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EVALUATION OF SIX ZIRCALOY-CLAD

U = 2 ^W/o Zr ALLOY TUBES MADE FOR
IRRADIATION IN THE VBWR TEST LOOP

D. F. Kaufman
W. J. Richmond

nuclear metals, Inc.
concord, massachusetts

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Nuclear Metals, Inc.
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TABLE OF CONTENTS

	<u>Page No.</u>
I. INTRODUCTION	5
II. SUMMARY	5
III. REFERENCES	6
IV. COMPONENTS	6
V. PREPARATION OF COMPONENTS	7
VI. CLEANING OF MAJOR COMPONENTS	9
VII. ASSEMBLY	9
VIII. EXTRUSION	9
IX. HEAT TREATMENT	10
X. OTHER POST-EXTRUSION OPERATIONS	10
XI. TABLES AND FIGURE	15

Tube 37 - Considered to be ruled out from the beginning. Extrusion pressure was too high, and the tube showed clad thinning (8.5 mils at rear taper of outer clad), surface roughness and pits.

Tube 38 - Considered a representative tube and sacrificed for an autoradiographic standard.

Tube 39 - Considerable white oxide formed in autoclaving operation; surface roughness of front end seal 30 units higher than 200 rms specification; maximum inner clad thickness 0.3 mil thicker than 18.0 specification; series of six pits, 3 of which exceed the 2 mil specification.

III. REFERENCES

The following documents constitute references for background information on the methods of fabrication and evaluation for fuel elements of this type.

- A. Report NMI-1179, "Fabrication and Properties of Large Diameter Zirconium-Clad Uranium Tubes with Zirconium End Seals", by J. L. Klein and J. M. Fitzpatrick, dated July 31, 1957.
- B. Progress Reports NMI-4353 through NMI-4359, and NMI-4361 through NMI-4369, from Nuclear Metals to du Pont, covering the period from July 29, 1957 through August 31, 1958.
- C. Letter of March 25, 1958 from J. L. Klein to P. H. Permar. This letter describes the fabrication procedure for tubes shipped to SRL as flow test tubes.
- D. Report NMI-4360, "Evaluation of Three Zircaloy-Clad U - 2% Zr Fuel Tubes", by J. L. Klein, dated April 19, 1958.

IV. COMPONENTS

The identities and analyses of the core, cladding and end seal components are given in Tables 2 and 3. The billet components are the same as those for the nine-tube program except as changed by shortening of the

I. INTRODUCTION

This report is an evaluation of enriched power tubes 37-42, extrusion Nos. 19889-19894. These tubes were made to provide one for irradiation testing in the General Electric Test Reactor, Vallecitos, California. The evaluation data are presented primarily in the form of tables; Table 1 is a key to the location of all tabulated data.

II. SUMMARY

A. Candidates for Irradiation

The evaluation data presented in this report shows that tubes 40, 41, and 42 meet irradiation specifications (Table 24) with minor exceptions as follows:

Tubes 40, 41, and 42: Non-bonds were detected over the rear taper in the ultrasonic test at an instrument setting of 1.7, while the specification calls for no detection above 1.6.

Tube 41: Maximum OD in the end seal is 3 mils above the specification of 1.484 inches.

Tube 42: Maximum inner clad thickness is 2.3 mils above specification limit of 18 mils.

Tubes 40 and 42: Surface roughness at the front end seals is 50 units above the 200 rms specification.

Of these three tubes, tube 41 was selected as the first candidate for irradiation because its core had the highest carbon content; tube 42 was next in preference.

B. Not Candidates for Irradiation

Tubes 37, 38, and 39 were eliminated as candidates for irradiation for the following reasons:

core and chamfering the outer front and rear core angle surfaces by 0.020 inch to allow for expansion. The assembled components may be seen in cross section in Figure 1. The billet core was shortened to produce an extruded core length of 32-36 inches.

The chemical analyses of all components meet specifications.

V. PREPARATION OF COMPONENTS

A. U - 2% Zr Core

The cores were cast in the NMI Foundry in a vacuum induction furnace. The melting stock consisted of 1/2 and 1-inch diameter 3.06% enriched uranium rods fabricated from National Lead Company ingots 31437, 31438, 31439, and 31440. Since the rods were not identified, however, the carbon content of the charge is not known. The zirconium added was in the form of sponge, SMZ 589. The castings were machined directly to the desired size prior to assembly.

B. Zircaloy-2 Front and Rear End Seals

The Zircaloy used for the end seals, like all the Zircaloy used for these tubes, was obtained from the Harvey Aluminum Company in the form of 6-1/2 inch rough-machined forgings made from arc-melted ingots. The Zircaloy was cut in about 4-1/2 inch lengths (enough to produce a front and rear end seal), heated to 1000°C, held 15 minutes and water quenched to break up the forging structure. The analysis of the forgings used, as supplied by Harvey, is given in Table 4.

C. Zircaloy Inner Sleeve

The Zircaloy inner sleeve was machined from tubing extruded from Harvey forging No. HZC 999, our No. SMZ 595. The analysis of this forging is given in Table 4. A Zircaloy billet, 6.350-inch OD by 1.640-inch ID, was canned in 16-gage copper and extruded at 1450°F in a 6-5/8 inch liner through a 2.350-inch die and over a 1.460-inch mandrel—a 12.3:1 extrusion ratio.

D. Zircaloy Outer Sleeve

The Zircaloy outer sleeve was made by cupping a copper-clad billet of Zircaloy in a 6-5/8 inch liner over a 5.400-inch diameter mandrel. The billet was heated to 1450°F before being pushed over the mandrel, which had a stop sleeve to make the short integral-end cup desired. The forging used was the same as that used for the inner sleeve.

E. Copper Inner Sleeve

Commercial seamless copper tubing, 1.630-inch OD by 0.065-inch wall, was used for the inner sleeve.

F. Copper Outer Sleeve

A 60° nose was spun on commercial seamless copper tubing, 6.500-inch OD by 0.065-inch wall to form the outer sleeve. The sleeve was vacuum degassed at 1250°F before use.

G. Copper Nose Plug

O.F.H.C. 6-inch diameter cast copper was upset at 1000 tons to 6-3/4 inches, machined to fit the 60° spun nose, and vacuum degassed at 1250°F.

H. Copper Rear End Plate

The rear end plate was machined from 3/8-inch plate and vacuum degassed at 1250°F.

I. Copper Evacuation Tube

The copper evacuation tube was 1/4-inch OD by 0.065-inch wall.

J. Copper-Nickel Disc

Copper - 10% nickel, cast in the NMI Foundry in a 5-1/2 inch diameter ingot, was upset at 1000 tons to 6-3/4 inches. The discs were machined and subjected to vacuum degassing at 1250°F.

VI. CLEANING OF MAJOR COMPONENTS

A. Zircaloy Components

Machined Zircaloy components were cleaned with trichloroethylene, then bright etched in a solution of $49\text{HNO}_3/49\text{H}_2\text{O}/2\text{HF}$; metal removal was maintained in the range of 0.5 - 1 mil per side.

B. U - 2% Zr Alloy Cores

Machined surfaces were cleaned in organic solvent, then polished dry in a lathe with 320-grit paper. After the lathe polishing, the cores were recleaned with organic solvent.

VII. ASSEMBLY

The core and Zircaloy components were carefully assembled (untouched by anything but clean metal), welded except for the seal-off weld, evacuated in the seal pin welder, and sealed off. The Zircaloy was then placed inside the partially welded copper can along with the copper-nickel disc, and the end plate was attached by welding. The copper cans were evacuated, heated to 300°F during evacuation and the copper evacuation tube sealed off by heating and hammer welding.

VIII. EXTRUSION

Extrusion conditions are outlined in Tables 5 and 5A. These tubes were extruded in one lot at the American Brass Company, Waterbury, Conn. As in the "nine tubes", an integral die was used. The only significant change made was in length of heating time, which was increased by one hour to assure a uniform billet temperature.

No breakthrough of Zircaloy through the copper was observed. It is believed that the longer heating time was the major factor in this improvement over some of the nine tubes described in reference B.

IX. HEAT TREATMENT

Tubes 37, 39, 40, 41, and 42 were heat treated in graphite lined-stainless steel angles contained in evacuated steel fixtures. The tubes were placed two in a container with a dummy normal tube (No. 36) to fill the odd space. The heating cycle was nine hours in an oil-fired furnace at $890 \pm 10^{\circ}\text{C}$. The heating fixture was water quenched in a cold quenching clamp after heat treatment. The growth in length during heat treatment may be seen in Table 7.

X. OTHER POST-EXTRUSION OPERATIONS

A. Sequence of Operations

The sequence of operations for the entire fabrication and evaluation procedure is presented in Table 6.

B. Core Weight, Composition, Length, Shift, Taper, Heat Treatment Growth

Data for these quantities are given in Table 7. All measurements meet specifications.

C. Bond Integrity

The Zircaloy-Zircaloy bonds at the end seals were found to be perfect upon performance of the notch fracture test after heat treatment. All five tubes prevented 650°F water and 750°F steam from penetrating between cladding and end seal to the core during 24-hour exposure in autoclave at each temperature. There was no evidence of bond line corrosion at the tube ends after autoclaving.

The Zircaloy-uranium bonds are considered satisfactory, since there were no blisters on the cladding after heat treatment.

Ultrasonic examination results are listed in Table 8. It may be noted that all values are within specification except the rear taper sections which were only 0.10 above specification in the worst cases.

D. Gaging Data

Gaging data and a summary table for OD and ID are given in Tables 9A-D and 10. The gaging data for wall thickness at the tube ends are given in Table 11. These measurements indicate agreement with specifications except for maximum ID over end seals of tube 41 (0.003 inch out of specification) and maximum wall thickness over the rear end seal of tube 37 (0.001 inch out of specification).

E. Clad Thickness

Clad thickness was determined by autoradiography just after pickling to remove copper. A standard was made by turning the OD clad from a 9-inch section of Tube 38 and taping Zircaloy strips of known thickness to it. Results are reported in Tables 12 and 13. All values are above the minimum specification with the exception of a value of 8.5 mils at the rear taper outer clad of tube 37, which renders the tube unsuitable for irradiation. The maximum clad thickness of the ID exceeded the specification in three of the five tubes. These values are somewhat doubtful since there was evidence of lead wrinkling and lack of contact of the film on the inside. It should be pointed out that autoradiographs of tubes 39-42, made from recycle cores, showed spots probably caused by segregation of a daughter product of thorium. This could cause a slight error in the values reported.

The autoradiographic technique is still not capable of yielding absolute clad thickness values; however, differences between average and extremes in clad thickness are significant. The latter quantities are related to the slope of the autoradiographic standard calibration curve which varies but little from one exposure to the next. These differences between average and extremes can be related to a calculated average clad thickness based on billet design, extrusion conditions, and the amount of cladding removed by etching.

F. Straightness and Bow

The straightness and straightening records for the six tubes are given in Table 14. It may be noted that the bow during autoclaving

is almost negligible and within specifications in all cases. This short tube length is much easier to straighten and keep straight than the longer 11-foot tubes.

G. Surface Inspection, Visual

Tables 15 through 20 give the original observations on surface. In general, the surface was slightly better than the nine tubes with the exception of the longitudinal surface striations. Three general types of surface imperfections were looked for on the Vallecitos tubes; only those in the first category were detected.

1. Imperfections Resulting from Extrusion

All six tubes contained some depressions in the cladding to a greater or lesser degree. Below is a list of depressions with depth measurements of the deeper ones:

Tube No.	Location	Depth (mils)
37	5-1/2F	1
39	22-1/4R	3.5
	18-3/16R	2.5
	14-3/16R	1.1
	10-1/8R	2.2
	6-1/8R	1.8
	2-1/8R	0.5
40	9-9/16R	0.8
	9-3/4R	1.5
41 and 42	Very minor defects	

It is believed that these defects originated during extrusion except for those on tube 39 which were probably caused by a defective roller on the run-out table. The most serious of the pits occurred in tube 39 but the deepest one is in the end seal. The 2.5-mil depression is in the taper area but not in the thinning. None of the above defects is considered serious enough to make any tube unsuitable for irradiation except those in tube 39.

2. Imperfections Resulting from Heat Treatment

These tubes were heat treated on graphite strip lined-stainless steel angle (7 hours, 890°C). No detrimental physical damage resulted from this contact during heat treatment.

3. Imperfections Resulting from Handling

No detrimental surface imperfections were introduced as a result of handling these tubes during the various processing steps.

H. Surface Inspection, Profilometer

Measurements of surface roughness were made with a Profilometer made by the Micrometrical Mfg. Co., Ann Arbor, Michigan and consisting of a type QC Amplimeter with a type MA Tracer. Table 21 lists the results of the measurements. It may be seen that the front end seals of three tubes contain local areas with RMS values above the specification limit of 200. Visually, it appears that this roughness is less over the core, which is the more critical part of the tube. The final measurements were made perpendicular to the tube axis over the end seals only because it was found that the sensing head left slight scratches on a freshly etched Zircaloy surface; it was decided not to risk measuring the roughness over the core as originally planned.

I. Full-Scale Autoclaving

The five tubes (in two lots) were autoclaved in 650°F water for 24 hours; the water was flashed to steam, and the autoclave test was continued for 24 hours in 750°F, 1500 psi steam. Examination of tubes 37 and 39, autoclaved together in the first lot, revealed white oxide on tube 39 and none on tube 37. It was found that tube 39 was water rinsed in the same tank (rinsed out before using) previously used to acid etch tube 37, causing contamination of the surface of tube 39 by acid and producing white oxide after autoclaving. It was necessary to reuse the tank since not enough separate tanks were available for the operation. Table 22 shows a high corrosion rate calculated from hydrogen released, as would be expected.

Tubes 40, 41, and 42 were given a two-minute etch before being autoclaved, and rinsed in a clean tank reserved for this purpose. Inspection after removal from the autoclave revealed the lustrous black oxide associated with tubes having good corrosion resistance. As would be expected, the corrosion rate calculated from hydrogen released was normal.

In summary, only tube 39 had white oxide after autoclaving.

J. Identification

The front end of each tube has been stamped with the extrusion number. In addition, the 0° reference position, upon which all evaluation work was based, has been indicated by a single center-position mark on the front face; angles are read clockwise with respect to the front face.

K. Disposition

Tube 37 - not candidate for irradiation; stored at NMI pending shipping instructions.

Tube 38 - scrap - used for standard.

Tube 39 - possible candidate for limited irradiation; stored at NMI pending shipping instructions.

Tube 40 - candidate for irradiation; stored at NMI pending shipping instructions.

Tube 41 - candidate for irradiation; in VBWR, Pleasanton, California (in reactor).

Tube 42 - candidate for irradiation; back up for VBWR, Pleasanton, California.

XI. TABLES AND FIGURETable 1

Key to Data and Summary Tables for Evaluation of Tube Nos. 37-42,
Extrusion Nos. 19889-19894

Subject	Table No.	Item
	1 2	Key Zircaloy and U - 2 ^W /o Zr core identities
Analyses	3 4	U - 2 ^W /o Zr cores Zircaloy forgings
	5 5A 6 7 8	Summary of fixed extrusion conditions Extrusion conditions and constants Sequence of operations Core weight; tube length, shift, taper, end seal length Bond integrity evaluation
Gaging	9A thru 9E 10 11	OD and ID: After heat treatment, straightening and abrading OD and ID: Summary Wall thickness of Zircaloy end seals
Clad Thickness	12 13	Summary - Autoradiography, inner Summary - Autoradiography, outer
Straightness	14	Record of bow measurements
Surface	15A thru 15E 16A thru 16E 17A thru 17E 18A thru 18E 19A thru 19E 20A thru 20E 21	As extruded, copper covered, OD As pickled, OD After first etch, before heat treatment, OD After heat treatment, before straightening, OD After autoclaving, OD After autoclaving, ID, borescope Surface roughness
	22,23	Corrosion amount during autoclaving
	Fig. 1	Specifications

Table 2

Identity of Zircaloy Forgings and U - 2^w/o Zr Castings
Used for Tube Nos. 37-42, Extrusion Nos. 19889-19894

	NMI No.	Harvey No.
I. Zircaloy-2		
A. Inner Cladding	SMZ 595	HZC 999
B. Outer Cladding	SMZ 595	HZC 999
C. Front End Seal	SMZ 618	HZC 997
D. Rear End Seal	SMZ 618	HZC 997
II. U - 2 ^w /o Zr Core Castings (Made at NMI)	Casting Number	Tube No.
	UX 1	37
	UX 3	38
	UX 7	39
	UX 13	40
	UX 22	41
	UX 26	42
		Extrusion No.
		19889
		19890
		19891
		19892
		19893
		19894

Table 3

Analysis of U - 2^w/o Zr Cores*

Tube No.	Analysis			
	w/o Zr		ppm C	
	Top	Bottom	Top	Bottom
37	1.90	1.87	165	45
38	2.30	2.22	170	110
39	2.00	2.03	35	30-45
40	2.36	2.32	85	50
41	1.86	1.90	200	195
42	2.02	2.03	70	95
Specification Required	1.5-2.5	1.5-2.5	500 max	500 max
Specification Desired	1.7-2.3	1.7-2.3		

* Top of casting becomes front of tube.

Table 4

Analysis of Zircaloy Forgings Used for Tube Components

	SMZ 595/596 HZC 999	SMZ 618 HZC 997	Specification No. MIL-Z-19859 (Ships) 3/14/57
A. Alloy Additions, ^{w/o}			
Tin	1.46	1.48	1.20-1.70
Iron	0.107	0.103	0.07-0.20
Chromium	0.092	0.093	0.05-0.15
Nickel	0.047	0.048	0.03-0.08
B. Impurities, ppm			
Aluminum	60	46	75
Boron	-	0.3	0.5
Cadmium	-	< 0.3	0.5
Carbon	-	102	500
Cobalt	-	< 10	20
Copper	-	< 20	50
Hafnium	-	< 125	200
Lead	-	< 20	130
Magnesium	-	< 10	20
Manganese	-	< 20	50
Molybdenum	-	< 10	50
Nitrogen	32	35	100 (ind.) 80 (av.)
Oxygen	960-1875*	845-1130*	- - -
Silicon	35	43	100
Titanium	< 20	< 20	50
Vanadium		< 10	- - -

* Determined at Nuclear Metals; all other values reported by Harvey Aluminum, Inc.

Table 5Summary of Fixed Extrusion Conditions
for Tubes 37-42

1. Extrusion press	2400-ton tube press, Am. Brass Co., Waterbury, Conn.,
2. Extrusion date	12/12/58
3. Diameter, inches	
a. Liner	6.625
b. Die	2.100
c. Mandrel	1.462
4. Ram speed, in./min	25
5. Billet heating	
a. Furnace temperature, °F	1200
b. Time in furnace	6 hours (sequence loading)

7. Extrusion ratio (based on tool sizes)

18.3

8. Nose plug

Cu - 10^w/o Ni

9. Mandrel thinning

None

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Table 5A

Vallecitos Enriched Tubes
Extrusion Conditions and Constants*

Tube No.	Billet Heating Temp. (°F)	Extrusion Forces (tons)		Calculated Extrusion Constant	
		Max	Running	Max	Running
37	1200	1900	1770	19.9	17.0
38	1200	1690	1500	17.8	15.7
39	1195	1690	1530	18.4	16.0
40	1200	1640	1570	18.3	16.4
41	1200	1670	1520	18.0	15.9
42	1200	1670	1500	17.8	15.7
Spec.	1190-1220				

* Extruded December 12, 1958.
 Heating time, 6 hours.
 No breakthrough occurred.

Table 6Sequence of Operations for Tubes 37, 39-42

Step	Operation
1.	Quality control of Zircaloy melting of core and composition check.
2.	Preparation of billet components, auxiliary components, and tools.
3.	Etching of billet components and polishing of core.
4.	Billet assembly, welding, leak testing, evacuation, seal off Zircaloy.
5.	Canning in copper, welding, evacuation at 300°F, seal off.
6.	Extrusion and roll cooling at ABC, Waterbury, Conn.; establish 0° reference--top of tube is extruded.
7.	Preliminary survey with GMC for approximate core end location.
8.	Visual inspection.
9.	Cropping of tube to 6 feet.
10.	Measurement of maximum bow.
11.	Rough straightening, gag press, to 1/8-inch maximum bow.
12.	Radiography at 120° intervals for accurate core end location.
13.	Pickling to remove copper.
14.	Visual inspection.
15.	Complete autoradiography.
16.	Measurement of surface roughness.
17.	Bright etching removal of approximately 1 mil/side.
18.	Visual inspection.
19.	Laying out gage length for heat treatment growth measurements.
20.	Heat treating tube on graphite strip lined-stainless steel angle in evacuated gettered container--7 hr 890 ± 10°C; water quench evacuated container; New England Metallurgical Corp.
21.	Visual inspection.
22.	Straightening to final specification.
23.	Measuring gage length for heat treatment growth.
24.	Ultrasonic bond test.
25.	Polishing of OD surface with wet 320 grit abrasive paper to remove about 0.2 mil/side.

(Cont'd. on next page)

Table 6 (Cont'd.)

Step	Operation
26.	Gaging OD with micrometer, ID with Federal Gage.
27.	Measurement of wall thickness at tube ends (1/2 inch in).
28.	Facing of tube ends to obtain total length of $44 \pm 1/8$ inch and threading ends per du Pont drawing STD-MDX-2253, LaPointe Machine Tool Co.
29.	Etching tube to remove about 3/4 mil/side.
30.	Etching tube in fresh etch bath to remove about 3/4 mil/side.
31.	Measuring surface roughness over end seals.
32.	Etching tube for 1 minute, rinsing in distilled H ₂ O.
33.	Autoclave and acceptance test; 24 hr, 650°F water; 24 hr, 750°F, 1500 psi steam.
34.	Visual inspection of OD, borescope inspection of ID.
35.	Measurement of bow.
36.	Milling holes for pins.
37.	Pickling for shipment.
38.	Etching 1.5 mils/side from remaining two 1/2-inch long corrosion control rings; corrode for 14 days in 750°F, 1500 psi steam; inspect and determine weight gain.

Sequence of Operations for Tube 38

Step	Operation
1-14.	Same as Table 6.
15.	Nine-inch section removed from center of tube.
16.	OD Zircaloy cladding removed by turning in lathe.
17.	Autoradiograph standard assembled.
18.	Two 1/4-inch rings cut from uniform core for clad thickness measurements.

693

020

Table 7

Vallecitos Enriched Tubes
Core Characteristics

Tube No.	Core Composition		Core Weight (gm)	Over-all Core Length (in.) (a)	Uniform Core Length (in.) (b)	Shift (in.) (c)		Taper (in.) (d)		Heat Treatment Growth (ΔL) (in.)
	w/o Zr	ppm C				Front	Rear	Front	Rear	
37	1.89	105	12703.1	35	21-1/8	5/8	2	5-3/4	5-1/4	+1/32
38	2.26	140	12626.6	34-1/16	22-3/4	1/4	1-1/4	4-3/8	5-1/2	-
39	2.02	35	12632.8	34	22	1/2	1-3/8	4-3/8	5-3/8	+5/32
40	2.34	70	12522.9	34-5/16	21-3/4	3/4	1	4-1/4	5-3/4	+3/32
41	1.88	200	12693.8	34-1/4	22-3/4	3/8	1-3/8	4-3/8	5-1/4	+3/32
42	2.03	85	12680.9	34	23-1/8	1/2	1/2	4-1/8	5-1/4	+3/32
Spec. Desired	1.5-2.5 1.7-2.3	<500	-	32-36 34	-	-	-	<6	<12	-

Front end seal length, 2-3/4 inches.

Total length shipped tube, 44 inches.

Drawing No. for machining ends, STD-MDX4-2253.

(a) Estimated accuracy of core length is $\pm 3/16$ inch.

(b) Estimated accuracy of uniform core length is ± 2 inches.

(c) Estimated accuracy of shift is $\pm 1/4$ inch.

(d) Estimated accuracy of tapers is ± 1 inch.

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Table 8
Vallecitos Enriched Tubes
Bond Quality (Post Heat Treatment)

Tube No.	Ultrasonic Threshold Data ⁽²⁾				
	Rear End Seal 20-26R(1)	Rear Taper 15-17R	Rear Core 8R	Front Core 8F	Front End Seal 20-26F
37	0.00	1.70	1.20	1.20	0.00
39	0.00	1.60	1.00	1.00	0.00
40	0.00	1.70	1.10	1.10	0.00
41	0.00	1.70	1.10	1.10	0.00
42	0.00	1.65	1.10	1.10	0.00
Spec.	<1.60	<1.60	<1.60	<1.60	<1.60

- (1) Positions are in inches front (F) or rear (R) from midlength of tube.
 (2) Threshold data: Lower number represents higher instrument sensitivity and better bond; a threshold value of 0.00 is sensitivity setting at which non-bond indication is noted; a value of 0.00 indicates that at maximum instrument sensitivity, no indication of non-bond was detected.

Lengths (in.)		
Total		72
Tip-to-tip core		35
Front	Taper	5-3/4
	Shift	5/8
	End Seal	18-1/2
Rear	Taper	5-1/4
	Shift	2
	End Seal	18-1/2

Table 9A
Gaging Results

Tube No.	37
Extrusion	19889
Condition	After heat treatment, straightening and abrading

	Station (in.) from mid-length of core)	OD					Spread, in mils	ID					Spread, in mils
		To obtain OD in inches, place 2.0 before number shown						To obtain ID in inches, place 1.4 before number shown					
		0°	45°	90°	135°	Av		0°	45°	90°	135°	Av	
End Seal	33F	79	89	82	73	81	16	77	80	77	71	76	9
	30F	79	89	84	76	82	13	78	80	77	72	77	8
	24F	80	85	79	74	80	11	78	81	77	75	78	6
	18F	80	85	81	74	80	11	75	79	74	70	75	9
Taper	16F	79	78	79	73	77	6	78	82	75	74	77	8
	14F	71	73	77	74	74	6	78	82	84	79	81	6
	12F	71	70	71	70	71	1	73	76	82	79	78	9
Uniform Core	6F	70	69	68	67	69	3	67	70	71	70	70	4
	0	66	70	67	64	67	6	66	71	70	70	69	5
	6R	69	73	70	66	70	7	69	73	71	71	71	4
Taper	12R	71	79	73	68	73	11	78	83	75	73	78	10
	14R	70	78	75	70	73	8	82	84	82	81	82	3
	16R	83	85	84	79	83	6	77	78	76	78	77	2
End Seal	18R	83	90	85	79	84	11	77	81	75	75	76	6
	24R	81	88	85	75	82	13	76	85	77	77	79	9
	30R	82	89	86	78	84	11	74	85	79	79	79	11
	33R	83	90	87	77	84	13	74	84	76	79	78	10

Summary

	OD (in.)			ID (in.)		
	Av	Max	Min	Av	Max	Min
End Seals	2.082	2.084	2.080	1.477	1.479	1.475
Uniform Core	2.069	2.070	2.067	1.470	1.471	1.469

Lengths (in.)		
Total		72
Tip-to-tip core		34
Front	Taper	4-3/8
	Shift	1/2
	End Seal	19
Rear	Taper	5-3/8
	Shift	1-3/8
	End Seal	19

Table 9B
Gaging Results

Tube No.	39
Extrusion	19891
Condition	After heat treatment, straightening and abrading

	Station (in.) from mid-length of core)	OD					Spread, in mils	ID					Spread, in mils
		To obtain OD in inches, place 2.0 before number shown						To obtain ID in inches, place 1.4 before number shown					
		0°	45°	90°	135°	Av		0°	45°	90°	135°	Av	
End Seal	33F	82	81	79	82	81	3	75	73	72	74	74	3
	30F	79	78	75	82	79	7	77	72	69	75	73	8
	24F	75	75	74	76	75	2	73	74	74	74	74	1
	18F	69	76	78	77	75	9	67	72	73	70	71	6
Taper	16F	72	75	76	75	75	4	71	74	77	73	74	6
	14F	67	68	70	68	68	3	76	79	82	78	79	6
	12F	66	66	68	68	67	2	69	70	71	70	70	2
Uniform Core	6F	65	65	63	65	65	2	66	65	64	66	65	2
	0	65	65	65	66	65	1	64	65	65	65	65	1
	6R	67	67	68	66	67	2	65	69	69	66	67	4
Taper	12R	67	70	67	68	68	3	68	70	72	71	70	4
	14R	74	75	67	73	72	8	77	74	74	78	76	4
	16R	79	78	76	80	78	4	72	71	70	72	71	2
End Seal	18R	81	79	79	81	80	2	71	70	70	71	71	1
	24R	78	80	81	80	80	3	73	76	76	74	75	3
	30R	79	78	76	85	80	9	80	73	73	80	77	7
	33R	79	78	78	85	80	7	79	73	71	80	76	9

Summary

	OD (in.)			ID (in.)		
	Av	Max	Min	Av	Max	Min
End Seals	2.079	2.085	2.069	2.074	2.080	2.067
Uniform Core	2.066	2.068	2.063	2.066	2.069	2.064

Lengths (in.)		
Total		72
Tip-to-tip core		34-5/16
Front	Taper	4-1/4
	Shift	3/4
	End Seal	18-7/8
Rear	Taper	5-3/4
	Shift	1
	End Seal	18-7/8

Table 9C
Gaging Results

Tube No.	40
Extrusion	19892
Condition	After heat treatment, straightening and abrading

	Station (in.) from mid-length of core)	OD					Spread, in mils	ID					Spread, in mils
		To obtain OD in inches, place 2.0 before number shown						To obtain ID in inches, place 1.4 before number shown					
		0°	45°	90°	135°	Av		0°	45°	90°	135°	Av	
End Seal	33F	78	82	81	81	81	4	71	72	74	73	73	3
	30F	78	80	81	81	80	3	72	74	76	75	74	4
	24F	76	77	79	78	78	3	71	75	77	76	75	6
	18F	78	77	79	79	78	2	70	72	72	71	71	2
Taper	16F	75	76	79	77	77	4	69	72	76	73	73	7
	14F	73	73	69	70	71	4	76	77	75	75	76	2
	12F	67	68	66	66	67	2	74	75	69	69	72	6
Uniform Core	6F	63	65	65	64	64	2	62	64	65	64	64	3
	0	64	65	65	68	66	4	64	66	66	65	65	2
	6R	67	68	67	67	67	1	66	69	70	67	68	4
Taper	12R	67	68	69	69	68	2	69	69	70	73	70	4
	14R	68	66	72	72	70	6	72	69	75	77	73	8
	16R	75	75	75	79	76	4	71	73	73	72	72	2
End Seal	18R	79	82	81	82	81	3	71	73	72	71	72	2
	24R	78	81	82	81	81	4	73	76	77	75	75	4
	30R	78	82	83	81	81	5	74	78	80	77	77	6
	33R	79	82	84	82	82	5	73	77	79	76	76	6

Summary

	OD (in.)			ID (in.)		
	Av	Max	Min	Av	Max	Min
End Seals	2.080	2.084	2.076	1.474	1.480	1.471
Uniform Core	2.066	2.068	2.063	1.465	1.470	1.462

Lengths (in.)		
Total		72
Tip-to-tip core		34-1/4
Front	Taper	4-3/8
	Shift	3/8
	End Seal	18-7/8
Rear	Taper	5-1/4
	Shift	1-3/8
	End Seal	18-7/8

(approx.)

Table 9D
Gaging Results

Tube No.	41
Extrusion	19893
Condition	After heat treatment, straightening and abrading

(approx.)

	Station (in.) from mid-length of core)	OD					Spread, in mils	ID					Spread, in mils
		To obtain OD in inches, place 2.0 before number shown						To obtain ID in inches, place 1.4 before number shown					
		0°	45°	90°	135°	Av		0°	45°	90°	135°	Av	
End Seal	33F	83	83	75	74	79	9	77	78	70	70	74	8
	30F	82	83	75	74	71	9	79	79	71	69	75	10
	24F	81	82	72	70	78	12	76	80	70	68	74	12
	18F	82	84	74	69	77	15	75	78	76	63	74	15
Taper	16F	80	81	74	71	76	10	74	77	70	68	72	9
	14F	76	76	73	71	74	5	78	79	76	75	77	4
	12F	71	68	66	65	68	6	78	77	73	73	75	5
Uniform Core	6F	68	66	65	66	66	3	68	67	67	67	67	1
	0	67	65	64	65	65	3	66	66	66	66	66	0
	6R	68	66	65	66	66	3	69	68	67	67	68	2
Taper	12R	70	68	67	67	68	3	72	70	68	71	70	4
	14R	69	68	67	66	68	3	78	79	76	76	77	3
	16R	75	75	75	74	75	1	74	71	73	75	73	4
End Seal	18R	82	82	79	78	80	4	73	73	71	70	72	3
	24R	83	85	77	75	80	10	78	80	72	71	75	9
	30R	85	87	77	74	81	13	82	84	73	71	78	13
	33R	83	85	79	78	81	7	79	80	75	73	77	7

Summary

	OD (in.)			ID (in.)		
	Av	Max	Min	Av	Max	Min
End Seals	2.078	2.087	2.069	1.475	1.484	1.463
Uniform Core	2.066	2.068	2.064	1.467	1.469	1.466

Lengths (in.)		
Total		72
Tip-to-tip core		34
Front	Taper	4-1/8
	Shift	1/2
	End Seal	19
Rear	Taper	5-1/4
	Shift	1/2
	End Seal	19

Table 9E
Gaging Results

Tube No.	42
Extrusion	19894
Condition	After heat treatment, straightening and abrading

	Station (in.) from mid-length of core)	OD					Spread, in mils	ID					Spread, in mils
		To obtain OD in inches, place 2.0 before number shown						To obtain ID in inches, place 1.4 before number shown					
		0°	45°	90°	135°	Av		0°	45°	90°	135°	Av	
End Seal	33F	82	82	75	75	79	7	77	77	71	70	74	7
	30F	82	81	76	76	79	6	78	77	72	72	75	6
	24F	81	80	74	73	77	8	78	78	72	71	75	7
	18F	83	82	75	75	79	8	75	75	67	67	71	8
Taper	16F	80	78	75	76	77	5	75	75	71	72	73	4
	14F	74	73	75	73	74	2	79	79	79	78	79	1
	12F	69	69	69	68	69	1	74	75	73	71	73	4
Uniform Core	6F	68	68	67	66	67	4	66	67	66	65	66	2
	0	67	65	68	66	67	3	64	67	66	66	66	3
	6R	69	67	67	66	67	2	68	71	68	67	69	4
Taper	12R	73	71	70	69	71	4	70	71	68	67	69	4
	14R	74	71	66	66	69	8	79	79	73	74	76	5
	16R	81	79	74	74	77	7	74	75	71	71	73	4
End Seal	18R	89	85	78	80	83	11	76	75	68	70	72	7
	24R	87	84	76	77	81	11	80	79	70	73	76	10
	30R	85	83	79	79	82	6	81	81	76	77	79	5
	33R	88	85	77	78	82	11	81	81	71	75	77	6

Summary

	OD (in.)			ID (in.)		
	Av	Max	Min	Av	Max	Min
End Seals	2.081	2.089	2.073	1.475	1.481	1.467
Uniform Core	2.067	2.069	2.065	1.467	1.471	1.464

Table 10

Summary of OD and ID Measurements of Vallecitos Enriched Tubes
(Dimensions in inches)

Tube No.	OD ^(a)						ID ^(b)					
	End Seals (32 Readings)			Uniform Core Section (12 Readings)			End Seals (32 Readings)			Uniform Core Section (12 Readings)		
	Av	Max	Min	Av	Max	Min	Av	Max	Min	Av	Max	Min
37	2.079	2.081	2.077	2.066	2.067	2.063	1.480	1.482	1.478	1.473	1.474	1.472
39	2.076	2.082	2.066	2.063	2.065	2.060	1.477	1.483	1.470	1.469	1.472	1.467
40	2.077	2.081	2.073	2.063	2.065	2.060	1.477	1.483	1.474	1.468	1.473	1.465
41	2.075	2.084	2.066	2.063	2.065	2.061	1.478	1.487	1.466	1.470	1.472	1.469
42	2.079	2.086	2.070	2.064	2.066	2.062	1.478	1.484	1.470	1.470	1.474	1.467
Spec.		2.086	2.060		2.070	2.050		1.484	1.468		1.477	1.457

NOTE: Measurements were made before final bright etch; figures reported here were derived by adding (or subtracting) 0.003 inch to (or from) the original measurements (0.003 inch = amount of metal removed from the diameter by the final bright etch.

(a) 0.003 subtracted from original measurement.

(b) 0.003 added to original measurement.

Table 11

Wall Thickness of Zircaloy End Seals
Vallecitos Enriched Tubes
 (Values in inches)

Tube No.	Front End			Rear End			Both Ends
	Av	Max	Min	Av	Max	Min	
37	0.300	0.305	0.295	0.303	0.312	0.292	0.301 ₅
39	0.300	0.303	0.293	0.300	0.307	0.297	0.300
40	0.300	0.303	0.296	0.301	0.307	0.294	0.300 ₅
41	0.298	0.303	0.293	0.301	0.307	0.296	0.299 ₅
42	0.300	0.301	0.298	0.301	0.304	0.299	0.300 ₃
Spec.		0.311	0.288		0.311	0.288	

NOTE: The above data has been corrected to final size by subtracting the three mils removed by etching.

Table 12

Summary of Estimated Final Inner Cladding Thickness Measurements
(mils) Inferred from Metal Removal and Autoradiography

Tube No.	Average Clad Thickness			Clad Thickness at Thick and Thin Spots					
	Initial Clad	Etched, Not Heat Treated	Heat Treated, Polished, Etched	Front Taper, Minimum	10F-0		0-10R		Rear Taper, Minimum
					Max	Min	Max	Min	
37	18.5	17.8	16.4	16.4	18.7	14.9	18.8	13.5	16.4
39	18.5	17.7	16.1	16.1	18.3	15.6	17.7	14.0	13.0
40	18.5	17.7	16.0	15.4	17.7	15.1	-*	13.3	10.5
41	18.5	17.7	15.9	17.3	16.6	12.9	17.5	13.6	14.2
42	18.5	17.6	15.9	16.3	20.3	13.9	17.7	14.5	-
Spec.				10.0	18	12	18	12	10.0

* Value beyond range of standard.

Table 13

Summary of Estimated Final Outer Cladding Thickness
Measurements (mils) Inferred from Metal Removal and Autoradiography

Tube No.	Average Clad Thickness				Clad Thickness at Thick and Thin Spots					
	Initial Clad	Etched, Not Heat Treated	Heat Treated, Polished	Heat Treated, Polished, Etched	Front Taper Minimum	10F-0		0-10R		Rear Taper Minimum
						Max	Min	Max	Min	
37	18.5	17.8	17.6	16.2	12.3	17.9	15.0	17.9	15.1	8.5
39	18.5	17.7	17.5	15.9	11.6	17.5	12.5	17.7	13.4	11.8
40	18.5	17.7	17.5	15.8	10.8	17.5	13.4	16.9	14.0	10.1
41	18.5	17.7	17.5	15.7	11.7	16.8	13.8	17.2	13.2	10.5
42	18.5	17.6	17.4	15.7	12.1	17.1	12.3	16.8	12.3	10.1
Spec.					10	18	12	18	12	10

Table 14

Record of Bow Measurements
 (Measurements in 64ths inches - maximum values)

Tube No.	As Extruded	After Heat Treatment	After Autoclaving
Span(in.)	72	72	42
37	8	11	3
38	8	-	-
39	8	5	2
40	16	6	1
41	4	9	2
42	8	6	2
Spec.	-	-	4

NOTE: Tubes straightened to 8/64 inch before heat treatment
 and <2/64 inch before autoclaving.

Table 15A

Condition: As extruded, copper covered

Over-all Length: 12' 8"

Tube No. 37

Ext. No. 19889

Date

Inspector W.J.R.+W.L.

Outer ☒ Inner ☐ Surface Inspection Record (Check Appropriate Blank)

Instructions: Record angle and distance from mid-length of meat and description of surface flaws, such as pits, seams, flats, gouges, ridges, etc. Also record general observations.

Flaw	Angle (deg.)	Distance Front (F) or Rear (R) from Mid-length of Meat
In general, bottom of extrusion had defects		
Severe tree bark effect	170	67-1/2 - .82F
Slight tree bark effect		3-1/2 - 4-1/2F
Medium tree bark effect	180	16-20-1/2R
	893	033

Table 15B

Condition: As extruded, copper covered

Over-all Length: 12' 8"

Tube No. 39

Ext. No. 19891

Date _____

Inspector W.L.+W.J.R.

Outer ☒ Inner ☐ Surface Inspection Record (Check Appropriate Blank)

Instructions: Record angle and distance from mid-length of meat and description of surface flaws, such as pits, seams, flats, gouges, ridges, etc. Also record general observations.

Flaw	Angle (deg.)	Distance Front (F) or Rear (R) from Mid-length of Meat
Slight tree bark effect	180	68-72F
Pin points		38-3/8R, 42-3/8R

693 034

Table 15C

Condition: As extruded, copper covered

Over-all Length: 12' 8"

Tube No. 40

Ext. No. 19892

Date

Inspector W.J.R.+W.L.

Outer ☒ Inner ☐ Surface Inspection Record (Check Appropriate Blank)

Instructions: Record angle and distance from mid-length of meat and description of surface flaws, such as pits, seams, flats, gouges, ridges, etc. Also record general observations.

Flaw	Angle (deg.)	Distance Front (F) or Rear (R) from Mid-length of Meat
Tree bark effect	180	67-75F
Roughness	170	10-14F
General roughness		Bottom of core area

Table 15D

Condition: As extruded, copper covered

Over-all Length: 12' 9"

Tube No. 41

Ext. No. 19893

Date 12/17/58

Inspector W.L.

Outer ☒ Inner ☐ Surface Inspection Record (Check Appropriate Blank)

Instructions: Record angle and distance from mid-length of meat and description of surface flaws, such as pits, seams, flats, gouges, ridges, etc. Also record general observations.

Flaw	Angle (deg.)	Distance Front (F) or Rear (R) from Mid-length of Meat
Tree bark effect	180	67-83F

Table 15E

Condition: As extruded, copper covered

Over-all Length: 12' 8"

Tube No. 42

Ext. No. 19894

Date

Inspector W.J.R.+W.L.

Outer ☒ Inner ☐ Surface Inspection Record (Check Appropriate Blank)

Instructions: Record angle and distance from mid-length of meat and description of surface flaws, such as pits, seams, flats, gouges, ridges, etc. Also record general observations.

Flaw	Angle (deg.)	Distance Front (F) or Rear (R) from Mid-length of Meat
Tree bark; good surface over core	180	66-77F

Table 16A

Condition: As pickled

Over-all Length: 6'

Tube No. 37

Ext. No. 19889

Date _____

Inspector W.J.R.+W.L.

Outer ☒ Inner _____ Surface Inspection Record (Check Appropriate Blank)

Instructions: Record angle and distance from mid-length of meat and description of surface flaws, such as pits, seams, flats, gouges, ridges, etc. Also record general observations.

Flaw	Angle (deg.)	Distance Front (F) or Rear (R) from Mid-length of Meat
Series of depressions	180	16-22R

893 038

Table 16B

Condition: As pickled

Over-all Length: 6'

Tube No. 39

Ext. No. 19891

Date 1/8/59

Inspector W.J.R., W.L., F.K.

Outer ☒ Inner ☐ Surface Inspection Record (Check Appropriate Blank)

Instructions: Record angle and distance from mid-length of meat and description of surface flaws, such as pits, seams, flats, gouges, ridges, etc. Also record general observations.

Flaw	Angle (deg.)	Distance Front (F) or Rear (R) from Mid-length of Meat
Depression	70	17-3/8F
Single pin point	96	2-1/8R, 6-1/8R, 10-1/8R, 14-3/16R, 18-1/4R, 22-1/4R, 26-5/16R, 30-3/8R, 34-3/8R
Extrusion depressions	141	11-1/2 - 31-1/4F

Table 16C

Condition: As pickled

Over-all Length: 6'

Tube No. 40

Ext. No. 19892

Date

Inspector W.J.R.+F.K.

Outer ☒ Inner ☐ Surface Inspection Record (Check Appropriate Blank)

Instructions: Record angle and distance from mid-length of meat and description of surface flaws, such as pits, seams, flats, gouges, ridges, etc. Also record general observations.

Flaw	Angle (deg.)	Distance Front (F) or Rear (R) from Mid-length of Meat
Extrusion pits	98	3-3/4F, 4-1/4F
Two pits, bright	270	9-1/2R, 9-3/4R

Table 16D

Condition: As pickled

Over-all Length: 12' 8"

Tube No. 41

Ext. No. 19893

Date

Inspector W.J.R.+W.L.

Outer ☒ Inner ☐ Surface Inspection Record (Check Appropriate Blank)

Instructions: Record angle and distance from mid-length of meat and description of surface flaws, such as pits, seams, flats, gouges, ridges, etc. Also record general observations.

Flaw	Angle (deg.)	Distance Front (F) or Rear (R) from Mid-length of Meat
Indiction of shift pattern not over taper	0-360	26-28F

Table 16E

Condition: As pickled

Over-all Length: 6'

Tube No. 42

Ext. No. 19894

Date

Inspector W.J.R.+W.L.

Outer ☒ Inner ☐ Surface Inspection Record (Check Appropriate Blank)

Instructions: Record angle and distance from mid-length of meat and description of surface flaws, such as pits, seams, flats, gouges, ridges, etc. Also record general observations.

Flaw	Angle (deg.)	Distance Front (F) or Rear (R) from Mid-length of Meat
Indication of shift pattern, not over taper	0-360	24-28F

Table 17A

Condition: After first etch, before heat treatment

Over-all Length: 6'

Tube No. 37
 Ext. No. 19889
 Date 1/10/59
 Inspector W.J.R.+F.K.

Outer ☒ Inner ☐ Surface Inspection Record (Check Appropriate Blank)

Instructions: Record angle and distance from mid-length of meat and description of surface flaws, such as pits, seams, flats, gouges, ridges, etc. Also record general observations.

Flaw	Angle (deg.)	Distance Front (F) or Rear (R) from Mid-length of Meat
Extrusion depressions	155	3-1/2 - 4-3/8F
Extrusion depressions		30-1/2 - 31R
Extrusion depressions	180	15-1/2 - 21R
Slight nick	336	34-1/2R

Table 17B

Condition: After first etch, before heat treatment

Over-all Length: 6'

Tube No. 39

Ext. No. 19891

Date 1/10/59

Inspector W.R.+F.K.

Outer ☒ Inner ☐ Surface Inspection Record (Check Appropriate Blank)

Instructions: Record angle and distance from mid-length of meat and description of surface flaws, such as pits, seams, flats, gouges, ridges, etc. Also record general observations.

Flaw	Angle (deg.)	Distance Front (F) or Rear (R) from Mid-length of Meat
Series of pits	102	6-1/8R, 10-1/8R, 14-3/16R, 18-3/16R, 22-1/4R, 26-5/16R, 30-5/16R, 34-3/8R
Extrusion depressions	144	11-5/8 - 13-1/8R
Pit	78	17-1/2F

Table 17C

Condition: After first etch, before heat treatment

Over-all Length: 6'

Tube No. 40
 Ext. No. 19892
 Date 1/10/59
 Inspector F.K.+W.M.

Outer ☒ Inner ☐ Surface Inspection Record (Check Appropriate Blank)

Instructions: Record angle and distance from mid-length of meat and description of surface flaws, such as pits, seams, flats, gouges, ridges, etc. Also record general observations.

Flaw	Angle (deg.)	Distance Front (F) or Rear (R) from Mid-length of Meat
Shift	0-360	11-1/4R
Extrusion depressions	192	3-3/4 - 4-1/2F, 32 - 34-1/4R
Two pin points	270	9-9/10R, 9-12/16R

Table 17D

Condition: After first etch, before heat treatment

Over-all Length: 6'

Tube No. 41
 Ext. No. 19893
 Date 1/10/59
 Inspector F.K.+B.M.

Outer ☒ Inner ☐ Surface Inspection Record (Check Appropriate Blank)

Instructions: Record angle and distance from mid-length of meat and description of surface flaws, such as pits, seams, flats, gouges, ridges, etc. Also record general observations.

Flaw	Angle (deg.)	Distance Front (F) or Rear (R) from Mid-length of Meat
One pin point	212	31-3/4R
Shiny area similar to shift	0-360	25F - 34-1/2F

Table 17E

Condition: After first etch, before heat treatment

Over-all Length: 6'

Tube No. 42
 Ext. No. 19894
 Date 1/10/59
 Inspector F.K.+B.M.

Outer ☒ Inner ☐ Surface Inspection Record (Check Appropriate Blank)

Instructions: Record angle and distance from mid-length of meat and description of surface flaws, such as pits, seams, flats, gouges, ridges, etc. Also record general observations.

Flaw	Angle (deg.)	Distance Front (F) or Rear (R) from Mid-length of Meat
Nick	51	30-3/8R
Shiny area similar to shift	0-360	23-31F

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Table 18A

Condition: After heat treatment, before straightening

Over-all Length: 6'

Tube No. 37
 Ext. No. 19889
 Date 1/14/59
 Inspector W.J.R.+F.K.

Outer ☒ Inner ☐ Surface Inspection Record (Check Appropriate Blank)

Instructions: Record angle and distance from mid-length of meat and description of surface flaws, such as pits, seams, flats, gouges, ridges, etc. Also record general observations.

Flaw	Angle (deg.)	Distance Front (F) or Rear (R) from Mid-length of Meat
Contact with container during heat treatment	30	28 - 28-3/8R
Contact with container during heat treatment	90	33-7/8 - 34-1/4F
Contact line	150	Entire length
Contact line	240	Entire length
Contact with tip of container	350	3 - 3/8R

Table 18B

Condition: After heat treatment, before straightening

Over-all Length: 6'

Tube No. 39
 Ext. No. 19891
 Date 1/10/59
 Inspector W.J.R.+F.K.

Outer ☒ Inner ☐ Surface Inspection Record (Check Appropriate Blank)

Instructions: Record angle and distance from mid-length of meat and description of surface flaws, such as pits, seams, flats, gouges, ridges, etc. Also record general observations.

Flaw	Angle (deg.)	Distance Front (F) or Rear (R) from Mid-length of Meat
Shift pattern		23-1/4 - 36R
Strap mark	12	34-1/8R
Contact line	174	Entire length
Contact line	264	Entire length

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Table 18C

Condition: After heat treatment, before straightening

Over-all Length: 72-3/16"

Tube No. 40
 Ext. No. 19892
 Date 1/14/59
 Inspector F.K.+B.M.

Outer ☒ Inner ☐ Surface Inspection Record (Check Appropriate Blank)

Instructions: Record angle and distance from mid-length of meat and description of surface flaws, such as pits, seams, flats, gouges, ridges, etc. Also record general observations.

Flaw	Angle (deg.)	Distance Front (F) or Rear (R) from Mid-length of Meat
Slight scrape from strap	0	31-3/8 - 32R
Graphite contact line	96	Entire length of tube
Graphite contact line	186	Entire length of tube
Contact lines from container	348	3-6R

Table 18D

Condition: After heat treatment, before straightening

Over-all Length: 72-3/16"

Tube No. 41

Ext. No. 19893

Date 1/15/59

Inspector F.K.+B.M.

Outer ☒ Inner ☐ Surface Inspection Record (Check Appropriate Blank)

Instructions: Record angle and distance from mid-length of meat and description of surface flaws, such as pits, seams, flats, gouges, ridges, etc. Also record general observations.

Flaw	Angle (deg.)	Distance Front (F) or Rear (R) from Mid-length of Meat
Contact line from container	0	32-1/4 - 33F
Slight scrape	0	26-1/2 - 27-1/4F
Graphite contact line	120	Entire length of tube
Graphite contact line	210	Entire length of tube
Scrape from removing tube from container	312-336	2-5/8 - 6-1/2F, 16F, 21 - 30-1/8F, 1-1/8 - 5-1/8R, 6-1/2 - 11-1/2R, 13-1/2 - 20-1/8R, 21-1/8 - 25-3/4R, 32-3/4 - 33-1/8R

Table 18E

Condition: After heat treatment, before straightening

Over-all Length: 72-5/32"

Tube No. 42
 Ext. No. 19894
 Date 1/15/59
 Inspector F.K.+B.M.

Outer ☒ Inner ☐ Surface Inspection Record (Check Appropriate Blank)

Instructions: Record angle and distance from mid-length of meat and description of surface flaws, such as pits, seams, flats, gouges, ridges, etc. Also record general observations.

Flaw	Angle (deg.)	Distance Front (F) or Rear (R) from Mid-length of Meat
Graphite contact line	114	Entire length of tube
Graphite contact line	204	Entire length of tube
Strap marks	240	35R
Strap marks	270	35R
Contact lines from container	330	10-5/8 - 11-1/4R
Scrapes from removing tube from container	336	9-1/2 - 10F, 34-35F, 5-3/4 - 7-3/8R, 21 - 22-1/4R, 33-3/8 - 34-1/2R

Table 19A

Condition: After autoclaving

Over-all Length: 43-15/16"

Tube No. 37
 Ext. No. 19889
 Date 2/4/59
 Inspector F.K.

Outer ☒ Inner ☐ Surface Inspection Record (Check Appropriate Blank)

Instructions: Record angle and distance from mid-length of meat and description of surface flaws, such as pits, seams, flats, gouges, ridges, etc. Also record general observations.

Flaw	Angle (deg.)	Distance Front (F) or Rear (R) from Mid-length of Meat
Tiny pin point	42	10-1/2R
Tiny dent	66	18-7/8R
Thin white line, possible white oxide	132	1/4 to 3/4F
Tiny pin point, possible white oxide	162	3/4F
Light scrape when removing tube from autoclave	174	19-7/8 to 20-1/4R
Tiny dent	300	18-7/8F
Tiny pin point, possible white oxide	330	13-5/8F

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Table 19C

Condition: After autoclaving

Over-all Length: 44"

Tube No. 40

Ext. No. 19892

Date 1/14/59

Inspector F.K.+B.M.

Outer ☒ Inner ☐ Surface Inspection Record (Check Appropriate Blank)

Instructions: Record angle and distance from mid-length of meat and description of surface flaws, such as pits, seams, flats, gouges, ridges, etc. Also record general observations.

Flaw	Angle (deg.)	Distance Front (F) or Rear (R) from Mid-length of Meat
Tiny pin point	300	18-3/4R
1/8" line (possible white oxide)	342	21R

Table 19B

Condition: After autoclaving

Over-all Length: 44"

Tube No. 39
 Ext. No. 19891
 Date 1/26/59
 Inspector F.K.

Outer ☒ Inner ☐ Surface Inspection Record (Check Appropriate Blank)

Instructions: Record angle and distance from mid-length of meat and description of surface flaws, such as pits, seams, flats, gouges, ridges, etc. Also record general observations.

Flaw	Angle (deg.)	Distance Front (F) or Rear (R) from Mid-length of Meat
White oxide mist	0-360	6R to 21R, 5-1/2F to 21F
White oxide spot	12	14-1/2R
White oxide line (1/16 inch in width)	54	
Thin white oxide spot	54	18-7/8F, 16-3/8F
Thin white oxide line	96	7-1/2F to 7-3/4F
Thin white oxide line	102	3-7/8 to 4-1/2R
Thin white oxide line	120	3R to 5R
Thin white oxide line	135	9R to 11-1/4R
	141	7-7/8 to 8-1/2R
Thin white oxide blotch	192	15-1/2R
Thin white oxide spot	240	13R
Thin white oxide blotch	270	16R
Thin white oxide spot	312	20-1/4R
Thin white oxide spot	348	19-1/2R
Thin white oxide dots	0-360	14-1/2R to 21R

Table 19D

Condition: After autoclaving

Over-all Length: 43-31/32"

Tube No. 41
 Ext. No. 19893
 Date 2/9/59
 Inspector F.K.

Outer ☒ Inner ☐ Surface Inspection Record (Check Appropriate Blank)

Instructions: Record angle and distance from mid-length of meat and description of surface flaws, such as pits, seams, flats, gouges, ridges, etc. Also record general observations.

Flaw	Angle (deg.)	Distance Front (F) or Rear (R) from Mid-length of Meat
Thin 3/8" line, possible white oxide	0	8-3/4R
Very light line, possible white oxide	6	15-3/4 - 16-1/4R
Light smear (1/8")	336	14-1/8R
Smear	324	1/2 - 1-1/2R

Table 19E

Condition: After autoclaving

Over-all Length: 44"

Tube No. 42
 Ext. No. 19894
 Date 2/9/59
 Inspector F.K.

Outer ☒ Inner ☐ Surface Inspection Record (Check Appropriate Blank)

Instructions: Record angle and distance from mid-length of meat and description of surface flaws, such as pits, seams, flats, gouges, ridges, etc. Also record general observations.

Flaw	Angle (deg.)	Distance Front (F) or Rear (R) from Mid-length of Meat
Tiny dent	276	18-3/4R
Tiny dent	102	19F

Table 20A

Condition: After autoclaving

Over-all Length: 43-15/16"

Tube No. 37
 Ext. No. 19889
 Date 1/4/59
 Inspector F.K.

Outer Inner ☒ Surface Inspection Record (Check Appropriate Blank)

Instructions: Record angle and distance from mid-length of meat and description of surface flaws, such as pits, seams, flats, gouges, ridges, etc. Also record general observations.

Flaw	Angle (deg.)	Distance Front (F) or Rear (R) from Mid-length of Meat
Light thin scratch, done when removing tube from autoclave.	60-120	1R to 22F
Light scratch	270-330	1/2R
Pit	330-30	3R

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Table 20B

Condition: After autoclaving

Over-all Length: 44"

Tube No. 39
 Ext. No. 19891
 Date 1/26/59
 Inspector F.K.

Outer Inner ☒ Surface Inspection Record (Check Appropriate Blank)

Instructions: Record angle and distance from mid-length of meat and description of surface flaws, such as pits, seams, flats, gouges, ridges, etc. Also record general observations.

Flaw	Angle (deg.)	Distance Front (F) or Rear (R) from Mid-length of Meat
White streak oxide	0-360	17R to 17F
Oblong shape drop (outer edge has white oxide)	60-120	10-3/4 to 9R
White oxide dots		9R to 22F
Round shape (outer edge has white oxide)		5R to 11-7/8F
White oxide streak		1R to 22F
White oxide streak	120-180	5R to 22R
Heavy white oxide streak	180-240	22R to 17R

Table 20C

Condition: After autoclaving

Over-all Length: 44"

Tube No. 40

Ext. No. 19892

Date 2/9/59

Inspector F.K.

Outer Inner ☒ Surface Inspection Record (Check Appropriate Blank)

Instructions: Record angle and distance from mid-length of meat and description of surface flaws, such as pits, seams, flats, gouges, ridges, etc. Also record general observations.

Flaw	Angle (deg.)	Distance Front (F) or Rear (R) from Mid-length of Meat
Raised spot	0-60	10F
Small scratch	0-60	20F
Pit	60-120	3R
Depression	120-180	14-1/2R
Pit		5-3/4R, 6F
Pit	180-240	3F
Row of extrusion pits	240-300	15-44R
Pits		2-1/2R, 5F, 15-1/2F, 14-1/2F
Pit	300-0	4R

893 060

Table 20D

Condition: After autoclaving

Over-all Length: 43-31/32"

Tube No. 41
 Ext. No. 19893
 Date 2/9/59
 Inspector F.K.

Outer Inner ☒ Surface Inspection Record (Check Appropriate Blank)

Instructions: Record angle and distance from mid-length of meat and description of surface flaws, such as pits, seams, flats, gouges, ridges, etc. Also record general observations.

Flaw	Angle (deg.)	Distance Front (F) or Rear (R) from Mid-length of Meat
Slight scratch	0-60	10R
Raised spot	180-240	5F
Pit	240-300	11F
Scratch	300-0	8R
Pits	300-0	3F, 10F

Table 20E

Condition: After autoclaving

Over-all Length: 44"

Tube No. 42
Ext. No. 19894
Date 2/9/59
Inspector F.K.

Outer Inner Surface Inspection Record (Check Appropriate Blank)

Instructions: Record angle and distance from mid-length of meat and description of surface flaws, such as pits, seams, flats, gouges, ridges, etc. Also record general observations.

Flaw	Angle (deg.)	Distance Front (F) or Rear (R) from Mid-length of Meat
Gage mark	0-60	9F, 20F
Raised spot	60-120	14R
Scratch	240-300	1R

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Table 21
Surface Roughness of Vallecitos Enriched Tubes
RMS microinches

Tube No.	After Pickle, Before Etch			After Etch ^(a)	
	Front End Seal 24F	Center Core 0	Rear End Seal 24R	Front End Seal 20F	Rear End Seal 20R
37	200-375	190-260	150-300	110-190	60-150
38	190-390	190-350	160-270	(b)	(b)
39	100-500	170-400	160-310	80-230	60-140
40	270-460	180-340	140-300	100-250	60-150
41	200-510	230-340	150-310	80-170	50-160
42	200-450	200-450	170-400	100-250	60-150
Spec.				200 max	200 max

(a) Measurements over core were not made because the sensing head was found to leave slight scratches on a freshly etched Zircaloy surface.

(b) Tube 38 was sectioned for autoradiographic standard and was therefore not processed to this stage.

Table 22

Corrosion Rates Calculated from Measurements of Hydrogen Released
During Autoclaving in Water Plus Steam for Tubes No. 37 and 39

1. Surface Area = 63.0 dm^2
2. Reaction - $\text{Zr} + 2 \text{H}_2\text{O} = \text{Zr O}_2 + 2 \text{H}_2$ (i.e., each mole of H_2 released is equivalent to $1/2$ mole of O_2 present as weight gain).
3. Data and Calculation:

	24 hours in 650°F Water	24 hours in 750°F, 1500 psi Steam	Total
*Hydrogen released, cm^3	440	2250	2690
Hydrogen released, moles	0.020	0.100	0.120
Oxygen weight gain, moles	0.010	0.050	0.060
Oxygen weight gain, mg	320	1600	1920
Zircaloy corrosion amount, mg/dm^2	5.1	25.0	30.1
Lustman and Kerze, p. 633	5.5	11.5	17.0

* $\pm 50 \text{ cm}^3$

NOTE: A small amount of hydrogen is tied up as zirconium hydride and, therefore, not released as gaseous hydrogen so that the calculated values of corrosion rate are lower than the true rates that would be obtained if it were possible to measure the weight gain directly.

Table 23

Corrosion Rates Calculated from Measurements of Hydrogen Released
During Autoclaving in Water Plus Steam for Tubes 40, 41, and 42

1. Surface Area = 94.5
2. Reaction - $\text{Zr} + 2 \text{H}_2\text{O} = \text{Zr O}_2 + 2 \text{H}_2$ (i.e., each mole of H_2 released is equivalent to $1/2$ mole of O_2 present as weight gain).
3. Data and Calculation:

	24 hours in 650°F Water	24 hours in 750°F, 1500 psi Steam	Total
*Hydrogen released, cm^3	500	1170	1670
Hydrogen released, moles	0.022	0.052	0.075
Oxygen weight gain, moles	0.011	0.026	0.037
Oxygen weight gain, mg	350	830	1180
Zircaloy corrosion amount, mg/dm^2	3.7	8.8	12.5
Lustman and Kerze, p. 633	5.5	11.5	17.0

* $\pm 50 \text{ cm}^3$

NOTE: A small amount of hydrogen is tied up as zirconium hydride and, therefore, not released as gaseous hydrogen so that the calculated values of corrosion rate are lower than the true rates that would be obtained if it were possible to measure the weight gain directly.

Specifications

(All dimensions in inches)

Part	Length	OD	ID	Condition
Nose Plug	2-19/32	6.355 $\begin{smallmatrix} +0.000 \\ -0.003 \end{smallmatrix}$	1.640 $\begin{smallmatrix} +0.003 \\ -0.000 \end{smallmatrix}$	Upset and vacuum degassed
Copper-Nickel Disc	1-1/8	6.355 $\begin{smallmatrix} +0.000 \\ -0.003 \end{smallmatrix}$	1.640 $\begin{smallmatrix} +0.003 \\ -0.000 \end{smallmatrix}$	Upset and vacuum degassed
Outer Sleeve	5.855	6.355 $\begin{smallmatrix} +0.000 \\ -0.003 \end{smallmatrix}$	6.137 $\begin{smallmatrix} +0.003 \\ -0.000 \end{smallmatrix}$	Cupped
Front End Seal	1.850	6.131 $\begin{smallmatrix} +0.000 \\ -0.003 \end{smallmatrix}$	2.151 $\begin{smallmatrix} +0.003 \\ -0.000 \end{smallmatrix}$	Heat treated
Core	1.310	6.097 $\begin{smallmatrix} +0.000 \\ -0.003 \end{smallmatrix}$	2.151 $\begin{smallmatrix} +0.003 \\ -0.000 \end{smallmatrix}$	As cast
Inner Sleeve	5.855	2.146 $\begin{smallmatrix} +0.000 \\ -0.003 \end{smallmatrix}$	1.640 $\begin{smallmatrix} +0.003 \\ -0.000 \end{smallmatrix}$	Extruded
Rear End Seal	2.100	6.131 $\begin{smallmatrix} +0.000 \\ -0.003 \end{smallmatrix}$	2.151 $\begin{smallmatrix} +0.003 \\ -0.000 \end{smallmatrix}$	Heat treated
Rear Weld Plate	0.250	6.134 $\begin{smallmatrix} +0.000 \\ -0.003 \end{smallmatrix}$	2.119 $\begin{smallmatrix} +0.003 \\ -0.000 \end{smallmatrix}$	As forged
End Plug	3/8	6.355 $\begin{smallmatrix} +0.000 \\ -0.003 \end{smallmatrix}$	1.640 $\begin{smallmatrix} +0.003 \\ -0.000 \end{smallmatrix}$	As rolled, vacuum degassed

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