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OPERATING REPORT - CORROSION TESTING OF
ALUMINUM-CLAD PU-AL FUEL ELEMENTS IN THE
C- 1 LOOP

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OPERATING REPORT
CORROSION TESTING OF ALUMINUM-CLAD
PU-AL FUEL ELEMENTS IN THE C-1 LOOP

E. C. Bennett

HANFORD ATOMIC PRODUCTS OPERATION
RICHLAND, WASHINGTON

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OPERATING REPORT
CORROSION TESTING OF ALUMINUM-CLAD
PLUTONIUM-ALUMINUM FUEL ELEMENTS IN THE C-1 LOOP⁽¹⁾

Introduction

The first series of tests in the C-1 Loop was designed to test the corrosion characteristics of several aluminum alloys at coolant temperatures up to 290 C. Details of the test are documented in Reference 1. Four fuel assemblies were irradiated. This report summarizes the operating history and the pertinent test data for each of these assemblies. Detailed operating data are available from References 2, 3, 4, 5 and 6.

Test History

C-1-1

The first fuel assembly, C-1-1, was charged into the C-1 Loop on January 20, 1964. Following reactor startup on January 22, the outlet coolant temperature was raised stepwise to 500 F to check the fuel assembly power generation. The power output appeared to be about 80 per cent of the predicted value. On January 23 operation at the design outlet temperature, 544 F, was attempted, but erratic behavior of the temperature controller precluded operation at this temperature.

During a minimum reactor outage on January 24 and 25, the temperature recorder-controller (TRC) was cleaned and re-adjusted, and a new valve stem was installed in the heat exchanger flow control valve to give equal percentage flow characteristics. Following reactor startup on January 26, the coolant outlet temperature was raised to 554 F, the test reference temperature. Operation continued at this level until January 28, when the core temperature of the upstream fuel element began to rise from its initial level of approximately 585 F. At approximately 1830, the rate of rise had increased to about 5 F/hr, and the core temperature was approaching the limit of 650 F set by Coolant Systems Development (CSDO), Hanford Laboratories. The coolant temperature was reduced first to 500 F, then to 450 F, in an attempt to maintain some level of high temperature operation. The core temperature, however, did not stabilize at either level, so the coolant temperature was reduced to the minimum obtainable, approximately 260 F. Operation was continued at this level until a reactor outage on February 8, and the assembly was discharged on February 10.

Throughout this period of operation, the water quality of the coolant in the loop was difficult to control. The oxygen content of the loop water was consistently high, averaging approximately .30 ppm compared to the specified maximum of 0.01 ppm. Repeated regeneration and replacement of the ion exchange resins did not alleviate the situation.

Table 1 gives the operating data for this test.

C-1-2

The C-1-2 fuel assembly was charged on February 10. Reactor operation was resumed on February 11 and the loop coolant outlet temperature was raised to 500 F

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by 2400 o'clock. The loop was operated continuously at this temperature until February 25, when the reactor was shut down for a scheduled outage.

A few hours before the shutdown, the #1 recirculation pump was taken out of service because of high motor amperage. No affect was noted on the test except for a 0.5 gpm reduction in coolant flow. During the outage, the pump was removed for repairs. The pump was sent to the vendor where onsite repairs did not correct the high amperage condition. Authorization was received to continue the test with one pump in service.

During this operating period, the core temperature rose gradually at about 5-10 F a day. Maximum temperature recorded was 694 F. CSDO set an operating limit of 25 F/12 hrs on the core temperature increase. Water quality continued to fluctuate, as in the C-1-1 test, but in general, the control was better during this period. Typical sample results are shown in Table 2.

Reactor operation was resumed on February 29, and test conditions were established by 2130 o'clock. Operation continued until March 2, when the loop scrambled the reactor. A surge in heat exchanger flow during TRC adjustments caused a low pressure trip, and an unexplained low-low flow condition during the dump cycle caused the scram. The loop was returned to recirculation during the scram recovery. The loop temperature, however, was held to a minimum until the process water in the loop could be purged out. Test conditions were resumed on March 16, and held until March 19, when a reactor scram caused a minimum outage. Test temperatures were restored on March 20 and held until March 24, completing the C-1-2 test. The fuel assembly was discharged on March 26.

After the loop dump on March 2, the fuel core temperature dropped back to 537 F at test conditions, indicating that some surface film had probably been dislodged by the dump cycle. The core temperature rose gradually as the test progressed, reading a maximum of 665 F shortly before the test was discharged.

Like the C-1-1 test, the major operating problem was water quality control. The oxygen content in the loop water could not be consistently maintained below the 0.01 ppm test limit. The outlet temperature controller (TRC) caused some temperature fluctuations, as well as the loop dump and reactor scram on March 2. This problem was corrected, however, when a leak in the controller air system was repaired and the instrument was re-adjusted. Tables 2 and 5 give operating data for this test.

C-1-3

Test C-1-3 was charged on March 26. The coolant pH for this test was lowered to 4.5 by adding phosphoric acid to the coolant supply. The other test conditions remained the same as in the previous tests.

Test conditions were first established on March 30 at 500 F coolant outlet temperature. On March 31, the loop dumped without scrambling the reactor, from a high temperature trip. A sudden drop in coolant temperature caused the TRC to

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close the heat exchanger flow control valve. The TRC did not respond quickly enough to the following temperature rise, and the coolant temperature exceeded the high temperature trip point. Since the reactor remained in operation, the loop could not be put back on recirculation until the next outage. During this time, 13 days, the fuel assembly was cooled by process water.

Test C-1-3 was discharged on April 13, 1964 because it was felt that the lengthy exposure to process water would seriously affect test results. Table 3 summarizes the operating data.

C-1-4

Test C-1-4 was charged on April 13 and test conditions were first established on April 17. The coolant pH for this test was adjusted to 4.5 with phosphoric acid. Operation continued at test temperature until April 29, when the reactor was shut down for an extended outage.

Because of the low pH requirement, makeup water was supplied from the storage tank. The oxygen content in the tank water could not be kept below the 0.01 ppm limit, in spite of a nitrogen blanket above the water and a sealed cover on the tank. During the extended outage, deionizing columns from the H-1 Loop were installed in the C-1 Loop makeup system to provide additional water treatment capacity. Water quality control improved markedly with the addition of this equipment although special procedures had to be developed to provide satisfactory water in the storage tanks. The primary cause of the problem was finally traced to the excessive amount of dissolved gases in the filtered water supplying the makeup system. These gases coat the ion exchange resins when the water pressure is reduced below 70 psig, preventing water contact with the resins. Operating the columns on a "batch" basis kept the gases in solution, and gave the desired water quality in the tank.

Operation was resumed at test conditions on May 8. On May 11, the loop dumped to process water cooling during a reactor scram. The rapid-fill makeup pump failed to maintain loop pressure during the cool-down period following the reactor scram. The loop was flushed with makeup water and returned to recirculation after about two and one-half hours. Examination of the pump showed that its failure was caused by worn piston seal O-rings. Test operation was resumed on May 13, but shortly after reaching test temperature, the C-1 Loop caused a reactor scram when the instrument air supply was inadvertently reduced below the lower limit during preventive maintenance work on the building air equipment. The loop was returned to recirculation during the scram recovery. Test conditions were restored on May 15, and were maintained until June 29, except for routine reactor shutdowns.

During this operating period, the core temperature of the fuel assembly gradually increased, indicating a slow but steady accumulation of film on the fuel surface. On June 29, the core temperature reached 750 F, the limit set by CSDO. The coolant outlet temperature was reduced to 480 F for the remainder of the test to maintain the core temperature below the limit. The reactor was shut down on July 9 for an extended outage. During the shutdown, some of the film on the

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fuel assembly broke loose and spread through the loop. Radiation levels rose to about 3R/hr at the loop piping near the reactor face, but decayed to about 1R/hr overnight. Flushing the loop with clean water further reduced the radiation level to about 500 mr/hr. The C-1-4 assembly was discharged on July 10, 1964 terminating this series of tests.

Tables 4 and 5 contain operating data for test C-1-4.

E. C. Bennett
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TABLE 1

C-1-1 DATA

Date	Time	Ti	To	Tc	Tb	AP	O ₂	Res	pH	Flow
1-20-64	C-1-1 charged									
1-21	1445	150	147	150	151	68	.005	2.0	6.8	15.7
1-22	2300	185	210	229	222	66	.34	1.0	6.4	15.6
1-23	2315	271	295	319	310	65	.46	.54	5.9	15.8
1-24	2330	107	108	108	108	73	.48	.45		
1-25	Reactor down									
1-26	2130	519	554	584	573	59				15.4
1-27	1330	518	554	584	573	60	.46			15.7
1-28	1825	515	553	734	574	65	.30	.63	6.2	14.6
	2230	461	500	594	520	68				14.6
1-29	2230	223	263	412	282	70	.05	.47	6.2	15.2
1-30	2230	226	265	414	285	70	.20	.40	6.2	15.3
1-31	2230	224	262	408	282	69	.28	.22	5.0	15.3
2-1	2230	224	261	406	281	69	.20		6.7	15.3
2-2	2230	223	260	405	280	69	.18	.39	6.4	15.3
2-3	1415	223	260	406	280	69	1.96			15.3
2-4	1430	220	257	400	276	69	1.24	.59	6.5	15.3
2-5	0910	218	255	394	273	69	.88	.25	6.0	15.3
2-6	0905	218	255	388	273	70	1.84	.56	6.45	15.4
2-7	0910	218	253	384	272	70	.13	1.8	6.5	15.3

Legend

Ti = Coolant temperature at test section inlet
 To = Coolant temperature at test section outlet
 Tc = Test element core temperature
 Tb = Coolant temperature in test section annulus
 AP = Pressure differential across test section
 O₂ = Oxygen content, ppm, in coolant
 Res = Resistivity of coolant, megohms
 pH = Hydrogen ion concentration in coolant (7.0 = neutral)
 Flow = Coolant flow, gpm

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TABLE 2

C-1-2 DATA

Date	Time	T1	To	Tc	Tb	AP	O ₂	Res	pH	Flow
2-10-64	C-1-2 charged									
2-12	0020	465	500	529	517	52	1.12	.6		16.3
2-13	0030	468	500	525	516	56	.28	.625		15.6
2-14	0030	466	500	536	518	64			6.4	14.7
2-15	0030	464	500	549	518	66	< .005	.748	6.2	15.1
2-16	0030	463	500	559	518	67	.02		4.9	15.6
2-17	0830	462	500	578	520	70	.02	1.68	7.5	15.5
2-18	0830	460	500	589	520	74	.10	1.8	6.6	14.3
2-19	0930	460	500	599	521	74	.13	.841	7.1	14.7
2-20	0930	461	500	611	521	75	.03	1.25	7.6	15.3
2-21	1020	456	500	635	420	77				15.0
2-22	0800	455	498	656	521	80				14.4
2-23	1650	455	499	662	521	79				15.3
2-24	0800	457	499	662	520	79	< .005	1.25	7.9	15.5
2-25	0800	457	498	668	520	78	< .005	1.3	6.4	15.8
	1100	455	499	694	522	72				15.2
	1530	83	83	84	84	60				17.5
2-26,27,28 - Reactor down										
2-29	2130	471	500	532	519	53	1.1	1.1	6.1	17.4
3-1	1000	468	500	556	618	55				16.9
3-2	0900	465	501	645	518	56	1.6	.95	6.85	17.7
	1100	299	323	342	335	55	Loop dump, scrambled			15.0
3-3	1100	194	228	255	241	52	1.92			14.4
3-4	1100	207	242	276	260	51	2.06	.840	5.8	14.4
3-5	1100	186	212	242	230	52	.008	1.37	6.58	14.3
	1300	87	87	90	90	54	Reactor down			13.6
3-6 Reactor down										
3-7	0200	166	191	214	203	51				14.3
3-8 no data										
3-9	1545	215	253	284	271	51				14.4
3-10	1525	212	248	285	266	51				14.7
3-11	1530	253	290	327	309	53	< .005			14.8
3-12	1500	217	253	292	273	51	< .005	1.37	6.3	14.4
3-13	1915	464	497	537	517	49				14.1
3-14,15 no data										
3-16	1340	463	500	563	518	51	.36	1.0	6.28	15.3
3-17	1000	462	497	563	515	51				15.4
3-18	0900	464	499	565	516	51		.72	7.4	15.3
3-19	1230	461	500	565	515	51		.56	7.55	15.5
	1530	228	263	327	280	54				15.8
3-20	1000	238	275	337	289	57	.62	.43	7.85	15.9
	1430	465	500	570	519	51				15.3
3-21,22 no data										
3-23	1445	465	500	660	517	53	< .005	.75	6.45	14.9
3-24	1430	465	500	611	517	54	< .005	.90	6.6	14.5
3-25,26 no data C-1-2 discharged 3-26-64										

Total time at temperature = 587 hours

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TABLE 3

C-1-3 DATA

Date	Time	Ti	To	Tc	Tb	ΔP	O ₂	Res	pH	Flow
3-26-64	C-1-3 charged									
3-27	2045	123	120	123	123	62	Reactor down			15.8
3-28,29	Reactor down, no data									
3-30	1500	425	464	492	480	53	.08	.63	4.8	16.0
	1530		500							
3-31	1440	463	500	535	521	51				16.3
	1830	Loop dumped, on process water								
4-1	1600	45	64	129	93					18.8
4-2	1330	45	62	127	142	89				18.8
4-3	1450	45	48	129	92	90				19.0
4-4,5,	No data recorded									
4-6	1120	46	73	131	93	91				19.0
4-7	0905	47	74	129	92	91				19.0
4-8	1315	46	75	132	93	91				19.0
4-9	1550	46	75	129	92	91				19.0
4-10	0815	46	75	129	90	91				19.0
4-11,12	No data recorded									
4-13	C-1-3 discharged									

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TABLE 4C-1-4 DATA

Date	Time	Ti	To	Tc	Tb	ΔP	O ₂	Res	pH	Flow
4-13-64	C-1-4 charged									
4-14	1900	79	77	81	79	53				14.4
4-15	0200	87	88	95	93	52	Δ.005			14.4
	0400	192	218	245	233	50				15.4
	1945	209	238	270	256	49				15.4
4-16	1530	215	248	280	266	49	Δ.005		4.3	15.5
4-17	1000	381	412	447	433	50				16.0
	1730	467	500	535	519	47				15.3
4-18	1000	467	500	541	519	50				15.1
4-19	1630	466	500	540	519	50				15.3
4-20	0815	467		536	518	49			4.4	15.4
4-21	0800	467		539	519	49	Δ.005		4.2	15.4
4-22	0800	467		538	519	49	.260		4.5	15.4
4-23	0800	466		539	517	49	.70		4.4	15.4
4-24	0800	466		544	519	49	.88		4.6	15.3
4-25	No data taken									
4-26	0800	468	501	550	521	51				15.2
4-27	0720	467	502	552	521	52			4.4	15.3
4-28	0800	463	495	557	512	49			4.8	15.5
4-29	0810	126	120	136	134	57	No samples from loop			15.5
4-30	1030	99	96	100	100	57	No samples from loop			15.6
5-1	1445	103	100	105	105	57			4.5	15.2
5-2	1345	108	105	110	109	59				15.9
	1655	180	197	235	208	55				16.0
5-3	No data taken									
5-4	1015	107	105	108	108	60				16.0
5-5	1100	113	113	114	113	60			4.5	16.2
	1450	175	192	232	208	55				16.1
5-6	0820	247	275	332	294	54				16.2
5-7	0930	257	290	344	308	54				16.1
5-8	0815	266	300	354	318	53	.06	.200	4.9	16.0
	1400	470	500	565	518	51			4.6	15.7
5-9	1300	469	498	576	518	52			4.3	15.5
5-10	2050	126	125	127	126	55	Loop dumped			16.3
5-11	0915	123	125	125	124	48	Reactor down			14.4
5-12	1200	228	255	292	272	53			4.5	16.2
5-13	0840	217	242	273	257	53	.92			16.2
5-14	0815	245	275	312	293	53	.90	.015	4.65	16.2
5-15	0814	244	273	309	292	53	.80	.088	4.6	16.2
	1230	468	500	538	517	49				15.8
5-16,17	No data taken									
5-18	0825	458	490	532	508	51	.08	.160	4.9	15.7
5-19	0815	462	500	542	518	51	.40	.175	4.9	15.5
5-20	0815	93	92	94	94	56				15.2

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TABLE 4C-1-4 DATA

Date	Time	T1	To	Tc	Tb	ΔP	O ₂	Res	pH	Flow
5-21	2100	218	243	279	257	53				15.9
5-22	1430	470	500	541	517	51	.08	.135	4.9	15.6
5-23	1120	464	492	537	514	51				15.6
5-24	No data taken									
5-25	0815	464	495	543	513	53	.20	.160	4.4	15.3
5-26	0825	468	500	558	519	53	.48	.300	4.6	15.2
5-27	0810	470	502	564	520	53	.48	.175	4.5	15.2
5-28	0820	473	504	573	522	53	.40	.300	4.7	15.2
5-29,30	No data taken									
6-1	0800	473	503	605	521	59	.52	.094	4.65	14.5
6-2	0750	473	503	615	522	59	∠.005	.388	4.8	14.5
6-3	0750	160	160	163	162	63				15.9
6-4	No data taken									
6-5	1505	107	106	109	108	68				16.5
6-6	0800	193	210	292	224	67				16.7
6-7	No data taken									
6-8	0820	244	273	368	287	65	.38		4.9	16.8
	1530	471	500	608	517	62				16.2
6-9	1530	473	503	589	480	62	.008	.070	4.8	15.9
6-10	1505	471	495	598	510	62	∠.005	.065	4.8	15.9
6-11	0815	473	500	609	516	62	∠.005	.095	4.7	15.7
6-12	0800	472	498	620	512	62	∠.005	.112	4.7	15.8
6-13	No data taken									
6-14	2300	102	100	103	104	69				16.0
6-15	1130	215	237	358	252	67				16.8
6-16	2140	473	500	655	517	62	.12	.068	4.15	15.9
6-17	1850	471	502	668	518	63	∠.005	.210	4.64	15.7
6-18	1730	464	495	670	511	63	∠.005	.160	4.6	15.7
6-19	1830	467	495	698	513	62	∠.005	.200	4.55	15.7
6-20	2010	472	495	712	518	62	∠.005	.200	5.25	15.7
6-21	2315	471	500	714	517	62	No samples taken			15.7
6-22	1515	472	500	713	517	66	∠.005	.080	4.25	15.4
6-23	1800	472	500	713	517	67	.016	.075	4.2	15.4
6-24	1810	470	500	713	516	67	.012	.095	4.3	15.3
6-25	1830	471	500	717	517	68	.016	.143	4.5	15.1
6-26	1900	470	500	717	517	69	.024	.170	4.65	15.0
6-27	0945	471	498	720	517	70	No samples			15.0
6-28	0915	470	600	738	516	70	No samples			14.8
6-29	2330	424	453	722	469	73	.024			15.2
6-30	1910	446	485	725	491	71	.04	.200	4.25	15.2
7-1	1715	449	475	725	494	72	.038	.200	4.4	15.1
7-2	1935	452	483	728	498	72	No data			15.1
7-3	No data taken									
7-4	1900	451	483	734	499	72	.016			15.1
7-5	No data taken									
7-6	1700	451	478	738	495		.04	.185	4.7	14.9
7-7	2025	453	482	743	498		.024	.185	4.7	14.8
7-8	1720	453	480	741	495		.016	.125	4.65	14.8
7-9	Reactor down									
7-10	C-1-4 discharged									

Total time at temperature = 1256 hours

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TABLE 5

AVERAGE TUBE POWERS ADJACENT TO C-1 FUEL ASSEMBLIES

<u>Tube Column</u>	<u>89</u>	<u>90</u>	<u>91</u>	<u>92</u>	<u>93</u>	<u>94</u>	<u>95</u>
C-1-2	1270 KW	1210	1160	1080	1030	728	593
C-1-4	1210	1170	1105	1120	1010	728	610

REFERENCES

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4. HW-81272, C-1 Loop Log Book, November 1, 1963 to April 17, 1964, E. C. Bennett, 5-6-63
5. HW-81735, C-1 Loop Operating Log, April 21 to date, E. C. Bennett, 4-9-64
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