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ROTARY ELONGATION OF URANIUM TUBING

BY

R. B. STECK
H. W. HESSELBROCK

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ABSTRACT

One hundred twenty-eight uranium tubes were rotary elongated successfully on a No. 1 Witter mill at the American Manufacturing Company of Texas (AMCOT), Fort Worth, Texas. The test was performed by the National Lead Company of Ohio on a small, shell-rolling mill which utilized the same three-roll rolling principle now in use in the Assel-type seamless tube mill. Feed stock for the test was supplied by extrusion and by centrifugal casting. Billets were preheated in a gas-fired muffle furnace and were protected by a continuous flow of argon. Evaluations were made of billet preheat temperature, mandrel heating, roll cooling, roll design, roll speed, feed angle, grain structure, and type of feed-stock. Slippage problems encountered in previous tests were corrected by roll design modifications, a reduction in roll rotational speed, and an increase in feed angle.

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1. INTRODUCTION

As a means of increasing reactor efficiency, the reactor sites have developed the tubular uranium fuel core. This development resulted from extensive investigations of fuel core geometries and evaluations of their reactor performance. The tubular fuel core has a greater surface-to-volume ratio than that of solid cores and, hence, provides an improvement in heat transfer. This, in turn, permits longer exposure periods and increased power levels in the reactors.

At the present time, many hollow fuel cores are fabricated from rolled rods by a sequence of machining, drilling, and reaming operations. An inherent disadvantage of the present process is that relatively large quantities of chips and other machining scrap are generated. For this reason, the National Lead Company of Ohio has been investigating alternate methods of producing tubular fuel core blanks. One of the most promising routes consists of the following operations:

1. Solid Casting
2. Rolling
3. Rotary Piercing
4. Rotary Elongation
5. Sink Reduction
6. Heat Treating
7. Final Machining

This proposed route differs from the present route principally in the rotary piercing, rotary elongation, and sink reduction steps. With the successful completion of the rotary elongation test, each of the operations in the proposed fabrication route has been demonstrated.

A discussion of the principles of rotary elongation may be found in section 9.1.

2. PREVIOUS WORK

The initial feasibility test for the rotary elongation of uranium tubes was held in the Bloomfield plant of the Westinghouse Electric Company in February, 1958.[1] The work was performed on a No. 1 Witter mill. The test was unsuccessful because of excessive slippage between the workpiece and the roll surfaces.

A second rotary elongation test was conducted on the same mill in June, 1959.[2] The mill roll speed was reduced to 43 rpm (128 rpm was used in the previous test). To reduce slippage, sand was poured between the workpiece and the roll surfaces. Although this alleviated the problem, feed efficiencies were low (5% to 13%). Reductions in area of 44% to 63% were achieved. Tube surfaces were free of gross defects; however, outer surfaces were relatively poor because of the effects of the sand and the roll slippage. The slippage induced a temperature increase at the outer surface of the uranium tube that resulted not only in a poor surface finish but also in grain growth near the surface.

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3. OBJECTIVES

The over-all objective of this rotary elongation test was to demonstrate the technical feasibility of the process. Specific objectives were as follows:

1. To define the necessary operating conditions for the equipment and investigate the limitations of the process.
2. To determine the effect of rotary elongation on uranium grain structure.
3. To develop reliable data for a cost evaluation.

4. SUMMARY OF RESULTS

Rotary elongation of uranium tubing was shown to be feasible on an Assel-type seamless tube mill. During the test, 128 tubes were successfully elongated. Results are listed below in terms of the major variables investigated.

4.1 BILLET PREHEAT TEMPERATURE

Successful rotary elongations were made with billets preheated between 1000°F and 1175°F. There was some evidence of radial cracks in tubes that were preheated to the lower temperatures. Most of the cracks were located along the inner surfaces of the tubes.

4.2 MANDREL HEATING

Billets were elongated with mandrels at room temperature and at 500°F. No differences in grain structure were detected along the inner surfaces of tubes elongated under these two conditions. There was less difficulty in extracting mandrels that were preheated to 500°F.

4.3 MANDREL LUBRICATION

Coated and uncoated mandrels were used in the test. The coated mandrels were less difficult to extract from the finished piece. Of the lubricants tested, the best results were obtained with Fiske 604.

4.4 ROLL COOLING

The initial rotary elongations were made without cooling the rolls with water. The periphery of the elongated tubes contained extremely large alpha-phase grains. These grains were believed to result from the temperature rise induced by work and friction. Cooling the rolls (and the outer tube surface) with water reduced the amount of grain growth.

4.5 ROLL PROFILE

Three types of rolls were used in the test. Two had humps, or shoulders, at their midpoints. One type was smooth. Highest efficiencies were recorded on tubes elongated with the rolls having 0.125-inch-humps.

4.6 ROLL SPEED

Nominal roll speeds of 25, 35, 45, and 70 rpm were used throughout the test; 35 rpm appeared to be the optimum roll speed.

4.7 ROLLING EFFICIENCY (Ratio of the actual delivery rate to the theoretical delivery rate).

During the production phase of the test (48 rotary elongations), the average rolling efficiency per tube was 95.34%. The average efficiency for the first reduction pass was 82.74%; the average efficiency for the final reduction was 107.94%.

4.8 REDUCTION IN AREA

Reductions in cross-sectional area of 25% to 45% were achieved. Optimum results were attained when taking relatively small reductions. For a 60% reduction, two rotary elongation passes of approximately 25% to 35% were used.

4.9 FEED ANGLE

Two sets of bearings were used to skew the rolls. The angles of skewness, or feed angles, were 3 and 6 degrees. Optimum results were received with the 6-degree feed angle.

4.10 SINK REDUCTION

A sink-reduction pass was simulated by elongating without use of an inner tool or mandrel. Inferior ID surfaces were obtained.

4.11 TYPE OF FEED STOCK

The type of feed stock used had no significant effect on rolling efficiency or metal quality. Feed stock was prepared by centrifugal casting and extrusion. Various heat treatments were employed.

4.12 CONCENTRICITY

Concentricity of finished tubes was almost independent of the quality of the starting billet. The average wall thickness variation of tubes processed in the production phase of the test was approximately 0.030 inch. Starting billets with large wall thickness variations were improved in concentricity; when the starting billets contained slight variations in wall thickness, the eccentricity increased.

4.13 WEIGHT LOSSES

The average weight loss per billet was approximately 0.4 lb. This loss was caused by oxidation and mechanical working.

4.14 GRAIN STRUCTURE

Severe, duplex grain structures were obtained during the first part of the test. When the feed angle was changed from 3 degrees to 6 degrees, all traces of duplexing were eliminated.

4.15 RETAINED BETA-SIZE GRAIN STRUCTURE

Two billets were elongated in the beta phase to obtain examples of a retained beta-size grain structure. The periphery of each billet contained large cracks and was extremely rough.

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5. DESCRIPTION OF EQUIPMENT

The rotary elongation test was performed at the American Manufacturing Company of Texas (AMCOT) during July and August, 1961, using their No. 1 Witter mill. This small shell-rolling mill (Figures 1 and 2) operates by the same principles of rotary rolling as the Assel-type seamless tubing mills. Several differences exist, however, between this mill and the conventional, three-roll, seamless tubing mills used in the steel industry. The industrial seamless tubing mill is capable of finer adjustment and has fully mechanized means of inserting the mandrel into the starting piece and in stripping the mandrel from the finished tube.

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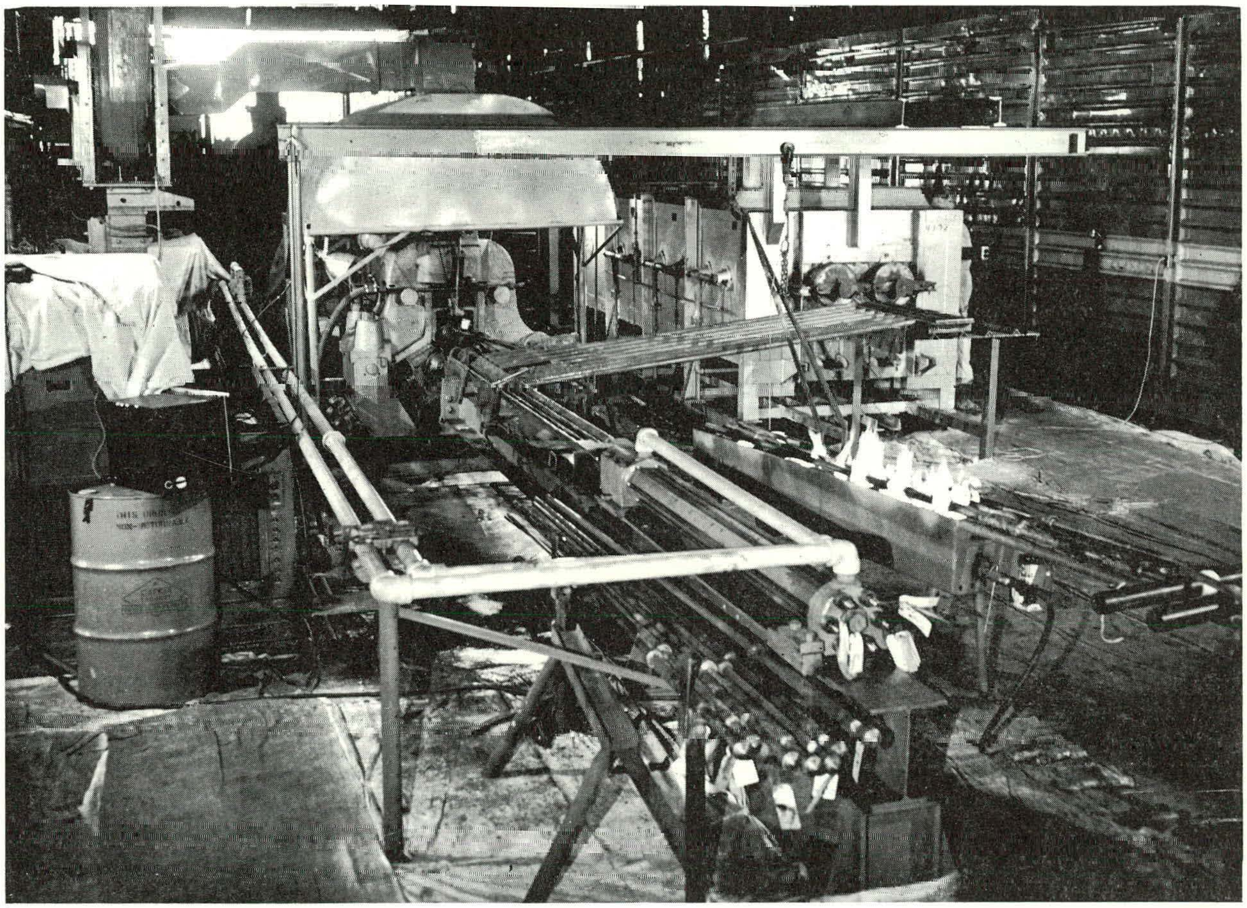

FIGURE 1 Over-All View of AMCOT No. 1 Witter Mill

The AMCOT mill was modified to meet the requirements of this test. The direction of rolling was reversed from that used in normal practice. In the original design of the mill, the workpiece was fed from the drive spindle end of the mill. The purpose of the change was to permit the workpiece to enter the mill over the small end of the rolls and to leave over the large end of the rolls. This produced an increasing rotational speed in the workpiece as it passed through the mill.

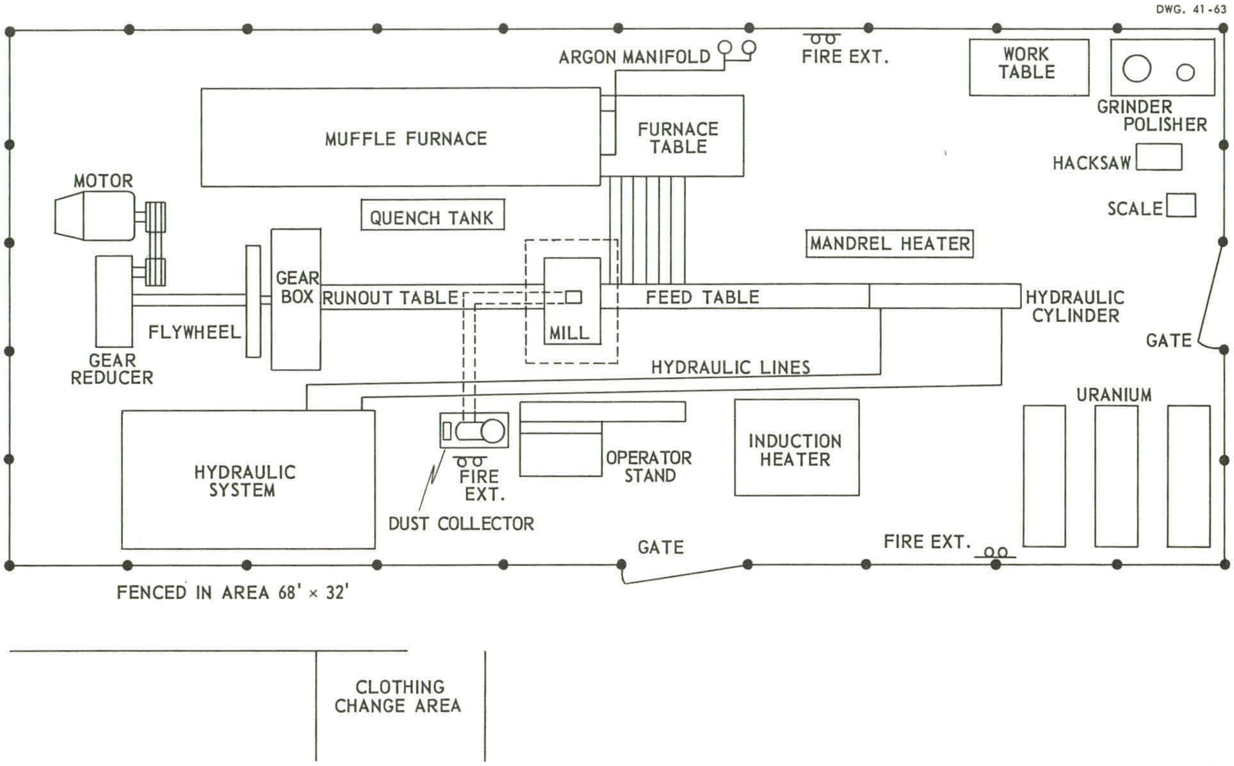

FIGURE 2 Plan View of AMCOT Mill Area

The mill was driven by a 300-hp, 700-rpm, 2300-v, a-c synchronous motor. Power was transmitted through a V-belt drive and a Falk gear reducer (Figure 3). The gear reducer operated at a reduction ratio of 4.22:1. The mill drive gear operated at a reduction ratio of 4.75:1. The total effect was to provide a base roll speed of 35 rpm. Sheaves and pulleys made available additional roll speeds of 25, 45, and 70 rpm.

Four sets of 10 ½-inch-diameter rolls were used during the test; (14-inch-diameter rolls had been used on the mill to produce shells). The use of the smaller diameter rolls was necessary to produce tubes with an OD of less than 2 inches. With a roll opening (gorge) of approximately 2¼ inches or less, the surfaces of the 14-inch-diameter rolls would have been touching.

Three sets of rolls were made from cast iron. The shoulders, or humps, on two of the sets were 0.220 inches and 0.125 inches. The third set of rolls was without a hump. Figure 4 shows the roll with the 0.220-inch hump. Twenty-four scallops, 0.020-inch deep by ½-inch wide by 5-inch long were machined into the surface of each roll inlet face. A fourth set of rolls was fabricated from a softer steel alloy; the roll shoulders were 0.125-inch high. Scallops 0.060-inch deep were machined into both inlet and outlet surfaces.

To prevent the rolls from overheating and to reduce oxidation of the uranium, cooling water was directed on the rolls and the tube periphery during rotary elongation. The water was pumped from a 200-gallon

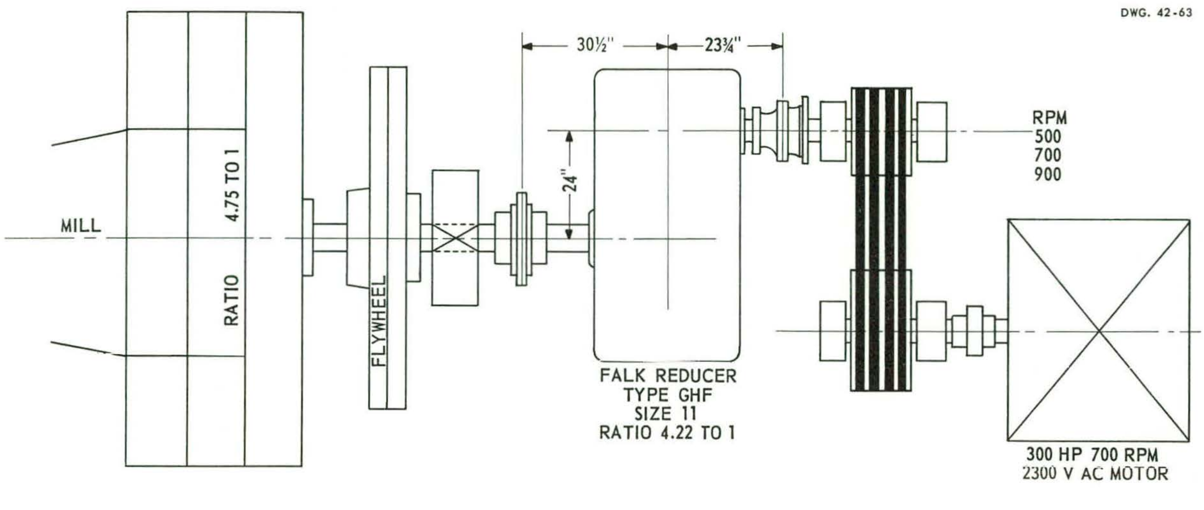

FIGURE 3 Schematic Diagram of Mill Drive System

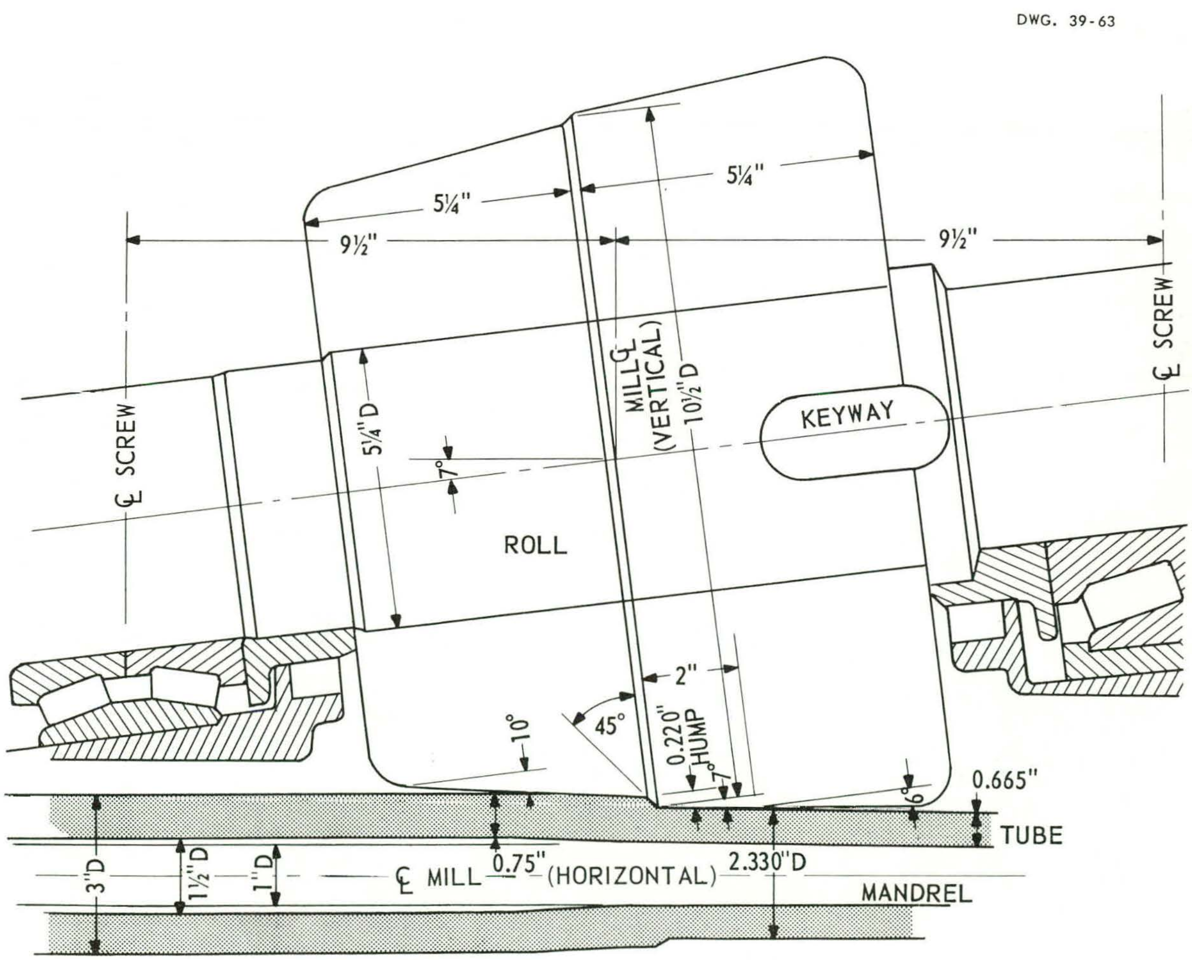

FIGURE 4 Roll Pass for 34.4% Reduction

tank in the scale pit beneath the mill and piped to spray heads. The water flow was approximately 5 to 10 gallons per minute. After use, the water drained into a trough under the mill base and thence into the pit tank. A filter in the recirculating system prevented uranium sludge from clogging the pump inlet.

A 5-inch hydraulic cylinder was used to move the workpiece and mandrel into the mill. Forward speed was maintained by a flow control valve. The hydraulic system also retracted the mandrel from the finished tube after elongation. Maximum pressure obtainable was 1500 psi.

Mandrels for the test were made from cold rolled steel in the following diameters: $1\frac{3}{16}$, $1\frac{1}{4}$, $1\frac{1}{8}$, 1, and 0.61 inches. Each mandrel was approximately 11-feet long. Two projections 30-inches apart were located at the rear of the mandrel. These projections or collars were gripped by a notched stripping bar attached to the hydraulic mechanism to withdraw the mandrel from the finished tube. Because the stroke of the hydraulic piston was less than the length of the tube, it was necessary to retract the mandrel in two steps.

A steel inlet cannon, located as closely as possible to the rolls, guided the workpiece into the mill (Figure 5). This reduced whipping of the rear end of the billet during rolling. A $\frac{1}{4}$-inch clearance was maintained between the ID of the inlet cannon and the OD of the feed stock.

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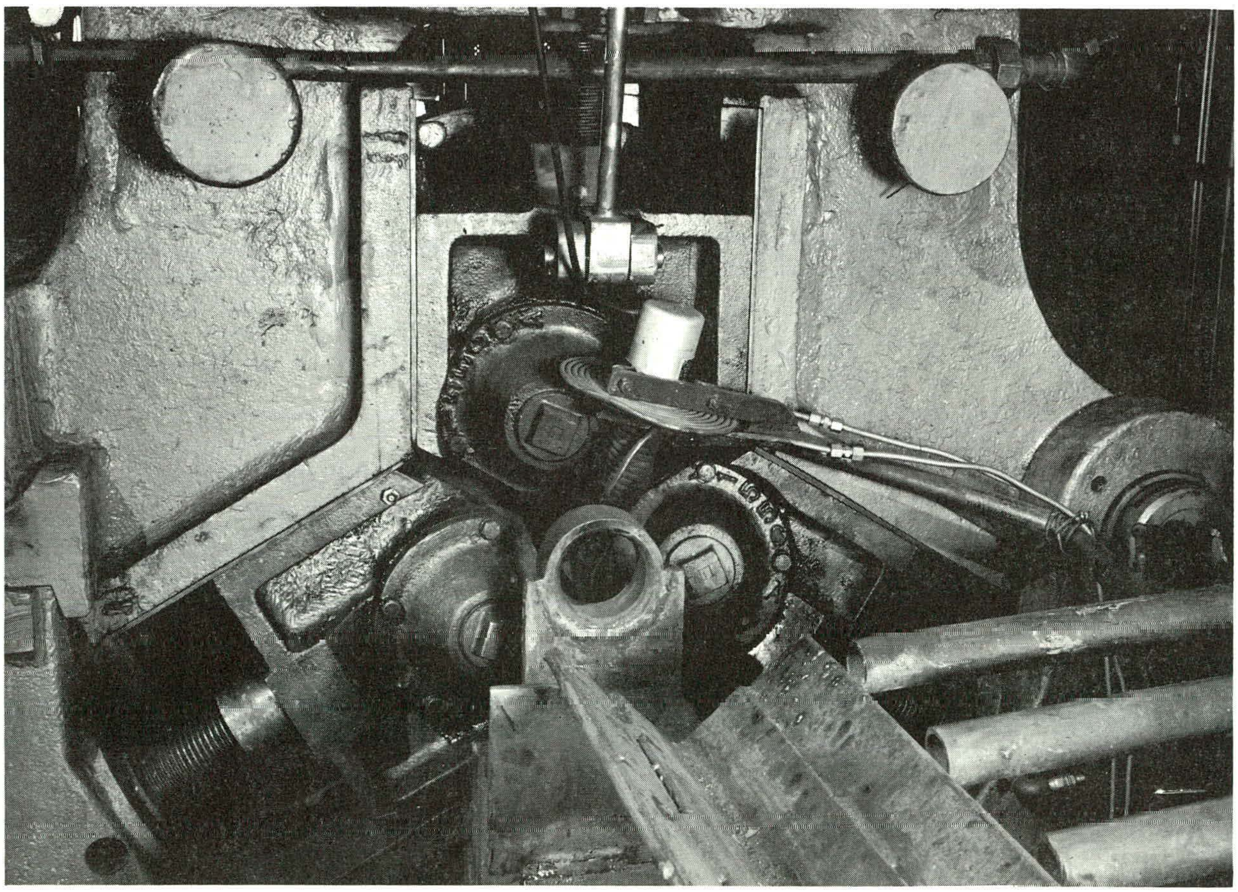

FIGURE 5 Inlet Side of Witter Mill Showing Inlet Cannon and Radiamatic Pyrometer

A steel outlet cannon and two sets of steel outlet guides were used to support the tube after it passed through the rolls (Figure 6). The outlet guides had detachable covers. The ID of the guides was $2\frac{5}{8}$ inches. This resulted in large clearances between the guides and the finished tubes when reductions in area of 30% to 40% were made.

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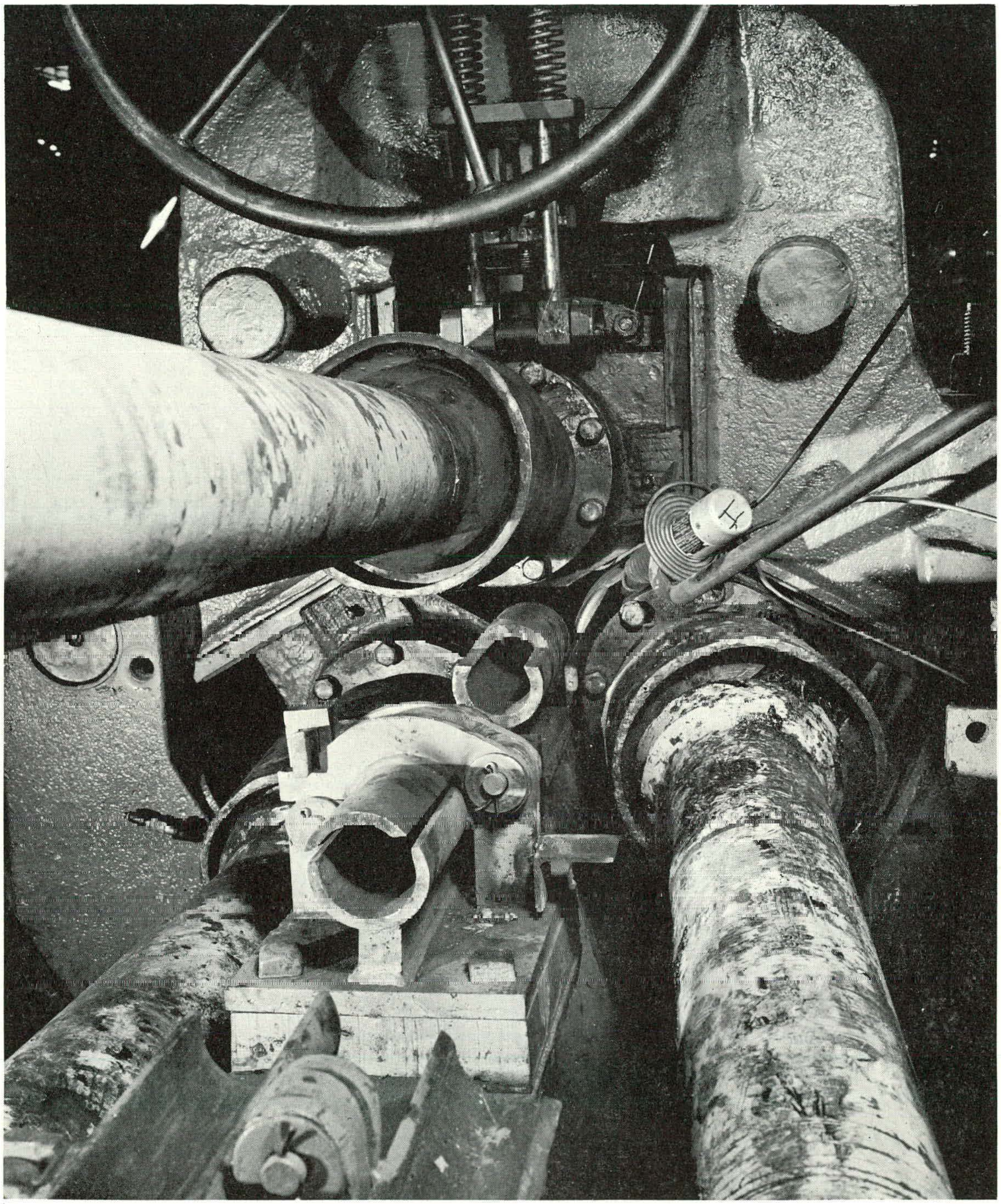

FIGURE 6 Outlet Side of Witter Mill Showing Outlet Cannon, Outlet Guides, and Radiamatic Pyrometer

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6. PROCEDURE

The typical procedure developed for rotary elongating uranium tubes and for evaluating the product was as follows:

6.1 FURNACE

1. Affix contact thermocouples to uranium billets with glass tape.
2. Manually load four uranium billets into gas-fired muffle furnace (Figure 7). Place two billets into each muffle.

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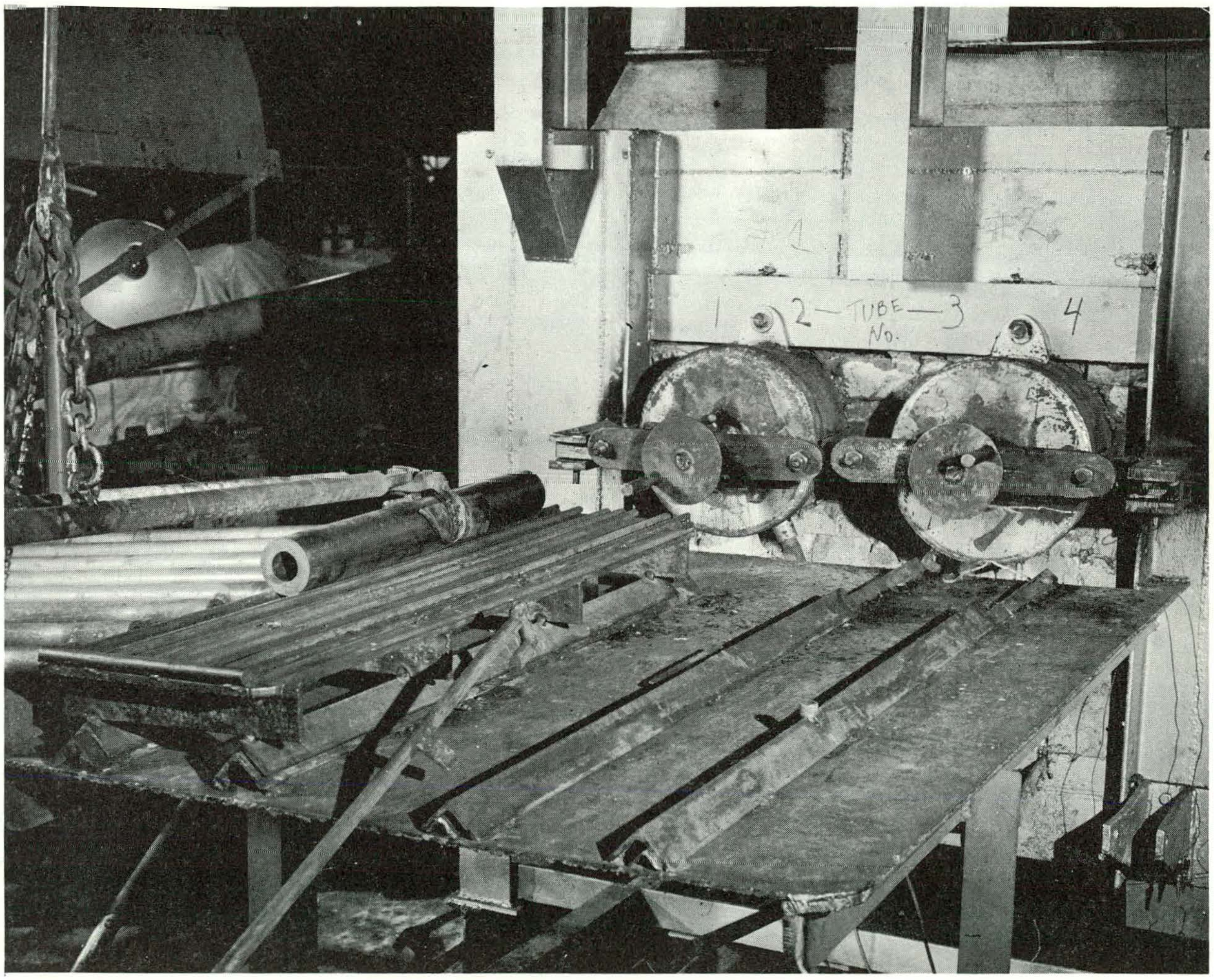

FIGURE 7 Front View of Gas-Fired Muffle Furnace and Furnace Table

3. Set argon flow meter at 20 cfh to provide protective atmosphere.
4. Adjust furnace gas burners to provide necessary rolling temperature in two-hour period (one hour for heating; one hour for soaking).
5. Record furnace and billet temperatures every 10 minutes during first hour, every 5 minutes during second hour. Adjust burners accordingly.
6. Check manometer periodically to ensure that muffle chambers are under positive pressure.

6.2 MANDREL

1. Place mandrel on rack of gas-fired, mandrel preheat furnace.
2. Adjust gas burner to heat mandrel to 500°F.
3. Check mandrel temperature with contact pyrometer.
4. Apply coating of lubricant to the mandrel with a brush. Let bake for 30 minutes. Immediately prior to rolling, apply two additional coats of lubricant to mandrel.

6.3 ROTARY ELONGATION

1. Check personnel for safety clothing and equipment (asbestos gloves, goggles, safety shoes, respirators, etc.).
2. Start mill motor. Check all rotating and moving parts of mill. Check mill condition against set-up sheet.
3. Record power readings of mill under "no load" condition.
4. Start motor of exhaust system over mill.
5. Provide cooling water to coil surrounding pyrometers. Turn on power to Radiamatic pyrometers and temperature recorder.
6. Record billet temperature.
7. Unload billet from furnace.
8. Remove thermocouple and glass tape.
9. Convey billet to mill inlet table.
10. Insert mandrel into billet.
11. Activate billet feeding mechanism to start billet into mill.
12. Turn on controlled volume of water as soon as billet starts feeding.
13. Record all cycle times, rolling time, power under load, etc.

14. After rolling has been completed, engage stripping chock to lock billet in position.

15. Remove billet pusher bar from forward drive mechanism. Place stripping bar in position.

16. Remove mandrel from finished tube with hydraulic stripping mechanism.

17. Remove covers from outlet guides. Quench tube in water trough to prevent uranium oxidation.

6.4 PRODUCT ANALYSIS

1. Measure length of tube. Weigh tube.

2. Crop two inches from both front and rear of tube.

3. Record OD, ID, and wall dimensions. Describe tube surfaces.

4. Cut metallographic sample from tube. Grind and polish sample. Etch sample and examine grain structure in longitudinal and transverse positions.

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7. FEED STOCK

Various types of normal uranium metal were used as feed stock for the test. The feed stock was prepared for the test by two methods: extrusion and centrifugal casting. The extrusions were made by the Bridgeport Brass Company at Adrian, Michigan; the centrifugal castings were made by National Lead Company of Ohio at Fernald, Ohio. The various types of feed stock and the number of billets of each type are listed in Table I.

TABLE I Test Feed Stock

Billet Types	No. of Tubes
A. EXTRUSION	
1. Statically cast, heat treated and extruded	84*
2. Statically cast and extruded	18
3. Statically cast, heat treated, extruded and OD turned (tapered)	14
B. CENTRIFUGAL CASTING	
1. Centrifugally cast	3
2. Centrifugally cast and heat treated	3
3. Centrifugally cast (3¼-inch OD) and turned (3-inch OD)	3
4. Centrifugally cast (3¼-inch OD) heat treated, and turned (3-inch OD)	3
TOTAL	128

*Includes two 3-inch-diameter solid bars.

The hollow, extrusion billets were cast in the 200-kw vacuum induction furnace in the National Lead Company of Ohio pilot plant annex. Typical grain structures of this material are shown in Figures 8 and 9. The uranium was melted in graphite crucibles coated with a magnesium zirconate ($MgZrO_3$) wash; the molten metal was poured into heated molds flame spray coated with $MgZrO_3$. The mold cores were hollow graphite cylinders. The melting cycle was as follows:

165 kw for 50 minutes
100 kw for 55 minutes
0 kw for 5 minutes, and pour.

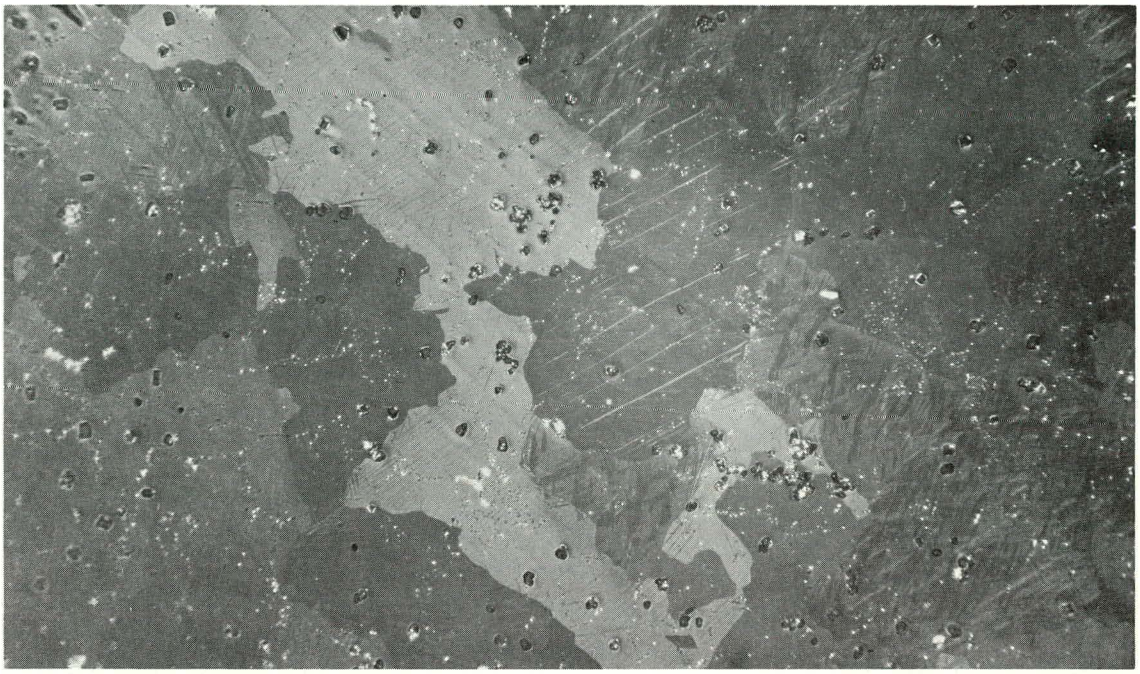
The maximum furnace pressure was approximately 40 microns of mercury; the temperature at the time of pouring was approximately 2550°F. The final billet size suitable for extrusion was 8¾-inches OD by 1¾-inches ID by 18-inches long. The average chemical analyses of the statically cast billets were as follows:

Boron	<0.2 ppm	Manganese	12 ppm
Carbon	400 ppm	Nickel	38 ppm
Chromium	10 ppm	Nitrogen	30 ppm
Iron	70 ppm	Silicon	15 ppm
Magnesium	<4 ppm	Density	18.95 g/cm^3

650 - 1

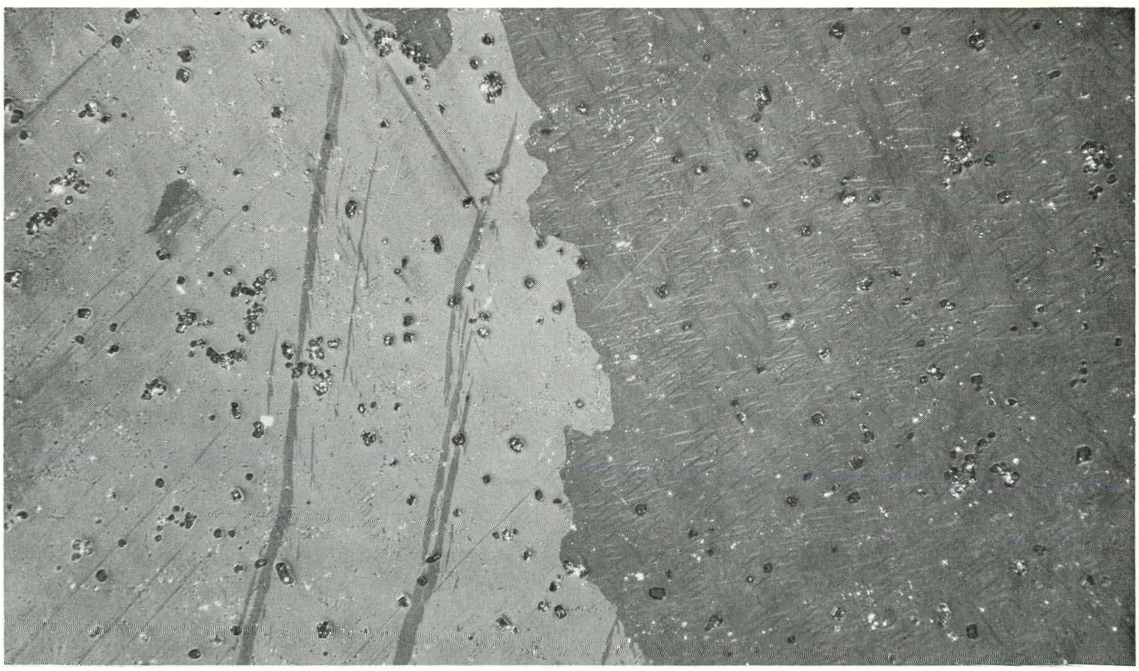
FIGURE 8 Typical, As-Cast, Alpha-Phase Grain Structure in Extrusion Billet (8¾-inches OD by 1¾-inches ID by 18-inches Long), Ingot No. 33277, Transverse Section. (0.7X)

650-56



A – Small Grains, Ingot No. 33299, Transverse Section (100X)

650-57

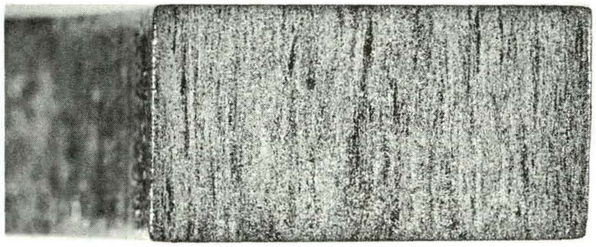


B – Large Grains, Ingot No. 33315, Transverse Section (100X)

FIGURE 9 Range of Grain Sizes Found in Statically Cast Extrusion Billets

Four billets were extruded without having received prior heat treatment; the remainder of the billets were triple-beta-heat-treated prior to extrusion. Grain structures of both types of billets after extrusion are shown in Figure 10.

652-10



A – Statically Cast, Beta Heat-Treated, and Extruded Feed Stock; Billet No. 33301 T5, Longitudinal Section (3X)

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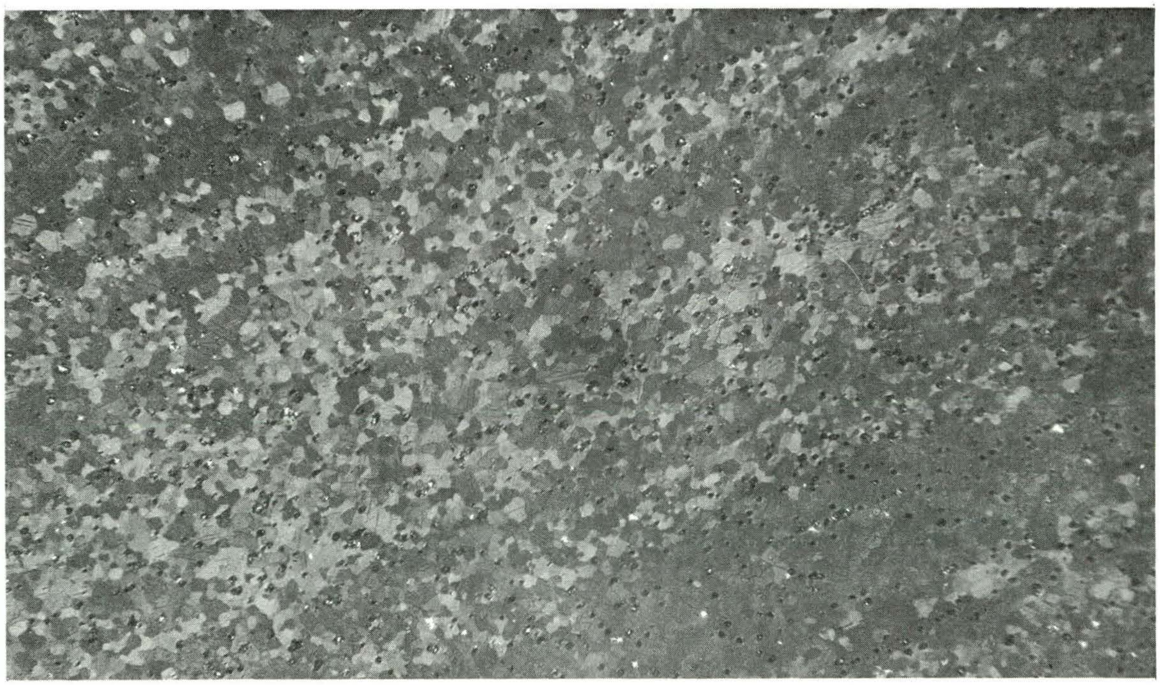
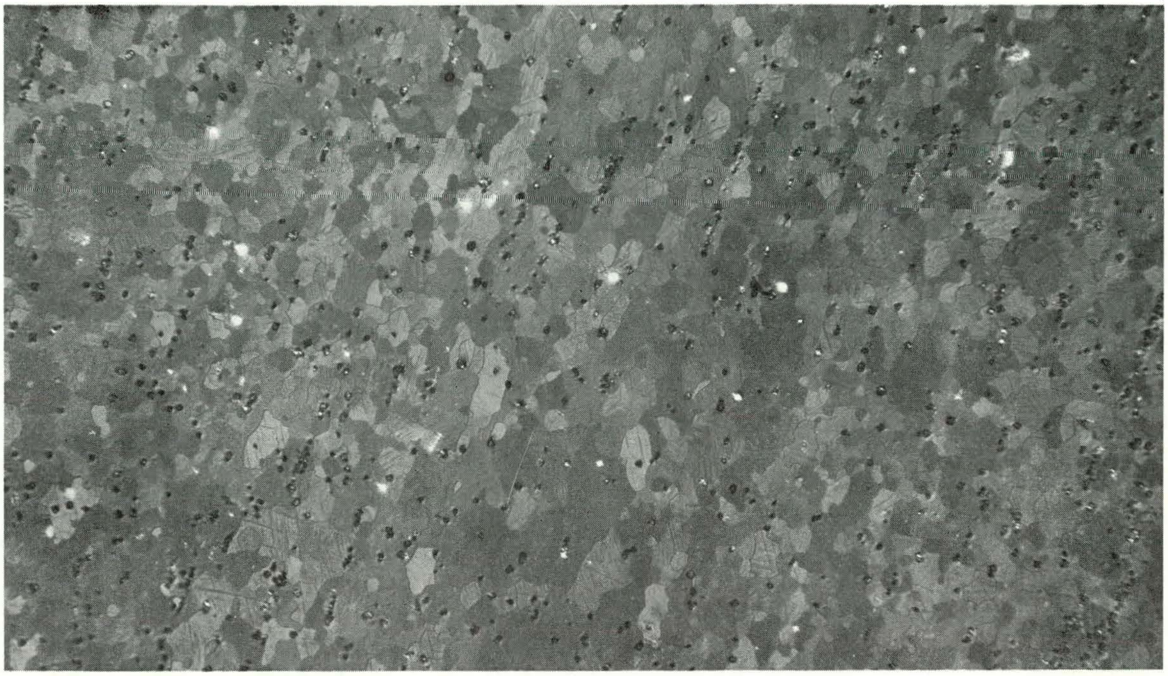


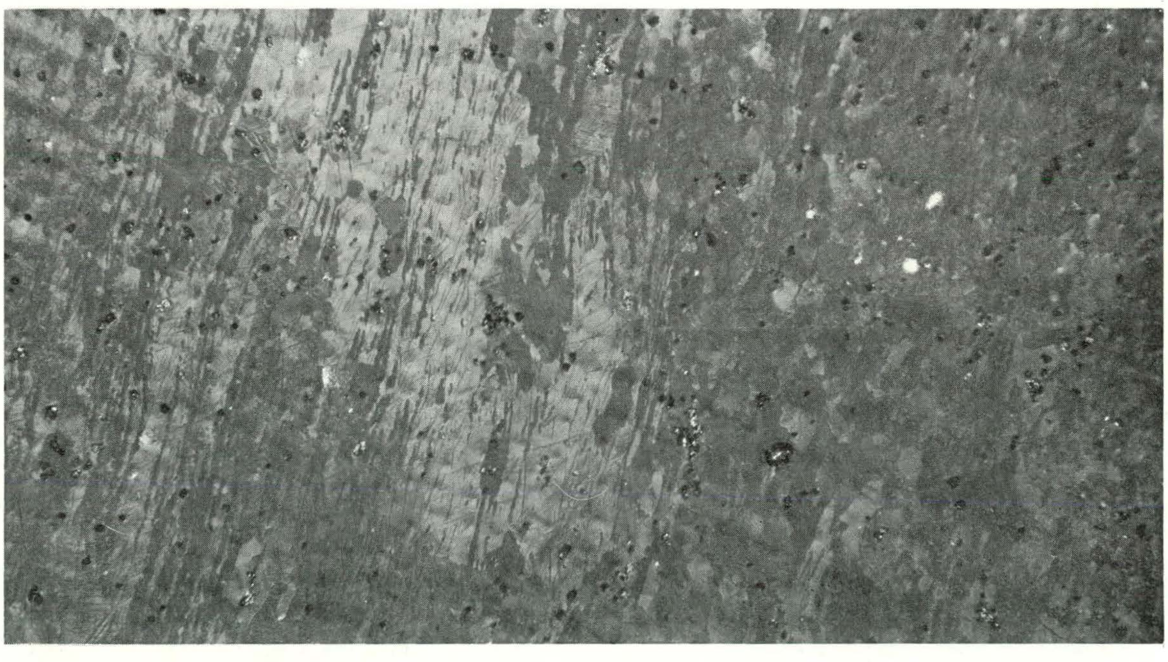
B – Statically Cast, Beta Heat-Treated, and Extruded Feed Stock; 100% Recrystallization, 0.020 mm Average Grain Size, Some Grain Clusters; Billet No. 33311 T5, Longitudinal Section (100X)

652-7



C – Statically Cast and Extruded Feed Stock; 85% Recrystallization, 0.020 mm Average Grain Size, Some Grain Clusters; Billet No. 33317 T6, Longitudinal Section (100X)

652-8



D – Statically Cast and Extruded Feed Stock, 5% Recrystallization, 0.020 mm Average Grain Size, Many Grain Clusters; Billet No. 33312 T1, Longitudinal Section (100X)

FIGURE 10 Comparison of Grain Structures in Extruded Feed Stock

The beta heat-treating cycle was as follows:

Heating Temperature:	$1350 \pm 10^{\circ}F$
Heating Time:	30 minutes
Transfer Time:	19 ± 1 seconds
Water Quench Temperature:	$80 \pm 15^{\circ}F$
Quench Time:	5 minutes

The extrusions were performed on Bridgeport Brass Company's No. 6 Loewy press. All billets were preheated to 1170°F in Houghton 980 salt. Heating time was approximately 80 minutes. Transfer time from the salt bath furnace to the extrusion press was approximately 1 minute. Tooling was preheated to 600°F; the mandrel, die, and liner were lubricated with Fiske 604 compound. Extrusion pressure at the start of each run was approximately 2750 psi; extrusion pressure during each run was approximately 2200 psi. The average extrusion time was 50 seconds. The calculated extrusion constants (K) at the start of each run and during each run were approximately 12.2 and 9.8 tons per square inch, respectively.

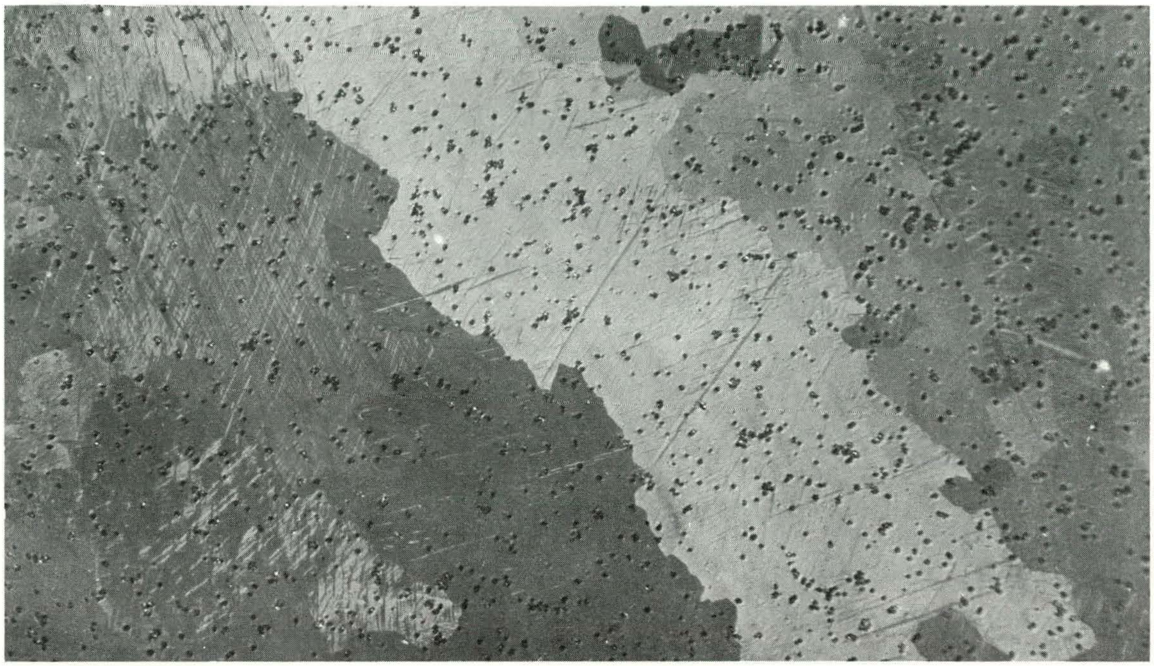
Twelve centrifugally cast tubes were used in the test. Grain structures of both non-heat-treated and heat-treated tubes are shown in Figures 11 and 12. Six were cast in 3-inch molds; six were cast in 3¼-inch molds and were subsequently machined to 3-inch OD size. Pouring temperature for each heat was 2650°F. Average furnace pressure was 50 microns of mercury; maximum pressure at the time of pouring was 130 microns of mercury. Mold rotational speeds were:

3-inch OD Tubes	rpm	3¼-inch OD Tubes	rpm
Casting	900 (35 gravities)	Casting	860 (35 gravities)
Cooling	400 (8 gravities)	Cooling	390 (8 gravities)

A – Billet No. P85, Transverse Section (1X)

B – Billet No. P94, Longitudinal Section (3X)

651-12



C – Billet No. P82, Longitudinal Section (100X)

FIGURE 11 Typical Alpha Structures in Centrifugally Cast Feed Stock

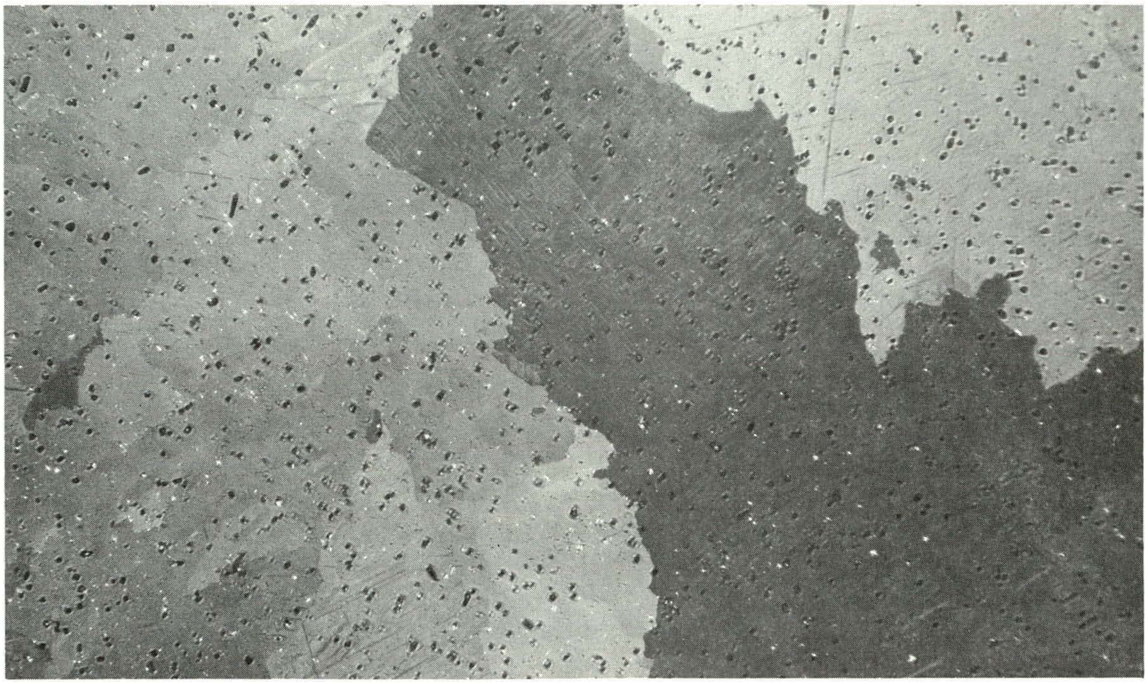
615-70

A – Billet No. P85, Transverse Section (1X)

651-21

B – Billet No. P105, Longitudinal Section (3X)

651-6



C – Billet No. P102, Longitudinal Section (100X)

FIGURE 12 Typical Beta Heat-Treated Structures in Centrifugally Cast Feed Stock

The average chemical analyses for the centrifugally cast tubes were as follows:

Boron	<0.2 ppm	Manganese	11 ppm
Carbon	492 ppm	Nickel	41 ppm
Chromium	8 ppm	Nitrogen	41 ppm
Iron	93 ppm	Silicon	50 ppm
Magnesium	<4 ppm	Density	18.92 g/cm^3

8. RESULTS

8.1 TEST PROGRAM

An acceptance test was made using steel feed stock to assure that the mill and auxiliary components were operating satisfactorily. At the conclusion of this acceptance test, the formal test program was initiated. The test was divided into three phases:

Phase A – Equipment Adaptability (Tubes 1 through 22)

Phase B – Investigation of Major Variables (Tubes 23 through 80 and 129 through 134)

1. Determination of Optimum Preheat Temperature
2. Evaluation of Effect of Roll Speed
3. Determination of Optimum Feed Angle
4. Evaluation of Effect of Roll Design
5. Miscellaneous
    a. Determination of Optimum Reduction in Area
    b. Evaluation of Rotary Elongation Without Use of Mandrel (Sink-Reduction)
    c. Procurement of Tube Profile
    d. Evaluation of Rotary Elongation in the Beta Phase

Phase C – Production Phase (Tubes 81 through 128)

1. Evaluation of Feed Stock
2. Evaluation of Multiple Elongation

The results of each phase of the test are discussed below. The complete test data are given in Table IV in the Appendix.

8.2 PHASE A, EQUIPMENT ADAPTABILITY

Twenty-two rotary elongations were made to test equipment, calibrate instrumentation, and establish the basic parameters of the process. Typical mill conditions were as follows:

Feed Stock:	Normal uranium, 3-inches OD by 1½-inches ID by 36-inches long
Billet Temperature:	1095°F to 1250°F
Mandrel Diameter:	1⅛, 1¼ inches
Mandrel Lubricant:	Fiske 604, Dag 170
Roll Profile:	0.220-inch shoulder
Roll Speed:	35, 45 rpm
Water Cooling:	None
Feed Angle:	3°

For this work, the average rolling time was approximately 4 minutes; the feed efficiencies were approximately 10% to 15%.

During the early trials, it became apparent that the gas-fired muffle furnace was not performing as well as expected. Because of the length of the two muffles, approximately 14 feet, it was difficult to control the temperature of the 30-inch-long billets. Furthermore, the mild steel racks that supported the billets lost their strength because of the long heating cycle (2 to 3 hours) and the weight of the feed stock. Consequently, inner muffles or retorts were inserted into each of the two muffles. The inner muffles were approximately 45 inches long. Stainless steel members were used to support the uranium billets. After these modifications were made to the furnace, control of billet temperature was satisfactory.

Billet temperatures were measured with chromel-alumel, glass-wrapped thermocouples. At first the thermocouples were embedded at the front, center, and rear of each billet. The maximum variation from front to rear and from edge to center of the uranium billet was 25°F. Because of the difficulty in drilling holes in uranium, other means of attaching the thermocouples were investigated. The most successful results were obtained by attaching thermocouples to the billet periphery with glass tape. This simplified means of installing thermocouples on the billet periphery was used successfully for the entire test.

To prevent oxidation of the billet during the preheat period, argon was passed into each retort at the rate of 20 cubic feet per hour. A lesser amount of argon would not prevent major oxidation; a greater amount of argon would not further reduce oxidation but would cool the billet being preheated in the muffles. The average weight loss during the preheating, rotary elongating, and quenching operations during the production phase of the test was 0.4 pound per piece. The bulk of the loss was attributable to oxidation during the time the piece was being elongated in open air.

Previous work had established the necessity of coating mandrels with a lubricant to ease their extraction from the elongated tubes. Fiske 604 and Dag 170 were tested. Better results were obtained with the Fiske 604, an aluminum flake suspension in oil; therefore, this material was used for the remainder of the test.

During the equipment adaptability test, the induction heating coil (discussed in Subsection 9.2, Induction Heating) was tested and calibrated. Time-temperature curves were plotted at varied power settings and feed rates (speed at which the tube entered the coil). The feed rates were 6, 12, 18, and 24 inches per minute (ipm). At this time it became standard procedure to gradually increase the power setting (and thus provide more heat to the rear of the workpiece) as the tube passed through the coil.

8.3 PHASE B, INVESTIGATION OF MAJOR VARIABLES

8.3.1 Determination of Optimum Preheat Temperature

The initial variable studied was the effect of billet preheat temperature on the rotary elongation operation. Twelve elongations (Tubes 23 through 34) were made during this portion of the test. During this time, the typical mill conditions were:

Feed Stock:	Normal uranium, 3-inches OD by 1½-inches ID by 36-inches long*
Billet Temperature:	1000°F, 1075°F, 1100°F, 1125°F, 1150°F
Mandrel Diameter:	1¼-inches

Mandrel Lubricant:	Fiske 604
Mandrel Preheating:	70°F, 500°F
Roll Profile:	0.220-inch shoulder*
Roll Speed:	35 rpm
Water Cooling:	None*
Feed Angle:	3°*

* *Unchanged from preceding test*

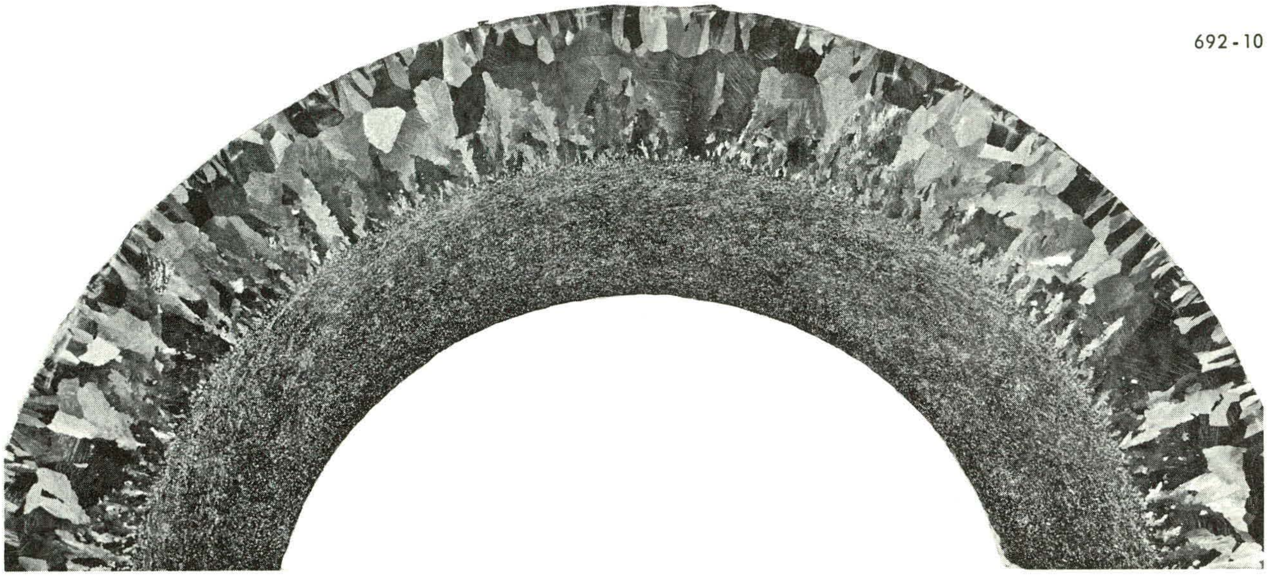
The average rolling time was 5.1 minutes and ranged from 4.3 minutes to 5.5 minutes. The average feed efficiency was 20.47% and ranged from 17.50% to 24.99%. Examination of the results did not reveal any effects due to preheat temperature. The grain structures from tubes of this group and from the preceding phase (Equipment Adaptability) were extremely poor. Every tube evidenced severe duplexing (Figures 13, 14, and 15).

692-22

FIGURE 13 Duplexed Grain Structure in Statically Cast, Beta Heat-Treated, Extruded, and Rotary Elongated Tube; Medium-Size Alpha Grains on Outside Diameter; Billet No. 33298 T5 (Front), Tube No. 3, Transverse Section (3X)

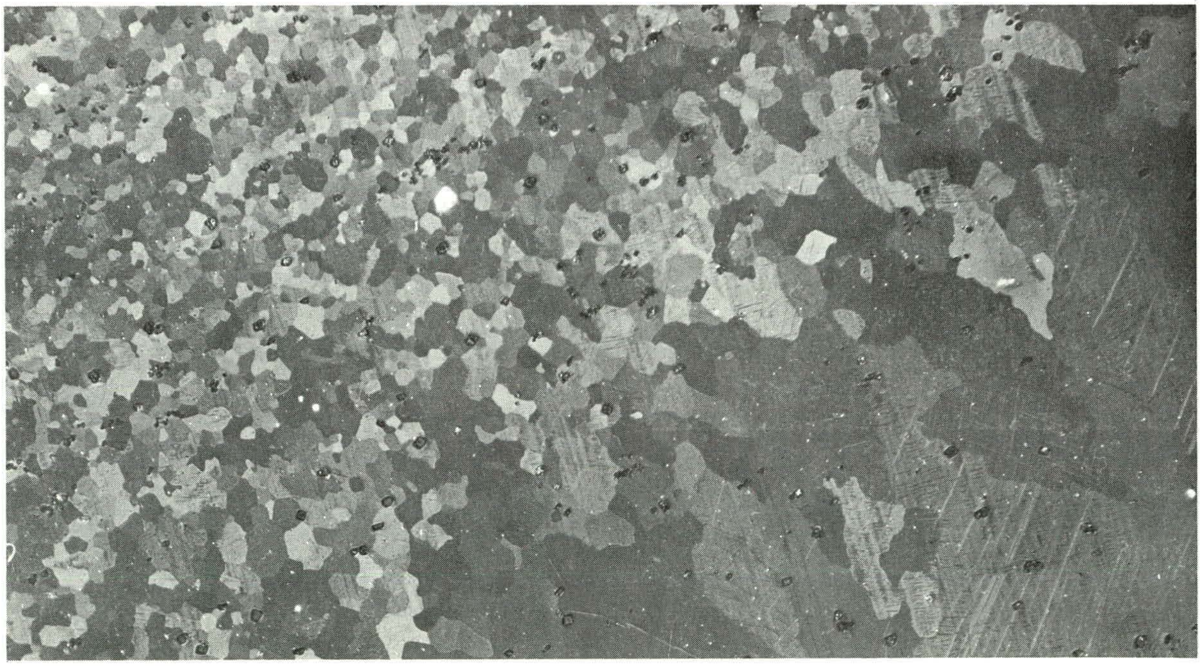
Examination of the duplexed structures revealed large, radially oriented grains. Initially, these were thought to be beta-phase grains. Closer examination did not show the harsh, jagged edges of the typical beta-phase structure. Consequently, it was assumed that these were large alpha-phase grains caused by an interaction of severe stress with a rise in billet temperature caused by working. Accordingly, as a means of preventing overheating, billets were preheated to lower temperatures than are normally used in working uranium.

692-10



A – Coarse Alpha Grains on Outside Diameter; Billet No. 33284 T2 (Rear), Tube No. 25; Transverse Section (3X)

692-2



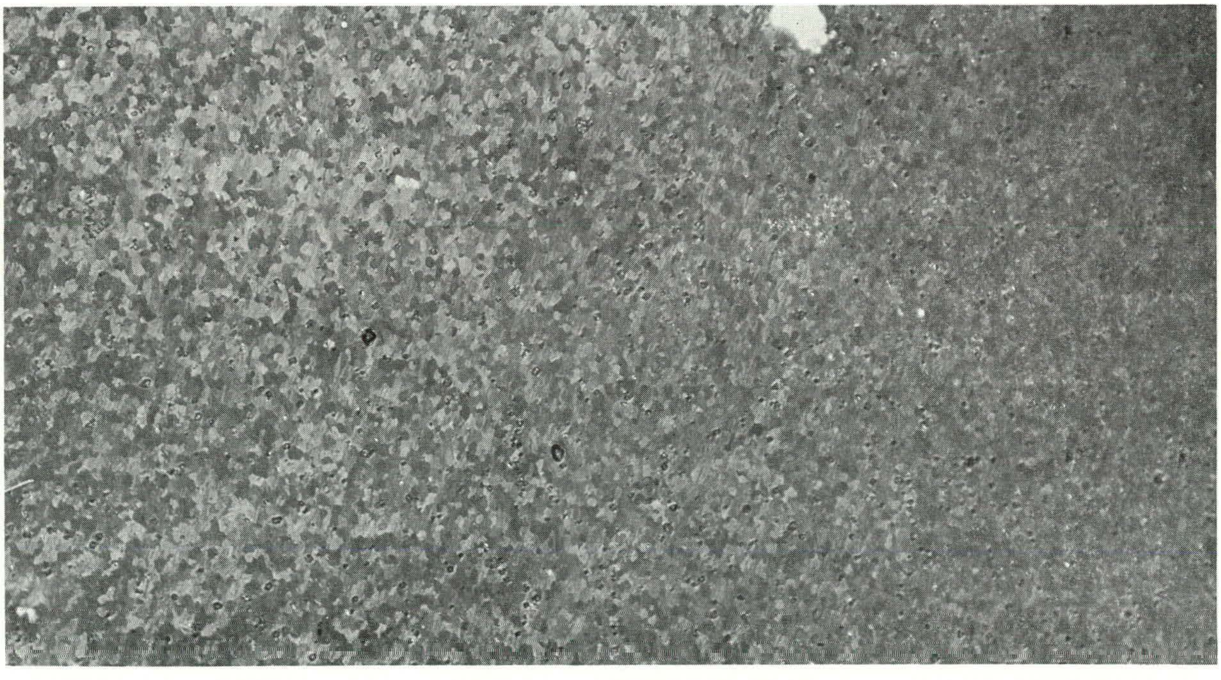
B – Interface of Duplexed Grain Structure; Billet No. 33284 T2 (Center), Tube No. 25; Longitudinal Section (100X)

FIGURE 14 Duplexed Grain Structure in Statically Cast, Beat Heat-Treated, Extruded, and Rotary Elongated Tube; Coarse Alpha Grains on Outside Diameter

692-11

A – Small Alpha Grains on Portion of Outside Diameter; Billet No. 33284 B4 (Rear), Tube No. 33; Transverse Section (3X)

692-1



B – Small Alpha Grains on Outside Diameter; Billet No. 33284 B4 (Center), Tube No. 33; Longitudinal Section (100X)

FIGURE 15 Duplexed Grain Structure in Statically Cast, Beta Heat-Treated, Extruded, and Rotary Elongated Tube; Small Alpha Grains on Portion of Outside Diameter

Some difficulty was experienced in extracting the mandrel from the finished tube. Increasing the pressure of the hydraulic cylinder from 1000 psi to the maximum available pressure, 1500 psi, improved extraction.

Ten additional elongations (Tubes 35 through 44) were made to investigate the use of the induction coil in maintaining billet temperatures. These billets were preheated to temperatures of 900, 1050, 1075, 1100, and 1125°F prior to insertion into the induction heating coil. It was determined that induction heating did not improve the rolling efficiency (the ratio of the actual delivery rate to the theoretical delivery rate) or the metal quality of the finished tubes.

Mandrels at room temperature and at 500°F were used. Those preheated to 500°F were extracted from the finished tubes with less difficulty. Accordingly, all subsequent rotary elongations were made with coated mandrels (three applications of Fiske 604) preheated to 500°F.

8.3.2 Evaluation of Effect of Roll Speed

Fifteen rotary elongations (Tubes 47 through 59, 131 and 132) were made to evaluate the effect of roll speed on rolling efficiency and metal quality. The roll speeds used for this portion of the test were 25, 35, 45, and 70 rpm. The basic mill conditions were as follows:

Feed Stock:	Normal uranium, 3-inches OD by 1½-inches ID by 36-inches long*
Billet Temperature:	1075°F, 1125°F, 1150°F
Induction Coil:	Yes
Mandrel Lubricant:	Fiske 604*
Mandrel Preheating:	500°F
Roll Profile:	0.220-inch shoulder*
Roll Speed:	25 rpm, 35 rpm, 45 rpm, 70 rpm
Water Cooling:	None*
Feed Angle:	3°*

* *Unchanged from preceding test*

Results of this phase of the test are shown in Table II.

TABLE II Effect of Roll Speed on Rolling Time and Rolling Efficiency

		Roll Speed (rpm)			
		25	35	45	70
Rolling Time (min)	High	5.0	6.1	7.4	8.0
	Low	3.9	4.3	5.2	4.1
	Average	4.6	5.4	6.4	5.8
Rolling Efficiency (%)	High	35.11	21.29	14.33	11.79
	Low	25.12	15.72	10.13	5.78
	Average	28.86	18.27	11.86	9.19

The results of this portion of the test showed that rolling efficiencies increased as roll speeds decreased. At this point it was not possible to determine the optimum roll speed for the operation because all of the rolling efficiencies were lower than expected.

One means of examining the function of roll speed on rotary elongation is to determine the frequency with which the workpiece comes in contact with the rolls. Normal uranium metal is sensitive to rate of strain. This sensitivity places added emphasis on pass design and roll speed as strain rate is a function of the amount of work done and the rate at which the work is accomplished. This relationship may be expressed in terms of frequency and velocity. Frequency may be defined as the number of times a point on the tube surface comes in contact with the rolls; velocity is used interchangeably with roll speed.

The 10½-inch roll diameter was approximately four times the outside diameter of the average tube. Therefore, the frequency of contact of an imaginary longitudinal line on the tube periphery with the three rolls will be 12 times the roll speed. Thus it can be seen that with a roll speed of 35 rpm the frequency of contact will be 420 times per minute. Multiplication of this value by the rolling time will provide the absolute number of times this line comes in contact with the rolls. At the 3-degree feed angle, the lowest frequency was 1400 roll contacts at 25 rpm.

When attempts were made to elongate billets at the 70-rpm roll speed, severe cracks and flaking appeared on the tube surfaces. The feed efficiency decreased to less than 10%. The frequency of contacts was greater than 5000 per tube. This was accompanied by a large temperature increase in the tube attributable to heat buildup through frictional losses in the process. Subsequent metallographic examination of grain structures indicated that the surface of each uranium tube had been transformed into the beta phase (Figure 16).

692-16

FIGURE 16 Rotary Elongated Tube, Roll Speed: 70 rpm; Beta-Phase Structure, Billet No. 33284 B3 (Rear), Tube No. 48, Transverse Section (3X)

8.3.3 Determination of Optimum Feed Angle

Two sets of bearings were provided for the test: 3 degrees and 6 degrees. All of the preceding work was performed with the 3-degree bearings. For this portion of the test, the 6-degree bearings were installed. Nine rotary elongations (Tubes 60 through 68) were made under the following basic conditions:

Feed Stock:	Normal uranium, 3-inches OD by $1\frac{1}{2}$-inches ID by 36-inches long*
Billet Temperature:	1025°F, 1075°F
Induction Coil:	No
Mandrel Diameter:	1, $1\frac{1}{8}$-inches
Mandrel Lubricant:	Fiske 604*
Mandrel Preheating:	500°F*
Roll Profile:	0.125-inch, 0.220-inch shoulder
Roll Speed:	35 rpm
Water Cooling:	None*
Feed Angle:	6°

* *Unchanged from preceding test*

There was a significant improvement in rolling efficiency and metal quality with the 6-degree feed angle. The average rolling efficiency was 57.61% and ranged from 22.67% to 84.94%. All traces of duplexed grain structures were eliminated. (Figure 17).

692-41

A – Billet No. 33000 T3 (Center), Tube No. 72; Transverse Section (3X)

692-182

B – Billet No. 33311 T4 (Rear), Tube No. 69; Transverse Section (3X)

692-76

C – Billet No. 33303 T4 (Center), Tube No. 68; Transverse Section (3X)

FIGURE 17 Typical Structures in Statically Cast, Beta Heat-Treated, Extruded, and Rotary Elongated Tubes; 6-Degree Feed Angle

The amount of reduction performed on the piece did not change. There was a great difference, however, in rolling time (average: less than 55 seconds). Under these conditions, the uranium was more susceptible to plastic flow. The number of contacts was reduced by a factor of seven (from 1400 per tube to

200 per tube). Frictional losses and the resulting heat buildup were drastically reduced. These improvements resulted in the complete elimination of duplexing.

8.3.4 Evaluation of Roll Design

Eight rotary elongations (Tubes 69 through 76) were performed to evaluate the effect of roll design on the process. The smooth rolls (no hump) were used in conjunction with the 6-degree bearings. There were no other changes from conditions in the previous test except that the roll speed was decreased from 35 rpm to 25 rpm.

The smooth rolls of this test were compared with the rolls having shoulders of 0.125 inches and 0.220 inches (the preceding test). The highest rolling efficiencies were obtained with the 0.125-inch-shoulder rolls. Therefore, they were used for all subsequent tests.

During this portion of the test on roll design evaluation, the use of water for cooling the rolls became established. The water prevented the rolls from overheating and reduced oxidation of the tube surface.

8.3.5 Miscellaneous

a. Determination of Optimum Reduction in Area (Tubes 41 through 46)

A $\frac{3}{4}$-inch to $1\frac{1}{4}$-inch tapered mandrel and tapered starting billets were used to determine the optimum reduction in area. Under existing mill conditions, reductions in area of 25% to 45% were achieved. Better surfaces were obtained at the smaller reductions.

b. Evaluation of Rotary Elongation Without Use of Mandrel (Tubes 69 through 74)

No inner tool or mandrel was used during the operation. The average rolling efficiency was approximately 70%. Inner diameter surfaces were poor, and eccentricity of the bore increased.

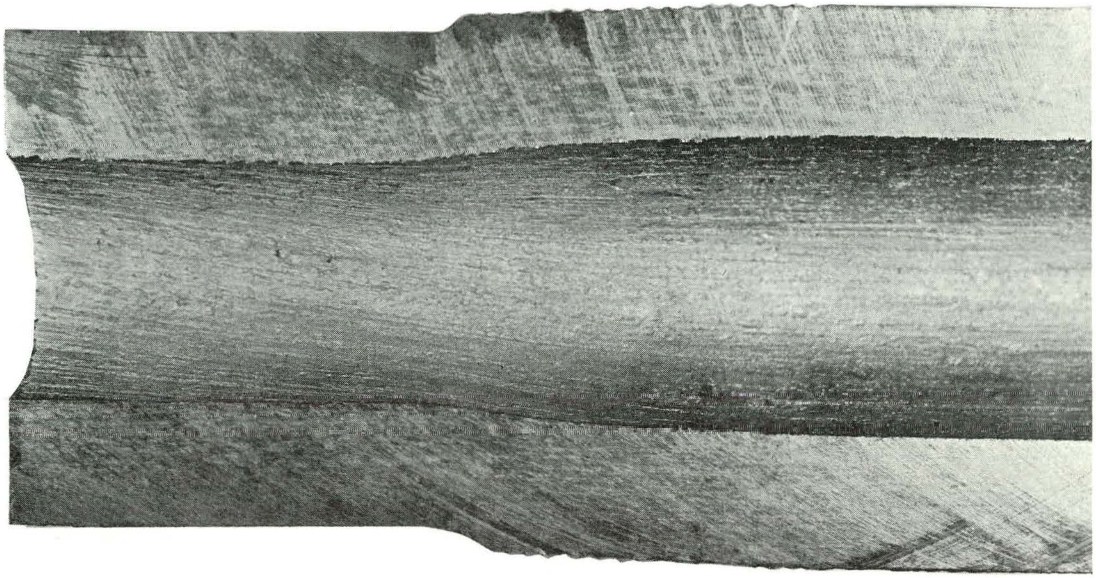
c. Evaluation of Tube Profile (Tubes 129 and 130)

Two tubes were stopped in the mill during the elongation operation (Figure 18). The tubes were split longitudinally to view the flow lines on the inner surface. The spiral striations on the outer surface of the tube would normally be eliminated by the outlet faces of the rolls.

d. Evaluation of Rotary Elongation in the Beta Phase (Tubes 133 and 134)

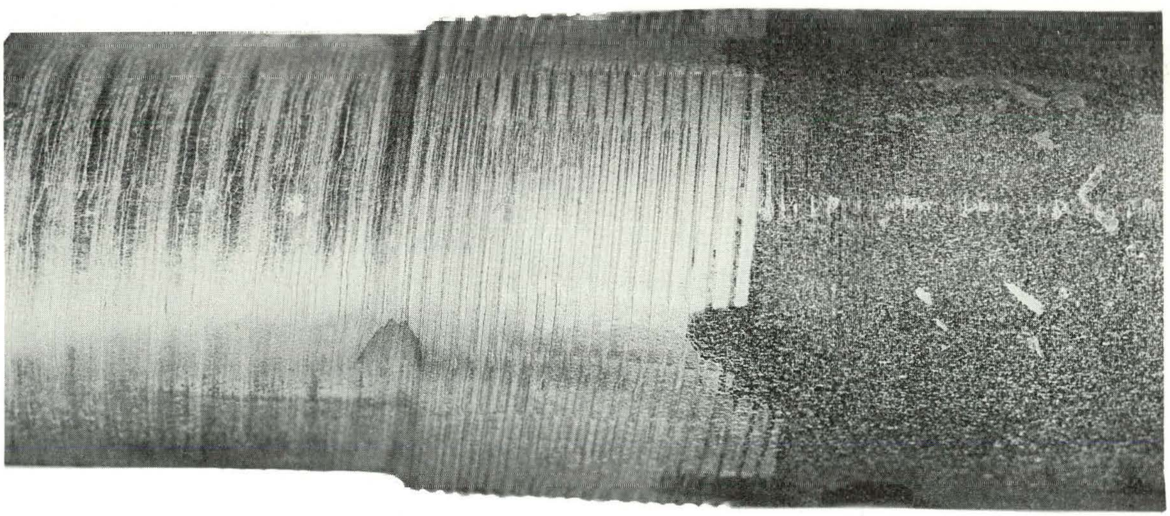
Two attempts were made to rotary-elongate tubes in the beta phase. The tubes cracked and flaked (Figure 19). The finished tubes resembled those that had transformed into the beta phase when rolled at 70 rpm.

842-5



A – Longitudinal Section Showing Inner Surface (1X)

842-6



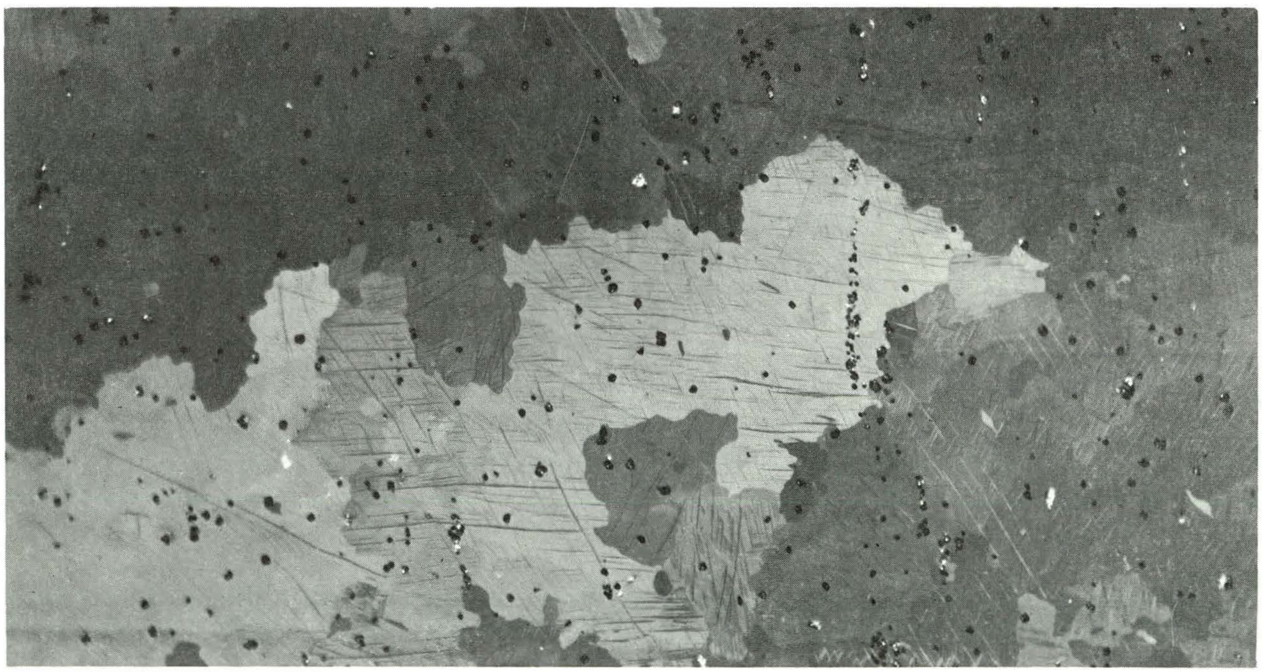
B – Outer Surface (1X)

FIGURE 18 Profile of Tube Stopped in Witter Mill During Rotary Elongation; Billet No. 33277 T5, Tube No. 130

842-8

A – Transverse Section (3X)

842-7



B – Longitudinal Section (100X)

FIGURE 19 Grain Structures of Tube Rolled in Beta Phase, 1270°F Preheat Temperature; Billet No. 33297 T2 (Center), Tube No. 133

8.4 PHASE C, PRODUCTION PHASE

8.4.1 Evaluation of Feed Stock (Tubes 81 through 104)

For Phase C, the following conditions were maintained:

Feed Stock:	Normal uranium, 3-inches OD by 1½-inches ID by 36-inches long
Billet Temperature:	1050°F (nominal)
Induction Coil:	No
Mandrel Diameter:	1, 1¼-inches
Mandrel Lubricant:	Fiske 604
Mandrel Preheating:	500°F
Roll Profile:	0.125-inch shoulder
Roll Speed:	35 rpm
Water Cooling:	Yes
Feed Angle:	6°

The purpose of the production phase was to supply feed stock in two sizes for a rotary forging test. It was necessary to elongate in two passes to obtain the desired reduction of approximately 60%. The target dimensions for the planned (two-pass) elongations were:

		Tube Type	
		A	B
First Pass	OD(in.)	2.35	2.60
	ID(in.)	1.00	1.25
Second Pass	OD(in.)	1.75	2.19
	ID(in.)	0.61	1.00

For the first pass, the average rolling efficiency (for both A and B tubes) was 82.74%. On the smaller size, the inner diameter of the tube did not close upon the mandrel. As a consequence, the tube bore was rough and eccentric.

8.4.2 Evaluation of Multiple Elongation (Tubes 105 through 128)*

For the second pass, 0.610-inch and 1.00-inch mandrels were used. The average rolling efficiency (for both A and B tubes) was 107.94%.** The average rolling efficiency for the combined production phase was 95.34%. Once again, the inner surface of the smaller tube (Type A) did not close upon the mandrel and the tube bore was consequently rough and eccentric.

* *The twenty-four billets represented in this phase are the billets rotary elongated in the preceding phase (Tubes 81 through 104).*

** *The theoretical delivery rate is based upon the rotational speed of the workpiece at the mill gorge. At the exit end of the rolls, the workpiece is rotating at a greater speed. Therefore, the actual rotational speed at the gorge, and rolling efficiencies greater than 100% may be achieved.*

There was little difference in metal quality or rolling efficiency noted between the various types of feed stock. The method of feed stock fabrication, heat treatment, and machining had no discernable effect.

Tubes were beta heat-treated to determine the effect of heat treatment on the rotary elongated tubing (Figure 20). The beta heat-treated tubes were rated according to HAPO grain-size standards. The average grain size was A5.

770 - 1

FIGURE 20 Grain Structure After Beta Heat Treatment of Statically Cast, Extruded, and Rotary Elongated Tube; Grain Size from A6 to A4 (A5 Average), Grains Rated by HAPO Standards, Average Grain Size of Standard HAPO Pieces is approximately A4.5; Billet No. 33317 T3 (Center), Tube No. 103; Transverse Section (3X)

9. DISCUSSION

9.1 DESCRIPTION OF ROTARY ELONGATION

The rotary elongator (Assel mill) was developed by Walter J. Assel to combine the functions of the conventional plug rolling and sizing operations in a single unit. When compared with the product from the conventional seamless tube mill, the product from the Assel mill exhibits closer dimensional control, improved concentricity, and better surface appearance.[3]

The Assel mill uses three rolls mounted 120-degrees apart. They are equidistant from and skewed at a small angle (the feed angle) to the horizontal axis of the mill. The feed stock is tubular and is elongated with a mandrel in its bore. The tube is fed into the opening of the rolls so that the axis of the tube is coincident with the horizontal axis of the mill.

The conical rolls may be described by the following characteristics (Figure 21):

1. *Inlet Clearance Radius.*
2. *Converging Inlet Surface.* This section of the roll grips the billet and imparts a forward rotational thrust to the workpiece. Some compressing or sinking action of the workpiece over the mandrel takes place at this position.
3. *Hump.* The hump, or shoulder, is characteristic of the Assel-type roll. The purpose of the shoulder is to cause an abrupt transverse flow of metal inward and thus reduce the tube diameter and wall thickness. The shoulder is located at the longitudinal midpoint of the roll.
4. *Outlet Reeling Surface.* This short surface functions in sizing the finished tubing and in delivering it from the mill.
5. *Relief Area.* The tube is disengaged from the roll in this section.
6. *Outlet Radius.*

The three conical rolls are mounted in tapered roller bearings. The rolls are enclosed in a double housing. In a conventional steel tube mill, one portion of the housing allows rotation of the roll-shaft around the mill axis; the other portion is in a fixed position. The forward feed of the tube through the mill is controlled by skewing each roll axis at an angle to the pass line. This angle is called the feed angle (Figure 21). In a Witter shell mill both portions of the housing are stationary. The roll is mounted in its housing so that its axis is skewed in relation to the mill axis. This angle is the feed angle. The roll housings must be changed for each change in feed angle.

The mill gorge is readily adjustable. A chain linkage connects the three roll assemblies so that all three move simultaneously and equally when the gorge is increased or decreased.

The workpiece enters the mill at the small ends of the rolls and leaves the mill at the large ends of the rolls. Thus, the surface speed of the workpiece increases as it proceeds from the roll inlet to the roll outlet. The original elongators operated in the reverse manner; that is, the speed of the piece decreased as it passed through the mill.

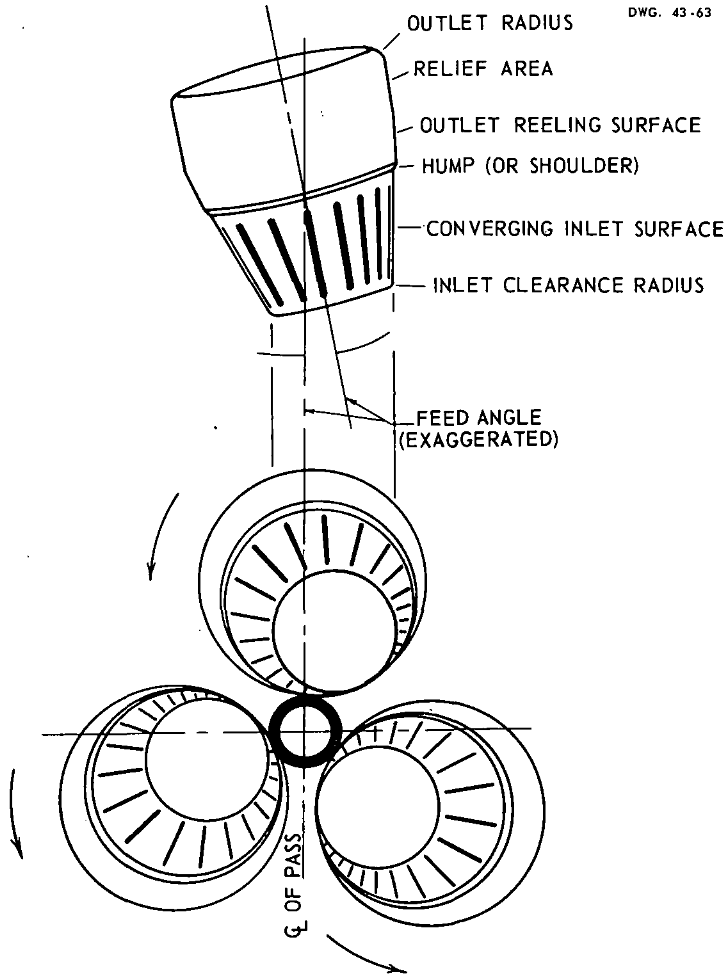


FIGURE 21 Arrangement of Rolls

When elongating steel tubing, the roll rotational speed is approximately 150 to 200 rpm; for uranium, the speed is reduced to 35 rpm (corresponding roll surface speed: 96 feet per minute). This produces a theoretical output speed of 13 feet per minute.

The Assel mill may operate with any of three types of mandrels: (1) full-floating, (2) semi-floating, and (3) retracting. The type used in this test was the full-floating mandrel, the least complicated of the three types. The mandrel is inserted into the hollow billet. The tube and mandrel (once the tube has been compressed onto the mandrel) pass through the mill together. After rolling, an extractor removes the mandrel from the elongated tube.

Prior to the test, Battelle Memorial Institute was asked to prepare a theoretical study on the rotary elongation of uranium tubing.[4] A summary of the Battelle report is given below.

In rotary elongation, the principal forces are considered to be (1) twisting of the deformed metal fibers, (2) tension in the workpiece caused by skewing of the rolls, thus producing a forward thrust, and (3) severe local compression where the workpiece is in contact with the rolls. The initial permanent deformation is caused by a band of external rolling forces. A minor amount of deformation occurs due to longitudinal forces and twisting of the metal fibers. This takes place until the inner wall of the tube touches the mandrel. Further deformation occurs at the roll hump. At that point, the tube is subjected to both external and internal loads, resulting in radial compression; the metal from the tube inner wall is squeezed on the mandrel and an internal pressure reaction is developed. Again, minor deformations occur due to secondary longitudinal and twisting forces.

The following conclusions were drawn by Battelle in their study:

1. During deformation, the outer and inner walls of the workpiece will be acted upon by torsional, compressive, and longitudinal stresses.
2. The axial force on each roll will be approximately 4,500 lb; the normal force will be almost 27,000 lb.
3. Providing that the coefficient of friction between hot uranium and cold steel is greater than 0.1, sufficient forward thrust of the tube through the mill will be available.
4. A high feed efficiency can be expected.
5. The temperature rise during rotary elongation will be between 50°F and 100°F for uranium.
6. Some elongated grain structures can be expected on the outer wall of the finished tube. A radially deformed structure will exist throughout the entire tube.

The above conclusions were based on the following assumptions:

1. The efficiency of the mill will be approximately 5% to 10%.
2. During deformation, heat losses and uranium oxidation will have a negligible effect on the process.
3. The deformation will be considered to be distributed over the entire tube circumference.
4. With regard to stress-strain response, hot uranium will be considered an ideal, plastic material.

When compared with the test results, these conclusions proved to be reasonably valid.

9.2 INDUCTION HEATING

In previous tests using a 3-degree feed angle, each elongation required 4 to 5 minutes. This permitted the trailing end of the billet to cool considerably. The primary purpose of the induction heater was, hence, to maintain billet temperatures during the elongation. The trailing end of the billet would be heated as the front end was elongated.

A 75-kw, 10,000-cps, two-station, Tocco induction heater was available for use in the rotary elongation test. This equipment was the property of U. S. Naval Ordnance from whom permission was obtained for its use in the test. The Ajax-Magnethermic Corporation, Youngstown, Ohio, designed and constructed an induction coil consisting of twelve turns of ⅜-inch, square copper tubing. The coil was 4½-inches OD by 3¾-inches ID by 6-inches long.

To determine anticipated heat losses during processing, cooling curves were constructed prior to the test. Sample pieces were heated and allowed to cool under simulated test conditions. It was determined that heat losses due to air cooling would be between 30°F and 45°F per minute (Figure 22).

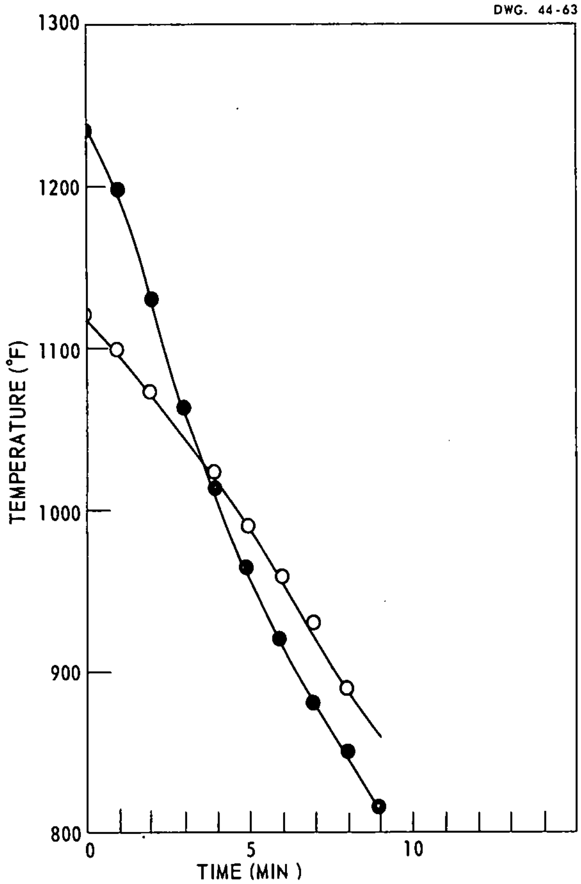


FIGURE 22 Cooling Curves for Rotary Elongation Test Billets (Feed Stock)

It was anticipated that the time required to transfer the uranium billet from the muffle furnace to the mill trough would be 15 to 30 seconds. If rotary rolling required from 3 to 5 minutes (based on 10% to 30% feed efficiency), there would be a temperature drop of approximately 150°F at the trailing end of the tube. A temperature gradient of this magnitude would undoubtedly have a deleterious effect upon consistency of grain structure. If tubes were rolled at these low efficiencies, the induction heater would be of benefit in maintaining billet temperature. However, if the tubes were rolled at higher feed efficiencies (70% to 100%), only 25 to 60 seconds would be required to roll each billet. Consequently, the heat losses during rolling would be negligible, and the induction coil would not be needed.

For the first half of the test, the induction heater was used to maintain billet temperatures. This work was performed at a feed angle of 3 degrees. The average rolling time was approximately 4 to 5 minutes. The induction coil added sufficient heat to the workpiece to prevent the trailing end of the billet from losing approximately 150°F in temperature.

During the latter half of the test, 6-degree bearings were installed in the mill. This change of feed angle resulted in rolling times of 25 to 50 seconds per billet. The heat loss due to cooling in open air was considered negligible. Consequently, use of the induction heater was abandoned.

9.3 TEMPERATURE MEASUREMENT

Radiation pyrometers were used to measure temperatures of billets entering and leaving the mill. Each Radiamatic head was inserted into a water-cooled copper coil to protect the instrument from ambient heat. The units were mounted on a rigid form as close as possible to the rolls (Figures 5 and 6). This type of pyrometer was chosen because it could be used to measure the temperature of a rotating target. The usual type of two-color or three-color pyrometer could not be utilized because of the absence of visible color in the workpiece. The major portion of the billets was preheated to 1000°F to 1150°F. Little, if any, color can be observed at these temperatures.

In radiation pyrometry, temperatures are measured by determining the amount and character of radiant energy in the form of heat rays emitted by an object. The rate of emission is dependent upon the temperature and surface condition of the target. The Radiamatic detector consists of a lens, thermopile and compensating shunt coil. The lens focuses the emitted radiant energy into the thermopile. The thermopile is composed of thermocouples wired in series to amplify the emf. The thermopile is sensitive to minute variations in radiant energy. The compensating coil is provided for changes in ambient temperature. A nickel coil is connected as an electrical shunt across the thermopile.

According to the Stefan-Boltzmann law of black body radiation, energy is proportional to the fourth power of the absolute temperature and to the emissivity of the material. Emissivity is a function of the nature of the material and surface condition. Because the surfaces of the uranium tubes were consistent in appearance, it was assumed that the Radiamatic pyrometers could be used with a reasonable degree of accuracy.

Prior to installation, the pyrometers were submitted to black box calibration. After the Radiamatic units were installed, temperature readings on uranium billets were checked against those obtained by means of embedded chromel-alumel thermocouples. Correction factors of 10°F and 60°F were used on the pyrometers located at the mill inlet and outlet, respectively.

9.4 POWER

One variable of importance was the amount of work performed on the uranium. A wattmeter was installed in series with the 300-hp mill motor. By counting the number of revolutions of the rotating disc while the motor was under "load" and by correlating this with the rolling time, the kilowatt-seconds and horsepower were determined. The power under "no load" was then deducted to reveal the power required to work the uranium.

Approximately 30 hp was used by the mill to elongate billets when the 3-degree bearings were used for elongating; approximately 120 hp was used when the 6-degree bearings were used. Because the watt-meter was not connected to a strip chart recorder, it was necessary to station a man at the meter to record the necessary data for computing power consumption. For this reason, power readings were not taken on every rotary elongation.

9.5 GRAIN ORIENTATION

Rotary elongation tends to twist the metal fibers as the workpiece passes through the mill. The amount of twisting can be controlled by changing mill settings. The direction of twisting can be reversed by changing the direction of working through either the piercer or elongator. Hence, it may be possible to use this characteristic of the process to achieve a more nearly random grain orientation in the metal produced.

10. SAMPLE CALCULATIONS

Test J-9 (Table III in the Appendix) was selected as a typical elongation to illustrate the calculations employed.

10.1 DATA

Roll Diameter: 10½ inches
Roll Speed: 35 rpm
Feed Angle: 6°
Gorge: 1.725 inches
Mandrel Diameter: 0.610 inch
Rolling Time: 28.0 seconds
Billet Dimensions: 2.331-inches OD by 1.00 inch ID by 36-inch
Billet Weight: 83 pounds
Product Dimensions: 1.762-inches OD by 0.610-inch ID by 59¼-inches long
Wattmeter (1 revolution): 88 seconds (no load)
17 seconds (load)

10.2 CALCULATIONS

1. Feed Rate: Billet Length ÷ Rolling Time
   36 inches ÷ 28 seconds
   1.286 inches/second
   77.14 inches/minute

2. Throughput: Billet Weight ÷ Rolling Time
   83 pounds ÷ 28 seconds
   2.964 pounds/seconds
   177.85 pounds/minute

3. Actual Delivery Rate: Product Length ÷ Rolling Time
   59¼ inches ÷ 28 seconds
   2.116 inches/second
   126.96 inches/minute

4. Theoretical Delivery Rate: Roll Circumference × Sine of Feed Angle × Roll Speed
   10½ inches × 3.1416 × sine 6° × 35 rpm
   120.88 inches/minute

5. Efficiency: Actual Delivery Rate ÷ Theoretical Delivery Rate
   126.96 inches/minute ÷ 120.88 inches/minute
   105.03 per cent

6. Displacement: [Cross-sectional Area of Billet — Cross-sectional Area of Product]
× Delivery Rate (Actual)

$$\frac{\pi}{4}\left[(2.331^2 - 1^2) - (1.762^2 - 0.610^2)\right]$$

× 2.116 inches/ second
2.827 cubic inches/second

7. Power: Meter Constant × Revolutions/second × Rolling Time
480 kw-hours/revolution × (1 rev/17 seconds – 1 rev/88 seconds)
× 3600 seconds/hour
2296 kw-seconds

8. Horsepower: Power ÷ Time

$$\frac{2296 \text{ kw-seconds}}{28 \text{ seconds}} \times \frac{\text{HP}}{0.746 \text{ kw}}$$

109.9 hp.

9. Power/Cubic Inch Displace: Power ÷ Displacement
2296 kw-seconds ÷ 2.827 cubic inches/second
812 kw-seconds/cubic inch/second

11. CONCLUSIONS

1. Uranium tubes were rotary elongated successfully on a 3-roll, Assel-type shell mill.

2. Feed efficiencies greater than 100% were achieved during the test.

3. Water cooling on the roll and tube surfaces reduced uranium oxidation and prevented tubes from entering the difficult-to-work transformation zone. Heat generated by friction and by mechanical work can be controlled by regulating water coolant flow.

4. It is believed that duplexed structures obtained in the early portion of the test were grain growth phenomena rather than changes into the beta phase. The sharp, jagged grains, typical of beta-phase uranium, were not present in photographs of grain structures.

5. Duplex structures were eliminated when the rate of working was increased by changing the feed angle from 3 degrees to 6 degrees.

6. No significant differences could be seen between the products of centrifugally cast and extruded feed stock.

7. No significant differences could be attributed to beta heat — treating the feed stock prior to the elongation operation.

12. RECOMMENDATIONS

1. After additional examination is made of the rotary piercing operation, it is recommended that a sequential test be made of the proposed fabrication route. Each individual operation (rolling, rotary piercing, rotary elongation, sink reduction, beta heat treatment, and final machining) has been shown to be technically feasible. After the metal has progressed sequentially through each operation and the interactions are determined, an accurate evaluation can be made. The ultimate consideration of the route would be based upon core performance in reactor tests, and cost analyses.

2. A furnace employing a shorter preheat cycle should be procured, especially if future pilot-scale or semiproduction tests are planned. The gas-fired muffle furnace operated satisfactorily during the test. Excellent temperature control was obtained by using a 2-hour heating and soaking cycle for each furnace loading of four billets. It is recommended that a cold-wall vacuum furnace be used. This would reduce the preheat time by approximately 65% and would lessen the amount of uranium oxidation.

3. A metered control of the water coolant recirculation system should be obtained. The amount of water sprayed on the roll surfaces and metal periphery is important to the process. An excessive amount of coolant will lower the tube temperature and thereby reduce metal plasticity; too little coolant may result in an excessive temperature rise in the billet.

4. A more efficient stripping mechanism should be installed. The size of the hydraulic cylinder should be increased to obtain a higher stripping pressure on the mandrel. An increased contact surface between the stripping bar and the mandrel collar would improve the stripping action.

5. The initial period of a pilot-scale or semiproduction test should be devoted to additional investigation of roll design. The roll profile is an important variable in controlling the rotary elongation operation. With the proper roll design and the use of stepped mandrels, it would be possible to determine optimum reductions in area and to gain closer dimensional control of the finished tubes.

6. Additional bearings to provide a feed angle of 8 degrees should be obtained. The change in efficiency resulting from the change from 3 to 6 degree bearings was sufficient to justify the additional examination.

7. Additional outlet guides should be obtained. The clearance between the finished tube and the outlet guides should be maintained at $\frac{3}{8}$ inch to support the elongated tubes properly. Adjustable roller guides could be used instead.

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15. APPENDIX

TABLE III Test Purpose

Number of Billets	Test Number	Purpose
22	A - 1 to A - 22	Pre - test startup — calibration of induction coil, lubricant, calibration of radiamatic pyrometers, mill alignment, and mandrel heating.
12	B - 1 - 1 to B - 1 - 12	Evaluation of billet preheat temperature
6	B - 2 - 1 to B - 2 - 6	Calibration and use of induction coil
4	B - 3 - 1 to B - 3 - 4	Evaluation of optimum reduction in area
2	C - 1 to C - 2	Evaluation of ID
13	D - 1 to D - 13	Evaluation of roll speed
4	G - 1 to G - 4	Evaluation of feed angle
5	E - 1 to E - 5	Evaluation of feed angle and roll profile
4	L - 1 to L - 4	Sink reduction
2	M - 1 to M - 2	Rolling of solid billet
2	K - 1 to K - 2	Roll profile evaluation
4	H - 1 to H - 4	Roll material evaluation
24	H - 5 to H - 28	Evaluation of feed stock (production).
24	J - 1 to J - 24	Evaluation of multiple elongation (production)
2	PO - 1 to PO - 2	Evaluation of tube profile
2	PO - 3 to PO - 4	Evaluation of roll speed
2	PO - 5 to PO - 6	Beta Phase Elongation

TABLE IV Data, Rotary Elongation Test
Material: Normal Uranium

Set-up Data										
Tube No.	1	2	3	4	5	6	7	8	9	10
Date	7-7-61	7-17-61	7-20-61	7-20-61	7-21-61	7-25-61	7-25-61	7-26-61	7-26-61	7-26-61
Test No. *	A-1	A-2	A-3	A-4	A-5	A-6	A-7	A-8	A-9	A-10
Billet No.	33305 T5	33308 T3	33298 T5	33299 T5	33316 T2	33299 T3	33317 T1	33299 T1	33317 T5	33310 T1
Billet Type **	A	A	A	A	B	A	B	A	B	A
Billet Length (in)	$36\frac{1}{16}$	$36\frac{1}{8}$	$36\frac{1}{16}$	$36\frac{1}{8}$	$35\frac{15}{16}$	$35\frac{15}{16}$	$35\frac{1}{8}$	$35\frac{3}{16}$	$36\frac{1}{16}$	35
Billet Weight (lb)	129.8	129.5	129.2	130.0	130.4	130.0	127.0	127.8	130.0	125.6
Furnace Temperature (°F)	–	1170	1155	1155	1250	1180	1150	1180	1180	1180
Roll Hump (in)	–	0.220	0.220	0.220	0.220	0.220	0.220	0.220	0.220	–
Feed Angle (deg)	–	3	3	3	3	3	3	3	3	–
Speed (rpm)	–	45	45	45	45	45	45	45	45	–
Water Cooling	–	No	No	Yes	No	No	No	No	No	–
Gorge (in., dia)	–	2.40	2.30	2.40	2.40	2.40	2.40	2.375	2.375	–
Mandrel (in., dia)	–	$1\frac{1}{4}$	$1\frac{1}{4}$	$1\frac{1}{4}$	$1\frac{1}{4}$	1	$1\frac{1}{4}$	$1\frac{1}{8}$	$1\frac{1}{8}$	–
Induction Coil	Yes	No	No	No	No	No	No	No	No	–
Results										
Rolling Time (min:sec)	–	3:50.0	3:59.0	5:53.6	4:32.6	5:47.0	3:43.0	4:01.2	3:12.0	–
Calculated Feed Rate (in./min)	–	9.27	9.06	6.13	7.93	6.22	9.68	8.98	11.24	–
Calculated Feed Rate (lb/min)	–	33.57	32.80	22.21	27.92	22.50	35.10	32.40	40.70	–
Delivery Rate (in./min)	–	15.21	16.26	9.55	13.03	9.37	15.78	13.82	17.84	–
Rolling Efficiency (%)	–	19.6	20.9	12.3	16.8	12.1	20.3	17.8	22.9	–
Horsepower (avg)	–	–	–	–	–	–	–	–	–	–
Displacement (cu in./sec)	–	0.578	0.641	0.325	0.456	0.263	0.552	0.460	0.589	–
Mandrel Stripping	–	No	No	No	No	Yes	No	Yes	No	–
Tube OD (in., avg)	–	2.326	2.291	2.384	2.375	2.353	2.355	2.343	2.343	–
Tube Length (in.)	–	$58\frac{1}{8}$	$64\frac{3}{4}$	$56\frac{1}{4}$	$59\frac{1}{16}$	$59\frac{1}{4}$	$58\frac{3}{4}$	$55\frac{1}{2}$	$57\frac{1}{16}$	–
Tube Weight (lb)	–	119.0	127.2	123.2	125.8	128.0	125.0	125.6	121.6	–

TABLE IV Data, Rotary Elongation Test (Continued)
Material: Normal Uranium

Set-up Data										
Tube No.	11	12	13	14	15	16	17	18	19	20
Date	7-27-61	7-27-61	7-27-61	7-27-61	7-31-61	7-31-61	8-1-61	8-1-61	8-1-61	8-2-61
Test No.*	A-11	A-12	A-13	A-14	A-15	A-16	A-17	A-18	A-19	A-20
Billet No.	33284 B1	33310 T5	33303 T1	33298 T1	33303 T2	33310 T4	33310 T2	33308 T1	33303 T3	33281 T4
Billet Type**	A	A	A	A	A	A	A	A	A	A
Billet Length (in)	$35\frac{1}{8}$	$35\frac{5}{16}$	$35\frac{1}{8}$	$35\frac{1}{16}$	$35\frac{15}{16}$	$36\frac{3}{16}$	$35\frac{7}{16}$	$35\frac{1}{8}$	36	$35\frac{7}{8}$
Billet Weight (lb)	127.2	129.2	127.2	127.2	130.0	129.6	127.0	126.8	130.1	129.2
Furnace Temperature (°F)	1150	1145	1145	1130	1095	—	1095	1150	1130	1100
Roll Hump (in)	0.220	0.220	0.220	0.220	0.220	—	0.220	0.220	0.220	0.220
Feed Angle (deg)	3	3	3	3	3	—	3	3	3	3
Speed (rpm)	45	45	45	45	45	—	45	45	45	45
Water Cooling	No	No	No	No	No	—	No	No	No	No
Gorge (in., dia)	2.375	2.375	2.438	2.375	2.375	—	2.375	2.375	2.375	2.40
Mandrel (in., dia)	$1\frac{1}{8}$	$1\frac{1}{8}$	$\frac{3}{4} - 1\frac{1}{4}$†	$1\frac{1}{8}$	$1\frac{1}{8}$	—	$1\frac{1}{8}$	$1\frac{1}{8}$	$1\frac{1}{8}$	$1\frac{1}{4}$
Induction Coil	No	No	No	No	No	—	No	No	No	No
Results										
Rolling Time (min:sec)	3:48.0	3:51.4	4:14.0	3:46.8	5:09.2	—	5:49.6	5:42.1	5:50.0	7:06.8
Calculated Feed Rate (in./min)	9.47	9.34	8.72	8.19	6.98	—	6.18	6.31	6.17	5.06
Calculated Feed Rate (lb./min)	34.30	33.80	31.60	29.60	25.29	—	22.21	22.74	22.35	18.34
Delivery Rate (in./min)	15.16	14.86	12.52	13.94	11.02	—	9.35	9.62	9.33	8.12
Rolling Efficiency (%)	19.5	19.1	16.1	17.9	14.2	—	12.0	12.4	12.0	10.4
Horsepower (avg)	—	—	—	—	—	—	—	—	—	—
Displacement (cu in./sec)	0.518	0.508	—	0.435	0.361	—	0.289	0.310	0.294	0.355
Mandrel Stripping	Yes	Yes	Yes	Yes	Yes	—	Yes	Yes	Yes	Yes
Tube OD (in., avg)	2.342	2.297	2.419	2.373	2.348	—	2.378	2.356	2.360	2.387
Tube Length (in)	$57\frac{7}{16}$	$57\frac{5}{16}$	$53\frac{1}{16}$	$52\frac{3}{4}$	$56\frac{3}{4}$	—	$54\frac{1}{2}$	$54\frac{7}{8}$	$54\frac{1}{2}$	$57\frac{3}{4}$
Tube Weight (lb)	125.0	124.6	125.0	120.8	127.9	—	124.8	124.4	127.8	127.0

TABLE IV Data, Rotary Elongation Test (Continued)
Material: Normal Uranium

Set-up Data										
Tube No.	21	22	23	24	25	26	27	28	29	30
Date	8-2-61	8-3-61	8-8-61	8-8-61	8-8-61	8-8-61	8-9-61	8-9-61	8-9-61	8-9-61
Test No.*	A-21	A-22	B-1-1	B-1-2	B-1-3	B-1-4	B-1-5	B-1-6	B-1-7	B-1-8
Billet No.	33281 T5	33301 T2	33301 T2	33284 B5	33284 T2	33281 T1	33284 T4	33281 T5	33281 T2	33306 T5
Billet Type**	A	A	A	A	A	A	A	A	A	A
Billet Length (in)	$35\frac{1}{4}$	$36\frac{1}{16}$	$36\frac{1}{16}$	$35\frac{1}{2}$	$36\frac{1}{16}$	$35\frac{1}{4}$	$35\frac{1}{8}$	$35\frac{7}{8}$	$36\frac{1}{16}$	$36\frac{1}{8}$
Billet Weight (lb)	127.2	129.4	129.4	127.8	130.6	127.0	130.2	129.4	130.2	130.0
Furnace Temperature (°F)	1100	—	1005	1000	1125	1125	1150	1145	1070	1070
Roll Hump (in)	0.220	—	0.220	0.220	0.220	0.220	0.220	0.220	0.220	0.220
Feed Angle (deg)	3	—	3	3	3	3	3	3	3	3
Speed (rpm)	45	—	35	35	35	35	35	35	35	35
Water Cooling	No	—	No	No	No	No	No	No	No	No
Gorge (in., dia)	2.40	—	2.375	2.375	2.375	2.375	2.40	2.40	2.40	2.40
Mandrel (in., dia)	$1\frac{1}{4}$	—	$1\frac{1}{4}$	$1\frac{1}{4}$	$1\frac{1}{4}$	$1\frac{1}{4}$	$1\frac{1}{4}$	$1\frac{1}{4}$	$1\frac{1}{4}$	$1\frac{1}{4}$
Induction Coil	No	Yes	No	No	No	No	No	No	No	No
Results										
Rolling Time (min:sec)	5:45.0	—	4:40.0	4:37.0	4:56.8	4:15.0	4:26.6	5:00.6	5:13.5	5:32.4
Calculated Feed Rate (in./min)	6.26	—	7.71	7.80	7.28	8.47	8.10	7.19	6.89	6.50
Calculated Feed Rate (lb./min)	22.70	—	27.97	28.28	26.40	30.71	29.37	26.07	24.98	23.57
Delivery Rate (in./min)	9.87	—	13.61	13.34	13.17	15.12	13.05	11.73	11.34	10.85
Rolling Efficiency (%)	12.7	—	22.5	22.1	21.8	25.0	21.6	19.4	18.7	17.9
Horsepower (avg)	—	—	45.0	41.1	39.2	39.2	38.8	34.4	33.8	32.4
Displacement (cu in./sec)	0.339	—	0.530	0.527	0.521	0.606	0.434	0.401	0.396	0.381
Mandrel Stripping	Yes	—	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Tube OD (in., avg)	2.378	—	2.310	2.301	2.300	2.291	2.402	2.387	2.376	2.373
Tube Length (in)	$56\frac{3}{4}$	—	$63\frac{1}{2}$	$61\frac{9}{16}$	$65\frac{1}{8}$	$64\frac{1}{4}$	58	$58\frac{3}{4}$	$59\frac{1}{4}$	$60\frac{1}{8}$
Tube Weight (lb)	125.0	—	127.2	122.4	130.6	127.0	130.2	129.4	127.6	127.4

TABLE IV Data, Rotary Elongation Test (Continued)
Material: Normal Uranium

Set-up Data										
Tube No.	31	32	33	34	35	36	37	38	39	40
Date	8-9-61	8-9-61	8-9-61	8-9-61	8-10-61	8-10-61	8-10-61	8-10-61	8-11-61	8-11-61
Test No.*	B-1-9	B-1-10	B-1-11	B-1-12	B-2-1	B-2-2	B-2-3	B-2-4	B-2-5	B-2-6
Billet No.	33306 T2	33299 T4	33284 B4	33299 T2	33284 T3	33306 T1	33306 T4	33284 T1	33284 B2	33301 T3
Billet Type**	A	A	A	A	A	A	A	A	A	A
Billet Length (in)	35 15/16	36 1/8	35 7/8	36 1/16	36 1/8	35 1/4	35 7/8	35 1/4	36	36
Billet Weight (lb)	129.2	130.2	130.2	130.6	130.4	126.6	129.6	127.4	130.6	129.2
Furnace Temperature (°F)	1110	1100	1125	1115	1125	1070	900	900	1050	1050
Roll Hump (in)	0.220	0.220	0.220	0.220	0.220	0.220	0.220	0.220	0.220	0.220
Feed Angle (deg)	3	3	3	3	3	3	3	3	3	3
Speed (rpm)	35	35	35	35	35	35	35	35	35	35
Water Cooling	No	No	Yes	Yes	No	No	No	No	No	No
Gorge (in., dia)	2.40	2.40	2.40	2.40	2.40	2.40	2.40	2.40	2.40	2.40
Mandrel (in., dia)	1 1/4	1 1/4	1 1/4	1 1/4	1 1/4	1 1/4	1 1/4	1 1/4	1 1/4	1 1/4
Induction Coil	No	No	Yes	Yes	No	No	Yes	Yes	Yes	Yes
Results										
Rolling Time (min:sec)	5:11.9	5:20.0	4:17.2	5:25.6	4:47.7	3:48.6	4:25.1	4:06.6	5:33.2	4:53.0
Calculated Feed Rate (in./min)	6.93	6.75	8.40	6.63	7.51	9.45	—	8.74	6.48	7.37
Calculated Feed Rate (lb./min)	25.13	24.47	30.46	24.04	27.23	34.26	—	31.65	23.50	26.72
Delivery Rate (in./min)	11.34	11.16	13.34	10.59	11.89	14.45	12.79	13.66	10.35	11.77
Rolling Efficiency (%)	18.7	18.5	22.1	17.5	19.7	23.9	21.1	22.6	17.1	19.5
Horsepower (avg)	35.0	35.0	—	33.6	33.4	36.6	34.8	—	—	—
Displacement (cu in./sec)	0.393	0.393	0.443	0.382	0.385	0.461	0.413	0.443	0.335	0.384
Mandrel Stripping	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Tube OD (in., avg)	2.380	2.371	2.405	2.357	2.417	2.424	2.435	2.415	2.417	2.413
Tube Length (in)	59	59 1/2	57 3/16	57 1/2	57	55	56 1/2	56 1/8	57 1/2	—
Tube Weight (lb)	127.2	127.8	126.0	127.2	127.6	124.6	126.5	125.2	127.8	—

TABLE IV Data, Rotary Elongation Test (Continued)

Material: Normal Uranium

Set-up Data										
Tube No.	41	42	43	44	45	46	47	48	49	50
Date	8-14-61	8-14-61	8-14-61	8-14-61	8-14-61	8-14-61	8-15-61	8-15-61	8-15-61	8-15-61
Test No.*	B-3-1	B-3-2	B-3-3	B-3-4	C-1	C-2	D-1	D-2	D-3	D-4
Billet No.	33277 B2	33314 T1	33309 T2	33309 T4	33284 T5	33301 T4	33302 T1	33284 B3	33310 T4	33310 T1
Billet Type**	C	C	C	C	A	A	A	A	A	A
Billet Length (in)	$36\frac{1}{16}$	$35\frac{5}{16}$	$36\frac{1}{16}$	36	36	$36\frac{1}{8}$	$35\frac{1}{4}$	$36\frac{3}{16}$	$36\frac{3}{16}$	35
Billet Weight (lb)	114.0	114.2	114.0	114.0	130.2	129.4	127.2	130.6	129.6	125.6
Furnace Temperature (°F)	1100	1130	1125	–	1045	1055	1070	1070	1120	–
Roll Hump (in)	0.220	0.220	0.220	–	0.220	0.220	0.220	0.220	0.220	–
Feed Angle (deg)	3	3	3	–	3	3	3	3	3	–
Speed (rpm)	35	35	35	–	35	35	70	70	70	–
Water Cooling	No	No	No	–	No	No	No	No	Yes	–
Gorge (in., dia)	2.40	2.20	2.20	–	2.40	2.40	2.30	2.30	2.35	–
Mandrel (in., dia)	$1\frac{1}{4}$	$1\frac{1}{4}$	$1\frac{1}{4}$	–	$\frac{3}{4} - 1\frac{1}{4}$†	$\frac{3}{4} - 1\frac{1}{4}$†	$1\frac{1}{8}$	$1\frac{1}{8}$	$1\frac{3}{16}$	–
Induction Coil	No	No	No	–	Yes	Yes	Yes	Yes	Yes	–
Results										
Rolling Time (min:sec)	11:18.8	4:17.5	7:00.0	–	5:31.0	4:55.1	4:07.0	5:00.0	7:59.3	–
Calculated Feed Rate (in./min)	3.18	8.39	6.06	–	6.53	7.32	8.74	6.30	4.51	–
Calculated Feed Rate (lb./min)	11.53	30.42	21.97	–	23.68	26.54	31.69	–	16.35	–
Delivery Rate (in./min)	4.51	14.97	10.83	–	10.15	11.39	14.27	10.50	6.99	–
Rolling Efficiency (%)	7.5	24.7	17.9	–	16.8	18.8	11.8	10.0	5.8	–
Horsepower (avg)	–	–	–	–	–	–	–	–	–	–
Displacement (cu in./sec)	–	–	–	–	–	–	0.513	–	0.232	–
Mandrel Stripping	Yes	Yes	Yes	–	Yes	Yes	Yes	Yes	Yes	–
Tube OD (in., avg)	2.419	2.208	2.186	–	2.416	2.400	2.295	2.303	2.339	–
Tube Length (in)	51	$64\frac{1}{4}$	$64\frac{5}{16}$	–	56	56	$58\frac{3}{4}$	$52\frac{1}{2}$	$55\frac{7}{8}$	–
Tube Weight (lb)	110.6	112.0	110.8	–	128.0	127.4	123.2	116.0	116.8	–

TABLE IV Data, Rotary Elongation Test (Continued)
Material: Normal Uranium

Set-up Data										
Tube No.	51	52	53	54	55	56	57	58	59	60
Date	8-16-61	8-16-61	8-16-61	8-17-61	8-17-61	8-17-61	8-17-61	8-17-61	8-17-61	8-18-61
Test No.*	D-5	D-6	D-7	D-8	D-9	D-10	D-11	D-12	D-13	G-1
Billet No.	33310 T1	33308 T2	33301 T1	33277 T1	33312 T5	33298 T4	33305 T5	33317 T4	33303 T5	33297 T3
Billet Type**	A	A	A	A	B	A	A	B	A	C
Billet Length (in)	35	$36\frac{1}{8}$	$34\frac{3}{4}$	—	36	$35\frac{1}{16}$	—	$35\frac{7}{8}$	$36\frac{1}{16}$	$35\frac{13}{16}$
Billet Weight (lb)	125.6	130.0	125.4	—	129.3	129.5	—	130.2	129.8	113.4
Furnace Temperature (°F)	1075	1120	1150	1080	1070	1070	1075	1080	1075	1085
Roll Hump (in)	0.220	0.220	0.220	0.220	0.220	0.220	0.220	0.220	0.220	0.125
Feed Angle (deg)	3	3	3	3	3	3	3	3	3	6
Speed (rpm)	25	25	25	45	45	45	35	35	35	35
Water Cooling	No	No	No	Yes	No	Yes	No	No	Yes	No
Gorge (in., dia)	2.35	2.35	2.35	2.35	2.35	2.35	2.35	2.35	2.35	2.20
Mandrel (in., dia)	$1\frac{3}{16}$	$1\frac{3}{16}$	$1\frac{1}{8}$	$1\frac{1}{8}$	$1\frac{1}{8}$	$1\frac{1}{8}$	$1\frac{1}{8}$	$1\frac{1}{8}$	$1\frac{1}{8}$	—
Induction Coil	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No
Results										
Rolling Time (min:sec)	4:50.0	3:52.8	5:00.0	6:30.6	5:12.2	7:25.2	5:27.4	6:07.2	4:20.8	—
Calculated Feed Rate (in./min)	7.45	9.28	7.20	5.53	6.92	4.85	6.60	5.88	8.28	—
Calculated Feed Rate (lb./min)	27.01	33.65	26.11	20.05	25.09	17.59	23.93	21.32	30.02	—
Delivery Rate (in./min)	11.38	15.17	10.85	8.64	11.15	7.88	10.77	9.51	12.88	—
Rolling Efficiency (%)	26.3	35.1	25.1	11.1	14.3	10.1	17.8	15.7	21.3	—
Horsepower (avg)	30.3	32.0	29.7	33.1	38.5	—	32.4	31.0	35.4	—
Displacement (cu in./sec)	0.340	0.611	0.434	0.360	0.375	0.348	0.468	0.400	0.404	—
Mandrel Stripping	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	—
Tube OD (in., avg)	2.391	2.363	2.370	2.348	2.333	2.317	2.326	2.343	2.371	—
Tube Length (in)	55	$58\frac{3}{8}$	$54\frac{1}{4}$	$56\frac{1}{4}$	58	$58\frac{1}{2}$	$58\frac{3}{4}$	$58\frac{7}{16}$	56	—
Tube Weight (lb)	121.6	127.7	122.4	122.6	127.1	123.2	126.1	128.2	125.1	—

TABLE IV Data, Rotary Elongation Test (Continued)
Material: Normal Uranium

Set-up Data										
Tube No.	61	62	63	64	65	66	67	68.	69	70
Date	8-18-61	8-18-61	8-18-61	8-21-61	8-21-61	8-21-61	8-21-61	8-21-61	8-22-61	8-22-61
Test No.*	G-2	G-3	G-4	E-1	E-2	E-3	E-4	E-5	L-1	L-2
Billet No.	33311 T1	33305 T4	33315 T2	33307 T4	33314 T3	33312 T2	33305 T2	33304 T4	33311 T4	33277 B3
Billet Type**	C	A	B	C	C	B	A	A	C	C
Billet Length (in)	$34\frac{15}{16}$	$35\frac{7}{8}$	$35\frac{31}{32}$	$36\frac{1}{16}$	$36\frac{1}{16}$	36	$35\frac{7}{8}$	$35\frac{15}{16}$	36	36
Billet Weight (lb)	111.4	128.4	129.8	113.6	111.4	128.4	128.6	128.1	114.8	114.2
Furnace Temperature (°F)	1085	1070	1070	1025	1020	1030	1025	1035	1030	1030
Roll Hump (in)	0.125	0.125	0.125	0.220	0.220	0.220	0.220	0.220	Smooth	Smooth
Feed Angle (deg)	6	6	6	6	6	6	6	6	6	6
Speed (rpm)	35	35	35	—	35	35	35	25	25	25
Water Cooling	No	No	No	—	No	No	No	Yes	No	No
Gorge (in., dia)	2.40	2.40	2.40	—	2.40	2.30	2.25	2.25	2.40	2.35
Mandrel (in., dia)	$1\frac{1}{8}$	$1\frac{1}{8}$	$1\frac{1}{8}$	—	$1\frac{1}{8}$	1	1	1	$1\frac{1}{8}$	$1\frac{1}{8}$
Induction Coil	No	No	No	—	No	No	No	No	No	No
Results										
Rolling Time (min:sec)	0:27.0	0:38.0	0:37.0	—	1:45.0	0:57.0	0:57.0	1:03.0	0:44.6	0:44.5
Calculated Feed Rate (in./min)	80.00	56.84	58.38	—	20.57	37.89	37.89	34.29	48.40	48.60
Calculated Feed Rate (lb./min)	290.07	206.10	211.70	—	—	137.40	137.40	124.30	154.50	153.90
Delivery Rate (in./min)	102.78	86.62	92.80	—	27.43	58.42	62.24	55.71	60.54	62.70
Rolling Efficiency (%)	84.9	73.2	76.7	—	22.7	48.3	51.4	46.0	70.1	72.6
Horsepower (avg)	37.1	109.9	111.9	—	—	95.6	118.2	79.1	—	—
Displacement (cu in./sec)	—	3.501	2.850	—	—	2.192	2.542	2.365	—	—
Mandrel Stripping	Yes	Yes	No	—	Yes	Yes	Yes	No	Yes	Yes
Tube OD (in., avg)	2.416	2.376	2.381	—	2.442	2.345	2.302	2.281	2.463	2.465
Tube Length (in)	$46\frac{1}{4}$	$56\frac{1}{8}$	$56\frac{1}{2}$	—	48	$55\frac{1}{2}$	$59\frac{1}{8}$	$58\frac{1}{2}$	45	$46\frac{1}{2}$
Tube Weight (lb)	111.0	128.0	129.5	—	111.4	128.4	128.6	128.1	114.8	114.2

TABLE IV Data, Rotary Elongation Test (Continued)
Material: Normal Uranium

Set-up Data										
Tube No.	71	72	73	74	75	76	77	78	79	80
Date	8-22-61	8-22-61	8-22-61	8-22-61	8-22-61	8-22-61	8-24-61	8-24-61	8-24-61	8-24-61
Test No.*	L-3	L-4	M-1	M-2	K-1	K-2	H-1	H-2	H-3	H-4
Billet No.	33311 T3	33300 T3	B-2	B-1	33310 T3	33315 T4	33317 T2	33316 T5	33315 T3	33315 T1
Billet Type**	C	C	D	D	A	B	B	B	B	B
Billet Length (in)	35⅞	36	36	36	36	35¾	36	36	36	34 15/16
Billet Weight (lb)	113.6	112.8	157.8	156.9	129.2	129.1	129.8	128.5	129.4	124.2
Furnace Temperature (°F)	1030	1045	1025	—	1020	1030	1030	1040	1050	1045
Roll Hump (in)	Smooth	Smooth	Smooth	Smooth	Smooth	Smooth	0.125	0.125	0.125	0.125
Feed Angle (deg)	6	6	6	6	6	6	6	6	6	6
Speed (rpm)	25	25	25	25	25	25	25	25	25	25
Water Cooling	No	No	No	No	No	No	No	Yes	Yes	Yes
Gorge (in., dia)	2.35	2.35	2.60	—	2.40	2.30	2.37	2.29	2.29	2.29
Mandrel (in., dia)	None	None	None	—	1⅛	1	1	1	1	1⅛
Induction Coil	No	No	No	No	No	No	No	No	No	No
Results										
Rolling Time (min:sec)	0:44.0	0:48.6	0:40.0	—	0:37.0	0:48.2	0:48.8	0:44.0	0:41.0	0:43.4
Calculated Feed Rate (in./min)	49.09	44.50	54.00	—	58.30	44.80	44.26	49.09	52.68	49.77
Calculated Feed Rate (lb./min)	154.70	139.20	234.30	—	211.60	162.30	160.48	178.00	191.00	180.50
Delivery Rate (in./min)	60.00	56.80	64.13	—	76.42	65.35	65.16	76.02	81.22	76.73
Rolling Efficiency (%)	69.5	65.8	74.0	—	88.5	75.7	75.5	88.1	94.1	88.9
Horsepower (avg)	—	—	—	—	75.6	76.0	—	—	—	—
Displacement (cu in./sec)	—	—	—	—	1.946	2.019	1.499	2.146	2.288	2.395
Mandrel Stripping	—	—	—	—	Yes	Yes	Yes	Yes	Yes	No
Tube OD (in., avg)	2.473	2.462	2.629	—	2.547	2.428	2.448	2.365	2.366	2.373
Tube Length (in)	44	46	42¾	—	47⅛	52½	53	55¾	55½	55½
Tube Weight (lb)	113.6	112.8	156.2	—	127.6	128.8	129.8	128.5	129.4	124.2

TABLE IV Data, Rotary Elongation Test (Continued)
Material: Normal Uranium

Set-up Data										
Tube No.	81	82	83	84	85	86	87	88	89	90
Date	8-25-61	8-25-61	8-25-61	8-25-61	8-25-61	8-25-61	8-25-61	8-25-61	8-25-61	8-25-61
Test No.*	H-5	H-6	H-7	H-8	H-9	H-10	H-11	H-12	H-13	H-14
Billet No.	33300 T4	P102	33277 T2	33307 T1	P105	P83	33300 T2	33305 T1	P104	P82
Billet Type**	A	E	A	A	F	G	A	A	H	G
Billet Length (in)	$36\frac{1}{32}$	$36\frac{1}{16}$	$35\frac{3}{4}$	$35\frac{3}{16}$	36	$36\frac{1}{16}$	36	—	$36\frac{1}{16}$	$36\frac{1}{32}$
Billet Weight (lb)	129.9	130.4	128.5	126.9	119.9	133.0	129.4	124.8	122.0	130.1
Furnace Temperature (°F)	1060	1080	1080	1075	1055	1040	1045	1035	1050	1060
Roll Hump (in)	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125
Feed Angle (deg)	6	6	6	6	6	6	6	6	6	6
Speed (rpm)	35	35	35	35	35	35	35	35	35	35
Water Cooling	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Gorge (in., dia)	2.30	2.30	2.35	2.35	2.35	2.35	2.35	2.35	2.35	2.35
Mandrel (in., dia)	1	1	1	1	1	1	1	1	1	1
Induction Coil	No	No	No	No	No	No	No	No	No	No
Results										
Rolling Time (min:sec)	0:33.0	0:29.0	0:32.8	0:33.6	0:30.0	0:35.1	0:34.6	0:34.6	0:37.2	0:49.2
Calculated Feed Rate (in./min)	65.45	74.48	65.85	64.29	72.00	61.54	62.43	62.43	58.06	43.90
Calculated Feed Rate (lb./min)	237.32	270.06	238.77	233.11	261.06	223.14	226.36	226.36	210.52	159.18
Delivery Rate (in./min)	103.64	117.41	103.81	100.45	104.00	98.72	98.41	95.38	85.48	68.90
Rolling Efficiency (%)	85.7	97.0	85.8	83.0	85.8	81.6	81.3	78.8	70.6	56.9
Horsepower (avg)	—	—	—	—	131.3	155.0	131.3	131.3	—	—
Displacement (cu in./sec)	2.335	3.582	3.167	3.027	3.147	2.969	2.954	2.880	2.592	2.072
Mandrel Stripping	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Tube OD (in., avg)	2.335	2.328	2.328	2.334	2.332	2.335	2.336	2.333	2.331	2.335
Tube Length (in)	57	$56\frac{3}{4}$	$56\frac{3}{4}$	$56\frac{1}{4}$	52	$57\frac{3}{4}$	$56\frac{3}{4}$	55	53	$56\frac{1}{2}$
Tube Weight (lb)	129.4	130.2	128.0	126.4	119.9	133.0	129.4	124.8	121.9	129.7

TABLE IV Data, Rotary Elongation Test (Continued)

Material: Normal Uranium

Set-up Data										
Tube No.	91	92	93	94	95	96	97	98	99	100
Date	8-25-61	8-25-61	8-25-61	8-25-61	8-25-61	8-25-61	8-28-61	8-28-61	8-28-61	8-28-61
Test No.*	H-15	H-16	H-17	H-18	H-19	H-20	H-21	H-22	H-23	H-24
Billet No.	33315 T5	33277 T4	P99	33316 T1	P94	P85	P103	33316 T3	P80	33316 T4
Billet Type**	B	A	F	B	H	E	F	B	G	B
Billet Length (in)	$35\frac{15}{16}$	$36\frac{1}{16}$	$35\frac{31}{32}$	$35\frac{5}{16}$	$36\frac{1}{32}$	36	36	$36\frac{3}{16}$	$36\frac{3}{32}$	$36\frac{1}{8}$
Billet Weight (lb)	129.0	129.3	121.2	127.6	122.0	130.5	121.1	130.6	130.5	130.6
Furnace Temperature (°F)	1050	1050	1070	1065	1060	1045	1060	1060	1060	1055
Roll Hump (in)	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125
Feed Angle (deg)	6	6	6	6	6	6	6	6	6	6
Speed (rpm)	35	35	35	35	35	35	35	35	35	35
Water Cooling	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Gorge (in., dia)	2.35	2.35	2.35	2.35	2.35	2.35	2.35	2.35	2.35	2.35
Mandrel (in., dia)	1	1	1	1	1	1	1	1	1	1
Induction Coil	No	No	No	No	No	No	No	No	No	No
Results										
Rolling Time (min:sec)	0:38.2	0:36.8	0:28.1	0:32.6	0:28.5	0:43.6	0:26.2	0:33.0	0:30.0	0:35.1
Calculated Feed Rate (in./min)	56.54	58.70	76.87	66.26	75.79	49.54	82.44	65.45	72.00	61.54
Calculated Feed Rate (lb./min)	205.01	212.84	278.72	240.25	274.81	179.63	298.92	237.32	261.06	223.14
Delivery Rate (in./min)	90.31	94.16	113.17	103.07	112.63	77.75	119.03	104.55	112.00	98.29
Rolling Efficiency (%)	74.6	77.8	93.5	85.2	93.1	77.8	98.4	86.4	92.6	81.2
Horsepower (avg)	—	—	—	—	—	—	—	—	—	—
Displacement (cu in./sec)	2.793	2.907	3.480	3.081	3.443	2.339	3.502	3.164	3.334	2.950
Mandrel Stripping	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Tube OD (in., avg)	2.321	2.322	2.324	2.338	2.327	2.335	2.345	2.332	2.340	2.336
Tube Length (in)	$57\frac{1}{2}$	$57\frac{3}{4}$	53	56	$53\frac{1}{2}$	$56\frac{1}{2}$	52	$57\frac{1}{2}$	56	$57\frac{1}{2}$
Tube Weight (lb)	129.0	129.3	120.6	127.0	121.4	130.2	120.8	129.7	130.3	129.5

TABLE IV Data, Rotary Elongation Test (Continued)
Material: Normal Uranium

Set-up Data Tube No.	101	102	103	104	105	106	107	108	109	110
Date	8-28-61	8-28-61	8-28-61	8-28-61	8-28-61	8-28-61	8-28-61	8-28-61	8-28-61	8-28-61
Test No.*	H-25	H-26	H-27	H-26	J-1(H-5)	J-2(H-6)	J-3(H-7)	J-4(H-8)	J-5(H-9)	J-6(H-10)
Billet No.	P98	P101	33317 T3	33312 T4	33300 T4	P102	33277 T2	33307 T1	P105	P83
Billet Type**	H	E	B	B	A	E	A	A	F	G
Billet Length (in)	36 1/8	36 1/32	36	35 7/8	36	36	36 1/8	36	35 15/16	36 1/16
Billet Weight (lb)	122.3	130.2	130.4	130.2	82.5	83.5	82.8	81.9	83.4	84.0
Furnace Temperature (°F)	1040	1035	1045	1045	1030	1040	1040	1040	1025	1030
Roll Hump (in)	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125
Feed Angle (deg)	6	6	6	6	6	6	6	6	6	6
Speed (rpm)	35	35	35	35	35	35	35	35	35	35
Water Cooling	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes
Gorge (in., dia)	2.55	2.55	2.55	2.55	1.725	1.725	1.725	1.725	1.725	1.725
Mandrel (in., dia)	1 1/4	1 1/4	1 1/4	1 1/4	0.610	0.610	0.610	0.610	0.610	0.610
Induction Coil	No	No	No	No	No	No	No	No	No	No
Results Rolling Time (min:sec)	0:24.3	0:26.1	0:31.0	0:33.5	0:26.9	0:27.1	0:25.6	0:26.0	0:27.9	0:27.4
Calculated Feed Rate (in./min)	88.89	82.76	69.68	64.48	80.30	79.70	84.38	83.08	77.42	78.83
Calculated Feed Rate (lb/min)	322.30	300.08	252.65	233.80	183.12	184.21	191.95	187.61	178.71	183.07
Delivery Rate (in./min)	112.35	110.92	92.90	85.52	132.70	130.07	138.28	135.60	126.88	130.84
Rolling Efficiency (%)	92.9	91.7	76.8	70.7	109.7	108.0	114.3	112.1	104.9	108.1
Horsepower (avg)	—	—	—	—	—	—	—	—	—	—
Displacement (cu in./sec)	2.428	2.345	1.951	1.773	3.097	2.872	3.073	3.025	2.845	2.988
Mandrel Stripping	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Tube OD (in., avg)	2.581	2.588	2.590	2.594	1.744	1.762	1.759	1.765	1.760	1.755
Tube Length (in)	45 1/2	48 1/4	48	47 3/4	59 1/2	58 3/4	59	58 3/4	59	59 3/4
Tube Weight (lb)	122.2	130.0	129.5	129.1	82.1	83.2	81.9	81.3	83.0	83.6

TABLE IV Data, Rotary Elongation Test (Continued)

Material: Normal Uranium

Set-up Data										
Tube No	111	112	113	114	115	116	117	118	119	120
Date	8-28-61	8-28-61	8-29-61	8-29-61	8-29-61	8-29-61	8-29-61	8-29-61	8-29-61	8-29-61
Test No.*	J-7(H-11)	J-8(H-12)	J-9(H-13)	J-10(H-14)	J-11(H-15)	J-12(H-16)	J-13(H-3)	J-14(H-18)	J-15(H-19)	J-16(H-20)
Billet No.	33300 T2	33305 T1	P104	P82	33315 T5	33277 T4	33315 T3	33316 T1	P94	P85
Billet Type**	A	A	H	G	B	A	B	B	H	E
Billet Length (in)	36	36	$35\frac{15}{16}$	$35\frac{15}{16}$	36	36	36	$35\frac{15}{16}$	36	36
Billet Weight	83.0	82.8	83.5	83.2	81.2	80.6	84.2	82.2	83.6	83.8
Furnace Temperature (°F)	1030	1020	1030	1030	1035	1040	1050	1035	1035	1035
Roll Hump (in)	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125
Feed Angle (deg)	6	6	6	6	6	6	6	6	6	6
Speed (rpm)	35	35	35	35	35	35	35	35	35	35
Water Cooling	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Gorge (in., dia)	1.725	1.725	1.725	1.725	1.725	1.725	1.725	1.725	1.725	1.725
Mandrel (in., dia)	0.610	0.610	0.610	0.610	0.610	0.610	0.610	0.610	0.610	0.610
Induction Coil	No	No	No	No	No	No	No	No	No	No
Results										
Rolling Time (min:sec)	0:25.7	0:26.1	0:28.0	0:28.5	0:25.7	0:25.1	0:27.2	0:25.9	0:28.6	0:27.4
Calculated Feed Rate (in./min)	84.05	82.76	77.14	75.79	84.05	86.06	79.41	83.40	75.52	78.83
Calculated Feed Rate (lb/min)	192.37	188.51	177.85	174.52	188.17	191.47	184.85	189.49	174.97	182.85
Delivery Rate (in./min)	140.08	137.93	126.96	125.53	137.74	140.14	134.56	113.44	125.09	130.83
Rolling Efficiency (%)	115.8	114.0	104.9	103.7	113.8	115.8	111.2	113.4	103.4	108.1
Horsepower (avg)	—	—	109.9	102.9	85.7	111.1	—	—	—	—
Displacement (cu in./sec)	3.265	3.171	2.827	2.872	3.053	3.102	3.351	3.140	2.778	2.987
Mandrel Stripping	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Tube OD (in., avg)	1.746	1.749	1.762	1.754	1.751	1.753	1.753	1.758	1.758	1.755
Tube Length (in)	60	60	$59\frac{1}{4}$	$59\frac{5}{8}$	59	$58\frac{5}{8}$	61	$59\frac{1}{4}$	$59\frac{5}{8}$	$59\frac{3}{4}$
Tube Weight (lb)	82.4	82.0	83.0	82.9	80.6	80.1	83.8	81.8	83.4	83.5

TABLE IV Data, Rotary Elongation Test (Continued)
Material: Normal Uranium

Set-up Data										
Tube No.	121	122	123	124	125	126	127	128	129	130
Date	8-29-61	8-29-61	8-29-61	8-29-61	8-29-61	8-29-61	8-29-61	8-29-61	8-30-61	8-30-61
Test No.*	J-17(H-21)	J-18(H-22)	J-10(H-23)	J-20(H-24)	J-21(H-25)	J-22(H-26)	J-23(H-27)	J-24(H-28)	PO-1	PO-2
Billet No.	P103	33316 T3	P80	33316 T4	P98	P101	33317 T3	33317 T3	33277 B1	33277 T5
Billet Type**	F	B	G	B	H	E	B	B	A	A
Billet Length (in)	36	36	36	36	$35\frac{15}{16}$	$35\frac{15}{16}$	$37\frac{7}{8}$	$36\frac{1}{16}$	35	$35\frac{7}{8}$
Billet Weight (lb)	85.2	82.6	84.0	81.8	96.8	97.4	98.0	98.4	111.6	114.6
Furnace Temperature (°F)	1045	1040	1040	1035	1050	1065	1065	1095	1025	1025
Roll Hump (in)	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125
Feed Angle (deg)	6	6	6	6	6	6	6	6	6	6
Speed (rpm)	35	35	35	35	35	35	35	35	35	35
Water Cooling	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Gorge (in., dia)	1.725	1.725	1.725	1.725	2.160	2.160	2.160	2.160	2.45	2.45
Mandrel (in., dia)	0.610	0.610	0.610	0.610	1	1	1	1	$1\frac{1}{4}$	None
Induction Coil	No	No	No	No	No	No	No	No	No	No
Results										
Rolling Time (min:sec)	0:27.9	0:25.6	0:27.6	0:24.9	0:26.7	0:25.4	0:25.0	0:24.0	0:31.2	—
Calculated Feed Rate (in./min)	77.42	84.38	78.26	86.75	80.90	85.04	86.40	90.00	69.23	—
Calculated Feed Rate (lb/min)	181.94	192.19	181.96	195.42	216.63	228.66	233.52	244.75	111.54	—
Delivery Rate (in./min)	129.30	139.45	129.35	142.17	109.27	114.57	117.00	122.50	86.06	—
Rolling Efficiency (%)	106.9	115.3	106.9	117.5	109.3	114.6	117.0	101.2	71.1	—
Horsepower (avg)	—	—	—	—	—	—	68.5	—	—	—
Displacement (cu in./sec)	2.938	3.146	2.969	3.242	1.845	2.035	2.074	2.162	—	—
Mandrel Stripping	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	—
Tube OD (in., avg)	1.772	1.757	1.757	1.757	2.193	2.186	2.189	2.195	2.503	2.457
Tube Length (in)	$60\frac{1}{8}$	$59\frac{1}{2}$	$59\frac{1}{2}$	59	$48\frac{5}{8}$	$48\frac{1}{2}$	$48\frac{3}{4}$	49	$44\frac{3}{4}$	$37\frac{7}{8}$
Tube Weight (lb)	84.6	82.0	83.7	81.1	96.4	96.8	97.3	97.9	110.0	113.8

TABLE IV Data, Rotary Elongation Test (Continued)
Material: Normal Uranium

Set-up Data				
Tube No.	131	132	133	134
Date	8-30-61	8-30-61	8-30-61	8-30-61
Test No.*	PO-3	PO-4	PO-5	PO-6
Billet No.	33309 T1	33297 T4	33297 T2	33314 T2
Billet Type**	A	A	A	A
Billet Length (in)	35	$35\frac{13}{16}$	$36\frac{1}{8}$	36
Billet Weight (lb)	111.0	114.2	114.4	115.0
Furnace Temperature (°F)	1120	1120	1270	–
Roll Hump (in)	0.125	0.125	0.125	–
Feed Angle (deg)	6	6	6	–
Speed (rpm)	45	45	35	–
Water Cooling	Yes	Yes	Yes	–
Gorge (in., dia)	2.35	2.35	2.35	–
Mandrel (in., dia)	$1\frac{1}{8}$	$1\frac{1}{8}$	1	–
Induction Coil	No	No	No	–
Results				
Rolling Time (min:sec)	0:22.0	0:25.4	0:40.0	–
Calculated Feed Rate (in./min)	98.18	85.04	54.00	–
Calculated Feed Rate (lb./min)	300.00	266.45	167.10	–
Delivery Rate (in./min)	132.95	118.11	71.91	–
Rolling Efficiency (%)	85.5	76.0	59.4	–
Horsepower (avg)	–	–	–	–
Displacement (cu in./sec)	–	–	–	–
Mandrel Stripping	Yes	Yes	Yes	–
Tube OD (in., avg)	2.364	2.367	2.392	–
Tube Length (in)	$48\frac{3}{4}$	50	$47\frac{15}{16}$	–
Tube Weight (lb)	110.0	112.8	111.4	–

* Refer to Table III

** Billet Type

A – Statically cast, heat treated, and extruded
B – Statically cast and extruded
C – Statically cast, heat treated, extruded, and OD turned (taper - 3.00 to 2.71 - inch OD)
D – Statically cast, heat treated, and extruded (solid bar)
E – Centrifugally cast, heat treated, and OD turned
F – Centrifugally cast and heat treated
G – Centrifugally cast and OD turned
H – Centrifugally cast

† Tapered Mandrel