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ZIRCALOY PROCESS TUBE HYDRATING PROBLEM

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GALVANIC CORROSION TEST MEASUREMENTS

ZIRCALOY PROCESS TUBE HYDRIDING PROBLEM

by

W. R. Thorson

August 21, 1967

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GALVANIC CORROSION TEST MEASUREMENTS
ZIRCALOY PROCESS TUBE HYDRIDING PROBLEM

I. INTRODUCTION

In September of 1965, a program was launched to investigate the cause and to determine appropriate corrective or preventive action for hydriding of Zircaloy process tubes in K Reactors. One phase of the investigation was specifically directed to the measurement of galvanic corrosion currents flowing between the Zircaloy process tube and the aluminum spacers. Production Test IP-807⁽²⁾ authorized in-reactor galvanic test measurements in order to secure data relating to the hydriding problem.

It is the purpose of this report to document all the galvanic corrosion current data recorded for tests in K Reactors during the investigation of the hydride problem. The galvanic test data contained in this document also provides a basis for the conclusions stated in the final report⁽¹⁾ which reviews the accomplishments of the test program.

II. SUMMARY

The galvanic potentials recorded for test measurements in the K Reactor process tubes, identifies the approximate location and magnitude of the corrosion currents generated between aluminum spacers and Zircaloy process tube. The flow of galvanic currents and subsequent release of hydrogen gas can be related to the hydriding of the Zircaloy tubes.

The data enclosed in this report indicate a substantial amount of galvanic action in the downstream dummy section of the process tube. There was no evidence of any galvanic action from the fuel elements which would contribute to the large galvanic currents measured in the downstream spacers.

The use of certain metal coatings on the aluminum spacers could reverse the galvanic cell polarity and cause corrosion of the process tube which would not be desirable.

III. DISCUSSION

General

Seven separate in-reactor galvanic tests were performed, two in KE Reactor and five in KW Reactor. These tests extended over a period of nine months. Some tests were repeated, and, in general, all tests were run under similar

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conditions. A great amount of data was recorded which appears as repetitive information; however, it was necessary to establish and verify results and trends through the use of repetitive testing and recording of galvanic data.

All corrosion potentials were measured between the aluminum spacers and the Zircaloy process tube in that part of the process tube downstream from the fuel elements. Standard spacers were modified for attachment of an insulated wire by means of a tapped screw on the inner surface of the spacer. Ceramic insulators were fitted to the end assemblies of some spacers in order to provide electrical isolation between elements of the test assembly for test current measurements. Wiring was run through the spacer inner annulus and out the end of the process tube assembly through a Conax pressure sealing assembly and terminated in an Amphenol connector located on the outside of the process tube nozzle assembly. The electrical connection to the process tube was made by means of placing a steel band around the outside of the barrel nozzle assembly. Test wiring from the Amphenol connector on the end of the process tube to the recorder was run up to the "D" machine room through step-plug access holes in the floor of the "D" machine room. Recorder and/or indicating instruments for measuring the galvanic currents were located in the "D" machine room.

Corrosion Test No. 1

Corrosion test No. 1 consisted of six aluminum spacers wired for reading the current flow from the process tube to the fuel element. Five spacers were completely insulated from metal contact with the process tube. The sixth spacer was not insulated from the process tube and had end-to-end metal contact with the upstream spacer.

Galvanic voltages were measured and recorded at specific intervals on all six test elements from the time of reactor start-up until the test was discontinued. It is interesting to note that test spacer No. 6 did not generate any corrosion potential until after several days of reactor operation. The probable reason for the lack of corrosion potential on test spacer No. 6 was that the test spacer was shorted to the process tube when first installed. After a period of time of exposure to the high temperature process water, the spacers became oxidized on the metal surface sufficient to insulate them from the process tube. The electrical insulation between the spacer and the process tube allows a galvanic current to flow in the external test circuit which appears as a potential measurement on the test recorder.

It should be noted from the data that negative potentials are shown for spacers during the period when the reactor coolant water was at a low temperature. This indicates that the Zircaloy tube is "anodic" with respect to the aluminum at low temperatures, whereas at higher temperatures the aluminum spacer is anodic with respect to the Zircaloy tube.

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It was found that the insulation of wiring within the reactor tube had a reliable expected life of two to three weeks. Readings taken of galvanic voltages after wiring insulation has failed may not indicate the actual galvanic current flow due to shorted wiring within the process tube.

The test was run with all external wiring "open circuit" when not used for recording instantaneous readings. The "open circuit" condition would tend to prevent any galvanic action during 95 percent of the test period.

Corrosion Test No. 2

Corrosion test No. 2 was assembled and wired similar to test No. 1 except that spacer No. 6 was insulated on the upstream end, and test spacer No. 2 and No. 4 were aluminum plated with 304 stainless steel. The data indicate that one stainless steel plated spacer was cathodic with respect to the Zircaloy tube; the other stainless steel plated spacer remained anodic, but yielded a very low galvanic voltage.

Readings of potential between combinations of pairs of spacers are shown. The highest potentials were recorded for measurements between stainless steel plated spacer and aluminum spacer.

The test wiring was shorted to ground during 95 percent of the test period which would allow the maximum amount of corrosion and the greatest release of hydrogen.

Corrosion Test No. 3

Corrosion test No. 3 is identical to test No. 2. Data taken indicate that both stainless steel spacers are cathodic with respect to the Zircaloy tube, and that the potential generated was considerable for these two test spacers.

The test was operated with all spacer wiring shorted to the process tube ground connection during 95 percent of the test period. This would permit the greatest release of hydrogen by corrosion current.

Corrosion Test No. 4

Corrosion test No. 4 consisted of only two aluminum spacers with one insulator separating them. Both spacers contained ribs and were, therefore, in contact with the process tube. The intent of this test was to determine the extent of galvanic voltages generated by upstream spacers and conducted to the test spacers by end-to-end contact. Due to a malfunction of the recorder, no data were recorded until after one week of reactor operation. The upstream test spacer showed a galvanic current of eight times the downstream spacer indicating the effect of the galvanic currents generated by a number of upstream spacers and conducted to the test spacer by end-to-end pressure contact.

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Corrosion Test No. 5

Corrosion test No. 5 consists of four dummy fuel elements wired for galvanic current measurements and are shown as test spacers 6 through 3 on Table No. 4.

Insulators were placed between all spacers, and ribs were removed from all test spacers so there would be no metal contact between the test spacers and the process tube except that for spacer No. 6 which was allowed to contact the upstream dummy perf used for separating the test unit from the uranium fuel element.

The purpose of this test was to determine the extent of the galvanic currents that might be generated by the process fuel elements and conducted downstream into the spacer, and likewise, the amount of galvanic current generated by each test spacer in the vicinity of the fuel element.

By comparing the galvanic current generated by test spacer No. 6 shown in Table No. 4 with the galvanic current of test spacer No. 4 shown in Table No. 4, we find very little increase in current for test spacer No. 6 indicating that the upstream fuel elements are not contributing to galvanic currents measured in the spacer. In Table No. 4, test No. 2 had an indicated galvanic current seven times as great as the indicated galvanic current for test spacer No. 6, further substantiating the theory that the large amount of galvanic currents are generated by the spacers in the vicinity of the process tube where hydriding of the process tube has been extensive.

Corrosion Test No. 6 and 7

Corrosion tests No. 6 and 7 were identical tests, run at two separate time periods in order to relate normal results and to eliminate any data that did not appear repetitive in both tests. The test consisted of two spacers located downstream next to the nozzle assembly and assembled with an insulator separating the two test spacers. The test was similar to test No. 4 except that the galvanic current generated by the upstream test spacer was connected to a strip chart recorder to obtain continuous galvanic current readings from the time before reactor start-up to some period of time at reactor normal operating temperature.

It was intended that the test would demonstrate the change in galvanic current between spacer and the process tube as the reactor effluent water increased in temperature during start-up. The test data indicate the effect of the process tube temperature on the generation of galvanic current. The evidence of the fast response of galvanic cell activity to a change in temperature was demonstrated by the recording of data taken during a reactor scram, where the galvanic cell current dropped to approximately zero value six minutes after reactor scram.

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IV. ACKNOWLEDGEMENTS

The author wishes to acknowledge the consulting service of B. Griggs of Battelle-Northwest - Corrosion and Coolant Chemistry, and the assistance of R. L. Woodward in conducting these tests.

V. REFERENCES

- (1) Alexander, W. K., "A Review of the K Area Zircaloy Process Tube Hydriding Problem," DUN-1623, October 24, 1966. (Confidential)
- (2) Alexander, W. K., "Production Test IP-807, Zircaloy Hydriding Evaluation and Control," RL-REA-2575, September 30, 1965. (Confidential)

W. R. Thorson

Senior Engineer
Plant Design

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TABLE NO. 1

TEST ASSEMBLY SPECIFICATIONS

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TEST NO. 1

REACTOR KE

TUBE NO. 5079

DATE INSTALLED 12-5-65

Test	Materials	Spacer Insulator		Ribs		Special Conditions
		Up Stream	Down Stream	Yes	No	
1	Aluminum	X	X		X	
2	Aluminum	X	X		X	
3	Aluminum	X	X		X	
4	Aluminum	X	X		X	
5	Aluminum	X	X		X	
6	Aluminum		X	X		

All readings taken on Digital Volt meter.

Galvanic cell wiring left open circuit when voltage readings not being taken.

upstream sequence.

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TABLE NO. 1

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TEST NO. 1

REACTOR KE

TUBE NO. 5079

DATE INSTALLED 12-5-65

Load Resistance	Galvanic Voltage - Millivolt Test						Date Time	Remarks
	1	2	3	4	5	6		
1 ohm	0	0	0	0	0	0	12-5-65 8:00 AM ↓	
10	0	0	0	0	0	0		
50	0	0	0	0	0	0		
100	0	0	0	0	0	0		
300	0	-1	-1	-1	0	0		
500	-1	-2	-1	-1	-1	0		
1K	0	-2	-2	-2	-1	0		
5K	-5	-11	-9	-7	-6	0		
10K	-11	-18	-16	-13	-11	0		
100K	-23	-42	-35	-23	-10	0		
1 ohm	0	0	0	0	0	0	12-6-65 10:00 AM ↓	
10	0	0	0	0	0	0		
50	0	0	0	0	0	0		
100	0	0	0	0	0	0		
300	0	-1	-1	0	0	0		
500	1	-3	-1	-1	-1	0		
1K	1	-5	-3	-2	-1	0		
5K	2	-20	-13	-7	-7	0		
10K	4	-29	-23	-11	-13	0		
100K	11	-71	-43	-24	-32	0		
1 ohm	14	11	6	9	12	52	12-7-65 1:30 PM ↓	
10	100	62	21	38	84	236		
50	220	105	27	53	198	380		
100	260	113	28	56	233	400		
300	313	120	29	57	270	---		
500	330	123	29	58	282	---		
1K	345	124	29	59	293	---		
5K	350	124	29	59	296	---		
10K	350	124	29	59	298	---		
100K	350	124	29	59	298	---		

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TABLE NO. 1

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TEST NO. 1

REACTOR KE

TUBE NO. 5079

DATE INSTALLED 12-5-65

Load Resistance	Galvanic Voltage - Millivolt Test						Date Time	Remarks
	1	2	3	4	5	6		
1 ohm 10 50 100 300 500 1K 5K 10K 100K	9 66 188 253 378 419 462 506 512 523	9 74 221 305 431 480 520 560 570 577	10 53 90 98 104 106 107 108 108 108	11 71 153 180 203 203 208 210 210 211	10 88 273 381 510 550 586 622 622 628	41 213 385 440 493 510 517 523 --- ---	12-8-65 1:00 PM ↓	
1 ohm 10 50 100 300 500 1K 5K 10K 100K	11 82 212 275 353 379 405 437 445 465	10 72 192 248 314 333 349 364 366 368	10 68 139 159 177 181 184 187 189 189	10 66 129 148 163 166 167 171 173 173	10 85 270 388 515 555 592 623 632 634	43 229 435 503 563 581 595 612 614 615	12-9-65 11:00 AM ↓	
1 ohm 10 50 100 300 500 1K 5K 10K 100K	12 90 220 278 350 375 394 413 415 416	9 68 183 237 299 317 325 337 338 342	10 72 164 197 227 234 253 258 259 261	10 67 148 175 200 208 211 215 216 216	11 90 276 385 516 557 595 629 634 638	49 254 471 534 585 610 624 638 643 646	12-10-65 2:00 PM ↓	

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TABLE NO. 1

TEST NO. 1

REACTOR KE

TUBE NO. 5079

DATE INSTALLED 12-5-65

Load Resistance	Galvanic Voltage - Millivolt Test						Date Time	Remarks
	1	2	3	4	5	6		
1 ohm 10 50 100 300 500 1K 5K 10K 100K	12 91 221 278 354 381 407 427 427 428	9 71 208 284 395 435 472 510 516 524	11 84 234 311 408 437 467 492 493 495	10 78 217 278 345 364 370 384 387 390	10 87 269 394 534 583 613 653 658 663	50 265 491 554 608 630 645 659 662 667	12-13-65 1:45 PM ↓	
1 ohm 10 50 100 300 500 1K 5K 10K 100K	10 76 202 266 344 374 402 440 450 458	10 83 253 372 543 605 666 726 734 739	13 102 287 400 558 607 656 710 721 732	12 100 322 450 610 664 721 783 792 798	12 94 279 391 546 596 648 707 719 735	56 315 560 640 712 730 756 756 757 758	12-15-65 2:00 PM ↓	
1 ohm 10 50 100 300 500 1K 5K 10K 100K	10 75 201 263 342 370 400 424 442 448	10 85 265 375 545 608 670 730 738 744	13 97 277 381 520 584 634 680 690 700	11 99 373 453 604 653 710 770 779 782	12 92 276 367 515 570 616 675 690 710	46 290 524 570 619 635 660 670 673 690	12-17-65 11:00 AM ↓	

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TABLE NO. 1

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TEST NO. 1

REACTOR KE

TUBE NO. 5079

DATE INSTALLED 12-5-65

Load Resistance	Galvanic Voltage - Millivolt Test 1						Date Time	Remarks
	1	2	3	4	5	6		
1 ohm 10 50 100 300 500 1K 5K 10K 100K	10 73 204 275 392 443 502 570 585 597	11 92 288 413 600 670 740 818 829 836	0 - - - - - - - - -	13 98 290 409 578 638 694 757 775 795	11 98 314 443 603 665 730 805 813 825	49 260 497 579 650 680 740 768 770 770	12-21-65 9:00 AM ↓	Test no. 3 wiring failure.
1 ohm 10 50 100 300 500 1K 5K 10K 100K	10 73 210 293 434 498 565 632 644 650	16 119 337 457 612 665 722 769 784 793	- - - - - - - - - -	11 80 245 346 506 561 612 662 672 685	12 92 277 390 540 598 650 704 718 730	55 280 503 590 664 694 719 740 747 746	12-22-65 1:30 PM ↓	Test no. 3 wiring failure. All voltage readings very erratic.
1 ohm 10 50 100 300 500 1K 5K 10K 100K	14 130 300 370 470 492 526 537 545 550	22 170 430 550 670 700 722 737 745 750	- - - - - - - - - -	13 91 280 380 460 491 530 560 564 570	17 120 290 370 450 460 500 503 504 514	37 207 383 460 500 540 550 560 560 560	12-28-65 9:00 AM ↓	Test no. 3 wiring failure. All voltage readings very erratic.

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TABLE NO. 1

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TEST NO. 1

REACTOR KE

TUBE NO. 5079

DATE INSTALLED 12-5-65

Load Resistance	Galvanic Voltage - Millivolt Test						Date Time	Remarks
	1	2	3	4	5	6		
1 ohm	32	46	45	45	45	46	1-3-66 9:30 AM ↓	All voltage readings very erratic.
10	200	264	243	220	244	274		
50	430	500	450	510	460	512		
100	515	568	520	570	525	575		
300	580	620	580	520	580	638		
500	605	630	604	647	610	640		
1K	620	606	620	655	620	640		
5K	640	607	630	655	630	640		
10K	660	613	645	660	640	640		
100K	660	630	650	660	645	643		
1 ohm	14	18	8	-	-	-	1-10-66 9:30 AM ↓	All voltage readings very erratic. Test discontinued. Amphenol plug at end of tube found to be full of water. Test removed 1-14-66
10	90	130	72	-	-	-		
50	275	360	170	-	-	-		
100	400	465	250	-	-	-		
300	520	600	380	-	-	-		
500	580	640	440	-	-	-		
1K	630	670	490	-	-	-		
5K	650	740	530	-	-	-		
10K	660	745	530	-	-	-		
100K	660	750	560	-	-	-		

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TABLE NO. 2

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TEST NO. 2

REACTOR KE

TUBE NO. 5079

DATE INSTALLED 1-14-66

Test Dummy No.	Spacer Material	Spacer Insulator		Ribs		Special Conditions
		Up Stream	Down Stream	Yes	No	
1	Aluminum	X	X		X	
2	Aluminum with type 304 stain- less steel plating.	X	X		X	
3	Aluminum	X	X		X	
4	Plated 304-SS	X	X		X	
5	Aluminum	X	X		X	
6	Aluminum	X	X	X		

All readings taken on Digital Volt meter.

Galvanic cell wiring left open when voltage readings not being taken.

Test assembly located downstream next to nozzle. Test spacers numbered in sequence upstream.

No voltage readings taken during first seven days after test installation due to a mismatch in amphenol connectors on the reactor rear face.

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TABLE NO. 2

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TEST NO. 2

REACTOR KE

TUBE NO. 5079

DATE INSTALLED 1-14-66

Load Resistance	Galvanic Voltage - Millivolt Test 1						Date Time	Remarks
	1	2	3	4	5	6		
1 ohm 10 50 100 300 500 1K 5K 10K 100K	0 0 1 2 5 8 14 33 38 48	0 -2 -7 -13 -31 -47 -74 -158 -202 -240	0 1 2 4 11 17 27 51 60 70	0 1 3 8 13 20 32 61 72 82	0 0 1 2 7 11 20 49 62 82	0 0 1 3 6 8 9 11 12 12	1-21-66 5:10 PM ↓	Reactor at low power level.
1 ohm 10 50 100 300 500 1K 5K 10K 100K	8 55 170 233 304 342 366 395 400 404	-1 -7 -26 -45 -78 -99 -114 -131 -134 -137	7 57 188 273 418 471 520 580 590 602	0 2 7 12 21 25 28 31 31 31	6 52 180 268 412 466 518 571 581 590	9 72 224 318 440 484 522 558 560 566	1-24-66 1:45 PM ↓	
1 ohm 10 50 100 300 500 1K 5K 10K 100K	8 61 174 237 332 371 409 447 455 461	0 -1 -5 -9 -15 -19 -21 -25 -25 -25	11 83 253 357 509 563 610 659 670 677	1 4 19 33 58 71 83 97 101 104	9 72 233 337 492 545 598 647 659 668	11 89 269 374 524 576 624 672 681 690	1-25-66 1:30 PM ↓	

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TABLE NO. 2

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TEST NO. 2

REACTOR KE

TUBE NO. 5079

DATE INSTALLED 1-14-66

Load Resistance	Galvanic Voltage - Millivolt Test 1						Date Time	Remarks
	1	2	3	4	5	6		
1 ohm 10 50 100 300 500 1K 5K 10K 100K	6 51 145 197 280 310 337 360 370 380	0 -2 -9 -14 -24 -27 -30 -34 -34 -34	8 61 197 285 428 476 530 585 595 603	1 4 17 30 55 68 81 96 99 102	6 52 181 270 420 477 530 585 596 606	8 68 212 305 446 498 551 601 611 620	1-27-66 2:00 PM	
1 ohm 10 50 100 300 500 1K 5K 10K 100K	9 69 185 245 319 346 368 391 397 403	-1 -7 -26 -41 -72 -86 -100 -114 -117 -120	10 77 226 321 475 528 572 640 656 667	0 2 7 13 24 30 38 45 48 51	9 66 219 320 481 542 598 662 677 688	11 80 248 350 496 554 605 658 672 682	2-4-66 1:15 PM	
Voltage Readings Between Test								
	MV			MV				
1-2 1-3 1-4 1-5 1-6 2-3 2-4 2-5 2-6	33 -13 16 -12 -11 -38 -3 -29 -27		3-4 3-5 3-6 4-5 4-6 5-6	33 -2 0 -30 -22 1		2-4-66 1:15 PM	Load resist- ance across leads between Minus readings indicates test unit no. on left is anodic. All others op- posite polarity.	

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TABLE NO. 3

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TEST NO. 3

REACTOR KW

TUBE NO. 3667

DATE INSTALLED 2-18-66

Test	Material	Spacer Insulator		Ribs		Special Conditions
		Up Stream	Down Stream	Yes	No	
1	Aluminum	X	X		X	
2	Plated 304-SS	X	X		X	
3	Aluminum	X	X		X	
4	Plated 304-SS	X	X		X	
5	Aluminum	X	X		X	
6	Aluminum	X	X	X		

All readings taken on Digital Volt meter.

Test 2 and 4 wiring shorted except when voltage readings were taken. Test 1, 3, 5, and 6 wiring left open except when voltage readings were taken.

Tube 3667 was installed new for this test.

Test assembly located downstream next to nozzle. Test numbered in sequence upstream.

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TABLE NO. 3

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TEST NO. 3

REACTOR KW

TUBE NO. 3667

DATE INSTALLED 2-18-66

Load Resistance	Galvanic Voltage - Millivolts Test 1						Date Time	Remarks
	1	2	3	4	5	6		
1 ohm 10 50 100 300 500 1K 5K 10K 100K	10 75 205 280 378 414 440 478 488 497	-1 -6 -27 -47 -88 -109 -134 -168 -174 -180	11 76 209 293 472 570 657 771 793 811	-1 -6 -25 -25 -89 -111 -140 -187 -193 -202	7 51 147 209 308 359 426 493 515 533	18 87 157 200 230 239 242 247 247 247	2-21-66 1:00 PM ↓	Readings on no. 6, erratic.
1 ohm 10 50 100 300 500 1K 5K 10K 100K	8 62 169 224 291 320 347 375 384 395	-1 -9 -37 -63 -118 -145 -175 -212 -220 -226	10 68 188 259 428 491 608 720 750 790	-1 -5 -20 -33 -65 -85 -115 -137 -145 -150	7 55 160 222 347 427 490 586 607 625	24 125 258 322 474 510 542 567 586 591	2-22-66 3:00 PM ↓	
1 ohm 10 50 100 300 500 1K 5K 10K 100K	7 58 156 208 280 310 330 355 363 373	-1 -10 -41 -69 -128 -161 -194 -235 -241 -247	9 64 179 247 406 483 580 697 720 750	-1 -6 -22 -37 -71 -92 -116 -154 -162 -166	7 55 153 214 323 403 481 547 585 598	23 125 247 390 450 510 535 - - -	2-23-66 2:30 PM ↓	Readings on no. 6 partically erratic.

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TABLE NO. 3

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TEST NO. 3

REACTOR KW

TUBE NO. 3667

DATE INSTALLED 2-18-66

Load Resistance	Galvanic Voltage - Millivolt Test D.						Date Time	Remarks
	1	2	3	4	5	6		
1 ohm 10 50 100 300 500 1K 5K 10K 199K ↓	7 52 141 195 264 288 310 338 346 354	-1 -11 -43 -72 -137 -169 -205 -250 -259 -266	8 59 168 236 385 467 548 663 691 715	-1 -4 -20 -35 -70 -92 -113 -148 -159 -170	6 48 145 206 320 412 476 565 581 597	21 114 235 275 450 490 520 --- --- ---	2-25-66 2:30 PM ↓	
1 ohm 10 50 100 300 500 1K 5K 10K 100K ↓	7 52 143 188 257 272 299 317 324 332	-1 -11 -45 -73 -142 -174 -213 -260 -269 -275	8 62 179 251 406 480 560 660 686 714	-1 -5 -21 -36 -73 -88 -111 -145 -156 -167	7 52 157 222 350 430 504 589 600 620	23 127 272 350 475 490 520 550 --- ---	2-28-66 2:30 PM ↓	
1 ohm 10 50 100 300 500 1K 5K 10K 100K ↓	6 48 132 176 232 266 290 309 314 321	-2 -11 -45 -74 -141 -177 -213 -262 -271 -281	8 60 173 243 399 470 539 660 684 719	-1 -5 -21 -35 -76 -87 -112 -147 -156 -162	6 49 151 217 340 408 476 562 590 597	20 116 258 300 412 430 490 520 --- ---	3-2-66 3:00 PM ↓	

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TEST NO. 3

REACTOR KW

TUBE NO. 3667

DATE INSTALLED 2-18-66

Load Resistance	Galvanic Voltage - Millivolt Test						Date Time	Remarks
	1	2	3	4	5	6		
1 ohm 10 50 100 300 500 1K 5K 10K 100K	6 46 130 175 233 259 290 313 318 329	-1 -11 -42 -68 -130 -167 -201 -251 -259 -268	8 59 171 243 390 465 547 663 693 727	-1 -4 -17 -27 -51 -66 -84 -109 -112 -121	7 52 159 228 364 437 517 615 634 652	23 131 292 379 480 530 550 575 --- ---	3-7-66 9:30 AM ↓	
1 ohm 10 50 100 300 500 1K 5K 10K 100K	5 38 113 155 214 240 264 290 300 307	-1 -10 -37 -61 -121 -155 -188 -239 -250 -255	6 47 146 211 350 420 498 617 647 685	-1 -4 -16 -26 -49 -62 -77 -108 -110 -113	5 41 135 199 324 393 470 570 506 606	19 110 254 337 460 490 544 592 --- ---	3-10-66 1:30 PM ↓	
1 ohm 10 50 100 300 500 1K 5K 10K 100K	5 42 119 161 216 240 262 283 289 296	-1 -10 -42 -71 -142 -180 -219 -282 -294 -306	7 52 157 224 257 419 504 618 656 677	-1 -6 -24 -39 -87 -103 -127 -171 -177 -187	6 47 144 210 336 401 482 570 590 610	13 49 244 334 464 517 540 615 627 650	3-18-66 2:00 PM ↓	

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TABLE NO. 3

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TEST NO. 3

REACTOR KW

TUBE NO. 3667

DATE INSTALLED 2-18-66

Load Resistance	Galvanic Voltage - Millivolt Test						Date Time	Remarks
	1	2	3	4	5	6		
1 ohm 10 50 100 300 500 1K 5K 10K 100K	5 42 121 163 217 244 281 307 319 329	-1 -9 -35 -60 -121 -153 -196 -258 -274 -288	7 53 161 231 367 441 529 689 738 778	-1 -4 -16 -26 -53 -68 -90 -123 -131 -138	7 52 160 231 366 438 525 643 673 700	15 105 274 376 508 561 617 692 709 723	3-23-66 2:15 PM ↓	
1 ohm 10 50 100 300 500 1K 5K 10K 100K	5 44 128 174 233 261 285 309 318 328	-1 -9 -36 -60 -122 -151 -197 -259 -276 -290	7 52 162 233 365 443 527 687 733 774	0 -3 -15 -27 -56 -69 -91 -122 -130 -136	7 49 146 210 336 421 520 639 668 699	16 103 271 377 509 558 614 690 707 721	3-25-66 2:00 PM ↓	
1 ohm 10 50 100 300 500 1K 5K 10K 100K	5 44 131 178 240 262 283 305 313 318	-1 -8 -34 -58 -113 -144 -185 -240 -253 -264	7 53 157 223 352 426 510 640 725 765	-1 -5 -20 -33 -63 -79 -100 -134 -147 -150	7 50 151 215 340 415 494 614 660 683	16 103 246 328 478 532 585 665 690 705	3-28-66 1:15 PM ↓	

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TEST NO. 3

REACTOR KW

TUBE NO. 3667

DATE INSTALLED 2-18-66

Load Resistance	Galvanic Voltage - Millivolt Test						Date Time	Remarks
	1	2	3	4	5	6		
1 ohm	5	-1	7	-1	7	15	3-31-66 2:15 PM ↓	
10	42	-8	53	-3	51	106		
50	124	-35	160	-16	162	273		
100	171	-62	233	-25	231	378		
300	218	-124	365	-54	342	506		
500	247	-157	443	-69	426	557		
1K	283	-197	529	-92	527	614		
5K	309	-259	689	-123	645	690		
10K	318	-276	741	-132	674	710		
100K	329	-292	772	-137	702	725		
1 ohm	6	-1	8	-1	9	20	4-6-66 1:30 PM ↓	
10	49	-9	63	-6	61	122		
50	133	-35	186	-23	178	278		
100	175	-59	262	-37	247	364		
300	225	-113	418	-71	370	506		
500	257	-142	490	-88	435	550		
1K	275	-180	610	-112	507	596		
5K	294	-230	760	-146	589	640		
10K	302	-241	790	-152	601	658		
100K	310	-250	840	-159	620	670		

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TABLE NO. 4

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TEST ASSEMBLY SPECIFICATIONS

TEST NO. 4&5 REACTOR KW TUBE NO. 5-4453
4-3667 DATE INSTALLED 5(5-16-66)
4(4-26-66)

Test Dummy No.	Spacer Material	Spacer Insulator		Ribs		Special Conditions
		Up Stream	Down Stream	Yes	No	
1	Aluminum	X		X		No. 1 loaded with 3 ohm resistor.
2	Aluminum		X	X		No. 2 loaded with 1 ohm resistor.
3	304-SS plated	X	X		X	No. 3 loaded with 3 ohm resistor.
4	Aluminum	X	X		X	No. 4 loaded with 3 ohm resistor.
5	Nickle plated	X	X		X	No. 5 loaded with 3 ohm resistor.
6	Aluminum		X		X	No. 6 loaded with 3 ohm resistor.

Test No. 4 Notes Spacers 1 & 2

No data recorded during first week of operation due to malfunction
of multipoint.

All data taken on multipoint recorder with 0-100 mv scale - 11 inch chart.

Test spacer no.1 in contact with tube nozzle.

Test No. 5 Notes Spacers 3, 4, 5, & 6

Data recorded on same multipoint recorder used for test no. 4

Test spacer no. 6 located one spacer space from downstream fuel element. Other
test spacers located in following sequence downstream -- no: 6, blank spacer
no. 5, no. 4, no. 3, blank spacer.

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TABLE NO. 4

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RECORDED GALVANIC VOLTAGES

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TEST NO. 4 & 5

Date	Time	No. - Millivolts						Remarks
		#1	#2	#3	#4	#5	#6	
5-18-66	10:00 AM	19	48	9	24	5	28	
	12:00 M	19	49	9	24	5	27	
	3:00 PM	20	53	10	25	5	28	
	6:00 PM	22	59	10		3	29	
	9:00 PM	21	55	10		3	29	
	12:00 M	20	50	10		2	29	
	6:00 AM	20	52	9		2	29	
5-19-66	10:00 AM	20	53	10		3	28	
	6:00 PM	22	57	10		2	29	
5-20-66	6:00 AM	21	55	8		2	28	
	10:00 AM	21	54	9		3	28	
	6:00 PM	21	53	9		5	28	
5-21-66	6:00 AM	20	49	7		1	28	
	10:00 AM	19	48	7		2	28	
	6:00 PM	19	47	7		5	28	
5-22-66	6:00 AM	18	43	6		2	28	
	10:00 AM	18	42	6		2	28	
	6:00 PM	18	42	6		2	28	
5-23-66	6:00 AM	18	42	6		1	28	
	10:00 AM	18	42	5		2	27	
	6:00 PM	18	42	5		1		
5-24-66	6:00 AM	18	42	6		1		
	10:00 AM	18	40	6		1		
	6:00 PM	18	42	5		0		
5-25-66	6:00 AM	17	41	5		-2		
	10:00 AM	17	40	5		-2		
	6:00 PM	17	40	4		-4		
5-26-66	6:00 AM	17	40	4		-4		
	10:00 AM	17	41	4		-5		
	6:00 PM	17	40	3		-8		
5-27-66	6:00 AM	--	--	4		-6		
	10:00 AM			4		-5		
	6:00 PM			4		-8		
5-28-66	6:00 AM			4		-5		
	10:00 AM			4		-7		
	6:00 PM			4		-8		
	8:00 PM			3				
		erratic ↓	erratic ↓		↓		↓	End of test recording

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TABLE NO. 5

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TEST ASSEMBLY SPECIFICATIONS

TEST NO. 6

REACTOR KW

TUBE NO. 3667

DATE INSTALLED 6-9-66

Test	Materials	Spacer Insulator		Ribs		Special Conditions
		Up Stream	Down Stream	Yes	No	
1	Aluminum	X		X		No. 1 not recorded.
2	Aluminum		X	X		No. 2 loaded with 5 ohm resistor.

All data taken on strip chart recorder, 0-100 mv with zero setting adjusted to 10 mv.

Test assembly located so that test assembly. No. 2 insulated from no. 1 but not from upstream elements.

Reactor operated two short time periods previous to this startup. No data recorded during first two reactor operating periods.

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TABLE NO. 5

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RECORDED GALVANIC VOLTAGES

TEST NO. 6

DATE	TIME	TEST VOLTAGE MV	DATE	TIME	TEST VOLTAGE MV
6-22-66 ↓	4:00 AM	0	6-23-66 ↓	3:00 PM	61
	5:00	5		4:00	63
	6:00	7		5:00	64
	7:00	8		6:00	65
	8:00	9		7:00	66
	9:00	11		8:00	67
	10:00	20		9:00	66
	11:00	25		10:00	65
	12:00	26		11:00	63
	1:00 PM	35		12:00	65
	2:00	46	6-24-66 ↓	1:00 AM	67
	3:00	58		2:00	68
6-23-66 ↓	4:00	55		3:00	69
	5:00	52		4:00	69
	6:00	47		5:00	68
	7:00	58		6:00	69
	8:00	68		7:00	67
	9:00	72		8:00	65
	10:00	74		9:00	64
	11:00	65		10:00	63
	12:00	68		11:00	64
	1:00 AM	72		12:00	65
	2:00	75		1:00 PM	65
	3:00	74		2:00	64
6-23-66 ↓	4:00	73		3:00	63
	5:00	72		4:00	63
	6:00	73		5:00	64
	7:00	66		6:00	66
	8:00	65		7:00	66
	9:00	63		8:00	67
	10:00	60			
	11:00	58			
	12:00	55			
	1:00 PM	55			
	2:00 PM	57			

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TABLE NO. 6

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TEST ASSEMBLY SPECIFICATIONS

TEST NO. 7

REACTOR KW

TUBE NO. 3667

DATE INSTALLED 8-5-66

Test Dummy No.	Spacer Materials	Spacer Insulator		Ribs		Special Conditions
		Up Stream	Down Stream	Yes	No	
1	Aluminum	X		X		No. 1 not recorded.
2	Aluminum		X	X		No. 2 loaded with 5 ohm resistor.

All data taken on strip chart recorder, 0-100 mv with zero setting adjusted to 10 mv.

Test assembly located so that test spacer no.1 in contact with nozzle assembly. No. 2 insulated from no. 1 but not from upstream spacer elements.

No data recorded until two days after reactor start-up. Test assembly conditions same as for test no. 6.

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TABLE NO. 6

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RECORDED GALVANIC VOLTAGESTEST NO. 7

DATE	TIME	TEST mV	REMARKS
8-30-66	11:00 AM	55	
9-2-66	1:10 PM	59	
9-15-66	10:00 AM	48	
9-15-66	7:00 PM	55	
9-16-66	5:00 AM	52	
9-16-66	5:00 PM	55	
9-16-66	11:00 PM	52	
9-17-66	7:10 AM	52	
9-17-66	3:00 PM	53