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REDUCTION OF THE AMOUNT OF DICHROMATE ADDED TO
REACTOR COOLING WATER - INTERIM REPORT -
PRODUCTION TEST-IP-321-A

By

E. J. Nesselson

June 19, 1961

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INTRODUCTION

Reduced process water treatment costs and incidental benefits of smaller hexavalent chromium discharge to the Columbia River provided incentives to conduct a half-reactor production test⁽¹⁾. The sodium dichromate ($\text{Na}_2\text{Cr}_2\text{O}_7 \cdot 2\text{H}_2\text{O}$) concentration in process water supplied to the far side of 105-C was lowered from a nominal value of 1.8 to 1.0 parts per million (ppm). This test was started September 26, 1960 and is still in progress. However, a sufficient amount of data is available now to permit an interim evaluation of the corrosion effects noted as a result of the change in inhibitor concentration.

SUMMARY AND RECOMMENDATIONS

Eight months have elapsed since the start of a half-reactor production test⁽¹⁾ at 105-C. The dichromate concentration of process water supplied to the far side was lowered to 1.0 ppm, while the water supplied to the near side was maintained at its normal level of 1.8 ppm. On the basis of data available to date, it is tentatively concluded that the reduced concentration does not affect the uniform or pitting corrosion of fuel jackets or the corrosion of aluminum process tubes. Rupture history has been normal and the concentration of chromium-51 in reactor effluent appears somewhat lower. The following course of action is recommended:

1. Continue the half-plant test at C Reactor until final evaluation of effects can be made. This may take an additional six months to one year.
2. Reduce the dichromate concentration at all other IPD reactors to 1.0 ppm, if the process water pH is 7.0 / .1. Inasmuch as the process water corrosivity is unknown at both reduced pH and reduced inhibitor concentration, a combined change is not desirable, now. Small-scale in-reactor testing combining these two revised water quality conditions should be evaluated by the first quarter of CY-1962.

CONDUCT OF THE TEST

Twelve columns of weighed CIIN metal were charged in ribbed aluminum process tubes (six on the near side of 105-C and six on the far side) and scheduled for variable goal exposure. Several columns of weighed CIVNS metal charged under FT-IP-272⁽²⁾, and placed in ribless zirconium tubes two weeks after the start of this test, fulfilled the test⁽¹⁾ provision that corrosion effects on self-supported fuel be evaluated also. Each ribbed aluminum tube charged with test metal was probologged before loading and again after the test metal was discharged or after a subsequent cycle of metal was irradiated.

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- (1) HW-65189, "Reduction of the Amount of Dichromate Added to Reactor Cooling Water, Production Test - IP-321-A", E. J. Nesselson, May 11, 1960, (Secret).
 - (2) HW-61669 C, "Production Test-IP-272-A, Pilot Test of Self-Supported Fuel Elements in Ribless Zirconium Process Tubes", R. E. Hall, August 27, 1959, (Secret).

RESULTSA. Fuel Element Weight Loss

Tabulations of weight loss of CIIN and CIVNS fuel elements versus position from the rear of the charge are presented in Tables I, II, III and IV.

1. Metal Exposure In Ribbed Aluminum Tubes

Table I shows tube operating conditions and fuel element weight loss for four metal columns cooled with process water containing 1.8 ppm sodium dichromate ($\text{Na}_2\text{Cr}_2\text{O}_7 - 2\text{H}_2\text{O}$). Table II shows similar type data for four metal columns cooled with process water containing 1.0 ppm sodium dichromate. One notes that the average of eight pieces of weight loss data in Table I for each charge ranges from 2.10 to 3.17 grams/slug for metal located on the control side of the reactor (cooled with water containing 1.8 ppm dichromate); and, that the average for an equal number of pieces of data in Table II ranges from 1.76 to 3.22 grams/slug for metal located on the test side of the reactor (cooled with water containing 1.0 ppm dichromate).

These data are depicted graphically in Figure 1. The curves drawn thereon pass through average weight loss values for fuel elements at a given position from the rear of the charge. The variation in plotted weight loss values is greatest in the actively-corroding portion of the tube; i.e., slug positions 9, 11, and 13. Variation from the mean, however, in charges cooled with water containing different dichromate concentrations (3.92 - 3.03 for slug No. 13, Figure 1), is a maximum of 0.89 grams/slug. This difference is regarded as being insignificant, particularly since tube powers and metal exposures are comparable (refer to Tables I and II). For orientation purposes, the equivalence between weight loss and uniform corrosion penetration of the aluminum jacket is as follows:

Slug Designation:	CIIN
Nominal Length:	8 inches
Can:	OD of 1.464" = 1.87 grams/mil
Spire:	ID of 0.375" = 0.48 grams/mil

Thus, a difference of 0.89 gram represents a difference in uniform corrosion penetration of 0.38 mil ($\frac{.89}{1.87 - .48}$). Perhaps the most

extreme test of how significant a difference in weight loss may be between fuel elements cooled with 1.8 or 1.0 ppm dichromate water, assuming that weight loss values translated to uniform corrosion penetration is a meaningful conversion, is to determine the largest maximum-minimum deviation for fuel elements cooled with water at the two inhibitor concentrations under examination where the slug contacted with 1.0 ppm water has a higher weight loss than that cooled with 1.8 ppm water. This extreme is observed in Figure 1 at slug position 13; it amounts to 2.60 grams (4.76 - 2.16), which represents an additional uniform penetration of 1.10 mils (2.60/2.35).

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TABLE I

TUBE OPERATING CONDITIONS & WEIGHT LOSS (GRAMS), CIIN FUEL

Reactor Side & Dichromate Concentration:	Near - 1.8 ppm			
Tube Number	<u>2157-C</u>	<u>2159-C</u>	<u>2561-C</u>	<u>3264-C</u>
Fuel Element Series	43W	40W	37W	46W
Time of Exposure, days above 90°C	54	54	54	54
Average Tube Power, KW	1055	1030	1000	1010
Average Tube Outlet Temperature, °C	96	94	95	92
Average Tube Inlet Temperature, °C	14	14	14	14
Average Coolant Flow Rate, gpm	51	51	52	51
Exposure, MWD/E	572	564	573	545

<u>Slug No. From Rear</u>	<u>2157-C</u> <u>ΔW</u>	<u>2159-C</u> <u>ΔW</u>	<u>2561-C</u> <u>ΔW</u>	<u>3264-C</u> <u>ΔW</u>	<u>Average, 4 values</u>
1	0.79	1.00	1.29	0.93	1.00
3	1.31	1.37	1.80	1.59	1.52
5	2.21	1.94	3.23	2.50	2.47
9	5.10	4.34	4.67	3.67	4.44
11	5.99	4.80	5.05	3.69	4.88
13	4.71	4.88	----	2.16	3.92
15	3.25	2.67	2.85	1.20	2.49
17	2.01	2.07	2.14	1.06	1.81
Average	3.17	2.88	3.00	2.10	

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TABLE II

TUBE OPERATING CONDITIONS AND WEIGHT LOSS (GRAMS), CIIN FUEL

Reactor Side and Dichromate Concentration:

Tube No:

Far - 1.0 ppm

	<u>3287-C</u>	<u>3383-C</u>	<u>2279-C</u>	<u>2284-C</u>
Fuel Element Series	38W	41W	42W	44W
Time of Exposure, Days above 90 C	54	54	54	54
Average Tube Power, kw	1050	1065	1035	1070
Average Tube Outlet Temperature, °C	94	93	94	95
Average Tube Inlet Temperature, °C	14	14	14	14
Average Coolant Flow Rate, gpm	52	53	52	52
Exposure, MWD/T	571	581	570	584

<u>Slug No. From Rear</u>	<u>3287-C</u> <u>Δ W</u>	<u>3383-C</u> <u>Δ W</u>	<u>2279-C</u> <u>Δ W</u>	<u>2284-C</u> <u>Δ W</u>	<u>Average, 4 values</u>
1	0.71	1.08	1.13	1.05	0.99
3	1.68	1.49	1.50	1.73	1.60
5	2.58	2.16	2.72	3.01	2.62
9	5.19	2.77	5.61	5.90	4.85
11	4.57	2.73	4.91	6.05	4.55
13	3.12	1.81	3.42	4.76	3.03
15	1.74	1.08	1.89	2.37	1.77
17	1.78	1.01	1.06	0.90	1.18
Average	2.67	1.76	2.78	3.22	

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FIGURE 1

SLUG WEIGHT LOSS VS. POSITION IN FUEL CHARGE AS A
FUNCTION OF INHIBITOR CONCENTRATION

2. Metal Exposed in Ribless Zirconium Tubes

Table III shows tube operating conditions and fuel element weight loss for four columns of CIVNS cooled with process water containing 1.8 ppm dichromate. Table IV shows similar type data for one column of fuel cooled with process water containing 1.0 ppm dichromate, and three columns of fuel cooled with process water where the dichromate concentration is uncertain, but probably 1.4 ppm (average of 1.8 and 1.0). One notes that the average of nine pieces of weight loss data in Table III for each charge ranges from 7.24 to 12.65 grams/slug for control metal. The average for nine pieces of data for tube 2289-C in Table IV is 11.44 grams/slug. It is noted in scanning Tables III and IV that the highest weight loss values are associated with slug position 7. A rigorous comparison of the maximum difference in weight loss, where the loss in weight of the test slug is greater than the loss in weight of the control slug, is noted in tubes 2289-C and 3869-C. These values are 19.03 and 12.57 grams, respectively. For a CIVNS element, the equivalence between weight loss and uniform corrosion penetration of the aluminum jacket is as follows:

Can: OD of 1.500" = 1.912 grams/mil
 Spire: ID of 0.378" = 0.481 grams/mil

Thus, an extreme weight difference of 6.46 grams (19.03 - 12.57) represents an additional uniform penetration of 2.7 mils ($\frac{6.46}{1.91 + 0.48}$). This difference, if real and reasonable, is not regarded as being particularly significant.

3. Agreement Between Predicted and Observed Weight Loss

Figure 2 is a plot of predicted versus observed weight loss for four selected columns of metal: 2 - CIIN at both dichromate concentrations and 2 - CIVNS at both dichromate concentrations. The predicted values were calculated in the following manner.

- Obtain slug heat flux and surface temperature for hole and annulus.
- Calculate a corrosion rate therefrom for hole and annulus.
- Convert corrosion rates to grams lost, knowing fuel dimensions and residence in-reactor.

It is noted that most of the observed weight losses, irrespective of inhibitor concentration, fall within .5 to 1.0 times the predicted weight losses. This level of agreement is within an acceptable range for slug corrosion. The nine pieces of data where observed values are less than half as much as predicted values are evenly divided between slugs contacted with water containing the two inhibitor concentrations - five with 1.0 ppm and four with 1.8 ppm dichromate. Of those values above the perfect agreement line, four of the six represent control fuel elements. It is inferred therefore, that the data presented in Figure 2 do not indicate greater corrosion was experienced by the test fuel elements than that experienced by the control fuel elements.

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TABLE III

TUBE OPERATING CONDITIONS AND WEIGHT LOSS (GRAMS), CIVNS FUEL

Reactor Side and Dichromate Concentration:	Near - 1.8 ppm			
Tube No.:	<u>1069-C</u>	<u>2264-C</u>	<u>3467-C</u>	<u>3869-C</u>
Fuel Element Series	55W	59W	54W	85U
Average Tube Power, kw	770	1140	1140	1070
Average Coolant Flow Rate, gpm	50	49	49	49
Exposure, MWD/T	836	769	773	853

<u>Slug No. From Rear</u>	<u>1069-C</u> <u>ΔW</u>	<u>2264-C</u> <u>ΔW</u>	<u>3467-C</u> <u>ΔW</u>	<u>3869-C</u> <u>ΔW</u>	<u>Ave., 4 values</u>
1	--	--	3.57	7.75	5.7
3	13.96	11.55	11.62	3.94	10.3
5	17.75	14.36	16.67	9.21	14.5
7	20.32	15.93	17.75	12.57	16.6
9	18.23	13.91	19.08	10.87	15.5
11	16.10	14.14	12.27	9.41	13.0
13	8.42	10.94	7.63	6.11	8.3
15	4.30	7.45	3.88	3.89	4.9
17	2.13	--	1.84	1.97	2.0
Average	12.65	12.61	10.45	7.24	

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TABLE IV
TUBE OPERATING CONDITIONS AND WEIGHT LOSS (GRAMS), CIVNS FUEL

Reactor Side and Dichromate Concentration	Far - 1.0 ppm	Middle - Between 1.8 & 1.0 ppm		
Tube No.	<u>2289-C</u>	<u>3873-C</u>	<u>3874-C</u>	<u>1076-C</u>
Fuel Element Series	53W	57W	58W	56W
Average Tube Power, KW	1125	660	1170	1140
Average Coolant Flow Rate, gpm	49	48	54	48
Exposure, MWD/T	856	774	884	866

Slug Number From Rear	<u>2289-C</u>	<u>3873-C</u>	<u>3874-C</u>	<u>1076-C</u>	Average, 3 values
	<u>Δ W</u>	<u>Δ W</u>	<u>Δ W</u>	<u>Δ W</u>	
1	3.26	10.36	2.82	15.66	9.6
3	6.80	16.18	8.42	17.47	14.0
5	17.30	---	14.24	20.28	17.3
7	19.03	21.23	13.08	22.05	18.7
9	18.53	21.59	12.66	17.41	13.9
11	16.97	16.83	9.86	11.23	12.6
13	10.84	7.68	6.11	5.70	6.5
15	6.54	3.99	3.10	---	3.6
17	3.74	1.90	2.34	1.93	2.1
Average	11.44	11.03	8.07	13.96	

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FIGURE 2

AGREEMENT BETWEEN PREDICTED & OBSERVED WEIGHT LOSS FOR SELECTED CHARGES OF FUEL ELEMENTS COOLED WITH PROCESS WATER AT TWO CORROSION INHIBITOR CONCENTRATIONS

●-2157-C (Loaded With CIN) 1.0 ppm Dichromate
 ●-2279-C (Loaded With CIN) 1.0 ppm Dichromate
 ▲-1069-C (Loaded With CIN) 1.8 ppm Dichromate
 ▼-2239-C (Loaded With CIN) 1.0 ppm Dichromate

B. Visual Examination of the Weighed Fuel

In general, light to moderate localized attack was apparent on the surface of all fuel elements. This attack was limited principally to the fuel elements located in the downstream portion of the tube, and took the form of:

1. Shallow and scattered pitting; the pitting frequency was equal for fuel elements on the test side and the control side of the reactor, and
2. Occasional hot spots that suggest fuel misalignment.

C. Aluminum Process Tube Corrosion

The results of in-reactor probologging for eight of the twelve tubes charged with weighed metal are given in Table V. It is noted that, with the data available, the indicated corrosion rates on the control side of the reactor range from 0.0 to 12.8 mils/year, and those on the test side of the reactor range from 0.0 to 9.6 mils/year. It must be recognized that interpretation of a probolog trace is somewhat of an art, and a minimum wall thickness measurement can deviate from a true value by as much as 3 mils. Inasmuch as the largest change in remaining wall thickness is 4 mils (tube 1158-C) and this change took place on the control side of the reactor, it would appear as though no greater corrosion rate has occurred or has yet been detected on the test side of the reactor. Recently, a practice was instituted to report 105-C probolog results in a more detailed manner; i.e., wall thickness at short intervals between 8½ and 16 feet from the rear VanStone flange (RVSF). Data for four tubes (two from each side of the reactor) for which recent measurements are available are shown in Figures 3, 4, 5, and 6. It is noted in interpreting these figures that the point of minimum wall thickness has shifted upstream in the tube from its previous position; this phenomenon is evident in both control tubes and test tubes. For instance, in Figure 3, the minimum wall thickness in tube 3561-C (a control tube) was 45 mils on 9-24-60 and this measurement extended for the entire distance between 8½ and 15½ feet from the RVSF. Probolog measurements performed on 1-16-61 indicate that the minimum wall thickness extends from 14½ to 16½ feet from the RVSF, and indeed, may really be from 12½ to 20 feet from the RVSF. Similar type conditions are shown in the remaining figures. These data indicate that a cause other than the inhibitor concentration is responsible for the upstream shift in the point of minimum wall thickness.

D. Rupture History Since Start of Test

Table VI lists the number, location, and type of fuel failures that have occurred since the test began. It is noted that six failures were experienced; three on the control side, one on the test side, and two in the middle. Deichman(3) reports an average old reactor rupture incidence of 12 to 15 per

(3) HW-67741, "Causes of Reactor Shutdowns", J. L. Deichman, December 19, 1960, (Secret).

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TABLE V

IN-REACTOR MEASUREMENT OF PROCESS TUBE CORROSION - C REACTOR

(All tubes charged with weighed metal - 9/23/60)

Tube No.	Location In-Reactor and Dichromate Concentration	Month and Year Installed	Probolog Measurements* on Charging PT-321		Probolog Measurements on or after Discharge of Metal		Time Elapsed, Years	Corrosion Mils/Year
			Date	Wt/Mils	Date	Wt/Mils		
1158	Near - 1.8 ppm	11/18/52	9/24/60	46	1/16/61**	42	.313	12.8
2157	" "	"	"	46	3/2/61***	43	.433	6.9
2159	" "	"	"	43	"	43	.433	0
2561	" "	"	"	44	N.Y.R.			
3264	" "	"	"	45	3/2/61***	44	.433	2.3
3561	" "	"	"	45	1/16/61**	42	.313	9.6
1190	Far - 1.0 ppm	11/18/52	9/24/60	43	1.16/61**	42	.313	3.2
2279	" "	"	"	44	3/2/61***	44	.433	0
2284	" "	"	"	41	N.Y.R.			
3287	" "	"	"	42	N.Y.R.			
3383	" "	"	"	43	N.Y.R.			
3589	" "	"	"	46	1/16/61**	43	.313	9.6

* HW-66923, "In-Reactor Measurements of Process Tube Corrosion, C-Reactor, Report 51", by D. E. Strege, dated September 28, 1960 (Unclassified).

** HW-68231, "In-Reactor Measurements of Process Tube Corrosion, C-Reactor, Report 7", by D. E. Strege, dated January 23, 1961 (Unclassified).

*** HW-68723, "In-Reactor Measurements of Process Tube Corrosion, C-Reactor, Report 17", by D. E. Strege, dated March 2, 1961 (Unclassified)

N.Y.R. - Not yet re-probologged.

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FIGURE 3

RESIDUAL WALL THICKNESS OF PROCESS TUBE 251-C

Remaining Wall Thickness, Mils.

— Tube Probologged 9-24-60
- - - Tube Probologged 1-16-61

FIGURE 4

RESIDUAL WALL THICKNESS OF PROCESS TUBE 2157-C

Remaining Wall Thickness, Mils

FIGURE 5

RESIDUAL WALL THICKNESS OF PROCESS TUBE 1190 C

Remaining Wall Thickness, Mils

———— Tube Probologged 9-24-60

- - - - - Tube Probologged 1-16-61

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RESIDUAL WALL THICKNESS, MILS

RESIDUAL WALL THICKNESS, MILS

— Tube Probable 9-24-60
--- Tube Not Logged 2-26-61

Distance From Root, Ft.

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TABLE VI

RUPTURE HISTORY AT 105-C SINCE START OF TEST

<u>Failure Date</u>	<u>Tube No.</u>	<u>Remarks</u>	<u>Reactor Side</u>
10-9-60	1656-C	Hole Failure	Control
11-6-60	2180-C	Hole Failure	Test
12-14-60	0957-C	Hole Failure	Control
12-25-60	2276-C	Second Generation Tube with High Ribs (has had history of several ruptures)	Middle
2-2-61	3275-C	Hole Failure	Middle
2-25-61	2361-C	Annular Failure	Control

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year. The experience at 105-C has been of this magnitude. It is noted, in addition, that four of the six ruptures were hole failures; in general, a hole failure is regarded as fuel quality oriented, and should have little relation to the water quality, if the quality is acceptable.

Rupture history may not be too meaningful a measure upon which to base the evaluation of a change in inhibitor concentration, particularly if rapid evaluation is desired. If one established, before testing, that the results of testing would not be unfavorable until twice as many failures occurred on the test side as on the control side of the reactor, a total of 45, (30 test and 15 control) would be required before one was certain the failure rate was caused by the change being evaluated.⁽⁴⁾

It is inferred, therefore, that too small a number of ruptures have occurred to permit an assessment of rupture incidence as a function of inhibitor concentration.

E. Chromium-51 In Reactor Effluent

Table VII lists the chromium-51 concentration in picocuries per milliliter in effluent samples obtained from the 107 basin, and the near and far-risers at 105-C. It is noted that a few of the riser samples are "flyers"; however, when the numbers are high, they are consistently higher on the near (control) side of the reactor - and if these values indicate a non-standard condition in the reactor at the time of sampling, a greater reservoir of Cr-51 probably existed on the control side in order that a greater purge or release could be detected. Based on the averages shown for both groups of riser samples, one is inclined to speculate that a reduction in process water dichromate level results in a modest, if not equal, reduction in effluent Cr-51 levels. This speculation may be confirmed as additional data became available.

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(4) HW-66830, "PITA-IP-12-I, Evaluation of Aluminum Components From Alternate Vendors", R. D. Saimer, September 20, 1960, (Secret)

TABLE VII
CONCENTRATION OF Cr-51 IN REACTOR EFFLUENT - 105-C, pc/ml.

<u>Date</u>	<u>SAMPLING LOCATION</u>		
	<u>Near Riser</u>	<u>107-Basin</u>	<u>Far Riser</u>
9-12-60		410	
10-3-60		310	
11-28-60		440	
12-19-60		310	
1-3-61	19,000		5,800
1-9-61	280		340
1-16-61	1,700		1,400
1-23-61	410		730
1-30-61	----		----
2-6-61	2,600		1,500
2-13-61	280		340
2-20-61	190		180
Average	~3,500	370	~1,500
Average, minus data of 1-3-61	~900		~750

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