UNCLASSIFIED

ANL-5132(Del.)

ARGONNE NATIONAL LABORATORY

P. O. Box 299
Lemont, Illinois

Photostat Price \$ 10.80

Microfilm Price \$ 3.90

Available from the
Office of Technical Services
Department of Commerce
Washington 25, D. C.

DELETED VERSION

Classification change to unclassified
Authorized by William J. Ford 2-12-57
Change by H. Kirsner Date 6-13-72

THE MANUFACTURE OF INTERNAL BLANKET AND FUEL BLANKET
SLUGS FOR THE EXPERIMENTAL BREEDER REACTOR

by

R. E. Macherey and S. T. Zegler

LEGAL NOTICE

This report was prepared as an account of Government sponsored work. Neither the United States, nor the Commission, nor any person acting on behalf of the Commission:

A. Makes any warranty or representation, express or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this report, or that the use of any information, apparatus, method, or process disclosed in this report may not infringe privately owned rights; or

B. Assumes any liabilities with respect to the use of, or for damages resulting from the use of any information, apparatus, method, or process disclosed in this report.

As used in the above, "person acting on behalf of the Commission" includes any employee or contractor of the Commission to the extent that such employee or contractor prepares, handles or distributes, or provides access to, any information pursuant to his employment or contract with the Commission.

December 1953

204 001

Operated by The University of Chicago
under

Contract W-31-109-eng-38

UNCLASSIFIED

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

3

TABLE OF CONTENTS

	<u>Page</u>
I. Introduction.	4
II. Equipment.	5
III. Rolling Stock.	9
IV. Preliminary Experimental Rolling.	10
V. Rolling of Blanket Slugs.	10
VI. Rolling of Rod for Upper and Lower Fuel Blanket Slug	12
VII. Heat Treatment and Testing.	13
VIII. Jacketing Fuel Blanket Slugs	18
IX. Metallographic Structures	19
X. Acknowledgements	19
References	20

204 002

REF ID: A54144
REPLASIFIED

THE MANUFACTURE OF INTERNAL BLANKET AND FUEL BLANKET SLUGS FOR THE EXPERIMENTAL BREEDER REACTOR

by

R. E. Macherey and S. T. Zegler

I. INTRODUCTION

Surrounding the core of the Experimental Breeder Reactor (EBR) is located the Internal Blanket (see Figure 2 of Reference 1). This blanket is comprised of natural uranium rods jacketed in stainless steel. The active portion of each rod is made up of five natural uranium slugs 0.873" diameter x 4.050" long. The slugs, stacked one on top of another, are held together and protected by a drawn-on stainless steel tube with welded end closures. These internal blanket rods are located inside the external blanket the manufacture of which has been described previously.⁽²⁾

Located immediately above and below the enriched uranium^(3, 4) section of each fuel element are the upper and lower blanket assemblies, respectively. These assemblies are comprised of natural uranium slugs 0.364" diameter jacketed in stainless steel.

Both the internal blanket and the upper and lower blanket slugs are subjected to thermal cycling and severe irradiation during pile operation; therefore, these uranium parts must be stabilized against growth, warp, and surface roughening. The best known manufacturing practice for the production of unalloyed uranium rods with minimum tendency toward growth, warp, and surface roughening is rolling to a uniform, fine grained structure followed by a fast beta treatment^(a) and an alpha anneal.

In the manufacture of these slugs every effort was made to produce high quality products. Uranium billets 3" square were cast in the foundry using reactor grade uranium as the charge. The billets were first rolled at 600°C to refine the cast structure making it amenable to low alpha (300°C) rolling. Finish rolling to appropriate diameter was done at 300°C to produce a uniform fine grained structure. The rolled structure was modified by a fast beta treatment and an alpha anneal for the stabilization against growth and warp. The slugs were finished to size by machining and grinding.

(a) The term "fast beta treatment" means the heating of uranium into the beta phase followed immediately by a water quench. This term is synonymous with "beta quench" and is at times loosely referred to as "beta treatment."

II. EQUIPMENT

A. Rolling Mills

The rolling of billets and rods was done on two different rolling mills. The breakdown of all billets was done on a 16" x 24", two-high mill. The finish rolling of the 1" diameter internal blanket rod was also done on this mill. The finish rolling of the fuel blanket rod to 0.384" diameter was done on a 9" x 16", two-high mill.

The 16" mill is pictured in Figure 1. The mill housings are of the closed top design, securely bolted together at the top and bottom. The screws for top roll adjustment are 5" diameter, 1/4" pitch Acme thread and are driven by a single 5 HP, D.C. motor through suitable gearing. Drum-type indicators graduated in mils are located on top of each screw for roll adjustment. The roll neck bearings are of bronze mounted in cast steel chocks. The top roll balancing mechanism (springs) is located in a pit beneath the mill stand.

The mill is driven by an industrial type, shunt wound, D.C. motor, 150/200 HP, 400/1200 RPM, 230 volt. This motor develops 150 HP at the base speed of 400 RPM and 200 HP at the top speed of 1200 RPM. Below the base speed, the motor develops constant torque. The D.C. power for the motor is supplied by a packaged motor generator set, Reliance, 200 V*S power unit.

The mill is driven through a 150 HP double reduction, combination drive and pinion stand. The total gear ratio is 15.56 to 1. All gears have double helical, Sykes cut teeth; and all bearings are of the roller bearing type. Bearings and gear faces are lubricated by a pressure oiling system. Power is transmitted from the pinions to the rolls by spindles equipped with universal couplings.

The entire operation of the mill, motor generator, and oil pump are controlled from the single control panel shown in Figure 2. In addition, meters which indicate generator output, mill motor power consumption and roll speed are located on this panel. The mill may be run in either direction; and the speed of rolling is controllable from the maximum speed of 300 ft/min down to nearly zero ft/min through a Ward-Leonard control.

Rolling on the mill is done entirely by hand. The mill is equipped with a foreplate to aid in the entry of the work. Strippers are provided to guide the work as it is delivered from the rolls. The stripper guides are shown in position on the delivery side of the mill in Figure 3.

The 9" x 16" mill is shown in Figure 4. The housings on this mill are also of the closed top design. The screws for adjusting the top roll position are driven by a gear motor through worm gears. The main mill

204 004
DECLASSIFIED

drive consists of a 60 HP, 500-1500 RPM, 230 volt D.C., shunt wound motor and combination double reduction drive and pinion stand. All gear teeth are double helical and all bearings in the drive are of the roller bearing type. The spindles are equipped with universal couplings. The functions of mill operation are performed from a single control panel similar to the control panel for the 16" mill. The 9" mill is equipped with Timken double row, tapered roller, roll neck bearings. The speed of rolling is controllable from 100 to 300 ft/min by motor field control only. Rolling on this mill is also done entirely by hand.

B. Rolls

The roll grooves in which the rough rolling of all the billets and the finish rolling of the internal blanket slugs were rolled are shown in Figure 5. It is noted that the top roll diameter, 16", is greater than the bottom roll diameter, 15-1/8". The top roll was made larger in diameter to assure that the bar, when delivered, is forced into contact with the stripper guide. This results in some bow in the delivered bar. The bow, however, is uniform from bar to bar; and the bar is much easier to handle than one in which no control is exercised over the warp, as when rolling with rolls of equal diameter. The roughening grooves are of open square design ending with a 1-1/2" diameter hand round pass. The open square groove is a straight sided groove in which the angle at the root of the groove is greater than 90°. This opening is provided to allow for spread without overfill of the groove. In the process of rolling, the work is rotated 90° in a plane transverse to the rolling direction before each subsequent pass. This places the shorter diagonal of the work in the longer diagonal of the roll groove, allowing area within the groove to accommodate spread. At the roots of the open square grooves, radii are cut to permit easier entry of the work in the grooves, to provide for smoother flow of work in the groove, and to minimize the tending for the work to fracture at the corners. The final groove in the roughing set is a hand round with sides drastically opened to 45°. In this groove, the 1-1/2" square is rounded for subsequent finishing passes. This groove had to be opened to this extent to accommodate the 1-1/2" square with a diagonal in the vertical position. To conserve roll space, the roughing passes were designed to be used with the mill screwdown. Several passes are made in each groove to keep the reduction per pass within reasonable limits. The pass schedule used for rough rolling will be discussed in Section V of this report.

The roll grooves cut in the finishing set of rolls are designed for making a variety of rounds and squares as shown in Figure 5. The reduction sequence for the rolling of finish rounds is modified oval-square. The finishing passes are guide rounds. Solid type guides, pictured in Figure 6, are provided to hold the leader ovals in correct position in the 1" and 3/4" round passes. These grooves were designed for a single pass rolling.

204 005

UNCLASSIFIED

7

The finishing grooves used in rolling the fuel blanket slugs are shown in Set "A," Figure 7. These grooves are hand round design,^(b) plug opened as shown under "Construction of Passes." This provides sufficient space, for the reduction used, into which the bar can spread without overfill. In rolling, two passes through a single groove are used. The first pass through a groove produces an "egg" - shaped cross section. For the second pass, the bar is rotated 90°, placing the long axis of the work vertically. This pass then rounds-up the bar.

C. Heating Equipment

The heating equipment used for preheating the uranium for rolling and for soaking between passes will now be described. All heating was done by immersion in a liquid at suitable temperature. Molten lead at approximately 600°C was used for heating to the breakdown rolling temperature. Oil at 300°C was used for heating to finish rolling temperature.

Lead was used as the heating medium for 600°C rolling to obtain faster heating, minimum oxidation during heating, better temperature control, and better surface finish. Lead at this temperature does not alloy with uranium which is covered with some oxide. Because of the faster heating rate and the exclusion of the atmosphere, metal loss through oxidation is considerably less for lead bath heating than for box furnace heating. The principal advantage of lead heating over furnace heating, however, is the closer temperature control, both during preheating and soaking during rolling. Unless very elaborate precautions are taken to obtain an almost absolutely inert atmosphere in a muffle furnace, correct and uniform temperature of the work is impossible. Through oxidation and reaction with other atmospheric gases, the temperature of the work can rise above the nominal furnace temperature and is very likely to be non-uniform along the rod length. Also, during rolling of uranium unprotected from the atmosphere, the temperature of the work rises, particularly in heavy sections, because of oxidation, internal friction, and friction between work and rolls. In order to prevent excessive temperature rise, the work must be cooled before further rolling is done. This presumably can be done in air, a furnace, or a lead bath. Cooling in air, however, is very unsatisfactory. Even though the over-all temperature of the bar may be lowered in this manner, temperature variation along the length of the bar is not evened out. In addition, to arrive at the exact moment to stop cooling to obtain the proper temperature is quite difficult. Attempting to bring a bar back to rolling temperature by returning it to a box furnace was unsuccessful. Through oxidation, the bar temperature often increased

(b) The hand round groove derives its name from the method of guiding the work in the groove. In rolling, it is necessary to hold the bar in an unstable position in the groove (long axis of the work held in the short axis of the groove). This is done by hand by the roller, thus the name hand round.

rather than decreased. The only adequate means to bring a rolled bar back to the proper temperature (either an increase or a decrease in temperature) is by immersion in a bath at the proper temperature where oxidation is minimized.

Oil heating for 300°C rolling was done for much the same reasons for which the lead was used. In addition, the oil film present on the rolled bar reduces the amount of air and equipment contamination over that produced when rolling at this temperature without oil.

In the lead tank furnace, the molten lead is contained in a cast, high nickel alloy, tank-type pot. The inside dimensions of the pot are 10" wide x 14" deep and 84" long. Heat is supplied by resistance elements surrounding the four vertical sides of the pot. Insulation contained in an outer shell is provided around the sides and bottom of the furnace. The furnace is rated 70 KW at 220 volts. The temperature is controlled by means of an L and N Micromax with the controlling thermocouple located close to the heating elements, the heating elements operating at a temperature somewhat higher than the desired lead temperature. A temperature-indicating thermocouple is provided within the lead bath. Graphite powder or charcoal is used to protect the lead from excessive oxidation and slag formation. A slot type exhaust hood is located on one side of the pot for taking care of the lead fume. The work is raised and lowered into the lead tank furnace on hooks by means of an electric hoist. The hoist is mounted on a monorail so that the hoist may be moved from the furnace to the mill for transport of the work. The lead tank furnace is shown in Figure 8.

Two tank-type oil furnaces were used for heating the rods for rolling at 300°C. One furnace is located in the vicinity of the 16" mill and the other adjacent to the 9" mill. The two furnaces are identical except for size. The larger of the two furnaces, located at the 16" mill, is rated at 20 KW and the smaller is rated at 10 KW. The oil is contained in fabricated, stainless steel tanks, 11" wide x 16" deep x 84" long and 10" wide x 14" deep x 72" long, respectively. The tanks are insulated on the sides and bottoms by means of powdered insulation. In both furnaces, the oil is heated by four immersion type heating elements, each rated at 2.5 and 5 KW in the small and large furnaces, respectively. The heating elements are located just above the tank bottoms. The elements are "U" shaped, and the terminal ends are brought out of the tanks through seals. The temperature of the oil in each furnace is controlled by means of a thermocouple, protected by a stainless steel well, located in the oil bath. The furnace contactors are operated by L and N Micromax Controllers. Since the oil used, Meltemp No. 7,^(c) smokes copiously at operating temperature, slot-type hoods are provided on each side of each furnace. This type of hooding leaves the top of the furnace open for easy access. The work is raised from and lowered

(c) Supplied by Metal Lubricants Corporation, Chicago, Illinois.

DECLASSIFIED

9

into the bath in wire baskets which are operated by means of double-acting air cylinders through a cable and pulley arrangement. An assembly drawing of the small oil tank furnace is shown in Figure 9. A photograph of the 20 KW furnace is shown in Figure 10.

D. Swaging Machine

The final sizing of the fuel blanket rod was done in the swager shown in Figure 11. This machine is a Size No. 4 Torrington rated at $5/8$ " diameter capacity. The machine is equipped with a two-die spindle and is driven by a 5 HP motor. The rollers which actuate the dies are carried in a cage and are permitted to float in the water-cooled housing. Dies and rolls are lubricated with circulating oil. The dies which were used for the final sizing of the fuel blanket rods will be discussed in Section VI of this report.

III. ROLLING STOCK

All of the rod for blanket and fuel blanket slugs was rolled from uranium billets cast in the ANL foundry. These billets were 3" square x 12" long. The melting stock for the billets was reject slug metal.

The billets were made in a quartz tube, vacuum induction furnace. The furnace consisted of a 12" I.D. x 13" O.D. quartz tube carried on a base and sealed with top and bottom plates. The vacuum was produced by a 100 cu ft/min Kinney Pump. The induction coil was located outside the quartz tube. Furnace insulation consisted of stabilized zirconia tile arranged inside the quartz.

Melting was done in graphite crucibles bored for bottom pouring and fitted with graphite stopper rods. The molds into which the metal was poured were made of graphite, split insert type. The inside dimensions of the mold were 3" square x 15" deep with $1/2$ " radii at the corners. The mold, as shown in Figure 12, was split to facilitate removal of the casting. For melting, the crucible was supported directly on the mold. This was done to heat the mold by conduction from the crucible and also directly by induction. For each heat, approximately 36 kg of reject slugs were loaded into a graphite crucible. The furnace was pumped down to between 35 and 150 microns, at which time the power was turned on. The metal was melted and superheated to approximately 1500°C , optical pyrometer measurement, in anywhere from 33 minutes to 1 hour and 32 minutes. The vacuum at time of pouring varied between 70 and 400 microns. After melting, the metal was bottom poured by lifting the stopper rod. The molds were outgassed in vacuum at 1200°C prior to the first use to prevent the formation of blow holes by the liberation of volatile material from the mold. After the first use, the molds were stored in an oven at 80°C to keep them dry.

204 008

DECLASSIFIED

10

The castings were of good surface quality and free of primary pipe. The top two inches of each casting were removed to determine the presence of secondary pipe. A section of the top and bottom of each casting was taken for chemical analyses.

A summary of the melting and casting data for the 3" square billets used for rolling the internal blanket slugs is given in Table I and for the billets used for the upper and lower fuel blanket slugs in Table II. Spectrographic analyses of some of the billets are given in Table III.

IV. PRELIMINARY EXPERIMENTAL ROLLING

Certain information was necessary before the production fabrication of the internal blanket and fuel blanket rod could be done. The first necessary information was the billet and bar heating rates in lead at 600°C and in oil at 300°C. These heating rates were obtained by measuring the temperature at the center of the billet or bar at various time intervals. The temperatures were measured by means of a thermocouple, the junctions of which were located in the bottom of small holes drilled radially to the center of the billet or bar. The heating medium, lead or oil, was excluded from the hole by means of a steel tube seated in a taper machined at the outer end of the hole. It was found in these tests that 10 minutes were required to heat the 3" squares to approximately 600°C in lead at that temperature and that 9 minutes were required to heat the 1-3/4" square bar to 300°C in oil.

Test rolling in the grooves of all three sets of rolls were made. The first billets rolled in the open square grooves had square corners. In rolling these billets, transverse cracks developed along the corners. This difficulty was eliminated by casting billets with 1/2" radii at the corners to match the 1/2" radii at the roots of the first open square pass.

Roll pass sequence to give the correct reduction without overfill was developed for each set of rolls by running test bars. The final pass sequence for the roughing and finish passes will be given in Sections V and VI of this report.

V. ROLLING OF BLANKET SLUGS

The blanket slugs as discussed previously were finished to a diameter of 0.873". It was decided to roll the rod for these slugs to approximately 1" diameter. Even though this diameter was much in excess of that required for clean up, it was chosen because the closest oversize pass on the 16" finishing roll set, Figure 5, was a 1" guide round.

204 009

DECLASSIFIED

A total of 30 billets, 3" x 3" x 12", were rolled for blanket slugs. Three hundred forty linear feet of 1" diameter rod resulted from rolling these 30 billets. Billets listed in Table I, were used as rolling stock for the fabrication of these blanket rods. All rods were stamped with the original billet number. An account of the fabrication practice is given below.

Following the casting of the billets, the first operation was rough rolling at approximately 600°C from 3" square to 1-3/4" square. The roughing rolls on the 16" x 24" mill were used. The temperature of 600°C was used to break up the cast structure thus putting it in a condition favorable for 300°C rolling. The rough rolling was stopped at 1-3/4" square so that approximately 75% reduction at 300°C would be made in rolling to 1" diameter.

The billets were preheated 15 minutes in lead at approximately 600°C, 10 minutes having been found sufficient for heating. The billets were rolled through the sequence of passes given in Table IV. The billet or bar was rolled twice through each pass, being turned 90° after the first time through, to produce a nearly symmetrical cross section. The reductions per pass were increased from 9% in the first pass to 13% in the final roughing pass. A rolling speed of 50 ft/min was used to keep the temperature rise during rolling within reasonable limits. Uranium during rolling is very susceptible to temperature rise due to oxidation, internal friction, and friction between work and rolls. In order to maintain the rolling temperature as closely as possible, the work was soaked 5 minutes in the lead at 600°C after each roll pass. This was done to quench out any temperature increase and equalize the bar temperature.

After the final 1-3/4" square pass the bars were water quenched. The bars at this stage were of reasonably good surface quality. Even though a considerable amount of lead heating had been done, very little adhering lead remained after rolling. Lead present on the rolled bar was removed during the water quenching operation.

The 300°C finish rolling from 1-3/4" square to 1" round was done in two stages. Rolling had to be interrupted at 1-1/2" diameter so that the 16" roughing roll set could be replaced with the 16" finishing roll set.

For the 300°C rolling, the 1-3/4" square bars were preheated 15 minutes in oil maintained at the rolling temperature. The bars were rolled to 1-1/2" diameter in the last four grooves of the roughing set. Rolling temperature was maintained by soaking the bar two minutes in oil at 300°C after every pass. After the 1-1/2" diameter pass, the bars were water quenched. The bars were also cut in half so that they would fit in the oil tank furnace throughout finish rolling.

DECLASSIFIED

204 010

12

Following a roll charge to the finishing passes, the bars were again preheated to 300°C by submersion in oil for 15 minutes. The bars were then rolled from 1-1/2" diameter to 1" diameter in six final passes. Again, the bars were soaked two minutes in oil at 300°C after each pass. The roll pass schedule for the 300°C rolling from 1-3/4" square to 1" diameter guide round is given in Table V.

Finish rolling proceeded without undue difficulty. The nominal 1" round bars varied from 0.990" to 1.000" in diameter. The only difficulty encountered was with the solid type guide used with the guide round finish pass. If the guides were set tight enough to hold the leader oval in correct position in the pass, the bar was difficult to enter and some peeling of slivers from the surface of the bar resulted. If the guides were loosened to eliminate this difficulty, the oval turned out of correct position in the pass. Since this could not be tolerated, the entering difficulty and abrasion had to be accepted. After rolling, the rods were water quenched and straightened by hand. Each of the two pieces of 1" diameter rod resulting from each billet was stamped with the parent billet number. These billet numbers are listed in Table I. The typical surface condition of the rod for blanket slugs is presented in Figure 13.

VI. ROLLING OF ROD FOR UPPER AND LOWER FUEL BLANKET SLUGS

The upper and lower fuel blanket slugs were finish machined to 0.362" diameter. The rods from which these slugs were made were fabricated to 0.375" diameter by a sequence of rolling and swaging processes. The rolling stock was uranium castings 3" x 3" x 12" with 1/2" radii at corners. The castings were first rolled to 1" diameter at 600°C. The 1" diameter rod was rolled at 300°C to 0.385"; this 0.385" diameter rod was swaged to 0.375" $\pm$ 0.001" diameter for centerless grinding. A detailed account of the manufacturing process used for this rod follows.

The billets used for rolling stock are listed in Table II. For rolling, the billets were preheated 15 minutes in lead at 600°C and rolled to 1" diameter using the pass schedules given in Table VI. To maintain rolling temperatures, the bars were soaked 5 minutes in lead at 600°C after every pass. After the 1-1/2" diameter pass, the bar was water quenched because rolling had to be interrupted for a roll change. After the roll change was made, the 1-1/2" diameter rod was preheated to rolling temperature of 600°C by immersion in lead for 15 minutes. The 1-1/2" diameter rod was then rolled to 1" diameter. Again a 5 minute soak between passes was used. A rolling speed of 50 ft/min was used for reasons discussed earlier. At 1" diameter, the rod was again quenched in water.

Prior to finish rolling, the 1" rods were cut into 9" lengths so as to fit into the oil tank furnace and to simplify hand round rolling. For rolling, the 1" diameter rods were heated 10 minutes in oil at 300°C. Rolling was

DECLASSIFIED

204 011

13

done in the hand round passes shown in Table VII, the design of which is given in Figure 7. In rolling to 0.385" diameter, the rods were run twice through each pass, being turned 90° after the first time through. To maintain rolling temperature, the rods were soaked 2 minutes in oil at 300°C after every second roll pass. A rolling speed of approximately 80 ft/min was used. Following the final roll pass the rods were quenched in water. A photograph of a slug cut from the finish rolled rod is shown in Figure 13.

The resulting rolled rod was about 5 mils out of round. Since this degree of out of roundness makes centerless grinding difficult, the rods were swaged to 0.375" $\pm$ 0.001" diameter with very little out of roundness. This swaging was done at 300°C after oil heating. The rods were swaged on the No. 4 Torrington using the die as shown in Figure 14, Die No. 10. This die, having a long blade, also straightened the rod to some extent.

The finished rods were practically free of defects. The 0.010" allowed on the diameter for grinding was adequate and only a few slugs were rejected. These rejected slugs come mainly from the ends of the rods.

VII. HEAT TREATMENT AND TESTING

After casting and rolling, the above described materials were saw cut into multiple lengths and stabilized by beta treatment and alpha annealing, details of which are described below. After heat treatment, all slugs were machined and ground to finished sizes. To test the effectiveness of beta treatment, each slug was checked by dilatometric and supersonic methods, correlated with behavior on thermal cycling.

A. Heat Treatment

Internal blanket slugs were beta treated in sections, approximately 1" diameter x 4-3/4" long by direct immersion in lead baths. The slugs were first preheated in one bath at 600°C and immediately transferred to another at 720°C $\pm$ 5°C, held for three minutes and water quenched. When later testing revealed that several slugs were not suitably beta treated, holding time was extended to five minutes.

The baths were contained in plain cast iron pots, 8" diameter x 14" deep and heated by Hevi-Duty resistance furnaces, Type MU-814, rated at 5 KW. Bath temperatures were controlled with a Micromax (Leeds and Northrup) controller acting in conjunction with a chromel-alumel thermocouple, located proximate to the furnace windings. Temperatures were measured with a Micromax recorder acting with a similar thermocouple enclosed in a steel well inside the bath.

204 012

DECLASSIFIED

14

With the described arrangement, temperatures were controlled within $\pm 5^{\circ}\text{C}$ within a zone 10" deep. Since total heat capacity was low, loads were necessarily limited to two slugs to avoid lowering bath temperatures.

The slugs were handled by means of steel wires attached to one end. Throughout heat treating and quenching, the slugs were suspended vertically lengthwise. Quenching equipment was simple, consisting wholly of a stainless steel tank, 11" wide x 24" long x 10" deep, containing running water at room temperature.

Upper and lower blanket slugs were beta treated in lengths of from 2-1/2" to 3", which were saw cut from the 0.375" diameter rods described above. Beta treating was done with the slugs sealed in an argon atmosphere inside stainless steel containers. The containers were approximately 1" I.D. x 2 feet long with a 1/16" wall thickness. One end was cap welded; the other, or upper end, sealed by rubber O-ring gasket and threaded cap. Connections were provided in the threaded cap for vacuum and argon.

The containers with an average of 10 slugs enclosed were first evacuated and then filled with argon (99.9% pure) to a positive pressure of about 10 pounds per square inch. They were then immersed vertically lengthwise in the previously described lead tank furnace at temperatures of 720°C - 740°C . After holding for one-half hour the containers were opened and then removed from the bath. The slugs were ejected into the water quench tank by simply inverting the container.

Annealing of all slugs was done in an argon atmosphere for 2 hours at 575°C . Slugs to be annealed were first stacked horizontally lengthwise within a stainless tube, 4" I.D. x 19" long. Both ends of the tube were cap welded, following which the tube was evacuated and filled with argon as above, through an entry at the mid-length. The container was then immersed horizontally lengthwise in the lead tank furnace (70 KW) described above. After holding for 2 hours, the container was air cooled to room temperature. One end was then opened by saw cutting and the slugs removed. As many as 50 internal blanket slugs or 250 upper and lower fuel blanket slugs were annealed in this manner at one time.

B. Dilatometer Testing

After heat treatment, all slugs were machined and ground to finished size and tested to check the effectiveness of the beta treatment. In dilatometer tests, the linear thermal expansion (25°C - 100°C) of beta treated slugs was found to be approximately twice that of alpha rolled slugs and was used to check the effectiveness of the heat treatment.

Internal blanket slugs were finished to 0.875" diameter x 4.050" long and tested with the dilatometer shown in Figure 15. The dilatometer is essentially a Vycor glass tube, 1-1/2" O.D. x 10-3/4" long with 1/8" wall thickness. A clear quartz disc, 1/2" thick, is fused to the bottom end.

DECLASSIFIED

204 013

15

Slugs to be tested were inserted at the open top and rested vertically on the sealed end. Thermal expansion was measured with the dial gauge (0.001"), which was actuated by a quartz push rod in contact with the top end of the slug. The gauge is supported by an aluminum clamp, which is linked to the glass tube by two locating screws. The thermal expansion of the tube is compensated for by this arrangement. A boiling water bath was used to heat the slug to 100°C.

In a preliminary study a number of heat treated and untreated slugs were tested and their expansion correlated with behavior on thermal cycling. Cycling was done in the Ecco induction heating unit between 100°C and 550°C a total of 376 times.⁽⁵⁾ Heating time on the cycle was 10-12 minutes; cooling time 20-25 minutes.

On dilatometer testing, beta treated slugs taken from various lots expanded from 0.0038" to 0.0043" in a 4.050" length. This corresponds to linear coefficients of from 12.5 to 14.2 microinches/inch/°C. Alpha rolled slugs expanded only from 0.0021" to 0.0023", corresponding to coefficients of from 6.9 to 7.2 microinches/inch/°C. Calculated coefficients are estimated to be accurate within $\pm 2.5\%$.

On thermal cycling, a beta treated slug (D-124) with a coefficient of 12.5 microinches/inch/°C grew in length at a rate of 28 microinches/inch/cycle to a total of 1.06% growth in 376 cycles. An alpha rolled slug (D-126) with a coefficient of 6.9 microinches/inch/°C grew in contrast at a rate of 308 microinches/inch/cycle to a total of 12.3% growth.

The stability of the beta treated slug as judged from previous investigation was considered suitable. Hence, an expansion of 0.0038" in a 4.050" length was set as a minimum for acceptance in later testing. Of the total number of slugs so tested, 13 were rejected.

Upper and lower fuel blanket slugs were tested in the finished lengths with the dilatometer shown in Figure 16. The dilatometer is constructed of nickel, which has a measured linear coefficient of 13.2 microinches/inch/°C between 25°C and 100°C. In use, test slugs were inserted in the slotted section of the tube, in contact with the nickel push rod attached to the dial gauge (0.0001"). The assembly was brought to uniform temperature (25°C) by immersing in a water bath and the dial gauge set to zero. The assembly was then transferred to another bath at 100°C, brought to uniform temperature, and the deflection from zero noted. Positive and negative deflections indicated, respectively, greater or lesser values than 13.2 microinches/inch/°C.

To determine the deflection which would indicate suitable beta treatment, four beta treated slugs which deflected to zero or positively as shown in Table VIII were thermal cycled. Thermal coefficients calculated from the measured deflections varied from 13.2 to 14.0 microinches/inch/°C. The noted coefficients are estimated to be accurate within plus or minus 2.5%.

DECLASSIFIED

204 014

16

Cycling was done in the Woosher between 50°C and 600°C, using a 5'-5'-5" (d) cycle, a total of 100 times. One alpha rolled slug which deflected negatively, corresponding to a coefficient of 6 microinches/inch/°C, was included in the test. The behavior of the entire series on cycling is summarized in Table VIII.

All beta treated slugs were relatively stable growing in lengths at rates which varied from $K = 12$ to $K = 24$. Due mostly to wrinkling, diameters also increased. The maximum growth in diameter, initially approximately 0.362", was 0.0016". Wrinkling was similar and slight in all specimens. The alpha rolled slug as expected grew at an appreciably higher rate, $K = 667$.

Although growth rates of the beta treated slugs varied, the behavior of all was considered suitable. In view of this, slugs deflecting to zero or positively in later testing were deemed acceptable.

C. Sonic Testing

Dilatometer testing was supplemented with a sonic test using a Sperry Reflectoscope, Type UR, Style 50 E 351. Testing was based on the screen patterns obtained with a 5 megacycle frequency on the lengths of suitably beta treated slugs. The pattern for such slugs revealed numerous discontinuities as shown in Figure 17 (Macro #10,264). The discontinuities are assumed related to coarse grain size. The pattern for fine grain alpha rolled slugs revealed a large major reflection as shown in Figure 18 (Macro #10,263) with only a few discontinuities.

The accuracy of the sonic test was evaluated by correlation with nickel dilatometer and fracture tests in a preliminary investigation here described. A series of specimens initially rolled [REDACTED] (89% R.A.) at 300°C and 600°C were heat treated in approximately 2" lengths for various times at 700°C (see Table IX). For short time heat treatments (up to 120 seconds) the specimens were directly immersed in a salt bath at 700°C, and then water quenched. One-half and 2 hour treatments were done in the same manner as that described above for the upper and lower blanket slugs. After beta treating, all specimens were annealed for 2 hours at 575°C in argon atmosphere. Subsequently one specimen of each duplicate pair was notched and cold fractured at the mid length. The fracture grain sizes of the series, including specimens as rolled and similarly alpha annealed, are shown in Figures 19 and 20. The second duplicate specimen was machined and ground to 0.364" diameter x 1.89" long and tested with the nickel dilatometer (25°C-85°C) and reflectoscope. The results of all tests are summarized in Table IX.

(d) Five minute holding time, five second transfer time.

DECLASSIFIED

204 015

17

Upon evaluating the results, specimens having coefficients greater than 13.2 microinches/inch/°C, the accepted minimum for EBR slugs, were assumed effectively beta treated. Based on this, good agreement was seen between dilatometric and sonic testing. Specimens effectively beta treated had coefficients varying from 14.1 to 15.0 microinches/inch/°C irrespective of prior rolling history. Sonic screen patterns for such specimens were all alike and similar to that shown in Figure 17. Ineffectively treated specimens had coefficients consistent with that of as rolled and annealed metal, and screen patterns were alike and similar to that of Figure 18. The pattern for specimen 6U-60 differed depending upon the end on which the sonic test was made. One end showed a pattern typical of fine grain, the other of coarse grain material, indicating the specimen was beta treated on only one end.

Although sonic testing appeared feasible for identifying effectively treated slugs, it was felt best to use this test in conjunction with dilatometer testing. The effect of grain size, fissures, cracks, and other discontinuities was not clearly defined and precluded using the test alone.

D. Thermal Cycling of Mock-Up Internal Blanket Rods

Four mock-up blanket rods were made as described below and thermal cycled to determine whether distortion of the jackets would occur as a result of stresses imposed by the dimensional instability of contained uranium. Cycling was done in the induction heating unit through temperature ranges which approximated those expected in pile operation.

Four rods designated #1, #2, #3, and #4 were fabricated as per print presented in Figure 21 and thermal cycled between 108°C and 480°C. Each rod consisted of five uranium slugs, 0.893" diameter x 4.050" long, jacketed in 0.020" wall stainless steel with ends capped and welded. The annulus between the slugs and the jacket wall was filled with sodium-potassium alloy.

Contained slugs were initially rolled to 75% R.A. at 300°C. Slugs in Rods #1 and #2 were beta treated 2 minutes at 725°C in a lead bath; water quenched and subsequently annealed 2 hours at 575°C. Slugs in Rods #3 and #4 were as rolled and similarly alpha annealed.

Cycling was done with the rods suspended vertically by a clamp. Rods #1 and #2 were cycled 300 times and Rods #3 and #4, 291 times between the temperatures shown below. The given temperatures are those attained on the surfaces of the rods at three points along the length.

18

Position on Rod	Cycling Range		Heating Rate	Cooling Rate
	Min	Max		
Top (tapped end)	200°C	460°C	26.2 ± 8°C/min	7.9 ± 2.5°C/min
Middle	120°C	480°C	32.5 ± 12.5°C/min	18.4 ± 7.2°C/min
Bottom	108°C	480°C	30.5 ± 6°C/min	20.5 ± 10.0°C/min

The results on cycling with regard to warp and dimensional changes are given in Table X. Rods #1 and #2, which contained the beta treated slugs warped only slightly, the maximum increase being 3.9 mils. Dimensional changes were negligible serving to indicate no distortion in any direction.

Rods #3 and #4, containing slugs in the rolled and alpha annealed condition (not beta treated), slipped from the clamps during cycling and warped badly. In Figure 22 (Macro M-7949), Rod #4 is shown after 291 cycles. The extreme warp condition of both rods precluded measurement of over-all dimensional changes. The lap weld at the top of Rod #3 joining the tapped plug to the jacket was totally sheared after cycling. Stresses imposed on the weld by growth of the contained slugs is held the cause of the shearing action. Dimensional changes in the individual slugs of Rod #3 are given in Table XI. In 291 cycles, lengths increased from 3.88% to 6.49% and diameters decreased from 2.13% to 3.02%. Slug #1 which was positioned at the top of the jacket grew the least. The smaller growth is believed due to the fact the slug was cycled through a smaller temperature range.

VIII. JACKETING FUEL BLANKET SLUGS

The natural uranium slugs (fuel blanket slugs) located at each end of the enriched fuel slugs were jacketed in 5 mil stainless steel.⁽¹⁾ This was considered necessary to prevent dilution of the enriched material should migration take place within the fuel rod. In addition the jacket served to identify the natural slugs particularly during assembly of the fuel elements.

The upper and lower fuel blanket assemblies are shown in Figures 23 and 24, respectively. The assemblies consist of natural uranium slugs and stainless steel tubular jacket and end caps. The upper blanket has three slugs as shown in Figures 25 and 26 - and the lower blanket has two slugs as shown in Figure 27. All slugs were ground to 0.364" diameter, and one end of each of the end slugs in both the upper and lower blanket was turned down to 0.354" diameter for a distance of 0.160" from the end. This was done to accept the end cap shown in Figure 21. These end caps were produced by a one operation draw and trim using the die and punch shown in Figure 28. Stainless steel, Type 347, discs, 5/8" diameter x 0.005" thick, were used as the blanks. The remainder of the cylindrical portion of the jacket was made of a Type 347 stainless steel tube, 0.370" I.D. x 0.005" wall thickness.

DECLASSIFIED

204 017

19

For assembly, the end caps were placed on each end slugs and the correct number of slugs for upper and lower fuel blanket assemblies were placed in the stainless tube. This whole assembly was then pressed with a punch through the die shown in Figure 29. The diameter of the die is such that the assembly is reduced approximately 2 mils in diameter to assure a tight fit. The cylinder above the die was found necessary to guide the work co-axially with the die.

IX. METALLOGRAPHIC STRUCTURES

The metallographic structures produced by 300°C rolling and by heat treatment, are shown in Figures 31, 32, 33, and 34. The structure of the hot rolled bar used for the finish rolling at 300°C is shown in Figure 30. The grain size of this material is approximately 0.025 mm. Stringers of inclusion developed on rolling are shown in the longitudinal photomicrograph. The 300°C rolling of both blanket and fuel blanket rod developed a very distorted, fine grain structure (Figures 31 and 32). Beta treatment of the 300°C rolled material produced a great increase in grain size (>0.1 mm). Beta treatment, however, did not alter the inclusion pattern. Photomicrographs of beta treated blanket and fuel blanket rods are shown in Figures 33 and 34.

Photographs of fracture samples of blanket and fuel blanket slugs both as 300°C rolled and beta treated are given in Figure 35. The very fine silky fracture of 300°C rolled metal has been changed to a much coarser one by beta treatment.

X. ACKNOWLEDGEMENTS

The authors are greatly indebted to J. L. Armstrong for the preparation of drawings, to H. V. Ross, A. A. Denst and the Special Materials Shop for the making of molds, crucibles, and other equipment, to Arthur Reed and John Dlouhy for the production of castings, to Frank Karasek, John Zic and Leonard Hanna for rolling of the rod, to Robert Noland and David Walker for development of the jacketing process, to Joseph Goleb for chemical analyses, to George Lindholm, Lawrence Arthur, and Roy Conner for the photographs, and to Frank Foote and James Schumar for encouragement, guidance, and review of the manuscript.

DECLASSIFIED

284 018

20REFERENCES

1. W. H. Zinn, et al., Feasibility Report, "Fast Neutron Pile for a Test of Conversion," ANL-4356, October 14, 1949.
2. R. E. Macherey, "Casting of Blanket Bricks, Ring, Plug, and Control Rods for the Experimental Breeder Reactor (CP-4)," ANL-5009, March 19, 1953.
3. A. B. Shuck, "Development of Methods for Casting and Fabricating Enriched Fuel Slugs," ANL-4617, April 18, 1951.
4. A. B. Shuck, "The Manufacture of Enriched Uranium Fuel Slugs for EBR," ANL-4847, April 20, 1953.
5. R. M. Mayfield and S. T. Zegler, "Thermal Cycling Equipment," ANL-4848, November 1, 1951.

DECLASSIFIED

204 019

21

Table I

MELTING AND CASTING DATA FOR ROLLING BILLETS
USED FOR INTERNAL BLANKET RODS

3" Square No.	Charge Wt., kg	Melting Time hrs.-min.	Pouring Temp., °C	Vacuum		Casting Wt., kg	Metal Recovery, %	Melting Data Recorded in Secret Note- book	
				min., microns	at pour, microns			No.	Page
D-67	36.76	1 5	1475	35	70	35.58	96.2	1453C	88
D-69	36.30	0 38	1475	100	100	35.38	97.5	1453C	90
D-72	36.0	0 40	1500	70	150	34.87	96.9	1453C	93
D-75	36.47	0 55	1475	100	100	34.47	95.3	1453C	96
D-76	76.01	3 20	1475	38	1040	73.60	96.8	1453C	97
D-77	36.37	1 5	1490	75	100	34.44	94.7	1453C	98
D-80	35.91	0 33	1350	65	300	34.92	97.2	1453C	101
D-81	75.85	1 57	1510	160	2000	73.93	97.5	1453C	102
D-82	35.25	0 48	1500	70	110	33.57	95.2	1453C	103
D-85	35.15	0 39	1500	45	110	35.83	--	1453C	106
D-87	35.65	1 0	1525	100	200	34.68	97.3	1453C	108
D-90	34.70	0 43	1530	75	100	33.33	96.1	1453C	111
D-92	35.60	1 0	1625	150	200	16.25	45.6	1453C	113
D-94	35.97	1 45	1500	70	200	34.48	95.9	1453C	115
D-96	35.35	0 48	1510	75	200	34.02	96.2	1453C	117
D-99	35.60	0 35	1525	90	150	34.26	96.2	1453C	120
D-101	35.85	0 38	1510	50	150	34.26	95.6	1453C	122
D-103	35.60	0 55	1550	60	300	34.02	95.6	1453C	124
D-105	35.95	0 40	1470	60	150	34.47	95.9	1453C	126
D-106	35.80	1 15	1475	75	200	34.24	95.6	1453C	127
D-108	38.86	1 32	1525	80	125	33.90	92.0	1453C	129
D-110	35.80	0 55	1455	125	400	34.02	95.0	1453C	131
D-112	35.80	0 44	1495	100	700	34.24	95.6	1453C	133
D-113	36.10	0 35	1510	70	200	34.54	95.7	1453C	134
D-115	35.85	1 10	1500	90	150	33.11	92.4	1453C	135
D-118	36.65	0 45	1500	40	800	35.38	96.5	1453C	139
D-119	36.30	1 0	1400	90	200	34.47	95.0	1453C	140
D-122	36.82	0 50	1700	100	800	34.93	94.9	1453C	142
D-124	36.40	1 5	1480	120	225	34.02	93.5	1453C	144
D-126	36.25	1 0	1500	125	200	34.47	95.1	1453C	146
D-129	36.55	0 55	1485	50	200	34.47	94.3	1453C	149
D-133	35.38	0 48	1475	40	400	35.38	--	1453C	153
D-135	36.40	1 25	1515	60	100	35.38	97.2	1453C	155

DECLASSIFIED

204 020

22

Table II

MELTING AND CASTING DATA FOR ROLLING BILLETS
USED FOR UPPER AND LOWER FUEL BLANKET RODS

3" Square No.	Charge Wt., kg	Melting Time, hrs.-min.	Pouring Temp., °C	Vacuum		Casting Wt., kg	Metal Recovery, %	Melting Data Recorded in Secret Note- book	
				min., microns	at pour, microns			No.	Page
2D-230	38.55	0 55	1500	125	1000	37.41	97.0	1839C	54
2D-232	38.50	0 50	1450	400	500	37.19	96.6	1839C	56
2D-234	38.25	0 40	1460	175	400	36.74	96.1	1839C	58
2D-236	38.70	0 40	1460	700	800	37.53	97.0	1839C	60
2D-238	38.45	0 40	1450	300	600	37.08	96.4	1839C	62
2D-240	38.60	0 43	1435	180	400	36.97	95.8	1839C	64
2D-242	38.65	0 40	1470	500	600	36.97	95.7	1839C	66
2D-243	82.35	1 25	1425	220	470	78.47	95.3	1839C	67
2D-245	38.15	0 50	1470	500	700	37.19	97.5	1839C	69
2D-246	38.75	0 55	1505	190	600	37.65	97.2	1839C	70
2D-248	38.65	0 47	1535	175	800	37.31	96.5	1839C	72
2D-250	38.65	0 60	1510	200	800	37.20	96.2	1839C	74
2D-251	38.42	0 55	1520	170	200	37.10	96.6	1839C	75
2D-252	38.52	0 47	1500	85	140	---	---	1839C	76
2D-254	38.70	0 50	1505	70	150	---	---	1839C	78
2D-255	38.65	0 50	1490	130	400	---	---	1839C	79

204 021

23

Table III

SPECTROGRAPHIC ANALYSIS OF 3" SQUARE ROLLING BILLETS

Casting No.	B	Be	Cr	Cu	Fe	Mg	Mn	Mo	Ni	Pb	Si	Cd
D-67	< .1	0.5	< 1	5	50	0.5	1	50	5	2	20	< 1
D-69	< .1	< .5	< 1	10	50	0.5	1	< 50	5	2	20	< 1
D-72	< .1	< .5	< 1	10	20	1	0.5	< 50	< 5	1	20	< 1
D-75	< .1	< .5	< 1	20	30	0.5	1	< 50	10	< 1	20	< 1
D-76	< .1	< .5	< 1	10	30	0.5	0.5	< 50	10	1	15	< 1
D-77	0.1	< .5	< 1	10	30	0.5	1	< 50	10	1	50	< 1
D-82	0.1	< .5	2	15	200	1	10	< 50	10	5	200	< 1
D-85	< .1	< .5	5	20	300	1	5	< 50	10	7	100	< 1
D-87	< .1	< .5	< 1	10	100	0.5	5	< 50	5	2	100	< 1
D-90	< .1	< .5	< 1	5	50	< .5	2	< 50	5	1	50	< 1
2D-230	< .1	< .5	5	33	20	3	1	< 20	5	5	10	< .5
2D-232	< .1	< .5	2	5	15	3	1	< 20	5	5	10	< .5
2D-234	< .1	< .5	2	3	20	2	1	< 20	5	10	10	< .5
2D-236	< .1	< .5	2	3	15	2	1	< 20	5	5	10	< .5
2D-238	< .1	< .5	1	3	10	1	0.5	< 20	5	2	10	< .5
2D-240	< .1	< .5	2	3	20	3	1	< 20	5	5	10	< .5
2D-242	< .1	< .5	2	3	15	3	1	< 20	5	2	10	< .5
2D-245	< .1	< .5	2	3	20	2	2	< 20	5	5	10	< .5
2D-246	< .1	< .5	2	3	20	2	1	< 20	5	5	10	< .5
2D-248	< .1	< .5	2	3	20	2	2	< 20	5	5	10	< .5
2D-250	< .1	< .5	2	3	20	2	0.5	< 20	5	1	10	< .5
2D-251	< .1	< .5	2	3	20	2	0.5	< 20	5	5	10	< .5
2D-252	< .1	< .5	2	3	20	2	0.5	< 20	5	1	10	< .5
2D-254	< .1	< .5	3	3	20	2	0.5	< 20	5	1	10	< .5
2D-255	< .1	< .5	2	3	20	2	0.5	< 20	5	1	10	< .5

Note: Elements listed below are below limit of detection.

Element	Limit, ppm	Element	Limit, ppm
Ag	< 1	Li	< 1
Al	< 20	Na	< 1
As	< 10	P	< 20
Bi	< 2	Sb	< 2
Ca	< 20	Sn	< 5
Co	< 5	Ti	< 50
K	< 10	Zn	< 20

DECLASSIFIED

204 022

24
Table IV

BREAKDOWN ROLL PASS SCHEDULE FOR 600°C,
INTERNAL BLANKET ROD ROLLING, 16" MILL

Pass Number	Pass Dimensions	Percent Reduction
1	2-3/4", 98° Open Square	9
2	2-5/8", 98° Open Square	9
3	2-1/2", 96° Open Square	9
4	2-3/8", 96° Open Square	10
5	2-1/4", 96° Open Square	10
6	2-1/8", 96° Open Square	11
7	2", 96° Open Square	11
8	1-7/8", 94° Open Square	12
9	1-3/4", 94° Open Square	13

Table V

FINISHING ROLL PASS SCHEDULE FOR 300°C,
INTERNAL BLANKET ROD ROLLING, 16" MILL

Pass Number	Pass Dimensions	Percent Reduction
1	1-5/8", 94° Open Square	14
2	1-1/2", 94° Open Square	15
3	1-5/8", Hand Round	8
4	1-1/2", Hand Round	7
5	1-3/8", Hand Round	16
6	1-1/4", Hand Round	17
7	1-1/8", 92° Open Square	12
8	1-1/8", Hand Round	21
9	15/16" x 1-1/4" Oval	17
10	1" Guide Round	25

204 023
DECLASSIFIED

25

Table VI

BREAKDOWN ROLL PASS SCHEDULE FOR 600°C UPPER
AND LOWER FUEL BLANKET ROD ROLLING, 16" MILL

Pass Number	Pass Dimensions	Percent Reduction
1	2-3/4", 98° Open Square	9
2	2-5/8", 98° Open Square	9
3	2-1/2", 96° Open Square	9
4	2-3/8", 96° Open Square	10
5	2-1/4", 96° Open Square	10
6	2-1/8", 96° Open Square	11
7	2", 96° Open Square	11
8	1-7/8", 94° Open Square	12
9	1-3/4", 94° Open Square	13
10	1-5/8", 94° Open Square	14
11	1-1/2", 94° Open Square	15
12	1-5/8", Hand Round	8
13	1-1/2", Hand Round	15
14	1-3/8", Hand Round	16
15	1-1/4", Hand Round	18
16	1-1/8", 92° Open Square	12
17	1-1/8", Hand Round	21
18	15/16" x 1-1/4" Oval	17
19	1" Guide Round	25

204 024

DECLASSIFIED

26

Table VII

FINISHING ROLL PASS SCHEDULE FOR 300°C UPPER
AND LOWER FUEL BLANKET ROD ROLLING,
ALL HAND ROUND PASSES, 9" MILL

Pass Number	Pass Diameter	Percent Reduction
1	0.920 "	8
2	0.849 "	15
3	0.783 "	15
4	0.722 "	15
5	0.666 "	15
6	0.614 "	15
7	0.575 "	12
8	0.539 "	12
9	0.504 "	13
10	0.473 "	12
11	0.443 "	12
12	0.422 "	9
13	0.402 "	9
14	0.382 "	10

204 025

DECLASSIFIED

Table VIII

RESULTS ON DILATOMETRIC AND CYCLIC TESTING
OF UPPER AND LOWER FUEL BLANKET SLUGS

Specimen No.	Heat Treatment	Ni Dilatometer Test		Thermal Cycling Results							
		Deflection (mils) at 100°C	T.E.C. 25°C-100°C Microinches/inch/°C	L_o (in)	Dia_o (in)	L_{100} (in)	$\frac{L_{100} - L_o}{L_o} \times 100$	K Micro-inches/in Cycle	Dia. 100 (in)	Change in Dia_o (in)	Wrinkling after 100 Cycles
1	As rolled and annealed 2 hrs at 575°C	-1.4	6.0	2.5292	0.3630	2.7042	6.92	667	0.3620	-0.0010	None
2	1/2 hr at 720°C-740°C Water quenched Annealed 2 hrs at 575°C	0.0	13.2	2.5298	0.3627	2.536	0.24	24	0.3635	+0.0008	Slight
3		0.05	13.4	2.5306	0.3624	2.535	0.16	16	0.3640	+0.0016	Slight
4		0.10	13.6	2.5304	0.3628	2.533	0.12	12	0.3642	+0.0014	Slight
5		0.15	14.0	2.5279	0.3628	2.532	0.16	16	0.3638	+0.0010	Slight

28

Table IX

CORRELATION OF DILATOMETRIC, SONIC AND FRACTURE TESTING
OF URANIUM ROLLED 89% R.A. AT 300°C AND 600°C

Spec. No.	Heat Treatment (1) Holding Time	Length (in) (25°C)	Deflection (mils) 85°C	T.E.C. Microinches/inch/°C	Sonic Test (2)	Fracture Grain Size (3)
3U-75	As rolled (300°C)	1.8990	-0.50	8.9	A	Fine
3U-52	2 sec	1.8989	-0.60	8.0	A	Fine
-53	5 sec	1.9005	-0.60	7.9	A	Fine
-54	10 sec	1.8918	-0.60	7.9	A	Fine
-55	20 sec	1.8970	-0.60	7.9	A	Fine
-56	30 sec	1.8980	-0.60	7.9	A	Coarse
-57	60 sec	1.8957	+0.10	14.1	B	Coarse
-58	120 sec	1.8953	+0.15	14.5	B	Coarse
-59	1/2 hr	1.8988	+0.20	15.0	B	Coarse
-60	2 hr	1.8991	+0.10	14.0	B	Coarse
6U-64	As rolled (600°C)	1.8988	-0.20	11.2	A	Fine
6U-55	2 sec	1.8985	-0.20	11.2	A	Fine
-56	5 sec	1.8993	-0.25	11.0	A	Fine
-57	10 sec	1.8992	-0.20	11.2	A	Fine
-58	20 sec	1.8986	-0.20	11.2	A	Fine
-59	30 sec	1.8993	-0.20	11.2	A	Fine
-60	60 sec	1.8991	-0.20	11.2	AB	Coarse
-61	120 sec	1.8920	+0.15	14.5	B	Coarse
-62	1/2 hr	1.8994	+0.20	15.0	B	Coarse
-63	2 hr	1.8900	+0.10	14.1	B	Coarse

(1) Heat treatment at 700°C followed by water quench; annealed 2 hr at 575°C.

(2) "A" represents pattern shown in Figure 18. "B" represents pattern shown in Figure 17.

(3) Actual grain size shown in Figures 19 and 20.

29.

Table X

WARP AND DIMENSIONAL CHANGES IN MOCK-UP INTERNAL BLANKET RODS ON THERMAL CYCLING (108°C-480°C)

Rod No.	Heat Treatment	Warp (mils) measured with Federal dial gauge on wheel balancer								
		Before Cycling			After Cycling ⁽¹⁾			Change in Warp		
		Top	Middle	Bottom	Top	Middle	Bottom	Top	Middle	Bottom
1	Beta treated and annealed	5.5	9.8	0.5	7.0	13.7	4.0	1.5	3.9	3.5
2		2.7	4.1	1.8	2.0	5.2	4.0	-0.7	1.1	2.2
3	Alpha rolled and annealed	2.0	6.5	4.5	(Not measured. See Figure 22)					
4		4.0	7.0	7.0						

Rod No.	Lengths (in); measured between flat ends				Diameters (in); measured at mid-lengths			
	Before Cycling	After Cycling ⁽¹⁾	Change	Percent	Before Cycling	After Cycling ⁽¹⁾	Change	Percent
1	22.1695	22.1670	-0.0025	-0.01	0.9398	0.9398	0.0000	0.0
2	23.0812	23.0819	0.0007	Nil	0.9399	0.9399	0.0000	0.0
3	22.1729	(Not Measured)			0.9405	0.9372	-0.0033	-0.35
4	23.0510				0.9408	0.9340	-0.0068	-0.73

(1) Rods #1 and #2 cycled 300 times; rods #3 and #4 cycled 291 times.

Table XI

DIMENSIONAL CHANGES IN SLUGS OF ROD #3 AFTER 291 CYCLES

Lengths before cycling 4.050" Diameters before cycling 0.893"						
Slug No.	Lengths (in)			Diameters (in)		
	After Cycling	Change	Percent	After Cycling	Change	Percent
1	4.207	0.157	3.88	0.874	-0.019	-2.13
2	4.313	0.263	6.49	Not Measured		
3	4.288	0.238	5.88			
4	4.272	0.222	5.48	0.866	-0.027	-3.02
5	4.289	0.239	5.90	0.869	-0.024	-2.69
				0.866	-0.027	-3.02

FIGURE 1. 16" x 24", 2-High Rolling Mill Viewed from Control and Feed Side.

28
Negative No. 106-853

FIGURE 2. Control Panel for 16" x 24" Mill Showing Operating Functions.

Negative No. 106-846

DECLASSIFIED

204 030

32

FIGURE 3. Stripper Guides Shown in Position on Delivery Side of 16" Mill.

Negative No. 106-851

DECLASSIFIED

204 031

33

FIGURE 4. 9" x 16", 2-High Mill Viewed from Control and Feed Side.

Negative No. 106-849

0000000000

204 032

34
ENTER 3" SQ OR 3" ROUND

35

DRIVE END

TO MAKE $\frac{3}{4}$ " ROUND USE PASSES (1) TO (2) TO (4) TO (6) TO (7) TO (9) TO (12)
 " " " " " " (1) TO (2) TO (3) TO (5) TO (11)
 " " SQUARES " " " (1) TO (2) TO (4) TO (6) TO (8) TO (10)
 SIZE OF SQUARES $1\frac{1}{8}$ " - 1" - $\frac{7}{8}$ " - $\frac{1}{2}$ " - $\frac{3}{4}$ "

FIGURE 5. Roll Groove Design, Roughing and Finishing Sets for 16" Mill

DECLASSIFIED

DECLASSIFIED

204-033

36

FIGURE 6. Guide for 1" Finish Round Pass 16" Mill.

Macro #13,752

204 034

DECLASSIFIED

DECLASSIFIED

DECLASSIFIED

204-035

FIGURE 8. 70 KW Lead Tank Furnace Used for Heating for Hot Rolling.

Negative No. 106-845

DECLASSIFIED

204

036

PART NO.	DESCRIPTION	DETAIL	LBS WGT	NO. OF Pcs
1	FRAME	10B/D-1	1	1
2	TANK HOUSING	10B/D-2	1	1
3	TANK	10B/D-3	1	1
4	BRAKET	10B/D-5	1	1
5	VAPOR DUCT	10B/D-4	1	1
6	COLLECTOR	10B/D-8	1	1
7	LING ADAPTER	10B/D-9	1	1
8	HANA APPL. MODEL #M13 ON 10B/D3	PURCH	1	0
9	" " " " " " #M13 ON LECTURE	PURCH	1	0
10	CABLE CLIP (STD B)	RUBR	8	8
11	CALROD HEATER (#A) #A2B1G2	PURCH	4	4
12	CALROD HEATER (#B)	PURCH	4	4
13	FULLEY & BRACKET ASS'LY	10B/D-6	4	4
14	1/8 IN STEEL CABLE	PURCH	16	14
15	1/2 IN RUBBER BELT F.U.T.	PURCH	5	3
16	FULLEY & BRACKET ASS'LY	10B/D-2	2	2
17	TENSION SPRING	PURCH	4	4
18	3/16 IN MACH BOLT 1/2 LG X NUT	PURCH	4	4
19	STEEL PIPE CAP 1" STAINLESS STEEL	PURCH	1	1
20	FULLEY & BRACKET ASS'LY	10B/D-2	2	2
21	NUT			
22	RET COCK (PWA#F702) 1/2"	PURCH	1	1
23	OIL LEVEL GAGE *	PURCH	1	1
24	GASKET			2
25	1/4 IN OD MACH TUBE 1/2 LG X END			2, 4
26	CONDENSER - HARD ALLOY FD1645	PURCH	2	2
27	2 1/2 IN O.D. 1/8 IN S.S.	PURCH	6	6
28	PFA-100 IN SCAB 3/16 IN TUB S.S.			5
29	DRESS BAR 1/2 x 1/4 x CHANNEL SS			10
30	DRYIN BAR	10B/D-7	1	1
31	1/4" x 1/4" x 90° STREET ELBOR	PURCH	1	1

FIGURE 9. Assembly Drawing of 10 KW Oil Tank Furnace

DECLASSIFIED

037561065710

204 - 037

42

FIGURE 10. View of 20 KW Oil Tank Furnace Used for Heating for 300°C Finish Rolling.

Negative No. 106-847

204 038

DECLASSIFIED

43
FIGURE 11. Swaging Machine Used for Sizing and Straightening Fuel Blanket Rods.

Negative No. 106-850

DECLASSIFIED

204 039

44
FIGURE 12. Graphite Mold Used for Casting Rolling Billets, Split Insert Type.

Negative No. 106-95

DECLASSIFIED

204 C40

45

FIGURE 13. Photograph of Blanket and Fuel Blanket Slugs as Rolled and as Machined.

Macro #13,742

DECLASSIFIED

204 041

NUMBER	A	B	C
1	.669	.712	.043
2	.630	.670	.040
3	.588	.626	.038
4	.553	.588	.035
5	.518	.551	.033
6	.479	.509	.030
7	.457	.509	.029
8	.434	.461	.027
9	.406	.432	.026
10	.382	.406	.024
11	.358	.381	.023
12	.336	.357	.021
13	.315	.335	.020
14	.295	.314	.019
15	.273	.295	.018
16	.259	.275	.016
17	.244	.260	.016
18	.220	.245	.020
19	.212	.230	.018
20	.199	.216	.017
21	.186	.202	.016
22	.174	.189	.015
23	.164	.178	.014
24	.153	.166	.013

BREAK ALL EDGES
 $\frac{1}{32}$ " CHAMFER
 FINISH GRIND ALL OVER

MATERIAL. HIGH ALLOY, HOT
 FORMING DIE STEEL
 HARDEN TO "Rc" 60-63

FIGURE 14. Swaging Die Design

204-042

DECLASSIFIED

DECLASSIFIED

48

FIGURE 15. Vycor Dilatometer Used for Measuring Thermal Expansion of Internal Blanket Slugs

Macro #10,714

204 043

DECLASSIFIED

49

FIGURE 16. Nickel Dilatometer Used for Measuring
Thermal Expansion of Fuel Blanket Slugs

Macro #10,715

DECLASSIFIED

204 644

50

FIGURE 17. Reflectoscope Screen Pattern for Beta Treated Slugs
Using Five Megacycle Frequency

Macro #10,263

1X

FIGURE 18. Reflectoscope Screen Pattern for Alpha Rolled Slugs
Using Five Megacycle Frequency

Macro #10,264

1X

DECLASSIFIED

204 045

51

FIGURE 19. Fracture Grain Sizes of Uranium Rolled to 89% R.A. at 300°C and heat treated at 700°C; water quenched. Annealed 2 hrs. at 575°C.

Macro #12,726

Approx. 2X

3U-75F	-52F	-53F	-54F	-55F	-56F	-57F	-58F	-59F	-60F
as rolled	2 sec	5 sec	10 sec	20 sec	30 sec	60 sec	120 sec	1/2 hr	2 hrs

FIGURE 20. Fracture Grain Sizes of Uranium Rolled to 89% R.A. at 600°C and heat treated at 700°C; water quenched. Annealed 2 hrs. at 575°C.

Macro #12,725

Approx. 2X

6U-64F	-55F	-56F	-57F	-58F	-59F	-60F	-61F	-62F	-63F
as rolled	2 sec	5 sec	10 sec	20 sec	30 sec	60 sec	120 sec	1/2 hr	2 hrs

204
046

52

3
3
A-1306-B 1 & 2

DET. NO.	NO. REQ'D.	DIMM. "Z"	DIMM. "Y"
1	6	$\frac{.375}{.370}$	$\frac{15}{16}$
2	2	$\frac{1.250}{1.245}$	$\frac{13}{16}$

CENTERS PERMISSIBLE

FIGURE 21. Test Rod for Thermal Cycling Inner Blanket Rods

DECLASSIFIED

204 047

53

FIGURE 22. Inner Blanket Rod #4 After 291 Cycles.

Micro 7949

11/16X

204 048

DECLASSIFIED

54

FINISH BOTH ENDS OF
TUBE AS SHOWN

CAP-EB-1139

SLUG-EB-1146

VIEW A
SCALE: 4"=1"

NOTE:

DRAW TUBING OVER SLUGS AND CAP.
DIA. DIMENSION APPLY AFTER DRAWING.
JACKET OVER SLUG.

FIGURE 23. Upper Fuel Blanket Assembly

55

FINISH BOTH ENDS OF
TUBE AS SHOWN AFTER DRAWING.

CAP-EB-1139

SLUG-EB-1145

VIEW A
SCALE: 4"=1"

NOTE:

DRAW TUBING OVER SLUGS AND CAP.
DIA. DIMENSION APPLY AFTER DRAWING
JACKET OVER SLUGS.

FIGURE 24. Lower Fuel Blanket Assembly

0000000000

207 050

FIGURE 25. Upper Blanket Slug

DECLASSIFIED

57

FIGURE 26. Upper Blanket Slug

DECLASSIFIED

204 051

58

FIGURE 27. Lower Blanket Slug

204 052

DECLASSIFIED

FIGURE 28. Cup Die Assembly

DECLASSIFIED

204-052A

60

FIGURE 29. Tube Guide and Die

204 053

DEC 05 1959

61

FIGURE 30. Transverse and Longitudinal Sections of 600°C Rolled Material Used as Stock for Finish Rolling of Blanket Slugs. Electro-etched, Bright Field.

Macro #13,860

Transverse

100X

Macro #13,859

Longitudinal

100X

DECLASSIFIED

204 054

62

FIGURE 31. Transverse and Longitudinal Sections of Inner Blanket Rod as 300°C Rolled, Electro-etched, Bright Field.

Macro #13,856

Transverse

100X

Macro #13,855

Longitudinal

100X

DECLASSIFIED

204 055

63

FIGURE 32. Transverse and Longitudinal Sections of Inner Blanket Rod after Beta Treatment and Anneal, Electro-etched, Bright Field.

Micro #13,858

Transverse

100X

Micro #13,857

Longitudinal

100X

DECLASSIFIED

204 056

64

FIGURE 33. Transverse and Longitudinal Sections of Fuel Blanket Rod
as 300°C Rolled, Electro-etched, Bright Field

Micro #13,862

Transverse

100X

Micro #13,861

Longitudinal

100X

204 057

DECLASSIFIED

FIGURE 34. Transverse and Longitudinal Section of Fuel Blanket Rod after Beta Treatment and Anneal, Electro-etched, Bright Field.

Micro #13,853

Transverse

100X

Micro #13,854

Longitudinal

100X

66

FIGURE 35. Fracture Samples of Inner Blanket and Fuel Blanket Slugs as Rolled and after Beta Treatment.

204 059

DECLASSIFIED