours, are listed in Table 3 for comparison with the transport estimated on the basis of a cumulative sample taken at the 300 Area. The sample was small for this purpose and the analyses were unusually difficult. The concentrations of nuclides in the sample were corrected to the time of sample pickup and the transport was obtained by multiplication of this value by the total river flow during the sampling period. In view of the analytical difficulties and the limitations of a shoreline sample, the measured transport can be considered little more than confirmation of the calculated estimate. The relationship between the amounts of I-131, Ba-140 and Ru-103 released and estimated in the river is about the same although these elements would be expected to behave quite differently in river isotope depletion processes. The fact that the relationship for Sr-89 + 90 is different may be the result of difficulties experienced in radiochemical analyses. Results for the previous week which is "normal" are shown for comparison.

The results of grab samples taken at 0930 on May 13 are included to show that residual fission products were moving down the river even though the Columbia River Monitor (Figure 1) no longer showed an increase. The cumulative sample taken the following week (May 13 through May 20) indicated that about 20 curies of I-131 had passed the 300 Area but about half of this was from normal reactor effluent releases.

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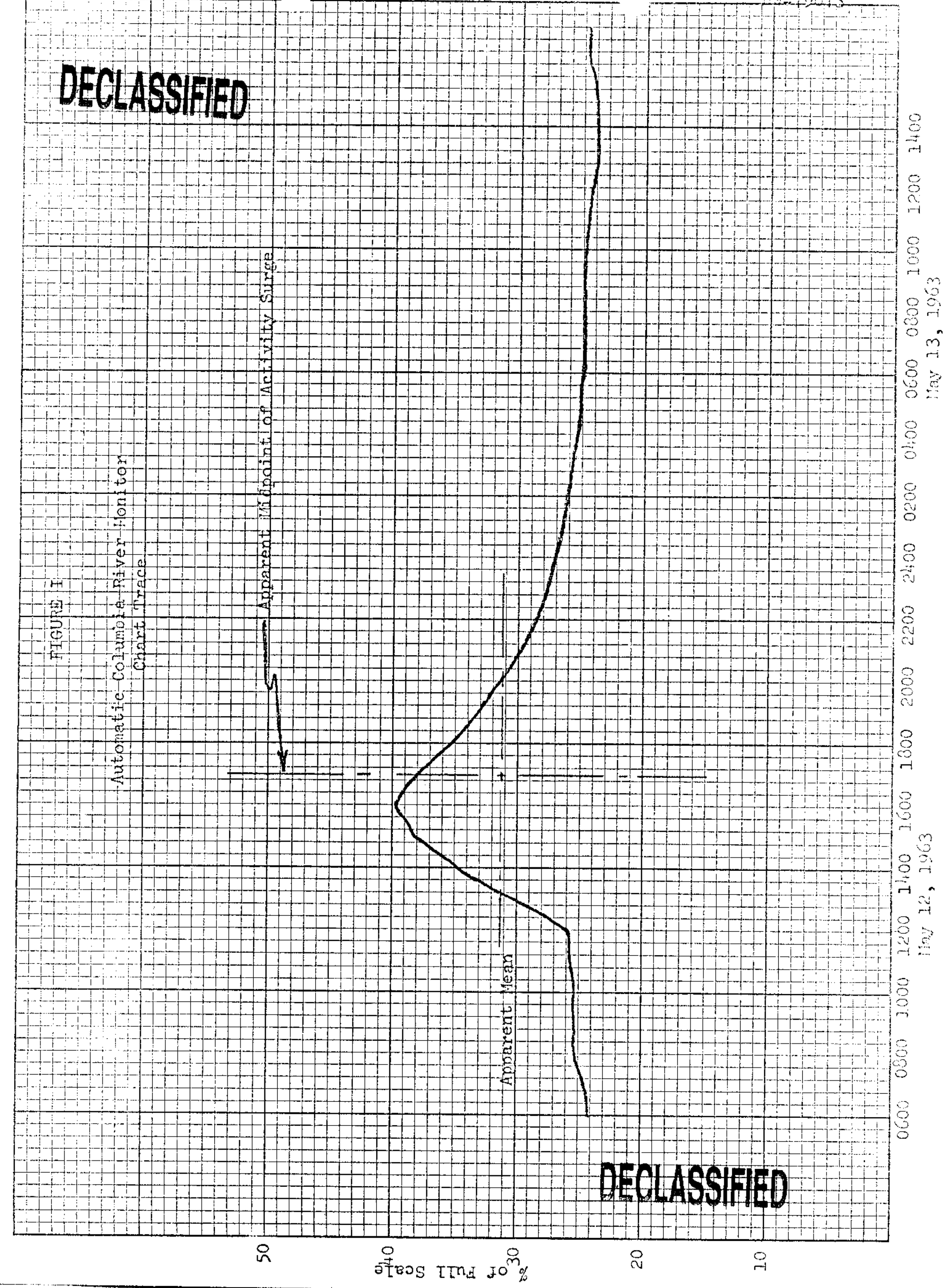
FIGURE I
Automatic Columbia River Monitor
Chart Trace
Apparent Midpoint of Activity Surge
Apparent Mean
0600 0800 1000 1200 1400 1600 1800 2000 2200 2400 0200 0400 0600 0800 1000 1200 1400
May 12, 1963
May 13, 1963
50
40
30
20
10
% of Full Scale

[redacted]

TABLE 1

Chronology of Events

Date	Time	Event
May 12	0100	Abrupt increase on rupture monitors at KE Reactor. Header monitor increased rapidly to full scale. Riser monitor increased to mid-range.
	0120	Estimated beginning of release of fission products to river.
	0140	Reactor shutdown. Corrosion of uranium sharply decreased because of drop in temperature of cooling water around ruptured fuel element.
	0330	Release rate of fission products reduced because flow of cooling water through the reactor reduced.
	1200	Abrupt increase in activity noted on Columbia River Monitor at 300 Area.
	1530-1630	Peak of activity transient about 150% of previous steady state noted on Columbia River Monitor at 300 Area.
	2100	Estimated time of arrival of leading edge of activity transient at Pasco.
	2300	Pasco Water Plant shutdown for the night. (A regular operating plan--not because of the presence of the fission products.)
May 13	0700	Pasco Water Plant resumed operation.
	0830	Routine sample pickup at Pasco for radiochemical analysis. Cumulative sample of river water, grab sample of river water and grab sample of filtered water picked up.
	0930	Routine sample pickup at 300 Area. Cumulative and grab samples of river water picked up.

[redacted]

TABLE 2

Columbia River Flow Rates

(Cubic feet per second)

May 1	122,000	May 16	110,000
2	123,000	17	115,000
3	125,000	18	117,000
4	124,000	19	118,000
5	125,000	20	87,600
6	128,000	21	98,000
7	124,000	22	91,900
8	132,000	23	89,200
9	140,000	24	176,000
10	149,000	25	210,000
11	137,000	26	204,000
12	118,000	27	206,000
13	116,000	28	213,000
14	103,000	29	229,000
15	102,000	30	220,000
		31	225,000

Mean Daily Discharge Below Priest Rapids Dam as reported by USGS, Current Records Center, Portland, Oregon.

[redacted]

TABLE 3

Transport of Fission Products

Columbia River at 300 Area

Radionuclides	Calculated Release 24 Hr. Decay (Curies)	Cumulative Sample 5/6 (0930) - 5/13 (0930) Concentration (pc/l)	Cumulative Sample 5/6 (0930) - 5/13 (0930) Transport (Curies)	Cumulative Sample 4/29 (0930) - 5/6 (0930) Concentration (pc/l)	Cumulative Sample 4/29 (0930) - 5/6 (0930) Transport (Curies)	Grab Samples 5/6 0930 (pc/l)	Grab Samples 5/13 0930 (pc/l)
Sr^{89+90}	180	80	190	6.5	14	5.4	45
Sr^{90}	2	<9	<20	0.56	1.2	0.61	1.4
I^{131}	170	44	100	<5.5	<12	4.7	40
Ba^{140}	360	100	230	7.1	15		
Np^{239}	4300	<3000	<7000			630	2000
R_4^{106}	3	<9	<20				
R_4^{103}	130	30	70				
Zr^{95}	210	70-200	160-470				

[redacted]

Drinking Water Contamination

Except for 100 Area water systems, the fission products were more readily available to the Pasco municipal water system than to any other drinking water supply. The Richland filter plant was not put in service until over a month later, the Kennewick water system uses collector wells which filter the water through several feet of river silt and sand, and other water users were further down stream where greater dilution, radioactive decay and river clean up reduced the availability. Because water usage had not reached its summer peak, the Pasco water plant was in operation only sixteen hours a day.

The time of arrival of the leading edge of the activity surge at Pasco was estimated above at about 2100 on May 12. Based on the amount of I-131 estimated as having passed the 300 Area and the amount of I-131 in the cumulative sample of river water at Pasco, it was estimated that nearly half the activity had passed Pasco by the time the sample was picked up at 0830, May 13. Dispersion in the McNary backwater between the 300 Area and Pasco would have depressed the peak activity and spread the activity surge out over a longer period of time. Therefore, it is not surprising that an amount of activity which passed the 300 Area in a period of four or five hours (Figure 1) would take nearly twelve hours to pass Pasco. It appears that the water plant was shut down most of the time the first half of the activity was going past in the river. It would also appear that the river water grab sample taken at 0830, May 13 must have contained nearly the maximum concentration of fission products. The results of analysis of that sample and a sample of the filter plant output taken at the same time are shown in Table 4. It is obvious that the activity surge had not passed through the water plant in the 3 1/2 hours of operation between the arrival of the activity at about 2100, May 12, and sampling time at 0830, May 13. As much as eight hours operating time might be required for passage of water through the plant. In the absence of better data it was necessary to assume that the maximum concentrations of fission products in the Pasco municipal water were the same as those found in the river water sample. This was a conservative assumption since some of the activity would have been removed by the water treatment process. Although an abnormal concentration of fission products in the sanitary water must have existed for a few days, it is impossible to estimate from information available how long a maximum concentration would have persisted.

Exposure Estimates

Radiation exposure estimates to persons drinking Pasco municipal water were made on the basis of the I-131 concentration measured in the grab sample of river water taken at 0830 on May 13. Because only the fission products Sr-89 + 90 and I-131 were measured in the water sample, concentrations of all other fission products were estimated by assuming that their relative abundance to I-131 was unchanged from that in the fuel element except for radioactive decay. Table 5 shows the radionuclides which could have contributed significantly to exposure from drinking water. Watson's dose conversion factors[4] were used except for the estimates of dose to the GI tract. For the latter, the MPC values in Handbook 69[5] were used according to the following formula:

[redacted]

$$\frac{(1500 \text{ mrem/year})(\text{F.P. Concentration} \times 2.2 \text{ liters})}{(2.2 \text{ liters/day})(365 \text{ days/year})(\text{MPC})} = \text{Dose in mrem}$$

The thyroid dose was estimated for both the 2 gram thyroid of an infant and for the 20 gram thyroid of an adult. The maximum incremental dose to the infant thyroid was about 8 mrem. This is small in comparison with the average annual radiation protection guide of 500 mrem suggested by the FRC.[6] The adult dose estimates were even smaller fractions of appropriate limits.

Thyroid counts were made in the Whole Body Counter on project employees who drank water at work locations downriver from 100K and on several Pasco residents who drank the water during the time the added contamination was in the system. The results are shown in Table 6. None of those who obtained this water on plant was also a resident of Pasco. One of the Pasco residents whose count was below detection level was a child about three years old. Using assumptions published by the ICRP[7] and assuming a 660 pc uptake by an adult, a thyroid burden of 70 pc would have been expected for the Pasco residents. The actual counts tend to confirm all the exposure estimates.

TABLE 4

Radioactivity in Columbia River

and Sanitary Water at Pasco

Radionuclides	Cumulative Sample of River Water 5/6 (0830) - 5/13 (0830) Concentration (pc/l)	Transport (Curies)	Grab Samples River 5/13 (0830) (pc/l)	Sanitary 5/13 (0830) (pc/l)
Total Beta			19,000	3,300
Rare Earths +Y			1,800	80
Na^{24}			1,300	660
P^{32}			200	33
Cr^{51}			2,600	2,600
Cu^{64}			2,000	410
Zn^{65}			540	79
As^{76}			1,300	150
Sr^{89+90}	11	26	400	12
Sr^{90}	0.59	1	4.5	0.41
I^{131}	19	44	310	6.1
Ba^{140}	4.5	10		
Np^{239}			6,300	510

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TABLE 5

Dose Estimates - Pasco Sanitary Water Users

Radionuclide	Concentration (pc/l)	2 gm Thyroid 1 liter Uptake (mrem)	20 gm Thyroid 2.2 liter Uptake (mrem)	Bone 2.2 liter Uptake (mrem)	GI 2.2 liter Uptake (mrem)	Total Body 2.2 liter Uptake (mrem)
Sr^{89}	330			0.22	0.033	0.006
90	3			0.19		0.012
91	120			0.002		
Y^{91}	410				0.055	
93	140				0.019	
Zr^{95}	370				0.025	
97	260				0.055	
Mo^{99}	530				0.011	0.001
Te^{129}	30	0.001				
132	400	0.006		0.002	0.052	0.001
I^{131}	300	5.8	1.3		0.002	0.002
132	410	0.29	0.064			
133	340	1.8	0.4		0.002	
135	60	0.096	0.02			0.004
Cs^{137}	3					0.0003
Ba^{140}	650			0.025	0.089	0.002
La^{140}	680				0.14	
Ce^{141}	520				0.024	
143	420				0.042	
144	110				0.045	
Pr^{143}	660				0.054	
Nd^{147}	270				0.018	
Np^{239}	7800				0.33	
Total Dose		8 mrem	2 mrem	0.5 mrem	1 mrem	0.03 mrem

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TABLE 6

I-131 Burden in Thyroid

Pasco Residents		100 Area Area	100 Area Shift*	Workers
1	80 pc	H	4-12	75 pc
2	72 pc	F	4-12	70 pc
3	38 pc	F	12-8	50 pc
4	28 pc	H	4-12	38 pc
5	BDL	D	12-8	BDL
6	BDL	D	8-4	BDL
		D	4-12	BDL
		F	8-4	BDL
		H	4-12	BDL

BDL - Below Detection Level of about 28 pc for the counting conditions.

*On May 12.

REFERENCES

(1) D. P. O'Keefe - Private Communication

(2) R. Niedner - Private Communication

(3) J. K. Soldat, "Columbia River Flow Time Calculations", HW-58312 Rev July 1, 1962.

(4) E. C. Watson to File, "Dose Conversion Factors", August 21, 1963.

(5) National Bureau of Standards Handbook 69, Maximum Permissible Body Burdens and Maximum Permissible Concentrations of Radionuclides in Air and Water for Occupational Exposure, Issued June 5, 1959.

(6) Federal Radiation Council, Report No. 2, "Background Material for the Development of Radiation Protection Standards", September 1961.

(7) Report of ICRP Committee II on Permissible Dose for Internal Radiation (1959) Health Physics, Vol. 3, June 1960.