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THE FABRICATION OF SMOOTH TUBES FOR LARGE MULTISTAGE FLASH EVAPORATOR DESALINATION PLANTS

F. J. Moran

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AEC-Department of the Interior
Interagency Agreement 40-50-65
OSW Agreement No. 14-01-0001-534

OFFICE OF SALINE WATER

THE FABRICATION OF SMOOTH TUBES FOR LARGE MULTISTAGE FLASH EVAPORATOR DESALINATION PLANTS

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NUCLEAR DESALINATION PROGRAM

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NOVEMBER 1969

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U. S. ATOMIC ENERGY COMMISSION

SUMMARY

The objective of this study is to investigate and evaluate methods of attaining low-cost condenser tubing for advanced large-scale multistage flash distillation plants. To this end, a comprehensive survey was made to determine the existing state of the art of tubing fabrication, industrial capacity to produce tubes, and possible improvements in technology to reduce costs.

A 250-Mgd multistage flash distillation plant would require nearly 30 million pounds of copper-alloy tube. Industrial capacity for producing seamless tubing of copper and copper alloys totals approximately 1 billion pounds per year; however, only 150 million pounds per year of the total industry output is copper-alloy tube of the type used in desalting plants. The bulk of the output from the industry is plain copper tubing for water, refrigeration, and air conditioning applications. This copper tubing is made largely with high-speed modern processing equipment such as tube reducers and bull blocks. Because of the limited quantities, the copper-alloy tubes (aluminum brass, copper-nickel, etc.) for condenser service are generally produced with slower and therefore less economical bench drawing equipment.

Development tests demonstrated the feasibility of processing copper-nickel tubes on the same facilities used to produce copper tubing, Examined in this light, the billion-pound annual output of the tube industry assures that the tube requirements for large-scale desalting plants can be accommodated with no strain on the tube industry.

A study of the application of advanced technology to seamless tube fabrication (continuous casting of tube shells with subsequent reduction on tube reducers and bull blocks) indicated that the fabrication costs, which average well above $.50 per pound with bench drawing equipment, could be reduced to approximately $.20 per pound in a facility producing 3 million pounds of tubing per month.

Development tests on welded copper-nickel tubes showed that tubing fabricated by welding flat strips into tubular shape is acceptable in quality and is economically competitive now; but over the long term, improvements in technology would probably give seamless tubing an economic advantage.

Tests showed the fabrication of thin-wall seamless titanium tubes by cold reduction to be uneconomical for use in desalination plants, largely because of the extremely slow output rate. An alternate way of producing titanium tubes more economically and in the quantities required for large plants appears to be by high-frequency welding of flat strips into tubular shape.

Eddy current testing was evaluated to determine its suitability for reliable and rapid detection of flaws in seamless or welded tubes. Acceptance of this test for seamless tubes is increasing. More work, however, is needed to improve the reliability of the test as applied to welded tubes.

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THE FABRICATION OF SMOOTH TUBES FOR LARGE MULTISTAGE FLASH EVAPORATOR DESALINATION PLANTS

1.0 INTRODUCTION

Design studies for large multistage flash evaporator desalination plants show that as much as 100 million feet of condenser tubing would be required for a 250-Mgd plant and that the cost of smooth tubes for the condensers is a major item in the total capital cost of such plants.

Accordingly, the achievement of significant reductions in the cost of tubing would reduce capital costs appreciably and therefore should ultimately lead to lower costs for fresh water distilled from the sea. Areas which appeared likely to yield tubing cost reductions were the application of proper specifications, the development of lower-cost fabrication methods, and the development of rapid inspection procedures for large production runs. The Office of Saline Water established a comprehensive study by the Oak Ridge National Laboratory to investigate methods of reducing costs of meeting the condenser tube requirements of large-scale multistage flash (MSF) desalination plants.

The objects of this study were as follows:

1. To ascertain the present state of the art of fabricating copper-nickel and titanium alloy tubing, including methods, limitations (as on length, diameter, wall thickness, grade of material, etc.), and costs; from this to identify possible means of reducing costs and/or improving the product; and to predict whether tubing development can ultimately result in substantial savings in evaporator costs.
2. To stimulate the industry to develop improved methods along the lines stated above.

The scope of this program involved the following:

1. Performing a continuous evaluation of the state of the art.
2. Developing specifications for the fabrication of reliable low-cost tubing.
3. With industrial contractor assistance as needed, making an evaluation of improved methods for fabricating seamless and welded tubes.

4. Making a survey of available nondestructive tube testing instruments of the eddy-current and ultrasonic types and determining their suitability for high-speed, in-line testing of smooth tubes for desalination plants.

2.0 STATE OF THE ART

2.1 Manufacturing Tubes of Copper-Nickel Alloy

A state-of-the-art survey of prevailing industrial production methods for fabricating seamless tubes from the copper alloys usually specified for seawater evaporator plants disclosed that the technology has changed little over the years. This is in contrast with the rapidly improving technology for making pure copper tubing for use in water, air conditioning, and refrigeration systems. For producing copper-alloy condenser tubes, almost all manufacturers follow the practice of batch casting the billets and converting them into thick-walled tube shells by hot extrusion or by hot piercing on a Mannesman piercing machine. The tube shells are then reduced to finished tube size by a series of draws on conventional drawbenches. Most of this tubing is straight drawn in a 20-60 foot range of mill lengths, although there exists in the industry some limited capability to produce straight drawn tubes somewhat in excess of 100 feet.

This rather static situation in the technology of fabricating seamless copper-alloy tubes can be attributed to the following:

1. Condenser tubes constitute only a minor part of the total tube output from most tube mills. Over 85% of production is devoted to copper tubes for water, air conditioning, and refrigeration. The market for condenser tubes simply has not been large enough to justify the capital costs for equipment to produce copper-alloy tubes by the most advanced methods. The demands for tubing of pure copper, on the other hand, have grown so rapidly that manufacturers usually have been able to keep their most efficient production lines fully occupied with the production of copper tubing.

2. Historically, the required tube lengths for heat exchanger tube bundles have been relatively short, usually in the 20-60 foot range which could be produced on a draw bench. As a result, it has been possible to meet the demands for condenser tubing of copper alloy materials by producing them on conventional draw benches which were on hand in the tube mills and were not routinely used in the production of pure copper tubing. In this way, tube mills have been able to satisfy limited demands for alloy condenser tubes without interrupting their unalloyed copper tube production operations which were performed with the efficient tube reducers and bull-block drawing units.

2.2 Application of Copper Tube Technology to Copper-Nickel Tubes

Recent fabrication tests conducted for the OSW have shown that the equipment and techniques currently used for producing low-cost seamless copper tubes can also be applied to the fabrication of 90-10 copper-nickel tubes.

There are three general phases or steps in the manufacture of seamless copper tube:

1. Casting of molten metal into billets which are subsequently sawed to the required length.
2. Converting sawed billets into crude heavy-wall tube shells several inches in diameter and approximately ten feet in length.
3. Reduction of tube shells to finished tube of the required diameter, wall thickness, and length.

In recent years industry has been shifting from batch casting to continuous casting and sawing of billets. As a result, product quality has improved and output has increased. Of even greater import is the emerging technology for continuous casting of copper metal directly into long-length tube shells, thus eliminating the need to extrude or pierce the billets into shells. The cast shells are usually three or more inches in diameter, but at least one fabricator is developing a technique for the continuous casting of long tube shells of 1-1/2-inch

O.D. and under. Progress is also being made in the direct chill continuous casting of billet and subsequent hot extruding into long, 2-inch-O.D. tube shells. Casting or extruding into a cross-section form of the smallest possible size has the advantage of minimizing the number of subsequent operations required to produce a finished tube product.

In conjunction with these advances in the forming of tube shells, there has been a move away from the use of conventional drawbenches to reduce the heavy-wall tube shells into finished tube. Bench drawing is slow and is limited as to the length of tubing it can produce. In addition, there is only about a 25 percent reduction per draw and many draws are required. Since for each draw the end of the tube must be swaged or "pointed" in order to insert it into the die, the accumulation of sawed-off points represents a considerable loss as primary scrap.

Much greater reductions per pass and reduced pointing losses are attainable by either cold forging or rolling of the tube shells.

The cold forging method is accomplished on a proprietary machine which reduces the tube shells to finished tube size in one operation. Throughput is relatively slow. This technique can also enhance the tube by generating integral inner fins, if desired. The commercial application of this process is presently limited to one tube fabricator.

In the more widely used process, rolling of the tube shells is performed on a tube reducer. Reductions of 90 percent per pass are possible at tube shell input speeds of thirty to forty feet per minute. In this process the tube shell is cold reduced by means of semi-circular, tapered-grooved dies that are rocked back and forth on a mandrel that controls the inside diameter of the tube. The rocking action of the roller dies progressively swages the tube walls to smaller diameters and thicknesses. Customarily such machines are used to reduce the tube shells to diameters of 2 inches or slightly less, after which the tubes are annealed and then reduced to the desired finished size by cold drawing.

The final series of cold draws to finished tube size is usually done as a sequence of straight draws on draw benches followed by a series of draws on small bull block units which process the tube into small diameter tube of long length in coil form. Each of these methods

provides about the same percent reduction per draw. However, because of the slow processing speed of the draw bench, even with multistrand units, the more efficient tube mills are gradually replacing draw benches with large high-speed bull-block units which can accept starting stock up to 2 inches in diameter.

In principle, reduction by block drawing is much the same as in bench drawing. Instead of a fixed-position drawing plug, however, a floating plug is used. The equilibrium of forces imposed on the plug during the drawing operation maintains the floating plug in position at the mouth of the die. The tube is pulled through the die box by the action of a revolving powered drum on which the reduced tube is wound. Such units can handle very long lengths of tube per draw and this significantly reduces the scrap losses accruing from swaging or "pointing" the end of the tube prior to each draw. Tube-drawing speeds range from 500 ft/min for the initial large diameter tube to 1500 ft/min for the final draws to small diameter.

However, to date these methods of production have not been routinely applied in the fabrication of copper alloy tubes for desalination plants, and the cost reductions which took place in copper tubing production have not yet affected the price of copper alloy tubing. The savings that can be achieved have been amply demonstrated in the production of copper tubing, however.

2.3 Welded Tubes of Copper-Nickel Alloy

The manufacture of welded copper-alloy tubes is a relatively new technology. The modern, high-speed strip-rolling mills, coupled with new high-frequency welding techniques, make it possible to produce welded tubes at costs that are competitive with those of seamless tubes. There are at present only a few producers of welded tubing, and their combined output is far below the total industry production of seamless condenser tubes.

The high-frequency welding process is capable of welding speeds in the range of 200 to 400 feet per minute. This process can be used in conjunction with a high-speed forming mill to produce welded tubing efficiently and economically. Coiled strip is fed from a reel into

the forming mill. The mill progressively shapes the strip into tube form with the edges continuously brought into abuttment at a weld point. High-frequency current of about 450 kc is led into the two abutting strip edges by means of sliding contacts. Almost instantly, the surfaces of the opposing edges are heated into the plastic temperature range. Squeeze rolls compress the edges together to complete a forge weld. The pressure exerted by the squeeze rolls expels some molten metal out of the seam and forms a flash or bead on both the outside and inside tube surfaces. This flash is removed by separate scarfing tools mounted outside and inside the tube. The welded tube next passes through a sizing operation to remove ovality, through the test coil of an eddy-current tester to insure quality control, and then onto a run-out table where a flying saw or shear cuts the tube to the required length. Thus, the process lends itself very readily to making the long length tubes contemplated for advanced types of MSF plants. Further, it offers the possibility of circumventing the problems of shipping long-length tubes by shipping rolls of strip instead and then forming and welding the tubes in on-site tube mills.

Two new welding methods, plasma arc and out-of-vacuum electron beam, are recent developments which have potential for tubing fabrication. Plasma arc welding is very much slower than the high frequency method, usually welding between five and ten feet per minute, but the plasma arc gives consistent weld quality and has very low equipment costs. Out-of-vacuum electron-beam welding is only half as fast as high-frequency welding and requires high equipment costs. However, the process produces a weld which is smooth and flat both inside and outside and this obviates the scarfing problems encountered with high-frequency welding. Both of these new methods are receiving attention from firms in the ferrous and nonferrous tube industries but as yet have not been applied to commercial tube production.

Other than the problems of fabrication, the welded tube has the problem of gaining acceptance by manufacturers of heat exchanger equipment. Among this group, there is evidence of a rather widespread opinion that the welded tube may not consistently have the strength and/or corrosion resistance of a seamless tube. At any rate, unless

the welded tubing becomes appreciably cheaper than seamless, there is likely to be little interest among user groups in pioneering its applications since the seamless tube is a proven item and is readily available in the sizes and lengths required for most tube bundles.

2.4 Manufacturing Tubes of Titanium

A survey of methods of fabricating seamless titanium tubes showed that such tubes are made either on draw benches or by cold reducing on tube reducers (pilger mills). Since titanium possesses rather poor drawing characteristics, the tube reducer method is usually favored. In this process, the heavy wall tube shell, previously hot-extruded from a copper-clad billet of titanium, is fed through a set of grooved roller dies which are moved backwards and forwards over the tube surface by the action of a crank drive system. Inside the tube is a tapered mandrel in fixed position. Action of the rolling dies against the internal mandrel effects a reduction in both the diameter and the wall thickness of the tube. With every cycle of the crank drive the tube is advanced an increment and simultaneously turned through a small angle. The purpose of the turning angle is to obtain an accurate circular cross section in the tube.

While this method can reduce the softer copper and copper alloys at quite high tube speeds, reduction of titanium is slow. Typical production rate for a small-diameter, thin-wall titanium tube is about 100 feet per hour. Obviously, such a slow speed precludes achieving low-cost quantity production of tubes for desalination plants. Firther, the tube length is limited by the floor space available to accommodate the long mandrel at one end and the run-out table at the other end of the system.

Only one fabricator presently markets a welded type of titanium condenser tube. Tubes are welded by the tungsten inert gas shielded (TIG) process. Strip is fed into a roll-forming mill, welded, ultrasonically tested, and then cut to the required length. Proprietary refinements in welding techniques produce a finished tube in the as-welded form without the need for either scarfing or planishing. Welding speed is reportedly an order of magnitude above conventional

TIG welding speeds. The process has long tube length capability, but only standard mill lengths are currently produced.

While the survey revealed that some development effort has been expended on fabricating tubes by high-frequency welding, the application is not yet commercial. Of two fabricators who have done development work, one managed to produce a rather satisfactory product but gave it up when cost studies showed that TIG welding, chiefly because of improved welding speeds and much lower equipment costs, was more economical. The other company has completed a development program on making tubes by high-frequency welding but has not yet seen fit to commercialize the product.

3.0 DEVELOPMENT OF IMPROVED PRODUCTION PROCESSES: COPPER-NICKEL TUBES

Conceptual design studies of advanced large-scale multi-stage flash plants indicated that there was a significant economic advantage in using condenser tubes that extended continuously through the full length of the evaporator.[1,2] Tube lengths up to approximately 350 ft were envisaged for such plants.[3] This length far exceeds the capacity of the conventional draw benches usually used by the tube industry to produce seamless copper-alloy condenser tubes but could readily be produced by the methods used in manufacturing tubing of pure copper. The Wolverine Tube Division of Calumet & Hecla agreed, under an ORNL subcontract, to develop low-cost fabrication methods for producing long lengths of copper-nickel tubing, to test the production methods by processing a limited amount of 90-10 and 70-30 copper-nickel tubing, and to develop cost data which could be used for reliably projecting copper-nickel tubing prices through 1970. The Wolverine Tube report on their work with seamless copper-nickel tubing is given in Appendix A.

3.1 Production Process Tests

The material processed by Wolverine Tube was 8-inch diameter 90-10 and 70-30 copper-nickel billets. The billets were hot extruded into 2.5-inch O.D. x .460-inch-wall tube shells, bench drawn to 1.750-inch O.D. x .110-inch wall, and annealed. The 1.750-inch-O.D., annealed,

heavy-wall tubes were then bull-block drawn to finished size in 360-ft coiled lengths.

The straightening and final sizing operations were performed on a combination roll-forming and straightening machine. The sizing removed the slight tube ovality incurred in coiling on the drum of the bull block and provided a degree of cold working of the annealed tube to raise the tensile properties to the level required by the specification. An eddy-current instrument, with the sensitivity adjusted to the highest level, was mounted in-line with this system and tested the tubes at approximately 80 ft/min. Some of the straightened 90-10 copper nickel was later similarly tested with the same eddy current equipment at 400 ft/min. The procedure used for testing as well as the standards used for calibration were as recommended by the Copper Development Association.

Dimensional and mechanical properties of representative samples of tube were all within the requirements of the interim specification.

3.2 Methods of Shipment

Wolverine proposed to ship 360-ft long lengths to the plant site in coil form and to perform straightening, testing, and cutting to length at the site. Shipment of coils would be in railroad box cars in knockdown returnable crates, readily handled by fork-lift truck. Each crate would be used three times before discarding.

Shipment of 110-ft straight lengths would require three railroad cars, the center car being a drop-end gondola type.

For straight lengths of 75-ft and under, the tubes would be shipped in open-top single gondola cars.

3.3 Projected Conversion Prices

Conversion prices for three tube sizes and three lengths for both 90-10 and 70-30 copper-nickel alloys are tabulated below. These conversion prices do not include the metal content. The prices are based on the process proposed by this report, extrapolated for larger volume, as well as on optimum processing procedures and practices. They include transportation from the Midwest to the Los Angeles area. The prices for 360-ft lengths are based on shipping in coil form and straightening

on site and do include the on-site processing cost. For comparison purposes, prices are also shown for tubes produced in quantity by present technology. In this instance, "present process" refers to the conventional method of drawing condenser tubes on straight draw benches.

PROJECTED 1970 CONVERSION PRICES PER FOOT
.035-IN. WALL SEAMLESS TUBE

Tube OD	90-10 Copper Nickel				70-30 Copper Nickel		
	Present Process	New Process			New Process		
	110-ft	60-ft	110-ft	360-ft	60-ft	110-ft	360-ft
in.	$/ft	$/ft	$/ft	$/ft	$/ft	$/ft	$/ft
5/8-in	.165	.121	.130	.150	.131	.136	.151
3/4-in.	.202	.140	.153	.155	.515	.164	.163
1-in.	.254	.185	.205	.199	.201	.218	.215

While the absolute value of the conversion prices quoted above may differ somewhat from one tube manufacturer to another, the prices nevertheless do serve to establish the relative savings (25% approximately) possible by incorporating block drawing in the fabrication of copper-nickel tubes.

4.0 ESTIMATED COST OF FABRICATING SEAMLESS COPPER-NICKEL TUBING

In response to inquiries about probable tubing costs for large desalting plants, commercial tubing fabricators did not indicate any price reduction for orders as large as a hundred million feet of tubing. As a result, it was decided to employ a management consultant familiar with the tubing industry to estimate the prices that might be expected with large-volume production in the future.

Accordingly, ORNL negotiated a subcontract with Bavier, Bulger & Goodyear authorizing them to make a thorough and detailed study of the costs associated with the production of seamless tubing for the desalination program.

The study was to provide tube prices for current and advanced production methods. Cost estimates were to be based on 90/10 cupronickel tubes, 1-inch and .750-inch in outside diameter, with .035-inch wall

thickness, and with lengths of 50, 100, and 360 feet. Detailed cost data were to be presented in such a manner that changes to processing, wage rates, etc., could be reflected in the end price. Tube prices were to be based on the most attractive production equipment and methods and were to show in detail the processing, labor, and overhead elements of total cost. Reasonable and proper profit margins for the industry were to be included in the pricing. The findings of this study are given in the Bulger report which is attached as Appendix B. The following paragraphs summarize the highlights and conclusions of their study.

4.1 Bavier, Bulger & Goodyear Cost Studies

The cost studies were based on three methods of manufacturing .750-inch-O.D. and 1.000-inch-O.D. x .035-inch wall cupronickel tubing:

The first method is based on continuously casting 3-1/2-inch-O.D. shells, tube reducing to 2.00-inch O.D. x .100-inch wall and then drawing on blocks to finished size. Coils are annealed at finished size and then either straightened and cut or level-wound. Testing is performed as part of the straight-and-cut or level-wind operation.

The second method is based on direct chill casting of billets which are cut to length and then extruded to shells 2-inch O.D. x .100-inch wall. Extruded shells are then block drawn to finished size, annealed, and either straightened and cut or level-wound as detailed above.

The third method is based on continuously casting small-diameter shells (1.500- or 1-inch O.D. x .250-inch wall), reducing the shells by a special small size reducer, and subsequently drawing to finished size on blocks similar to the two methods covered above.

4.1.1 Fabrication Method No. 1

Cast Billets and Tube Reduced Shells 3 1/2-inch O.D. x .350-inch Wall

1. Conversion selling price (excluding metal) for 1-inch O.D. x .035-inch wall 90/10 cupronickel tubing produced by continuously casting 3.5-inch shells with subsequent tube reducing and block drawing is estimated at $.1872 a pound for 50-foot lengths, $.1907 a

pound for 100-foot lengths, and $.1997 a pound for 360-foot lengths.

2. Conversion selling price for .750-inch O.D. x .035-inch wall for the same lengths is estimated at $.1892, $.1927, and $.2018 a pound.

3. Variations in conversion selling price for a specific size result from different yields because of "breakers" plus different handling costs for straight lengths at shipping. Level-wound coils can be easily handled by a fork truck using minimum manpower and space. Straight lengths require special handling equipment and an increased crew because of the nature of the operation. The increased crew also requires extra supervision.

4. A mill designed to produce tubing by this method would be capable of producing approximately 2,750,000 pounds a month and would necessitate an investment of approximately $11,500,000.

5. Mills are in existence at the present time using practices close to those recommended, but these mills are producing copper rather than cupronickel.

4.1.2 Fabrication Method No. 2

Cast Billets and Extruded Shells 2-Inch O.D. x .100-Inch Wall

1. The overall manufacturing methods are based on direct chill casting of billets which are sawed to length and then extruded into 2-inch O.D. x .100-inch wall shells. Two-inch O.D. shells have been broken down into coils of finished size and level wound. Conversion selling price, excluding metal, for 1-inch O.D. x .035-inch wall 90/10 cupronickel produced by this method is estimated at $.1910 for 50-foot lengths, $.1955 for 100-foot lengths, and $.2038 for 360-foot lengths.

2. Conversion selling price for .750-inch O.D. x .035-inch wall for the same lengths is estimated at $.1927, $.1972, and $.2063.

3. A mill designed to produce tubing by this method would be capable of producing approximately 5,000,000 pounds a month and would necessitate an investment of approximately $21,000,000.

Conversion selling prices through this method are approximately the same as continuously casting 3-1/2-inch O.D. shells, but the investment is twice as large.

4. There is a mill in existence at the present time using practices close to those recommended, but this mill is producing copper rather than cupronickel.

4.1.3 Fabrication Method No. 3

Continuously Cast Shells 1.00/1.25-Inch O.D. x .250-Inch Wall

1. The overall manufacturing method is based on continuously casting shells 1 or 1-1/4-inch O.D. x .250-inch wall, reducing in one pass to either 1.05-inch O.D. x .045-inch wall or .810-inch O.D. x .042-inch wall (based on finished size), and then drawing to finished size. Annealing and level-winding are the same as other methods. Conversion selling price, excluding metal, for 1-inch O.D. x .035-inch wall 90/10 cupronickel tubing produced by this method is estimated at $.2038 per pound for 50-foot lengths, $.2079 for 100-foot lengths, and $.2178 per pound for 360-foot lengths.

2. Conversion selling price for .750-inch O.D. x .035-inch wall for the same lengths is estimated at $.2641, $.2697, and $.2830.

3. A mill designed to produce tubing by this method would be capable of producing approximately 1,250,000 pounds a month and would necessitate an investment of approximately $6,500,000.

4. There is no mill in existence at the present time using these practices, but considerable development work is in process.

4.2 Overall Conclusions

A. Selling price detail shows the two commercial processes to be competitive with estimated conversion selling prices of $.19 to $.21 a pound. Major difference between the two methods is the investment required to fully utilize efficiencies of equipment. The continuously cast and tube reducer method would require capital investments of $11,500,000 as against $21,000,000 for cast and extrude.

The tube reducing method also provides a second advantage over the casting/extrude method inasmuch as the length of coils is only limited by the length of the runout table after the reduction operation. This advantage might provide substantial economies at the fabrication site through the use of large level-wound coils.

B. The experimental process (continuously casting small diameter shells) is competitive at the 1-inch O.D. size, but is not competitive at the 3/4-inch O.D. size where conversion selling prices are over $.28 a pound. These costs can be substantially reduced through increased running speeds at both the casting and the reducing operation. This method has the advantage that the total investment is $6,500,000 and, through improved running speeds, can be reduced to under $5,000,000. The reduced investment enables a greater number of concerns to produce tubing, thereby increasing competition. Increased competition, of course, will lead to improved methods and reduced prices. It should be pointed out that estimated investments are based on "starting from scratch," and producers currently in the business can convert manufacturing methods at a substantially lower cost.

5.0 Welded Tube Fabrication

For many years, the customary method of producing tubes was to fabricate them as a seamless product by a series of drawing operations. In recent years, welded tubes have also been commercialized. Originally, the practice involved roll-forming thick strip, or skelp, into tubular shape, closing the seam by either heliarc or resistance welding, and drawing the resulting tube shell through dies to finished tube size. This welded-and-drawn technique still accounts for much of the ferrous tube produced today.

A later development in tubing fabrication has been the commercial application of radio frequency resistance welding. This type of welding is applicable to the welding of most ferrous and non-ferrous metals and alloys. More often the process is referred to as high-frequency welding, and it is this type of welding that is concerned in the ensuing discussion of welded tubing for desalination applications. Quite a number of companies are applying high-frequency welding to the manufacture of carbon steel, stainless steel, and aluminum tubing, but only a few make copper or copper-alloy tubing by this method. Contrary to the practice for seamless copper and brass tubes, no price schedules are published for high-frequency welded tubes of these materials. Tubes are produced on job-orders only; consequently, it is difficult to obtain prices for comparing with seamless tube.

In high-frequency welding, the strip is of the same thickness as the required wall thickness of the finished tube. The process is faster and simpler than the welded-and-drawn method. Welding is done at the normal production speeds of the forming mill, in the range of 200-400 ft/min, and finished tubes are produced in the as-welded condition in a one-pass operation.

An added requirement of this process, however, is the continuous scarfing of both inner and outer surfaces of the seam weld in order to remove metal expelled by the action of the squeeze rolls. Internal scarfing is no problem if the tubes are of sufficient diameter to accommodate the scarfing tool, but for tubes having an inside diameter less than .500 in., internal scarfing is not feasible by present techniques.

Since tubes of very long length can be readily produced by welding of strip, the process appears attractive for on-site production. Compact rolls of strip would present few problems in shipping to a desalting plant site where a tube mill was set up to convert the strip into long straight tubes.

A problem area with the welded tube is the need of a highly reliable non-destructive test which can be performed in-line with the welding operation. As discussed in the section on quality control, ultrasonics is not suitable for testing at tube speeds exceeding 125 ft/min. Eddy-current testing, on the other hand, is not limited by the tube speeds typically encountered in high-frequency welding, but the welded tube presents other problems for this type of test. While there is confidence in the ability of eddy current to detect such typical defects as cracks, pin-holes, dents, and inclusions, there is divergent opinion within the industry as to the level of confidence that should be placed in eddy-current testing of the seam weld. Of particular concern is the detection of low-strength "paste" welds principally incurred by variations in the welding current. Close regulation of the welding power supply will keep paste welds at a low incidence, but their infrequent occurrence nevertheless presents a serious problem in quality control. In such areas of the weld, the opposing surfaces appear to be fused together sufficiently

so that no defect is detectable when metallurgically sectioned and examined; yet the weld lacks strength. While some development testing has been done in this area, further efforts seem warranted.

5.1 Development Program

In order to gain an insight into the cost areas involved in making welded tube, the OSW supported a development program with Tubotron, Inc., for welding tests on 90-10 copper-nickel alloy.

The objectives of this program were to obtain a breakdown on fabricating costs, to determine the maximum welding rate feasible for tubes of 1 in. O.D. x .035 in. wall, and to make an economic comparison between in-plant and on-site produced tubes. In addition, an evaluation was to be made of eddy-current testing as applied to welded tube. The Tubotron report is given in full in Appendix C.

Finally, an evaluation of the Tubotron work was to be performed by the management consultant firm of Bavier, Bulger & Goodyear, whose report is given in Appendix D. The earlier BB&G study on seamless tubes and the subsequent evaluation of the welded tube would provide an economic comparison between the seamless and welded approaches to low-cost tube for large-scale desalting plants.

5.2 Tubotron Welding Tests

The initial phase of the work was the fabricating of several 360-ft straight lengths of 1-in. O.D. x .035-in. wall 90-10 copper-nickel tube. The primary purpose in making the long lengths was to demonstrate the feasibility of continuously removing the weld chip during internal scarfing. This was satisfactorily demonstrated, but details of the technique of chip removal were regarded as proprietary by Tubotron.

Some 40,000 feet of tube were produced to provide the basis for establishing the economics of welded tube. Inasmuch as the quantity was rather low to assure firm cost data, Tubotron drew extensively from their day-to-day cost experience in welding tubes for the commercial market. Tubes of the 40,000-ft lot were cut into 36-ft and 14-ft lengths for use within the OSW test program.

For reasons discussed more fully in their report, which is given in Appendix C, the Tubotron economic comparison indicated that tubes produced on-site would cost $.004/ft more than tubes produced in-plant. This would be more than offset, however, by the $.020/ft charge to ship in-plant tubes to the desalination plant site. Thus, there would be a significant overall cost advantage of $.016/ft in producing tubes on-site. However, the shipping cost developed by Tubotron is higher than that developed for a similar shipping scheme in the earlier program on producing seamless copper-nickel tubes by bull-block drawing. The shipping cost for this program was $.006/ft. Assuming the validity of this figure, the net difference in favor of the on-site tube is but $.002/ft.

Attempts to confirm either of these shipping costs in conversations with representatives of the freight industry were not very satisfactory. While there was some support for $.006/ft as a possible rate, most shippers stressed that a meaningful rate for shipping tubes in the very large quantities required for large-scale desalting plants could be arrived at only by negotiating an actual shipping contract.

For the eddy-current test evaluations, Tubotron produced tubes with weld defects by deliberately reducing the welding power. While the limited amount of testing on a relatively few samples was not sufficient to be conclusive in regard to the ability to detect "paste" welds, results nevertheless were encouraging.

5.3 Bavier, Bulger & Goodyear Evaluation

The BB&G study was based principally on first-hand observations of the welding tests at Tubotron. Information on price projections for strip was supplied to BB&G by personal contacts within the strip industry.

The results of the BB&G study showed that the welded tube is currently competitive with the seamless tube. However, if the seamless tube technology improves as predicted in the BB&G study on seamless copper-nickel tubes, the picture could very well change. Uprated technology could significantly lower the conversion costs for seamless tube. In order for the welded tube cost to decrease competitively,

lower strip costs would be necessary. BB&G were of the opinion that the conversion cost for copper-nickel strip could be reduced only if volume were high and facilities were engineered to properly produce the product. Even so, the BB&G study indicated that the seamless tube ultimately would be slightly more economical than the welded tube.

Also, it was their opinion that the welded tube was a less reliable product than the seamless tube. They felt that the long seam weld presented additional opportunities for the occurrence of tube defects and that such defects would quite often go undetected by eddy-current test. In their earlier report, they expressed a low level of confidence in eddy current as applied to the testing of welded tubes. In summary, they believed the welded tube would not only cost more than seamless but also, in addition, would present greater exposure to failures in service.

5.4 Conclusions

According to the BB&G evaluation, low-cost welded copper-nickel tube will be possible only if the tube is produced in reasonably high volume. At any rate, it appears likely that cost reductions via improved technology will not be forthcoming since the overall technology for the welded tube is already fairly sophisticated. The strip mills of today are, for the most part, modern, efficient, high-speed systems. High-frequency tube welding mills are in a similar state of modern development.

If, then, higher volume is the key factor in lowering the cost of the welded tube, it would appear that a major problem facing the welded tube is its gaining acceptance by user groups. In the past, the seamless condenser tube enjoyed exclusive use since it was the only type of tube available. This is even yet largely the case inasmuch as only a small amount of welded copper-nickel tube is presently manufactured.

Once user acceptance is gained, welded tubes appear to have potential for reducing tube costs in the intermediate term. For very large quantities, the Bavier, Bulger & Goodyear seamless tube study indicates that seamless tubing is again competitive in cost.

6.0 QUALITY CONTROL

In addition to making chemical and mechanical tests to insure that the tubing is of the proper chemistry and metallurgy, it has been customary over the years to subject condenser tubing to a hydrotest (as per ASTM B-111) prior to packaging for shipment. The additional handling and time consumed in testing add to the tube cost. Also, the test reveals only actual leaks and "weepers" and contributes no information on discontinuities which may lead to premature failure after the tubes have been installed. For desalination plant tubing, particulary in view of the large quantities involved and the possibly long lengths to be handled, hydrotesting would appear to be unduly expensive, difficult to apply, and unable to reveal discontinuities which might adversely affect the life of the tubes.

As a result of rapid advances in the field of nondestructive testing, there are now available testing instruments of the ultrasonic and eddy-current type which, properly utilized, can detect in tubing not only actual leaks such as cracks and pinholes but also potential causes of failure such as pores, inclusions, deep scratches, dents, etc.

6.1 Ultrasonic Testing

Ultrasonic testing is employed extensively in the testing of reactor-grade tubing where rigid quality control prevails. Tube lengths are usually short and easy to handle; tubes can be rotated in passing the test probe; and testing is done at relatively slow tube speeds with the emphasis more on ensuring quality than on achieving economy of testing. For in-line testing of desalination plant tubing in some of the long lengths contemplated, however, the tubes cannot be rotated (such as during the final block draw, or uncoiling and straightening, or in passing through a forming and welding tube mill). Although there are available ultrasonic testing devices with probes which orbit or spin around the tube, none can test at tubes speeds greater than 125 feet per minute. This is considerably below the production speeds anticipated for desalination plant tubing.

6.2 Eddy Current Testing

On the other hand, eddy-current testing is applicable to very high tube speeds. Also, since it is customary to use a test coil which fully encircles the tube, there is no need to rotate the tube. As a result, eddy-current instruments lend themselves very well to being mounted in the final phase of tube fabrication to provide 100% in-line testing at negligible expense.

There are, however, some unresolved problems of eddy-current testing. A major difficulty is the lack of uniformity in the method of applying eddy current to tube being tested. Other than in certain military or naval specifications, there are no hard-and-fast eddy-current testing procedures in use. Within the brass tube industry, the CDA (Copper Development Association) has developed a recommended eddy-current test procedure. Many tube mills are now using this procedure and are offering to include eddy-current testing of tube orders at no extra charge. However, tubes produced at different mills and eddy-current tested as per the CDA procedure will not necessarily represent the same level of quality because the test procedure still allows too much variation. The selections of optimum test frequency, test coil diameter and design, sensitivity, and testing speed are left to the discretion of each tube manufacturer. For making up calibrating tubes, the manufacturer is also permitted to select either filed notches or radially drilled holes as artificial discontinuities.

One other factor which can have a significant effect on the validity of the eddy-current test is the signal-to-noise ratio characteristic of the particular instrument used. (By signal is meant the instrument's response to relatively abrupt changes in conductivity caused by cracks, inclusions, dents, scratches, etc. Noise is understood to be the background signals resulting from nondetrimental chemical, metallurgical, and dimensional variations introduced during fabrication of the tubing.) Use of an instrument with an inherently low S/N ratio may permit bad tubing to pass undetected if the noise response is high enough to mask signals resulting from significant defects. Conversations with prominent individuals in the

nondestructive testing field indicate that the S/N ratio should not be less than 2.5/1.

There is a need for developing realistic standards for checking the performance and calibration of the test instrument. Also, in order to permit the instrument to automatically reject defective tubes, there must be established the proper signal level at which an alarm signal is triggered so that tube quality will be maintained at the desired level. To accomplish all this, eddy-current tests must first be made on lengths of tubing which contain typical natural defects. Next, the tubes must be examined metallurgically to determine the types of defects, their geometry, and their orientation in the tubes. From a study of the metallographic data thus obtained and comparing it with eddy-current signal tracings made previously, a judgment can be made to decide what constitutes a rejectable defect. Once this has been decided, the corresponding signal level on the test strip charts will be considered as the reject level to be used. Finally, reference specimen tubes are made up by incorporating in lengths of good tube artificial discontinuities of a size and type which will produce signals equivalent to the reject level. Generally, such artificial discontinuities are easily repeatable filed transverse notches or radially drilled holes. These are sometimes generated by electrical discharge machining, but there is no conclusive evidence that artificial discontinuities machined by this technique produce better test results.

7.0 INTERIM OSW SPECIFICATION FOR COPPER-NICKEL TUBING FOR MSF PLANTS

Desalting applications require a set of condenser tubing specifications which would cover the fabrication of low-cost copper-nickel tube of such quality that a 20-30 year service life would be assured. For this purpose, the standard condenser tubing specifications of ASTM B-111 were modified to provide for new methods of manufacture, lighter wall thickness, harder temper, longer length, and different methods of testing. The revised specifications cover seamless and welded tubes of 90/10 and 70/30 copper-nickel alloys in outside diameters of 5/8-inch to 1 1/4-inch, inclusive; in .035-inch, .042-inch,

.049-inch wall thicknesses; and in lengths up to 350 feet. The specifications might also be used to cover tubes of other dimensions as agreed on between purchaser and supplier.

Under these specifications tubing would be made in accordance with ASTM B-111 condenser tube specifications, with the following exceptions:

1. Temper. The temper of the straightened tube in the cold worked finish temper at room temperature shall conform to the following:

Alloy	Tensile Strength psi, (min)	Yield Strength psi (min)
90/10 Cu Ni	65,000	60,000
70/30 Cu Ni	70,000	65,000

Tensile tests will be performed to verify temper requirements.

2. Testing. Tubing produced under this specification will be subjected to 100% eddy-current type nondestructive test. Eddy-current test to be performed per Copper Development Association recommended practice.

3. Packing. Tube will be boxed for shipment. Adequate wrapping will be provided to protect the tubes from dust and moisture during shipment and storage. Packing shall be accomplished in a manner which will insure acceptance by a common carrier and will afford protection against physical or mechanical damage during direct shipment from the supply source to the using activity.

8.0 WEST COAST TEST MODULE TUBE EXPERIENCE

The .750-inch O.D. x .035-inch wall 90-10 copper-nickel tubes produced for the West Coast Test Module provided the first industry experience with the OSW tentative specification previously described.

The seamless drawn tubes were supplied by Anaconda American Brass Company. Approximately 70% of the production order was made in their Buffalo, New York, mill; the remainder was made in their Los Angeles Division plant. All tubes were produced in accordance with the OSW interim specification, the chief departures from the ASTM B-111 specification being that the tubes were produced in hard temper and were eddy-current tested rather than hydrotested.

While tube fabricators anticipated no serious problesm in producing hard temper 90-10 copper-nickel tubes, some concern existed among user groups as to whether hard tubes could be rolled into steel tube sheets without incurring leaking joints.

In order to determine if use of such hard tubes was feasible, the OSW arranged with Foster Wheeler Corporation to conduct a series of roller expanding tests. The results showed that, provided a proper tube rolling procedure is used, conventional roller expansion equipment can effectively seal hard temper copper-nickel tubes into steel tube sheets. While measured residual stresses were high in some instances, the low plant operating temperatures precluded any concern over stress corrosion cracking.

The tubes produced by Anaconda at Los Angeles were rated of acceptable quality when received by the subcontractor who was to fabricate the evaporator. However, when the first shipment of Buffalo tubes arrived, four of the total forty-eight boxes of tubes were opened and approximately thirty individual tubes examined visually. From this spot check, four tubes were judged as unacceptable because of surface blemishes and pock marks. A 27-inch sample piece containing a defect was sent to Buffalo for examination where the defect was found to be a surface lamination which triggered a reject signal when run through the eddy-current test instrument.

The result was that the prime contractor for the module rejected all tubes and insisted on complete reinspection. Subsequently, OSW notified Anaconda of the rejection and requested Anaconda advice on the reinspection procedure to be followed. In the meantime, the last shipment from Buffalo, eight boxes, was received damaged in rail transit.

Anaconda took the four boxes of rejected tubes and the eight boxes damaged in transit to their Los Angeles tube mill for a detailed inspection. Meantime, in order to avoid further delays in an already tight construction schedule, a decision was made to proceed with the evaporator assembly using the tubes on hand, with each tube to be visually inspected immediately prior to insertion in the tube bundle. At the completion of the job, the tubes would then be simultaneously tested en masse by hydrotesting the assembled tube bundles.

At the Los Angeles mill, the eddy-current equipment previously used to test Los Angeles' production on the order was set in accordance with the OSW interim specification and 463 pieces of tube rerun. Sixteen tubes triggered a reject signal. By visual examination, the tubes were categorized as follows:

1. In four tubes, no defects were observed; when run through again, no signal was triggered. The tubes were presumed acceptable.

2. Nine tubes had circumferential chafing marks caused by rubbing together in shipment. By visual estimate, the marks were less than .005-inch deep, were fresh, and apparently not in the tubes when shipped from Buffalo.

3. One tube had a nail hole. Since the boxes were not nailed at Buffalo, the assumption was that the hole occured after examination at the subcontractor's plant site.

4. One tube had a depression near one end, apparently caused by a chip of foreign material mechanically pressed into the tube surface and subsequently removed. Anaconda felt the depression would not impair the life of the tube but was nevertheless enough to trigger a signal and should have been rejected in Buffalo.

5. One tube had a surface lamination extending for several feet near one end. Anaconda felt it should have been rejected at Buffalo.

A subsequent metallurgical examination of several surface lamination type discontinuities showed measured depths of .008 inch, .0048 inch, and .002 inch. On eddy-current test the first triggered a reject signal, the second was marginal, and the last triggered no reject signal despite six reruns.

Anaconda concluded that only two of the tubes retested at Los Angeles and one other tube (detected earlier by OSW visual check) contained defects which should have been cause for automatic rejection at Buffalo on the initial eddy-current test. Anaconda took the position, therefore, that no inspection is exact and that contradictory results on only three tubes out of 464 was a reasonable figure. Further, they were convinced from long experience that visual inspection and hydrotesting did not provide the reliability and repetitiveness possible with eddy-current testing. On the basis of the retesting

results, therefore, Anaconda stated that the eddy-current inspection at Buffalo prior to shipment should be regarded as competent and in accordance with the requirements of the OSW specification.

The tubes were subsequently installed in the evaporator condenser bundle, and the tube ends were rolled into the steel tube sheets. The ends of the brine heater tubes were fusion welded to the copper-nickel tube sheet cladding.

During the 18-psig air test of the evaporator shell, the condenser tube sheet joints were soap tested with only one leak being found. This was repaired by rerolling.

Testing of the brine heater after it had been installed disclosed a number of ruptured tubes, but these were attributed to the freezing of residual undrained hydrotest liquid at the Eastern fabrication shop site. Retesting after replacing and, in some cases, after plugging, the defective tubes revealed a few weeping welded joints. These were repaired by roller expanding of the tube ends.

In all, the module tube experience indicated that hard temper tubes of 90-10 copper nickel are easier to handle, are less subject to handling damage, and can be roller expanded by conventional techniques to give leak-tight joints in steel tube sheets.

As an independent test, three hard temper tubes were sent to the OSW's test station at Wrightsville Beach, N. C., for Baldwin-Lima-Hamilton to install in their 16-stage pilot plant for scale investigations. The Office of Saline Water requested BLH to have their experienced field service crew install the tubes in place of three old tubes in the existing pilot plant tube bundle. The new hard-temper tubes were installed and rolled into the tube sheets by the regular method without any difficulty. The tube sheet seals did not leak and the hard-temper tubes met all specifications as installed in the tube bundle.

9.0 SPLICING OF TUBES FOR USE IN MSF PLANTS

In considering the possible use of condenser tubes several hundred feet long, there was some concern that scrap losses might cause tube costs actually to be higher unless means were available

for replacing defective sections in long tubes. Suitable splice welding equipment was not available in the brass tube industry since there had never been any need for it; condenser tubes were customarily produced and used in short lengths which made it feasible to reject or to replace the entire tube.

However, splice-welding equipment was found to be in use in the aerospace industry, where it is used principally for welding thin-wall titanium, stainless steel, and aluminum tubing. Both Astro-Arc Company of Sun Valley, California, and Merrick Engineering, Inc., of Nashville, Tennessee, market compact split-head welding units which differ somewhat in outward appearance but internally are very similar. In each case a split bevel gear, powered by a motor in the weld head handle, orbits a tungsten inert gas shielded electrode around the tube joint circumference to produce an autogenous weld (weld made without filler). The entire assembly clamps around the butted tube ends, and neither the weld head nor the tubing moves during the welding process. A combined power supply and sequence programmer automatically starts rotation of the electrode, high-frequency arc ignition, controls the welding current (including build-up at the start of the weld and slow decrease to prevent cratering at the finish), shielding gas flow, and stops rotation at completion. The units are portable and adaptable for use in the field.

9.1 Weld Tests

Although no contracts were let for developing condenser tube splicing, a limited number of weldments were made up for test by Astro-Arc using copper-nickel and titanium tube samples.

The welds in titanium tubing (1-inch O.D. x .016-inch wall) were of excellent quality. The welds were free of cracks, inclusions, and porosity. Weld bead contours were excellent; only a slight depression was evident on the outside, and the inner bead was essentially flush. Tensile tests showed the strength of the welds to be equal to or greater than that of the tube itself.

Less favorable results were obtained with the copper-nickel tubes (90-10, .750-inch O.D. x .035-inch wall and 70-30, 7/8-inch O.D. x

.049-inch wall). Most of the welds were characterized by a high degree of porosity. A significant degree of sag was noted in many of the welds resulting in objectionably high inner weld beads. Tensile tests showed the tubes to be weakest at the heat affected zone of the welds. While additional work on developing welding techniques for this material would very likely improve the appearance and contour of the welds, porosity would still be a problem. The likely solution to this problem is to employ filler metal (AWS-5.7) containing a small percentage of titanium which acts as a scavenging agent to absorb pore-forming gases. To use filler successfully, however, means that a method would have to be developed for automatically feeding the filler wire into the weld head. One major brass tube fabricator has reportedly achieved some degree of success in developing this type of equipment.

9.2 Splice Welding Costs

The cost of making a tabular butt weld with this kind of equipment will vary somewhat, depending on the application scheme followed. With one man to operate the welder and two men for handling and positioning the tubing, squaring and cleaning the tube ends, etc., it should be possible to average one weld per eight minutes. For such an arrangement, the cost per weld would be about $3.25. One or two such welds would appear to be justifiable in order to salvage rejected 350-foot tubes by splicing in good tube to replace defective sections. However, producing long tubes by butt-welding common 50-foot mill lengths would add considerably to the long tube cost. For instance, forming a 350-foot tube by welding end to end seven 50-foot tubes would increase the cost for the long tube by 5.5¢/foot.

9.3 Evaluation of Weld Integrity

Since the circular weld would be parallel with the eddy-current flow, such welds could not be checked by passing the tube through a conventional eddy-current test coil. Some consideration has been given to this matter, however, and the problem has been discussed with a number of reliable manufacturers of nondestructive testing equipment. The general consensus was that some variation of eddy-current test

could likely be developed to adequately test welds of this type. Basically, an eddy-current test probe could be mounted exterior to the tube and directed against the surface of the weld. The probe would be given an oscillatory motion to sweep across the face of the weld and either made to revolve circumferentially around the tube or fixed in place with the tube rotating against it.

9.4 Conclusion

In the light of subsequent development work on fabricating long tubes by block drawing, however, the whole question of splice welding of tubes appears to be largely academic. Earlier fears that reject rates would be high have not been substantiated. There is good reason to expect that long copper-nickel tubes can be block drawn like copper and that rejections will not be significantly greater than presently experienced in producing water and refrigeration tubing in long continuous lengths. Hence, there appears to be no strong demand for splice welding. If there were a demand, it appears a satisfactory process could be developed.

10.0 DEVELOPMENT OF IMPROVED PRODUCTION PROCESSES: TITANIUM TUBES

In addition to the development tests on seamless copper-nickel tubes, Wolverine Tube Division also contracted to perform somewhat similar tests on seamless titanium tube in long lengths. Difficulty encountered in drawing titanium, however, made it necessary to use a tube reducer rather than a bull-block to achieve the desired reductions. The full Wolverine Tube report is included as Appendix E. The following paragraphs summarize their findings.

10.1 Production of Titanium Tubing

To substantiate the feasibility of producing 200-foot continuous lengths of 1-inch O.D. seamless titanium tubing in .012-inch, .016-inch and .020-inch minimum wall thicknesses using the tube reducing ("rocking") process, 3-inch O.D. x .225-inch-wall titanium extrusions suitable for producing ASTM B-338-65 tubing were used as the starting material. Two basic processes were used to produce the three tube sizes: Process No. 1 incorporated one in-process anneal; Process No. 2 was identical,

but without the annealing step. All base tubes were processed through the first and second tube reductions to the 1.660-inch O.D. size without vacuum annealing.

A total of 28 lengths of 1.000-inch O.D. tubing was produced with a finished length greater than 200 feet. One intermediate tube that had not been annealed was also reduced to the 1.000-inch O.D. x .020-inch wall size to determine if any in-process annealing was necessary.

All finished tubing appeared to be good quality. Because the desired final wall sizes were specified as a minimum wall thickness, the tube reducer tooling was designed to produce a .014-inch, .018-inch, and .022-inch respective average wall thickness. One tube processed to the 1.000-inch O.D. x .020-inch wall final size without an in-process anneal finished with a slightly heavier wall (.024-inch to .026-inch wall) than the (.022-inch wall) material that had been annealed. This was due to the greater amount of springback in this more heavily cold worked material.

The tube reducing rates for all reductions were essentially fixed by the machine design and the area reduction being employed. Higher feed rates were attempted but the feed rate could not be increased significantly above approximately 100 feet per hour.

10.2 Coiling Tests

The coiling investigation was accomplished to determine if long length thin-wall titanium tube could be coiled, shipped to the plant site, and uncoiled for use.

Twelve 35-foot lengths were cut from each of the three wall sizes produced, and three 35-foot lengths were taken from the "hard" .024-inch wall tube.

All tube could be coiled to 8-foot diameters or less with the exception of the .014-inch wall material. This tube size would experience buckling of the inside wall unless the coil diameter was increased above 11 feet; hence, coiling of this tube wall was discontinued.

All lengths of the .018-inch, .022-inch, and the .024-inch (hard) tube coiled without difficulty. The .018-inch wall tube could be coiled

to diameters as small as 63 inches, and the .002-inch and .024-inch (hard) tubes were coiled to diameters as small as 49 inches.

10.3 Uncoiling and Straightening

After coiling, all tubes were uncoiled using a standard 12-roll Torrington straightner. All tubes straightened into lengths generally suitable for insertion into heat exchangers with a typical total bow less than 2 in. over a 35-ft length.

Tube ovality generally ranged from .008 in. to .020 in. after uncoiling. This was beyond the .012 in. allowed by the tentative titanium tube specification; however, tube ovality would be improved if the coiling machine were specifically set up for a constant tube diameter and wall, as would be the case in production uncoiling.

After uncoiling, all tubes were again eddy current tested to determine if any degradation in quality occurred as a result of the coiling/uncoiling. No significant changes were found.

All cold worked tubing met the seamless titanium tube interim specification for annealed tubing with exception of the Process No. 2 (no in-process annealing) 1-in.-O.D. x .024-in.-wall material, and all coiled/uncoiled tube. The heaviest wall (.024 in.) tube produced without an anneal failed to meet the 12 x the nominal wall minimum flattening test and all coiled/uncoiled tube was outside the ovality tolerance permitted by the tube specification. The ovality problem is of some concern; however, a properly designed tube uncoiler should be capable of meeting the plus/minus .006-in. tolerance specified.

It is interesting to note that although the tubing was heavily cold worked, the mechanical property data indicated considerable ductility, since the tube could be flared to increase its diameter by as much as 45% without splitting although the tensile strength was nearly 130,000 psi with 14% elongation.

In extrapolating the process for producing 360-foot finished lengths from the experience accumulated with 200-foot lengths an in-process vacuum anneal was included, since it is doubtful that fully cold worked titanium can be consistently uncoiled and subsequently roller expanded into tube sheets without a higher incidence of splitting or failure to seal.

From the coiling attempts conducted it is uncertain that the .012-inch wall tube can be successfully coiled on a production basis due to diameter buckling. Improved coiling and uncoiling equipment specifically designed for the .012-inch wall, however, might be able to overcome the buckling problem.

10.4 Nondestructive Testing

The tubes were eddy-current tested using a Magnetic Analysis 10KC tester with the sensitivity adjusted to the highest level.

After coiling and uncoiling, these tubes were retested under the same sensitivity settings to determine if any detrimental effects resulted from the coiling/uncoiling.

Samples of each of the tubes coiled/uncoiled were also tested using immersion ultrasonic inspection techniques.

Typical samples from each of the three tube walls produced were subjected to this ultrasonic test using a Sperry Model No. UM721 Reflectoscope. No defect areas were found.

From the testing results all material produced was considered high quality tubing.

10.5 Shipping Methods

The long length coils would be shipped to the desalination plant site in knock-down returnable crates by rail (or truck). Each crate would contain four 5-ft diameter titanium coils.

At the desalination plant site the crates containing the coiled tube would be unloaded by conventional means and moved to the uncoiling-finishing station adjacent to the evaporator.

It is anticipated that one straightener and accompanying handling, inspection and processing equipment, and a three-man crew would have a finishing capacity of approximately 8 million feet per year per shift. An around-the-clock operation could finish nearly 30 million feet per year.

10.6 Projected Prices

The Wolverine projected selling prices for 360-foot-length seamless titanium tubes are presented below. For comparison purposes, current

base prices are shown also.

Estimated Costs of 1-inch-Diameter Titanium Tubes

.012-inch Wall	.016-inch Wall	.020-inch Wall
$0.962/ft (1970)	$1.119/ft (1970)	$1.264/ft (1970)
-	1.30/ft (1968)	1.32/ft (1968)

The projected selling prices for seamless titanium tube in 360-foot lengths are based upon titanium billet prices remaining at $3.00 per pound; on the production processing recommended in this report which includes one in-process vacuum anneal; on transportation from the midwest to the Los Angeles area; and on shipping in coils, uncoiling, and straightening at the installation site. These prices do not include any additional on-site processing.

11.0 WELDING OF TITANIUM TUBES TO TITANIUM-CLAD STEEL TUBE SHEETS

In order to establish a reliable welding procedure which would be applicable to the field erection of tube bundles for titanium-tubed desalination plants, a subcontract was negotiated with the Revere Copper and Brass Company to develop satisfactory procedures for welding thin-wall titanium tubes to titanium-clad steel sheets. For this work, the Revere automatic tube welding gun was used. The variables investigated were joint design, welding speed, amperage, shielding gas flow, backside shielding, and prepurge and postpurge times. Weld quality was evaluated by metallographic examination and mechanical testing. Their final report is given in Appendix F and is summarized in the following paragraphs.

The Revere automatic tube welding gun used for this investigation consisted of an inert gas shielded tungsten arc torch which rotated around a mandrel inserted in the mouth of the tube to be welded. The tungsten arc melted the tube and tube sheet material, allowing them to flow together to produce an autogenous (no filler metal) weld.

For a typical weld gun sequence, triggering the gun initiates a 3-second flow of prepurge shielding gas. After this, a high-frequency current establishes the arc and the torch rotation begins. Rotation

continues 360° plus a 30° overlap to re-fuse the start of the weld. At this point, the current begins decaying to a level which will eliminate any craters when the arc is broken. Gas flow continues for a timed period to shield the weld while it cools. The torch completes the second revolution where it stops automatically and is ready for another weld.

11.1 Materials

The tube material for the welding tests was unalloyed Grade 2 titanium in the following types and sizes:

a. 3/4-inch O.D. x .022-inch wall seamless tube
b. 3/4-inch O.D. x .020-inch wall heliarc welded tube
c. 1-inch O.D. x .018-inch wall seamless tube
d. 1-inch O.D. x .016-inch wall high-frequency welded tube

The plate material was 1.125-inch-thick A212 Grade B steel explosively clad (Detaclad) with 1/8-inch-thick Grade 1 titanium. The titanium surface was partially machined off to obtain the thinner claddings required for the test weldments.

11.2 Surface Preparation and Joint Design

Since titanium is less tolerant of contaminants than many other metals, precautions were exercised to insure that the metal surfaces were bright and clean before welding. The outside surfaces of the tubes and the tube sheet face were sanded, after which the surfaces were degreased in a xylene base cleaner and thoroughly dried prior to welding. Under these conditions, no difficulties were encountered which were attributable to lack of cleanliness.

Several joint designs were studied. These included joints with the tube ends slightly recessed, with the tube ends flush, and with the tube ends projecting slightly beyond the face of the tube sheet. Both straight and flared tube sheet holes were evaluated. In the latter case, the tube ends were also flared but to a somewhat smaller flare angle. The tube-to-tube sheet hole clearances were in accordance with the TEMA (Tabular Exchanger Manufacturers Association) recommendations. Prior to starting the weld, contact was established between the tube wall and the hole by lightly rolling.

The most satisfatory joint design was found to be a straight hole with the end recessed .030-.040 inch below the surface of the tube sheet. The arc path was maintained about .020-.025 inch outside the tube sheet hole. This in effect melted off the corner of the hole to allow molten metal to flow down to the end of the tube. With this type of joint design, the tube end was slightly removed and shielded from the arc; the arc, therefore, was prevented from melting out the thin tube wall beyond the area where the tube sheet was in the molten condition.

11.3 Tensile Test Results

The tensile strengths of the weldments were slightly in excess of 70,000 psi. In testing the welds to the break point, half of the tubes fractured through or adjacent to the weld; the other half fractured through the tube wall near the back side of the tube sheet.

11.4 Minimum Cladding Thickness

With respect to cladding thickness, it was found that a 1/16-inch titanium cladding was sufficient to permit the production of high quality welds using the optimum welding conditions. However, it was also demonstrated that relatively small changes in welding conditions such as welding current could produce very detrimental results with this cladding thickness because of iron pick-up in the weld bead and the formation of hard brittle areas in the weld at the titanium-steel interface. The 1/16-inch cladding left no margin of safety for such eventualities as the need for rerunning a weld as a repair procedure or every the possibility of cutting out a weld to install a new tube. Revere recommended, therefore, that the minimum cladding thickness considered should be 3/32-inch and that a 1/8-inch cladding should not be considered unreasonably heavy.

11.5 Gas Shielding

The use of argon shielding on the surface of the weld proved to be completely satisfactory. Tests results of the welding showed that inert gas shielding on the back side of the tube sheet was not necessary since there was not a sufficient volume of air present in the

crevice between the tube and the tube sheet to produce a detrimental amount of contamination during the welding cycle. Although helium and argon-helium mixtures were tried, superior weld quality and appearance were obtained using 100% argon as the shielding gas.

11.6 Seam Welded Tubing

Welded tubing, produced by both tungsten inert gas welding and high-frequency welding, was successfully welded into the tube sheets using the same conditions as used for the seamless tubing of the same size. There was no indication that either type of tube welding would influence the welding of the tube into tube sheets.

11.7 Production Rates

The typical weld cycle for the sizes of tube used in the tests was 15 seconds. Allowing another 15 seconds for removing the gun and inserting it in another tube, it should be theoretically possible for an operator to make 120 welds per hour if all the necessary cleaning and light rolling of the tubes were done ahead of time. Experience with this type equipment, however, indicates that 350 to 400 welds per 8-hour shift would be a more realistic production rate. On an actual production job in the field, the welding should be done using a skip pattern of welding to minimize heat buildup in any one area and to help control tube sheet wrapage.

The use of a clad tube sheet and of a recessed tube end in a straight hole is covered by U. S. Patent No. 3,257,710 which was issued on June 28, 1966.

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APPENDIX A

REPORT 18-NP-67

EVALUATION OF TECHNICAL FEASIBILITY OF DEVELOPING LOW COST FABRICATION METHOD FOR LONG LENGTH COPPER NICKEL TUBE FOR DESALINATION WORK

WOLVERINE TUBE DIVISION
CALUMET & HECLA, INC.

for

UNION CARBIDE CORPORATION
NUCLEAR DIVISION
OAK RIDGE, TENNESSEE

SUBCONTRACT 2829

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November 1967

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ABSTRACT

The technical feasibility of producing long length (up to 360 ft.) seamless copper-nickel tube was established. Cost data were projected to 1970 and the logistics of transportation to plant site were studied. Results indicate a lower cost method of producing long length copper-nickel tube for evaporators for desalination plants is available.

FOREWORD

This Final Report covers the work performed under Subcontract 2829 by the Wolverine Tube Division of Calumet & Hecla, Inc. for the Union Carbide Corporation, Nuclear Division, Oak Ridge, Tennessee. It consisted of an evaluation of technical feasibility of developing low cost fabrication method for long length copper-nickel tube for desalination work.

The work was carried under the coordination of Mr. H. E. Honkala, Engineering Services Manager, with the actual processing being performed in the Decatur, Alabama, Plant of Wolverine Tube.

INTRODUCTION

As a result of the ever increasing demands for fresh water over the world, a significant requirement to convert sea water into fresh water has been identified. Demonstration plants have been built to determine the economics of various systems. The erection and design of desalting plants call for new concepts to attain maximum economy. Thus, the need to investigate new methods of producing long lengths of copper-nickel tubes for the evaporator in multistage distillation plants became apparent.

With this objective, a contract was made between the Union Carbide Corporation, Nuclear Division, and the Wolverine Tube Division of Calumet & Hecla, Inc., to develop low cost fabrication methods for producing long length seamless copper-nickel tubes by the cold reduction process. This contract provided for processing a limited amount of 90-10 and 70-30 copper-nickel to 3/4" OD x .035" minimum wall thickness in continuous coiled lengths of approximately 360 ft, with a proposed ORNL specification as a guide. Further, this contract required generating cost data to provide the basis of reliable projection of prices through 1970, and a study of methods of transporting long length coils and straight lengths of 60-360 ft., to desalination plant construction sites.

EVALUATION OF ALTERNATE PROCESSES

To investigate the feasibility of producing the long length copper-nickel condenser tube, the following limited program was formulated.

The material for processing was taken from an existing inventory of 8" diameter 70-30 and 90-10 copper-nickel billets with the following nominal composition in percent by weight:

	90-10 Copper-Nickel	70-30 Copper-Nickel
Cu	87.5/89.0	67.5/70.0
Ni	9.0/11.0	29.0/32.0
Fe	1.10/1.35	.4/.6
Mn	.5/.7	.5/.7
C	.05 max.	.05 max.

A total of 65 billets weighing approximately 10,700 pounds was processed during the investigation. They were divided between the two alloys as follows:

90-10 copper-nickel
43 billets x 12", approximately 8,100 pounds

70-30 copper-nickel
22 billets x 10-1/2", approximately 2,600 pounds

The blocks were extruded on a 2,400-ton horizontal extrusion press into 3-1/2" diameter tube shells. Press capacity made it necessary to use the short billet for the stronger 70-30 alloy. The as-extruded 90-10 and 70-30 tubes were respectively about 10' and 8-1/2' long.

The tubes were processes to the following schedule:

Extrude 3.5" nominal OD x .460" wall
Swage one end
Lubricate by dipping in water soluble lubricant
Bench draw 2.875" OD x .300" wall
Bench draw 2.437" OD x .218" wall
Anneal both 90-10 and 70-30 copper nickel
Reswage end
Bench draw 2" OD x .155" wall
Bench draw 1.750" OD x .110" wall
Anneal .025/.050 mm grain size both 90-10 and 70-30 copper-nickel

Carbide dies and mandrels were used for each draw. At this stage, the 90-10 tubes were 72' long and the 70-30 tubes were 57' long. Nine of the above tubes were then bull blocked to near finish size or finish size in four draws. Various draw schedules were tried to determine the best sequence.

Three 1.750" OD tubes were processed to final size by each of three alternate processes to determine the method of obtaining the required final temper. The three processes were:

Alternate Process I

Anneal .865" OD coils
Bull block draw .750" OD x .037" wall
Straighten

Three 90-10 alloy tubes were processed this way.

Alternate Process II

Bull block draw .760" OD x .037" wall
Anneal coils to .010/.020 mm grain size
Straighten and size to .750" OD

Three 70-30 alloy tubes were processed this way.

Alternate Process III

Bull Block draw .750" OD x .037" wall
Anneal .005/.101 mm grain size
Straighten

Three tubes of each of 70-30 and 90-10 alloy were processed this way.

The 90-10 and 70-30 alloy tubes produced were respectively about 450' and 360' long.

The dimensions and mechanical properties of the resulting tubes were:

	ORNL Spec. Requirement	Alternate I	Alternate II	Alternate III
90-10 Copper Nickel				
Tube OD	.750 ± .004	.748 ± .004		.747 ± .002
Tube Wall	.035 min.	.035/.038		.036/.0375
Tensile strength psi	50,000 min.	62,100		52.500
Yield strnegth psi		60,600		31,700
Expansion % ID	20 min.	Over 30		Over 30
Hardness Rockwell B		60-70		41/44
70-30 Copper Nickel				
Tube OD	.750 ± .004		.750 +.002 - .003	.748 ± .004
Tube wall at any point	.035 min.		.0365/.0375	.0365/.038
Tensile strength psi	65,000 min.		68,100	63,700
Yield strength psi			44,600	39,800
Expansion % ID	20 min.		Over 30	Over 30
Hardness Rockwell B			61/65	56/60

PROCESSING OF DEMONSTRATION LOTS

Evaluation of above data eliminated Processes I and III. The following variation of Alternate II was used to draw the remaining 1-3/4" OD tubes to the .765" OD x .038" wall size:

1.750" OD x .110" wall
Block draw (60") 1.496" OD x .085" wall
Block dras (60") 1.240" OD x .065" wall
Block draw (60") 1.013" OD x .053" wall
Block draw (60") .855" OD x .041" wall
Block draw (36") .765" OD x .038" wall

The lubricant used on the blocks was Etna 586 with carbide draw dies and mandrels. Results were good with no major problems encountered.

After bull blocking on the 60" drum, coils sprang out to 75"-85" diameter. Coils from the 36" drum were up to 48" in diameter. The 48" diameter coils were too wide for the available annealing furnace and were recoiled to 44" OD. A device was improvised to accomplish this. After recoiling, the coils were strapped with steel strips and annealed to .005/.020 mm grain size. All coils were annealed except two of each alloy which were held for straightening from the hard drawn temper.

Straightening and sizing of the annealed coils was initially attempted on a 12-roll straightener with staggered rolls to which a set of opposing rolls was added for sizing. Excessive OD marking resulted. In the final process, the coils were straightened successfully with a roll forming machine with five pairs of opposing rolls. The tubes were eddy current tested as they emerged from the straightening and sizing machine at approximately 80 ft/minute.

Some of the 90-10 copper nickel was tested with the same eddy current equipment at 400 ft/minute after passing through a multiple roll straightner. The procedure used for testing as well as the standards used for calibration were as recommended by the Copper Development A sociatin Inc.; a copy of their recommendation is included in the Appendix. (Appendix C)

The unannealed coils of both alloys were also straightened, sized, and eddy current tested successfully on the roll forming equipment.

The work done established the process' feasibility. Additional effort would be necessary to develop optimum processing schedules, procedures, and tooling to determine the best equipment designs and to establish the process and quality controls.

Dimensional and mechanical properties of representative samples of tube shown below are all within the requirements of the proposed specification ORNL-1:

Copper Nickel	OD	Wall	Strength Tensile psi	Strength Yield psi	% Expansion ID
90-10	.749"/.753"	.038"/.040"	53,800	35,800	49
	.750"/.752"	.0375"/.040"	54,500	38,401	49
	.749"/.751"	.0375"/.040"	55,200	37,800	50
70-30	.750"/.754"	.038"/.040"	67,800	44,800	42
	.751"/.753"	.0375"/.0395"	67,800	44,800	41
	.750"/.753"	.038"/.0395"	67,800	44,800	35

Properties of the 70-30 copper nickel material straightened and sized from the unannealed coils were:

OD	Wall	Strength Tensile psi	Strength Yield psi	% Expansion	RB
.748"/.752"	.036"/.038	99,800	89,000	51.5	93/94
.746"/.752"	.036"/.038"	99,900	85,800	41.1	93/94

Mechanical properties of the 90-10 copper nickel material straightened and sized from the unannealed coils were:

Tensile Strength psi	Yield Strength psi	RB
85,400		85/86
85,000	77,600	85/86

The finished tube was cut into lengths specified by the contractor. The inventory of material on hand is shown in Appendix A. A complete processing procedure is included in Appendix B with the optimum draw schedule. Improvements can be expected with further processing.

ON-SITE PROCESSING OF LONG COILS

The problems of transporting 360' straight lengths are quite formidable. Therefore, the alternate of shipping in coile form and on-site straightening and sizing was studied.

In this alternate, long length coils would be shipped to the site on railroad cars in knockdown returnable crates. From the car, they would be moved either into storage or to the tube straightening/finishing equipment by fork lift truck. Individual coils would be lifted out of the crates by the chain hoist on a swinging boom and placed on a payoff reel. The tube would be fed into the roll forming machine which would straighten, size, and discharge a straight length onto a table. This runout table would be provided with automatic cutoff equipment to permit cutting to the desired exact lengths up to 360'. The cut tubes would be discharged into portable racks which could be moved into storage or to transport tubes to the evaporator assembly site. On-site preparation stops at the straight tube discharge do not include assembly into the evaporators.

On-site preparation of the long length coils would require the following equipment:

1. Fork lift truck to unload crated coils and move to straightening setup.
2. Small chain hoist to lift coils from crates and place on payoff table.
3. Payoff reel.
4. Roll forming machine for straightening and cutting.
5. Runout table - 370' long.
6. Eddy current tester.
7. Cutoff equipment.
8. Tube trucks for receiving straightened and cut tube.

Estimated cost of equipment for one finishing facility for on-site preparation of tubes would be approximately $90,000. This does not cover site preparation, foundations, buildings, or provision for electrical power and compressed air. A three-man crew would be required to operate the equipment. In addition, a supervisor would be needed who could handle more than one crew. This manpower would deliver tubes to storage or the evaporator but would not insert tubes into the evaporator.

Based on development work, this method could be used to straighten hard tubes should tubes of greater strength be required.

One on-site finishing line on one 8-hour shift would furnish approximately 8 million feet/year. Three-shift operation would produce approximately 24 million feet of finished tube ready for assembly.

EVALUATION OF TRANSPORTATION PROBLEMS

Packaging, loading, and transporting costs involved with 60-360' lengths in coiled and straight form were considered in analysis of transportation problems.

For straight lengths 75' and under, the tube can be shipped by rail in open top gondola cars. It would be packed in wooden containers with a gross weight less than 8,000 pounds. Typical containers would hold the following number of 75' tube lengths:

Tube OD	Tube/Box	Tube Wt./Box	Gross Wt./Box
5/8"	327	6,500 lbs	7,800 lbs
3/4"	215	5,175 lbs	6,300 lbs
1"	121	3,950 lbs	5,100 lbs

This would involve no unusual problems in loading or unloading. Cars are available to handle maximum weights of approximately 120,000 pounds.

Shipment of the 110' straight lengths will require three railroad cars. The center car would be drop end gondola type. A flat car would be reauired on each end to take up the overhang and to permit the ends of the boxes to slide on a base as the cars move around curves. The boxes would be approximately 13" wide x 12" high with special blocking and strapping to hold the load together. Approximately 20 boxes could be loaded on a gondola car depending on the capacity of the car and the weight per box. Boxes would require special construction and higher quality lumber to withstand the unusual stress of loading and transportation.

Long length coils up to 360' can be most economically shipped in knockdown returnable crates approximately 4' square x 40" high. For the 3/4" OD size, this container would hold six 360' level wound coils approximately 44" in diameter and 5" high weighing 120 pounds/coil. Level winding the tube, similar to cable, insures tangle-free uncoiling, makes a more compact coil, and simplifies handling and protection against damage. A standard box car would hold 48 such crates with a gross weight of approximately 41,000 pounds for 3/4" OD tube.

Returnable knockdown crates provide tne most economical packaging for shipping tube in coil form because the substantial container expenxe can be spread over several loads. These crates would provide good protection in shipment, a storage capability when necessary, and a package which can readily be picked up by fork lift truck. For costing purposes, it was estimated that this crate would be used three times.

Discussions with railroad representatives have not established any method of shipping the straight 125' - 360' long lengths. The only apparently feasible method would be to load the tube on several flat cars or open end gondolas. Six cars would probably be needed for the 360' length. The tubes would have to be able to bend and move with

respect to the other as the cars went around curves and underwent changes in elevation. Special packaging would probably be needed to prevent tubes from rubbing against each other, and limit the weight on any tube which might prevent it from moving.

An evaluation of the comparative transportation cost of 75' straight lengths versus 75' coils shows a cost for the 3/4" OD size of $0.0154/ft straight versus $0.0146/ft for the coil. The lower cost for the coils results from the considered use of a returnable crate in the case of the coils.

PROJECTED 1970 PRICES

Conversion prices for three tube sizes and three lengths for both 90-10 and 70-30 copper nickel alloys were calculated and are tabulated below. These conversion prices do not include the metal content. The cost of metal can be obtained by projecting the Wholesale Commodity Price Index for the Nonferrous Metal Group published by the U. S. Department of Commerce. The prices are based on the process proposed by this report, extrapolated for larger volume, as well as optimum processing procedures and practices. They include transportation from the Midwest to the Los Angeles area. The prices for 360' lengths are based on shipping in coil form and straightening on site and do include the on-site processing cost.

PROJECTED 1970 CONVERSION PRICES PER FOOT
.035" WALL SEAMLESS TUBE TO SPEC. ORNL-1

Tube	90-10 Copper Nickel				70-30 Copper Nickel		
	Present Process	New Process			New Process		
OD	110'	60'	110'	360'	60'	110'	360'
5/8"	.165	.121	.130	.150	.131	.136	.151
3/4"	.202	.140	.153	.155	.151	.164	.163
1"	.254	.185	.205	.199	.201	.218	.215

CONCLUSIONS

1. It is technically feasible to produce both 90-10 and 70-30 copper nickel seamless in continuous lengths up to 400' by cold reduction processes utilizing block drawing.

2. The drawing, coiling, recoiling, annealing, straightening, and eddy current testing of the long lengths have been demonstrated.

3. A process has been established which produced 3/4" OD x .035" wall tube which meets the requirements of proposed specification ORNL-1.

4. Shipment of long straight lengths up to approximately 125' long is feasible.

5. No satisfactory method of shipping straight lengths over 125' has been established. The only established method to deliver lengths over 125' is in coil form.

6. On-site preparation of straight lengths from long coils is technically feasible.

7. Prices for finished tube in 60', 110', and 360' lengths can be estimated and have been projected to 1970.

8. A quality product for desalination plants can be provided by the methods outlined in quantity and at reasonable prices.

APPENDIX A

Inventory of Finished Material to Specification ORNL-1

Size

.750" OD x .035" minimum wall

Quantity

442 pieces, 2,933 pounds, x 20 feet 90-10 copper nickel

50 pieces) approx. x 75 ft 70-30 copper nickel
8 pieces) 1,448 pounds x 30-70 ft random 70-30 copper nickel

APPENDIX B

Processing Procedure

90-10 and 70-30 Copper Nickel to 3/4" OD x .035" Minimum Wall

Cast 8" diameter billet, 100" length.

Saw 11" length.

Heat billets - 70-30 2000°F; 90-10 1900°F.

Extrude 3.5" nominal OD x .460" wall.

Swage one end.

Lubricate, dipping, water soluble lubricant.

Bench draw 2.875" OD x .300" wall.

Bench draw 2.437" OD x .218" wall.

Anneal both alloys .025/.050 mm grain size.

Reswage one end.

Bench draw 2" OD x .155" wall.

Bench draw 1.750" OD x .110" wall.

Anneal both alloys .025/.050 mm grain size.

Cut points.

Point, draw, 60" blocks, 1.496" OD x .085" wall.

Point, draw, 60" blocks, 1.240" OD x .065" wall.

Point, draw, 60" blocks, 1.013" OD x .053" wall.

Point, draw, 60" blocks, .855" OD x .041" wall.

Point, draw, 36" blocks, .765" OD x .038" wall.

Recoil to 45" maximum coil diameter; band with steel straps.

Anneal .005/.020 mm grain size.

Straighten, size, to .750" OD ± .004 x .035" minimum wall.

Eddy current test, CDA standards.

Cut to desired length.

Inspect.

Pack.

Ship.

In the case of 360' coils, the annealed coils would be crated and shipped to the site for final straightening and sizing. In this case the eddy current test would be performed during recoiling with special setup and equipment.

Carbide dies and mandrels used on all draws.

With additional processing, further modifications and refinements can be anticipated.

APPENDIX C

RECOMMENDED PRACTICE FOR EDDY CURRENT TESTING OF COPPER AND COPPER ALLOY HEAT EXCHANGER AND CONDENSER TUBES

Scope

This recommended practice describes the procedure to be followed in eddy current testing copper and copper alloy heat exchanger tubes, applicable to tubes 1/2″ to 1″ outside diameter inclusive and wall thickness 0.049″ to 0.095″ inclusive.

Ordering Information

Inquiries and orders shall specify when tubes are intended to be eddy current tested.

Description of Terms

(*a*) ***Eddy current testing.*** — Testing of tube by passing the tube lengthwise through a circular search coil unit energized with an alternating current at one or more frequencies. The resistive and inductive properties of the energized coil are modified by the tube passing through it. The extent of the modification of the coil characteristics is determined by the discontinuities, dimensions, conductivity and magnetic permeability of the tube metal and the distance between the coil and the tubular product. The changes in coil characteristics due to these variables are made by suitable amplifying devices, to actuate either an audio or video signal or both or make a recorded graph of the fluctuations in the coil characteristics. Signals caused by discontinuities on either the external or internal surface, or subsurface and totally contained within the tube wall are obtained by suitable adjustment of the testing device sensitivity.

(*b*) ***Frequency.*** — The number of complete cycles of alternating electrical current per second induced into the tubular product. For eddy current testing as described herein the frequencies selected normally are between 1 Kc and 125 Kc.

(*c*) ***Discontinuity.*** — Any change in the uniformity of the metal mass. Discontinuities that affect the electrical characteristics of the tube or may not be detrimental to the end use of the product.

(*d*) ***Sensitivity Setting.*** — The setting of the equipment control system which regulates the general discontinuity detection capacity of the unit.

(*e*) ***Calibrating Tube.*** — Tube with artificial discontinuities used for adjusting the sensitivity setting and periodic calibration to determine if the device is functioning reliably.

Requirements for the Calibrating Tube

(*a*) The tube used to adjust and calibrate the sensitivity of the testing device shall be sound and of the same alloy, temper and nominal dimensions as the lot of tubes being tested and shall be of such length as to permit the required spacing of the artificial discontinuities made on it.

(*b*) Artificial discontinuities made on the tube shall be centered as nearly as possible on one element of the tube. The selection of the type of discontinuity to be used for any testing frequency shall be solely at the discretion of the manufacturer, who may select either of the following types:

Round bottom notches on the outside of the tube.
Holes drilled radially through the tube wall.

Requirements for the Artificial Discontinuities on the Calibrating Tube

(*a*) ***Round Bottom Notches.*** — Four notches shall be made with a 1/4″ diameter No. 4 cut straight round file by stroking in a substantially straight line perpendicular to the axis of the tube. The depth of the notch shall be as shown in Table I, subject to a tolerance of plus and minus 0.0005″. Notches shall be spaced at least 18 inches apart and at least 18 inches from the end of the tube.

Table I. Notch Depth

WALL THICKNESS OF TUBE (In Inches)	Nominal Outside Diameter of Tube			
	1/2″ to 5/8″ Incl.	Over 5/8″ to 3/4″ incl.	Over 3/4″ to 7/8″ Incl.	Over 7/8″ to 1″ Incl.
	DEPTH OF NOTCH (In Inches)			
0.049	0.007	0.007	0.0075	0.0075
.058	.007	.0075	.0075	.008
.065	.0075	.0075	.008	.008
.072	.0075	.0075	.008	.0085
.083	.0075	.008	.0085	.009
.095	——	.008	.0085	.009

This recommended practice is used by the Industry as applicable to commercial material, in the absence of other specifications by the purchaser.

RECOMMENDED PRACTICE FOR EDDY CURRENT TESTING OF COPPER AND COPPER ALLOY HEAT EXCHANGER AND CONDENSER TUBES (Continued)

(*b*) *Drilled Holes.* — Four holes spaced at least 18 inches apart and at least 18 inches from the end of the tube shall be drilled radially through the tube wall, care being taken to avoid distortion of the tube while drilling. The diameter of the drilled holes shall be as shown in Table II.

Table II. Diameter of Drilled Holes

NOMINAL OUTSIDE DIAMETER OF TUBE	DIAMETER OF DRILLED HOLES
1/2″ to 3/4″ incl.	0.025″ (No. 72 drill)
Over 3/4″ to 1″ incl.	0.031″ (No. 68 drill)

Eddy Current Sensitivity Setting

(*a*) Selection of optimum frequency, coil diameter and design, phase discrimination and other circuitry, as well as speed of testing, shall be at the discretion of the tube manufacturer.

(*b*) The testing device shall be adjusted to the lowest sensitivity required to detect at least two (2) of the four (4) notches or two (2) of the four (4) drilled holes when the calibrating tube passes through the test coil at the regular production speed (feet/minute) used in testing the tubes. (See Note 1).

(*c*) When adjusting the device sensitivity or when making periodic calibration of the device it is desirable that the calibrating tube be run through the test coil with the artificial discontinuities at an angle that will avoid distortion of the discontinuities by the driving roll mechanism.

(*d*) The testing device shall be calibrated at the start of the test run and at least once every 8 hours of continuous operation, or whenever improper functioning of the testing unit is suspected.

Testing Procedure

(*a*) The lot of tubes shall be passed through the testing device adjusted to sensitivity as described Tubes with dis continuities indicated by the device shall be set aside. These tubes may at the option of the manufacturer be reprocessed and retested. (See Note 2).

(*b*) The tube may be tested in the final annealed temper or in the drawn temper prior to the final anneal, unless otherwise agreed upon by the manufacturer and the purchaser.

Note 1: Sensitivity settings are indicated by arbitrary numbers on dials on the control panel of the testing device. These numerical settings differ between devices of different makes. It is therefore not proper to translate a numerical setting on one device to that of another make. Even in devices of the same design and from the same manufacturer, sensitivity settings to detect the same defect may vary slightly from device to device. Therefore undue emphasis on the similarity of the numerical value of sensitivity settings is not justified. The sensitivity settings of the device should be those which experience indicates will result in reliable detection of undesirable material.

Note 2: This testing procedure is a valuable addition to the inspection practices in current use. However, the performance of the test unit should be reviewed from time to time by reexamination of the tubes selected as satisfactory and more particularly tubes rejected as defective to avoid unwarranted waste of good usable material.

This recommended practice is used by the Industry as applicable to commercial material, in the absence of other specifications by the purchaser.

APPENDIX B

Union Carbide Corporation
Nuclear Division

DESALINIZATION SEAMLESS TUBING COST STUDY

Subcontract No. 2914

October 6, 1967

BAVIER, BULGER & GOODYEAR
Management Consultants
NEW HAVEN, CONN. 06525

UNION CARBIDE CORPORATION, NUCLEAR DIVISION

DESALINIZATION SEAMLESS TUBING COST STUDY

Subcontract No. 2914

I. ASSIGNMENT

A. Subcontract No. 2914 dated April 3, 1967, between Union Carbide Corporation, Nuclear Division and Bavier, Bulger and Goodyear authorized study of costs to produce seamless tubing for the desalinization program.

B. Statement of Work

1. Study will provide tube prices for current and advanced production methods. Tube prices to be based on 90/10 cupro nickel 1" and .750" O.D. and .035 wall thickness. Tubes to be used in increments of 100, 150 and 360 feet.

2. Tubes must meet specifications outlined in seventh draft of "Proposed Specification for Welded and Seamless Copper Nickel Tubing for Desalinization Plants".

3. Tube prices to be based on most attractive production equipment and methods and reflect in detail processing, labor and overhead items of cost. Prices to include reasonable and proper profit margins for the industry.

   a) Detail to be presented in such a manner that changes to processing, wage rates, etc. can be reflected in the end price.

4. Results of copper nickel seamless tubing contract (Wolverine) and copper nickel welded tubing contract (Tubotron) to be evaluated and tubing prices estimated for the fabrication methods developed relative to the prices of seamless tubing. Welded tubing prices to be based on data supplied by Union Carbide.

C. Revision to Statement of Work

1. Statement of Work was expanded on May 2, 1967 as a result of meeting in Washington, D. C. on April 28th. Revisions and expansion included:

   a) Changes in lengths to 50, 100 and 360 feet.

   b) An evaluation of the effect of the proposed specification (ORNL-1) compared to ASTM B-111 with regard to costs, reliability of tube and manufacturing problems was added to the project.

I. C. 1. c) An assessment of industry capacity for furnishing tubing for large desalinization plants was also added.

d) Evaluation of outside contracts was revised from one of analysis of statistical results to one of observation at the subcontractors' facilities. Included were trials at Wolverine-Dearborn Heights, Detroit and Decatur, along with Olin-Tubotron trials.

II. GENERAL ANALYSIS

A. There is some confusion in industry regarding what is acceptable as a 90/10 cupro nickel tube for use in desalinization projects. Quality specifications as proposed are close but more liberal than Condenser Tubing ASTM B-111. Adherence to the exact letter of any specification might be a problem if both the supplier and the user don't cooperate on a practical basis. Most industry applications result in following specifications for functional design while permitting deviations from specifications providing such deviations do not affect end performance. There is some indication that industry, in general, permits deviations through practical considerations in condenser tubing yet is not certain as to the rigidness of desalinization inspection standards. This uncertainty could result in extreme variation in processing techniques and costs.

1. Problem is compounded as a result of inadequacies of inspection and testing procedures by both the producer and user through visual or electro-mechanical testing techniques.

2. Contacts with equipment manufacturers and brass mills, as a part of this study, resulted in various interpretations from "Desalinization requirements call for a high quality cupro nickel water tube" to "Desalinization requirements call for a super high quality condenser tube".

3. Additional confusion is also introduced through:

a) Interpretation that 1000 ft. straight lengths is a requirement as a "source" for desalinization tubing.

b) General industry experience producing cupro nickel tubing in large quantities. Cupro nickel requirements are usually small and are, therefore, handled as "special orders" in most mills, and as a result do not reflect the most efficient practices and manufacturing methods. This situation is typical of any industry where major equipment expenditures and management time are expended to efficiently produce large volume orders thereby minimizing investment and time for improvements covering small volume or special orders.

B. The factors detailed in the preceding paragraph affect costs and costs determine prices. It was necessary to assume certain conditions for the purpose of completing this study and these conditions are as follows.

II. B. 1. Cupro nickel tubing used in desalinization installations can tolerate some imperfections without affecting overall performance of the installation.

2. Most tubing produced today is sound and when quality problems occur processing problems result, thereby automatically highlighting substandard quality. Substandard tubes normally result in problems causing breakers or are of a nature that can be visually observed during the processing cycle.

3. Eddy-current testing (or the equivalent) can be upgraded so that those defects that neither create processing problems or are visually observable can be determined as a part of a production operation.

C. Based on the conditions detailed above, this study considers 90/10 cupro nickel similar to regular copper tubing, processed the same as copper tubing but requiring extra care at casting, additional horsepower at the various processing steps and higher annealing temperatures. Quality standards were considered similar to those covering standard water tubing except for more rigid testing as can be developed through improved application of eddy-current testing.

1. The interpretation of quality standards cannot be overstressed and specific recommendations will be covered later in this report.

D. The position taken in this report that cupro nickel tubing can be processed similar to copper is supported by:

1. Contacts with major producing companies where it was stated (in the case of two companies) that 90/10 can be reduced the same as copper requiring no anneals from casting to the finished sizes specified.

2. Actual experience of BB&G representatives in the rod and wire field where 90/10 cupro nickel processing was standardized with copper processing techniques and with the exception of yield, melting and metal costs, was costed from the same data.

a) One major producer is presently processing a "lot" of 90/10 cupro nickel using the same general practices and equipment as is used for copper tubing to determine actual cost factors.

E. In summary, 90/10 cupro nickel is a relatively easy alloy to process providing metal is soundly cast. Metal can be reduced to finishing sizes without an anneal; therefore, modern copper tubing mills can be utilized to produce tubing for the desalinization program. Running speeds may be slightly reduced due to additional horsepower requirements but this variable will not be appreciable and can be offset through equipment changes.

III. INDUSTRY CAPACITY

A. Industry seamless tubing capacity for copper and copper alloys totals approximately 1,000,000,000 pounds per year. Actual shipments for the calendar year 1964 totalled 984,000,000 pounds and for 1965, 992,000,000 pounds as per the U. S. Department of Commerce, Business and Defense Service Administration and Copper Development Association. Approximately 15% of these total shipments were in alloys with the remaining shipments in copper tubing.

B. Most of the industry capacity could be used to produce 90/10 cupro nickel tubing through the introduction of continuously cast billets and shells. This conversion does not represent a major capital expenditure and most mills will find it necessary to convert to continuous casting over the next few years to remain competitive in their normal product line.

C. A problem exists with regard to the ability of the various mills to produce 360' lengths. Production of tubes in 360' lengths requires blocks rather than benches and only part of the industry has converted to block drawing practices. At the present time the Cerro plant located in St. Louis, Missouri, the Chase plant located in Montpelier, Ohio and the Wolverine plant located in Detroit, Michigan possess the capability of producing long lengths. The combined capacities of these three mills is estimated at approximately 150-200,000,000 pounds per year which represents 15-20% of industry capacity. It should be pointed out that other mills are presently converting to block drawn practices and by 1972 the major part of the industry capacity should be capable of drawing long lengths.

   1. The three major mills listed above do not represent the total industry block drawing capacity inasmuch as other major mills are partially converted and some small mills have also converted to block drawing methods.

D. Estimated annual requirements for the desalinization program of 6,000,000 pounds within one year, 24,000,000 pounds the second year, building up to 60,000,000 pounds by 1972 do not represent a major part of industry capacity. In summary, 1972 estimated requirements represent less than 5% of normal industry shipments inasmuch as desalinization tubing can be produced at the same facilities that produce copper tubing. Only problems are the necessity to install additional continuous casting units and to install drawing blocks.

   1. These practice revisions represent normal technical and process developments in the industry and should be accomplished with or without the desalinization program.

   2. It should be pointed out that the seamless tubing industry has made great strides towards economy in recent years and the most modern mills can be utilized to produce cupro nickel tubing when large volume requirements justify the introduction of cupro nickel in these mills.

IV. COMPARISON OF SPECIFICATIONS ASTM B-111 AND ORNL-1

A. A detailed comparison of ASTM B-111 versus ORNL-1 is included in Exhibit "A" and a general analysis of variations between the two specifications is included in Exhibit "B".

B. Major specification problem is not variations between ASTM B-111 and ORNL-1 but rather coordination of inspection, testing and interpretation in the areas of voids, discontinuities, inclusions.

C. Summary Conclusions

Major variations between ASTM B-111 and ORNL-1 that would affect costs and/or reliability of tubing are as follows:

1. Revision of chemical specifications -

   ORNL-1 calls for tighter chemical analysis control than ASTM B-111 through lower lead limits as well as the addition of limits for carbon, phosphorus and sulfur. These tighter controls will either reduce the amount of scrap the producer can use or increase off-analysis percentage after casting. In either case, it is estimated that closer chemical analysis will increase costs 2 to 4 mils.

2. Temper -

   Revision to temper specifications as presented in ORNL-1 permits manufacture of hard drawn tubes without any annealing, where ASTM B-111 requires at least one anneal. The elimination of annealing will reduce costs approximately 1¢/pound but it is believed that users will require an anneal thereby eliminating the saving. For this reason, an anneal has been included in detail cost studies included in this report.

3. Revision to gauge tolerance should permit some economies through reduction in off-size tubing scrap and through reduced die and plug changes. Offsetting these cost reductions is a potential increase of material usage through greater wall thickness. It is not believed that this revision will have any effect on costs inasmuch as the producers should control gauges closely so as to effectively control material usage.

4. Revision of specified testing procedures represents a major factor of costs as well as affecting the end quality of product. ORNL-1 calls for eddy-current testing while ASTM B-111 calls for hydrostatic testing. Hydrostatic testing of short lengths costs 2¢/pound compared to ¼¢/pound for eddy-current testing at any length. Therefore, revised testing procedures represent a substantial reduction in costs. The problem connected with such a saving is that it is a generally accepted fact in the industry that eddy-current testing procedures leave much to be desired. As pointed out in the exhibits, standards must be

IV. C. 4. cont'd

developed and testing operators must be trained on proper interpretation of standards. It is not believed, under present conditions, that eddy-current testing will be 100% satisfactory for the desalinization program. On the other hand hydrostatic testing, estimated at 2¢/pound in short lengths, will be more expensive and extremely awkward when utilized for long lengths or coils. It may be that hydrostatic methods are impractical on a large volume basis. It is BB&G's recommendation (as covered later in the report) that eddy-current testing methods be improved so that long length tubes can be tested on a continuous basis as part of the normal manufacturing process.

5. Splicing welds are specified in ORNL-1 but this has been ignored in this study. Present techniques are not commercialized, therefore cost studies have been based on reduced yield through "breakers".

V. SHIPPING PRACTICES

A. Overall cost analysis highlights shipping methods as a factor that could appreciably affect costs.

1. Methods, for the purposes of this cost study, were based on the following:

a) 50' and 100' lengths to be shipped in straight lengths, bundled and cradled, on 100' flat cars.

(1) Flat cars of 90' lengths have been observed by BB&G personnel and it is alleged that 100' cars are available.

b) 360' lengths to be shipped as level wound coils on cores in increments of 360' lengths. On site, special purpose equipment would be necessary to straighten and cut to length.

(1) Coil length would be determined by cast or extruded shell weight. The more progressive mills are now capable of producing 580 to 1600 pound coils.

(a) A 1200 pound level wound coil would contain eight 360' lengths when cut to length on site.

(2) Level wound coils on cores would provide a more dense shipping package, simplify handling at the fabrication site, in transit and in the field. Damage would be at a minimum and special handling equipment unnecessary. Long length coils in the field would offer the same economies as in the tube mill when compared to short or straight lengths.

V. A. 1. b) (2) (a) Some producers object to level winding as against loose coils produced on blocks and crated inasmuch as level winding equipment requires a substantial investment.

(3) An alternate approach is to ship long lengths as straight tube. One major supplier has successfully shipped 200' tubes by the use of three flat cars. This practice does not appear practical as:

(a) Method necessitates special loading equipment at the tube fabrication site.

(b) Tubes are awkward to handle.

(c) Method may require special routing over the rails.

(d) Method substantially increases exposure to damage.

VI. COST STUDIES

A. Cost studies have been completed based on three methods to manufacture .750" and 1.000" x .035 wall cupro nickel tubing.

1. The first method is based on continuously casting 3½" shells, tube reduced to 2.00" O.D. x .100 wall and then drawn on blocks to finished size. Coils are annealed at finished size and then either straightened and cut or level wound. Testing is performed as part of the straight and cut or level wind operation.

2. The second method is based on DC casting of billets which are cut to length and then extruded to shells 2" O.D. x .100 wall. Extruded shells are then block drawn to finished size, annealed and either straightened and cut or level wound as detailed above.

3. The third method is based on continuously casting small diameter shells (1.500 or 1" O.D. x .250 wall) and then reducing by a special small size reducer and subsequently drawing on blocks similar to the two methods covered above.

4. The first two methods detailed above are commercial manufacturing methods that approximate practices in effect for copper tubing today. The third method has not been commercialized but development trials are in progress and the method should become "commercial" within the next few years.

a) The third method has been included as an important factor in this study inasmuch as it minimizes investment thereby allowing new producers into the field with the normal resultant competition in pricing. The overall approach of continuously casting small diameter cross-sections has been successful in the production of rod but the operation after casting is one

VI. A. 4. a) cont'd

of rolling where high density (solid mass) is combined with rolling speeds of 300-600'/minute. In the case of tubing, the second operation is tube reducing which combines a hollow shape with slow speeds, therefore negating the major advantage gained in the case of rod. It is believed that equipment will be developed in the near future to permit comparatively high speed reducing of the small cross-sections thereby gaining the same substantial advantage in cost as has been gained for rod.

B. Detailed cost studies have been based on the following:

1. Contacts with equipment producers and tube manufacturers. Included were furnace, continuous casting, tube reducing, block drawing and extrusion manufacturers as well as small and major tube producers. Visitations were made to facilities of both equipment and tube manufacturers.

2. The fabrication of completely new facilities to produce cupro nickel tubing by the various methods. $14.00 a square foot construction cost was used to cover both land and buildings.

   a) The assumption that cupro nickel tubing would be produced in new facilities substantially increases investment requirements but reflects offsetting economies through improved methods and equipment.

3. The inclusion of an anneal at the finish sizes although present specifications permit the elimination of this anneal.

4. Processing of a maximum length coil consistent with process limitations. All coils to be processed in the maximum length and then cut to specified length at finished size to meet specific order requirements.

   a) Major economies have been made in both the tube and wire industries in recent years through maximizing coil lengths. This principle has been followed in all three cost studies.

5. In-process scrap losses as follows:

   a) Casting losses of 10% except in the case of small diameter continuously cast tubes where losses were estimated at 5%.

   b) Extrusion losses of 20% consisting of butt loss of 10%, shell loss of 7% and plug loss of 3%. "Breaker" loss of 3% for 50' lengths, 5% for 100' lengths and 10% for 360' lengths.

      (1) One major mill estimates their "breaker" loss for copper tubing to be 1% for 100' or less lengths and 3% for long lengths. Breaker losses have been estimated high so that end figures will be conservative.

VI. B. 5. b) (2) The development of commercial splice welding equipment can substantially reduce "breaker" loss thereby reducing overall costs through improved yields.

c) Overall quality rejection rate of 5% due to defects and discontinuities.

6. Liberal variance performance of 20% on all direct labor operations.

7. Plant capacity based on two shift operation in the tube mill with balanced production based on the process in the casting operation.

a) Capacities have been reduced by yield allowances plus an additional 10 to 20% for labor variance.

b) In actual practice, capacities would be greater than indicated through improved performance (labor variance) and intelligent use of overtime and third shift operations.

8. Hourly rates, manning and administrative costs are consistent with industry practices.

9. Return on investment after federal taxes of 10%. Reference to the cost study detail will highlight the fact that the allowance for federal taxes and profits represents a substantial part of total conversion selling price. These estimates are based on a 10% return on investment after federal taxes which is a considerably fair rate of return.

a) These profits have also been calculated against gross sales and reflect a profit range of 5.6-6.6% which indicates satisfactory performance by general industry standards.

VII. <u>CONTINUOUSLY CAST SHELLS 3½" x .350 WALL - COST STUDY</u>

A. Details are included in Exhibit "C".

1. Capacity and conversion selling price are summarized on page 1, broken down by casting, tube mill, selling and administration, freight, federal tax and profit factors by 50, 100 and 360' lengths.

2. Monthly operating costs covering casting are summarized on page 2 and are supported by equipment requirements, investment and other pertinent data on page 3.

3. Monthly operating costs for tube reducing and block drawing are detailed on page 4 which is supported by equipment requirements, investment and practices on pages 5 and 6.

4. Selling and administrative costs are summarized on page 7.

VII. B. The overall manufacturing method is based on continuously casting shells 3½" O.D. x .350 wall which are reduced by a tube reducer to 2" x .100 wall. 2" shells are then broken down in coils to finish size, annealed and level wound as part of the eddy-current testing.

1. Drawing practices specified include one extra draw above equipment manufacturers' recommendation and running speeds are conservative.

2. Crew sizes are also conservative inasmuch as some mills are currently planning to reduce block drawing crews from either 2 or 2½ men to 1 or 1½ men.

C. No specific detail has been provided covering difference in cost for processing coils through a straight and cut machine as against level winding. Both pieces of equipment would be fed with maximum length coils. Eddy-current testing is the limiting factor regarding productivity inasmuch as it is eddy-current testing that limits running speeds of 250' a minute. Either method requires one operator in attendance at the take-off end of the machine plus supporting personnel to feed coils to payoff. Both methods require approximately $90,000 investment per unit; therefore, either method will result in approximately the same operating and investment cost.

D. Conclusions:

1. Conversion selling price (excluding metal) for 1" x .035 wall 90/10 cupro nickel tubing produced by continuously casting shells with subsequent tube reducing and block drawing is estimated at $.1872/lb. for 50' lengths, $.1907/lb. for 100' lengths and $.1997/lb. for 360' lengths.

2. Conversion selling price for .750" x .035 wall for the same lengths is estimated at $.1892, $.1927 and $.2018 per pound.

3. Variations in conversion selling price for a specific size result from different yields due to "breakers" plus different handling costs for straight lengths at shipping. Level wound coils can be easily handled by a fork truck using minimum manpower and space. Straight lengths require special handling equipment and an increased crew due to the nature of the operation. The increased crew also requires extra supervision.

4. A mill designed to produce tubing by this method would be capable of producing approximately 2,750,000 pounds a month and would necessitate an investment of approximately $11,500,000.

5. Mills are in existence at the present time using practices close to those recommended but these mills are producing copper rather than cupro nickel.

VIII. CAST BILLETS AND EXTRUDED SHELLS 2" x .100 WALL - COST STUDY

A. Details are included in Exhibit "D".

1. Capacity and conversion selling price are summarized on page 1, broken down by casting, extrusion, tube mill, selling and administration, freight, federal tax and profit factors by 50, 100 and 360' lengths.

2. Monthly operating costs covering casting are summarized on page 2 and extrusion on page 3, and are supported by equipment requirements, investment and other pertinent data on page 4.

3. Monthly operating costs and block drawing are detailed on page 5 which is supported by equipment requirements, investment and practices on pages 6 and 7.

4. Selling and administrative costs are summarized on page 8.

B. The overall manufacturing methods are based on DC casting of billets which are sawed to length and then extruded into 2" x .100 wall shells. 2" Shells have been broken down into coils of finished size and level wound.

C. Conclusions:

1. Conversion selling price, excluding metal, for 1" x .035 wall 90/10 cupro nickel produced by this method is estimated at $.1910 for 50' lengths, $.1955 for 100' lengths and $.2038 for 360' lengths.

2. Conversion selling price for .750" x .035 wall for the same lengths is estimated at $.1927, $.1972 and $.2063.

3. A mill designed to produce tubing by this method would be capable of producing approximately 5,000,000 pounds per month and would necessitate an investment of approximately $21,000,000.

   a) Conversion selling prices through this method are approximately the same as continuously casting 3½" shells but the investment is twice as large.

4. There is a mill in existence at the present time using practices close to those recommended but this mill is producing copper rather than cupro nickel.

IX. CONTINUOUSLY CAST SHELLS 1.00/1.25" O.D. x .250 WALL - COST STUDY

A. Details are in Exhibit "E".

1. Capacity and conversion selling price are summarized on page 1, broken down by casting, tube mill, selling and administration, freight, federal tax and profit factors by 50, 100 and 360' lengths.

IX. A. 2. Monthly operating costs covering casting are summarized on page 2 and are supported by equipment requirements, investment and other pertinent data on page 3.

3. Monthly operating costs for tube reducing and block drawing are detailed on page 4 which is supported by equipment requirements, investment and practices on pages 5 and 6.

4. Selling and administrative costs are summarized on page 7.

B. The overall manufacturing method is based on continuously casting shells 1 or 1¼" x .250 wall which are then reduced in one pass to either 1.05" x .045 wall or .810" x .042 wall (based on finished size) and then drawn to finish size. Annealing and level winding are the same as other methods.

C. Conclusions:

1. Conversion selling price, excluding metal, for 1" x .035 wall 90/10 cupro nickel tubing produced by this method is estimated at $.2038 for 50' lengths, $.2079 for 100' lengths and $.2178 for 360' lengths.

2. Conversion selling price for .750" x .035 wall for the same lengths is estimated at $.2641, $.2697 and $.2830.

3. A mill designed to produce tubing by this method would be capable of producing approximately 1,250,000 pounds per month and would necessitate an investment of approximately $6,500,000.

4. There is no mill in existence at the present time using these practices but considerable development work is in process.

X. OVERALL CONCLUSIONS

A. Selling price detail shows the two commercial processes to be competitive with estimated conversion selling prices of $.19 to $.21 a pound. Major difference between the two methods is the investment required to fully utilize efficiencies of equipment. The continuously cast and tube reducer method would require $11,500,000 as against $21,000,000 for cast and extrude.

1. The tube reducing method also provides a second advantage over the casting/extrude method inasmuch as length of coils are only limited by the length of the runout table after the reduction operation. This advantage might provide substantial economies at the fabrication site through the use of large level wound coils.

B. The experimental process-namely, continuously casting small diameter shells is competitive at the 1" size but is not competitive at the 3/4" size where conversion selling prices are over $.28/pound. These costs can be substantially reduced through increased running speeds

X. B. cont'd

at both the casting and reducing operation. This method has the advantage that the total investment is $6,500,000 and through improved running speeds can be reduced to under $5,000,000. The reduced investment enables a greater number of concerns to produce tubing thereby increasing competition. Increased competition, of course, will lead to improved methods and reduced prices.

1. It should be pointed out that estimated investments are based on "starting from scratch" and producers currently in the business can convert manufacturing methods at a substantially lower cost.

C. Selling price and cost analysis, detailed in this report, conflicts with general price structure experienced by OSW to date. For example, 3/4" x .035 wall 90/10 cupro nickel is estimated at $.19-$.21/pound for conversion selling price. The actual bids as of September 15, 1966 (Invitation No. OSW 1150) showed five companies bidding on the same size tubing with conversion selling prices varying from a minimum of $.44 to a maximum of $.78/pound. Details are in Exhibit "F". This extreme variation necessitates a review of estimated costs and selling prices to determine overall accuracy.

1. Estimated cost and selling price data included in this report is accurate while conservative in the areas of practices, direct and indirect labor, investment and yields. Manning has been determined on a liberal basis and equipment costs based on the best equipment available today.

2. There is a possibility that costs may be greater than estimated in the areas of departmental variable overhead costs such as supplies and maintenance. Some of these costs were difficult to secure and necessitated estimates. The major point to consider is that a substantial increase in these costs will not appreciably affect the end answer.

3. An alternate method of checking the accuracy of the figures is to compare conversion values determined in this report with conversion values of copper water tubing. Exhibit "G" details water tube conversion selling price based on a recent price list. It shows that the price per foot listed for 3/4" O.D. x .036 wall water tube is $.2595. List prices are discounted based on market conditions and order volume. Discounts vary from time to time and from customer to customer but investigation determined that this same product has sold for $.2017 a foot after discounts. Converting this price (after 2% discount for payment in ten days) from a foot factor to a pound factor after excluding metal shows a selling price of $.2725/pound. Conversations with people in the field have indicated that the same product has sold for $.1450 over metal during extremely competitive periods. Comparison of these two prices with the "study prices" indicates accuracy of analysis.

X. D. Variation in excess of $.20/pound might indicate either inefficient operation or poor pricing upon the part of the producers. This is not necessarily the case for the following reasons:

1. Only the more modern mills are operating close to practices outlined in this report and those using modern facilities are producing copper and not cupro nickel.

2. Estimated costs are based on volume operation and experience which, to date, have not been the case.

3. Estimated costs are based on achievement of satisfactory quality performance through normal metal manufacturing processes.

E. It should be pointed out that efficient production of seamless tubing appears to be more economical than the welded strip method of fabrication. This conclusion will be finalized after trials are conducted at Tubotron on completion of development contract.

XI. RECOMMENDATIONS

A. Cost analysis conclusion drawn in this report is that cupro nickel tubing can be sold substantially below present price schedule while reducing costs to end user and earning profits for the producer. It also indicates economies secured can insure a large market for the tube industry. Major problem of achieving these economies is to convince the industry that the market is of sufficient size to justify production of cupro nickel tubing through modern facilities and that such tubing will be of satisfactory quality to insure both minimum costs and satisfactory profits.

B. Specific Recommendations

1. A program be established to determine definite quality levels of 90/10 cupro nickel tubing to be used for desalinization programs and that these quality levels be practical and easily understood. This would require a definition of what flaws could be tolerated as well as the development of testing procedures to economically insure adherence to these standards.

2. Industry be given a development contract to produce cupro nickel tubing through regular copper water tubing production lines utilizing standards determined in (1) above. Successful production of cupro nickel tubing through such facilities would gradually lead to price reductions as experience is gained.

XII. DEVELOPMENT TRIALS

A. BB&G has observed both titanium and cupro nickel trials at the Solverine plants of Dearborn Heights, Detroit and Decatur.

1. Titanium

Base material costs for titanium sponge combined with costly

XII. A. 1. cont'd

manufacturing processes clearly indicate that economic justification for the use of titanium tubes in the desalinization program must be based on reduced metal usage through lighter gauge tubes. Coiling trials at Wolverine indicated problems connected with the scratching and collapsing of titanium tubes when coiled in either .018" or .014" wall thickness. While these problems may be overcome through equipment development, the Wolverine trials clearly highlighted the danger signal with regard to the planned use of light wall titanium.

2. Cupro Nickel

Cupro nickel trials highlighted no specific problems other than that the producer was conducting trials off-line while cupro nickel tubes could have been produced through the regular manufacturing process providing schedules permitted. The major value of cupro nickel trials was in the area of securing producer's interest in the program. BB&G's contact with the industry has indicated a high degree of complacency or disinterest concerning the desalinization program. An alternate approach to securing interest might be direct contact with top personnel in the producers' field highlighting requirements, sales level and potential profits. Once interest is achieved, the producers can proceed without any additional assistance.

3. Recent trials conducted by Yorkshire Metals, located in England and summarized by Mr. P. T. Gilbert on December 8, 1966, indicate that .024" wall cupro nickel can be substituted for the .035" wall presently specified. Experiments indicate .024" wall to be satisfactory with regard to dent and corrosion resistance based on corrosion rate over the projected life of tubing. Economies through substitution of .024" wall tube can be substantial when one considers a gain of 50% in length when compared to .035 wall. Analysis of processing shows one extra draw would be required for .024" wall over those draws required for .035" wall.

4. Suggested Future Development Program

Initiate action to conduct trials using .024, .022, .020 and .018 wall tubing.

Exhibit "A"

COMPARISON - ASTM B-111 VS. ORNL-1

PERTINENT ITEMS ONLY

B-111	ORNL-1
Seamless tubes of copper and various alloys up to 2" incl.	Seamless and welded copper-nickel tubes: 90/10 and 70/30 copper nickels in O.D.'s of 5/8" to 1¼"; in .035", .042", .049" wall thicknesses and lengths up to 350 feet.

Manufacture

Material should be of such quality and purity that the finished product shall have properties and characteristics prescribed in this specification and shall be cold worked to the specified size.	a) Seamless tube made by any method. b) Welded tube shall be made from flat-rolled products by automatic welding process with no addition of filler metal in the welding operation. The finished tube shall be in the as-welded condition and shall meet the requirements of seamless tube in this specification.

Temper

70/30 Cupro-nickel supplied either as annealed or drawn, stress relived. 90/10 may be supplied in either light drawn or annealed temper. Tubes supplied in light drawn temper shall pass the expanding test.	70/30 Cupro Nickel - Tensile Strength 65,000 psi min. 90/10 Cupro Nickel - Tensile Strength 50,000 psi min.

Chemical Composition

B-111		ORNL-1
86.5 min.	Copper	86.5 min.
9.0-11.0	Nickel	9.0-11.0
0.05	Lead	0.02
1.0 to 1.8	Iron	1.0 to 1.8
1.0 max.	Zinc	1.0 max.
1.0 max.	Manganese	1.0 max.
	Carbon	0.05 max.
	Phosphorus	0.02 max.
	Sulfur	0.02 max.

Flattening Tests

B-111

Test tubes in the annealed condition shall be flattened on different elements throughout the lengths remaining after specimens for the expanding and metallographic tests have been taken. Each element shall be slowly flattened by one stroke of a press. A micrometer caliper set at 3X wall thickness shall pass over the tube freely throughout the flattened part except at the points where a change in element of flattening takes place. The flattened elements shall not show cracking or rupture clearly visible to the unaided eye.

ORNL-1

Annealed tube specimens 12" in length shall be flattened on different elements throughout the length. Each element shall be slowly flattened by one stroke of a press. A micrometer caliper set at 3X wall thickness shall pass over the tube freely throughout the flattened part except at the points where the change in element of flattening takes place. The flattened elements shall not show cracking or rupture clearly visible to the unaided eye.

Hydrostatic Test

Each tube shall stand without showing weakness or defects an internal hydrostatic pressure sufficient to subject the material to a fiber stress of 7000 p.s.i.

Expansion Test

Tubes selected for test shall be capable of withstanding the following expansion of its inside diameter at one end by driving a pin having a taper of 1½"/ft. into the tube. The expanded tube shall show no cracking or rupture visible to the unaided eye.

Annealed	70/30	30%	Expansion of tube to original inside diameter
	90/10	30%	
Light Drawn	90/10	30%	
Hard Drawn, and annealed	70/30	20%	

One end of each tube specimen shall withstand, with no visible cracking or rupture, having a pin with a taper of 1½"/foot driven into it until the following expansion of the I.D. has been achieved:

70/30 Cupro nickel 10%

90/10 Cupro nickel 10%

Length

The length of the tubes shall not be less than that specified when measured at a temperature of 20°C but may exceed the specified value by the amount as follows:

50 ft.	1/4"
100 ft.	3/8"

(Nothing specified over 100 ft.)

At room temperature, the finished tube shall not be less than the specified length; the Purchaser shall include an allowance for installation. Both ends of the straight tube may be supplied as cut.

Outside Diameter

B-111

The O.D.of the tubes shall not vary from the following amounts by more than the following amounts as measured by "Go" and "No-Go" ring gauges:

0.500 and under	±.002"
over 0.500 to 0.740 incl.	±.0025"
over 0.740 to 1.000 incl.	±.003"
over 1.000 to 1.250 incl.	±.0035"

For copper-nickel tubes the tolerances in each size class shall be 0.0005" larger than the above tolerances.

ORNL-1

The O.D. of the tubes shall not vary from that specified by more than the following amounts as measured at both ends of the tube and at 25% and 75% of the length.

O.D.	Variation
5/8" - 1" inclusive	± .004"
Over 1"-1¼" incl.	± .005"

For tubes supplied in coils, the above tolerances shall apply to the finished straightened tubes.

Wall Thickness

No tube at its thinnest point shall be less than the thickness specified.

Squareness of Cuts

The angle of cut of the end of any tube may depart from the square of any tube by not more than the following:

Tube O.D.

Over 5/8" 0.016" per inch of dia.

(omitted)

Tensile Requirements

B-111

	T.S., min.	Y.S. min.	El. in 2" min.
70/30 annealed	52,000	18,000	
70/30 drawn, stess relieved	72,000	50,000	12% (up to .048" wall)
90/10 annealed	40,000	15,000	

ORNL-1

70/30 annealed	65,000 min.
90/10 annealed	50,000 min.

Exhibit "B"

COMPARISON OF SPECIFICATION
ORNL-1 VS. ASTM B-111

GENERAL

Scope

B-111 does cover a wider range as to O.D.'s going up to 2" diameter. ORNL-1 specifically indicates lengths up to 350 feet where B-111 does not limit lengths but does state normal condenser tube requirements do not exceed 100 feet; therefore no standards have been established.

Manufacture

B-111 and ORNL-1 are identical for seamless tubes. ORNL-1 expanded its scope by including welded tubes. There is a restriction on a limited scale to the methods of producing tube by the exclusion of filler material; however, this would not be unduly restrictive as this is the usual manner of fabricating thin wall tubing.

Temper

B-111 specifically states the temper requirements for annealed and drawn material. To meet these tempers it would be necessary to anneal either at finish or at some other intermediate point. The ORNL-1 specification, as written, can be construed by the producer to mean any temper can be supplied if it meets the minimum tensile strength values. This would eliminate the single anneal required and would result in a cost savings. However, the acceptance of tubing in this hard of a temper is questionable as illustrated by the objections from the fabricator concerning hard drawn tubing produced for the west coast prototype.

Chemical Composition

The ORNL-1 specifies lower lead limits as well as including limits for carbon, phosphorus and sulfur. These values could tend to increase the production costs. It is general practice to use scrap metal to its limit to reduce costs. By limiting the lead, it will limit the percentage of scrap that can be used or result in remelting resulting from off-analysis.

Hydrostatic Test

This is not specified in ORNL. ORNL covers the use of eddy-current or some other similar method for the detection of flaws and defects. The requirement for eddy-current testing in place of hydrostatic testing will result in a reduction in cost. Eddy current testing can be integrated into another operation such as straightening and cutting to length. Hydrostatic testing is a separate operation requiring extra handling.

Through reviewing comments of the user group, it should be noted that a number require a hydrostatic test and do not accept eddy-current testing as a substitute. The matter of testing for defects is a controversial subject, inasmuch as eddy-current testing is dependent upon the establishment of standards that are meaningful and correct operator adjustment according to these standards.

Expansion Tests

The ORNL specification has reduced the percent deformation from 30% to 10%. This could reduce cost in that it would reduce the amount of rejections if this is a problem. We would not expect this to be a problem unless the processing was such that excessive cold work was imparted to the tubes and not annealed at finish. If the temper requirements are left as in the ORNL specification, it would be our recommendation that the expansion tests be changed to conform to B-111 as an additional safeguard as to temper.

Length

The lesser restrictions of the ORNL will assist the producer in that less care as to length measurement would be required. As we are recommending coiled stock, this becomes less of a problem.

Outside Diameters

The wider tolerances of the ORNL specification should result in a potential cost savings. The wider tolerances would enable the producer to minimize his internal rejection rates and also allow him to reduce tool changes because of this parameter; however, the users were most consistent in their objection to this lessening of this particular dimension. This we assume to be a result of anticipated assembly problem on-site. It is our opinion that eventually this specific tolerance will have to be altered to meet the end user's requirements.

It should also be pointed out that producers will probably conform to ASTM B-111 specification internally so as to control material usage.

Squareness of Cuts

The ORNL specification does not specify this as a requirement. We feel that its omission does tend to reduce the cost but not appreciably. As we are recommending long coils to be cut on the site, this particular aspect is satisfactory as is.

Exhibit "C"

COST & SELLING PRICE SUMMARY

CONTINUOUSLY CAST SHELLS 3½" x .350" WALL

A. CAPACITY-NET POUNDS

Cast Capacity	3,224,448#/Month
Tube Mill Capacity	3,970,440#/ "
Tube Mill Capacity Adjustment for 20% Labor Variance	3,308,687#/ "
USE	3,250,000#

Net Pounds Produced:

50' Lengths @ 92% Yield	2,990,000#
100' " @ 90% "	2,925,000#
360' Coils @ 85% "	2,762,500#

B. COST & SELLING PRICE

	50' Lengths		100' Lengths		360' Lengths	
1.00" x .035 Wall	Cost/Mo.	Cost/Net #	Cost/Mo.	Cost/Net #	Cost/Mo.	Cost/Net #
Cast	$67,290	$.0225	67,290	$.0230	67,290	$.0244
Tube Mill	164,825	.0551	164,825	.0564	161,293	.0584
S & A	91,550	.0310	91,550	.0313	91,550	.0331
Freight	44,850	.0150	43,875	.0150	41,438	.0150
Fed. Tax	95,000	.0318	95,000	.0325	95,000	.0344
Profit	95,000	.0318	95,000	.0325	95,000	.0344
Selling Price/#		$.1872		$.1907		$.1997
.75" x .035 Wall						
Cast	67,290	.0225	67,290	.0230	67,290	.0244
Tube Mill	170,696	.0571	170,696	.0584	167,165	.0605
S & A	91,550	.0310	91,550	.0313	91,550	.0331
Freight	44,850	.0150	43,875	.0150	41,438	.0150
Fed. Tax	95,000	.0318	95,000	.0325	95,000	.0344
Profit	95,000	.0318	95,000	.0325	95,000	.0344
Selling Price/#		$.1892		$.1927		$.2018

Investment: $8,358,900 in Buildings, Land & Equipment plus an additional $3,000,000 for working capital.

CASTING COSTS

CONTINUOUS CAST SHELLS 3½" x .350

MONTHLY OPERATING COSTS

	Cost/Month
Direct Labor	
$2.604/M pounds x 3,224,448 #	$ 8,400
Overhead	
Direct Labor Variance	1,680
Casting Shop General Foreman	1,250
Casting Shop Shift Foremen (3)	2,550
Indirect Labor:	
3 Scrap Handlers @ 3.00/hr.	1,440
4 Technicians @ 3.50	2,240
3 Fork Truck Drivers @ 2.75	1,320
3 Sweepers @ 2.50	1,200
3 Utility Men @ 3.50	1,680
3 Maintenance Men @ 4.00/hr.	1,920
Casting Shop Supplies $3.89/1000#	12,543
Maintenance Supplies	3,000
Depreciation	6,773
Taxes	1,250
Insurance	500
Gas .079/gal. - 19 gal./hr. or .93/1000 #'s	3,165
Water - 34,000 gal./day per unit .06/1000 #'s	204
Electricity - .012/KWH #1.37/1000 #'s	4,663
Scrap & Shrinkage - est.	5,000
Fringe Benefits-27.5% of Payroll ($23,680)	6,512
	$67,290

Depreciation

Building - $280,000 - 24 yrs. or $972/month
Equipment - $835,400 - 12 yrs. or 5801/ "

Total 6773/month

Note: Costs based on 20 day month - Actual capacity based on 21 day month would be approximately 3,400,000 pounds.

CASTING COSTS

CONTINUOUS CAST SHELLS 3½" x .350

A. EQUIPMENT REQUIREMENTS

1. Five 200 KW Hydraulic T.H. Furnaces - 1800 #/Hr.

2. Five Two Strand Casting Unit - 1600#/Hr.
   3½ x .350 - 13.4#/foot
   Casting Rate - 12" minute per strand

3. Each unit produces 38,400# per 24 hour day; therefore 5 units will produce 192,000#/day which will support two shifts @ the tube reducer or an approximate 3,000,000 pounds per month.

B. INVESTMENT - BUILDING & EQUIPMENT

Building (20,000 sq. ft.)	$ 280,000
Ajax Magnathermic Furnace (5)	174,000
Continuous Casting Units (5)	350,000
Spare Parts (Shells, Inductors, etc.)	35,000
Scrap Processing Equipment	45,000
Service Equip. (Pumps, Compressors, Air Ram)	25,000
Handling Equipment	35,000
Test Equipment	70,000
	1,014,000
10% Contingencies	101,400
	$1,115,400

C. DIRECT LABOR COSTS - (per 20 Day Month)

Gross Pounds Produced	3,840,000
Yield 90% - Net Pounds	3,456,000
Net after Setup Loss-4.0 Hrs/60 producing hrs. 6.7%	3,224,448
Manning - 5 men/shift - 20 days	2,400 hrs.
Pounds per man hour	1,344
Hours per 1000 pounds	.744
Direct Labor Cost/M# @ $3.50/hr.	2.604
" " " /pound	.00260

D. SUPPLIES

Item	Est. Life	Unit Cost	Cost/60 hrs. 96,000#	Cost/1000#'s
Graphite Dies	60 hrs./die	$ 76.00	$152.00	1.583
Crucible	300 hrs.	290.00	58.00	.604
Seal	60 hrs./die	16.00	16.00	.167
Thermocouple	120 hrs.	6.42	3.21	.033
Protection Tube	240 hrs.	16.46	4.11	.043
Holding Furnace	24 mos.	2500.00	12.50	.130
Melting Furnace Lining	1000 hrs.	1500.00	90.00	.938
				$3.498
		Adjusted for 90% Yield -		$3.89

TUBE REDUCING & BLOCK DRAWING

CONTINUOUSLY CAST SHELLS - 3½" x .350 WALL

MONTHLY OPERATING COSTS

	1.0" x .035		.750 x .035	
	Coils	Str. Lgth	Coils	Str. Lgth
Direct Labor	$17,218	$17,218	$20,761	$20,761
Overhead				
Setup Labor	1,722	1,722	2,076	2,076
Direct Labor Variance	3,444	3,444	4,152	4,152
Tube Reducing Foremen (2)	1,700	1,700	1,700	1,700
Block Drawing " (2)	1,700	1,700	1,700	1,700
Level Wind " (2)	1,700	1,700	1,700	1,700
General " (2)	2,500	2,500	2,500	1,700
Shipping Foreman (1 or 2)	850	1,700	850	1,700
Indirect Labor:				
Grinding - 6 @ 3.50	3,360	3,360	3,360	3,360
QC - 4 @ 3.00	1,920	1,920	1,920	1,920
Maint. -10 @ 3.50	5,600	5,600	5,600	5,600
Shipping4-to 8 @ 3.00	1,920	3,840	1,920	3,840
Mat'l Handling 6 @ 3.00	2,880	2,880	2,880	2,880
Sweepers - 3 @ 2.50	1,200	1,200	1,200	1,200
Clerks - 4 @ 2.00	2,400	2,400	2,400	2,400
Anneal Oper. 4 @ 3.00	1,920	1,920	1,920	1,920
Operating Supplies	7,500	7,500	7,500	7,500
Maintenance Supplies	3,500	3,500	3,500	3,500
Depreciation	43,000	43,000	43,000	43,000
Taxes	8,000	8,000	8,000	8.000
Insurance	3,250	3,250	3,250	3,250
Electricity	7,000	7,000	7,000	7,000
Water	1,200	1,200	1,200	1,200
Gas	3,000	3,000	3,000	3,000
Fuel Oil	3,500	3,500	3,500	3,500
Packing Supplies	15,000	15,000	15,000	15,000
Fringe Benefits (27.5%)	14,309	15,071	15,576	16,337
Totals	$161,293	$164,825	$167,165	$170,696

Depreciation:

Building - $2,100,000 @ 24 years - 7,300/month
Equipment- $5,143,500 @ 12 years - 35,700/ "

$43,000

TUBE REDUCING & BLOCK DRAWING

COSTS

CONTINUOUSLY CAST SHELLS 3½" x .350 WALL

		Gross Pounds/Shift
A. EQUIPMENT REQUIREMENTS		
1.	One three strand tube reducer	99,360
2.	Five 84" Draw Blocks 3/4" Tube	111,000
	Four " " " 1.0" "	108,000
3.	One Continuous Annealing Furnace 12,500#/Hr.	100,000
4.	Four Level Winder-Eddy-current Testers 3/4"	111,120
	Two " " " " " 1.0"	106,560

B. INVESTMENT (Based on 3/4" Requirements)

Building (150,000 sq. feet)	$2,100,000
Three Strand Tube Reducer	1,000,000
Five 84" Blocks - Conv. etc.	1,750,000
One Furnace	550,000
Four Level Winders	360,000
Grinding & Support Equipment	250,000
Handling Conveyor	425,000
Fork Truck-Misc. Support	150,000
	$6,585,000
10% Contingencies	658,500
	$7,243,500

C. MONTHLY CAPACITY & DIRECT LABOR COSTS

1. Gross pounds produced/month (20 days) - two shifts - 3,970,440

2. Direct Labor Costs (based on $3.50/hr.)

1.0 x .035	$17,218
.075x .035	$20,761

REDUCTION PRACTICE

CAST 3½" SHELLS - 3½" x .350 WALL - REDUCE - BLOCK DRAW

1.00 x .035

Operation	Unit Wgt	Machine	Size Start	Size Finish	% Red.	Strip Pkge	Strip Lgth	Running Speed (min.)	Minutes/Tube Run	Minutes/Tube Hdle	Minutes/Tube Tot.	St.	Adj. Min/ Tube	SH/ 100 Tube	Cr. Sze	Tot. SH/ Tube
Reduce-3 Stands	600#	Tube Reducer	3½ x .035	2.00 x .100	83%	S.L.	258'	34.5'	7.55	-0-	7.55	3	2.52	4.83	2.0	9.66
Draw	600	84" Block	2.00x .100	1.72 x .084	27%	Coils	358'	400'	.90	.90	1.80	1	1.80	3.45	2.5	8.63
Draw	600	84" Block	1.72x .084	1.47 x .067	32%	Coils	528'	500'	1.06	.70	1.76	1	1.76	3.37	2.5	8.43
Draw	600	84" Block	1.47x .067	1.26 x .054	31%	Coils	760'	750'	1.01	.70	1.71	1	1.71	3.28	2.5	8.20
Draw	600	84" Block	1.26x .054	1.05 x .045	31%	Coils	1130'	1000'	1.13	.70	1.83	1	1.83	3.51	2.5	8.78
Draw	600	84" Block	1.05x .045	1.00 x .035	25%	Coils	1450'	1250'	1.16	1.00	2.16	1	2.16	4.14	2.5	10.35
Eddy C. Test/Wind	600	Level Winder		1.00 x .035		Coils -Core	1450'	250'	5.80	1.25	7.05	1	7.05	13.51	1.5	20.27
														36.09		74.32

or .001239/#

3/4" x .035

Operation	Unit Wgt	Machine	Size Start	Size Finish	% Red.	Strip Pkge	Strip Lgth	Running Speed (min.)	Minutes/Tube Run	Minutes/Tube Hdle	Minutes/Tube Tot.	St.	Adj. Min/ Tube	SH/ 100 Tube	Cr. Sze	Tot. SH/ Tube
Reduce-3 Stands	600#	Tube Reducer	3½ x .035	2.00 x .100	83%	S.L.	258'	34.5'	7.55	-0-	7.55	3	2.52	4.83	2.0	9.66
Draw	600	84" Block	2.00x .100	1.720 x .084	27%	Coils	358'	400'	.90	.90	1.80	1	1.80	3.45	2.5	8.63
Draw	600	84" Block	1.72 x.084	1.470 x .067	32%	Coils	528'	500'	1.06	.70	1.76	1	1.76	3.37	2.5	8.43
Draw	600	84" Block	1.47x .067	1.260 x .054	31%	Coils	760'	750'	1.01	.70	1.71	1	1.71	3.28	2.5	8.20
Draw	600	84" Block	1.26x .054	1.020 x .047	31%	Coils	1090'	1000'	1.09	.70	1.79	1	1.79	3.43	2.5	8.58
Draw	600	84" Block	1.02x .047	.810 x .042	30%	Coils	1535'	1250'	1.23	.70	1.93	1	1.93	3.70	2.5	9.25
Draw	600	84" Block	.81x .042	.750 x .035	23%	Coils	1940'	1500'	1.29	1.00	2.29	1	2.29	4.39	2.5	10.98
Eddy C. Test/Wind	600	Level Winder		.750 x .035		Coils -Core	1940'	250'	7.76	1.25	9.01	1	9.01	17.27	1.3	25.91
														43.72		89.64

or .001494/#

Conversion - Minutes per Tube to Std. Hours/Tube

A) Allowances - 20.0 minute lunch
24.0 minutes Personal - SU/CU
10.0 minutes Minor Delay & Breaks

54.0 minutes or 12.8% - USE 15%

B) Time per Tube x 115% ÷ 60 x 100 = SH per 100 Tubes

Note: Above reductions represent one extra pass above recommendation of Equipment Man.

SELLING AND ADMINISTRATIVE COSTS

CONTINUOUSLY CAST SHELLS 3½" x .350 WALL

	Monthly Cost	
President	$3,500	
Vice President of Finance	2,000	
General Accountant	1,000	
Vice President of Manufacturing	2,500	
Plant Superintendent	1,250	
Plant Engineer	1,500	
Ass't Engineers (2)	2,000	
Plant Metallurgist	1,500	
Ass't Metallurgists (2)	2,000	
IE Manager	1,500	
Ass't IE's (2)	2,000	
Production Control Manager	1,250	
Ass't PC Manager	1,000	
Expeditor & Clerks (4)	3,000	
Accounting Department (6)	4,200	
Purchasing Agent	1,250	
Clerk	600	
Personnel Manager	1,250	
Secretary & Clerks (8)	4,800	40,600
Vice President of Sales	2,500	
Field Sales (6)	7,500	
Order Processing Manager	1,250	
Office Manager	1,000	
Technical Sales (3)	3,750	
Secretary & Clerks (4)	2,400	18,400
Fringe Benefits (20%)	11,800	
Office Supplies	3,800	
Telephone & Telegraph	2,250	
Depreciation	3,500	
Travel	5,200	
Meetings & Conventions	1,000	
Advertising	1,000	
Legal, Auditing & Consulting Services	1,500	
Miscellaneous	2,500	32,550
Total		$91,550

Exhibit "D"

COST & SELLING PRICE SUMMARY

CAST & EXTRUDE

A. CAPACITY-NET POUNDS

Cast Capacity - Net	7,020,000#
Extrusion Capacity - Gross - Less 10% Labor Variance	7,076,160#
Extrusion Capacity-Net - Adjusted for 10% Labor Variance	5,660,928#
Tube Mill Capacity Adjusted for 15% Labor Variance	5,728,660#
USE	5,661,000#

Net Pounds Produced:

50' Lengths @ 92% Yield	5,208,120#
100' " @ 90% "	5,094,900#
360' " @ 85% "	4,811,850#

B. COST & SELLING PRICE

	50' Lengths		100' Lengths		360' Lengths	
1.00 x .035 Wall	Cost/Mo.	Cost/Net #	Cost/Mo.	Cost/Net #	Cost/Mo.	Cost/Net #
Cast	97,815	$.0188	97,815	$.0192	97,815	$.0203
Extrude	108,392	.0208	108,392	.0213	108,392	.0225
Tube Mill	229,234	.0440	229,234	.0450	222,170	.0455
S & A	133,470	.0256	133,470	.0262	133,470	.0277
Freight	78,122	.0150	76,412	.0150	72,178	.0150
Fed. Tax	175,000	.0334	175,000	.0344	175,000	.0364
Profit	175,000	.0334	175,000	.0344	175,000	.0364
Selling Price/#		$.1910		$.1955		$.2038
.750" x .035 Wall						
Cast	97,815	.0188	97,815	.0192	97,815	.0203
Extrude	108,392	.0208	108,392	.0213	108,392	.0225
Tube Mill	238,159	.0457	238,159	.0467	231,095	.0480
S & A	133,470	.0256	133,470	.0262	133,470	.0277
Freight	78,122	.0150	76,412	.0150	72,178	.0150
Fed. Tax	175,000	.0334	175,000	.0344	175,000	.0364
Profit	175,000	.0334	175,000	.0344	175,000	.0364
Selling Price/#		$.1927		$.1972		$.2063

Investment: $15,980,000 in Buildings, Land & Equipment plus $5,000,000 for working capital.

CASTING COSTS

CAST & EXTRUDE

Monthly Operating Costs

	Cost/Month
Direct Labor	
$.7688/M pounds x 7,076,160#	$ 5,440
Overhead	
Direct Labor Variance	1,088
Casting Shop Foreman (2) (startup)	1,250
Indirect Labor:	
8 Scrap Handlers @ $3.00/hr.	3,840
3 Technicians @ 3.50	1,680
1 Fork Truck Driver @ 2.75	440
2 Sweepers @ 2.50	800
2 Utility men @ 3.50	1,120
1 Saw Grinder @ 3.75	600
4 Maintenance Men @ 4.00	2,560
Casting Shop Supplies:	
Casting Molds (6 molds/12 mos. @ $2500/mold)	1,250
Linings, jet ports, bricks	2,000
Lubricants	2,100
Misc. (Refractories-thermocouples, etc.)	2,500
Saw Blades	1,150
Maintenance Supplies	6,000
Depreciation	10,638
Taxes	1,965
Insurance	800
Gas (.05/100 cu.ft.-15,000 cu.ft.-ton @ 90% yield)	29,239
Water 12,000 gal./hr. or 11,520,000 gal./mo. @ .25/M	2,880
Electricity	2,400
Scrap & Shrinkage	10,900
Fringe Benefits (27.5%)	5,175
	$97,815

Depreciation

Building - $140,000 @ 24 years or $ 486/month
Equipment -$1,461,900 @ 12 years or $10,152/ "

Total $10,638

EXTRUSION COSTS

CAST & EXTRUDE

MONTHLY OPERATING COSTS

Direct Labor	
$1.1449/M# x 6,289,920#	$ 7,201
Overhead	
Setup Labor	720
Direct Labor Variance	1,440
Extrusion Foremen (2)	2,500
Indirect Labor:	
6 Die Maintenance Men @ $3.50	3,360
2 Technicians @ $3.50	1,120
2 Sweepers @ $2.50	800
2 Utility Men @ $3.50	1,120
4 Maintenance men @ $4.00	2,560
Supplies:	
Extrusion tools $4.80/1000#	30,192
Miscellaneous	2,500
Depreciation	32,333
Taxes	5,820
Insurance	2,000
Water	500
*Electricity (Induction Heater & Gen.)	8,500
Fringe Benefits (27.5%)	5,726
	$108,392

Depreciation

Building - $490,000 - 24 years or $ 1,701/month
Equipment -$4,411,000 - 12 years or $30,632/ "

Total $32,333

*Induction Heater 200 KWH/Ton @ $.012/KWH

CASTING & EXTRUSION COSTS

CAST 10" BILLET - EXTRUDE 2.00" O.D. x .100 WALL SHELL

A. EQUIPMENT REQUIREMENTS

1. One AS & R Shaft Furnace - 70,000 #/Hr.

2. One Six-Head DC Casting Unit - 60,000 #/Hr.

3. One 5,500 Ton Extrusion Press to extrude 2.0" x .100" wall Shell at rate of 42 Shells per hour. Billets weigh 585# with extrusion scrap at 20% (Butt 10%, Shell 7%, Plug 3%). Each Shell weighs 468# as extruded for a net production per hour of 19,656#'s.

B. INVESTMENT - BUILDING & EQUIPMENT

Building (Casting 10,000 sq.ft. - Extrusion 35,000 sq.ft.)	$ 630,000
Shaft Furnace	1,000,000
Linings, jetports, bricks, etc.	24,000
Scrap Processing Equipment	60,000
Service Equipment	35,000
Handling Equipment	50,000
Testing Equipment	70,000
Billet Saw & Handling Equipment	90,000
Extrusion Press	3,850,000
Utilities	195,000
Tube Equipment (Runout tables, etc.)	356,000
	6,360,000
10% Contingencies	636,000
	$6,996,000

C. DIRECT LABOR COSTS -(per 20 day month)

1. Casting

Gross Pounds produced (based on DC Casting-single shift)	#9,600,000
Yield 90% Net Pounds	8,640,000
Adjustment for 1.5 hour daily startup-shutdown	7,020,000
Manning - 9 men/shift/20 Days (1 Charger, 1 Furnace Operator, 5 Casters, 2 Saw Operators)	1,440 Hrs.
Pounds/man hour	4,875
Hours/1000 pounds	.205
Direct Labor Cost @ 3.75/hr.	.7688

2. Extrusion

Gross Pounds produced (2 shifts)	7,862,400
Net Pounds (20% extrusion loss)	6,289,920
Manning-6 men/shift (Operator, Die Man, Dummy, Load Billets, Shear End & Relief Man)	1,920 Hrs.
Pounds per Man Hour	3,276
Hours per 1000 Pounds	.3053
Direct Labor Cost/1000 pounds @ $3.75	1.1449

BLOCK DRAWING COSTS

CAST & EXTRUDE 2.0 x .100 WALL SHELLS

MONTHLY OPERATING COSTS

	1.0 x .035 Wall		.750 x .035 Wall	
	Coils	Str.Lgths	Coils	Str.Lgths
Direct Labor	27,016	27,016	32,401	32,401
Overhead				
Setup Labor	2,702	2,702	3,240	3,240
Direct Labor Variance	5,403	5,403	6,480	6,480
Block Drawing Foremen (4)	3,400	3,400	3,400	3,400
Level Wind Foremen (4)	3,400	3,400	3,400	3,400
General Foremen (2)	2,500	2,500	2,500	2,500
Shipping Foremen (2 or 4)	1,700	3,400	1,700	3,400
Indirect Labor:				
Grinding - 6 @ 3.50	3,360	3,360	3,360	3,360
QC - 6 @ 3.00	2,880	2,880	2,880	2,880
Maint. -12 @ 3.50	6,720	6,720	6,720	6,720
Shipping-8 or 16 @ 3.00	3,840	7,680	3,840	7,680
Sweepers - 3 @ 2.50	1,200	1,200	1,200	1,200
Clerks - 8 @ 2.00	4,800	4,800	4,800	4,800
Anneal Op. - 8 @ 3.00	3,840	3,840	3,840	3,840
Operating Supplies	10,000	10,000	10,000	10,000
Maintenance Supplies	3,500	3,500	3,500	3,500
Depreciation	55,100	55,100	55,100	55,100
Taxes	10,250	10,250	10,250	10,250
Insurance	4,150	4,150	4,150	4,150
Electricity	8,000	8,000	8,000	8,000
Water	1,200	1,200	1,200	1,200
Gas	5,200	5,200	5,200	5,200
Fuel Oil	6,000	6,000	6,000	6,000
Packing Supplies	26,000	26,000	26,000	26,000
Fringe Benefits (27.5%)	20,009	21,533	21,934	23,458
Totals	$222,170	$229,234	$231,095	$238,159

Depreciation:

Building - $2,100,000 @ 24 years - 7,300/month
Equipment - $6,884,000 @ 12 years - 47,800/ "

Total $55,100

BLOCK DRAWING COSTS

CAST & EXTRUDE 2.0" x .100 WALL SHELL

	Gross Pounds/Shift
A. EQUIPMENT REQUIREMENTS	
1. Nine 84" Draw Blocks 3/4"	179,010
Seven " " " 1.0"	168,490
2. Two Continuous Annealing Furnaces 12,000#/Hr.	200,000
3. Seven Level Winder-Eddy-Current Testers 3/4"	187,390
Five " " " " " 1.0"	169,250

B. INVESTMENT

Building (150,000 sq. ft.)	$2,100,000
Nine 84" Blocks - Conv. etc.	3,150,000
Two Furnaces	1,100,000
Seven Level Winders	642,000
Grinding & Support Equipment	250,000
Handling Conveyors, Cranes, etc.	625,000
Fork Truck - Misc. Support	300,000
	8,167,000
10% Contingencies	816,700
	$8,983,700
USE	$8,984,000

C. MONTHLY CAPACITY & DIRECT LABOR COSTS

1. Gross Pounds Required (2 shifts x 20.0 days/month) — 6,660,000

   (Actual capacity 2 shifts for 3/4 = 6,739,000# and for 1.0" = 7,160,000#)

2. Direct Labor Costs (based on 3.50/hr)

1.0" x .035	$27,016
3/4" x .035	$32,401

REDUCTION PRACTICE

CAST & EXTRUDE 2.0" x .100 WALL SHELLS

1.00 x .035

Operation	Unit Wgt	Machine	Size Start	Size Finish	% Red.	Strip Pkge	Strip Lgth	Running Speed (min.)	Minutes/Tube Run	Minutes/Tube Hdle	Minutes/Tube Tot.	St.	Adj. Min/ Tube	SH/ 100 Tube	Cr. Sze	Tot. SH/ Tube
Draw	468#	84" Block	2.00 x .100	1.72 x .084	27%	Coils	279'	400'	.70	.90	1.60	1	7.60	3.07	2.5	7.68
Draw	468	84" Block	1.72 x .084	1.47 x .067	32%	Coils	412'	500'	.82	.70	1.52	1	1.52	2.91	2.5	7.28
Draw	468	84" Block	1.47 x .067	1.26 x .054	31%	Coils	593'	750'	.78	.70	1.48	1	1.48	2.84	2.5	7.10
Draw	468	84" Block	1.26 x .054	1.05 x .045	31%	Coils	881'	1000'	.88	.70	1.56	1	1.56	2.99	2.5	7.48
Draw	468	84" Block	1.05 x .045	1.00 x .035	25%	Coils	1131'	1250'	.90	1.00	1.90	1	1.90	3.64	2.5	9.10
Eddy C. Test/Wind	468	Level Wind.		1.00 x .035		Coils -Core	1131'	250'	4.52	1.25	5.77	1	5.77	11.06	1.5	16.59
														26.51		54.23
														or .001159/#		

3/4" x .035

Operation	Unit Wgt	Machine	Size Start	Size Finish	% Red.	Strip Pkge	Strip Lgth	Running Speed	Minutes/Tube Run	Minutes/Tube Hdle	Minutes/Tube Tot.	St.	Adj. Min/ Tube	SH/ 100 Tube	Cr. Sze	Tot. SH/ Tube
Draw	468#	84" Block	2.00 x 1.00	1.720 x .084	27%	Coils	279'	400'	.70	.90	1.60	1	1.60	3.07	2.5	7.68
Draw	468	84" Block	1.72 x .084	1.470 x .067	32%	Coils	412'	500'	.82	.70	1.52	1	1.52	2.91	2.5	7.28
Draw	468	84" Block	1.47 x .067	1.260 x .054	31%	Coils	593'	750'	.78	.70	1.48	1	1.48	2.84	2.5	7.10
Draw	468	84" Block	1.26 x .054	1.020 x .047	31%	Coils	850'	1000'	.85	.70	1.55	1	1.55	2.97	2.5	7.43
Draw	468	84" Block	1.02 x .047	.810 x .042	30%	Coils	1197'	1250'	.96	.70	1.66	1	1.66	3.18	2.5	7.95
Draw	468	84" Block	.81 x .042	.750 x .035	23%	Coils	1513'	1500'	1.01	1.00	2.01	1	2.01	3.85	2.5	9.63
Eddy C. Test/Wind	468	Level Wind.		.750 x .035		Coils -Core	1513'	250'	6.05	1.25	7.30	1	7.30	13.99	1.3	18.19
														32.81		65.26
														or .00139/#		

Conversion - Minutes per Tube to Std. Hours/Tube

A) Allowances - 20.0 minute lunch
24.0 minutes Personal - SU/CU
10.0 minutes Minor Delay & Breaks
54.0 minutes or 12.8% - USE 15%

B) Time per Tube x 115% ÷ 60 x 100 = SH per 100 Tubes

Note: Above reductions represent one extra pass above recommendation of Equipment Man.

CAST & EXTRUDE 2.00 x .100 WALL SHELL

SELLING & ADMINISTRATIVE COSTS

	Monthly Cost	
President	$ 4,000	
Vice President of Finance	2,000	
General Accountants (2)	2,000	
Vice President of Manufacturing	2,500	
Plant Superintendents (2)	2,500	
Plant Engineer	1,500	
Ass't Engineers (4)	4,000	
Plant Metallurgist	1,500	
Ass't Metallurgists (4)	4,000	
Industrial Engineering Manager	1,500	
Ass't IE's (4)	4,000	
Production Control Manager	1,250	
Ass't PC Manager	1,000	
Expeditor & Clerks (6)	4,500	
Accounting Department (8)	5,600	
Purchasing Agent	1,250	
Clerks (2)	1,600	
Personnel Manager	1,250	
Secretary & Clerks (12)	7,200	52,750
Vice President of Sales	2,500	
Field Sales (10)	12,500	
Order Processing Manager	1,250	
Office Manager	1,000	
Technical Sales (5)	6,250	
Secretary & Clerks (8)	3,600	27,100
Fringe Benefits (20%)	15,970	
Office Supplies	6,600	
Telephone & Telegraph	3,900	
Depreciation	6,100	
Travel	9,050	
Meetings & Conventions	2,000	
Advertising	2,000	
Legal, Auditing & Consulting Services	3,000	
Miscellaneous	5,000	53,620
Total		$133,470

Exhibit "E"

COST & SELLING PRICE SUMMARY

CONTINUOUSLY CAST SHELLS 1.00/1.25" O.D. x .250" WALL

A. CAPACITY NET POUNDS	1.00 x .035	.750 x .035
Cast Capacity	1,863,462	1,383,557
Tube Mill Capacity	2,230,200	1,672,720
Tube Mill Capacity Adjustment for 20% Labor Variance	1,858,420	1,393,878
USE	1,860,000	1,384,000
Net Pounds Produced:		
50' Lengths @ 92% Yield	1,711,200	1,273,280
100' " @ 90% "	1,674,000	1,245,600
360' Coils @ 85% "	1,581,000	1,176,400

B. COST & SELLING PRICE

	50' Lengths		100' Lengths		360' Lengths	
1.00" x .035 Wall	Cost/Mo.	Cost/Net #	Cost/Mo.	Cost/Net #	Cost/Mo.	Cost/Net #
Cast	62,301	$.0364	62,301	$.0372	62,301	$.0394
Tube Mill	100,830	.0589	100,830	.0602	98,522	.0623
S & A	51,100	.0299	51,100	.0305	51,100	.0323
Freight	25,668	.0150	25,110	.0150	23,715	.0150
Fed. Tax	54,375	.0318	54,375	.0325	54,375	.0344
Profit	54,375	.0318	54,375	.0325	54,375	.0344
Selling Price/#		$.2038		$.2079		$.2178
.750" x .035 Wall						
Cast	60,193	.0473	60,193	.0483	60,193	.0512
Tube Mill	97,158	.0763	97,158	.0780	94,850	.0810
S & A	51,100	.0401	51,100	.0410	51,100	.0434
Freight	19,099	.0150	18,684	.0150	17,646	.0150
Fed. Tax	54,375	.0427	54,375	.0437	54,375	.0462
Profit	54,375	.0427	54,375	.0437	54,375	.0462
Selling Price/#		$.2641		$.2697		$.2830

Investment: $5,525,410 in Buildings, land and equipment plus an additional $1,000,000 for working capital.

CASTING COSTS

CONTINUOUS CAST SHELLS 1.00/1.25" O.D. x .250 WALL

Monthly Operating Costs

	1.00" O.D. x .250 Wall For .750 x .035	1.250" O.D. x .250 Wall For 1.00 x .035
DIRECT LABOR		
1.00 x .250" Wall-$4.855/M# x 1,383,557#	$ 6,718	-
1.25 x .250" Wall-$3.605/M# x 1,863,462#	-	$ 6,718
OVERHEAD		
Direct Labor Variance	1,344	1,344
Casting Shop General Foreman	1,250	1,250
Casting Shop Shift Foremen (3)	2,550	2,550
Indirect Labor:		
4 Combination Scrap Handlers-Utility @ 3.25	2,080	2,080
3 Technicians @ 3.50	1,680	1,680
3 Fork Truck Drivers @ 2.75	1,320	1,320
3 Sweepers @ 2.50	1,200	1,200
4 Maintenance Men @ 4.00	2,560	2,560
Casting Shop Supplies-1.00 @ 13.201/M#	18,264	-
1.25 @ 9.800/M#	-	18,264
Maintenance Supplies	1,500	2,250
Depreciation	6,204	6,204
Taxes	1,250	1,250
Insurance	500	500
Gas $.079/gal.-12 gal./hr.-480 hrs./month x 4 Units	1,820	1,820
Water 34,000 gal./day per Unit	165	165
Electricity .012/KWH or 1.37/1000#	1,895	2,553
Scrap & Shrinkage	2,200	2,900
Fringe Benefits (27.5%)	5,693	5,693
Total Cost	$60,193	$62,301

Depreciation:

Building - $420,000 - 24 years or $1,458/month
Equipment- $683,410 - 12 years or $4,746/month

$6,204

CASTING COSTS

CONTINUOUS CAST SHELLS 1" & 1¼" O.D. x .250 WALL

A) EQUIPMENT REQUIREMENTS

1. Four 120 KW ET-2 Hydraulic Tilt Furnaces - 850#/Hr.

2. Four 4-Strand Casting Unit
   1.0" x .250" = 2.26 lbs./foot @ 18.0"/min. = 813#/Hr. for 4 Strands
   1.25 x .250" = 3.04 lbs./foot @ 18.0"/min. = 1095#/Hr. for 4 Strands

3. Each unit produces 19,512# at the one inch size and 26,280# at the 1¼" size per 24 hour day; therefore, four units will produce an approximate monthly capacity level of 1,561,000#'s for the 1.0" size and 2,100,000#'s for the 1¼" size.

B) INVESTMENT - BUILDING & EQUIPMENT

Building - 30,000 sq. feet	$420,000
Ajax Magnathermic Furnace (4)	107,100
Continuous Casting Units (4) 50' Run-out	280,000
Spare Parts (shells, inductors, etc.)	28,000
Scrap Processing Equipment	45,000
Service Equipment (pumps, compressors, air ram)	25,000
Handling Equipment	28,000
Test Equipment	70,000
	$1,003,100
10% Contingencies	100,310
Total	$1,103,410

C) DIRECT LABOR COSTS - 20 DAY MONTH

	1.0 x .250 Wall	1.25" x .250 Wall
Gross Pounds Produced	1,560,960	2,102,400
Yield 95% - Net Pounds	1,482,912	1,997,280
Net after setup loss 4.0 hrs./60 producing hours or 6.7%	1,383,557	1,863,462
Manning-4 men/shift-20 days	1920 Hrs.	1920 Hrs.
Pounds per Man Hour	721.0	971.0
Hours per 1000 pounds	1.387	1.030
Direct Labor Cost/M# @ $3.50/Hr.	$4.855	$3.600
Direct Labor Cost/#	.00486	.00361

D) SUPPLIES

Item	Estimated Life	Unit Cost	Cost/60 Hrs. 1.0" 32,520#	Cost/60 Hrs. 1.25" 43,800#	Cost/1000# 1.0"	Cost/1000# 1.25"
Graphite Die	60 hrs./die	56.00	$224.00	$224.00	6.888	5.114
Crucible	300 hrs.	290.00	58.00	58.00	1.784	1.324
Seal	60 hrs./die	16.00	16.00	16.00	.492	.365
Thermocouple	1.20 hrs.	6.42	3.21	3.21	.099	.073
Protection Tube	240 hrs.	16.46	4.11	4.11	.126	.094
Holding Furnace	24 mos.	2500.00	12.50	12.50	.384	.285
Melting Furnace Lining	1000.00	1500.00	90.00	90.00	2.768	2.055
					12.541	9.310
		Adjusted for 95% Yield			13.201	9.800

TUBE REDUCING & BLOCK DRAWING

CONTINUOUSLY CAST SHELLS 1.25/1.00" x .250 WALL

Monthly Operating Costs

	1.00 x .035 Wall		.750 x .035 Wall	
	Coils	St. Lengths	Coils	St. Lengths
Direct Labor	$12,248	$12,248	$12,248	$12,248
Overhead:				
Set-up Labor	1,225	1,225	1,225	1,225
Direct Labor Variance	2,450	2,450	2,450	2,450
Tube Reducing Foremen (2)	1,700	1,700	1,700	1,700
Finishing Foremen (2)	1,700	1,700	1,700	1,700
Shipping Foremen (1 or 2)	850	1,700	850	1,700
General Foremen (2)	2,500	2,500	2,500	2,500
Indirect Labor:				
Grinding - 3 @ 3.50	1,680	1,680	1,680	1,680
Q.C. - 2 @ 3.00	960	960	960	960
Maintenance- 4 @ 3.50	2,240	2,240	2,240	2,240
Shipping -2-4 @ 3.00	960	1,920	960	1,920
Sweepers - 2 @ 2.50	800	800	800	800
Clerks - 2 @ 2.00	640	640	640	640
Anneal.Oper. 3 @ 3.00	1,440	1,440	1,440	1,440
Mat'l Handl. 4 @ 3.00	1,920	1,920	1,920	1,920
Operating Supplies	4,200	4,200	3,225	3,225
Maintenance Supplies	1,750	1,750	1,750	1,750
Depreciation	27,063	27,063	27,063	27,063
Taxes	5,000	5,000	5,000	5,000
Insurance	2,200	2,200	2,200	2,200
Electricity	3,500	3,500	3,000	3,000
Water	500	500	500	500
Gas	1,500	1,500	1,500	1,500
Fuel Oil	1,750	1,750	1,750	1,750
Packing Supplies	8,585	8,585	6,388	6,388
Fringe Benefits (27.5%)	9,161	9,659	9,161	9,659
	$98,522	$100,830	$94,850	$97,158

Depreciation:

Building - $1,050,000 @ 24 years = $ 3,646/month
Equipment- $3,372,000 @ 12 years = $23,417/month

$27,063

TUBE REDUCING & BLOCK DRAWING

COSTS

CONTINUOUSLY CAST SHELLS 1.25/1.00" O.D. x .250 WALL

	Gross Pounds/Shift	
	1.00/.035	.750/.035
A. Equipment Requirements		
1. 7 Single Strand Tube Reducers	55,755	41,818
2. Two 84" Draw Blocks	72,720	54,540
3. Three Level Winder-Eddy-Current Testers	69,750	52,312

B. Investment

1. Building (75,000 sq. ft.)	$1,050,000
2. 7-Tube Reducers	1,250,000
3. 2-84" Block-Conveyors, etc.	700,000
4. 1 Furnace - 5000#/Hour	250,000
5. 3 Level Winders - E.C. Testers	270,000
6. Grinding & Support Equipment	100,000
7. Handling Conveyors	250,000
8. Fork Truck - Misc. Support	150,000
	4,020,000
10% Contingencies	402,000
	$4,422,000

C. Monthly Capacity & Direct Labor Cost

	1.00/.035	.750/.035
1. Gross Pounds Produced/Month (20 days)	2,230,200	1,672,720
2. Direct Labor Costs (based on $3.50/hr)	$12,248	$12,248

REDUCTION PRACTICE

CAST 1.00 OR 1.25" O.D. X .250 WALL SHELL - REDUCE - BLOCK DRAW

Operation	Unit Wgt.	Machine	Size Start	Size Finish	% Red.	Strip Pack-age	Strip Lgth	Run. Speed Ft/ Min.	Minutes per Tube Run	Minutes per Tube Hdle	Minutes per Tube Total	# St.	Adj. Min/ Tube	SH/ 100 Tubes	Crew Size	Total SH/ Tube
1.00/.035																
Reduce	150	Tube Reducer	1.250x .250 Wall	1.05x .045	83%	Str. Lgths	283'	36'	7.86	-	7.86	1	7.86	15.07	.5	7.54
Draw	150	84" Block	1.05x .045	1.00x .035	25%	Coils	360'	500'	.72	1.00	1.72	1	1.72	3.30	2.5	8.25
Eddy-Cur. Test/Wind	150	Level Winder	-	1.00x .035	-	Coils/ Core	360'	250'	1.44	1.25	2.69	1	2.69	5.16	1.5	7.74
																23.53
													or .001569/#			
3/4/.035																
Reduce	112.5	Tube Reducer	1.00x .250 Wall	.81 x .042	83%	Str. Lgths	286'	36'	7.86	-	7.86	1	7.86	15.07	.5	7.54
Draw	112.5	84" Block	.81x .042	.75 x .035	23%	Coils	360'	500'	.72	1.00	1.72	1	1.72	3.30	2.5	8.25
Eddy-Cur. Test/Wind	112.5	Level Winder	-	.75x .035	-	Coils/ Core	360'	250'	1.44	1.25	2.69	1	2.69	5.16	1.5	7.74
																23.53
													or .002092/#			

Note: Weights based on finished length of 360'.

SELLING AND ADMINISTRATIVE COSTS

CONTINUOUS CAST SHELLS 1.25/1.00 x .250 WALL

	Monthly Cost	
President	$3,000	
General Accountant	1,500	
Vice President, Manufacturing	2,000	
Plant Superintendent	1,250	
Plant Engineer	1,250	
Assistant Engineer	1,000	
Plant Metallurgist	1,250	
Assistant Metallurgist	1,000	
Industrial Engineering Manager	1,250	
Assistant IE	1,000	
Production Control Manager	1,250	
Expediting Clerks (2)	1,500	
Accounting Department (4)	2,800	
Purchasing Agent	1,000	
Personnel Manager	1,000	
Secretary & Clerks (5)	3,000	$25,050
Vice President, Sales	2,000	
Field Sales (3)	3,750	
Order Processing Manager	1,250	
Technical Sales	1,250	
Secretary & Clerk (2)	1,200	9,450
Fringe Benefits (20%)	6,900	
Office Supplies	1,500	
Telephone & Telegraph	1,000	
Depreciation	1,500	
Travel	2,500	
Meetings and Conventions	500	
Advertising	500	
Legal, Auditing & Consulting Services	1,000	
Miscellaneous	1,200	16,600
Total		$51,100

Exhibit "F"

COMPARISON OF PRICES

BB&G Cost Study

	Conversion Selling Price/#		
	50' Lengths	100' Lengths	360' Lengths
3/4" x .035 Wall	$.1892	$.1927	$.2018

Actual Bids - Sept. 15, 1966 Quote (Invitation No. OSW 1150)

	Conversion Selling Price/#
Company A	$.440
" B	$.498
" C	$.533
" D	$.647
" E	$.782

Exhibit "G"

WATER TUBE PRICING

Description	O.D.	Wall	Wgt/Foot	Price/Foot
5/8 Type L	3/4"	.042	.362	$.294
5/8 Type M	3/4"	.030	.263	.225
	Average	.036	.3125	$.2595

Price per Foot - List	$.2595
Price per Foot Net (after discounts)	.2017
Price per Pound	$.6454
Less 2% Discount (10 days)	.6325
Less Copper Cost (.36/#)	.2725

Note

1/2 Type M has sold for $.145 over metal during competitive periods.

APPENDIX C

UCC SUBCONTRACT NO. 2888

REPORTS, FINDINGS, AND EVALUATION

TUBOTRON, INC.

Process Description

The process of high frequency welding tube from strip consists basically of the following steps:

a. Roll forming the flat strip into an approximately circular cross section.

b. High frequency heating the strip edges to the plastic temperature range of the metal.

c. Forcing the heated edges together between the welding rolls and obtaining a forged weld. This results in a plastic upset of metal on the inside and outside of the tube.

d. Removing the upset weld bead on the outside and usually also on the inside of the welded tube.

e. Cooling the tube in the cooling trough.

f. Sizing the cooled tube to precise finished dimension.

g. Non-destructively inspecting the tube (if the tube manufacturers mill is so equipped).

h. Cutting the tube "on-the-fly" to the required mill length.

i. Dumping the tube into a finished tube collection station at the outlet end of the tube mill line.

Chip Removal

The removal of the inside weld flash is a relatively complex operation and often requires refined and sophisiticated hardware. This bead removal is normally done on the tube mill immediately after the weld has been produced. The tooling required must be located within the tube and the metal cutting process is performed without the benefit of the operator being able to observe the operation. The loose chip generated from this metal cutting operation normally passes downstream with the tube and therefore rests loosely within the tube as it is ejected from the tube mill.

Tube mill manufacturers are usually hesitant to furnish the required internal scarfing tooling due to the complexity of the process and the individual and often special requirements of the tube manufacturer. The tube manufacturer therefore most generally designs his own special tooling for the purpose of internal scarfing the welded tube. The minimum inside diameter that can be internally scarfed is determined by a number of factors which may vary from manufacturer to manufacturer. Some of these factors are type of material to be cut, welding speed to be obtained and condition and precision of cut required. Tubotron has

developed tooling to remove the inside weld flash on tube slightly less than .500" I.D. The height of the residual weld bead following scarfing can normally be held to less than .006" and in some cases has been held to as little as .002" by Tubotron. Field experience has shown that these bead heights permit rolling tube into tube sheets with ease.

It is necessary to remove from the tube the loose chip which lies within the tube after it exits from the tube mill. Individual manufacturers have their own methods of performing this operation and these are normally of a proprietary nature. Tubotron, under provisions of this Subcontract, has produced several coils of 360 foot continuous lengths of welded tube which has been internally scarfed and from which the loose chip has been removed successfully by proprietary method.

Welding Speed

Maximum welding speed is determined by a number of factors. These include speed range of the mill, horsepower of the mill, electrical capacity of the welding unit associated with the mill, the metal cutting operation associated with weld bead removal, strip forming control in the roll forming operation, and maximum operating speed of the flying cutoff at any given tube diameter and wall thickness.

The maximum possible welding speed for welded copper nickel tube in the sizes contemplated for desalination application has not been fully determined, but is estimated to be in the range from 175 FPM to 225 FPM. Higher speeds up to possibly 300 FPM appear feasible on a tube mill especially designed for the manufacture of the type of condenser tube envisioned for use in desalination plants.

Tube Lengths

The total, continuous lengths of welded tube is normally limited only by the length of the coiled stock or skelp from which it is made. This length is a factor of coil weight as expressed in pounds/inch of coil width and thickness of the strip material. Tubotron has produced cable sheathed tubing in continuous lengths in excess of 11,000 feet. Several lengths of coiled tube measuring 360 feet were produced under the provisions of this Subcontract. Welded tube is normally manufactured in straight length but coiling would, of course, be indicated for the extremely long lengths referred to above. Tube lengths in the range of 360 feet for use in a desalination module could be produced on-site in straight lengths and transported from the tube mill to the installation site by specially designed handling equipment.

Current Cost, In-Plant Production

The requirement of this paragraph for a current quotation for in-plant production is summarized in the table which follows. In addition to

Price Quotations for In-plant Tubes

The following prices are for in-plant production of sixty (60) million feet of any one of the following items. Tubing is to be furnished in coils of from 70' - 360' length, in as-welded temper and finish, with internal weld flash removed:

High frequency welded 90/10 Cupro-Nickel tube, 1" O.D. x .035" wall	$0.3629/ft
High frequency welded 70/30 Cupro-Nickel tube, 1" O.D. x .042" wall	$0.4968/ft
High frequency welded 90/10 Cupro-Nickel tube, 3/4" O.D. x .035" wall	$0.2777/ft
High frequency welded 70/30 Cupro-Nickel tube, 3/4" O.D. x .042" wall	$0.3755/ft

Tube prices are predicated upon strip cost of:

90/10 Cupro-Nickel	$0.7643/lb
70/30 Cupro-Nickel	0.9046/lb

Strip prices are based on constituent metal costs of:

Copper	$0.4200/lb
Nickel	0.9550/lb
Iron	0.0250/lb

tubing prices, the quotation reflects the strip costs upon which these prices are predicted together with current raw material costs for the principal components of both alloys.

A conservative yield of 90% usable tube from original strip quantity has been allowed in the cost estimate. It is felt that specialized equipment planned for this application would improve this rate appreciably but experience is not adequate at this point to anticipate this saving. It should be noted that, while the strip costs indicated are commodity levels for welded tubing production, it is considered likely that substantially lower levels could be obtained on the basis of firm orders of the volume indicated.

In order to establish a reasonable cost basis, it has been necessary to make certain assumptions. First, it has been assumed that complete production during an 18-month period would be compatible with construction requirements. As a corollary to this, costs have been based upon a need for a new tube mill with 100% utilization for this project during the initial 18-month period and lesser utilization through the balance of a normal 10-year amortization period. Associated with the mill would be all auxiliary equipment including a coiler, since shipment of long-length tube would be practical only in coiled form.

Current Cost, On-Site Production

Because the equipment needed for in-plant production of an order of this magnitude would be largely identical to that needed for on-site production, it is possible to evaluate on-site production costs on a comparative basis, incorporating only those items of difference which would affect the cost.

It has been assumed that the following facilities would be made available on-site without cost to Tubotron, Inc.:

1. An appropriate building with normal services (light, heat, etc.) and crane facilities.

2. Adequate power and water sources available inside or immediately outside the building for equipment connection.

3. Unimproved floor space for mill foundation installation at Tubotron's expense without preparation other than normal excavating.

If the preceding facility is provided, the incremental cost of on-site facilities and equipment can be divided into two categories. The first, to be amortized completely over the 18-month site operation would include foundation and installation cost and the cost of removal of the equipment to Tubotron's plant upon completion. Estimates for this portion are as follows:

Foundation and installation		$35,000.00
Removal and transportation		15,000.00
Amortization cost per foot - $0.0008.	Total	$50,000.00

The cost of equipment installation at Tubotron's plant is incorporated in the in-plant cost figure.

The second class of incremental costs is for equipment to be utilized 100% for the on-site operation and applicable, at some reduced utilization level, to later in-plant operations. This would include the following:

Tube finishing line (cutting, cleaning, and preparation including intermediate conveyors)		$150,000.00
Machine Shop facilities		15,000.00
	Total	$165,000.00

From this total we must deduct the cost of the coiler, incorporated in the in-plant equipment cost, which is not applicable to on-site production. This represents a cost of $20,000.00 leaving a net of $145,000.00 of differential cost. Amortized at 100% utilization for 18 months and at one-third average utilization for the balance of the normal ten year period, this yields $0.0009 per foot. Thus the total incremental cost of equipment amortization for on-site production would be $0.0017 per foot.

Efficient field production, necessary to attain the established production objectives, will entail appreciable increases in labor cost relative to in-plant manufacture. Competent supervision would, of course, be essential. It has been assumed that both supervision and skilled mill and maintenance personnel would have to be hired and trained locally before transfer to the site or drawn from present staff. In either case, substantial living allowances would be added to basic salary rates. The numerical majority of personnel could be unskilled labor hired at the site but, since a project of this scope will undoubtedly result in labor shortages in the immediate area, substantial increases in labor rates are anticipated. Finally, in order to assure continuity of production, provision must be made for extra personnel who would be only partially effective under normal circumstances.

Taking these factors into account, we have estimated an increased labor cost of $0.0023 per foot.

This cost is predicated upon the use of a 26 man total crew expanding 12,960 man-hours to produce sixty (60) million feet of tube, incorporating all direct labor for mill and finishing operations, quality control and supervision. For lot quantities of the same order of magnitude, the rate of 216 man-hours/million feet is regarded as applicable

Man-hours are based on an average production rate of 5000 feet/hours which, in relation to the welding speeds discussed in Section III, allows for both normal "down" time due to tool changes, etc., and for holidays, breakdowns, etc. The production rate is regarded as a conservative one.

Based upon the preceding information, on-site production would entail $0.0040 per foot additional cost relative to in-plant production on a current basis.

In order to fully develop the practicality and economy of on-site production, it would be necessary to assign a value to the facilities made available, a factor which would vary depending upon the site location, the required tube length (as a factor in establishing building parameters and affecting continued use of the building for other purposes) and, of course, the elimination of on-site straightening and, possibly, annealing facilities necessitated by the use of coiled tubing.

Because strip freight to the point of manufacture is included in the basic prices shown, the cost of shipping tube manufactured in-plant may be applied in its entirety to offsetting on-site cost additions. Although this factor is not within the assigned scope of this contract, some evaluation has been performed.

Both ocean and rail shipment were evaluated for comparison of freight costs with on-site production cost increments, assuming a San Diego site and using 360-foot coils as a basis for evaluation.

For ocean freight, container shipments would be feasible eliminating any need for packaging. Due to the low weight/volume ratio of tube coils and minimum weight charges involved, the cost of such shipments would be approximately $0.0250/ft.

For rail freight, packaging would be necessary and, again in relation to the weight/volume ratio, only a reusable container would be practical. On this basis, using the largest cars available, the freight cost of outbound shipments could be reduced to $0.0141/ft. However, the additional costs of crating and the cost of returning the knocked-down crates for re-use would increase the cost to a minimum of $0.0200/ft to $0.0225/ft.

Without regard to straightening and, if required, annealing facilities at site for handling coiled tube, a minimum differential of $0.0160/ft, ($0.0200 minimum tube freight cost - $0.0040 on-site manufacture cost increment) or approximately one (1) million dollars on a 60 million foot requirement to offset site cost items and represent overall cost savings for on-site production.

The preceding figures are predicated on relatively "tight" coils which, depending upon the diameters, wall and length required, may not be feasible. Even a minor increase in required coil diameter would substantially increase the freight cost due to the size limits of both types of shipment vehicles.

III. 1970 Cost - In-Plant or On-Site Production

Accurate forecast of 1970 tube prices must be regarded as impossible. Taking the individual factors affecting such a forecast into account, we consider the following variations probable:

Basic Material Cost

The volatility of base copper pricing is such that even a probable forecast is difficult. However, it is likely that some increase in ingot cost, perhaps 5% to 10%, must be assumed. Current indications are that the base price of nickel may also show significant increase during the next two years. The relatively stable cost of iron, unfortunately, will have no noticeable effect in this alloy.

Strip Cost

Barring major change in the national economy before 1970, the steady increase in labor rates will undoubtedly result in a 15%-25% labor increase in that area. Since labor represents only a portion of the conversion cost from ingot to strip and conversion represents only 30%-50% of the strip cost, the effect on the gross cost of strip is likely to be a far smaller percentage, perhaps 5%-7%.

Tube Cost

The effect of labor increases on tube cost would almost exactly parallel the situation on strip cost. In total, it may be reasonable to anticipate an increase of 5%-10% in the total price of tube by 1970.

In view of the small differential between in-plant or on-site costs, it is felt that approximately the same difference would be maintained under 1970 conditions.

Eddy Current Test Evaluation

Tubotron, Inc. and Union Carbide Corp., Nuclear Division, entered into an agreement known as Subcontract No. 2888, and dated April 5, 1967. Article I, paragraph 3 of said Subcontract requires an evaluation of in-line, non-destructive test procedures of welded tubing. This evaluation is to include the following:

a. Continuously charting the response of the eddy current testing device to the condition of various test lengths of welded tubing.

b. Laboratory check and examination of test lengths prepared as above.

c. Correlation of deliberate defects with eddy current test charts.

d. Correlation of (a), (b), and (c) with ORNL reference standards using the eddy current test device.

These tests have been completed and results are being reported herewith.

Description of Work

Theory and Equipment

Eddy current testing is a non-destructive test method commonly employed in the tubing industry where it is considered a valuable quality control tool. A brief discussion of the basic theory of eddy current inspection and of the equipment used follows herewith.

Eddy currents flow in electrically conductive material when this material is in an alternating electromagnetic field. The depth and amplitude of these induced eddy currents are related to the electrical conductivity and magnetic permeability of the material and on the frequency of the imposed electromagnetic field. The eddy currents generated within the part to be tested penetrate to a depth which is inversely proportional to the inspection frequency and material conductivity. Changes in electrical conductivity rather than magnetic permeability are significant in the inspection of welds. The induced eddy currents change the electrical properties of the coil used to induce them, and these changes are measured and compared to standards to permit an evaluation of the measurement obtained and their relation to a defect condition.

The test equipment used by Tubotron in the continuous 100% inspection of welded tube on the tube mill basically consists of an enclosing type of sensing coil assembly, usually referred to as a differential coil arrangement. This differential coil system can be considered to consist of three separate coils. One of these three coils induces eddy currents in the tube which it encloses and the other two coils "sense" or "read" the such generated eddy currents. The two closely spaced sensing coils thus compare two separate but closely adjacent sections of the tube to be tested. These two coils are connected to an electrical bridge type circuit which is balanced when both sensing coils are excited equally. A "defect" or discontinuity passing through one coil is thus differentially compared to reading obtained by the other coil enclosing a "normal" section of the tube, and an unbalance will result in the bridge circuit. The degree of unbalance can be measured and in effect becomes the "defect" signal. The chief disadvantage of the differential coil is usually considered to be the fact that long uniform defect conditions

will only be monitored at the beginning and end of the defect. A uniform defect condition, however, is not typical in welded tube manufacture and this disadvantage is therefore not considered of great consequence.

The production test equipment consists essentially of the test coil assembly, an electronic console which contains power supplies, amplifiers, filtering systems, visual and audio readouts, strip chart recording devices, and associated electrical hardware to permit monitoring of the test signal and setting of the test frequency, sensitivity, and defect threshold level. Line production equipment at Tubotron is also equipped with a solenoid operated paint spray gun arrangement which automatically marks the suspect area of the tube as detected by the eddy current unit.

Standard Defects

Standard artificial defects in the welded 90/10 copper nickel tube were produced in accordance with proposed specification (ORNL-1) for seamless and welded copper nickel tube for MSF Desalination Plants, and CDA Application Data 127-6 entitled "Recommended Practice for Eddy Current Testing of Copper and Copper Alloy Heat Exchanger and Condenser Tubes." The tentative ASTM specification entitled "Tentative Recommended Practice for Electromagnetic (Eddy Current) Testing of Seamless Copper and Copper Alloy Heat Exchanger and Condenser Tubes" was also used. The standard defects machined into the sample tubes were as follows:

1. Four notches .006" in depth produced by use of 1/4" diameter No. 4 cut straight round file stroking perpendicular to the axis of the tube.

2. .031" diameter (No. 68 drill) drilled holes through the tube wall.

Additional test samples of tube were prepared by the contractor containing less severe defects than the standard ones listed above. The purpose of producing the smaller defects was to determine the sensitivity of the in-line test apparatus to these lesser defects, which were as follows:

1. .004" notch depth.

2. .025" diameter (No. 72 drill) drilled holes.

Artificial Defects

The Subcontract (Article 1, paragraph 3) provided for ORNL submission to Tubotron of reference standards. These standards were to have been produced artificially so as to be equivalent to weld conditions

exhibiting incomplete fusion or other margnial weld conditions. The subcontractor was notified subsequently that ORNL would be unable to furnish such standards and the subcontractor therefore decided to attempt to produce such samples himself. Results are reported in Section III-c. of this report.

Production Defects

Continuous in-line eddy current testing was performed during the normal manufacturing operation. Defects generated were identified by means of the normal paint spray method and the audio/visual defect signals.

Description of Investigation

Equipment Used

The equipment normally used by the subcontractor is an FW-400 fully integrated eddy current test system produced by the Magnaflux Corp. This system uses a differential coil arrangement through which the tube passes immediately after it exits from the sizing mill. The test coil is connected to the control console which amplifies and analyzes the signal obtained. An automatic alarm system is activated when a discontinuity ("defect") occurs. This signal is so connected as to cause an alarm to sound, a defect light to come on, and an electrically operated paint spray gun to become activated and mark the suspect area of the tube automatically. This suspect area can be subsequently be submitted to further examination or removed for rejection, as required. The test system is also provided with a strip chart recorder which can be used to obtain a permanent record of the eddy current test.

In addition to its standard FW-400 system, Tubotron also performed additional tests using equipment manufactured by the Magnetic Analysis Corp. This equipment was made available to Tubotron specifically in connection with this evaluation. Magnetic Analysis Corp. provided their most advanced instrument known as "ERIC" (Extended Range Indicator Console). It was possible to obtain some comparative data between the two eddy current test instruments employed, although limited availability of the "ERIC" prohibited the generation of test charts. Responses obtained from the "ERIC" were essentially the same as those from the FW-400.

FW-400 testing was done at 25 kc, "ERIC" frequencies used were 7.5 kc and 22 kc. It was found that the "ERIC" was somewhat more sensitive to lateral tube movement within the test coil and this resulted in some false signals caused by tube vibration during and after flying cut-off operation. No effort was made to eliminate these false signals, although it is believed that correct phase control determination could eliminate those readily.

Response to Standard Defects

The eddy current test response to the standard defects as discussed in paragraph II-b. above were in general accordance with requirements set forth in the standards previously referenced. Response to the lesser standard defects as defined in II-b. were somewhat less reliable but still in accordance with the tentative recommended practice specification referenced above.

Response to Artificial Defects

Eddy current test responses to marginal or incomplete fusion or welds has become of interest with the advent of high frequency welded tubing, and Tubotron therefore made a special effort to produce "controlled" weld defects and to observe the eddy current test responses to these conditions.

Artificial weld defects were produced by gradually reducing weld electrical power to a level at which it was believed that deffective welds resulted.

From strip chart recordings which resulted from these tests, it was noted that almost continuous defect signals were recorded indicating discontinuity or other changes of a sufficiently non-uniform nature to cause unbalance of the system. This type of non-uniformity is considered typical for a weld defect, and is therefore subject to discovery by the eddy current test method.

Production Defects

Normal eddy current test procedures were used during the production run of the required 40,000 feet of tubing. The testing resulted in the isolation of certain defects such as scarfing tool marks, dents, and "no-weld" or incomplete weld conditions routinely associated with the beginning and end of each production run from an individual, separate coil of strip material. Except for the artificial weld defects discussed in Section III-a., no additional production weld discontinuities were obtained during the normal course of production.

Summary and Conclusion

Non-destructive eddy current testing is considered to be a valuable quality assurance tool for use with a high frequency tube welding operation. The installation of the test equipment directly into the mill line helps the operator and inspector to discover a process change that may result in defective product. The immediacy of the on-mill inspection technique therefore minimizes the generation of questionable or rejectable material. A thorough knowledge of eddy current test principles and available equipment and equipment

adjustments offer the tube manufacturer an important means of quality assurance. The enclosing type of test coil inspects not only the weld area but also the entire cross-section of area of the tubing. In general, defects which do not affect the electrical conductivity of the test specimen will not be discovered by the eddy current tester. Most defects, however, do affect relative conductivity so that the eddy current test method becomes sensitive to this condition. It must be clear that this non-destructive inspection method, just as every other test method, does not correct any defects but only points them out to the operator who must then make the necessary machine adjustments. The most important ingredient in the tube welding process, just as in any other process, is that it is developed to a high degree of reliability. Eddy current testing then becomes an additional and important quality control tool to further assure product and process uniformity and acceptability.

APPENDIX D

WELDED COPPER-NICKEL TUBE EVALUATION

OCTOBER 1, 1968

BAVIER, BULGER & GOODYEAR
Management Consultants
NAUGATUCK, CONNECTICUT

WELDED COPPER-NICKEL TUBE EVALUATION

OCTOBER 1, 1968

I. ASSIGNMENT

A. Union Carbide Corporation requested Bavier, Bulger & Goodyear to review trials conducted by Tubotron, welding 1" O.D. x .035 wall, 90/10 copper-nickel tubes. Assignment included the evaluation of welded tubing as a practical method of providing the necessary tubing for the various desalinization programs, as well as a judgment opinion of the cost to produce tubing by the welded method.

1. It was also suggested that Bavier, Bulger & Goodyear review the Tubotron report (Subcontract No. 2888) after issuance of said report by the Tubotron Corporation. This report has not been received to date and is not included in the scope of the present evaluation.

B. A trip was conducted to Somerset, New Jersey on June 13, 1968 to observe trial run of welded copper-nickel tubing for the desalinization program.

II. ANALYSIS OF WELDED COPPER-NICKEL TUBE FOR DESALINIZATION PLANTS

A. Tubotron's contract calls for the production of 40,000 feet of 90/10 copper-nicket tubing, evaluation of alternate methods of removing flash chip, correlation of eddy current testing procedures, evaluation of corrosion performance of 1" x .035 wall and projected selling prices. Strip yields and prices were also to be estimated as well as welding running speeds and costs.

B. Some tubing had been processed by June 13, 1968 and three lengths of 35 ft. diameter coils were observed on the roof of the office. The estimated lengths were 300 to 375 feet, quality looked satisfactory.

C. 12-15' lengths were produced during the course of the visit on June 13, 1968. Production run lasted approximately 30.0 minutes. Tubing was formed on a German mill made by Mannersmann Meer AG, welded on AMF Thermatool High Frequency Resistance Welding Head, outside and inside flash chip scarfed, sized, eddy current tested on a Magnaflux machine and cut to length on a flying saw. The tubing was generally of good quality, satisfactorily passing both flaring and flattening tests. Tubing was processed at 150'/minute and production line was manned by a crew of four.

D. Impression gained by observer was that substantial commercialization through production trials will be required before a factual evaluation regarding both product design and costs can be determined.

II. E. Current status of program highlighted two major problems with regard to the use of welded tubing for the desalinization program. The first is in the area of Magnaflux testing. As pointed out in BB&G's study dated October 6, 1967, Subcontract No. 2914, titled Desalinization Seamless Tubing Cost Study, ".....it is a generally accepted fact in the industry that eddy current testing procedures leave much to be desired." The problems associated with seamless tubing are magnified when applied to welded tubing. Seamless tubing produced from sound castings will normally result in a quality product. Welding procedures present additional opportunities for failures. It is the opinion of writers that exposure to quality failure in welding is far greater than through seamless tubing, thereby increasing the requirement for reliability in testing procedures. The second problem associated with welded tubing pertains to removal of the flash chip from the inside diameter of the welded tube. A scarfing tool satisfactorily removes the chip on continuous runs from the outside of the tube. A scarfing tool removing the internal fin also removes the chip continuously, but observed trials were of welded tubes that were cut to length after the scarfing operation. The short lengths, 12-15', permitted removal of the chip as well as visual inspection. The internal scarfing applied to 350' lengths could present major problems with regard to removal of chips. Discussions with the Tubotron personnel indicated that satisfactory trials on continuous length had been conducted, details of which would not be provided inasmuch as the method was proprietary. In the opinion of BB&G, the removal of chips from continuous lengths presents a much greater problem than short lengths and could be a major problem in the program unless satisfactory methods are developed commercially.

F. Summary

Welded tubing can be used effectively in the desalinization program providing Magnaflux or equal testing procedures are developed to insure reliability of welds as well as the formed strip and methods are developed to either eliminate flash from the inside of the weld or to effectively scarf welds and remove chips in continuous lengths.

III. COST EVALUATION

A. As pointed out previously in this report, Tubotron cost figures have not been finalized, therefore evaluation was made on judgment based on past experience in the industry.

B. Strip Cost

Book price for 90/10 Cupro Nickel strip at .035 gauge (cost above metal) is .4338¢/pound based on copper at 42¢/pound and nickel at 95.5¢/pound. Price of the strip alone would eliminate welded copper-nickel tubing from contention if this cost of approximately 43¢ per pound were the ultimate. Reference to BB&G's report "Desalinization

III. B. (cont'd.)

Seamless Tubing Cost Study" indicates estimated copper-nickel seamless tubing cost could be 19-20¢/pound (conversion selling price above metal) providing volume encourages industry to engineer facilities to produce the product. The problem highlighted in the previous report whereby potential prices are far below present book prices exists for strip as for tube. Again, the major problem is low volume and facilities engineered for products other than copper-nickel. If copper-nickel strip is compared to a commodity strip product (such as 70/30 brass for automotive radiators), conversion selling prices can be substantially reduced providing volume is high and facilities are engineered to properly produce the product. Cupro Nickel strip, produced in volume, could be sold for an estimated value above metal costs between 15 and 17¢/pound, in the opinion of writers.

C. Welding Costs

BB&G has estimated welding costs at 7¢/pound. This estimate is based on a two man crew operating a welding line at 150'/minute but does not include scrap allowance. It also includes provisions for freight, administration and profit. Profits are based on a 10% return on investment, considering investment per line to be approximately $500,000. An approximate estimate of figures is included in Exhibit "A". Figures are based on minimum information and can be refined as additional information is provided.

IV. OVERALL SUMMARY

A. Welded copper-nickel tubing presents development and quality problems in order to assure reliability of tubing through satisfactory testing as well as the removal of the inside flash on continuous lengths caused by welding.

B. Assuming quality and process problems are eliminated, welded tubing will represent an increased cost over seamless tubing. This conclusion is based on the estimate that, ultimately, strip will sell for 15-17¢ above metal with an additional .07 for welding and shipping.

C. Successful purchasing of copper-nickel strip at a satisfactory price must be combined with commercialization of testing and scarfing and chip removal methods applicable to continuous lengths if the product is to be considered for desalinization programs. Assuming success, welded tube will cost more than seamless tube and will present greater exposure to failures than seamless tubing. In opinion of writers, emphasis should be on seamless tubing if desalinization projects are to be engineered with smooth wall tubing.

WELDED TUBE SELLING PRICE

3/4" x 035 WALL TUBING

Direct Labor Costs		Cost/#
2 man crew at $3.50 per hour producing at 150'/min. at 80.0 machine utilization = 2200#'s/hour		.0032
Overhead (Based on previous study)		.0260
	Sub-total	.0292
S & A - 30% of conversion		.0087
Freight (Based on previous study)		.0150
	Total Cost	.0529
	Provision for Fed. Tax	.0060
	Profit	.0060
	Total Cost	.0649
	USE	$ .070

Profit: Based on $500,000.00 investment per line with two shift capacity at 700,000 lbs. per month.

a) Return on investment - 10% - $50,000 per year at $4200.00/month

b) Profit per # after Fed. Taxes $.006

APPENDIX E

EVALUATION OF TECHNICAL FEASIBILITY OF DEVELOPING LOW COST FABRICATION METHOD FOR LONG LENGTH THIN WALL SEAMLESS TITANIUM TUBE FOR DESALINATION PLANTS

E&D Report No. 19-NP-67

WOLVERINE TUBE DIVISION
CALUMET & HECLA, INC.

for

UNION CARBIDE CORPORATION
NUCLEAR DIVISION
OAK RIDGE, TENNESSEE

SUBCONTRACT NO. 2706

April, 1968

By:

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ABSTRACT

The technical feasibility of producing long length (360') seamless titanium tube for desalination plant applications was demonstrated. The method of coiling this long length at the production facility, shipping to the desalination plant site, and uncoiling for insertion into the evaporator was studied and is considered feasible and practical. Cost data for long length titanium tube is projected for 1970 and the recommended process for producing 360' finish lengths in 1.000" OD x .012", - .016", and - .020" minimum wall is presented.

I
INTRODUCTION

The need for converting sea water and brackish water into fresh water is increasing; however, the high conversion cost has limited the construction of desalination plants, except in remote areas where other sources of water are not available. With the advent of nuclear reactors for electrical power generation, the projected cost of converting sea water into fresh water is approaching 30 cents to as little as 10 cents per 1,000 gallons when the plant design utilizes a nuclear power plant as a source of heat. In an effort to further reduce this conversion cost, conceptual designs of very large desalination plants have been formulated. Some of these large plant designs employing the distillation process require long length tubing (360-ft. continuous lengths) for the evaporator portions of the plant.

Titanium, being highly resistant to corrosion in sea water, is one of the prime tubing candidates for desalination applications. However, the technical feasibility of producing long-length, thin-wall seamless titanium tubing had not been demonstrated, nor low cost production methods investigated.

The Union Carbide Corporation, Nuclear Division, Oak Ridge, Tennessee; having a contract with the Atomic Energy Commission and the Department of the Interior, Office of Saline Water, to perform desalination research, development, and engineering services; contracted the Wolverine Tube Division of Calumet & Hecla, Inc. to accomplish the development, production, and investigation required for seamless titanium tubing.

The objective of this contract was to "conduct an evaluation of the technical feasibility of providing suitable designs and cost estimates for developing low-cost fabrication methods for producing thin wall seamless titanium tubes by the cold reduction method for use in desalination plants".

The work outlined was:

1. Tube reduce heavy wall, large diameter base tube into acceptable thin wall, small diameter tube (1" OD x .012", .016", and .020" wall thicknesses) in 200-ft. continuous lengths.

2. Evaluate this tube by destructive and nondestructive testing and determine the preferred test methods.

3. Demonstrate that 200-ft. continuous lengths can be produced on a production basis.

4. Demonstrate coiling and uncoiling and nondestructive testing of samples from the 200-ft. lengths.

5. Evaluate the tubing's mechanical properties.

6. Extrapolate the process and cost of producing 360-ft. continuous lengths of tubing.

7. Investigate methods of on-site preparation of long lengths of coiled titanium for installation into evaporators.

8. Evaluate the optimum economic rate of tubing fabrication.

9. Generate sufficient economic data to permit extrapolation of seamless titanium tube prices through 1970.

All tube reduction and annealing was accomplished at Wolverine's Special Metals Plant in Dearborn Heights, Michigan, and all coiling/uncoiling was accomplished at Wolverine's Detroit Plant.

II
EXPERIMENTAL PROCESSING

To substantiate the feasibility of producing 200-ft. continuous lengths of 1" OD seamless titanium tubing in .012", .016", and .020" minimum wall thicknesses using the tube reducing ("rocking") process, the following was accomplished:

Approximately 1589 pounds of annealed 3" nominal OD x .225" wall titanium extrusions suitable for producing ASTM B338-65 tubing were taken from inventory for processing into the three finish tube sizes. These base tubes had been extruded from 8" OD billets, conditioned, and inspected. Seven different ingots were used. The billet certifications for this material are attached in Appendix A. The starting lengths used varied from 7.3' to almost 17', dependent upon the final tube size and the number of multiple lengths planned to be produced from each starting length.

Two basic processes were used to produce the three tube sizes - Process No. 1 (Figure 1) which incorporated one in-process anneal and Process No. 2 (Figure 2) in which no annealing was accomplished. Both processes are outlined on the following pages.

PROCESS NO. 1

1" OD x .012" Wall	1" OD x .016" Wall	1" OD x .020" Wall
Take from stock 2.960" OD x .205" Wall	Take from stock 2.960" OD x .205" Wall	Take from stock 2.960" OD x .205" Wall
First Tube Reduction 2.000" OD x .076" Wall	First Tube Reduction 2.000" OD x .076" Wall	First Tube Reduction 2.000" OD x .076" Wall
Cut to 20.99' length	Cut to 26.80' length	Cut to 32.60' length
Second Tube Reduction 1.660" OD x .042" Wall	Second Tube Reduction 1.660" OD x .055" Wall	Second Tube Reduction 1.660" OD x .067" Wall
Cut to 42.30' length	Cut to 42.30' length	Cut to 42.30' length
Anneal 4 Hrs. at 1225°F	Anneal 4 Hrs. at 1225°F	Anneal 4 Hrs. at 1225°F
Final Tube Reduction 1.000" OD x .014" Wall	Final Tube Reduction 1.000" OD x .018" Wall	Final Tube Reduction 1.000" OD x .022" Wall
Cut 12ea. 35' length samples Inspect	Cut 12ea. 35' length samples Inspect	Cut 12ea. 35' length samples Inspect
100 psi air-under-water test	100 psi air-under-water test	100 psi air-under-water test
Eddy Current Test	Eddy Current Test	Eddy Current Test
Coil & Check Dimensions	Coil & Check Dimensions	Coil & Check Dimensions
Straighten	Straighten	Straighten
Check Dimensions Re-Eddy Current Test	Check Dimensions Re-Eddy Current Test	Check Dimensions Re-Eddy Current Test
Ultrasonic Test	Ultrasonic Test	Ultrasonic Test

Figure 1. Process No. 1 used for producing 1" OD long length thin wall titanium tubing (with in-process anneal).

PROCESS NO. 2

1" OD x .012" Wall	1" OD x .016" Wall	1" OD x .020" Wall
Take from stock 2.960" OD x .205" Wall	Take from stock 2.960" OD x .205" Wall	Take from stock 2.960" OD x .205" Wall
First Tube Reduction 2.000" OD x .076" Wall	First Tube Reduction 2.000" OD x .076" Wall	First Tube Reduction 2.000" OD x .076" Wall
Cut to 20.99' length	Cut to 26.80' length	Cut to 32.60' length
Second Tube Reduction 1.660" OD x .042" Wall	Second Tube Reduction 1.660" OD x .055" Wall	Second Tube Reduction 1.660" OD x .067" Wall
Cut to 42.30' length	Cut to 42.30' length	Cut to 42.30' length
Final Tube Reduction 1.000" OD x .014" Wall	Final Tube Reduction 1.000" OD x .018" Wall	Final Tube Reduction 1.000" OD x .022" Wall
Inspect Cut to length	Inspect Cut to length	Inspect Cut to length
100 psi air-under-water test	100 psi air-under-water test	100 psi air-under-water test

Figure 2. Process No. 2 used for producing 1" OD long length thin wall titanium tubing (no anneal).

A. Tube Reducing

To reduce processing costs, all base tubes were processed through the first and second tube reductions to the 1.660" OD size without vacuum annealing. The first reduction was accomplished using a large tube reducing machine capable of reducing up to a 3" outside diameter starting tube, but both the second and the final tube reductions were accomplished utilizing a smaller tube reducer capable of accepting tubing with a maximum starting diameter of only 2" (See Figure 3). The use of this machine was mandatory since it was the only machine modified to accept inlet tube lengths up to 48 feet. All tubes at the 1.660" OD size had a minimum length of 42.3 feet, the starting length necessary to meet the 200-ft. minimum length at the 1.000" OD final size.

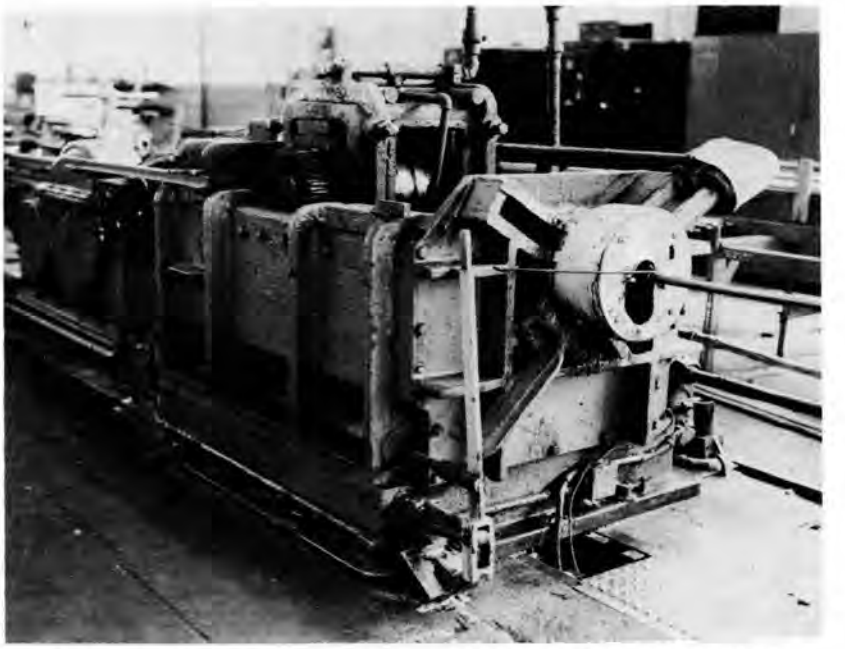


Figure 3 Tube reducer utilized for producing finish 1" OD x 200' minimum length, thin wall titanium tubing.

Originally, all material was to be vacuum annealed at the 1.660" OD intermediate size. This required two furnace loads due to the quantity of tubing. Because of the length (up to 45'), it was also necessary to double-end this material; i.e., anneal with one end of the tubes in the 36' muffle portion of the vacuum furnace and the remainder of the tubes projecting into the 36' cold zone, then reversing the direction of this load and repeating the vacuum anneal. One load of tubes was annealed in a vacuum of less than 1.0×10^{-4} mm Hg for 4 hours at 1225°F. Plant production scheduling prevented the second load of remaining tubes from being annealed at this time, and, therefore, only the annealed intermediate size tubing was initially reduced to the final size. This consisted of ten lengths of 1.660" OD x .067" wall, eleven lengths of 1.660" OD x .055" wall, and seven lengths of 1.660" OD x .042" wall. All finish 1" OD tube met the 200' minimum length requirement with most tube measuring nearly 238 feet (one piece of 1" OD x .013" wall measured 250 feet); however, some lengths were lost during initial tube reducing since it was necessary to cut an occasional tube so that tooling dimensions, etc., could be checked and the tube ID could be inspected for any evidence of lubrication problems. One 1.660" OD x .067" wall intermediate tube that had not been annealed was also reduced to the 1.000" OD x .020" wall size at this time to determine if any in-process annealing was necessary.

In tube reducing the long length finish tube, it was necessary to run the tubing being produced through a hole in the outside wall of the plant housing the tube reducing machine and a temporary wooden run-out trough extension (See Figure 4) was constructed to support the long length being produced. Handling this tube was somewhat difficult due to flexing from the light wall.

Figure 4 Temporary tube reducer run-out trough extension used for producing long length titanium tubing.

A total of 28 lengths (6,735 feet) of 1.000" OD tubing was produced with a finishing length greater than 200 feet (1,775 feet of .014" wall; 2,885 feet of .018" wall; and 2,075 feet of .022" wall). A photograph of this tube is shown in Figure 5.

Figure 5 Thin wall titanium tube produced by tube reducing to size via Process No. 1. Tubing all 1" OD x 200' or greater.

All tubing produced during the first attempt at producing the 1.000" OD x 200' long final tube size appeared to be good quality. Because the desired .012", .016", and .020" final wall sizes were specified as a minimum wall thickness, the tube reducer tooling was designed to produce a .014", .018", and .022" respective average wall thickness. One tube processed to the 1.000" OD x .020" wall final size without an in-process anneal finished with a slightly heavier wall (.024" to .026" wall) than the (.022" wall) material that had been annealed. This was due to the greater amount of die separation in this more heavily cold worked material.

Prior to reducing the balance of the 1.660" OD material awaiting an anneal to the final size; all testing, coiling, straightening, and retesting was accomplished on the 1.000" OD material initially produced. The results of the tests and coiling investigations will be found in the following sections of the report dealing with this work. However, because the tube quality, coiling, straightening, and retesting appeared to be good on the one length of 1.000" OD x .024" wall tube produced without annealing, it was decided to attempt tube reduction of the remaining unannealed intermediate size material to the three final tube sizes. Therefore, eight lengths of 1.660" OD x .067" wall, fourteen lengths of 1.660" OD x .055" wall, and ten lengths of 1.660" OD x .042" wall intermediate size tubes were processed into their respective final .014", .018", and .022" wall sizes according to Process No. 2.

Since tube reducing 200-foot continuous lengths had been previously demonstrated by the tube reduction of 28 tubes via Process No. 1, it was decided to cut the intermediate 1.660" OD hard tube now

being reduced into shorter multiple lengths, finishing at 70' to 90' since these lengths could be more easily handled. Also, should a vacuum anneal be deemed necessary to accomplish this final reduction, the now shorter intermediate size tube could be annealed without scheduling a special double-end vacuum anneal. As a matter of convenience, all 200' minimum lengths previously produced were also cut into 75' multiple lengths for handling and temporary storage.

The tubing reduced to final size without any vacuum annealing ran well; however, due to the excessive cold work, the wall thickness varied more than that previously experienced and the walls were generally from .002" to .004" heavier than the target sizes. All tubing produced during this run is shown in Figure 6.

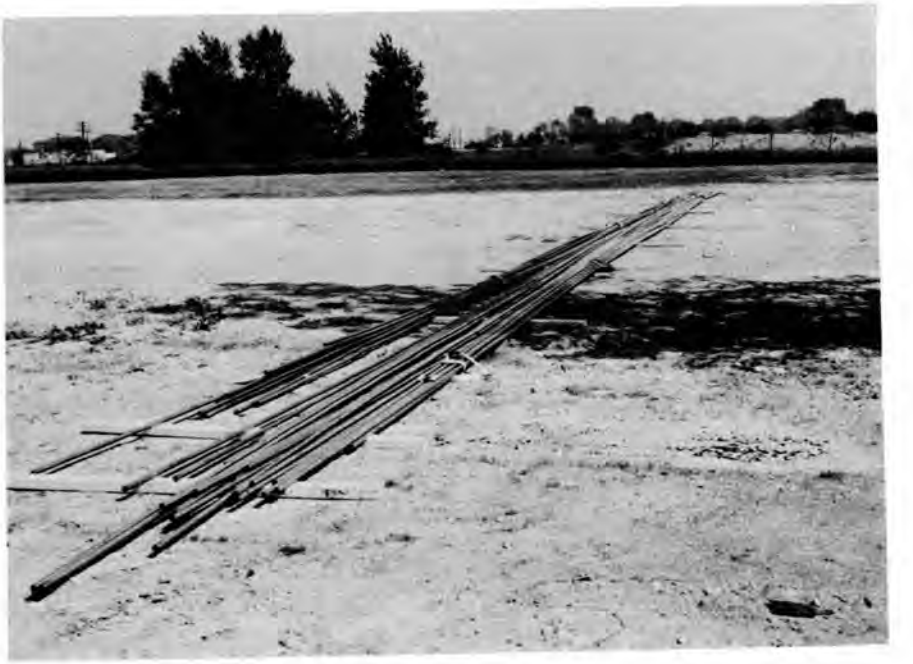


Figure 6 Thin wall titanium tube produced by tube reducing to size via Process No. 2. Tubing all 1" OD x approximately 90' long.

A total quantity of 6,220 feet of 1" OD titanium tube (1,724 feet of .014" wall; 1,626 feet of .018" wall; and 2,860 feet of .022" wall) was produced without vacuum annealing via Process No. 2.

The tube reducing rates for all reductions were essentially fixed by the machine design and the area reduction being employed, but during the course of each reduction higher feed rates were attempted in an effort to reduce projected production costs. In all cases, the feed rate could not be increased significantly above the standard rate for titanium.

B. Coiling, Uncoiling, and Tube Quality

1. Coiling

The coiling investigation was accomplished to determine if long length thin wall titanium tube could be coiled, shipped to the plant site, and uncoiled for use. The coiling experiments were accomplished with representative lengths cut from each size of the tubing processed with an anneal prior to the final tube reduction (Process No. 1) and three samples taken from the one length of 1" OD x .024" wall tube that had been produced from hard tube (Process No. 2).

Twelve 35' lengths were cut from each of the three wall sizes produced and three 35' lengths were taken from the "hard" .024" wall tube. Samples for mechanical tests were also taken from all material. The 35' tubes were then nondestructively tested using 100 psi air-under-water and an eddy current test. No leaks were detected and no indications other than surface scuffing marks from the tube reducing were noted from the eddy current test. The tubes were then shipped to Wolverine Tube's Detroit Plant for coiling and uncoiling. A Conran Coiler (See Figure 7) was utilized for all coiling. The target coil size for this material was a bunch coil with a maximum diameter of 8 feet.

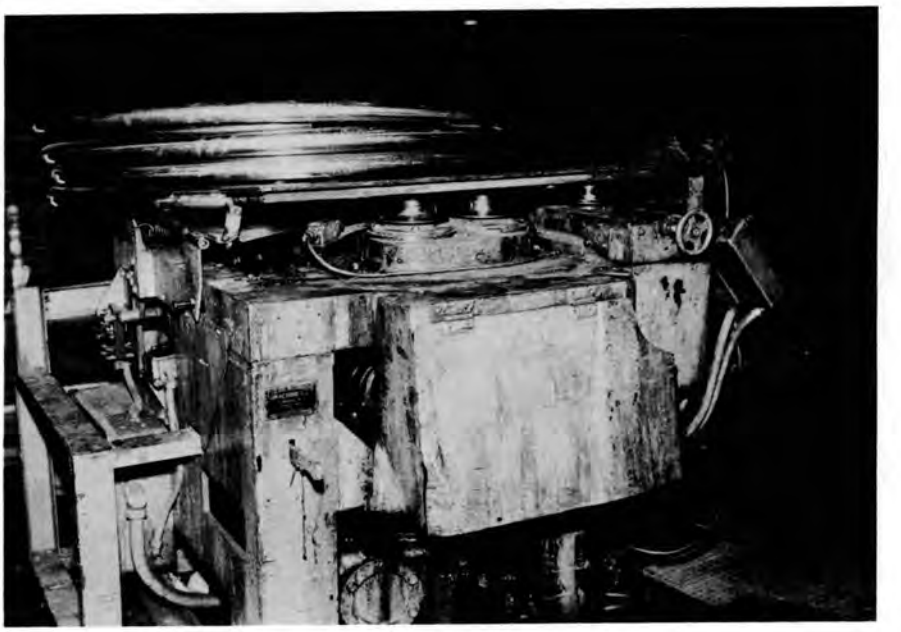


Figure 7 Conran Coiler utilized for coiling sections taken from long-length thin-wall titanium tube - 2" OD copper being coiled.

All tube could be coiled to 8-ft. diameters or less with the exception of the .014" wall material. This tube size would experience buckling of the inside wall unless the coil diameter was increased above 11'; hence, coiling of this tube wall was discontinued. Typical buckling is shown in Figure 8.

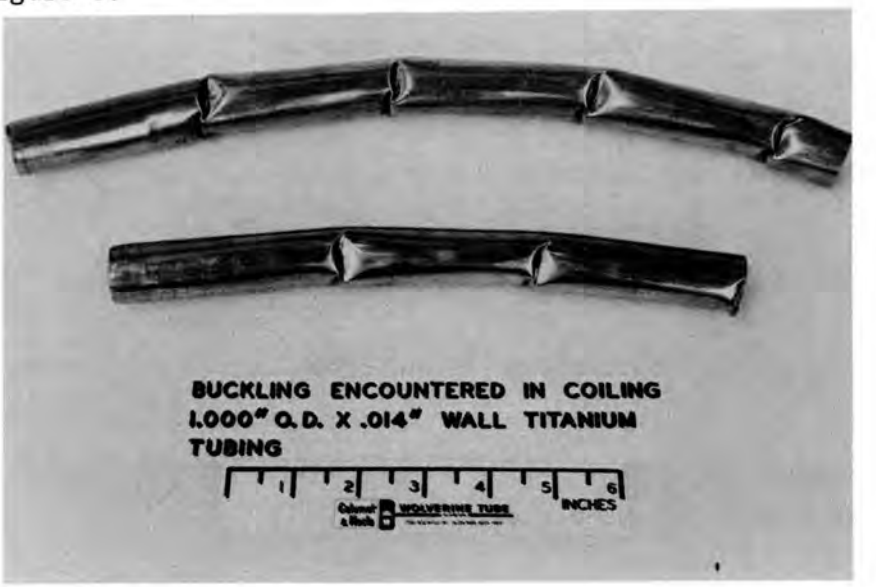


Figure 8 Coiling failure.

All lengths of the .018", .022", and the .024" (hard) tube coiled without difficulty. The .018" wall tube could be coiled to diameters as small as 63" and the .022" and .024" (hard) tubes were coiled to diameters as small as 49". A typical coil is shown in Figure 9.

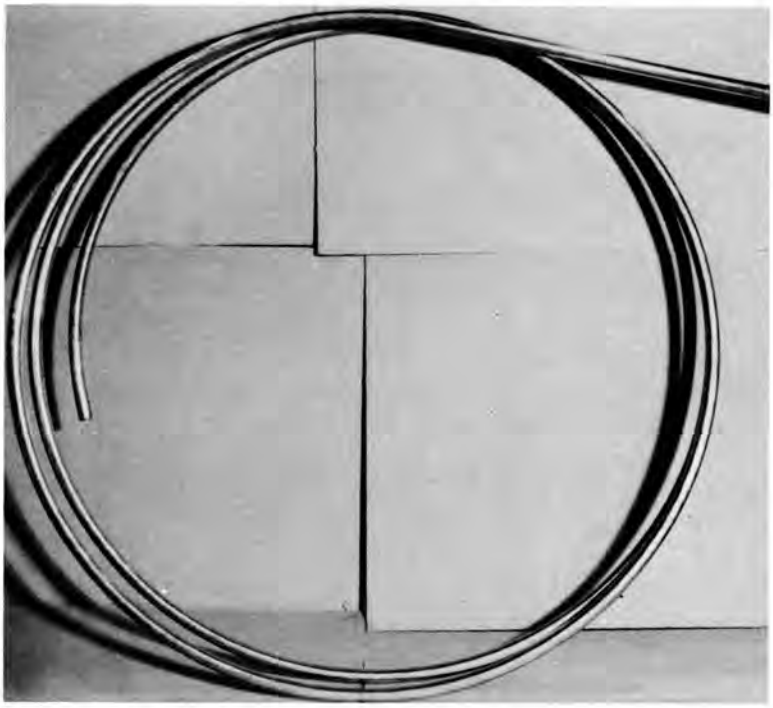


Figure 9 Typical coil produced from a 1.000" OD thin wall by 35-ft. long titanium tube. Coil diameter approximately 63".

The tube diameter variations from the coiling/uncoiling for all tubes are listed in Table I, Page 14.

2. Uncoiling

After coiling, the diameter variation in each tube was recorded and all tubes were uncoiled using a standard 12-roll Torrington straightener using rolls designed for straightening 1" OD copper tube. See Figure 10.

TABLE I

Tube Outside Diameter Variation

Tube Size and Identification	Diameter After Processing Indicated (Inches)		
	Tube Reduced	Coiled (Coil Dia.)	Uncoiled (Total Bow)
1.000" OD x .014" Wall			
No. 8B	1.000"-1.001"	.995"-1.016" (11')[1]	.977"-1.019" (1-1/2")
1.000" OD x .018" Wall			
No. 11A	1.000"-1.001"	.991"-1.018" (81")	.990"-1.008" (1")
No. 11B		.993"-1.017" (91")	.992"-1.007" (1")
No. 11C		.990"-1.016" (91")	.988"-1.010" (1")
No. 4A		.996"-1.016" (91")	.992"-1.009" (1")
No. 4B		.995"-1.019" (68")[2]	.992"-1.010" (1")
No. 4C		.993"-1.019" (81")	.990"-1.006" (1")
No. 4D		.996"-1.017" (96")	.993"-1.007" (1")
No. 4E		.995"-1.018" (92")	.995"-1.007" (2")
No. 6A		.994"-1.017" (92")	.988"-1.012" (1")
No. 6B		.999"-1.011" (96")	.988"-1.016" (1-1/2")
No. 6C		.996"-1.018" (68")	.993"-1.005" (19")
No. 6D		.996"-1.019" (68")	.983"-1.023" (1")
1.000" OD x .022" Wall	1.001"-1.002"		
No. 8A		.991"-1.016" (89")	.993"-1.006" (2-1/2")
No. 8B		.991"-1.017" (52")	.990"-1.007" (1-1/2")
No. 8C		.990"-1.018" (52")	.990"-1.006" (2")
No. 8D		.991"-1.018" (52")	.992"-1.008" (1")
No. 10A		.991"-1.018" (49")	.991"-1.009" (1-1/2")
No. 10B		.991"-1.017" (52")	.991"-1.007" (1")
No. 10C		.991"-1.018" (67")	.990"-1.007" (1")
No. 10D		.991"-1.016" (67")	.992"-1.008" (1")
No. 5A		.991"-1.017" (67")	.992"-1.010" (1-1/2")
No. 5B		.997"-1.001" (98")	.992"-1.007" (1")
No. 5C		.990"-1.017" (49")	.989"-1.006" (1")
No. 5D		.992"-1.019" (50")	.991"-1.008" (1-1/4")
1.000" OD x .024" Wall	1.004"-1.005"		
No. 11A		.996"-1.018" (53")	.999"-1.009" (36")
No. 11B		.999"-1.016" (60")	1.000"-1.008" (5' 1/2")
No. 11C		.997"-1.016" (49")	.997"-1.010" (6-1/2")

Note: 1 - Coiler initially set for 96" coil diameter, but coil buckled.
2 - Coiler initially set for 50" coil diameter, but coil buckled.

Figure 10 Torrington 12-roll Straightener used for uncoiling all titanium tube coils. A 1" OD titanium tube is being straightened from a coil to the left of the machine (not included in photo).

This type of straightener could be used for uncoiling since it is not necessary that the tubes rotate during straightening, as in the case of a cross roll straightener. All tubes were straightened into lengths generally suitable for insertion into heat exchangers with a typical total bow less than 2" over a 35' length. However, since it was necessary to alter and adjust the straightener for each tube wall, the initial tube straightened for each wall size often had a considerable amount of bow; the 1" OD x .024" wall (Process No. 2) hard tube initially uncoiled had a bow greater than 6 feet due to the excessive springback in this highly cold worked material. (See Figure 11) Some tube breakage also occurred during uncoiling as a result of the last 4' of the tubes hitting the first roll of the straightener as it left the pay-off reel.

Figure 11 Typical and varying amounts of bow resulting after uncoiling 1" OD thin wall titanium from 5' diameter coils.

The tube outside diameter variation as a result of coiling and uncoiling is presented in Table I, Page 14. The tube ovality generally ranges from .008" - .020" after uncoiling which is beyond the .012" allowed by the tentative ORNL titanium tube specification; however, tube ovality would be improved if the coiling machine were specifically set up for a constant tube diameter and wall, as would be the case in production uncoiling.

After uncoiling, all tubes were re-eddy current tested to determine if any degradation in quality occurred as a result of the coiling/uncoiling. No significant changes were found and the details of this test are presented in the Tube Quality section of this report.

3. Tube Quality

All as-tube-reduced tube produced by both Processes No. 1 (with an in-process anneal) and Process No. 2 (no anneals) was essentially identical in visual appearance. The tube surface was slightly better than normal ASTM B338-65 Grade 2 titanium tube; however, some very slight outside diameter surface scuffing was apparent on all tubing produced (See Figure 12).

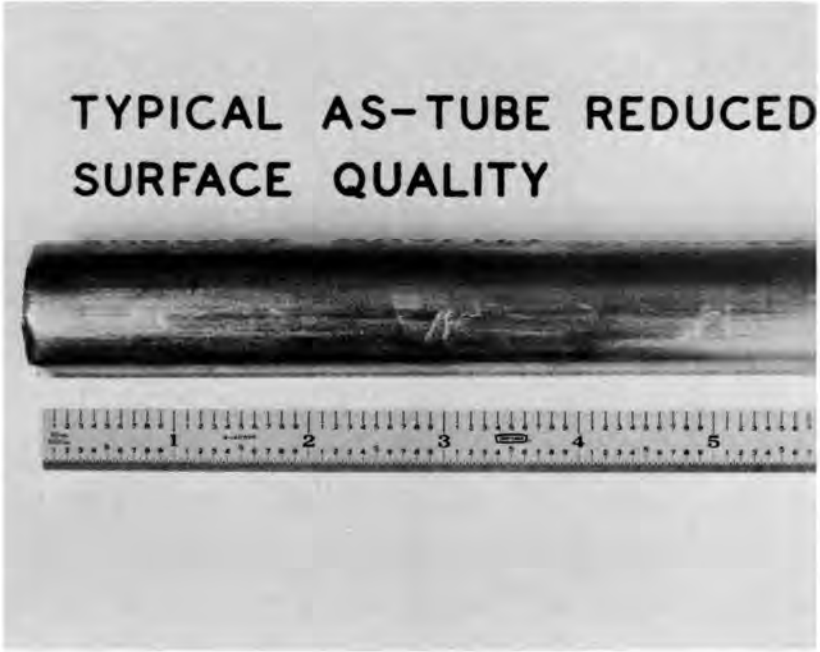


Figure 12 1" OD thin wall 200-ft. minimum length titanium tube. Note very fine longitudinal scuffing marks.

These scuffing marks could be completely eliminated by lightly abrading the outside diameter surface with a very fine plastic wire sponge similar to a scouring pad and, therefore, it is not considered a serious type of surface marking.

Representative samples were taken from all as-tube-reduced and coiled/uncoiled tube for mechanical property testing. These data, along with the tube dimensions, are presented in Table II, Page 19. All cold worked tubing met the Oak Ridge National Laboratory seamless titanium tube specification for annealed tubing with the exception of: The Process No. 2 (no in-process annealing) 1" OD x .024" wall material and all coiled/uncoiled tube. The heaviest wall (.024") tube produced without an anneal failed to meet the 12-times-the-nominal-wall minimum flattening test both before and after coiling and all coiled/uncoiled tube was outside the ovality tolerance permitted by the tube specification. The ORNL specification, however, was intended for annealed tubing and not heavily cold worked material. The ovality problem is of some concern; however, a properly designed tube uncoiler should be capable of meeting the plus/minus .006" tolerance specified. If not, a larger ovality tolerance must be permitted.

It is interesting to note that, although the tubing was heavily cold worked, the mechanical property data (Table II) indicates considerable ductility, since the tube could be flared to as much as a 45% diameter increase without splitting (Figures 13 and 14 show the typical flares produced) although the tensile strength was nearly 130,000 psi with 14% elongation.

TABLE II

Dimensions and Mechanical Properties of Long Length Thin Wall Titanium Tube

Processing Step	Target Dimensions (Inches)		Actual Dimensions (Inches)		Tensile Strength (X1000 psi)		% Elong. 2"	% Flare 60° Cone	Flattening Distance Between Platens (Inches)
	OD	Wall	OD	Wall	Ultimate	Yield			
Process No. 1									
As-Tube Reduced	1.000	.014	.999/1.003	.011/.0155	126.7/131.6	92.7/129.2	(1)	21.0/32.9	.150
After coiling/uncoiling			.978/1.018	.001/.0155	166.2/165.0	142.2/147.2	(1)	25.9(2)/27.0(2)	.150
As-Tube Reduced	1.000	.018	.998/1.003	.015/.018	126.7/127.7	92.7/108.9	(1)	27.6(2)/39.2	.150
After coiling/uncoiling			.990/1.010	.015/.018	143.8/145.7	120.3/121.3	14.0	30.1(2)/36.0(2)	.150
As-Tube Reduced	1.000	.022	.999/1.002	.020/.024	123.0/125.2	111.2/114.2	14.0/14.5	40.4/42.2	.150
After coiling/uncoiling			.988/1.009	.020/.024	137.4/138.4	97.0/109.5	13.0/14.0	44.1/45.5	.150
Process No. 2									
As-Tube Reduced	1.000	.014	1.002/1.005	.015/.016	129.5/136.7	(3)	(1)	22.0/25.8	.200
As-Tube Reduced	1.000	.018	1.003/1.005	.020/.021	134.2/138.0	126.3/130.8	(1)	25.6/29.4	.200
As-Tube Reduced	1.000	.022	1.002/1.004	.023/.026	135.9/142.6	128.4/140.9	(1)	20.0/31.0	.330
After coiling/uncoiling			.990/1.016	.023/.026	144.7/146.8	132.8/144.7	(1)	29.1/33.0	.425
ORNL Specification Proposed for Titanium	.994/1.006	.012min. .016min. .020min.	---	---	50.0min.	---	---	10min.	12 x nom.wall

Notes: (1) Broke Outside of Gage Length
(2) Tube Collapsed
(3) Broke in Jaws, Yield not Obtained.

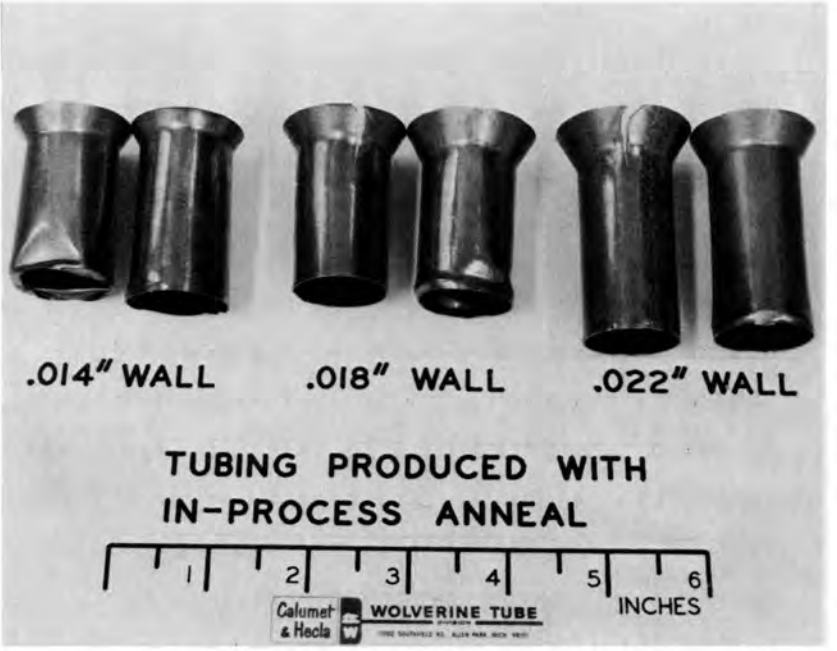


Figure 13 Typical 60° included angle tube flaring of thin-wall long-length titanium tube. Process No. 1 (one in-process anneal) material.

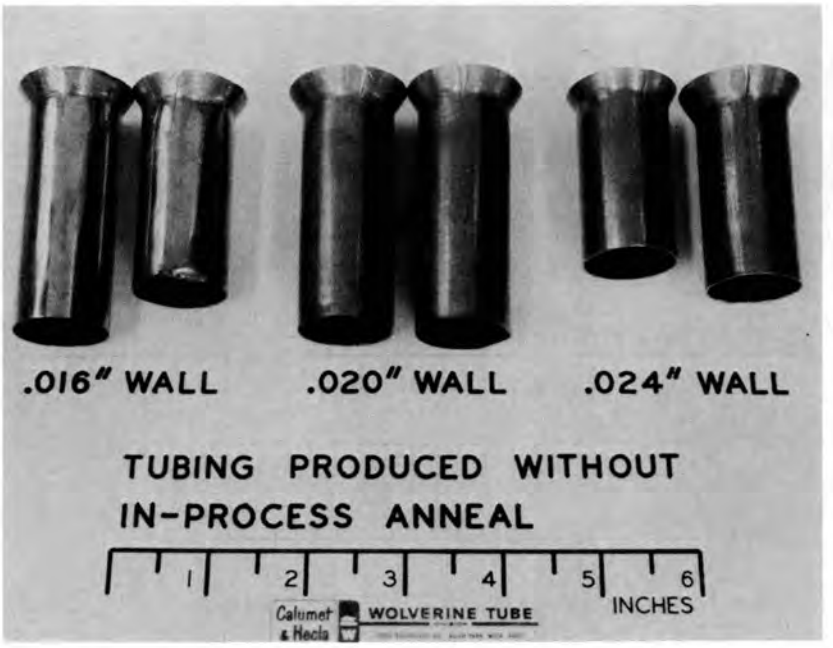
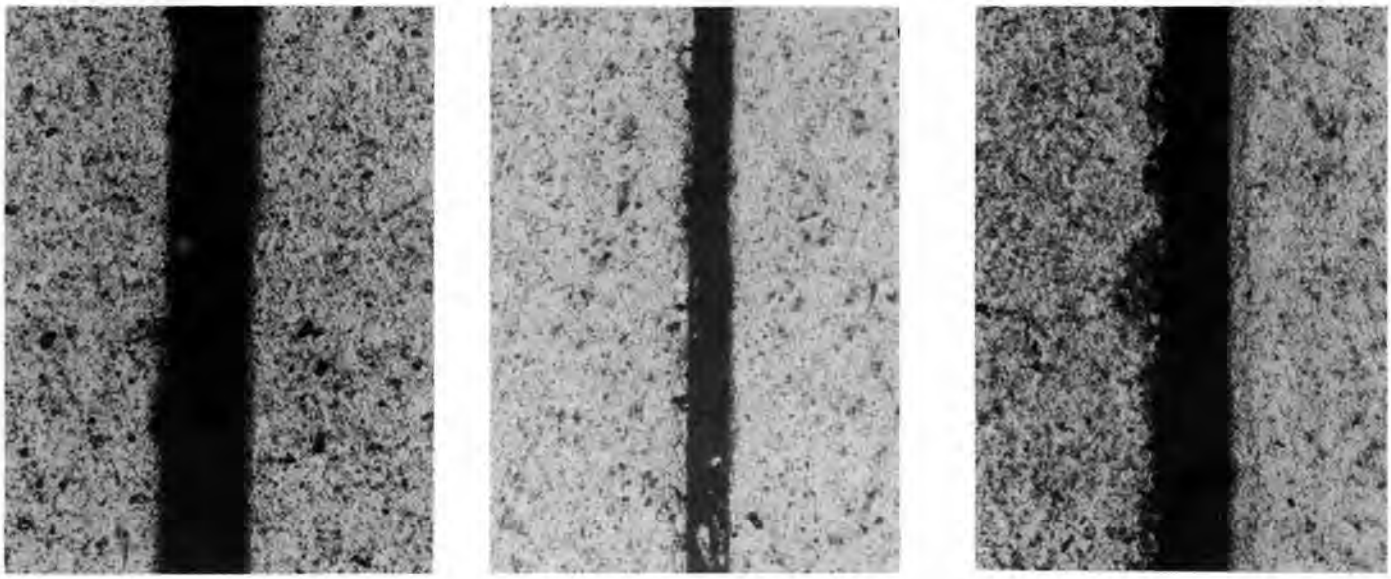


Figure 14 Typical 60° included angle tube flaring of thin-wall long-length titanium tube. Process No. 2 (no anneal) material.

As shown in the photographs of the flare samples, some tubes did not flare to failure because the diameter buckled during the axial loading -- a further indication of the ductility in the material.

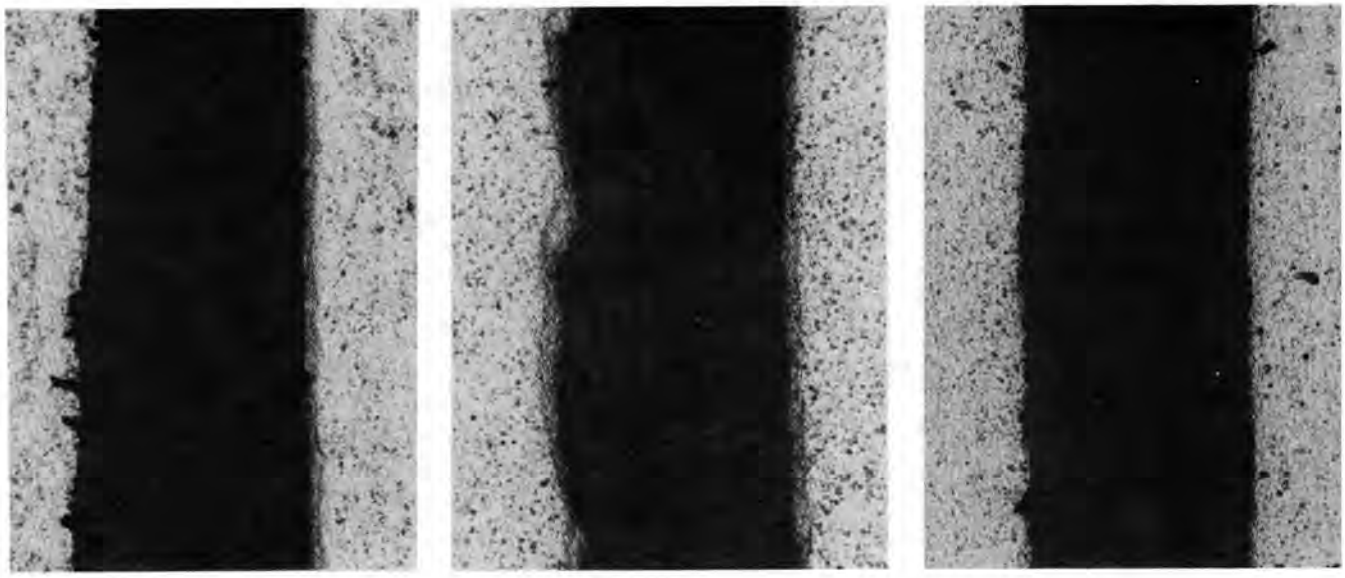
The tensile elongation was not obtained for some tube samples since the fractures occurred outside the gage area. On some of the tube produced without an intermediate anneal (Process No. 2) it was difficult to tensile test the light wall material because the ultimate and yield strengths were very close. Considerable breakage in the jaws was also encountered.

Samples from all tubes were mounted, polished, and examined on the metallograph. Typical longitudinal sections of the surface quality for the tubing produced are shown in Figures 15 and 16.



ID surface OD surface .014" Wall | ID surface OD surface .018" Wall | ID surface OD surface .022" Wall

Figure 15 Typical as-polished and etched tube surfaces for Process No. 1 (in-process annealed) 1" OD long-length titanium tubing. Outside diameter surface on right side, inside diameter surface on left side longitudinal section. 250 diameters mag.



ID surface OD surface ID surface OD surface ID surface OD surface
.015" Wall .020" Wall .024" Wall

Figure 16 Typical as-polished and etched tube surfaces for Process No. 2 (no in-process anneal) 1" OD long-length titanium tubing. Outside diameter surface on right side, inside diameter surface on left side. Longitudinal section. 250 diameters mag.

4. Nondestructive Testing

Prior to coiling, all twelve 35-ft. length tubes cut from the longer .014", .018", and .022" tube walls produced via Process No. 1 were eddy current tested using a Magnetic Analysis 10KC tester and a differential coil designed for 1" OD tubing. The sensitivity was adjusted to the highest level and recorded for each tube such that a tube would pass through the tester without triggering the alarm. After coiling and uncoiling, these tubes were retested under the same sensitivity settings to determine if any detrimental effects resulted from the coiling/uncoiling. In all cases, the eddy current sensitivity was essentially the same except for a few tubes that had been dented or abraded on the surface as a result of the additional handling between tests.

Because the eddy current testing equipment utilized for this evaluation is not considered as reliable as ultrasonic testing, samples of each of the tubes coiled/uncoiled were also tested using immersion ultrasonic inspection techniques for tubes containing both outside and inside diameter notches oriented both longitudinally and transversely to the tube axis. These rectangular notches were .125" long x .005" wide x .002" deep and were produced in representative tubes cut from each of the three tube sizes being tested by electrolytic machining.

A trace from one of the ultrasonic standards is shown in Figure 17. A tube tested showing any indication greater than the shortest indication produced from this calibration tube was considered a reject.

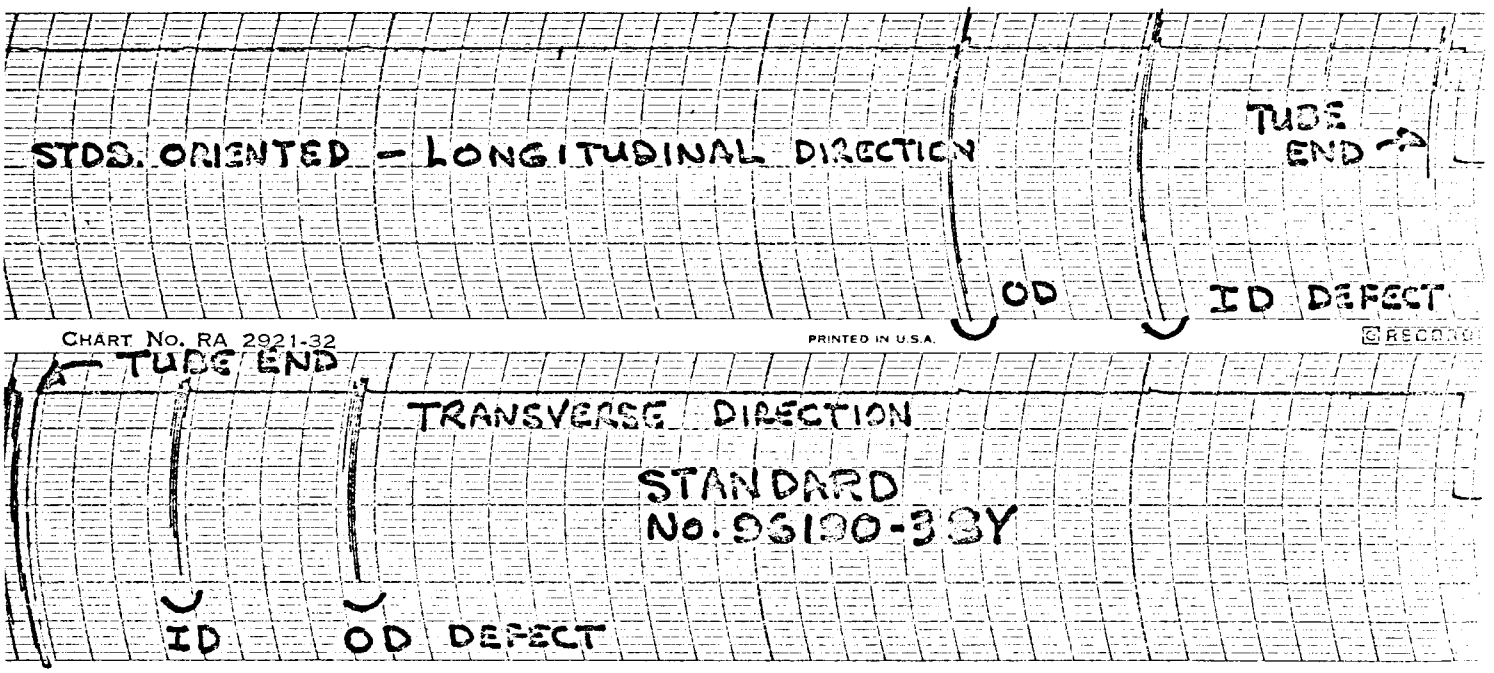


Figure 17 Typical trace produced from a calibration tube utilized for ultrasonic testing. 1" OD x .014" wall titanium tube.

Typical samples from each of the three tube walls produced were subjected to this ultrasonic test using a Sperry Model No. UM721 Reflectoscope. No defect areas were found, but some indications were encountered due to the tubes' being bowed slightly. (The ultrasonic test is extremely sensitive to straightness, especially for light wall material.) From the testing results all material produced is considered high quality tubing.

III

RECOMMENDED PROCESS FOR 360-FT. LENGTH TUBE

The tube quality of both Process No. 1 and Process No. 2 material was extremely good. However, the coiling experiments and the dimensional and mechanical property data indicate that all tube produced without annealing (Process No. 2):

1. Was difficult to uncoil without excessive bowing.
2. Did not meet the flattening test per the ORNL tentative specification.
3. Exhibits fully cold worked mechanical properties with similar tensile ultimate and yield strengths.

In extrapolating the process for producing 360-ft. finished lengths from the experience accumulated with 200-ft. lengths, an in-process vacuum anneal was included since it is doubtful that fully cold worked titanium can be consistently uncoiled and subsequently roller expanded into tube sheets without a higher incidence of splitting or failure to seal.

To produce 360-ft. finished lengths of seamless titanium tubing will require changes to the tube reducing machine. The changes necessary are:

1. Increase the length of the mandrel rod and extend the clamp assembly so that intermediate tube up to 79 feet long can be tube reduced to final size.
2. Beef up the indexing gear train such that the heavier tube being tube reduced to size will not overtax the presently used indexing mechanism.
3. Install a large diameter light-weight mandrel rod (perhaps an alloy steel pipe) so that the total weight of rod and tube being indexed is reduced.

An outline of the recommended process for producing 370-ft. lengths in 1.000" OD x .012", .016", and .020" walls is presented in Figure 18. These lengths are eddy current tested during coiling to 60" diameter level wound coils and then pressure differential tested for leaks. The pressure differential test is equivalent to an air-under-water test. The 370-ft. length produced allows for losses in finishing to the 360-ft. straight length at the desalination plant site.

The 1.000" OD x .012" wall tube was included in the process outline; however, from the coiling attempts conducted, it is uncertain that the .012" wall tube can be successfully coiled on a production basis due to diameter buckling. Improved coiling and uncoiling equipment specifically designed for the .012" wall might be able to overcome the buckling problem and for this reason the process was included.

Producing the millions of feet of long length titanium tubing projected for the desalination plants being proposed will require an entire production facility entirely devoted to producing this tubing. The present process outlined in Figure 18 is designed for producing the 370-ft. length 1.000" OD titanium in the existing Dearborn Heights Plant with only relatively minor modifications to one or more tube reducing machines and procurement of coiling equipment, etc. This plant is capable of providing nearly one million feet per year of titanium tube in the sizes specified at the present time in addition to supplying the nuclear industry with Zircaloy fuel sheath tubing.

PROCESS FOR 360-FT. LENGTH TUBE

1" OD x .012" Wall	1" OD x .016" Wall	1" OD x .020" Wall
Take from stock 2.960" OD x .205" Wall	Take from stock 2.960" OD x .205" Wall	Take from stock 2.960" OD x .205" Wall
First Tube Reduction 2.000" OD x .076" Wall	First Tube Reduction 2.000" OD x .086" Wall	First Tube Reduction 2.000" OD x .108" Wall
Cut to 30.45' length	Cut to 35.79' length	Cut to 35.78' length
Anneal 3-1/2 Hrs. at 1225°F	Anneal 3-1/2 Hrs. at 1225°F	Anneal 3-1/2 Hrs. at 1225°F
Second Tube Reduction 1.660" OD x .038" Wall	Second Tube Reduction 1.660" OD x .050" Wall	Second Tube Reduction 1.660" OD x .058" Wall
Third Tube Reduction 1.000" OD x .012" Wall	Third Tube Reduction 1.000" OD x .016" Wall	Third Tube Reduction 1.000" OD x .020" Wall
Trim end, cut to 370' length	Trim end, cut to 370' length	Trim end, cut to 370' length
Eddy Current Test Coil to 60" diameter	Eddy Current Test Coil to 60" diameter	Eddy Current Test Coil to 60" diameter
Final Inspect Pressure Differential Test Pack	Final Inspect Pressure Differential Test Pack	Final Inspect Pressure Differential Test Pack
Ship to Site	Ship to Site	Ship to Site

Figure 18. Recommended process for producing 360-ft. length light wall titanium tubing and coiling for shipment.

IV

ON-SITE PREPARATION OF LONG LENGTH COILS

The long-length coils would be shipped to the desalination plant site in knock-down returnable crates by rail (or truck). Each crate would contain four titanium coils or 225 pounds of material. The gross weight of each crate would be nearly 300 pounds, which can be easily handled by fork lift trucks. The best coil size would be a level wound coil with a minimum diameter of 5 feet (as determined from the coiling study). Four coils will then fit into a 4' x 6' x 6' crate. Dividers could also be included in the crate to prevent the light wall tube diameter from buckling or denting; however, since the tube being shipped is essentially cold worked and in a level-wound coil form, damage should not be a problem.

At the desalination plant site, the crates containing the coiled tube would be unloaded by conventional means and moved to the uncoiling-finishing station adjacent to the evaporator.

The uncoiling-finishing area is envisioned as a temporary building designed to house:

1. A carrousel rack conveyor feeding the coils from outside the building to the uncoiling machine.
2. A pay-off reel.
3. A straightening station with a run-out extending from the building.
4. Eddy current test equipment.
5. Cut-off, deburr equipment.

In addition to this equipment, movable storage racks are required outside the building designed to accommodate the finished 360-ft. titanium straight tube ready for installation.

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At the uncoiling area the coils would be unpacked and placed on the carrousel feed to a pay-off reel feeding the uncoiling machine designed for uncoiling light-wall tube. In line with the uncoiler would be an eddy current test station which would check for reject tubing (dents, and mechanical damage) incurred during the uncoiling operation. The straight tube would discharge onto long run-out tables and then move on rollers for cutting to exact length. Movable racks for storage of the straightened finished tubes would accommodate the high volume of tube being produced.

It is anticipated that one straightener and accompanying handling, inspection, and processing equipment, and a three-man crew would have a finishing capacity of approximately 8 million feet per year per shift. An around-the-clock operation could finish nearly 30 million feet per year.

V

PROJECTED 1970 PRICES

The projected selling prices for 1" OD x .012", .016", and .020" minimum wall seamless titanium tube in 360-ft. lengths is presented. The prices are based upon titanium billet prices remaining at $3.00 per pound; the production processing recommended in this report which includes one in-process vacuum anneal; transportation from the Midwest to the Los Angeles area; and shipping in coils, uncoiling, and straightening at the installation site. These prices do not include any additional on-site processing.

Projected 1970 Selling Prices Per Foot
1" OD Seamless Titanium Tube x 360-Ft.
Produced to Tentative ORNL-2 Specification

.012" Wall	.016" Wall	.020" Wall
$0.962/Ft.	$1.119/Ft.	$1.264/Ft.

VI
CONCLUSIONS

1. The production of 1.000" OD x .012", .016", and .020" minimum wall seamless titanium tube in lengths up to 250 ft. has been demonstrated.

2. The tubing produced from both processes (Process No. 1 with an in-process anneal and Process No. 2 with no anneals) is considered very high quality material as determined by destructive and nondestructive tests.

3. On the basis of the 12,955 ft. of 1.000" OD long-length tubing produced, the production of 360 ft. continuous lengths is considered feasible.

4. Coiling and uncoiling of the tube sizes produced has been demonstrated and coiling is considered feasible for 360-ft. lengths. The 1.000" OD x .012" minimum wall tube size may not be suitable for coiling.

5. The tube produced with an in-process anneal (Process No. 1) met all requirements of the ORNL specification for titanium tubing.

6. The tube produced without any anneal (Process No. 2) did not meet the flattening test required by the ORNL specification for titanium tube.

7. After uncoiling, the ovality of all 1.000" OD tube exceeded the ±.006" required by the ORNL specification. The total at-a-point ovality ranged from .020" to as much as .040" for this tubing, but this can be improved by coiling/uncoiling equipment designed for light wall material.

8. Titanium tubing in 1.000" OD x .012", .016", and .020" minimum wall thickness in lengths finishing at 360' can be produced by the tube reduction method with modifications to one tube reducing machine at the Dearborn Heights Plant.

9. One in-process anneal is considered necessary for the titanium tube produced to facilitate coiling/uncoiling and rolling-in without tube failures.

10. Eddy current testing is considered suitable for testing long length titanium tubing.

11. Shipment of 360' length tubing can be accomplished by coiling to a minimum diameter of 5', in level wound coils, crating, and placement on rail cars or truck, and uncoiling at the evaporator site.

12. To accomplish the coiling/uncoiling, etc., additional equipment must be provided and a temporary building must be constructed at the desalination plant site.

APPENDIX F

FINAL REPORT

THE AUTOMATIC WELDING OF TITANIUM TUBES TO TITANIUM CLAD STEEL TUBE SHEETS

SUBCONTRACT NO. 2712
(REVERE XX1259)

SUBMITTED TO

OAK RIDGE NATIONAL LABORATORY
UNION CARBIDE CORPORATION
NUCLEAR DIVISION
OAK RIDGE, TENNESSEE 37830
(MR. B. E. MITCHELL)

FOR

OFFICE OF SALINE WATER

BY

REVERE COPPER AND BRASS INCORPORATED
RESEARCH AND DEVELOPMENT CENTER
ROME, NEW YORK 13440

JULY 25, 1967

Submitted: W. V. Waterbury, Manager
Welding Section

Approved: E. S. Bunn
Vice President

ABSTRACT:

Satisfactory welding procedures have been developed for consistently producing high quality welds between thin walled titanium tubes and titanium clad tube sheets. The effects of various welding variables have been studied and are reported herein.

OBJECT:

To establish a reliable procedure for producing high quality welds between titanium tubes and titanium clad tube sheets by automatic welding methods which would be applicable to the field erection of tube bundles for desalination plants.

CONCLUSIONS:

1. The best joint design is the use of a straight hole with the tube end slightly recessed below the surface of the tube sheet.

2. Contact between the tube wall and the hole may be achieved either by flaring the tube end slightly or by lightly rolling.

3. Inert gas shielding on the back side of the tube sheet is not required.

4. The minimum thickness of the titanium cladding should be 3/32".

5. No difficulties were encountered in the use of either the tungsten inert gas or high frequency welded tubing.

6. The estimated production rate for welding is 350 to 400 tube ends per man per shift.

INTRODUCTION:

On October 25, 1965 the Research and Development Center of Revere Copper and Brass submitted a proposal to the Oak Ridge National Laboratory for a study to develop satisfactory procedures for welding titanium tubes to titanium clad tube sheet using the Revere Automatic Tube Welding Gun. The tube material for this study was to be 3/4" x 0.016" wall titanium and the plate material was to be 1 1/8" thick A212 steel clad with 1/8" of titanium by explosive bonding. It was proposed to machine off some of the titanium to obtain thinner claddings. The variables to be investigated

INTRODUCTION: (CONTINUED)

were joint design, the welding variables of speed, amperage, shielding gas, back side shielding and prepurge and postpurge times. The quality of the welds was to be evaluated by metallographic examination and mechanical testing.

A revised proposal submitted on January 3, 1966 provided for the inclusion of welded tubing made by tungsten inert gas and high frequency welding to determine whether these materials will weld the same as the seamless grades of tubing. The complete scope of the contract is given in Appendix B.

PROCEDURE:

A. Materials

1. Plate - The plate material obtained for welding consisted of 15 sq. ft. of 1 1/8" thick A212 Grade B steel explosively clad with 1/8" of B265 Grade 1 titanium by duPont. The cladding analysis is given in Appendix I.

2. Tubing - The tubing obtained for welding consisted of four types and sizes of tubing of B265 Grade 2 material having the analyses listed in Appendix I.

   a. 3/4" x 0.022" wall - Seamless - Wolverine Tube Division of Calumet and Hecla, Detroit, Michigan

   b. 3/4" x 0.020" wall - Tungsten Inert Gas Welded - Titanium Metals Corporation of America, West Caldwell, New Jersey

   c. 1" x 0.018" wall - Seamless - Reactive Metals Inc., Niles, Ohio

   d. 1" x 0.016" wall - High Frequency Welded - Titanium Metals Corporation of America

B. Welding

1. Welding Gun Sequence - The Revere Automatic Tube Welding Gun being used for this investigation is essentially a gas shielded tungsten arc torch which is rotated around a mandrel inserted in the tube being welded. The tungsten arc melts and flows the tube and tube sheet material to produce an autogenous weld without the addition of filler metal. When the gun trigger is activated to initiate the welding cycle a flow of shielding gas is started for a prepurge. After a timed prepurge a high frequency current initiates the welding arc and the welding torch rotation is started. The torch rotation continues 360° plus a 30° overlap to re-fuse the start of the weld at which point a current decay is initiated to reduce the welding

PROCEDURE: (CONTINUED)

current to a level which will eliminate any crater when the arc is broken. The shielding gas flow is continued for a timed period to protect the weld and the tungsten electrode while they cool. The welding torch completes the second revolution where it stops automatically and is ready for another weld. Figure 1 shows the welding gun in position for welding in an experimental tube bundle and the power source and control console.

2. Survey of Joint Designs - The initial work was done on the 3/4" x 0.022" wall seamless tubing because it was considered that this material would be the easiest to develop procedures for. Prior to use the tubing was cut into 12" lengths, the ends were faced off in a lathe and the outside surfaces of the tube ends were sanded lightly to remove any surface contaminants prior to degreasing.

The 12" x 12" square clad tube sheets were thoroughly checked by ultrasonic testing to assure the integrity of the bond. Indications in some cases which were originally thought to indicate lack of bond later proved to be false except in one instance where a blister in the cladding was evident and this plate was not used. The plates were drilled with 3/4" diameter holes on 1 1/4" centers using a square grid pattern for ease of sawing for weld examination. The surface of the titanium cladding was lightly sanded and thoroughly degreased prior to welding.

The basic joint designs studied are shown in Figure 2. Variations of these designs consisted of changes in the location of the tube end and of changes in the depth to which the tube holes were countersunk. The initial welding was done using joint design (a) with the tube end flush with the tube sheet surface. All experimental welding was done with the tube sheet in the vertical plane and the tubes horizontal.

The tube end was flared slightly with a swaging tool prior to "setting" the tube in the hole with a stop tool having a pilot which enters the bore of the tube and a square shoulder which will stop against the face of the tube sheet as the flared tube is driven into the hole. Other welding conditions were:

TABLE I

Shielding gas	Argon 20 cfh
Gas prepurge	3 seconds
Gas postpurge	15 seconds
Welding speed	6 seconds per revolution
Arc length	0.015-0.020"
Amperage	60-70 amps. DCSP

PROCEDURE: (CONTINUED)

These welding conditions resulted in slightly too little penetration of the weld and also in the weld bead rolling over into the bore of the tube trapping the bearings. Dye penetrant testing of these welds, however, showed no leaks and metallographic examination showed the welds to be sound and free from porosity.

In order to prevent the weld bead from rolling over into the bore of the tubes the next series of welds was made using the double tapered joint design shown in Figure 2(d). This joint design leaves a substantial gap between the end of the flared tube and the tube sheet and it was found that with the very light wall tubing being used the tube tended to melt back regardless of the location of the arc. Since this condition is very similar to a tube extension it was not felt practical to use any tube extension for this or for the other joint designs.

A large number of welds were then made using the joint designs shown in Figures 2(b) and (c) with the tube ends positioned flush with the tube sheets. With these joint designs it was found that it was practical to repeatedly make good welds if very close attention was paid to the joint setup and to the location of the arc relative to the tube-tube sheet interface. It was found, however, that when the tube sheet holes were reamed to provide 0.008"-0.010" clearances such as would be necessary for tubing a heat exchanger, the very light walled tubes still tended to melt back and that it was sometimes impossible to repair these areas by merely rerunning the weld.

Based on these results efforts were again directed to the joint design shown in Figure 2(a) but with the tube end recessed below the surface of the tube sheet. Varying depths of recess were tried and 0.040" was settled on as giving the best weld contour and the most reproducible conditions. The following welding conditions were established which gave the best weld contour and a minimum weld cross-section approximately equal to the tube wall thickness:

TABLE II

Joint Design	Figure 2(a) with 0.008-0.010" clearance
Tubing	0.022" wall seamless
Tube Sheet	1/16"-1/8" cladding
Tube End Position	Recessed 0.040"
Welding Speed	6 seconds/revolution
Amperage	75 amps. DCSP
Arc Length	0.015"
Tungsten (Thoriated)	1/8" diameter ground to a 30° point
Arc Path	0.020"-0.025" outside hole on tube sheet face
Shielding Gas	20 cfh Argon
Gas Prepurge	3 seconds
Gas Postpurge	15 seconds

PROCEDURE: (CONTINUED)

Using these welding conditions excellent welds were consistently produced either with the tubing flared with a 10° included angle flaring tool prior to being "set" in the tube sheet with a stop tool or with the tubing being positioned and then contact rolled into the hole with a dry rolling tool to hold it during the welding operations. Figure 3 shows the excellent uniform appearance of the welds made using these conditions. Welds stamped GRL were lightly rolled and those marked GRH were "hard" rolled. Figure 4 is a photomicrograph of a typical cross-section through a weld made using these conditions.

A number of joints were also "hard" rolled into the holes to make sure that rolling in excess of that needed to hold the tubes would not be detrimental and no weld defects or "blowouts" were experienced. It was found, however, that if a minute amount of oil was placed between the tube wall and the hole in the tube sheet prior to rolling a "blowout" in the weld would occur in each joint.

Eight welds made using these conditions were tested to determine the strength of the welds by cutting off the tubes about 5" behind the tube sheet and welding the end of the tube closed. A mandrel was then inserted in the tube against the closed tube end and the tube pushed out of the tube sheet in a tensile machine in such a manner that the weld is tested in tension. Figure 5 shows the manner in which the welded joints are positioned in the tensile machine for testing. The tensile strengths are calculated on the basis of the cross sectional area of the tube wall. Four of the tubes fractured through or adjacent to the weld at strengths of 71,800, 69,900, 74,800 and 78,600 psi while the other four fractured through the tube wall near the back side of the tube sheet at strengths of 72,800, 72,800, 79,600 and 72,800 psi respectively.

3. Shielding Gas - The welding gun is designed so that the arc is initiated by a high frequency overlay current and argon shielding gas is generally preferred because the arc initiates better in it than in helium. However, a number of welds were made with 75% He-25% A to determine if there was any advantage to a predominantly helium atmosphere but no advantage was found from a welding standpoint.

A sample of a weld made using the 75% He-25% A shielding as well as a similar sample using 100% argon shielding was submitted to Titanium Metals Corporation of America for evaluation regarding shielding and any possible contamination particularly on the outside of the tube in the crevice between the tube and tube sheet. Their results confirmed our finding that there was no difference between the two shielding gases and that any contamination was limited to a very minor degree of surface oxidation which did not have any effect on weld ductility.

PROCEDURE: (CONTINUED)

To check this further a series of welds was made with argon and a second series with 75% He plus 25% A. Some welds in each series were rerun a second time to simulate a repair procedure which should have accentuated any contamination which might occur.

The tensile strength of these welds was checked as described above with the following results which show no significant difference between the two shielding gases or between the single or two pass welds:

TABLE III

Shielding Gas	Weld Type	Strength (PSI)	Failure
Argon - 20 cfh	Single Pass	72,800	Edge of Weld
Argon - 20 cfh	Single Pass	70,900	Edge of Weld
Argon - 20 cfh	Single Pass	71,800	Tube
Argon - 20 cfh	Rerun	76,700	Edge of Weld
Argon - 20 cfh	Rerun	74,800	Tube
Argon - 20 cfh	Rerun	72,800	Tube
75% He-25% A - 20 cfh	Single Pass	75,700	Tube
75% He-25% A - 20 cfh	Single Pass	71,800	Edge of Weld
75% He-25% A - 20 cfh	Single Pass	71,800	Edge of Weld
75% He-25% A - 20 cfh	Rerun	77,700	Tube
75% He-25% A - 20 cfh	Rerun	79,600	Edge of Weld
75% He-25% A - 20 cfh	Rerun	72,800	Tube

4. Welding Speed - Normally it is desirable to weld as fast as possible from both a metallurgical as well as from an economical standpoint. Most of the experimental welding was performed at a speed of 6 seconds per revolution but some welds were made at 9 second per revolution to see if this improved metal flow. No advantages were found so slower speeds were not pursued.

5. Cladding Thickness - In order to investigate the minimum cladding thickness required for welding it was planned to machine off varying amounts of titanium to leave the amount desired. In practice it was found that this was difficult to control accurately because of the out-of-flatness of the plates. Several plates were press flattened as much as possible and approximately 1/16" of titanium was machined off leaving 1/16" thickness of cladding on the tube sheet. This was found to be sufficient for welds made using the optimum welding conditions established of 75-80 amps at a speed of 6 seconds/revolution. When the welding current was increased slightly, however, to 95 amps, the depth of penetration was increased to the point where iron pick-up in the weld occurred. This was accompanied by gross porosity in the weld, globules of undissolved iron

PROCEDURE: (CONTINUED)

in the weld bead and the formation of a brittle diffusion layer at the titanium-iron interface through which cracking occurred. These effects are shown in Figures 6 and 7 showing welds in areas where the cladding was 0.050" and 0.055" thick respectively. Thus it is apparent that the 1/16" cladding is an absolute minimum thickness and that this provides no margin of safety for such eventualities as repair welding procedures or cutting a weld out to replace a tube.

6. Welded Tubing - The 3/4" x 0.020" wall TIG welded tubing was welded using the straight hole, an 0.040" recessed tube end and the other welding conditions listed in Table II. No difficulty was experienced with the welded tubing and as far as could be determined the weld in the area of the seam was just as good as in other areas.

The 1" x 0.018" wall seamless and the 1" x 0.016" wall high frequency welded tubing were both welded satisfactorily using an 0.030" recessed tube end in a straight hole at a speed of 6 seconds/revolution and an amperage of 85-90 amps with the other conditions shown in Table IV. No problem was encountered with the welding of these tubes and the reproducibility was good. If high frequency tubing was used in production the internal flash would have to be scarfed off or a notched bearing would have to be used. Figure 8 shows the typical surface appearance of welds made using these two types of tubing.

TABLE IV

Joint Design	Figure 2(a)
Tubing	1" x 0.018" wall seamless 1" x 0.016" wall HF welded
Tube Sheet	3/32"-1/8" cladding thickness
Welding Speed	6 seconds/revolution
Amperage	85-90 amps. DCSP
Arc Length	0.015"
Tungsten (Thoriated)	1/8" diameter ground to a 30° point
Arc Path	0.020"-0.025" outside hole on tube sheet
Shielding Gas	20 cfh Argon
Gas Prepurge	3 seconds
Gas Postpurge	15 seconds.

DISCUSSION:

A. Welding Procedure

The results of this investigation have demonstrated that it is possible to produce high quality welds with a high degree of reproducibility between titanium tubes and titanium clad tube sheets. At the same time it must be recognized that the relatively light wall gauge of the tubes under consideration makes the welding procedures more critical than they would be if heavier wall tube were being used.

In any automatic welding of tubes to tube sheets cleanliness of the components is of utmost importance if acceptable quality welds are to be achieved and titanium is probably less tolerant of contaminants than many other materials. For all of the experimental welding the tube ends were machined square, the outside surfaces were sanded, the tube sheet face was sanded and both the tubes and tube sheets were degreased in a xylene base cleaner and thoroughly dried prior to welding. Under these conditions no difficulties were encountered which were attributable to lack of cleanliness but it was found that when a small amount of oil was intentionally introduced into the joints porosity and blowholes resulted in each weld. If a procedure of rolling the tubes into the holes was adopted, the roller would have to be used dry and the use of air tools should be avoided since the air exhaust often carries oil fumes which have been found to contaminate tube sheets in the past. Sufficient care must be taken in all of the steps of assembly of a unit to insure that a high level of cleanliness is maintained prior to welding.

The results of the welding have shown that inert gas shielding of the back side of the tube sheet is not necessary because there is not a sufficient volume of air present in the crevice between the tube and tube sheet to produce a detrimental amount of contamination during the welding cycles used. The use of argon shielding on the surface of the weld has proven completely satisfactory and is preferred from a welding standpoint. Normal prepurge times of three seconds and postpurge times of fifteen seconds have proven satisfactory in preventing any surface discoloration of the weld or adjacent areas. In actual practice the reason for the relatively long postpurge is to protect the tungsten electrode during cooling because the weld itself is practically cold to the touch as soon as the gun can be withdrawn from the tube after the arc is extinguished.

The most satisfactory joint design was found to be a straight hole with the tube end recessed 0.030"-0.040" below the surface of the tube sheet as shown in Figure 2(a). The arc path is maintained about 0.020"-0.025" outside the hole which in effect melts off the corner of hole and flows the molten metal down to the end of the tube. Using this joint design the tube end is slightly removed and shielded from the arc and the arc does not have as much tendency to melt out the tube wall beyond the area where the tube sheet is molten leaving a hole or a "stitched" weld. The joint designs such as Figure 2(b), (c) and (d) with countersunk holes and flared tube ends are more

DISCUSSION: (CONTINUED)

adaptable to the use of flush tube ends, but it was found with these joints that unless the arc path and arc length were just right the tube wall was prone to melting back too far thus leaving holes in the weld which were difficult and sometimes impossible to repair by rerunning with the gun because the tube wall was melted away too deeply. Using the straight hole with the recessed tubes the few defects which were encountered were able to be repaired by rewelding with the welding gun.

The use of a clad tube sheet and of a recessed tube end in a straight hole is covered by U.S. Patent No. 3,257,710 which was filed November 25, 1960 and issued on June 28, 1966 to F. X. Brown et al and assigned to Westinghouse Electric Corporation. No determination of the validity of this patent has been made although we believe there is a large amount of prior art in both the use of clad tube sheets and in the use of recessed tubes.

With respect to cladding thickness it was found that a 1/16" cladding thickness was sufficient to permit the production of good quality welds using the optimum welding conditions listed in Table II of the Procedure. It was also demonstrated that relatively small changes in welding conditions such as welding amperage could produce very detrimental results with this cladding thickness because of iron pick-up in the weld bead and the formation of hard brittle areas in the weld and at the titanium-steel interface. Obviously, the 1/16" cladding leaves no margin of safety for such eventualities as the need for rerunning a weld as a repair procedure or even the possibility of cutting out a weld to install a new tube. It is recommended, therefore, that the minimum cladding thickness considered should be 3/32" and that a 1/8" thick cladding should not be considered unreasonably heavy.

In the experimental welding one aspect of the clad tube sheets which caused a considerable amount of difficulty was the waviness or out-of-flatness of the plates as received. The welding gun is designed to rest against the tube sheet at three points, two of which are fixed feet and the third is a microswitch designed to prevent activating the welding cycle until the gun is firmly in position against the tube sheet. When the tube is perpendicular to the tube sheet the gun is also held perpendicular by the mandrel in the bore of the tube and in many areas it was found that the waviness of the tube sheet made it difficult to locate the welding gun so that the limit switch would be depressed and closed. Also in welding light walled tubes it is desirable to use a relatively short arc to concentrate the arc and locate the area of fusion precisely. With a wavy tube sheet the arc length varies as the gun rotates around the tube circumference and in some cases this can result in stubbing out the arc in some areas while having a desired arc length in others. Tube sheet flatness on copper metals has not been found to be a problem with normal tube sheet flatness tolerances so it is recommended that explosively clad tube sheets should be held within these tolerances for welding (e.g. ASTM B171).

DISCUSSION: (CONTINUED)

B. Welded Tube Vs. Seamless Tube

Welded tubing, produced by both tungsten inert gas welding and high frequency welding, was successfully welded into the tube sheets using the same conditions as used for the seamless tubing of the same size. There was no indication that either type of welding would influence the welding of the tube into tube sheets.

C. Probable Production Rates

The optimum welding procedure developed for 3/4" x 0.022" wall tubes was the use of a straight hole with the tube end recessed 0.040" below the tube sheet surface, 20 cfh of Argon shielding gas, a 3 second prepurge time, a welding speed of 6 seconds/revolution, a welding current of 75-80 amps DCSP, an arc length of 0.015" and a 15 second postpurge gas flow. Using this welding cycle the time required to make each weld is 3 seconds for the gas prepurge plus 12 seconds for gun cycling, since the welding gun makes two revolutions for each weld, or a total time of 15 seconds. Allowing 15 seconds for the operator to remove the gun and insert it into a new tube it would be theoretically possible to make two welds per minute or 120 welds per hour providing all the necessary cleaning and setting or rolling of the tubes was done ahead of the operator. In actual production, however, it has been found that an operator can't work at this pace and experience has indicated that 350 to 400 welds per 8 hour shift is a realistic production rate. If the welder is also required to perform any operations such as setting of tubes or final cleaning, the production rates will obviously be lower. It is recommended that production welding should be done using a skip pattern of welding to minimize the heat build-up in any one area and to help control tube sheet warpage as a result of welding.

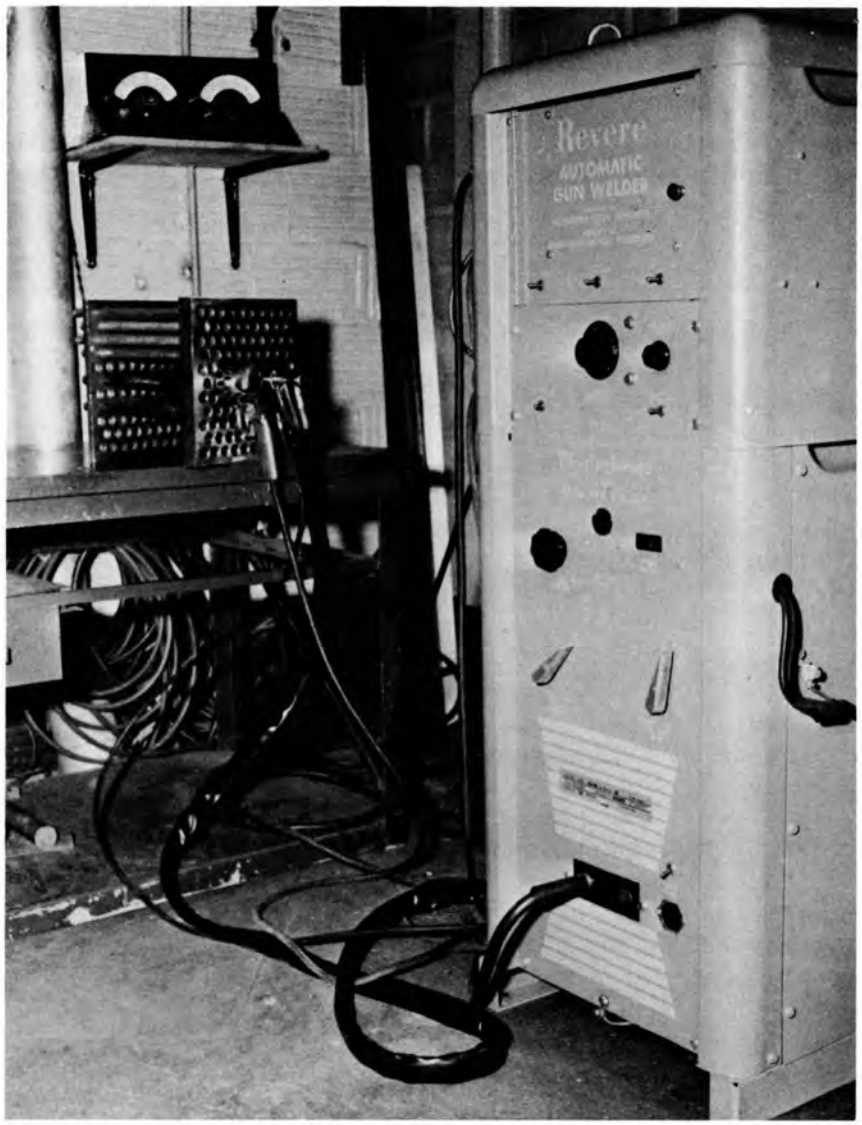

Figure 1: Shows the Revere Automatic Tube Welding Gun in position for welding and the power source and control console.

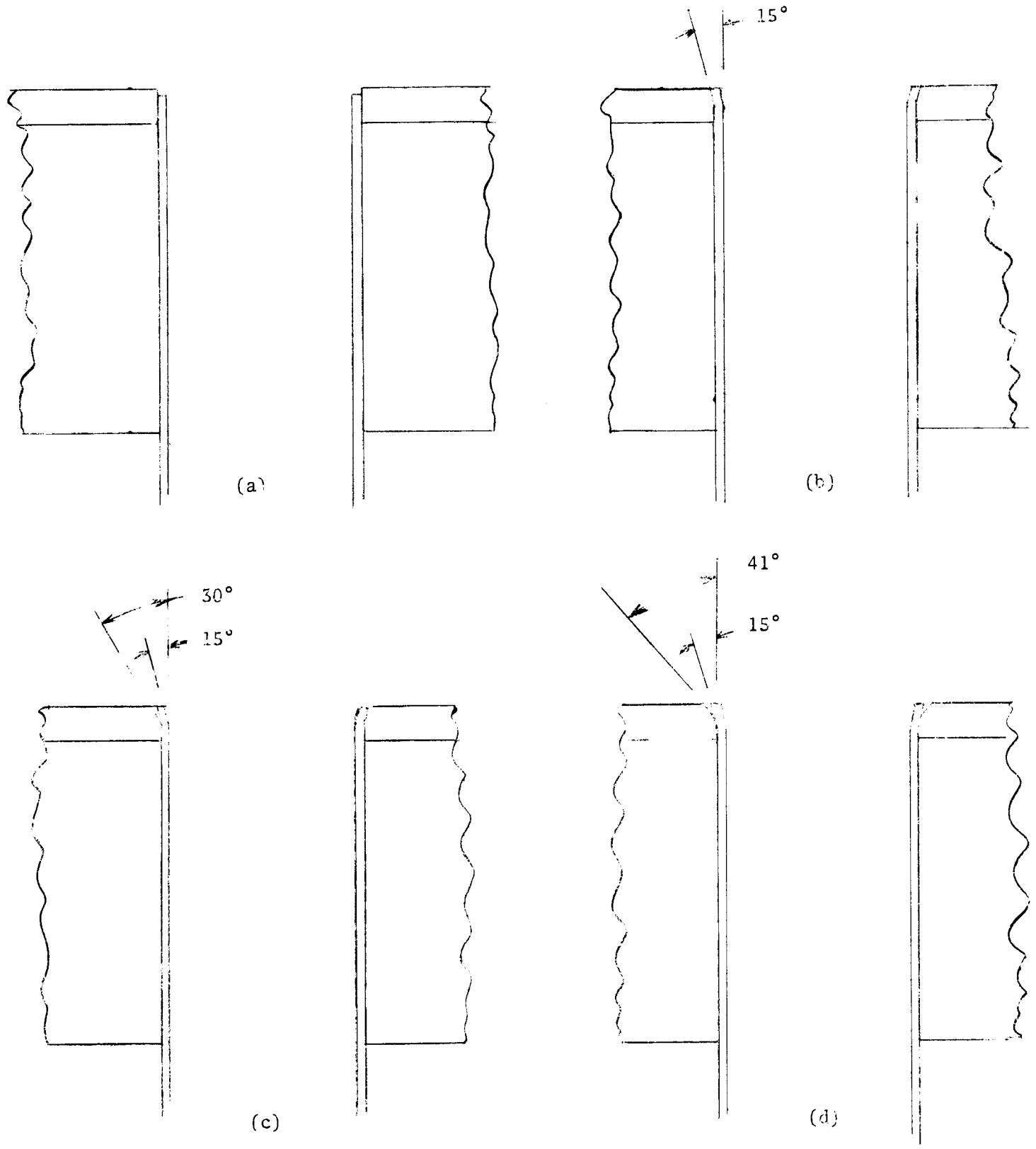

Figure 2: Joint designs studied. The joint shown in sketch (a) was determined to be the preferred design.

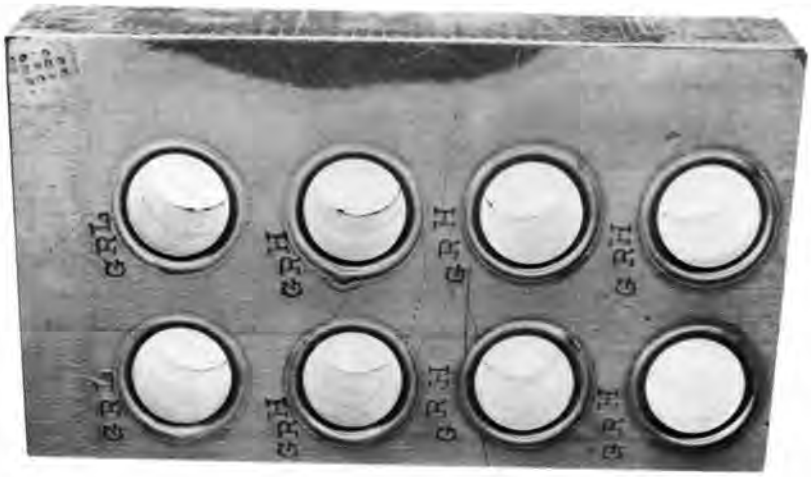

Figure 3 Magnification: 3/4X approx.

Illustrates the excellent surface appearance of welds in 3/4" x 0.022" wall tubing using the conditions shown in Table II. Welds designated GRL are rolled lightly and those labeled GRH are rolled hard prior to welding.

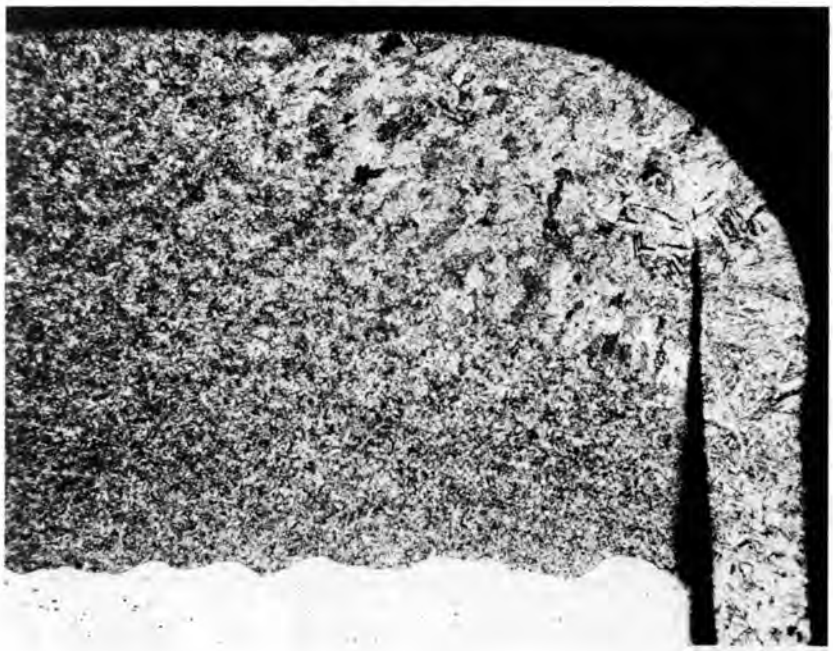

Figure 4 Magnification: 25X

A typical photomicrograph of a good weld between a 3/4" x 0.022" wall seamless tube and a 0.110" cladding thickness as shown in Figure 3.

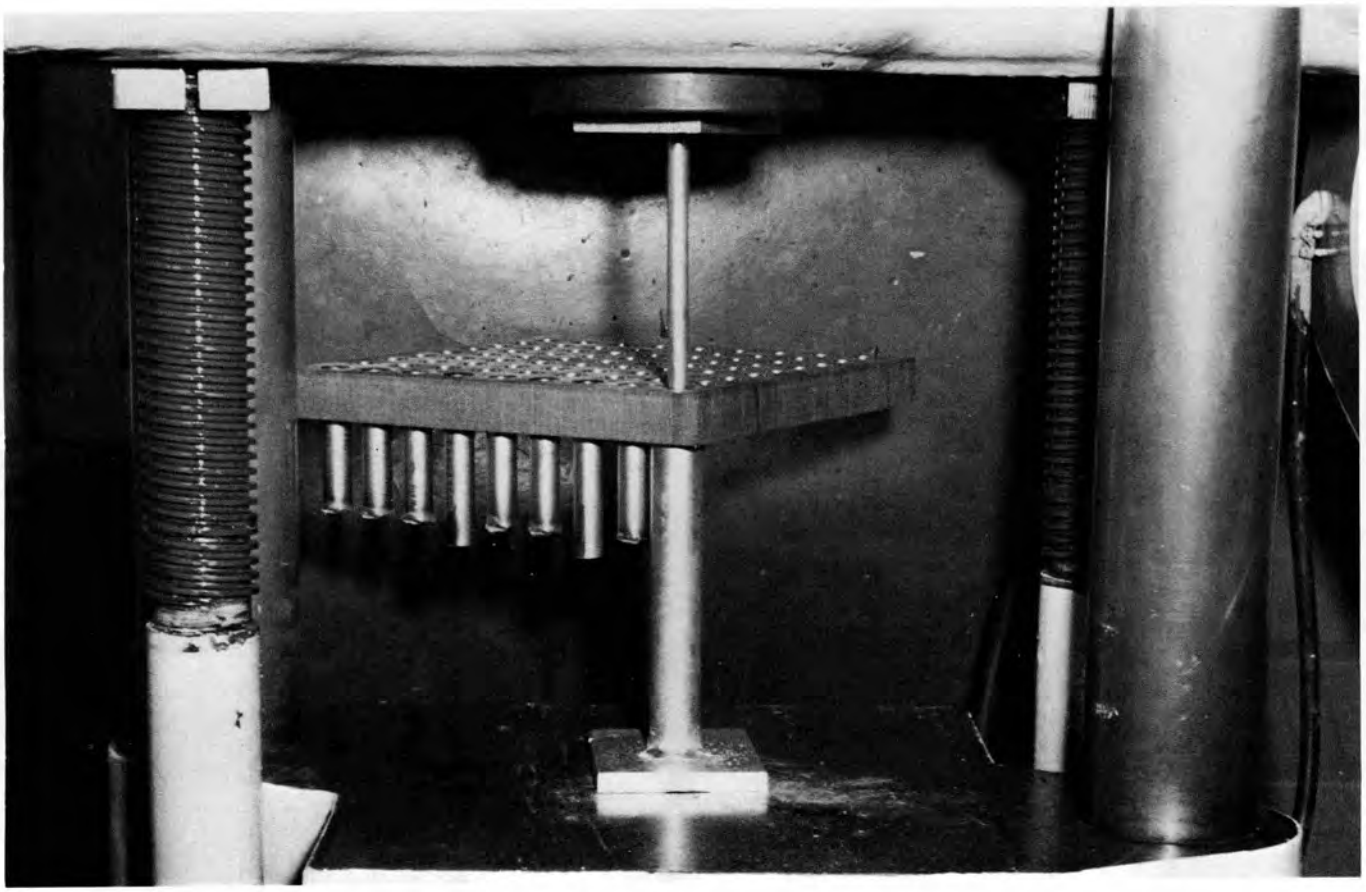

Figure 5: Illustrates the positioning of the tube sheet in a tensile machine with the titanium tube being pushed into the hollow support member by the rod pushing against the closed bottom end of the tube.

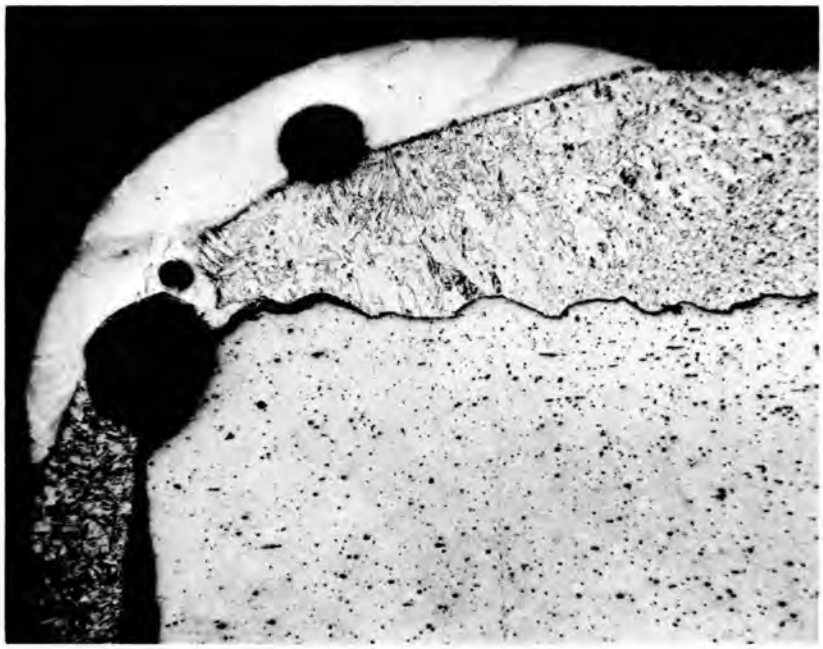

Figure 6 Magnification: 25X

Illustrates high iron content weld bead and porosity resulting from excessive weld penetration. Cladding thickness 0.050".

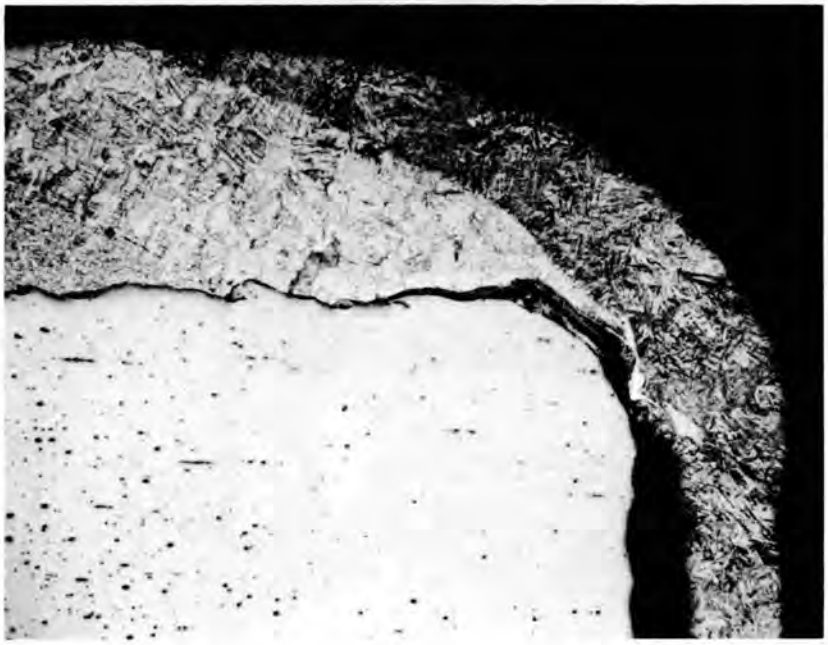

Figure 7 Magnification: 25X

Illustrates cracking through brittle diffusion zone between titanium cladding and steel resulting from excessive weld penetration. Cladding thickness 0.055".

Figure 8 Magnification: 3/4X approx.

Illustrates the appearance of welds using 1" x 0.018" wall seamless tubes in the top row and 1" x 0.016" wall high frequency welded tubes in the bottom row. Welding procedures are shown in Table IV and the right hand tube in each row has been re-run to simulate a repair procedure.

APPENDIX I

Analysis of Tube Sheet Cladding and Tube Materials
From Material Certification Reports

Material	Tube Sheet Cladding	3/4" x 0.022" Seamless	3/4" x 0.020" Welded	1" x 0.018" Seamless	1" x 0.016" Welded
Supplier	DuPont	Wolverine	Timet	Reactive	Timet
Carbon	0.023%	0.09%	0.023%	0.02%	
Nitrogen	0.006		0.011	0.01	
Iron	0.06	0.005	0.10	0.16	
Oxygen	0.07	0.012	0.16	0.11	0.140%
Hydrogen	0.004		70 ppm	18 ppm	73 ppm
Copper		0.023			
Lead		0.12			
Palladium		0.11			

APPENDIX B

WORK SCOPE UNDER SUBCONTRACT 2712

1. Investigation of cladding thickness on weld quality and determination of minimum allowable without embrittlement.

2. Establishment of proper joint design, such as whether tubes extend outward from the tube sheet, are flush, or are recessed.

3. Evaluation of straight, countersunk, and double-tapered tube holes.

4. Evaluation of the required parameters to produce leak-tight joints of adequate strength. Parameters shall include welding speed, arc length, amperage, gas mixtures and flow rates, and front and back side shielding.

5. Determination of whether welded tube behaves differently from seamless tube. Approximately nine hundred (900) welds shall be made for evaluation purposes.

6. Conducting metallographic studies and tensile tests to determine the results of the above tests.

7. Compilation of report which will include the recommended joint design, cleaning procedures suitable for field application, and welding practice. Also, the report will include an estimate of the number of tube welds per day one man could make working under average conditions, based on Seller's field experience.

Moran FJ
THE FABRICATION OF SMOOTH TUBES FOR LARGE MULTISTAGE FLASH EVAPORATOR DESALINATION PLANTS
Oak Ridge National Laboratory, Oak Ridge, Tenn.
ORNL Report No. TM-2750 (November 1969) 169 p

This report covers the state of the art of tubing fabrication, industrial capacity to produce tubes, and possible improvements in technology to reduce costs. The present copper tubing output is about one billion pounds per year and is produced with high-speed tube reducers and bull blocks. Copper-alloy tubes for condenser service amount to 150 million pounds per year, generally produced with slower and less economical bench drawing equipment. Production tests demonstrated the feasibility of processing copper-nickel tubes on the same facilities used to produce copper tubing. Present fabrication costs for seamless copper-nickel tubing average well above $.50 per pound with bench drawing equipment, but could probably be reduced to approximately $.20 per pound in an advanced-technology facility producing three million pounds of tubing per month. Copper-nickel tubes can be fabricated by welding flat strips into tubular shape but over the long term, seamless tubing will probably be cheaper. The fabrication of thin-wall seamless titanium tubes by cold reduction is uneconomical, and high-frequency welding of flat strips into tubular shape is more promising. Eddy current testing was reliable for detection of flaws in seamless tubes. More work, however, is needed to improve the reliability of the test as applied to welded tubes.

*HORIZONTAL TUBE EVAPORATORS + COMPONENT COSTS + *CONDENSERS + *COPPER ALLOYS + ECONOMIC EVALUATIONS + *FABRICATION METHODS + WELDING + METAL DRAWING + METAL ROLLING + OSW SPONSORED + *TITANIUM + *TUBING(METAL)

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