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TITLE

PT-IP-364A: Fabrication of Elements
Brazen Closure, 1.6% Enriched, 2 w/o Zirconium
Core - KER Size Tube-Elements (KAEAL)

AUTHOR

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PT-IP-3644: Fabrication of Elements
Braze Closure, 1.6% Enriched, 2 w/o Zirconium Core
KER Size Tube-Tube Elements (KAEAL)

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Fuels Fabrication Development
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PT-IP-364A: Fabrication of Elements
 Brazed Closure, 1.6% Enriched, 2 w/o Zirconium Core
 KER Size Tube-Tube Elements (KAEAl)

INTRODUCTION

More exposure data are urgently needed on brazed NPR fuel closures. Therefore, this test was designed to obtain irradiation data on the brazed closure on a tube-tube geometry. A 1.6% enriched, 2 w/o zirconium core was chosen for this test to gain a faster exposure rate. The brazing alloy for this test was composed of 84 Zry-2 + 4 Be + 12 Fe.

SUMMARY

Five fully-inspected inner tubes and five outer tubes were submitted for irradiation in the KER facilities. In addition to this test, four outer tubular elements were fabricated as heater tubes for the thermocoupled irradiation test PT-IP-314A Supp. E. There are two spare inner elements and two spare outer elements.

Closure was made by brazing a Zircaloy-2 end cap into a recess with the 84 Zry-2 + 4 Be + 12 Fe brazing alloy. This particular brazing alloy was chosen for its low melting temperature, high corrosion resistance, and good wettability of the uranium.

The fabrication sequence was as follows:

1. Cut extrusions to 18-inch lengths.
- 2.* Heat treat:
  - a. Inner tubes: 7 minutes 730 C Nusal salt, 5 sec. air delay, water quench.
  - b. Outer tubes:
    - 1) first group: 7 minutes 730 C Nusal salt, 5 sec. air delay, water quench.
    - 2) second group: 10 minutes 730 C Nusal salt, 10 sec. air delay, oil quench.
    - 3) third group: 5 minutes 730 C Nusal salt, 10 sec. air delay, oil quench.
- 3.* Remove extrusion copper and bright etch.
4. Face to 17-inch lengths saving a sample for metallography.

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* For inner elements and first and second group of outer elements reverse steps 2 and 3 and add a vapor blast after each step.

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NMI-47303

5. Field mill end-cap machined with .01 to .015 inch finish.
6. Machine recess to 0.300 inch with flat surface. Remove uranium flash with hydrochloric acid.
7. Vapor blast and bright etch.
8. Braze at 950 C, 10^{-4} mm of Hg with the Zry-2 + 12 Fe + 4 Be braze alloy.
9. Vapor blast and bright etch ends.
10. Machine weld contour:
  - a. Inner tubes: contour 1/32 inch deep, 1/16 inch wide.
  - b. Outer tubes: contour 1/32 inch deep, 1/32 inch wide.
11. Electron beam weld closures.
12. Stamp identification numbers.
13. Attach fuel supports:
  - a. Inner tubes: spot weld Zircaloy-2 rails.
  - b. Outer tubes: spot weld Zircaloy-2 studs for attaching iron rails.
14. Bright etch, rinse in stop bath, water rinse.
15. Autoclave 72 hours in 300 C water, inspect, then autoclave for 48 hours in 400 C steam.
16. Final inspection:
  - a. Autoradiography.
  - b. Visual inspection.
  - c. Micrometer measurements.
  - d. Electronic warp and eccentricity measurements.
  - e. Destructive examination of extra elements.
17. Attach iron supports to outer elements.
18. Charge make-up.

FABRICATION HISTORY

1. Material for this test was coextruded by Nuclear Metals, Inc, under contract No. AT-(30-1)-1565. Complete extrusion data are given in NMI-4730.⁽¹⁾

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(1) Jordan, E. F., R. N. Randall, and H. F. Sawyer, "Production and Evaluation of Enriched KER Size Fuel Elements," NMI-4730, August 20, 1959.

Fuel element prefix numbers are coded to NMI's extrusion numbers as follows:

	<u>Material Prefix</u>	<u>NMI Extrusion</u>
Inner Tubes:	EAN-8, 13 & 14	21130
	EAN-10	21131
	EAN-9	21132
	EAN-11 & 15	21133
	EAN-12	21134
Outer Tubes:	EAN-16	21115
	EAN-17	21075
	EAN-18	21074
	EAN-19	21116
	EAN-20	21117

2. These extrusions were cut into 18-inch lengths. A suffix number was added to the prefix which corresponded to the distance in inches from the front of the extrusion. In some cases with the inner tubes there is no suffix number. This indicates that only one piece of reactor quality material was taken from that extrusion. Complete extrusion evaluation data were taken and recorded in a separate notebook and will not be included in this report.
3. The inner tubes and first batch of outer tubes had the copper stripped by dipping in 70 C nitric acid until the copper had been removed, then immersed in hydrochloric acid to open any copper pockets, then into nitric acid again for final cleaning. The elements were then bright etched and measurements were taken. The second and third batches of outer tubes were heat-treated with the extrusion copper in place.
4. Heat treatment was performed to give some grain refinement and provide a faster uranium etching rate during chemical milling. In each instance the heat treatment gave the same structure; therefore, the severity of the quench in the latter outer tubular elements was reduced to avoid subjecting the coextruded bond to unnecessary stresses.

Inner tubes: Heat in 730 C Nusal salt for 7 minutes, allow for a 5 sec. delay then quench in cold water.

Outer tubes:

- a. First batch: same as above. This included elements EAN-16-128, 16-23, 16-92, 16-73, 16-41, 17-59, 16-110, 17-41, 17-23.
- b. Second batch: Heat in 730 C Nusal salt for 10 minutes, 10 sec. air delay then quench in room temperature Houghto-Quench "G" oil. This included elements EAN-17-78, 17-97, 18-21, 18-40, 18-59, 18-78, 18-96, 18-113.
- c. Third batch: Heat in 730 C Nusal salt for 5 minutes, 10 sec. air delay then quench in room temperature Houghto-Quench "G" oil. This included elements EAN-19-59, 19-21, 19-118, 19-96, 20-21, 19-40, 19-72, 20-40.

5. Cut fuel elements to 17-inch lengths and face ends. Remove a half-inch sample from one end for metallography. This sample will remain on file until after irradiation as a control and reference.
6. The inner elements and first batch of outer elements were straightened on the three-roll straightening device. In general, the pieces were straightened satisfactorily, but many undesirable side effects were noted.

Only the inner tubes and first batch of outer tubes were straightened. The other elements were acceptable in the as-extruded condition.
  - a. Inner elements: These were all heated in 650 C Nusal salt for 15 minutes then placed in the roller and rolled with 1.21 tons force for five minutes. They were then heated in air to 400 C for two hours to remove residual stresses. All of these elements had dents rolled into the surface from the salt.
  - b. Outer elements: First batch only. Elements EAN-16-41 and 16-128 were handled in the very same manner as the inner tubes except they were rolled at 1.44 tons. Again, the surfaces were marred from the salt. The remainder of the first batch were heated in argon to 650 C, then rolled with 1.12 tons. These pieces showed severe pitting during acid milling.
7. Acid milling was done in horizontal tanks, rotating the elements 90° every 10 minutes. Rapid metal removal was noted at first but this rate decreased as the depth increased.
  - a. Inner elements: These were milled in 5 M HCl at a temperature of 50 - 55 C to a depth of 0.200 inch. The etching rate varied from 1.4 to 3.4 mils per minute.
  - b. Outer tubes, first batch: These were milled in 2 M FeCl₃ at room temperature to a depth of 0.200 inch. The etching rate was 0.5 to 2.5 mils per minute. Ferric chloride was used to lessen the possibility of explosion in the bath. The first five elements pitted very badly. The remaining three elements were vapor-blasted on the O.D. only prior to etching. Where the furnace thermocouple was in contact with the inner surface of the element, severe pitting occurred. Only one element from the first batch was salvaged; namely, EAN-17-41.
  - c. Second and Third batches: These were acid milled in 3 M HCl at a temperature of 60 - 65 C. These were milled to 0.250 inch in 2 hours 30 minutes. No difficulties were encountered during the milling operation.
8. After acid milling, the material was machined on a collet lathe to a depth of 0.300 inch, maintaining a flat bottom on the recess. Difficulty was obtained in machining the outer elements. The zircaloy jacket was spun outward due to machine tool pressure. A restraining ring was placed around the outer surface and a mandrel placed inside the tubes to prevent this deformation.

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After machining, the ends were again treated with hydrochloric acid to remove any uranium adhering to the jacket.

9. Both the inner and outer surfaces were vapor-blasted so as to remove the surface hydride. In general, one vapor-blast pass cleaned the surface. After vapor-blasting, the surfaces were bright etched, rinsed in water, dipped into the stop bath solution, then water rinsed and dried with acetone.
10. Different methods were used in brazing the outer and inner elements. In each case the uranium surface was etched with nitric acid to remove surface oxide. The braze powder (-10 +35 mesh) was poured directly onto the uranium surface. Required amounts were:

KER Inner Tubes	2.4 gm
KER Outer Tubes	3.5 gm

The 0.250 inch thick Zircaloy-2 cap was bright etched, then dropped on top of the braze alloy. This assembly was placed inside the vacuum chamber so that the element extended into the bottom three turns of the induction coil. The chamber was evacuated to 5×10^{-4} mm of Hg before heating was begun.

The inner tubes were brazed on a fixed time cycle of one minute-20 seconds in which the end cap region was gradually brought to a temperature of 950 C in 20 seconds, then held constant for 45 seconds. The graphite pressure pad forced the cap down onto the uranium with a 1000 gm weight which forced the braze alloy up along the cap-jacket interface. At the end of the brazing cycle the power was shut off and the fuel element was allowed to cool to about 600 C in vacuum, then either helium or argon was admitted to speed up the cooling rate. Inner tube brazing data are summarized in Table I.

Outer tubes were brazed on a fixed time cycle of two minutes. The end cap was heated to 950 C as rapidly as possible then held at this temperature. The first and part of the second batch of material was brazed exactly the same as the inner tubes. However, metallographic examination indicated a poor bond. Thus the remainder of the second batch and all of the third batch was brazed by the following technique: The end cap region was heated as rapidly as possible to 950 C. After one minute the pressure pad was lowered onto end cap and held in place with a 2000 gm weight. The main vacuum valve was then closed and the chamber was pressurized to atmospheric pressure with helium. At the end of the cycle the power was shut off and the element allowed to cool to 100 C in helium. Metallographic examination revealed 100% bonding in the closure region. Outer tube brazing data are summarized in Table II.

11. A weld contour was machined on the end of each element. The inner tube had a contour 1/32 inch deep and 1/16 inch wide machined into both the O.D. and I.D. The outer tube had a 1/32 inch deep and 1/32 inch wide contour machined into both the O.D. and I.D. After machining, the ends were vapor-blasted and bright etched.

12. Welding was done in an electron beam welding unit operating at a pressure of 5×10^{-5} mm of mercury. A single pass weld was made on each element. In general, the resulting welds were smooth with very little metal overhang.
13. Zircaloy-2 supports were welded onto the inner tubes at 90° intervals on both ends. These rails were 0.200 inch in height, 1/4 inch wide, and 1-1/2 inches long, spot welded on each end.
14. Iron rails were to be used on the outer tubes. These were to be held in place by Zircaloy-2 studs projection-welded to the element and spun over the iron support. This method is described in detail by Wheeler elsewhere.⁽²⁾ The supports were 1/4 inch wide, 1-1/4 inches long, and 0.900 inch in height.
15. After inspection the elements were stamped with the marking numbers, then bright etched, rinsed in water, then held in deionized water until loading in the autoclave.
16. The elements were suspended vertically in stainless steel racks which had a heavy autoclave film on the surface. A dual autoclave cycle was used on all the elements. The first portion of the cycle was a 72-hour test in 300 C, 1800 psi water to test for galvanic corrosion. The second portion of the test was in 400 C, 1500 psi steam for 48 hours to provide a penetrating test for any defect which escaped the water test. All elements passed both tests.
17. After autoclaving, the elements were carefully inspected and micrometer measurements were again made. Then the elements were measured on the electronic warp and eccentricity measuring device. These data are not reported here as they essentially duplicate those of the mechanical measurements.
18. After measurement, iron supports were attached to the outer tubes.
19. Elements were then arranged according to charge make-up. Heater tubes for PT-IP-314A-Supp E were outer tubes, numbers EAN-17-41, 17-97, 19-118, and 19-96.

Tube-tube charge make-up was as follows:

Identical Mark, Both Elements Unnumbered End	Outer Element	Inner Element
.	17-78	15-2
. .	20-40	12
. . .	19-59	9-32
. . . .	19-40	10-30
. . . . .	19-77	11

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(2) Wheeler, R. G., "Steel Self-Supports for NPR Outer Tube Fuel Elements," October 10, 1960, HW-67068 (SECRET).

20. Destructive evaluation of the rejected elements yielded the following results:

a. Inner tubes:

Bond - A minimum of 80% bonded surfaces. Any unbonding occurred at the center of the braze line. Most (90%) of the elements examined were 100% bonded.

Voids - Very little porosity was observed. Any visible voids did not exceed 1/32 inch in diameter.

b. Outer tubes:

Bond - All tubes brazed by the second technique were 100% bonded. Those brazed by the first technique varied from 0 to 100% unbonded. The completely unbonded pieces were readily detected by length measurement or observing the cap. If the cap was cocked, the interface was unbonded.

Voids - No porosity was observed in any of the material brazed by either technique.

21. Various data are included with this report in tabular form. These tables include the following:

Table I	Inner Tube Brazing Data
Table II	Outer Tube Brazing Data
Table III	Summary of Fuel Element Fabrication
Table IV	Inner Element Measurements
Table V	Outer Element Measurements

Table I

Inner Tube Brazing Data

Induction Coil 1-3/4" I.D. x 2-3/4" high x 11 turns
 Braze Powder 7ry-2 + 12 Fe + 4 Be

2.4 gms/side
 -10 + 14 mesh

Element Number		Date	Time	Time From Final Rinse To Vacuum (Min.)	Vacuum Pumpdown Time (Min.)	Heating Time To 950 C sec	Time At 950 C sec	Depress Cap sec from 0	Sample Height In Coil	Sample Turns In Coil	Brazing Power ave. KW
EAN		Brazed	Brazed								
8-31	Numbered End	9/9/60	2:30	---	---	20"	1' 0"	50"	1-3/8	4	6
	Unnumbered End		3:55	---	---	20"	1' 0"	50"	1-3/8	4	6
9-32	Numbered End	9/12/60	11:50	1' 45"	1' 48"	20"	1' 0"	50"	1-3/8	4	6
	Unnumbered End		12:50	2' 40"	3' 45"	20"	1' 0"	50"	1-3/8	4	6
9-50	Numbered End	9/12/60	10:40	---	---	20"	1' 0"	50"	1-3/8	4	6
	Unnumbered End		11:00	3' 30"	1' 48"	20"	1' 0"	50"	1-3/8	4	6
9-89	Numbered End	9/12/60	1:48	2' 15"	1' 33"	20"	1' 0"	50"	1-3/8	4	6
	Unnumbered End		2:07	2' 05"	2' 0"	20"	1' 0"	50"	1-3/8	4	6
10-30	Numbered End	9/12/60	1:58	2' 43"	2' 0"	20"	1' 0"	50"	1-3/8	4	6
	Unnumbered End		2:16	1' 50"	1' 48"	20"	1' 0"	50"	1-3/8	4	6
10-48	Numbered End	9/12/60	11:15	2' 05"	2' 15"	20"	1' 0"	50"	1-3/8	4	6
	Unnumbered End		11:30	2' 40"	2' 0"	20"	1' 0"	50"	1-3/8	4	6
11	Numbered End	9/12/60	11:25	2' 15"	2' 10"	20"	1' 0"	50"	1-3/8	4	6
	Unnumbered End		11:43	1' 50"	1' 40"	20"	1' 0"	50"	1-3/8	4	6
12	Numbered End	9/12/60	12:00	2' 10"	1' 40"	20"	1' 0"	50"	1-3/8	4	7
	Unnumbered End		1:05	2' 10"	1' 33"	20"	1' 0"	50"	1-3/8	4	6
13	Numbered End	9/9/60	3:00	---	---	20"	1' 0"	50"	1-3/8	4	6
	Unnumbered End		3:15	---	---	20"	1' 0"	50"	1-3/8	4	6
14	Numbered End	9/12/60	10:59	4' 30"	2' 56"	20"	1' 0"	50"	1-3/8	4	6
	Unnumbered End		10:30	---	---	20"	1' 0"	50"	1-3/8	4	6
15-1	Numbered End	9/12/60	1:13	2' 01"	1' 30"	20"	1' 0"	50"	1-3/8	4	6
	Unnumbered End		1:30	2' 34"	1' 47"	20"	1' 0"	50"	1-3/8	4	7
15-2	Numbered End	9/12/60	1:21	2' 39"	1' 35"	20"	1' 0"	50"	1-3/8	4	6
	Unnumbered End		1:40	2' 48"	2' 35"	20"	1' 0"	50"	1-3/8	4	6

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Table II

Outer Tube Brazing Data

Induction Coil 2-1/8 inches I.D. x 2-1/2 inches high x 10 turns
 Braze: 3.4 grams/side Zry-2 + 12 Fe + 4 Be -14 Mesh +20 mesh

Element Number EAN	Date Braze	Time Braze	Time Final Rinse To Vacuum (Min.)	Vacuum Pumdown Time (Min.)	Brazing Time (Min.)	Time At 950 C sec	Depress Cap sec from 0	Admit Helium sec from 0	Ave KW	Coil Turns	Height in Coil Inches	
Batch No. 1												
16-128	Numbered	10/3/60	1:47	2' 20"	5' 0"	1' 30"	75	45	None	2	5	1
	Unnumbered		2:10	3' 12"	1' 41"	1' 30"	75	45	None	2	5	1
16-23	Numbered				No Data Available				None			
	Unnumbered								None			
16-92	Numbered	10/3/60	2:02	1' 0"	1' 55"	45"	35	30	None	2	5	1
	Unnumbered		2:20	2' 37"	4' 15"	1'	45	30	None	2	5	1
16-73	Numbered	10/3/60	3:40	30' 32"	3' 0"	1' 30"	75	45	None	2	5	1
	Unnumbered	10/4/60	8:15	2' 5"	2' 14"	1' 30"	75	45	None	2	5	1
16-41	Numbered	9/30/60	9:30	3' 0"	2'	1' 30"	75	45	None	2	5	1
	Unnumbered	10/3/60	1:35	4' 34"	2'	1' 30"	75	45	None	2	5	1
17-59	Numbered	10/3/60	2:35	13' 30"	2' 27"	1' 30"	75	45	None	2	5	1
	Unnumbered	10/4/60	8:12	3' 34"	2' 50"	1' 30"	75	45	None	2	5	1
16-110	Numbered	10/4/60	8:30	3' 4"	1' 56"	1' 30"	75	45	None	2	5	1
	Unnumbered		9:05	1' 50"	1' 45"	1' 30"	75	45	None	2	5	1
17-41	Numbered	10/4/60	8:19	2' 4"	2' 11"	1' 30"	75	45	None	2	5	1
	Unnumbered		8:47	1' 56"	9' 35"	1' 30"	75	45	None	2	5	1
17-23	Numbered	10/4/60	9:22	7' 42"	1' 50"	1'	45	45	None	2	5	1
	Unnumbered		9:55	3' 9"	1' 30"	1' 30"	75	45	None	2	5	1
Batch No. 2												
17-78	Numbered	10/7/60	2:40	4' 20"	3' 0"	2'	100	45	1' 15"	2	3	1-1/8
	Unnumbered		3:35	2' 0"	2' 03"	2'	100	45	1' 15"	2	3	1-1/8
18-113	Numbered	10/5/60	2:45	12' 25"	2'	1'	45	45	None	2	8	1-7/8
	Unnumbered		3:15	3' 15"	2'	1'	45	45	None	2	8	1-7/8

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Table II (Cont.)

				Time	Vacuum							Height
Element Number		Date	Time	Final Rinse	Pumpdown	Brazing		Depress	Admit	Ave	Coil	in
EAN		Brazed	Brazed	To Vacuum	Time	Time	Time At	Cap	Helium	KW	Turns	Coil
				(Min.)	(Min.)	(Min.)	950 C sec	sec from 0	sec from 0			Inches
18-59	Numbered	10/4/60	10:12	4' 59"	29' 56"	1'	45	45	None	2	5	1
	Unnumbered		10:30	2' 20"	2'	1'	45	45	None	2	5	1
18-96	Numbered	10/4/60	9:50	2' 34"	1' 42"	1'	45	45	None	2	5	1
	Unnumbered		10:05	5' 20"	1' 43"	1' 30"	75	45	None	2	5	1
17-97	Numbered	10/7/60	2:35	2' 30"	2' 0"	1' 30"	75	45	None	2	3	3/8
	Unnumbered		3:05	6' 30"	2' 05"	2' 0"	100	45	1' 15"	2	3	3/8
18-21	Numbered	10/7/60	2:50	2' 55"	2' 0"	2' 0"	100	45	1' 15"	2	3	3/8
	Unnumbered		3:15	4' 18"	2' 02"	2' 0"	100	45	1' 15"	2	3	3/8
18-40	Numbered	10/5/60	3:30	5' 39"	1' 48"	1' 30"	75	45	None	2	3	3/8
	Unnumbered	10/7/60	2:25	4' 10"	2' 0"	3' 0"	150	45	None	2	3	3/8
18-78	Numbered	10/5/60	3:05	5' 57"	2' 09"	1'	45	45	None	2	8	1-7/8
	Unnumbered		3:25	2' 32"	1' 45"	1'	45	45	None	2	8	1-7/8

Batch No. 3

19-77	Numbered	10/15/60	10:05	3' 30"	6' 45"	2' 0"	100	45	1' 30"	2	3	3/8
	Unnumbered		10:20	2' 45"	2' 20"	2' 0"	100	45	1' 15"	2	3	3/8
19-118	Numbered	10/15/60	11:35	2' 55"	2' 55"	2' 0"	100	45	1' 15"	2	3	3/8
	Unnumbered		11:50	3' 0"	2' 0"	2' 30"	130	45	1' 15"	2	3	3/8
20-40	Numbered	10/15/60	10:45	4' 50"	2' 02"	2' 0"	100	45	1' 30"	2	3	3/8
	Unnumbered		11:00	4' 05"	2' 05"	2' 0"	100	45	1' 15"	2	3	3/8
19-40	Numbered	10/15/60	10:35	2' 50"	2' 18"	2' 0"	100	45	1' 15"	2	3	3/8
	Unnumbered		10:50	2' 45"	2' 20"	2' 0"	100	45	1' 15"	2	3	3/8
19-21	Numbered	10/15/60	11:25	1' 50"	2' 05"	3' 0"	150	45	1' 15"	2	3	3/8
	Unnumbered		11:40	5' 45"	1' 0"	2' 0"	100	45	1' 15"	2	3	3/8
20-21	Numbered	10/15/60	10:15	2' 55"	1' 47"	2' 0"	100	45	1' 15"	2	3	3/8
	Unnumbered		10:30	3' 58"	2' 45"	2' 0"	100	45	1' 15"	2	3	3/8
19-96	Numbered	10/15/60	1:35	2' 50"	1' 98"	2' 0"	100	45	1' 15"	2	3	3/8
	Unnumbered		1:50	2' 30"	2' 10"	2' 0"	100	45	1' 15"	2	3	3/8
19-59	Numbered	10/15/60	1:40	4' 08"	2' 14"	2' 0"	100	45	1' 15"	2	3	3/8
	Unnumbered		2:00	2' 05"	1' 45"	2' 0"	100	45	1' 15"	2	3	3/8

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Table III

Summary of Fuel Element Fabrication

<u>Element Number</u>	<u>Location</u>	<u>Remarks</u>
<u>Inner Tubes</u>		
9-50	Met. Examination	Rejected due to extrusion defect.
10-48	Met. Examination	Rejected due to extrusion defect.
13	Met. Examination	Rejected due to extrusion defect.
14	Met. Examination	Rejected due to extrusion defect.
8-31	Met. Examination	Rejected due to extrusion defect.
15-1	Spare	Outer surface dented from straightening.
9-32	PT	Match with outer tube 19-59, marked . . . .
15-2	PT	Match with outer tube 17-78, marked . .
11	PT	Match with outer tube 19-77, marked . . . . .
9-89	Spare	Shallow groove on jacket.
12	PT	Match with outer tube 20-40, marked . . .
10-30	PT	Match with outer tube 19-40, marked . . . . .
<u>Outer Tubes</u>		
16-128	Met. Examination	Pitted jacket from acid milling.
16-23	Met. Examination	Pitted jacket from acid milling.
16-92	Met. Examination	Pitted jacket from acid milling.
16-73	Met. Examination	Pitted jacket from acid milling.
16-41	Met. Examination	Pitted jacket from acid milling.
17-59	Met. Examination	Pitted jacket from acid milling.
16-110	Met. Examination	Inner clad pitted from acid milling.
17-23	Met. Examination	Inner clad pitted from acid milling.
17-41	Heater Tube	None
17-78	PT	Match with inner tube 15-2, marked . .
18-113	Spare	Out-of-cycle element.
18-59	Spare	Small spot of braze metal on I.D.
18-96	Met. Examination	Rejected due to braze metal on I.D. of element.
17-97	Heater Tube	0.005 inch groove between rails on one end.
18-21	Spare	Broken rail numbered end.
18-40	Spare	Good element.
18-78	Met. Examination	Rejected due to failure in welding.
19-77	PT	Match with inner tube 11, marked . . . . .
19-118	Heater Tube	Marred surface next to rail on unnumbered end.
20-40	PT	Match with inner tube 12, marked . . .
19-40	PT	Match with inner tube 10-30, marked . . . . .
19-21	Met. Examination	Rejected due to extrusion defect.
20-21	Spare	Ends slightly deformed during machining.
19-96	Heater Tube	None
19-59	PT	Match with inner tube 9-32, marked . . . .

Table IV

Production Test and Spare Elements Only

Inner Element Measurements

Element No.	Heat Treatment Dimensional Changes						After Heat Treatment Measurements										Measurements After Brazing and Welding					
	(-)		(-)		Bow (+)		Depth of Recess	Length	Uranium Length	Cap O.D.	Cap I.D.	Diameter	Bore	Cap* O.D.	Cap* I.D.	O.D.		I.D.		Length	Max. Low	
	Δ O.D.	Δ I.D.	Δ L	Pre	Post	Δ B (-)										Below Cap	Below Cap	Below Cap	Below Cap			
15-1 Num	-0.001	-0.002	0.035	0.086	0.085	0.001	0.312	16.957	16.338	0.978	0.562	1.053	0.500	0.031	0.018	1.057	1.049	0.501	0.499	16.838	0.009	
15-1 Unnum							0.307			0.977	0.559	1.054	0.501	0.033	0.014	1.057	1.049	0.501	0.497			
15-2 Num	0.002	0.001	0.035	0.032	0.071	0.039	0.304	16.989	16.375	0.976	0.560	1.051	0.502	0.031	0.014	1.055	1.049	0.499	0.497	16.875	0.009	
15-2 Unnum							0.310			0.978	0.563	1.052	0.500	0.030	0.019	1.056	1.046	0.501	0.500			
11 Num	0.004	0.002	0.048	0.016	0.056	0.040	0.310	16.950	16.332	0.977	0.560	1.053	0.502	0.032	0.014	1.057	1.049	0.500	0.497	16.832	0.008	
11 Unnum							0.308			0.974	0.559	1.053	0.500	0.035	0.015	1.057	1.048	0.502	0.499			
11-89 Num	0.005	0.001	0.033	0.026	0.040	0.014	0.314	17.010	16.372	0.974	0.562	1.052	0.500	0.034	0.018	1.054	1.044	0.497	0.494	16.872	0.005	
11-89 Unnum							0.304			0.973	0.563	1.048	0.498	0.031	0.021	1.057	1.047	0.497	0.498			
12 Num	-0.005	-0.001	0.033	0.061	0.094	0.033	0.308		16.395	0.975	0.561	1.052	0.500	0.033	0.017	1.058	1.047	0.498	0.496	16.895	0.007	
12 Unnum							0.314	16.987	16.332	0.977	0.558	1.051	0.500	0.030	0.014	1.057	1.049	0.499	0.496			
10-30 Num	0.004	0.000	0.024	0.035	0.147	0.112	0.341			0.974	0.563	1.050	0.498	0.032	0.021	1.054	1.045	0.499	0.498	16.832	0.009	
10-30 Unnum							0.324	16.969	16.328	0.972	0.561	1.051	0.499	0.035	0.018	1.053	1.047	0.499	0.495			
							0.317			0.974	0.561	1.053	0.500	0.035	0.017	1.059	1.049	0.501	0.496	16.828	0.008	
										0.977	0.560	1.054	0.499	0.033	0.017	1.057	1.048	0.500	0.498			

* Diametral gap. Take 1/2 of this value for radial gap.

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Table V

Outer Element Measurements

Production Test, Heater Tube and Spare Elements only

Element Number	B a t c h	Heat Treatment Dimensional Changes						After Heat Treatment Measurements										Measurements After Brazing and Welding					
		(+)	(+)	(+)	Bow (+)		Depth of Recess	Length	Uranium Length	Cap O.D.	Cap I.D.	Diameter	Bore	Cap* O.D.	Cap* I.D.	O.D.		I.D.		Length	Bow		
		ΔO.D.	ΔI.D.	ΔL	Pre	Post										ΔB	Below	Below					
																	Cap	Cap	Cap			Cap	
15-59 N	3	0.000	0.006	---	---	0.030	---	0.301	16.935	16.322	1.772	1.498	1.822	1.450	0.006	0.004	1.829	1.819	1.447	1.448	16.807	0.020	
UN								0.312			1.770	1.497	1.823	1.451	0.005	0.001	1.837	1.820	1.448	1.448			
15-40 N	3	0.003	0.010	---	---	0.028	---	0.310	16.937	16.314	1.771	1.495	1.822	1.452	0.007	0.003	1.827	1.813	1.452	1.447	16.755	0.025	
UN								0.313			1.773	1.498	1.822	1.451	0.005	0.002	1.827	1.815	1.447	1.446			
20-40 N	3	0.003	0.007	---	---	0.008	---	0.325	16.931	16.310	1.770	1.500	1.822	1.450	0.008	0.008	1.828	1.813	1.446	1.446	16.785	0.016	
UN								0.296			1.771	1.499	1.822	1.450	1.007	0.007	1.828	1.815	1.446	1.450			
15-77 N	3	0.000	0.008	---	---	0.015	---	0.316	16.934	16.303	1.770	1.498	1.822	1.450	0.008	0.004	1.826	1.817	1.452	1.449	16.800	0.021	
UN								0.315			1.772	1.501	1.824	1.450	0.006	0.009	1.830	1.817	1.450	1.448			
17-78 N	2	0.004	0.004	0.017	0.021	0.009	(-)	0.308	16.932	16.321	1.771	1.499	1.822	1.453	0.007	0.002	1.823	1.815	---	---	16.825	0.07	
UN								0.303			1.773	1.500	1.821	1.453	0.006	0.003	1.829	1.813	---	---			
15-96 N	3	0.001	0.006	---	---	0.042	---	0.315	16.930	16.296	1.770	1.501	1.824	1.451	0.010	0.006	1.829	1.817	1.449	1.450	16.800	0.025	
UN								0.319			1.771	1.496	1.824	1.451	0.009	0.001	1.828	1.816	1.450	1.449			
15-113N	3	0.003	0.006	---	---	0.049	---	0.328	16.937	16.295	1.770	1.499	1.826	1.450	0.012	0.005	1.835	1.817	1.451	1.452	16.775	0.033	
UN								0.314			1.770	1.502	1.823	1.450	0.009	0.008	1.833	1.818	1.445	1.451			
17-41 N	1	0.004	0.002	0	0.020	0.032	0.012	0.312	16.929	16.296	1.770	1.495	1.822	1.448	0.008	0.003	1.824	1.814	---	---	16.800	0.004	
UN								0.321			1.771	1.497	1.822	1.448	0.007	0.005	1.828	1.816	---	---			
17-27 N	2	0.003	0.004	0.007	0.024	0.036	0.012	0.312	16.893	16.276	1.771	1.500	1.822	1.452	0.007	0.004	1.830	1.813	---	---	16.780	0.027	
UN								0.305			1.770	1.499	1.824	1.452	0.008	0.003	1.841	1.811	---	---			
20-21 N	3	0.007	0.001	---	---	0.038	---	0.311	16.935	16.311	1.772	1.501	1.820	1.450	0.004	0.006	1.830	1.817	1.449	1.451	16.805	0.018	
UN								0.313			1.770	1.500	1.820	1.450	0.006	0.006	1.829	1.812	1.448	1.448			
15-40 N	2	0.002	0.003	0.025	0.001	0.038	0.037	0.301	16.895	16.289	1.771	1.498	1.822	1.450	0.007	0.004	1.821	1.810	---	---	16.793	0.031	
UN								0.305			1.770	1.499	1.824	1.449	0.010	0.006	1.824	1.814	---	---			
15-59 N	2	0.001	0.001	0.018	0.026	0.016	(-)	0.307	16.840	16.238	1.771	1.500	1.822	1.449	0.007	0.007	1.834	1.821	---	---	16.842	0.023	
UN				(+)				0.295			1.770	1.499	1.823	1.449	0.009	0.006	1.833	1.822	---	---			
15-113N	2	0.003	0.002	0.021	0.038	0.040	0.002	0.300	16.924	16.326	1.772	1.499	1.823	1.450	0.007	0.005	1.824	1.819	---	---	16.830	0.031	
UN								0.298			1.771	1.501	1.823	1.451	0.008	0.005	1.830	1.814	---	---			

* Diametral gap. Take 1/2 of this value for radial gap.

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