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ORNL-TM-1179

PROCUREMENT AND QUALITY EVALUATION OF Nb-1% Zr STOCK
FOR BOILING ALKALI METAL CORROSION STUDIES

T. K. Roche

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ORNL-TM-1179

Contract No. W-7405-eng-26

METALS AND CERAMICS DIVISION

PROCUREMENT AND QUALITY EVALUATION OF Nb-1% Zr STOCK
FOR BOILING ALKALI METAL CORROSION STUDIES

T. K. Roche

AUGUST 1965

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ABSTRACT

Tubing, plate, and bar stock of Nb-1% Zr were procured for evaluation in boiling alkali metal systems. Costs for this material, together with the results of evaluating its quality upon receipt from the various vendors, are presented.

INTRODUCTION

Tubing, plate, and bar stock of Nb-1% Zr were procured for evaluation in boiling alkali metal systems. This report describes the details of the procurement, including results of subsequent evaluation to establish and/or confirm quality. It should be noted that the bulk of the material was ordered and received during the first half of 1962, thereby representing products of the state-of-the-art at that time.

MATERIAL PROCUREMENT

Specifications

The material was procured according to the specifications listed below. Liquid-penetrant inspection as specified in MET-NDT-4 was also included as part of each specification.

<u>Item</u>	<u>Specification Number</u>
Seamless tubing	MET-RM-B 202; Rev. No. 2
Plate	MET-RM-B 1; Rev. No. 1
Bar	MET-RM-B 102

In summary, the specifications stated that all finished items of the alloy were to receive a final anneal for 1 hr at 2200 to 2250°F in vacuum or an inert atmosphere from a condition of 50% minimum final

cold reduction for the tubing and 20 to 40% minimum cold reduction for the plate and bar. Each item was to meet the chemical composition requirements shown in Table 1.

Table 1. Specified Chemical Composition of Finished Items of Nb-1% Zr

Element	Composition	
	(wt %)	(ppm max)
Niobium	98.2 (min)	
Zirconium	0.8-1.2	
Carbon		100
Nitrogen		200
Oxygen		300
Hydrogen		20
Boron		1
Cadmium		5
Cobalt		30
Hafnium		100
Iron		500
Lead		50
Manganese		100
Molybdenum		1000
Nickel		200
Silicon		300
Tantalum		1000
Titanium		500
Tungsten		500
Vanadium		200
Total Rare Earths		100

Minimum tensile properties specified for the annealed material were 35,000 psi tensile strength, 25,000 psi yield strength (0.2% off-set), 10% elongation in 2 in. for tubing, and 15% elongation in 2 in. for plate and bar.

The tubing was to withstand crack-free flaring at room temperature to a diameter of at least 1.15 times the nominal diameter over a tapered mandrel having a 74° included angle. The plate was to withstand crack-free bending at room temperature through 180° angle around a diameter equal to twice the nominal thickness with the axis of the bend parallel to the direction of rolling.

Hardness of the finish material was not to exceed Rockwell B-80 or the equivalent.

The allowable variation in wall thickness of the tubing was $\pm 10\%$ of the nominal, and the variation in outside diameter was not to exceed the following:

<u>Outside Diameter</u> (in.)	<u>Allowable Variation</u> (in.)
< 1	+0.005
1.0-1.5 (incl)	+0.007
1.5-2.0 (excl)	+0.008
2.0-2.5 (excl)	+0.010
2.5-3.0 (excl)	+0.012
3.0-4.0 (incl)	+0.015

The maximum deviation in straightness of the tubing was to be 0.060 in./3 ft along any plane. Variations in dimensions of plate and sheet were to conform to the latest issue of Aeronautical Material Specification (AMS) 2242, and variations in dimensions of bar were to conform to AMS 2241C.

All finished material was to be free of oxide or scale and any other foreign material. The tubing was to be free of defects that exceeded 5% of the nominal wall thickness or 0.003 in., whichever was the larger. (This specification on allowable tube wall defects would not be applicable for thin wall tubing.) For plate and bar, defects could not exceed 5% of the thickness or 0.005 in., whichever was the smaller.

A certified statement and test report was to be submitted by the vendor acknowledging conformity of the materials to the specifications. Also, samples from the same lot as the finished material were to be received at ORNL for checking chemical analyses.

Vendors

The tubing was purchased from Vendor A and the plate and bar were purchased from Vendor B. As will be indicated, the 0.375-in.-OD tubing from Vendor A was found to be of unacceptable quality; thus most of this tubing was returned to the vendor, who subsequently replaced it. An additional lot of 0.375-in.-OD tubing was procured from Vendor C on ORNL Subcontract 1112.

Material

The various items of Nb-1% Zr that were received, together with the delivery schedules and costs, are presented in Tables 2, 3, and 4.

QUALITY EVALUATION

Procedure

To determine the quality of the as-received material, dimensions were checked and visual, liquid penetrant, radiographic, and ultrasonic inspections were carried out. Metallographic examination was performed on selected tubing samples for grain size determination and to investigate the nature of flaws indicated by the nondestructive testing techniques. An attempt was made to condition samples of the previously mentioned 0.375-in.-OD tubing of unacceptable quality by centerless grinding the outside diameter and acid etching the inside diameter. The results of this attempt are presented. Chemical analyses for zirconium, carbon, oxygen, hydrogen, and nitrogen were made on several of the specimens submitted by the vendors for comparative purposes. The results of the ORNL evaluation to determine conformity to the specifications are presented below, together with the vendors' test results.

Results

The results of chemical analyses, tensile testing, and hardness determinations on the finished items are presented in Tables 5 and 6. In general, the chemical analyses were satisfactory with minor exceptions. The specifications on carbon and oxygen were slightly exceeded

Table 2. Delivery Schedule for Nb-1% Zr Procured for Evaluation
in Boiling Alkali Metal Systems

Item Number	Vendor	Item	Size (in.)	Quantity			Date		
				(lb)	(ft)	(ft ²)	Ordered	Promised	Received
1	A	Tubing	0.250 OD × 0.065 wall	6.7	47		11-22-61	3-15-62	4-3-62
2	A	Tubing	0.375 OD × 0.065 wall	24.5	102.3		11-22-61	3-15-62	4-25-62
2 ^a	A	Tubing	0.375 OD × 0.065 wall		75.5		10-1-62		4-1-63
3	C	Tubing	0.375 OD × 0.065 wall		77.6		7-20-62	9-1-62	10-1-62
4	A	Tubing	1.0 OD × 0.065 wall	7.5	10		1-29-62	5-15-62	4-12-62
5	A	Tubing	1.5 OD × 0.065 wall	31	28.2		1-29-62	4-1-62	5-31-62
6	A	Tubing	1.9 OD × 0.125 wall	67.8	24		1-29-62	5-15-62	7-13-62
7	A	Tubing	3.25 OD × 0.125 wall	42.5	9		1-29-62	5-15-62	7-3-62
8	B	Plate	0.125 × 12 × 48	44.9		8.07	1-29-62	4-1-62	5-4-62
9	B	Plate	1 × 4 × 6	9.3			1-29-62	4-1-62	4-25-62
10	B	Bar	1.56 diam × 12	7.5			1-29-62	4-1-62	4-25-62

^aThis tubing represents that quantity of Item 2 replaced by the vendor due to defects in the original 102.3 ft of tubing.

Table 3. Material Cost of Nb-1% Zr Procured for Evaluation
in Boiling Alkali Metal Systems

Item Number	Quantity			Material Cost		Total
	(lb)	(ft)	(ft ²)	(\$/lb)	(\$/ft)	
1	6.7	47		208.00	30.00	\$1410.00
2	24.5	102.3		175.00	42.00	4296.00
3		77.6			32.00	2483.00
4	7.5	10		138.00	104.00	1040.00
5	31	28.2		111.00	122.00	3441.00
6	67.8	24		126.00	356.00	8544.00
7	42.5	9		144.00	680.00	6120.00
8	44.9		8.07	50.00		2245.00
9	9.3			50.00		465.00
10	7.5			57.00		428.00
				Total		\$30,472.00

Table 4. Quality Evaluation Cost and Total Cost of Nb-1% Zr Procured for Evaluation in Boiling Alkali Metal Systems

Item Number	Quality Evaluation					Total	Grand Total ^f
	Vendor	Oak Ridge National Laboratory					
	Test Cost ^a	Chemical Analysis ^b	NDT ^c	Metallography ^d	Physical Metallurgy ^e		
1			\$ 128.00	\$ 30.00	\$ 580.00	\$ 738.00	\$ 2148.00
2			144.00	135.00	580.00	859.00	5155.00
3			144.00	30.00	580.00	610.00	3093.00
4	\$ 115.00	\$ 50.00	69.00	30.00	580.00	844.00	1884.00
5	115.00	50.00	128.00	15.00	580.00	888.00	4329.00
6	128.00	50.00	116.00		580.00	874.00	9418.00
7	155.00		116.00		580.00	851.00	6971.00
8			56.00		580.00	636.00	2881.00
9		50.00	31.00		580.00	661.00	1126.00
10		50.00	44.00		580.00	674.00	1102.00
Total	\$ 513.00	\$ 250.00	\$ 832.00	\$ 240.00	\$ 5800.00	\$ 7635.00	\$ 38,107.00

^aChemical analysis and flare test on tubing. Where no test cost is tabulated, it is included in material cost.

^bChemical analysis at approximately \$10/element.

^cRadiography, liquid penetrant, ultrasonic, and vidigage inspection at approximately \$50/man-day.

^dConventional metallographic procedures at approximately \$15/hr/sample.

^eHandling of material, paper work, analysis of results of quality evaluation at approximately \$11/hr for three man-months uniformly distributed for convenience.

^fSum of material cost plus quality evaluation cost.

Table 5. Chemical Analyses of Nb-1% Zr Procured for Evaluation in Boiling Alkali Metal Systems

Item Number	Chemical Analyses ^a										
	Vendor						ORNL				
	Nb (wt %)	Zr (wt %)	C (ppm)	O (ppm)	H (ppm)	N (ppm)	Zr (wt %)	C (ppm)	O (ppm)	H (ppm)	N (ppm)
1	99.0	0.84	95	220	4.2	84					
2		1.05	100	180	4.1	84					
2 ^b	> 98.2	1.05	110	330	6	68					
3	> 98.9 ^c		70	230	5.5	59					
4	> 98.8	1.0	30	210	3.2	63	0.7±0.1	70	200	5	66
5	98.9	1.0	< 30	280	3.4	58	0.9±0.1	50	160	4	57
6	98.8	0.92	< 30	210	13	60	0.8±0.1	90	170	9	55
7	98.8	1.05	130	270	4.1	50					
8 ^d		1.07	14	49	< 10	66					
9 ^d		0.96	19	81	< 10	84	0.91±0.03	120	49	6	33
10 ^d		0.82	14	53	< 10	42	0.9±0.1	60	87	16	33

^aConcentrations of other elements listed in Table 1 were found to be within specifications according to vendors' test reports.

^bReplacement of 0.375-in.-OD × 0.065-in.-wall tubing from Vendor A.

^cNiobium analysis of ingot.

^dIngot analysis by vendor; product analysis by ORNL.

Table 6. Room-Temperature Tensile Properties and Hardness of Nb-1% Zr Procured for Evaluation in Boiling Alkali Metal Systems

Item Number	Tensile Properties			Hardness			
	Ultimate Tensile Strength (psi)	Yield Strength (psi)	Elongation (%)	R_B		DPH	
				Range	Average	Range	Average
1	38,100	23,000	41.5			86.9-87.6	87.4
	38,400	23,600	41.5				
2	42,100	26,500	43.5			89-130	104
	42,200	27,000	40.0				
2 ^a	36,600	19,900	41.0		52(OD)		
	36,500	18,700	39.0		36(ID)		
3	55,000	39,000	30.0				
4	40,700	24,700	44.0	28-30	29		
	40,600	23,700	41.0				
5	35,800	25,000	31.0	25-27	26		
	35,800	25,000	33.0				
6	37,400	23,600	44.0	37-40	39		
	37,500	24,100	46.5				
7	38,800	24,800	53.0	41-47	46		
	38,100	23,800	56.0				
8	37,500	21,400	40.0	31-37	34		
9 ^b	36,600	26,500	36.0	40-47	43		
10 ^b	33,300	18,900	52.5	19-35	27		

^aReplacement 0.375-in.-OD × 0.065-in.-wall tubing from Vendor A.

^bTest bar 0.505 in. in diameter.

for item 2 (replacement 0.375-in.-OD × 0.065-in.-wall tubing from vendor A), as was the carbon specification for item 7 (3.25-in.-OD × 0.125-in.-wall tubing from vendor A). The ORNL analysis on item 9 (1- × 4- × 6-in. plate from vendor B) indicated a carbon content of 20 ppm above specification. Most material showed yield strengths slightly less than the specified minimum of 25,000 psi. Item 3 (0.375-in.-OD × 0.065-in.-wall tubing from vendor C) was significantly stronger as a result of stress relieving at 1850°F instead of annealing at 2200 to 2250°F.

Samples from all lots of tubing and plate were reported by the vendors to have successfully passed flare and bend tests, respectively, according to specifications. Dimensional checks and results of the various inspections performed on the finished items follow.

Tubing: 0.250-in.-OD × 0.065-in.-Wall - Vendor A

Six pieces of this tubing, designated by the ORNL Metals and Ceramics Division as R-1328-A, were received. Three pieces of the tubing were 86 in. each in length, and the other three were 100, 102, and 103 in. long; or a total length of 563 in. (47 ft). The diameter of the tubing, measured every 12 in. along the length of the tubes, varied from 0.253 to 0.254 in.; while the wall thickness, measured on samples cut from the ends of two tubes, was 0.063 in.

On visual inspection at ORNL, a few shallow appearing defects on the outside diameter of three pieces of the tubing were observed. Liquid penetrant inspection by the vendor and ORNL revealed no visible defects. Radiography at ORNL disclosed occasional high-density particles and faint, discontinuous, longitudinal inside-diameter striations; ultrasonic inspection at ORNL showed approximately 22 in. of the tubing to exhibit indications > 5% of the wall thickness when compared to a stainless steel standard.

Metallographic examination of a transverse section of this tubing showed the longitudinal striations on the inside diameter to penetrate the wall to a depth of 0.001 to 0.003 in. This measurement was made in an area that was shown not to have defects > 5% of the wall thickness by ultrasonic inspection. Striations of this nature are believed to be the result of scoring upon removal of the mandrel following tube drawing operations. The tubing had a recrystallized grain size of ASTM 6 to 8. The microstructure and inside-diameter defects are shown in Fig. 1.

Tubing: 0.375-in. OD × 0.065-in. Wall - Vendor A

Nine pieces of this tubing, designated R-1298-A, were received. The tubing was in lengths of 161, 161, 147, 139, 127, 123, 123, 123, and 122 in., or a total length of 1226 in. (102 ft). The diameter of the

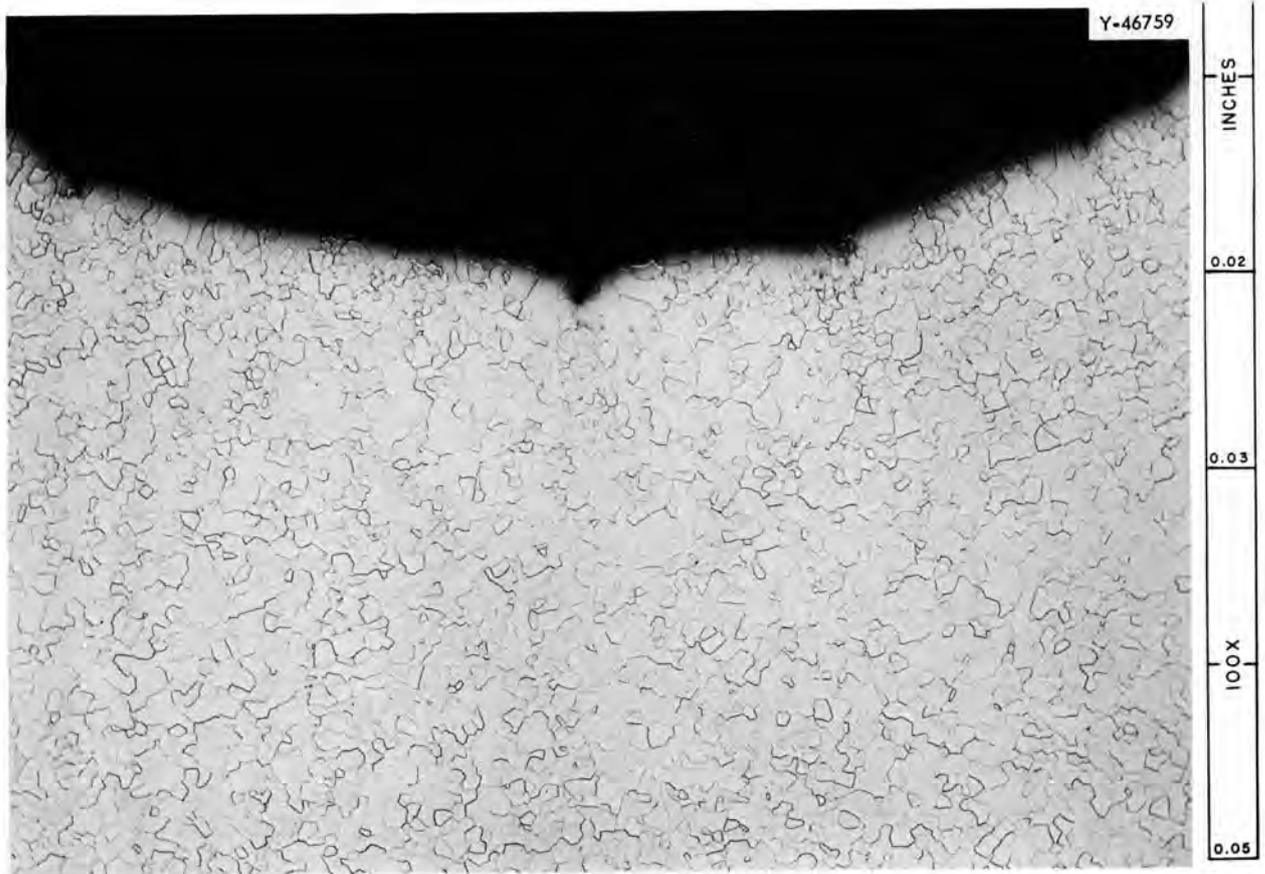


Fig. 1. Inside Diameter Defects on As-Received 0.250-in. OD \times 0.065-in. Wall Nb-1% Zr Tubing from Vendor A. Transverse section.

tubing, measured every 12 in. along the length of the tubes, was 0.379 to 0.381 in.; while the wall thickness, measured on samples cut from the ends of two tubes, varied from 0.067 to 0.069 in.

Visual inspection at ORNL disclosed grinding marks, pits, and gouges on the outside diameter. Liquid penetrant inspection by the vendor showed this tubing to be acceptable with no visible defects, while this same inspection at ORNL revealed numerous indications on the outside diameter resulting from the visually observed defects. Radiographic inspection at ORNL on only one piece of tubing disclosed longitudinal striations on the inside diameter; and the response to ultrasonic inspection at ORNL was high background signals.

The grinding marks, pits, and gouges observed visually on the outer diameter of this tubing are shown in Fig. 2. The most severe gouges observed were estimated to be $> 10\%$ of the wall in depth. The transverse



Fig. 2. Outside Diameter Defects on As-Received 0.375-in. OD \times 0.065-in. Wall Nb-1% Zr Tubing from Vendor A. Tubing returned to vendor for replacement. Approximately 9 \times .

grinding and polishing marks on the outside diameter could not be detected in a longitudinal metallographic sample; hence, their depth was considered to be no more than 0.002 in., which is approximately equivalent to the depth obscured through the rounding of the metallographic sample edge during preparation. Inside diameter cracks and folds measuring up to 0.007 in., as shown in Fig. 3, were present in a transverse section through an area with longitudinal inside-diameter striations. These flaws opened up (or were already present) to a maximum depth of 0.013 in. when a half section of the tubing was bent flat. The recrystallized grain size of this tubing was ASTM 4 to 7.

Surface conditioning experiments were performed at ORNL. It appeared that most of the outside diameter flaws could be removed, as it was possible to centerless grind a specimen from 0.379-in. OD to 0.366-in. OD



Fig. 3. Inside-Diameter Defects on As-Received 0.375-in. OD \times 0.065-in. 0.065-in. Wall Nb-1% Zr Tubing from Vendor A. Tubing returned to vendor for replacement. Transverse section.

with a 200-grit wheel and obtain a smooth-appearing surface. Also, an attempt was made to acid etch the inside diameter with a solution of 70 parts HNO_3 and 30 parts HF for the purpose of surface improvement. However, after removing 0.009 in. from the wall on the inner-diameter side, images of the striations were still visible.

Because of the poor quality of this lot of tubing, approximately 75 ft of the tubing was returned to the vendor for replacement.

Tubing: 0.375-in. OD \times 0.065-in. Wall (Replacement) - Vendor A

Thirteen pieces of this tubing, designated R-1409-A, were received. The length of each piece was 83, 82, 82, 77, 66, 66, 66, 65, 65, 65, 65, 64, and 60 in., or a total length of 906 in. (75 ft). The diameter, measured every 12 in. along the tube lengths, was 0.3771 to 0.3785 in.

Liquid penetrant inspection by the vendor disclosed no visible defects, while this same inspection at ORNL detected indications that affected a total length of 7 in. of tubing. Ultrasonic inspection at ORNL disclosed indications $> 5\%$ of the wall thickness in approximately 37 in. of tubing.

Tubing: 0.375-in. OD \times 0.065-in. Wall - Vendor C

Eight pieces of this tubing were received and designated R-1354-A and R-1363-A. The lengths of the tubing were 142, 139, 135, 129, 128, 126, 96, and 37 in., or a total length of 932 in. (78 ft). The diameter, measured every 12 in. along the tube lengths, ranged from 0.3750 to 0.3779 in., while the wall thickness, measured by vidigage, varied from 0.062 to 0.066 in.

On visual inspection at ORNL, shallow-appearing striations on the inside diameter were noted. Liquid penetrant inspection by the vendor revealed no visible defects. Ultrasonic inspection was performed by the vendor, and on four of the eight pieces of tubing indications greater than those from a 0.004-in.-deep notch were detected, affecting a total length of 82 in. The second ultrasonic inspection at ORNL disclosed no indications $> 5\%$ of the wall thickness in any of the tubing of this lot, but defects < 0.003 in. deep, associated with the inside diameter, were detected. The areas marked as defective by the vendor had the highest defect level. The vendor reported inside-diameter defects as deep as 0.005 in. after metallographic examination of a specimen taken from a defective area in the tubing. Two specimens were submitted to ORNL by the vendor. These were sectioned longitudinally and showed longitudinal striations on the inside diameter. This condition was typical for this lot of tubing and is illustrated in Fig. 4. Metallographic examination revealed inside-diameter "scallop" generally 0.0005 to 0.001 in. deep and occasionally 0.002 in. deep. These defects are shown in Fig. 5.

Because of furnace limitations, this lot of tubing was stress relieved only at 1850°F; hence, the microstructure is only slightly recrystallized.

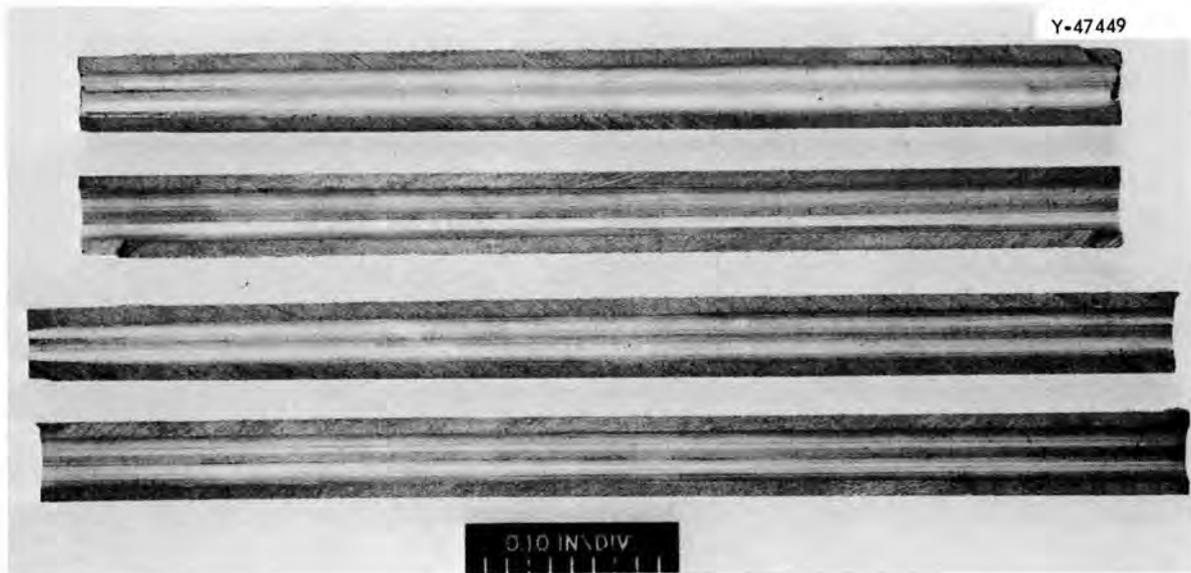


Fig. 4. Inside-Diameter Striations on As-Received 0.375-in.-OD \times 0.065-in.-Wall Nb-1% Zr Tubing from Vendor C. Approximately 1X.

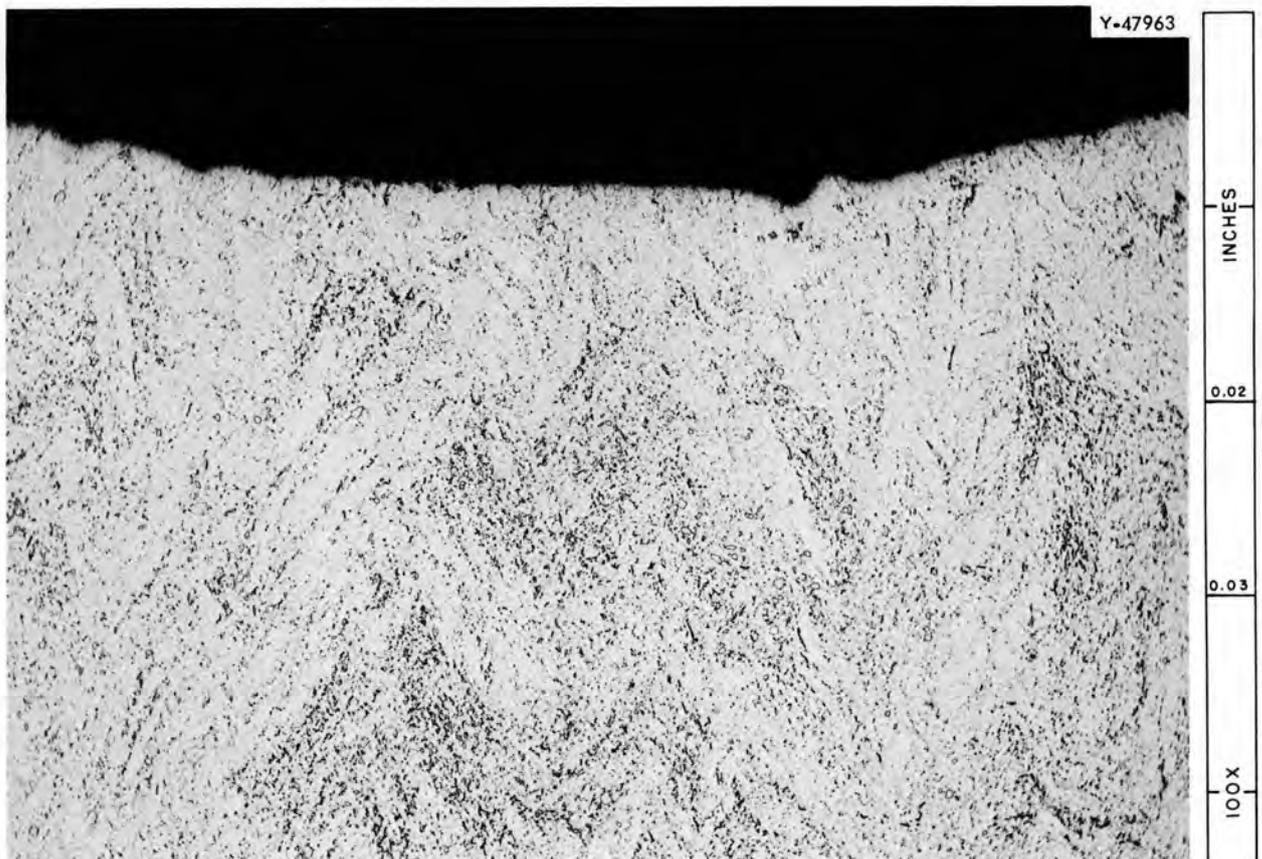


Fig. 5. Inside-Diameter "Scallops" on As-Received 0.375-in.-OD \times 0.065-in.-Wall Nb-1% Zr Tubing from Vendor C. Transverse section.

Tubing: 1.0-in.-OD × 0.065-in.-Wall - Vendor A

One piece of this tubing was received and designated R-1327-A. Its length was 120 in. (10 ft). The diameter of the tube, measured at 6-in. intervals along the length, varied from 0.997 to 1.002 in., while the wall thickness, measured at the ends of the tube, ranged from 0.068 to 0.073 in.

On visual inspection at ORNL, several shallow-appearing flaws on the outside diameter were noted. A spiral marking was observed along the tube length on the inside diameter, probably as a result of a roll-off operation to remove the drawing mandrel or of a tube-straightening operation. Liquid penetrant inspection by the vendor and ORNL showed no visible defects. When the tube was radiographically examined at ORNL, closely spaced transverse markings were apparent on the film, possibly related to polishing marks on the outside diameter. Several questionable areas were also noted. Ultrasonic inspection at ORNL disclosed no indications of discontinuities as great as 5% of the wall thickness. Metallographic examination showed the recrystallized grain size to be ASTM 5 to 8. The microstructure of a sample taken from the end of the tube is shown in Fig. 6. There were on the inside diameter discontinuous areas approximately 0.003-in. deep that did not appear to be completely recrystallized.

Tubing: 1.5-in. OD × 0.065-in. Wall - Vendor A

Five pieces of this tubing, designated R-1310-A, were received. The lengths of the tubing were 71, 70, 69, 63, and 60 in., or a total length of 333 in. (28 ft). The diameter, measured at intervals of 12 in. along the length of the tubes, was 1.496 to 1.502 in., while wall thickness measurements, taken at 12-in. intervals along the tube lengths, showed the wall thickness to be 0.063 to 0.069 in.

Visual inspection at ORNL showed a few shallow-appearing defects on the outside diameter. Liquid penetrant inspection by the vendor indicated this tubing to be acceptable, with no visible defects, while this same inspection at ORNL disclosed several shallow-appearing indications on the outside diameter. Radiographic examination at ORNL showed evidence of longitudinal inside-diameter striations. Several other flaws were

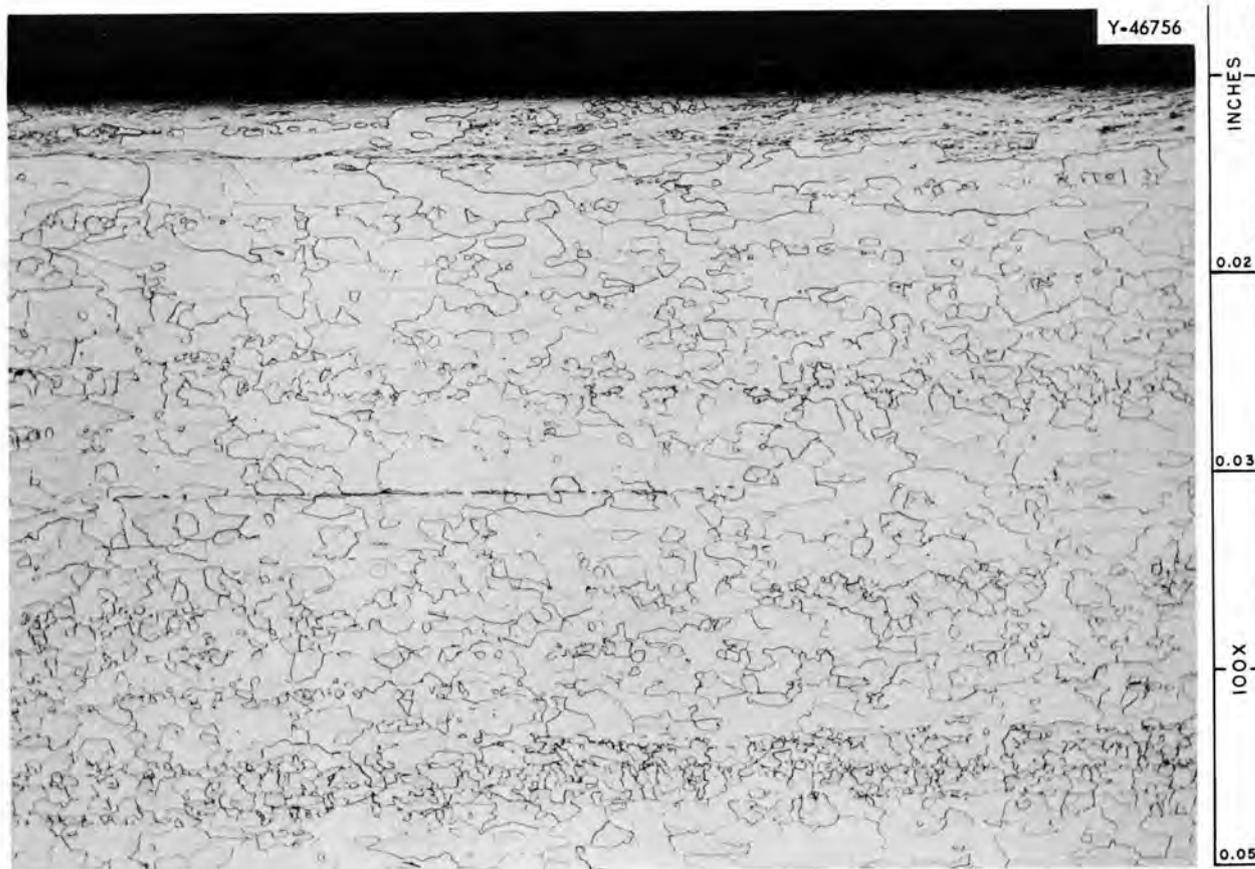


Fig. 6. Microstructure of As-Received 1.0-in.-OD \times 0.065-in.-Wall Nb-1% Zr Tubing from Vendor A. Longitudinal section. 100X.

also indicated. Ultrasonic inspection at ORNL revealed no indication $>$ 5% of the wall thickness. Metallographic examination of a specimen from this lot of tubing showed a grain size of ASTM 4 to 7.

Tubing: 1.9-in.-OD \times 0.125-in. Wall - Vendor A

This tubing, designated R-1330-A, was received in six lengths of 54, 53, 52, 52, 52, and 48 in., or a total length of 311 in. (26 ft). The diameter, measured in 6-in. intervals along the tube lengths, was 1.8945 to 1.9068 in., while the diameter measurements, made every 6 in. along the tubes, showed the wall thickness to be 0.113 to 0.142 in.

Visual inspection at ORNL disclosed a few shallow-appearing defects on the outside diameter of five tubes, and all tubes showed a few shallow-appearing scratchlike marks on the inside diameter. Liquid penetrant inspection by the vendor indicated this tubing to be acceptable, with no

visible defects, while this same inspection at ORNL revealed a few outside-diameter indications. Radiographic examination at ORNL showed cracklike indications on four tubes. Several other flaws were indicated on four tubes of the six received. No indications as great as 5% of the wall thickness were detected by ultrasonic inspection at ORNL.

Tubing: 3.25-in. OD × 0.125-in. Wall - Vendor A

Three pieces of this tubing, designated R-1326-A, were received in lengths of 37, 36, and 36 in., or a total length of 109 in. (9 ft). The diameter, measured at 6-in. intervals, was 3.2439 to 3.2554 in., while vidigage measurements, made every 6 in. along the tube lengths, showed the wall thickness to be 0.122 to 0.134 in.

Visual inspection at ORNL disclosed several outside-diameter defects on each tube. Slight inside-diameter flaws were observed near the ends of two tubes. Liquid penetrant inspection by the vendor indicated this tubing to be acceptable with no visible defects, while this same inspection at ORNL revealed several outside-diameter indications on each tube. Radiographic examination at ORNL disclosed defects at each end of one tube corresponding to defects observed visually. Ultrasonic inspection at ORNL detected no indications as great as 5% of the wall thickness.

Plate: 0.125 × 12 × 48 in. - Vendor B

Instead of receiving two pieces of the size plate given above to make up the required 8 ft² of material, one piece, 0.125 × 12 × 22.25 in., and two pieces, 0.125 × 12 × 37.25 in., were received and designated R-1299-A.

Liquid penetrant inspection by the vendor disclosed no laps, cracks, or delaminations, while this same inspection at ORNL revealed several indications on each piece of plate. Radiographic examination at ORNL disclosed a few spots, indicating high-density areas in the smaller plate and two areas with questionable cracks in one piece of the larger plate. The film was streaked with light and dark areas that resembled a prior cold-worked grain pattern in the material. No indications were observed on ultrasonic inspection at ORNL.

Plate: 1 X 4 X 6 in. - Vendor B

One piece of this plate, designated R-1295-A, was received. Liquid penetrant inspection by the vendor and ORNL detected no laps, cracks, or delaminations. On radiographic inspection at ORNL three spots representing high-density areas in the plate were noted. The response to ultrasonic inspection at ORNL was background signals of undetermined origin.

Bar: 1.56-in. Diam X 12-in. Length - Vendor B

One length of this material, designated R-1296-A, was received. Liquid penetrant inspection by the vendor and ORNL disclosed no laps, cracks, or delaminations. Ultrasonic inspection at ORNL detected no indications.

CONCLUDING REMARKS

A summary of the quality evaluation results obtained on the Nb-1% Zr stock is presented in Table 7. In the interest of time the specifications were waived in those instances where these results fell short of those specified. Prior to releasing this material for evaluation in boiling alkali metal systems, the defective areas were marked and the recommendation was made that these areas be avoided as far as possible in the construction of test hardware.

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Table 7. Summary of Quality Evaluation Results on Nb-1% Zr
Procured for Evaluation in Boiling Alkali Metal Systems

Item Number	Vendor	Item	Size (in.)	Quality Evaluation Results
1	A	Tubing	0.250 OD × 0.065 wall	<u>Chemistry</u> - ok <u>Tensile Properties</u> - yield strength 1400-2000 psi low <u>Dimensions</u> - ok <u>Inspection</u> <u>Visual</u> - Few shallow OD defects <u>Radiographic</u> - Longitudinal ID striations <u>Liquid Penetrant</u> - ok <u>Ultrasonic</u> - Indications > 5% of wall in approximately 22 in. of tubing
2	A	Tubing	0.375 OD × 0.065 wall	<u>Chemistry</u> - ok <u>Tensile Properties</u> - ok <u>Dimensions</u> - Maximum OD oversize 0.001 in. <u>Inspection</u> <u>Visual</u> - Grinding marks, pits, and gouges on OD <u>Radiographic</u> - Longitudinal ID striations <u>Liquid Penetrant</u> - Numerous OD indications <u>Ultrasonic</u> - High background signals Note: 75 ft of this tubing returned to vendor for replacement
2	A	Tubing (replacement)	0.375 OD × 0.065 wall	<u>Chemistry</u> - C content 10 ppm high; O content 30 ppm high <u>Tensile Properties</u> - Yield strength 5100-6300 psi low <u>Dimensions</u> - ok

Table 7 (continued)

Item Number	Vendor	Item	Size (in.)	Quality Evaluation Results
				<u>Inspection</u> <u>Liquid Penetrant</u> - OD indications on approximately 7 in. of tubing <u>Ultrasonic</u> - Indications > 5% of wall in approximately 37 in. of tubing
3	C	Tubing	0.375 OD x 0.065 wall	<u>Chemistry</u> - ok <u>Tensile Properties</u> - ok <u>Dimensions</u> - ok <u>Inspection</u> <u>Visual</u> - Longitudinal ID striations <u>Liquid Penetrant</u> - ok <u>Ultrasonic</u> - ID defects < 0.003 in. deep
4	A	Tubing	1.0 OD x 0.065 wall	<u>Chemistry</u> - ok <u>Tensile Properties</u> - Yield strength 300-1300 psi low <u>Dimensions</u> - Minimum OD undersize 0.003-in. maximum wall thickness oversize 0.0015 in. <u>Inspection</u> <u>Visual</u> - Few shallow OD defects <u>Radiographic</u> - Several questionable flaws <u>Liquid Penetrant</u> - ok <u>Ultrasonic</u> - No indications > 5% of wall
5	A	Tubing	1.5 OD x 0.065 wall	<u>Chemistry</u> - ok <u>Tensile Properties</u> - ok <u>Dimensions</u> - Minimum OD undersize 0.004 in.

Table 7 (continued)

Item Number	Vendor	Item	Size (in.)	Quality Evaluation Results
				<u>Inspection</u> <u>Visual</u> - Few shallow OD defects <u>Radiographic</u> - Longitudinal ID striations. Several other flaws indicated <u>Liquid Penetrant</u> - Few OD indications <u>Ultrasonic</u> - No indications > 5% of wall
6	A	Tubing	1.9 OD x 0.125 wall	<u>Chemistry</u> - ok <u>Tensile Properties</u> - yield strength 900-1400 psi low <u>Dimensions</u> - Minimum OD undersize 0.0055 in. maximum wall thickness oversize 0.0045 in. <u>Inspection</u> <u>Visual</u> - Few shallow OD and ID defects <u>Radiographic</u> - Several flaws noted including cracklike indications <u>Liquid Penetrant</u> - Few OD indications <u>Ultrasonic</u> - No indications > 5% of wall
7	A	Tubing	3.25 OD x 0.125 wall	<u>Chemistry</u> - C content 30 ppm high <u>Tensile Properties</u> - Yield strength 200-1200 psi low <u>Dimensions</u> - Minimum OD Undersize 0.006 in. <u>Inspection</u> <u>Visual</u> - Several OD and ID defects

Table 7 (continued)

Item Number	Vendor	Item	Size (in.)	Quality Evaluation Results
				<u>Radiographic</u> -- Two defects noted <u>Liquid Penetrant</u> -- Few OD indications <u>Ultrasonic</u> -- No indications > 5% of wall
8	B	Plate	0.125 × 12 × 48	<u>Chemistry</u> -- ok <u>Tensile Properties</u> -- Yield strength 3600 psi low <u>Inspection</u> <u>Radiographic</u> -- Two questionable cracks. Few high-density spots <u>Liquid Penetrant</u> -- Several indications noted <u>Ultrasonic</u> -- No indications
9	B	Plate	1 × 4 × 6	<u>Chemistry</u> -- C content 20 ppm high <u>Tensile Properties</u> -- ok <u>Inspection</u> <u>Radiographic</u> -- Three high-density spots <u>Liquid Penetrant</u> -- ok <u>Ultrasonic</u> -- Background signals of undetermined origin
10	B	Bar	1.56 diam × 12	<u>Chemistry</u> -- ok <u>Tensile Properties</u> -- tensile strength 1700 psi low. Yield strength 6100 psi low. <u>Inspection</u> <u>Liquid Penetrant</u> -- no indications <u>Ultrasonic</u> -- no indications



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