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IN-REACTOR MONITORING OF ZIRCALOY-2 PRTR PRESSURE TUBES, PART III

JULY 1963 - NOVEMBER 1963

P. J. PANKASKIE

DECEMBER 1963

HANFORD LABORATORIES

HANFORD ATOMIC PRODUCTS OPERATION
RICHLAND, WASHINGTON

GENERAL ELECTRIC

AEC-GE RICHLAND, WASH.

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By

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Materials Development
Reactor and Fuels Research and Development Operation
Hanford Laboratories

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INTRODUCTION

This is the third in a series of report on a surveillance program of in-reactor monitoring of Zircaloy-2 pressure tubes in the Plutonium Recycle Test Reactor (PRTR). The PRTR represents one of the first major elevated temperature applications of Zircaloy-2 as a load bearing structural material. In-reactor monitoring consists of (1) measuring the process tube inside diameters to detect creep, (2) measuring the gas gap between the process and aluminum calandria shroud tubes to indirectly detect bowing, (3) examining the process tube with a borescope-TV combination to detect mechanical damage or unusual localized corrosion areas, and (4) measuring the depth of marks caused from mechanical damage or localized corrosion.

The results of in-reactor inspections made before July, 1962 were reported in HW-73701 REV and HW-74731.[1, 2] The results of inspections made from July,1962 through November,1963 are reported here.

SUMMARY AND CONCLUSIONS

From July, 1962, through November, 1963, all Zircaloy-2 pressure tubes in all 85 process channels of the PRTR were inspected at least once, and a few were inspected several times. These inspections showed that approximately 1700 new fretted areas formed in the pressure tubes. There are now approximately 3200 fretted areas in all tubes in the PRTR.

An increase in fretted areas associated with the fuel element end bracket spacers appears to be roughly proportional to the number of times fuel elements were charged into each pressure tube.

During this reporting period, there was a significant increase in the number of fretted areas associated with single fuel rod wire wraps as compared to the number associated with end bracket spacers.

There was no observable fretting corrosion associated with the circumferential fuel bundle bands on the Al-Pu or mixed oxide type fuel elements.

Enlarging the contact area of the end bracket spacers from ~1.5 x 12.5 mm (~1/16 x 1/2 in.) to ~6 x 12.5 mm (~ 1/4 x 1/2 in.) significantly reduced the severity of tube wall penetration by fretting. In no case did penetrations, associated with enlarged pads, exceed 0.025 mm (0.001 in.). There is some reason to believe that end bracket spacer pad enlargement also caused a decrease in severity of fretting associated with single rod spiral wire wraps but apparently had no effect on incidence.

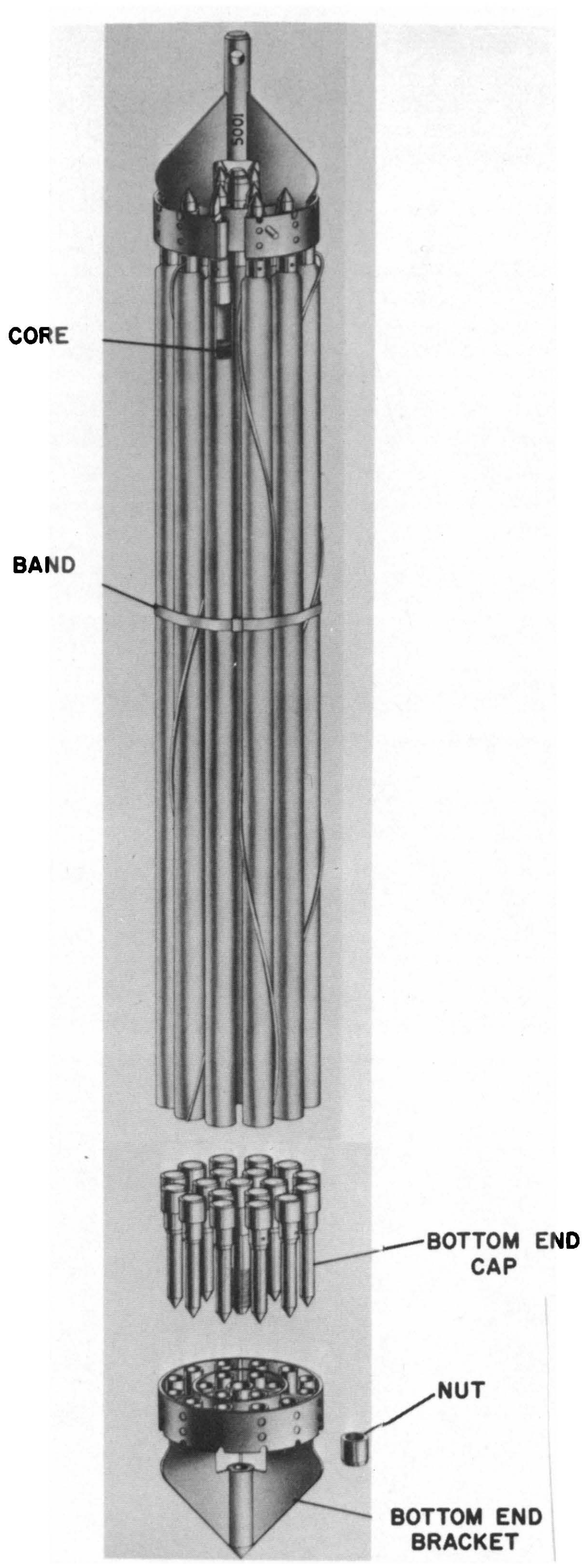
Five pressure tubes were discharged during this reporting period. Two of these five were discharged because of suspected defects with depths of ~1/2 mm (~0.020 in.) or greater.

DISCUSSION

Fuel Geometry

During this reporting period, the PRTR used fuel elements with a 19-rod cluster configuration and core materials of UO_2 and PuO_2. The UO_2 elements are constructed differently from Al-Pu and mixed oxide elements. The Al-Pu and mixed oxide fuel elements are essentially the same except for the differences in overall weight. The essential structural difference between these and the UO_2 element is that the 19-rod bundle is held together by circumferential bands rather than a spiral bundle wire wrap as is the case for the UO_2 element (see Figure 1). Since about May, 1962, no new UO_2 spiral wire wrapped fuel elements were manufactured for use in the PRTR.

Beginning about May, 1962, new mixed oxide elements were constructed with enlarged area spacer pads at the upper and lower end brackets. These enlarged area pads are about 6 mm wide and 12 mm long (1/4 x 1/2 in.). Following the whole reactor inspection of June, 1962, a recommendation was made to enlarge the spacer pads on all elements then in the PRTR, providing it could be done without excessive damage to fuel elements. As a



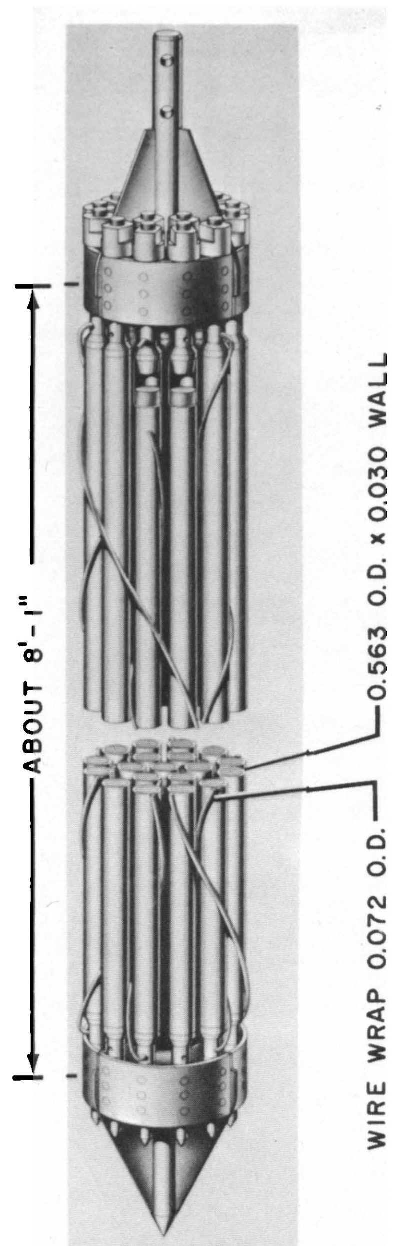


FIGURE 1

19-Rod PRTR Fuel Elements

PuAl Type (left)

UO_2 Type (above)

result, all mixed oxide elements were repadded with 6 x 12 mm (1/4 x 1/2 in.) spacers. None of the UO_2 or Al-Pu type fuel elements were repadded.

The average number of UO_2 type fuel elements has decreased from 30 to 10 during this reporting period.

Visual Inspections

Since June, 1962, 110 visual inspections in the 85 process channels were made. These inspections show that, during this inspection period, the number of fretted areas in the pressure tubes has roughly doubled, and there are now approximately 3200 fretted areas distributed throughout the 8 ft active lengths of the pressure tubes (see Appendix B). The fretted areas are categorized according to location and cause of fretting as follows:

(1) vertical marks associated with the spacer pads on the bracket at the top end of the fuel element
(2) vertical marks associated with the spacer pads on the bracket at the bottom end of the fuel element
(3) marks about 15° from vertical and associated with the wire wrap on individual fuel rods
(4) marks about 45° from vertical and associated with the bundle wire wrap which spirals about the periphery of the bundle of 19 individual fuel rods that make up a PRTR fuel element
(5) unclassified marks whose origin cannot be related to any of the above.

Appendix B shows the distribution of fretted areas and unclassified markings in the pressure tubes in accordance with the above categories. Since June, 1962, at which time all pressure tubes were inspected during one reactor outage, an average of about eight tubes were visually examined each reactor operating month. Several process channels were examined more frequently.

Four process channels were reorificed to provide a flow rate about 7% above average to determine whether a slight increase in flow rate would increase the incidence and/or severity of fretting corrosion. There is not yet a clear cut effect. In fact, for these four process channels (1641, 1643, 1746, 2047) the increase in number of fretted areas appears to be less than the average for all process channels even though the four process channels operated for at least several months with spiral wire wrapped UO_2 fuel elements.

In about May, 1962, the first experimental "wide pad" (~ 6 x 12 mm) mixed oxide fuel element was charged into the PRTR. This element was charged into a process channel in which a new pressure tube was also installed to determine clearly the effect of enlarging the area of the end bracket spacer pads which contact the inside surface of the pressure tube. These initial experiments were made in one of the two process channels which had previously exhibited the most severe fretting with both UO_2 and Al-Pu fuel elements. Repeated visual examinations clearly showed that the severity of the fretting corrosion associated with the enlarged area end bracket spacer pads was reduced. Based on measurements made in subsequent inspections, it is apparent that enlarging the pad area has substantially reduced the severity of fretting corrosion associated with the end bracket spacer pads. To date no fretted areas, associated with the enlarged area pads, were found that exceeded 0.025 mm (0.001 in.) in depth. It also appears that "repadding" reduced to some extent the severity of fretting corrosion associated with the spiral wire wraps on individual fuel rods. There is, however, no evidence that the incidence of fretting corrosion has been altered.

Since the number of UO_2 fuel elements used in the PRTR was generally diminishing, and since repadding was not expected to alter either the incidence or severity of fretting associated with bundle wire wraps, none of the UO_2 type fuel elements were repadded. For similar reasons, none of the Al-Pu fuel elements were repadded.

Considering all observations made since June, 1962, it appears that the overall severity of fretting corrosion is substantially less than was the case for reactor operation before June, 1962. Since June, 1962, five new marks, with depths greater than 0.25 mm (0.010 in.) have been found in four process channels (see Appendix A). Three of these marks originated through fretting corrosion (two associated with fuel element end bracket spacer pads and one associated with the spiral wire wrap on a single fuel rod). The origin of the other two marks are unknown and they do not now appear to be attributable to fretting action. On the whole, most newly fretted areas are less than 0.025 cm (0.001 in.) deep.

Since June, 1962, there has been an average of about 10 UO_2 type fuel elements used in the PRTR that were neither repadded nor redesigned. It appears that factors other than enlargement of the end bracket spacer pads on the mixed oxide fuel elements helped decrease the severity of frettting corrosion. While there are no clear cut observations to define all such factors, one that may have contributed to the reduction in severity of fretting corrosion was the replacement of the straightening vane just upstream of the inlet tee on the lower ring header. During decontamination of the primary coolant system in the latter part of 1962 a broken vane on the flow straightener was found. Failure was generally attributed to corrosion fatigue.[3]

Process channel inspection in June, 1962, showed that the majority of severely fretted process channels were close to and to the left of the inlet tee of the lower ring header. Process channels close to and to the right of the inlet tee were generally less affected. Inspection data, obtained after replacement of the flow straightener, shows no such patterns. Hence, one is inclined to conclude that the failed vane of the flow straightener did adversely affect both the incidence and severity of fretting in some of the process channels. Moreover, if the same basic cause of the severe fretting were also the cause for failure of the one vane in the flow straightener, a more uniform pattern of severe fretting in all process channels adjacent to the inlet tee would have been expected.

There now appears to be some indication that certain process channels sustain more fretting when charged with a particular fuel element. Table I lists process channels which have sustained appreciably more fretting than is typical. In about one half of these process channels, the greater incidence of fretting can be associated with a particular fuel element. In the remainder of these cases, it is attributable to either or both of two fuel elements. In Process Channel 1653, at least 52 of 71 new fretted areas were formed during the period when Fuel Element 1049 was in the channel. Both the incidence and severity was greater than average for the PRTR.

Two moderately fretted areas associated with the narrow spacer pads of the end brackets on the fuel elements were found in Process Channel 1354. In this channel the general severity of fretting is above average but the incidence is only moderately greater than average. Between the inspections of June, 1962, and June, 1963, the only fuel elements charged into this process channel were 5053 and 5066. The narrow end bracket spacer pads of either or both of these Al-Pu fuel elements caused moderately severe fretting. Process Channel 1548 sustained 28 new fretted areas while charged with Fuel Element 1099. Inspection of this fuel element in December, 1963, revealed a broken wire wrap. Although this fuel element was recharged in Process Channel 1548 eight times, it is believed that the greater incidence of fretting is attributable to the broken wire wrap since the bulk of the new fretted areas are of the bundle wire wrap category (see Appendix B). One might suspect that if this fuel element had not been recharged so frequently the severity of fretting might have been greater and the incidence reduced.

Process Channel 1647 incurred a great incidence of fretting in both the single rod and bundle wire wrap categories while charged with Fuel Elements 1067 and 1039. Based on residence time and number of rechargings, it is believed that most of the fretting was associated with Fuel Element 1067. After final discharge, Fuel Element 1067 was found to have a broken fuel rod wire wrap. The time during which this wire was broken is not known. Perhaps the incidence of fretting in the single rod wire wrap category is attributable to the broken rod wire wrap. However, the greatest incidence of

TABLE I

FRETTING CORROSION BEHAVIOR OF FUEL ELEMENT AND PROCESS CHANNEL COMBINATIONS SINCE JUNE, 1962[a]

Process Channel	New Fretted Areas	Element	Element Type	Residence, Months	Times Charged Into Process Channel	Fretted Areas Associated With Listed Fuel Element
1346[b]	52	5090 or	Al-Pu	7	4	42
		5171	Moxtyl	1	2	
1354	20	5053 or	Al-Pu	2	2	20 (one 0.010 in. one 0.015 in. at U&L FES; see Appendix B)
		5066	Al-Pu	4	2	
1445	30	5087 or	Al-Pu	2	2	30
		5060	Al-Pu	4	2	
1457	32	5115 or	Moxtyl	2	2	32
		5131	Moxtyl	4	2	
1546	36	5074 or	Al-Pu	3	2	36
		5030	Al-Pu	5	3	
1548[c]	28	1099	UO_2	5	8	28
1552	43	1098	UO_2	5	4	43
1558	41	5113 or	Moxtyl	3	2	32
		5140	Moxtyl	10	4	
1647[d]	54	1067 or	UO_2	7	4	54
		1039	UO_2	1	1	
1659	29	1097	UO_2	4	4	29
1653	71	1049	UO_2	6	5	52 (one 7 mil UFES, one 12 mil SRW; see Appendix B)
1956	53	1034	UO	5	5	33+
2053	37	1030	UO_2	5	2	25 (one 6-8 mil mark; see Appendix B)
		1049	UO_2	1	1	
		1050	UO_2	1	2	
1350[e]	20	1021	UO_2	3	3	20
		1033	UO_2	1	1	
		1034	UO_2	2 1/2	3	
1651	25	1100	UO_2	6	4	25

(a) The fuel elements listed here are only those which exhibit unusual corrosion behavior.

(b) Experienced difficulties in charging Fuel Element 5171 on April, 1963.

(c) When examined December, 1963, Fuel Element 1099 had a broken wire wrap.

(d) When examined June, 1963, Fuel Element 1067 had a broken single fuel rod wire wrap.

(e) When examined February, 1963, Fuel Element 1050 had a broken wire wrap.

fretting was in the bundle wire wrap category for which there is no obvious reason. Process Channel 1350 operated with UO_2 Fuel Elements 1050, 1021, 1033, and 1034 between the inspections of 6/62 and 6/63. During this period there was an increase of 13 fretted areas in bundle wire wrap category. Subsequent fuel element inspections disclosed a broken wire wrap on Fuel Element 1050; broken wraps are currently the prime suspects for the cause of the bundle wire wrap fretting. Fuel Element 1034, however, was charged into this process channel 3 times for a total residence time of about 2 1/2 months. Since the performance of Fuel Element 1034 appears to have been poor in Process Channel 1956, it may also have been the cause of the fretting in Process Channel 1350. If so its performance appears to have been somewhat better in Process Channel 1350 than in Process Channel 1956. Fuel Element 1100 was charged into Process Channel 1651 only four times for a total residence of about 6 months. During this period 25 new fretted areas were formed of which 17 were in the bundle wire wrap category. Examination in December, 1963, disclosed a broken wire wrap which is believed to be the cause of the bundle wire wrap fretting.

From data in Table I, it is apparent that unusual fretting behavior is not readily related to defective fuel elements; and, hence, there must be other reasons for such behavior. Another possibility is the relative differences in the diameters of fuel elements and pressure tubes. However, at this time, there are not sufficient data to attempt any such correlations.

The pressure tubes from Process Channels 1358 and 1558 were discharged during this reporting period for suspected defects. Figure 2 shows a positive replica of the suspected defect found in Process Channel 1358. In-reactor measurements showed this suspected defect to be about 0.5 mm (0.020 in.) deep, 3 mm (1/8 in.) wide, and 6 mm (1/4 in.) long. Destructive examinations confirmed these measurements. The origin of this suspected defect is not now known. Its location in the pressure tube does not correspond to fuel element end brackets, spiral wire rod or bundle wraps, or fuel element bands. Hence, it does not appear that this suspected defect originated from fretting action.

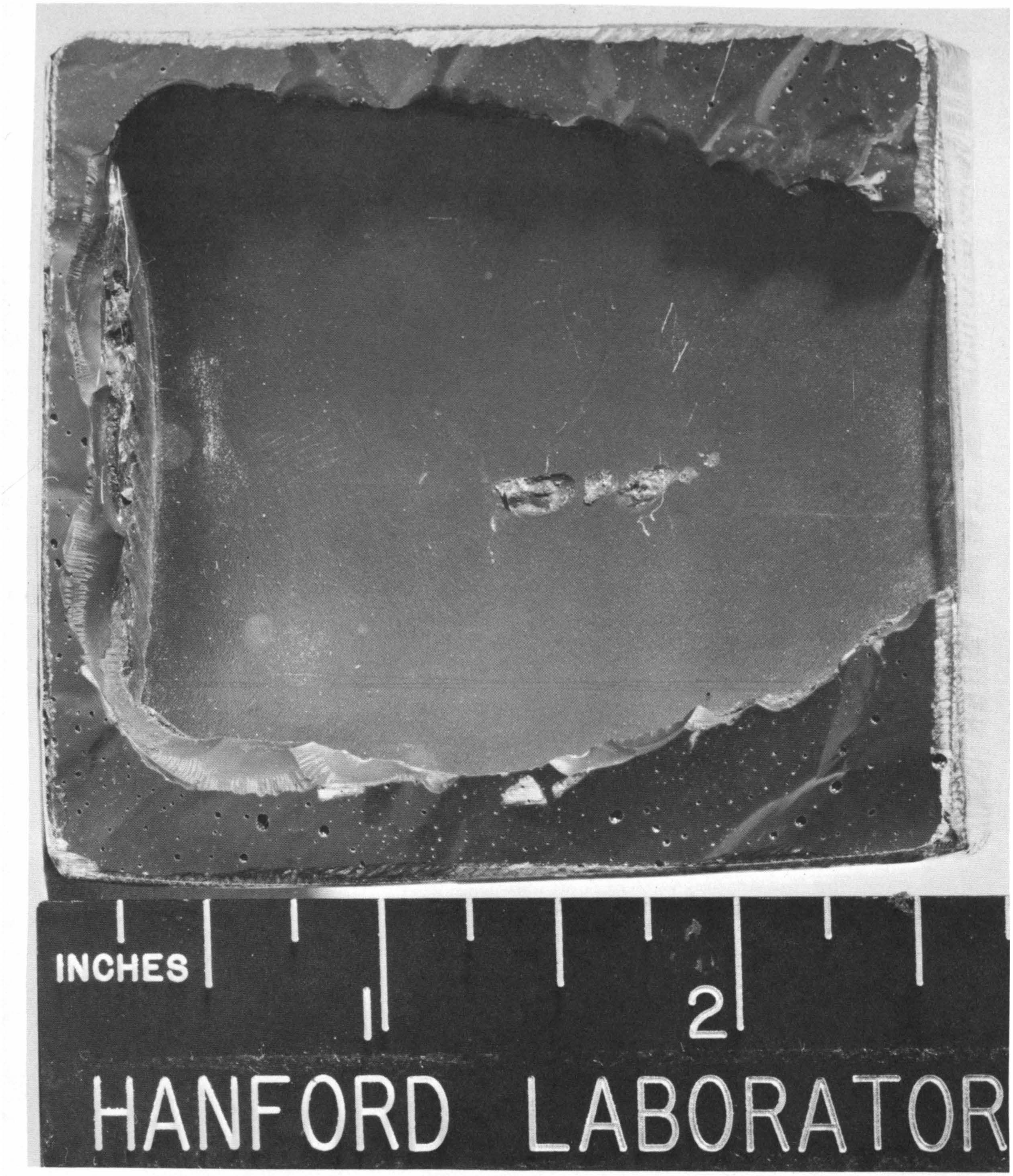


FIGURE 2

Suspected Defect Inside Tube in Process Channel 1358

~2-1/2X

Negative No. 0632307

AEC-GE RICHLAND, WASH.

Figure 3 shows the suspected defect found in Process Channel 1558. Its shape, location and orientation also indicate that this suspected defect did not originate from fretting action. In-reactor measurements and examination suggest a "blister" type defect. Its radial dimension is about 0.5 mm (0.020 in.). This pressure tube has not yet been destructively examined.

Diameter and Gas Gap Measurements

Inside diameter and gas gap measurements were made during each scheduled inspection through about June, 1963. At this time, these measurements were discontinued because of excessive radiation damage to these measuring instruments. These measurements will be resumed upon installation of new instruments scheduled for January, 1964. Results of measurements through June, 1963, showed no significant changes in inside diameter and therefore little or no creep deformation. Gas gap measurements showed that the helium gas annuli for those tubes measured were within specified limits.

ACKNOWLEDGMENTS

The author wishes to express his appreciation to L. D. Turner for his helpful discussions and valuable reactor operations information and to D. R. Doman and P. M. Jackson for their help in conducting the in-reactor inspection.

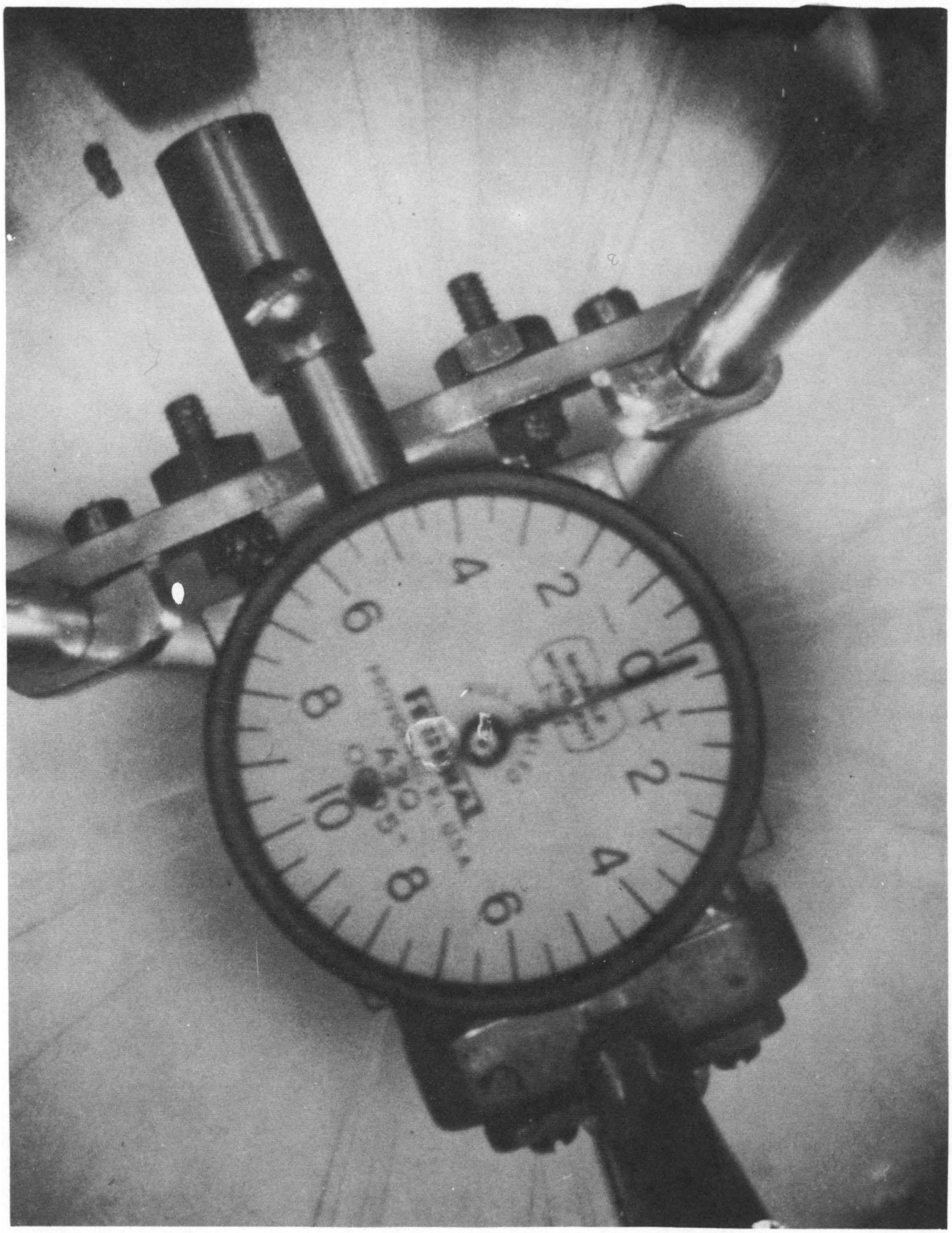


FIGURE 3

Suspected Defect Inside Tube in Process Channel 1558
~2-1/2X

Negative No. 0632607-1
AEC-GE RICHLAND, WASH

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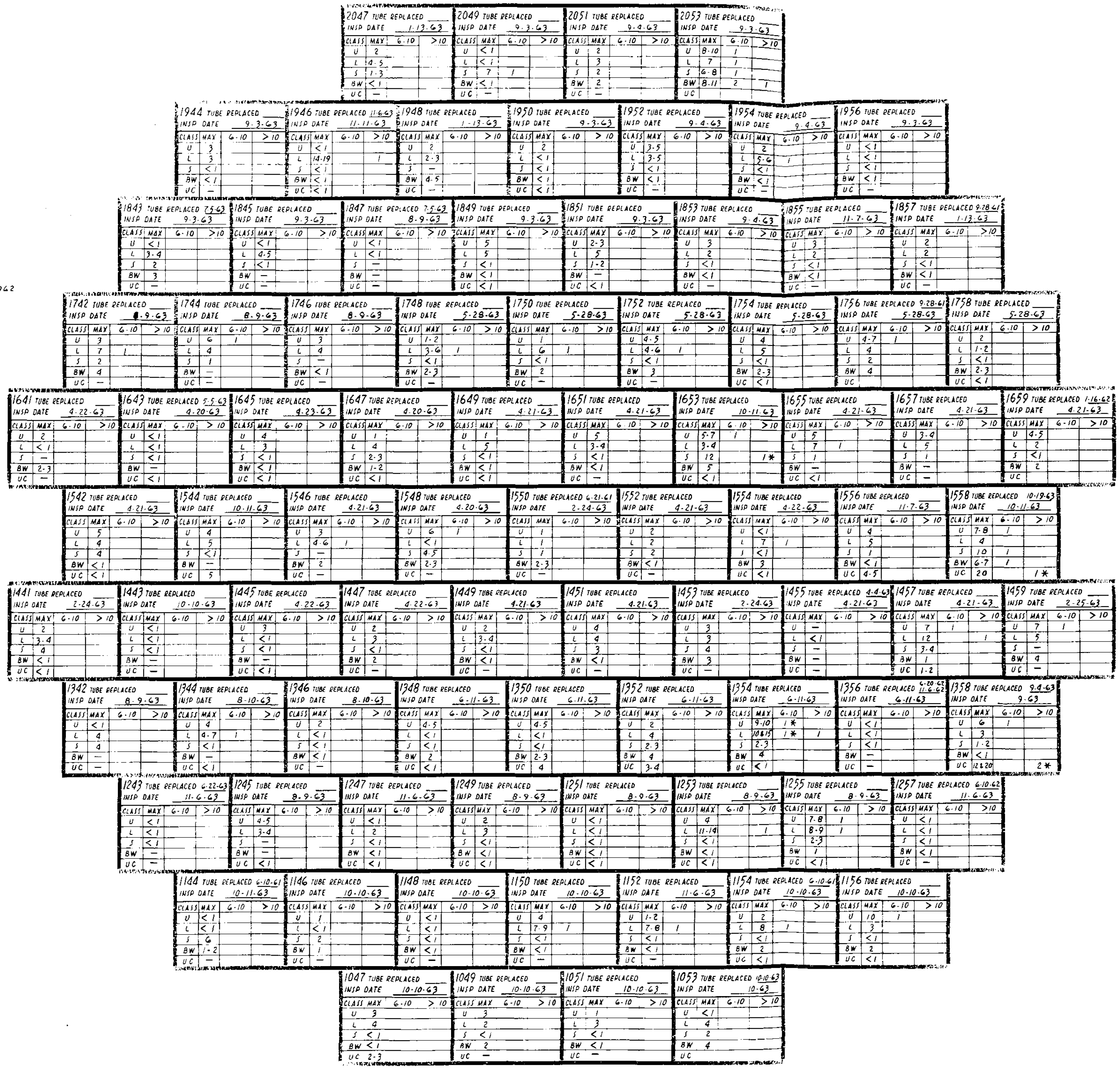
2. D. R. Doman and P. J. Pankaskie. In-Reactor Monitoring of Zircaloy-2 PRTR Pressure Tubes, Part II, May and June 1962, HW-74731. August, 1962.

3. J. J. Cadwell. Quarterly Progress Report, Metallurgy Research, October, November, and December, 1962, HW-76228. January, 1963.

2047 TUBE REPLACED			
INSP DATE			
CLASS	MAX	6-10	> 10
U			
L			
S			
BW			
UC			

U UPPER END BRACKET
L LOWER END BRACKET
S SINGLE ROD WIRE WRAP
BW BUNDLE WIRE WRAP
UC UNIDENTIFIED AS TO ORIGIN

* NEW FRETTED AREAS SINCE JUNE 1962



APPENDIX A

PRTR Process Tube Inspection

APPENDIX B

SUMMARY OF INSPECTIONS SINCE MAY 1962

P. C.	Inspection Dates	LFES	UFES	BW	SRW	Uncl.	Totals	Change
1047	6-62	4	3	3	--	3	13	--
	10-63	10	11	12	4	2	39	26
1049	6-62	2	4	15	--	4	25	--
	10-63	8	9	16	6	3	42	17
1051	6-62	6	2	7	2	4	21	--
	10-63	15	15	8	4	--	42	21
1053	5-62	3	1	1	--	--	5	--
	2-63	3	3	9	2	--	18	13
	10-63	12	3	9	2	--	27	9
1144	6-62	7	5	6	2	1	21	--
	10-63	9	11	17	6	--	43	22
1146	6-62	8	4	10	4	--	26	--
	10-63	11	5	16	4	--	36	10
1148[(a)]	5-62	14	4	--	--	--	18	--
	10-63	23	13	--	11	3	50	30
1150[(a)]	6-62	8	5	--	1	2	16	--
	10-63	21	16	1	5	--	43	27
1152	6-62	6	3	1	2	1	13	--
	11-63	12	7	2	6	--	27	14
1154[(a)]	6-62	4	2	13	2	--	21	--
	10-63	15	10	13	8	3	49	28
1156[(b)]	6-62	5	2	3	1	1	12	--
	2-63	8	2	9	2	--	21	9
	10-63	10	5	7	5	10	37	16
1243	New tube installed on 6-22-62							
	12-62	1	2	--	--	--	3	--
	11-63	4	6	--	8	--	18	15
1245	6-62	10	8	--	--	1	19	--
	8-63	15	14	--	--	2	31	12
1247	6-62	6	4	--	--	--	10	--
	11-62	9	6	--	--	--	15	5
	11-63	11	9	4	5	1	30	15
1249[(a)]	6-62	6	9	--	3	2	20	--
	8-63	16	12	--	15	5	48	28
1251	6-62	3	2	2	--	1	8	--
	8-63	6	7	5	--	2	20	12

APPENDIX B (contd.)

P.C.	Inspection Dates	LFES	UFES	BW	SRW	Uncl.	Totals	Change
1253[b]	6-62	6	5	4	6	4	25	--
	8-63	13	13	4	6	--	36	11
1255	6-62	5	4	5	3	4	21	--
		12	8	2	2	2	26	5
1257	New tube installed 6-10-62							
	12-62	1	--	--	--	--	1	--
	11-63	10	4	--		2	16	15
1342	6-62	5	1	--	7	--	13	--
	8-63	11	4	--	5	--	20	7
1344	6-62	4	3	--	2	5	14	--
	8-63	9	7	--	11	2	29	15
1346[c]	6-62	7	3	--	--	--	10	--
	8-63	23	10	10	19	--	62	52
1348	5-62	1	1	1	--	--	3	--
	1-63	5	4	4	--	--	13	10
	6-63	8	9	10	5	3	35	22
1350	6-62	4	4	28	6	--	42	--
	6-63	7	8	41	6	--	62	20
1352[a]	6-62 (Broken wire	5	4	3	6	2	20	--
	wrap found on F.E. 1050 on 2-63)	16	10	9	7	6	48	28
1354[b]	6-62	8	5	1	8	4	26	--
	6-63	14	11	4	12	6	46	20
1356	New tube installed 6-20-62							
	11-62	2	--	--	3	--	5	--
	New tube installed 11-6-62							
	12-62	1	2	--	--	--	3	--
	1-63	1	2	--	--	--	3	0
	6-63	11	5	--	2	--	18	15
1358[d]	6-62	2	5	11	--	2	20	--
	6-63	9	6	13	5	2	35	15
	9-63	9	6	14	4	3	36	1
	New tube installed 9-4-63							
1441	6-62	3	4	3	10	--	20	--
	2-63	5	6	4	7	1	23	3
1443[a]	6-62	4	4	1	--	--	9	--
	12-62	8	11	--	--	--	19	10
	1-63	9	14	--	11	--	34	15
	10-63	20	19	--	18	--	57	23

APPENDIX B (contd.)

P. C.	Inspection Dates	LFES	UFES	BW	SRW	Uncl.	Totals	Change
1445[c]	6-62	4	7	--	1	1	13	--
	4-63	11	13	--	18	1	43	30
1447	6-62	3	2	8	2	1	16	--
	4-63	9	10	16	6	--	41	25
1449[a]	5-62	5	1	--	1	--	7	--
	4-63	13	5	--	12	--	30	23
1451	6-62	3	4	3	10	--	20	--
	2-63	6	4	14	6	--	30	10
1453	6-62	3	2	10	--	2	17	--
	2-63	3	4	10	4	--	21	4
1455	6-62	6	7	6	--	3	22	--
	New tube installed 4-4-63							
	4-63	3	--	--	--	--	3	--
1457[b, c]	6-62	8	3	5	3	--	19	--
	4-63	12	9	7	19	4	51	32
1459	6-62 (Broken wire	2	6	7	--	--	15	--
	wrap found on F. E. 1029 on 12-63)	2	6	7	--	--	15	0
1542	6-62	3	3	4	5	--	15	--
	4-63	4	4	8	5	--	21	6
1544	6-62	5	3	1	--	5	14	--
	4-63	16	6	1	--	5	28	14
	10-63	17	8	2	2	4	33	5
1546[c]	6-62	5	4	1	1	--	11	--
	4-63	11	14	--	22	--	47	36
1548[c]	6-62 (Broken wire	6	4	9	8	--	27	--
	wrap found on F. E. 1099 on 12-63)	6	8	29	12	--	55	28
1550	New tube installed 6-21-61							
	6-62	2	1	7	--	--	10	--
	2-63	5	4	7	--	--	16	6
1552[c]	6-62	1	2	1	--	--	4	43
	4-63	19	6	18	4	--	47	43
1554	6-62	10	3	10	--	3	26	--
	4-63	16	11	14	6	2	49	23
1556	6-62	14	6	--	5	2	27	--
	11-63	14	8	1	5	1	28	1

APPENDIX B (contd.)

P.C.	Inspection Date	LFES	UFES	BW	SRW	Uncl.	Total	Change
1558[c, d]	6-62	6	3	16	4	1	30	--
	2-63	8	3	20	14	2	47	17
	10-63	19	7	24	19	2	71	24
	Tube discharged 10-11-63							
1641	High flow orificed ~7-62							
	6-62 (Broken wire	--	6	7	1	3	17	--
	12-62 wrap found on	1	6	4	8	--	19	2
	F.E. 1044 on	5	9	14	1	--	29	10
	12-62)							
1643	High flow orificed ~7-62							
	New tube installed 5-5-62							
	6-62	3	2	3	--	3	11	--
	4-63	7	8	--	5	1	21	10
1645	6-62	3	2	--	--	--	6	--
	11-62	3	2	1	--	--	7	1
	4-63	10	4	3	5	4	26	19
1647[c]	6-62	4	3	6	2	--	15	--
	4-63	8	7	41	11	2	69	54
1649[c]	5-62	1	1	--	--	--	2	--
	4-63	5	2	18	5	1	31	29
1651[c]	6-62	5	3	--	--	2	10	--
	4-63	7	4	17	7	--	35	25
1653[b, c]	6-62	6	4	12	5	--	27	--
	4-63	11	9	14	16	--	50	23
	8-63	11	4	28	24	--	67	17
	10-63	10	9	55	24	--	98	31
1655	6-62	7	10	--	4	2	23	--
	4-63	16	18	--	10	--	44	21
1657	6-62	5	4	--	1	--	10	--
	4-63	14	13	--	5	--	32	22
1659	New tube installed 1-16-62							
	6-62	5	2	4	--	--	11	--
	4-63	6	3	17	1	--	27	16
1742	6-62	3	2	9	5	--	19	--
	8-63	12	12	5	2	--	31	12
1744	6-62	12	4	--	2	--	18	--
	8-63	18	14	--	1	--	33	15
1746	6-62	11	3	--	--	--	14	--
	8-63	14	7	5	--	--	26	8

APPENDIX B (contd.)

P. C.	Inspection Date	LFES	UFES	BW	SRW	Uncl.	Total	Change
1748	6-62	5	6	10	3	4	28	--
	5-63	15	5	7	13	3	43	15
1750	6-62	3	1	23	6	1	34	--
	5-63	3	3	29	7	--	42	8
1752[a]	6-62	9	5	1	--	--	14	--
	5-63	16	14	5	6	--	41	26
1754	6-62	9	4	6	4	4	27	--
	11-62	Data not recorded						
	5-63	15	11	7	7	3	43	16
1756	Tube from P. C. 1857 installed on 9-28-61							
	6-62	13	5	9	5	2	34	--
	5-63	19	6	11	7	1	44	10
1758	6-62	5	6	8	1	--	20	--
	5-63	8	7	8	7	1	31	11
1843	6-62	4	--	--	10	--	14	--
	9-63	9	4	13	6	--	31	17
1845	5-62	13	3	--	--	--	16	--
	9-63	21	10	--	6	--	37	21
1847	6-62	8	6	--	1	7	21	--
	11-62	12	8	--	--	7	27	7
	5-63	14	9	--	8	4	35	8
	New tube installed 7-5-63							
	8-63	1	1				2	
1849	6-62	7	5	6	7	--	25	--
	9-63	14	11	11	20		56	31
1851	6-62	6	3	2	4	--	15	--
	9-63	11	1-	--	6	--	27	12
1853	6-63	9	7	--	1	5	22	--
	9-63	20	12	1	2	--	35	13
1855[a]	5-62	7	1	--	--	--	8	--
	11-63	13	11	--	5	3	32	24
1857	New tube installed 9-28-61							
	5-62	4	4	1	1	3	13	--
	6-62	4	5	2	2	1	14	1
	1-63	5	5	5	1	--	16	2
1944	6-62	3	2	4	3	1	13	--
	9-63	9	8	4	12	--	33	20
1946[d]	6-62	4	6	17	2	--	29	--
	9-63	11	7	18	5	--	41	12
	Tube removed 11-6-63							

APPENDIX B (contd.)

P. C.	Inspection Date	LFES	UFES	BW	SRW	Uncl.	Total	Change
1948	6-62	8	6	3	3	2	21	--
	11-62	11	7	--	6	1	25	4
	12-62	No measurements obtained						
	1-63	14	10	11	--	--	35	10
1950	6-62	5	5	--	--	5	15	--
	9-63	17	10	5	4	--	36	21
1952	6-62	10	5	2	5	2	24	--
	9-63	12	10	--	10	--	32	8
1954	6-62	6	4	14	4	--	28	--
	9-63	13	15	8	11	--	47	19
1956[c]	6-62	1	1	--	--	--	2	--
	9-63	10	4	33	8	--	55	53
2047	Hi-flow orificed 7-62							
	6-62	2	3	4	1	6	16	--
	1-63	7	8	11	3	--	29	13
2049	6-62	4	1	--	7	--	12	--
	9-63	6	4	11	6	--	27	15
2051	6-62	5	6	8	--	--	19	--
	6-63	11	13	10	3	--	37	18
2053[b, c]	6-62	4	3	11	2	--	20	--
	8-63	7	5	25	4	--	41	21
	9-63	12	6	28	8	3	57	16
As of 6-62 total marks		451	306	376	195	109	1437	
in indicated number of PC's		85	85	56	52	39		
Average number of marks per tube		~5	~4	~6	~4	~3		
As of 11-63 total marks		975	724	798	561	110	3174	
in indicated number of PC's		85	85	63	73	38		
Average number of marks per tube		~11	~8	~8	~8	~3		
Increases in number of marks		524	418	422	366	1	1737	
Percentage increase		116	137	112	188	0		

Average number of fretted areas per tube as of 6-62 17
Average number of fretted areas per tube as of 11-63 37

(a) Indicates tube wherein the large increase in incidence of fretting corrosion is attributable to a large number of fuel elements charge-discharges.
(b) Indicates defect 10 mils or greater in depth.
(c) Indicates tube where the large increase in incidence of fretting corrosion is probably attributable to a specific element (see Table I).
(d) Indicates defect 20 mils or greater in depth.

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