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SUBJECT: Analysis of the Status of Chromium In
Solution Under In-Pile Conditions

TO: G. H. Jenks 6329

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The data presented in this memo have evolved from the in-pile corrosion program as a result of the concerted effort of all the members of the in-pile corrosion group of the Homogeneous Reactor Project. Although the data has been accumulating since the inception of this program, this constitutes the first attempt to assemble and interpret the chromium data with the view of determining the chromium species present in solution under in-pile conditions.

Allen¹ claims chromate in acid solution (presumably existing as dichromate) is reduced to chromic ion under irradiation, but that increasing the pH to the alkaline side completely reverses the reaction. Others^{2,3} have shown that the reduction of dichromate under irradiation involves reaction with some product resulting from the irradiation of water. More recently Hochanadel and Davis⁴ have studied the reduction of chromate by radiation under a variety of conditions, some of which closely approximate those in the in-pile loops. They found that under some conditions chromate was reduced upon irradiation and proposed the following steps in the mechanism for the reduction:

The rate of reduction was found to be greater in solutions saturated with hydrogen than in those saturated with O_2 . The addition of CuSO_4 to the solution increased the rate of reduction at high temperatures. This effect was explained by the catalytic activity of CuSO_4 on the reduction of chromate.

The proposed mechanism was the initial reduction of cupric ion by the hydrogen with the cuprous ion then reducing the chromate.

At the higher temperature (250°C) the thermal reduction as catalyzed by the CuSO_4 proceeded much more rapidly than the radiation produced reduction.

Halpern⁵ has shown that dichromate may be reduced in the absence of radiation by hydrogen in the presence of a copper salt catalyst. The kinetics of this reaction suggest that only one hydrogen molecule and one copper ion participate in the rate determining step and that the rate of reduction is independent of the chromium concentration. According to Halpern the mechanism is a two step process with the rate controlling step entailing the displacement of a hydride ion from the hydrogen molecule to the catalyst.

Both Halpern⁵ and Allen⁶ have noted an inefficiency of the reduction process in solutions containing high sulfuric acid concentrations. Allen attributes this effect to removal of radicals by the action of the acid,

while Halpern explains it in terms of competition from the back reaction,

Hochanadel and Davis further found that with oxygen saturated chromic solutions complete oxidation to chromate was achieved under irradiation at 25°C. High temperatures promoted the oxidation, and the rate of reduction of chromate in solutions containing both hydrogen and oxygen was less than in

those with only hydrogen. This indicates that under in-pile conditions one may observe either oxidation or reduction or both simultaneously depending on the gases present in the solution.

Tables 1 through 19 present data from previous in-pile bomb and loop experiments pertinent to an analysis of chromium behavior in these systems. The bomb data include only the stainless steel bombs and those Zircaloy bombs which contained steel or high chromium specimens or to which chromium was initially added. All the loop experiments are included since steel was present in large amounts in all of these.

Both initial and final solution concentrations are given for the loops. The final sulfuric acid concentration is not given in the case of the bombs since it is usually obtained by an ionic balance and is subject to considerable uncertainty. The solution pH is a measure of the acid concentration for both the loops and the bombs although in the case of the loops some dilution of the samples may have occurred and no correction has been made for such dilution. Average power densities for the loops are calculated for the loop as a whole.

These data do not necessarily give the true amounts of corrosion products in solution in the loops since corrosion in the sampling lines might account for a portion of the sample contents. The bombs are free of this complication since no sampling lines are involved. However, in both the bombs and loops the possibility exists that the iron and chromium found may be in the colloidal state rather than in solution. Other factors which may cause error in these determinations are the possible sorption of the ionic species by the oxide film and the volatilization of the chromium in the bomb precipitates as chromyl chloride during the dissolution process. Furthermore, the

solutions after removal from the loops or bombs may not have entirely the same constitution as during its in-pile exposure at a higher temperature. With these limitations on the data, one can only speculate as to the true situation from some of the more obvious results.

Loop GG had 320 ppm chromium initially added to the solution as CrO_3 which would form dichromate in the acid solution. During the course of the run the chromium concentration dropped from an initially high value to a low, reasonably constant value. Loop DD with 100 ppm as CrO_3 initially also showed a similar gradual decrease over a period of time. In-pile bomb Z-8 showed a decrease from 189 to 97 ppm chromium in 368 hours of operation. These results indicate that dichromate is apparently being lost from the solution during the course of a run. It is possible that this loss occurs by reduction of the chromium + 6 followed by hydrolysis of the chromic ion to an insoluble form. One possibility would be hydrolysis to the hydrous chromic oxide which becomes insoluble in acids when heated⁷.

Other correlations may be made with the existing data if one accepts the above model for chromium behavior, namely that both oxidation and reduction may occur in solution with higher temperature promoting oxidation and loss of chromium from solution being a result of the reduction of chromium + 6 followed by hydrolysis of chromium + 3. For instance, loop L-2-14 showed an increase in chromium concentration during the course of the run as compared to a decrease or slightly fluctuating value for most other loops. Since the loop was 0.42 m in H_2SO_4 , reactions (9) and (10) or (11) might account for a decrease in the rate of reduction of chromium + 6 while the corrosion of the steel in the system would be promoted. Therefore, one

might expect this net increase in chromium. Other loop experiments exhibit a rough proportionality between the average chromium concentration and the H_2SO_4 concentration although not as strikingly as loop L-2-14.

More general trends in the chromium behavior as related to certain variables must be sought due to the difficulty encountered in separating the effects of these variables. Although some ambiguity arises from this approach, the following correlations are offered in further support of the proposed model.

Experiments which were run at high temperatures show, on the average, more chromium in solution than those run at lower temperatures. Furthermore, loop samples taken with the reactor at power show less chromium in solution than those taken with the reactor down. As previously mentioned, the high temperature should promote chromium + 6 formation; and the rate of reduction, controlled by the hydrogen or radical concentration, should decrease as the reactor power level decreases.

In regard to power density another interesting correlation may be noted. Under steady state conditions in the loops the hydrogen concentration is given as,

$$[H_2] = \frac{K_1}{K_m [Cu^{++}]} \quad (12)$$

where K_1 is the rate of hydrogen production, K_m is the molar rate constant for the copper catalyzed recombination of radiolytic gas, and $[Cu^{++}]$ is the copper ion concentration. If both reduction of chromium + 6 and gas recombination proceed according to Halpern's mechanism one may write for the reduction of dichromate in the solution,

$$-\frac{d[Cr_2O_7^{2-}]}{dt} \propto K_m [H_2] [Cu^{++}] \quad (13)$$

Substituting for the steady state hydrogen concentration in equation (13)

one obtains

$$-\frac{d[\text{Cr}_2\text{O}_7^{2-}]}{dt} \propto K_1 \quad (14)$$

or in other words the rate of reduction of chromium + 6 should be proportional to the solution power density. Table 19, however, shows that the trend is for the chromium concentration to be higher the higher the average core power density. This would seem to indicate, at first thought, that chromium + 3 may be the stable form in solution. On the other hand, it may be that the only function of increased power density is to promote corrosion and thereby increase the chromium concentration no matter what to stable form may be.

In four loop experiments, DD; L-4-8, L-2-15, and L-4-18, approximately equal average amounts of iron and chromium were found in solution. However, the other loops do not exhibit this agreement and there appears to be no well defined relation between these two corrosion products. Although the data presented does not conflict with the proposed model, it does not conclusively show that this is the true situation existing in the in-pile solutions. It should be noted that other interpretations may be placed on the same data. In fact, if the iron found in these solutions is iron + 3, a similar solubility might be expected for chromium + 3. It may well be that both oxidation states of chromium exist in in-pile solutions simultaneously. For conclusive evidence as to the nature of the chromium in such solutions, experiments specifically designed for this purpose would probably have to be conducted.

Table 1 Zircaloy In-Pile Bomb Data

Bomb Designation	Dates In and Out	Solution Concentrations Before and After						Temperature (°C)	Exposure Time (hr)	Solution Power Density (w/ml)	Chemical Analyses					
		Exposure					Fe				Cr		Ni			
		UO ₂ SO ₄ (m)	CuSO ₄ (m)	H ₂ SO ₄ (m)	Other (ppm)	pH	Soln. (γ/ml)				Ppt. (γ/tot.)	Soln. (γ/ml)	Ppt. (γ/tot.)	Soln. (γ/ml)	Ppt. (γ/tot.)	
Z-5	3/10/55	0.17	0.02	0.0	--	2.40	250	427.2	4.5	3	--	--	--	103	--	
	4/2/55	0.17	0.01	--	--	1.90	280	69.6	4.3							
Z-8	2/9/55	0.18	0.02	0.05	189 Cr	1.20	250	368.2	11.4	0	25	97	66	46	26	
	3/1/55	0.19	0.01	--	97 Cr	1.50										
Z-9	4/14/55	0.17	0.007	0.0	--	2.40	250	101.3	7.9	0	35	4	83	40	14	
	4/22/55	0.17	0.001	--	--	1.85	280	58.9	7.5							
Z-18	5/1/56	0.04	0.06	0.04	670 Cr	1.25	280	158.9	4.9	11	--	62	--	19	--	
	5/9/56	0.03	0.04	--	61 Cr	1.40										
L62-104	6/4/57	0.17	0.03	0.03	--	1.30	250	20.5	8.5	0	680	145	154	384	36	
	6/17/57	0.14	0.01	--	--	2.30	280	256.3	8.0							
L62-106	5/7/57	0.17	0.03	0.06	--	1.05	280	180.5	8.1	173	480	128	83	478	30	
	5/19/57	0.17	0.02	--	--	1.60										
L62-112	7/9/57	0.17	0.03	0.06	--	1.05	280	279.4	8.9	62	100	113	0	152	90	
	7/26/57	0.13	0.01	--	--	2.90										

Table 2 Stainless Steel In-Pile Bomb Data

Bomb Designation	Dates In and Out	Solution Concentrations Before and After					pH	Temperature (°C)	Exposure Time (hr)	Solution Power Density (w/ml)	Chemical Analyses					
		Exposure				Fe Soln. (γ/ml)					Fe Ppt. (γ tot.)	Cr		Ni		
		UO ₂ NO ₃ (m)	CuSO ₄ (m)	H ₂ SO ₄ (m)	Other (m)							Cr Soln. (γ/ml)	Cr Ppt. (γ tot.)	Ni Soln. (γ/ml)	Ni Ppt. (γ tot.)	
H-93	7/26/55 9/7/55	0.17 0.17	0.01 0.01	0.03 --	-- --	1.50 2.65	250	522	7.4	7	--	17	--	1818	--	
H-94	9/27/55 11/15/55	0.18 0.25	0.01 0.009	0.03 --	-- --	1.50 --	250	769	8.4	667	6250	240	0	1466	0	
H-95	12/8/55 2/2/56	0.04 0.04	0.05 0.06	0.02 --	-- --	1.20 1.85	250 280	530 ^{1/2} 545	2.4	17	6	364	32	624	58	
H-96	2/14/56 3/20/56	0.17 0.12	0.01 0.01	-- --	0.0011 K ₂ Cr ₂ O ₇ --	2.40 3.50	250	604	10.6	5	6960	101	70	234	465	
H-97	8/7/56 9/5/56	0.17 0.16	0.04 0.04	0.03 --	0.17 MgSO ₄ --	1.50 1.85	250	580	6.6	31	6250	57	26	375	37	
L68-103	12/18/56 1/8/57	0.17 0.16	0.01 0.01	0 --	-- --	2.50 3.00	250	897	6.5	6	430	366	0	284	26	

Table 3. In-Pile Loop DD Data

Sample Number	Hours of Operation	Chromium Concentration (γ /ml)	Nickel Concentration (γ /ml)	Iron Concentration (γ /ml)	pH	Reactor Status (U-Up) (D-Down)
1	2	70	--	--	--	D
2	13	68	--	--	--	"
3	23	61	--	--	--	"
4	29	61	--	--	--	"
5	52	47	--	--	--	"
6	73	40	--	--	--	"
7	95	18	--	--	--	"
8	120	3	92	--	--	"
9	193	15	134	24	--	"
10	289	15	296	18	--	"
11	436	19	408	20	--	"
12	466	41	392	26	--	"

Solution Concentrations:

UO_2SO_4	0.17 <u>m</u>	0.17 <u>m</u>
CuSO_4	0.03 <u>m</u>	0.03 <u>m</u>
H_2SO_4	0.0085 <u>m</u>	0.0 <u>m</u>
CrO_3	0.002 <u>m</u>	0.0005 <u>m</u>

Temperature: Main Stream - 250°C Pressurizer - 280°C

Average Power Density: 0.39 w/ml

Loop Material: 347 SS

Table 4. In-Pile Loop/FY Data

Sample Number	Hours of Operation	Chromium Concentration (Y/ml)	Nickel Concentration (Y/ml)	Iron Concentration (Y/ml)	pH	Reactor Status (U-Up) (D-Down)
1	68	30	178	92	1.55	D
2	71	13	173	95	1.55	"
3	161	17	577	33	1.65	"
4	163	7	631	58	1.65	"
5	234	11	715	85	1.70	"
6	236	7	546	68	1.75	"
7	330	47	739	41	1.50	"
8	332	70	778	50	1.75	"
9	402	25	1000	34	1.70	"
10	404	25	984	43	1.70	"
11	497	12	1141	32	1.88	"
12	499	23	1115	34	1.88	"
13	572	46	935	50	1.80	"
14	576	46	846	35	1.80	"
15	688	13	859	28	1.90	U
16	692	25	866	29	1.90	D

Solution Concentrations:

UO_2SO_4	0.17 <u>m</u>	0.17 <u>m</u>
$CuSO_4$	0.03 <u>m</u>	0.03 <u>m</u>
H_2SO_4	0.04 <u>m</u>	0.026 <u>m</u>

Temperature: Main Stream - 250°C Pressurizer - 280°C

Average Power Density: 0.67 w/ml

Loop Material: 347 SS

Table 5. In-Pile Loop GG Data

Sample Number	Hours of Operation	Chromium Concentration (γ /ml)	Nickel Concentration (γ /ml)	Iron Concentration (γ /ml)	pH	Reactor Status (U-UP) (D-Down)
1	45	182	--	--	1.30	U
2	47	133	--	--	1.30	"
3	78	89	58	24	1.30	"
4	80	53	103	32	1.30	"
5	83	35	82	18	1.45	"
6	85	38	91	23	1.50	"
7	99	32	188	12	1.50	"
8	121	28	263	14	1.50	"
9	169	12	470	29	1.60	"
10	191	11	440	25	1.60	"
11	240	1	746	14	1.60	"
12	270	26	520	27	1.65	"
13	337	25	854	5	1.70	"
14	365	5	684	5	1.70	D
15	433	6	698	7	1.70	U
16	505	1	791	17	1.70	"
17	553	10	984	15	1.70	"
18	604	5	905	20	1.70	"
19	678	1	833	17	1.75	"
20	721	1	939	21	1.85	"
21	769	1	1046	21	1.88	"
22	843	1	749	21	2.15	"
23	894	1	923	18	1.95	"
24	937	1	929	49	2.00	"
25	1010	1	954	14	1.90	"
26	1058	1	1572	15	1.70	"

Solution Concentrations:

UO_2SO_4 - 0.17 $\underline{\text{m}}$ 0.17 $\underline{\text{m}}$
 CuSO_4 - 0.03 $\underline{\text{m}}$ 0.03 $\underline{\text{m}}$
 H_2SO_4 - 0.04 $\underline{\text{m}}$ 0.015 $\underline{\text{m}}$
 320 ppm Cr (as CrO_3) - 1 ppm

Temperature: Main Stream - 250°C Pressurizer - 280°C

Average Power Density: 0.67 w/ml

Loop Material: 347 SS

Table 6. In-Pile Loop EE Data

Sample Number	Hours of Operation	Chromium Concentration (γ /ml)	Nickel Concentration (γ /ml)	Iron Concentration (γ /ml)	pH	Reactor Status (U-Up) (D-Down)
1	33	--	--	--	1.75	D
2	55	--	7	12	1.95	U
3	76	--	61	--	2.05	D
4	148	--	138	12	2.05	U
5	173	15	159	12	1.90	D
6	197	--	200	15	2.00	U
7	245	8	234	80	2.05	"
8	317	--	441	120	2.05	"
9	364	--	361	9	2.00	"
10	412	--	403	6	2.10	"
11	484	--	318	13	2.10	D
12	532	2	423	19	1.95	U
13	581	--	534	17	2.00	"

Solution Concentrations:

UO_2SO_4 - 0.17 $\underline{\text{m}}$ 0.17 $\underline{\text{m}}$
 CuSO_4 - 0.03 $\underline{\text{m}}$ 0.03 $\underline{\text{m}}$
 H_2SO_4 - 0.008 $\underline{\text{m}}$ 0.004 $\underline{\text{m}}$

Temperature:

Main Stream - 250°C

Pressurizer - 280°C

Average Power Density:

0.60 w/ml

Loop Material:

347 SS

Table 7. In-Pile Loop L-4-8 Data

Sample Number	Hours of Operation	Chromium Concentration (Y/ml)	Nickel Concentration (Y/ml)	Iron Concentration (Y/ml)	pH	Reactor Status (U-Up) (D-Down)
1	78	32	95	--	1.40	U
2	151	22	470	30	1.45	"
3	197	20	655	15	1.50	"
4	241	16	802	16	1.60	"
5	313	5	497	35	1.45	"
6	361	11	922	21	1.80	"
7	411	21	933	37	1.60	"
8	481	3	859	18	1.70	"
9	530	--	939	47	1.50	"
10	577	--	838	34	1.80	"
11	651	--	919	19	1.70	"
12	697	--	861	21	1.85	"
13	749	26	1093	25	1.65	D
14	819	--	1004	31	1.60	U
15	865	16	1087	22	1.70	"
16	915	30	963	38	1.60	"
17	986	42	1062	19	1.60	"
18	1083	28	1311	10	1.70	"
19	1153	25	1398	13	1.65	"
20	1201	--	1070	5	1.70	"
21	1249	15	1037	19	1.75	"
22	1321	--	1045	24	1.80	"
23	1370	--	1316	37	1.80	"
24	1418	24	1134	39	1.65	D
25	1491	--	1069	21	1.85	U
26	1536	--	1057	25	1.70	"
27	1585	--	1252	29	1.85	"

Solution Concentrations:

UO_2SO_4 - 0.17 m 0.17 m
 CuSO_4 - 0.03 m 0.03 m
 H_2SO_4 - 0.026 m 0.017 m

Temperature: Main Stream - 250°C Pressurizer - 280°C

Average Power Density: 0.68 w/ml

Loop Material: 347 SS

Table 8. In-File Loop L-4-11 Data

Sample Number	Hours of Operation	Chromium Concentration (Y/ml)	Nickel Concentration (Y/ml)	Iron Concentration (Y/ml)	pH	Reactor Status (U - Up) (D-Down)
1	17	32	33	16	1.45	D
2	40	40	51	15	1.50	U
3	91	24	437	5	1.55	D
4	112	64	625	5	1.65	"
5	157	71	828	43	1.70	"
6	182	211	1053	110	1.55	U
7	254	79	1388	44	1.55	"
8	302	119	1614	45	1.55	D
9	342	71	1344	36	1.80	U
10*	375	21	72	47	1.40	D
11	447	48	512	76	1.55	U
12	453	--	--	--	--	"
13	495	61	814	61	1.55	"
14	546	128	884	28	1.65	"
15	616	156	961	38	1.70	"
16	665	437	832	47	1.70	"
17	714	140	1059	33	1.70	D
18	785	184	948	28	1.80	U
19	834	107	1236	23	1.80	D
20	882	89	1109	41	1.80	"
21	953	166	1377	34	1.75	"
22	1002	92	1202	41	1.70	U
23	1049	52	1510	15	1.85	"
24	1121	22	--	35	1.80	"

Solution Concentrations:

 UO_2SO_4 - 0.17 m 0.14 m CuSO_4 - 0.03 m 0.023 m H_2SO_4 - 0.04 m 0.022 m

Temperature:

Main Stream - 250°C

Pressurizer - 280°C

Average Power Density:

0.77 w/ml

Loop Material:

347 SS

* New Solution charged to loop.

Table 9. In-Pile Loop L-4-12 Data

Sample Number	Hours of Operation	Chromium Concentration (γ /ml)	Nickel Concentration (γ /ml)	Iron Concentration (γ /ml)	pH	Reactor Status (U-Up) (D-Down)
1	85	30	62	2	1.55	D
2	143	39	90	51	1.65	U
3	215	4	158	46	1.60	"
4	262	66	202	36	1.60	D
5	295	90	231	34	1.55	"
6	311	72	207	43	1.50	U
7	383	90	192	24	1.60	"
8	430	124	304	29	1.70	D
9	480	--	--	--	--	U
10	599	45	248	28	1.60	"
11	648	53	350	79	1.70	"
12	718	68	413	46	1.55	"
13	775	42	--	41	1.35	D
14	831	42	358	49	1.55	"
15	878	41	590	57	1.30	U
16	926	31	312	59	1.50	"
17	998	105	507	71	1.50	"
18	1046	4	509	52	1.65	"
19	1166	54	633	46	1.70	"
20	1214	85	525	50	1.50	D
21	1262	22	371	34	1.80	"
22	1334	10	593	32	1.45	"
23	1382	39	556	31	1.40	"

Solution Concentrations:

UO_2SO_4 - 0.17 m 0.17 m

$CuSO_4$ - 0.03 m 0.03 m

H_2SO_4 - 0.03 m 0.025 m

Temperature:

Main Stream - 250°C

Pressurizer - 280°C

Average Power Density:

0.83 w/ml

Loop Material:

T1 55 AX, 347 SS

Table 10. In-Pile Loop L-2-10 Data

Sample Number	Hours of Operation	Chromium Concentration (Y/ml)	Nickel Concentration (Y/ml)	Iron Concentration (Y/ml)	pH	Reactor Status (U-Up) (D-Down)
1	28	--	38	62	2.10	D
2	139	150	60	214	1.90	"
3	184	96	55	85	2.10	"
4	256	44	80	40	1.85	U
5	280	47	90	40	1.90	"
6	352	57	117	40	1.90	"
7	520	124	130	58	1.90	"
8	592	100	102	32	2.00	"
9	688	125	109	--	1.90	"
10	736	--	146	54	2.00	"
11	784	170	236	--	1.95	"
12	855	170	248	--	1.95	"
13	924	90	215	35	1.90	"
14	1024	131	271	70	1.80	"
15	1095	117	247	17	1.90	"
16	1192	138	285	39	1.90	"
17	1264	175	269	37	2.00	"
18	1360	115	209	55	1.90	"
19	1432	95	412	62	1.98	"
20	1528	71	333	39	1.95	"
21	1600	135	300	81	2.00	"

Solution Concentrations:

UO_2SO_4 - 0.04 m 0.04 m
 CuSO_4 - 0.008 m 0.008 m
 H_2SO_4 - 0.018 m 0.016 m

Temperature: Main Stream - 280°C Pressurizer - 295°C

Average Power Density: 0.54 w/ml

Loop Material: 347 SS

Table 11. In-Pile Loop L-4-13 Data

Sample Number	Hours of Operation	Chromium Concentration (γ/ml)	Nickel Concentration (γ/ml)	Iron Concentration (γ/ml)	pH	Reactor Status (U-Up) (D-Down)
1	72	--	41	28	1.70	U
2	114	72	101	155	1.95	"
3	186	--	199	--	--	"
4	234	168	302	134	1.90	"
5	282	70	333	33	1.95	"
6	354	--	318	--	1.90	"
7	402	276	512	42	2.00	D
8	450	146	388	36	1.85	U
9	522	--	416	--	--	"
10	618	91	475	39	1.90	"
11	690	--	--	--	--	"
12	738	74	661	60	1.85	"
13	786	117	581	--	1.90	D
14	858	--	547	--	--	U
15	931	89	543	143	--	"
16	1026	98	514	82	--	"
17	1028	--	--	--	1.90	"

Solution Concentrations:

UO_2SO_4	-	0.17 M	0.17 M	} in D_2O
CuSO_4	-	0.03 M	0.03 M	
H_2SO_4	-	0.03 M	0.019 M	

Temperature: Main Stream - 250°C Pressurizer - 280°C

Average Power Density: 0.69 w/ml

Loop Material: 347 SS

Table 12. In-File Loop L-2-15 Data

Sample Number	Hours of Operation	Chromium Concentration (γ /ml)	Nickel Concentration (γ /ml)	Iron Concentration (γ /ml)	pH	Reactor Status (U-Up) (D-Down)
1	69	--	93	145	1.95	D
2	111	--	73	56	2.15	U
3	184	37	100	144	1.75	"
4	230	53	135	81	1.90	"
5	278	--	--	--	1.80	D
6	350	54	157	32	1.80	U
7	402	110	162	33	1.80	D
8	449	--	--	--	1.80	U
9*	476	127	23	293	1.60	D
10	491	171	39	55	1.80	U
11	539	161	19	94	1.75	"
12	587	--	86	--	1.80	"
13	658	143	199	81	1.75	"
14	706	45	125	70	1.80	"
15	755	--	--	--	1.60	"

Solution Concentrations:

UO_2SO_4 - 0.17 m 0.17 m
 CuSO_4 - 0.015 m 0.015 m
 H_2SO_4 - 0.03 m 0.028 m

Temperature: Main Stream - 278°C Pressurizer - 298°C

Average Power Density: 2.12 w/ml

Loop Material: 347 SS

* New solution charged to loop.

Table 13. In-Pile Loop L-4-16 Data

Sample Number	Hours of Operation	Chromium Concentration (γ /ml)	Nickel Concentration (γ /ml)	Iron Concentration (γ /ml)	pH	Reactor Status (U-Up) (D-Down)
1	113	13	29	44	1.85	D
2	122	42	37	27	1.80	D
3	146	28	34	53	1.90	U
4	193	--	100	93	1.75	"
5	241	15	52	104	1.80	"
6	289	22	38	35	1.85	"
7	362	101	78	39	1.60	"
8	458	54	89	40	1.75	"
9	529	18	121	44	1.65	"
10	625	89	257	87	1.75	"
11	697	74	173	149	1.85	"
12	793	61	225	153	1.70	"
13	865	121	235	140	1.70	"
14	961	49	312	142	1.80	"

Solution Concentrations:

UO_2SO_4 - 0.17 $\underline{\text{m}}$ 0.17 $\underline{\text{m}}$

CuSO_4 - 0.015 $\underline{\text{m}}$ 0.015 $\underline{\text{m}}$

H_2SO_4 - 0.025 $\underline{\text{m}}$ 0.023 $\underline{\text{m}}$

Temperature:

Main Stream - 280°C

Pressurizer - 295°C

Average Power Density"

0.59 w/ml

Loop Material:

347 SS

Table 14. In-Pile Loop L-2-14 Data

Sample Number	Hours of Operation	Chromium Concentration (Y/ml)	Nickel Concentration (Y/ml)	Iron Concentration (Y/ml)	pH	Reactor Status (U-Up) (D-Down)
1	35	117	0	--	0.40	D
2	91	118	95	--	.50	U
3	161	--	--	--	.65	"
4	257	--	--	291	.70	"
5	329	--	--	520	.75	"
6	497	357	276	1225	.80	"

Solution Concentrations:

UO_2SO_4	-	0.17 <u>m</u>	0.17 <u>m</u>
CuSO_4	-	0.17 <u>m</u>	0.15 <u>m</u>
H_2SO_4	-	0.42 <u>m</u>	0.37 <u>m</u>

Temperature: Main Stream - 280°C Pressurizer - 300°C

Average Power Density: 2.31 w/ml

Loop Material: 347 SS

Table 15. In-File Loop L-2-17 Data

Sample Number	Hours of Operation	Chromium Concentration (Y/ml)	Nickel Concentration (Y/ml)	Iron Concentration (Y/ml)	pH	Reactor Status (U-Up) (D-Down)
1	45	75	29	--	1.95	D
2	100	33	39	42	1.30	U
3	172	42	68	75	1.80	"
4	220	54	16	89	1.75	"
5	268	67	58	108	1.80	"
6	340	70	100	102	1.80	D
7	388	71	122	80	1.80	D
8	508	46	135	108	1.80	U
9	556	59	98	99	1.85	"
10	604	33	153	144	1.75	"
11	616	11	24	51	1.70	"
12	651	36	53	103	1.80	"
13	723	53	87	103	1.70	"
14	795	43	125	118	1.70	"

Solution Concentrations:

UO_2SO_4	-	0.04 <u>m</u>	0.04 <u>m</u>
CuSO_4	-	0.005 <u>m</u>	0.005 <u>m</u>
H_2SO_4	-	0.025 <u>m</u>	0.023 <u>m</u>

Temperature: 300-315°C

Average Power Density: 0.56 w/ml

Loop Material: 347 SS

Table 16. In-File Loop L-4-18 Data

Sample Number	Hours of Operation	Chromium Concentration (γ /ml)	Nickel Concentration (γ /ml)	Iron Concentration (γ /ml)	pH	Reactor Status (U-Up) (D-Down)
1	44	--	18	60	2.05	D
2	100	--	0	61	2.05	U
3	388	98	0	77	2.00	D
4	437	62	75	35	2.05	D
5	508	81	100	31	2.00	U
6	580	68	99	54	1.95	"
7	676	50	142	85	2.05	"
8	748	12	148	50	2.05	"
9	844	32	161	64	2.05	"

Solution Concentrations:

UO_2SO_4	-	0.17 M	0.17 M	} In D_2O
CuSO_4	-	0.07 M	0.07 M	
H_2SO_4	-	0.02 M	0.018 M	

Temperature: $235^\circ - 265^\circ\text{C}$

Average Power Density: 0.62 w/ml

Loop Material: 347 SS

Table 17. In-Pile Loop L-2-19 Data

Sample Number	Hours of Operation	Chromium Concentration (γ/ml)	Nickel Concentration (γ/ml)	Iron Concentration (γ/ml)	pH	Reactor Status (U-Up) (D-Down)
1	5	--	--	0	1.00	D
2	17	85	--	0	1.20	"
3	57	29	14	0	1.15	"
4	74	79	4	117	1.40	"
5	111	58	51	50	1.20	"
6	207	30	113	47	1.10	"
7	279	9	178	188	1.20	U
8	398	10	223	338	1.15	"
9	590	189	292	34	1.20	D
10	687	108	361	100	0.90	U
11	734	131	362	44	1.00	"
12	854	17	483	44	1.10	"
13	926	11	586	69	1.10	"
14	1022	41	479	100	1.15	"
15	1094	0	641	49	1.05	"

Solution Concentrations:

UO_2SO_4	-	0.17 $\underline{\text{m}}$	0.17 $\underline{\text{m}}$
CuSO_4	-	0.02 $\underline{\text{m}}$	0.02 $\underline{\text{m}}$
H_2SO_4	-	0.10 $\underline{\text{m}}$	0.113 $\underline{\text{m}}$
Li_2SO_4	-	0.20 $\underline{\text{m}}$	0.022 $\underline{\text{m}}$

Temperatures: 280° - 295°C

Average Power Density: 1.81 w/ml

Loop Material: 347 SS

Table 18. In-Pile Loop L-2-21 Data

Sample Number	Hours of Operation	Chromium Concentration (Y/ml)	Nickel Concentration (Y/ml)	Iron Concentration (Y/ml)	pH	Reactor Status (U-Up) (D-Down)
1	47	0	--	--	1.15	D
2	63	--	135	35	1.25	"
3	109	--	64	0	1.45	U
4	180	112	210	0	1.45	"
5	228	273	467	0	1.15	"
6	276	262	402	0	--	"
7	348	82	415	11	--	"
8	396	140	416	30	1.60	"
9	444	175	444	14	1.20	"
10	516	121	452	23	--	"
11	564	64	344	100	1.45	"
12	612	48	506	--	1.35	"
13	684	137	704	83	1.40	"
14*	695	54	42	27	1.05	D
15	719	93	266	30	1.75	"
16	753	60	533	46	1.75	"
17	791	132	510	114	1.33	U
18	794	140	537	21	1.50	D
19	802	82	560	17	1.65	"
20	811	80	653	19	--	"
21*	822	157	0	0	1.20	U
22	843	42	225	0	1.55	"

Solution Concentrations:

UO ₂ SO ₄	-	0.17 M	0.17 M
CuSO ₄	-	0.022 M	0.022 M
		0.012 M	0.012 M
		0.024 M	0.024 M
H ₂ SO ₄	-	0.041 M	0.033 M
		0.037 M	0.029 M
		0.042 M	0.034 M

In D₂O

Temperature:

Main Stream - 280°C

Pressurizer - 295°C

Average Power Density:

1.40 w/ml

Loop Material:

347 SS

* New solution charged to loop.

Table 19. Average Concentrations in In-Pile
Loops

Loop	Average Chromium Concentration	Average Iron Concentration	Average Core Power Density
	(Y/ml)	(Y/ml)	(w/ml)
DD	18	22	1.25
FF	26	50	2.56
GG	44	19	3.29
EE	--	--	3.57
L-4-8	20	25	3.21
L-4-11	105	38	4.34
L-4-12	53	43	2.49
L-2-10	115	60	3.31
L-4-13	120	75	2.65
L-2-15	100	99	12.7
L-4-16	55	82	3.80
L-2-17	50	94	3.98
L-2-14	197	679	14.3
L-2-19	61	79	12.4
L-4-18	58	57	2.17
L-2-21	116	32	--

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