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THE MANUFACTURE OF ENRICHED ZPR-III FUEL PLATES

by

Frank L. Yaggee

October 1956

Metallurgy Division

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by

Frank L. Yaggee

ABSTRACT

This report is essentially a procedural account of the fabrication of certain enriched ZPR-III fuel plates for use in the ANL fast critical experiments at Arco, Idaho.

A total of 208.92 kilograms of fully enriched, unalloyed uranium was processed. Of this amount 202.74 kilograms was received in the form of Oak Ridge type reduction buttons and 6.18 kilograms as pressed-powder plates.

The completed fabrication consisted of 720 rectangular fuel plates having the nominal dimensions 3 in. x 2 in. x 1/8 in. Their combined weight of 159.21 kilograms represents 76.22% of the weight of enriched material processed. The final distribution of the enriched material was as follows:

<u>Form</u>	<u>w/o of Material Processed</u>
Finished Fuel Plates (720)	76.22
Remeltable Stock	15.91
Nonremeltable	7.85
Analytical Samples	0.02
	<hr/> 100.00

INTRODUCTION

The ANL fast critical facility at Arco, Idaho, commonly referred to as ZPR-III, utilizes highly enriched uranium fuel in the form of rectangular plates. As part of the ZPR-III design these fuel plates are of several different sizes to permit a variation in the core configuration by changing the stacking arrangement. Mechanical dilution of the fuel is achieved by interlacing the highly enriched fuel plates with rectangular plates of non-fissionable aluminum and natural uranium.

This report is primarily concerned with the manufacture of the 720 enriched fuel plates, measuring 3 in. x 2 in. x 1/8 in., and comprising 63.7% of the fuel complement of ZPR-III. The fabrication was initiated on

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July 12, 1955, and completed on October 11, 1955. It was undertaken at ANL to forestall a delay in the start-up date for ZPR-III when difficulties were encountered in the originally proposed fabrication by powdered metal techniques.

The manufacturing operation described herein consists essentially of the vacuum-melting and casting of unalloyed uranium, and the subsequent fabrication of the cast billets into ZPR-III fuel plates by rolling, shearing, stamping and machining. Batch processing and continuous material accountability were conditions necessarily imposed by the nature of the material being fabricated. Except for these factors and the rigid specifications to be met by the finished fuel plates, the over-all process is representative of the techniques ordinarily employed in the fabrication of natural uranium. This process is summarized in Figure 1 in the nature of a flow diagram showing the various operations and the sequence of their performance.

The enriched uranium was received and stored in the 16F area from whence the manufacturing process was directed. Much of the melting and casting and final machining, and all of the rolling, shearing and stamping, was performed outside the 16F area on existing equipment used primarily in the working of natural uranium. Assignment of the various operations was as follows.

A. Operations Performed Within the 16F Area

1. Notching and breaking of reduction buttons.
2. Preparation of the melting charge.
3. Melting and casting.
4. Billet cropping prior to rolling.
5. Deburring and machining of stamped fuel plates.
6. Inspection of fuel plates.
7. Identification and weighing of fuel plates prior to shipment.

B. Operations Performed Outside the 16F Area

1. Melting and casting.
2. Hot rolling.
3. Cold finishing.
4. Shearing rolled plate into stamping blanks.
5. Stamping of fuel plates.
6. Deburring and machining of stamped fuel plates.

This assignment of operations was necessary because of the lack of certain equipment in the 16F area and because of a need to augment the casting and machining capacity of the 16F area in order to meet the expressed urgency for the delivery of the finished fuel plates. Metal leaving the 16F area in the course of the fabrication was handled in a manner consistent with the

accepted rules and regulations for the handling and storage of fissionable materials. While outside this area each batch of material was accompanied by a Special Materials Representative and a Security Guard. Each working area was roped off to exclude unauthorized personnel and the area continuously monitored for possible air contamination.

For purposes of material accountability all weighings were made to the nearest ten milligrams. A special effort was made to collect all residues produced in the course of processing and a batchwise material balance was made after every operation resulting in a division of the principal part. Whenever possible weighings were made directly of the metal and all separable residues. Difference values were necessarily assigned to those residues which were incapable of being weighed directly.

SPECIFICATIONS

The specifications set forth for the completed ZPR-III fuel plates are as follows:

Fuel Enrichment

93.0 - 94.0 w/o U²³⁵

Dimensional Tolerances

Length	3.000 - 3.005 in.
Width	1.990 - 1.995 in.
Thickness	0.120 - 0.122 in.
Flatness	within 0.002 in. T.I.R.
Squareness	within 0.003 in.

Physical Requirements

The "width" dimension of the completed fuel plates is to be parallel to the rolling direction.

The variation in weight between individual fuel plates must not exceed a maximum of 1%.

The original "thickness" and "squareness" specifications were 0.122 in.-0.124 in. and 0.002 in., respectively. These were modified by agreement with H. V. Lichtenberger, F. W. Thalgott and D. Okrent.

The permissible weight variation is based upon a calculated theoretical weight assuming the minimum allowable volume and a density of 18.8 grams per cc. Accordingly, the weight per fuel plate is 220.61 grams as derived from the following calculation:

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$$L_{\min} \times W_{\min} \times T_{\min} \times k \times \rho = \text{Theoretical Weight per Fuel Plate}$$

$$3.000 \times 1.990 \times 0.120 \times 16.38 \times 18.8 = 220.61 \text{ grams}$$

where:

$L_{\min}$ = minimum length (inches)

$W_{\min}$ = minimum width (inches)

$T_{\min}$ = minimum thickness (inches)

k = conversion factor (16.38 cc/cu. in.)

ρ = assumed density (18.8 g/cc).

Assuming a mean value of 220.61 grams, the actual variation in weight between fuel plates can range from 219.51 grams to 221.70 grams. It was, however, agreed that the actual weight of individual fuel plates may differ slightly from this calculated value provided the variation in weight between fuel plates did not exceed the specified 1% maximum. It was further agreed that the weight of heavy fuel plates would be adjusted by drilling or punching 1/8 in. diameter holes.

RAW MATERIAL

The feed material consisted of 208,917.48 grams of highly enriched uranium in the form of reduction buttons and scrap pieces of pressed-powder plates. Of this amount 21 reduction buttons, weighing 52,738.76 grams, and one batch of pressed-powder plates (S.M. Batch 1011-22), weighing 6177.93 grams, were received from Sylvania Electric Products, Inc., Hicksville, New York. The remainder of the enriched material was received from the Y-12 plant at Oak Ridge. This latter amount consisted of 39 large reduction buttons weighing 144,810.08 grams and two separate batches of broken buttons (S.M. Batches 188-1 and 188-2) weighing 1800.36 grams and 3390.35 grams, respectively. All of the enriched material is listed in Tables II and III, together with the as-received weights of the individual batches.

The 21 smaller reduction buttons were clean in surface appearance and devoid of obvious surface deposits, such as powdery oxide, unreduced fluoride and other foreign matter. In general these buttons were representative of the metal received from Oak Ridge in the past, measuring $3\frac{1}{4}$ in. in diameter by $1\frac{1}{2}$ in. thick at the very center and ranging in weight from 1800 grams to 3000 grams. Broken pieces of two such reduction buttons are shown in Figure 2.

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The scrap plates included in the shipment of enriched material from Sylvania were received in various lengths and in widths and thicknesses of 3 in. x 1/8 in., respectively. The surface was covered with a loose black oxide which rubbed off easily during handling. Because of this loose surface oxide and the nature of the material, pressed powder, these plates proved to be the least suitable for melting of all the material received.

The 39 larger reduction buttons were essentially disks 4 1/4 in. in diameter by 1/2 in. thick and ranged in weight from 3000 grams to 3800 grams. The surface of these reduction buttons contained numerous shallow crevices and craters, as typified in Figure 3. All showed traces of residual calcium occurring as small surface deposits of white oxide, presumably carried over from the bomb reduction process. Isolated patches of powdery uranium oxide were also found in the surface crevices of several of these buttons, but only one or two showed traces of unreduced fluoride. Foreign matter collected from the surface of the worst appearing button weighed approximately 200 milligrams. Although these buttons were inferior in appearance and purity by previous standards they were not considered rejectable.

The enriched uranium was received at ANL as three separate shipments, each accompanied by an SM-8 form (Numbers F-149, F-153, and F-154) listing the U^{235} weight of individual buttons based on their net SF shipping weight. These data were used to compute the per cent U^{235} contained in each cast billet, which values are compared with the ANL reported values in Table I. The agreement is of the same order as obtained in previous fabrications of a similar nature.

Preparation of the Melting Charge

The weight of the melting charge varied fortuitously from a low of 6177.93 grams to a high of 8021.70 grams. The lower value happened to be the weight of a batch of scrap powdered metal plates (S.M. Batch 142-1030) received from Sylvania, whereas the latter value is near the upper limit necessarily imposed by criticality considerations. Within this range the charge weight of individual melts was largely determined by the nature of the material charged and its packing characteristics within the limited volume of the crucible. Because of the poor packing characteristics of irregular pieces of reduction button, the majority of the melts consisting of such material generally weighed 6600-6800 grams. In contrast, melts consisting of reduction button and remelt scrap or entirely of remelt scrap (Melts 8-16B, 30-16F and 33-16B through 40-16B) weighed somewhat more, usually in the range 6900-8021.70 grams, because of the closer packing obtained with the remelt scrap (less void space in the crucible). The entire fabrication of 40 melts can be summarized according to "charge weight" in the following manner:

REF ID: A61111

<u>Wt. of Charge</u>	<u>No. of Melts</u>
Less than 6500 grams	1
6500 - 6800 grams	27
6800 - 7000 grams	7
7000 - 8021 grams	5
Total	40

In the preparation of the melting charge individual reduction buttons were chilled in liquid nitrogen and broken into pieces of suitable size in a 10,000-psi capacity hydraulic press. The working area of the press was enclosed in a hood to permit maximum recovery of the enriched material. A historical sample consisting of a few small fragments (0.17 - 0.40 gram) was taken from each broken button for future reference in the event a question should arise concerning the purity or the isotopic analysis of the button or the cast billet of which it is a part. Similar samples were omitted in the case of buttons 6182, 6183, 6184, and 6185. A weight balance was made to ascertain the breaking loss, if any, and the broken pieces assigned to a particular melting charge. A portion of a melting charge containing the broken pieces from two small reduction buttons is shown in Figure 2.

Melts consisting entirely of reduction button contained either three and a fraction of the smaller buttons or two and a fraction of the larger ones. The smaller reduction buttons were easily broken after chilling in liquid nitrogen, but the same was not true of the others. The large reduction buttons (see Figure 3) had to be notched with a series of V-shaped grooves $1/8$ in. - $1/4$ in. deep before chilling and breaking, and the broken pieces were more difficult to load into the crucible. The notching was done in a conventional shaper (Steptoe-Western) while the button was submerged in water containing H_3BO_3 . Weights of individual buttons before and after the breaking operation are listed in Tables II and III. Since turnings are not directly remeltable as such only 95.60-99.10% of the larger button weight was available for charging as compared to 99.97-99.99% in the case of the smaller buttons. Remelt scrap and rejected fuel plates are indicated in Figure 1.

Melting and Casting

The enriched uranium was induction melted and cast under vacuum into a coated graphite mold. Cast billets were produced at the rate of one per day in each of two vacuum melting units, the average billet dimensions being $9\frac{3}{4}$ in. x $3\frac{1}{8}$ in. x $3/4$ in. Melts bearing a 16F designation (1-16F, 3-16F, 5-16F, etc.) were made in the portable melting furnace shown in Figure 4. Those bearing a 16B designation (2-16B, 4-16B, etc.) were made outside the 16F area in a vacuum melting unit of slightly different design.

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The crucible and mold arrangement used for these particular melts is shown in Figure 5. A cylindrical zirconia insulator containing a closely fitting cylindrical tantalum heater was placed around the loaded crucible assembly resting atop the graphite mold. The vacuum envelope of the furnace was formed by a $5\frac{1}{4}$ in. diameter by 26 in. long Vycor tube which sealed at top and bottom against greased silicone-rubber gaskets recessed into water-cooled flanges. With the Vycor tube in place the water-cooled stopper rod extension was manipulated to effect a mechanical linkage with the tantalum hood attached to the top of the ceramic stopper-rod. The melting unit shown in Figure 4 is completely assembled and ready for melting and casting. The water-cooled induction coil is located external to the Vycor tube and its position can be varied in the vertical direction. Power was supplied by a "Tocco" motor-generator set capable of delivering a maximum of 15 kw at 10,000 cycles.

The accompanying vacuum system consisted of a 6 in. oil fractionating pump backed by a 6 in. booster and two, two-stage mechanical pumps which could be operated individually or in parallel. The valve arrangement was such as to permit the isolation of the high vacuum section from the furnace section while the latter was open to the atmosphere. In operation the furnace section was pumped down to a pressure of the order of 50-100 microns through a $2\frac{1}{2}$ in. diameter by-pass, using one of the two-stage mechanical pumps. At this pressure the by-pass section was closed and the furnace volume opened to the high vacuum section through a 6 in. quickly acting vacuum valve. If the high vacuum section was warmed up and in operation, the furnace pressure could be reduced to 5×10^{-5} mm Hg within 15-20 minutes after the 6 in. vacuum valve was opened. The metal charge was heated slowly to 1000°C to avoid cracking the crucible, then at a more rapid rate to the desired pouring temperature. When the charge had been melted and sufficiently superheated the melt was poured by raising the stopper-rod extension.

With few exceptions, the majority of the present castings were poured at 1290° - 1300°C . The metal temperature was read with an optical pyrometer by sighting into the crucible through a glass port in the top of the furnace with the aid of a right angle prism placed over the glass port. The corresponding mold temperature was obtained with the aid of a thermocouple located approximately $4\frac{3}{4}$ in. from the top of the mold, as shown in Figure 5. This temperature varied from 582° - 700°C (1080° - 1292°F), depending upon the relative position of the top of the mold with respect to the induction coil and the rate of heating. Pressures of the order of 3×10^{-3} mm Hg to 2×10^{-5} mm Hg were recorded at the pouring temperature, using a conventional ionization gage. This variation in pressure was a function of the degree of calcium contamination of the metal charge.

After pouring a melt the furnace was allowed to cool overnight, under vacuum, before being disassembled. Removal of the cast billet from the mold and consolidation of the melting residue were carried out in a ventilated hood equipped with suitable filters to minimize air contamination. The cast billet, shot and skull, and such remelt stock as resulted from overcharging (extra-heavy sprue or unmelted pieces of reduction button resulting from bridging in the crucible) were weighed and their combined weight balanced against the weight of the material charged. These data are summarized in Table IV.

Commercially available high purity magnesia ceramics were used; these included the crucible, stopper rod and crucible cover. The crucible has a $3\frac{1}{8}$ in. I.D. and a depth of 7 in. measured from the lowest point at the base of the $7/16$ in. diameter bottom pouring hole. Allowing for the $5/8$ in. diameter magnesia stopper rod and the slightly rounded bottom tapering toward the pouring hole, the available volume for containing the metal charge was calculated to be slightly less than 49.4 cubic inches. This fact together with the peculiar geometry of the individual pieces making up the melting charge made the loading operation a painstaking one. The crucible cover was a $3/8$ in. thick disk with a center hole to accommodate the stopper rod and a $5/8$ in. diameter sight hole located along some arbitrary radius. The outside diameter matched that of the crucible.

In the operation the cover was reused repeatedly and on occasion a crucible was reused if, on close inspection, there were no signs of cracking near the base. Stopper rods were never reused because of their greater susceptibility to failure as shown by previous experience. All ceramics were turned over to the Special Materials representative upon being retired.

The graphite billet mold was of the type shown in Figure 6. It measured $4\frac{3}{4}$ in. O.D. by 15 in. long and contained a rectangular cavity 10 in. x $3\frac{1}{4}$ in. x $3/4$ in. The tapered top matched the external taper of the bottom of the crucible and the machined grooves permitted effective outgassing of the cavity during pouring. Each mold was washed with a brushed-on coating of magnesium zirconate and dried overnight in a 250°C oven before being used. The mold cavity was brushed clean and the coating procedure repeated after each use.

Billet Cropping

The cast billets were cropped prior to hot rolling, the single exception being the billet produced in melt 1-16F. The cropping operation was performed in a manner similar to that used in notching the larger reduction buttons, namely, in a conventional shaper (Steptoe-Western) with the billet submerged in water containing boric acid. The cropped billet, machine turnings and cropped top were weighed individually and their combined weight balanced against the original cast billet weight.

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The decision to crop the billets before hot rolling was made strictly in the interests of material accountability and in consideration of the fact that the rolling operation was to be performed outside the 16F area. During the hot rolling of the first billet (1-16F) it was found that the "after-drip," the last bit of metal dripping from the crucible onto the solidified casting, was only mechanically attached and separated from the casting in the course of this operation. This same material, weighing an estimated 15-30 grams per billet, was not easily detached from the billet before rolling. Thus, the cropping operation was deemed necessary in order to minimize the weight loss, in rolling, to that usually incurred when using salt at 600°C as the heating medium. Since the billets were totally devoid of shrinkage cavities, which is usually the reason for cropping billets to be rolled, the cropping operation would have been unnecessary in the case of natural uranium or uranium of very low enrichment.

Data relating to the weights of individual billets before and after cropping are given in Table V. The amount of turnings produced per billet in the cropping operation averaged 1.03% of the cast billet weight, excluding billet 40-16B. In the latter instance both rolling surfaces of the billet were "scalped" to remove the numerous cold-shuts resulting from too low a pouring temperature.

A cropped billet is shown in Figure 7.

Hot Rolling

The equipment used in the hot-rolling operation is shown in Figure 8 and consisted primarily of a 11 in. x 16 in. United Rolling Mill, a Hevi Duty resistance furnace containing a salt bath (84 in. x 10 in. x 12 in. deep) and a water quench tank (72 in. x 12 in. x 12 in. deep) which is not visible in the photograph. This equipment is located outside the 16F area and is generally used in the fabrication of natural uranium and various ferrous and nonferrous metals and alloys. The asbestos sheets covering the floor in the vicinity of this equipment were reclaimed along with the various other residues.

The cropped billets were hot rolled one at a time and at a maximum rate of four billets per eight-hour day. A 15-minute preheat in salt at 600°C (Houghton 235) preceded the first rolling pass, and this was followed by a 3-minute reheat between successive passes. The rolling schedule consisted of 11 reduction passes at a mill speed of 80 fpm and an average reduction in thickness per pass of 15%. After the final rolling pass the 0.130 in. thick plates were again reheated in salt at 600°C for 3 minutes and water quenched. Boric acid (H_3BO_3) crystals were dissolved in the quench water as an added precaution in the event that any plate should accidentally double back on itself and assume a configuration comparable to that of several shorter plates spaced at random intervals in a moderating medium. The water-quenched plates were rinsed with ordinary tap water, dried and stored in the Special Materials vault for the cold-finishing operation.

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The 3-minute reheat following the last rolling pass was found to be necessary in order to eliminate minor edge cracking and permit closer dimensional control in the subsequent cold-finishing operation. This anneal was also effective in eliminating the corner cracking observed in several fuel plates stamped from more severely worked material.

Cold Finishing

The hot-rolled and annealed flats were cold reduced to a final thickness of 0.120 in.-0.122 in. in a 16 in. x 24 in. United Rolling Mill. Portions of the mill and the adjoining power driven conveyor tables were covered with vinyl plastic, in the manner shown in Figure 9, to minimize contamination of the equipment with U^{235} .

Although the total amount of cold reduction was practically the same for all plates (approximately 0.010 in.), the per cent reduction per pass and the number of passes varied with the individual plates, presumably because of the observed variation in metal purity. Plates of the required flatness (within 0.002 in.) were obtained at an optimum rolling speed of 50 fpm.

The general appearance of the enriched uranium plates after cold finishing is typified in Figure 10. The surface of these plates is covered with a hard, semilustrous oxide which does not rub off during normal handling. Unlike the length dimension which varied in a manner directly proportional to the weight of the cropped billet, the width dimension of $3\frac{1}{4}$ in. did not vary appreciably between plates.

Shearing and Stamping

The shearing setup is shown in Figure 11. Here, as in the case of the cold-finishing operation, portions of the machine were covered with vinyl plastic to minimize contamination of the equipment.

The actual shearing operation was performed in a manner very similar to the shearing of ordinary sheet steel. One end of the rolled plate was sheared square as a reference, then the remaining length of plate was sheared into $3\frac{1}{4}$ in. x $2\frac{1}{4}$ in. wide stamping blanks using the pre-set stop located behind the shearing blade. A metal chute was provided to guide the sheared pieces and any small metal fragments into a tray where they were collected by a Special Materials representative. At this point the stamping blanks and scrap ends obtained from each plate were weighed directly and their combined weight balanced against the previously recorded weight of the cropped billet. The weight of enriched material chargeable to the rolling and shearing operations was determined by difference and averaged 18.56 grams per billet. This material is recoverable, by chemical techniques, from the Houghton 235 salt and the quench water, both of which were salvaged upon completion of the fabrication.

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The fuel plates were stamped to size, 3.005 in. x 1.995 in. in. a Loshbough and Jordan Punch Press having a rated capacity of 22 tons. A high carbon, high chromium die steel bearing the trade name "SUPERDIE" was used at a Rockwell "C" hardness value of 57. The press was necessarily modified to permit an estimated 75% overloading; the flywheel speed was increased and two $1\frac{3}{4}$ in. diameter tie bolts were used to add rigidity to the frame. Ventilation of the area in the vicinity of the punch and die was affected with a horn-shaped intake placed immediately behind the punch and die and attached to an existing and suitably filtered exhaust system. Material losses were minimized by fashioning a flexible vinyl plastic enclosure around the punch and die set and collecting the smaller metal fragments in a steel tray.

Fuel plates were stamped in batches corresponding to the cast billets from which they originated. A weight balance was made on each batch of stamped material as an accountability check. The stamping scrap in the form of "picture frames," was earmarked for charging into future melts along with shear scrap, as indicated in Figure 1. Weight data covering the rolling, shearing and stamping operations are given in Table VI.

The stamping operation began with melt 11-16F when it became evident that the 0.003 in. squareness specification could not be met by end-milling. Prior to this the cold-finished plates were sheared into fuel plates measuring $1/32$ in. oversize on length and width and within 0.005 in.-0.008 in. square, using suitable fixtures. These were then to be end-milled, in groups of four, to the final length, width and squareness in the manner shown in Figure 12. This procedure proved unsatisfactory primarily because of the inherent lack of rigidity in the "Bridgeport" milling head.

Deburring

Deburring was necessary to remove the sharp edges and burrs left by the stamping die and to provide the rounded edges called for in the specifications. An ordinary file was used to round the edges as the plates were held in a vise, under water, in the manner of Figure 12. The water served to eliminate air contamination and as a collector of the filings which were subsequently reclaimed.

INSPECTION

A. Visual

This was the first of a series of inspections imposed upon the completed fuel plates to ascertain their acceptability. Rejections based upon this inspection numbered thirty pieces in all and were limited to two types

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of surface defects, namely, (1) longitudinal edge cracking and (2) surface inclusions. Most of the edge cracking occurred in the shearing operation as the result of an excessively dull or misaligned shear blade. In a few instances similar edge cracking was observed in the stamping operation as the result of an improper clearance between the punch and die. The physical nature of the cold finished stamping blanks was such as to require a greater die clearance than that used in the stamping of dimensionally similar plates of aluminum and normal uranium, the latter as a compressed powder. The surface inclusions consisted of pieces of solidified salt (Houghton 235) imbedded in a few isolated areas of the plate, possibly during the last hot rolling pass.

The several causes for rejection of fuel plates and the number of rejections of each type are listed in Table VIII.

B. Length and Width

The length and width dimensions were checked in the manner shown in Figures 13 and 14, using dial indicators. Johansson blocks were used to zero the indicators at the lower specified limits of length and width; the exact zero settings were 3.000 in. and 1.990 in., respectively. Readings obtained by this method were both rapid and accurate.

C. Flatness and Thickness

The original specifications called for a flatness expressed as 0.002 in. T.I.R. (Total Indicator Reading), suggesting that the measurements were to be made over the 2 in. x 3 in. surfaces of the fuel plates with a surface-gage. Besides being unnecessarily laborious, this method of flatness measurement suffers from an inability to distinguish variations in thickness from true warp, and the reproducibility of the measured values is questionable. As a result, an alternate method was adopted with the approval of H. V. Lichtenberger and F. W. Thalgott, both of whom share in the responsibility for the operation of the ZPR-III facility. This alternate method employs the "push-through" gage shown in Figure 15. Fuel plates passing through this gage in a "free-fall" were accepted as being within the specified flatness and thickness limits. Failure of a fuel plate to pass through such a gage would indicate a thickness greater than the maximum allowable value or excessive warp, or both. The thickness of such a fuel plate was easily checked with a hand micrometer, and if found to be within the specified limits the plate was rejected for excessive warp. If, on the other hand, the thickness was found to be in excess of the stated maximum value the fuel plate was set aside for "fly-cutting" in the final machining operation, then rechecked for warp. Only two fuel plates were rejected because of excessive warp, representing a calculated 0.23% of the total number made.

D. Squareness

Squareness was checked with the apparatus, built especially for this purpose by the ANL Central Shops, shown in Figure 16. A steel block, ground square, was used to zero the dial indicators and to check the zero setting at periodic intervals. Four squareness readings were made on each fuel plate: two readings along each 2 in. width. Specifically, a reading was made with the fuel plate in the position shown, then a second reading taken along the same edge after rotating the plate 180°. These two readings were then repeated along the opposite edge of the fuel plate. Fuel plates showing a difference in indicator readings greater than 0.003 in. were rejectable as being outside the limits of the specified squareness. In most cases fuel plates rejected on this basis were reclaimed by careful end-milling, provided the length and width dimensions were at the upper limit so as not to result in undersize plates after milling.

The majority of the rejections for "out-of-squareness" occurred in fuel plates produced in the first ten melts (castings 1-16F through 10-16B) prior to the introduction of the stamping operation into the manufacturing process. Only two stamped fuel plates were rejected for want of squareness.

E. Weight

The lower weight limit per fuel plate was arbitrarily fixed at 219.70 grams, giving an acceptable weight spread of 2.20 grams or an acceptable weight range of 219.70-221.90 grams in conformity with the maximum specified weight variation of 1.0 w/o. The majority of the completed fuel plates fell within this weight range as a matter of course.

Fuel plates were weighed individually on a Mettler Gram-atic balance (Type E-5 SPEZ, No. 6906) having a 1-kilogram capacity. Each weight was recorded on a piece of label-on tape which was attached to the fuel plate itself. The weights of "heavy" fuel plates were adjusted in the final machining operation. Light fuel plates, those weighing less than the indicated minimum of 219.70 grams, were rejected as remeltable scrap.

FINAL MACHINING

The final machining setup is shown in Figure 12 and is essentially the same used to "square," by end-milling, the fuel plates from melts 1-16F through 10-16B before the introduction of the stamping operation. This operation was inserted at this point to reclaim those fuel plates that have passed all inspections, except for thickness and weight, and exceed the maximum tolerable limits with respect to these properties. When necessary the fuel plate thickness was corrected by "fly-cutting"

which, in most instances, automatically adjusted the weight to the proper value. Where further weight adjustment was necessary it was accomplished by drilling 1/8 in. diameter holes. All machining was done under water containing boric acid.

IDENTIFICATION FOR SHIPMENT

Figure 17 shows a typical ZPR-III fuel plate which has passed inspection and is ready for shipment, except for the stamping of an identifying number. The 720 fuel plates produced were numbered consecutively from 831 through 1550, each number being preceded by the letter E. These numbers were applied with conventional letter stamps and were placed along the 2 in. width, parallel to the rolling direction of the parent rolled plate.

Since the application of the identifying number usually changed the weight slightly, each fuel plate was subsequently re-weighed prior to shipment.

FUEL PLATE DENSITY

Density measurements were made in the case of fuel plates from 16 of the last 19 melts, beginning with melt 22-16B. Carbon tetrachloride was used as the density-measuring medium and in most cases two plates were selected at random from each designated melt to serve as the density specimens. The measure density values are given below.

Melt No.	Density (g/cc)	Melt No.	Density (g/cc)	Melt No.	Density (g/cc)
22-16B	18.69 18.68	28-16B	18.66	34-16F	18.70 18.69
23-16F	18.68 18.64	30-16F	18.76 18.75	35-16B	18.70 18.70
24-16B	18.68 18.67	31-16F	18.73 18.76	36-16B	18.68 18.69
25-16F	18.68 18.66	32-16B	18.72 18.71	37-16F	18.68 18.68
26-16B	18.71	33-16B	18.74 18.72	38-16B	18.71 18.71
27-16F	18.70 18.70				

Calc. Average Density 18.70 g/cc.

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REMARKS

The fuel plate fabrication herein described was completed without serious difficulty and did not give rise to any problems hitherto unknown in the working of uranium. Its uniqueness lay in the amount of enriched material processed and in the fact that most of the fabrication was necessarily performed outside the 16F area by personnel the majority of whom are not ordinarily assigned to the 16F area. A special effort was made to schedule the operations such that at no time could there be an assemblage of enriched material in excess of the nominal casting weight (6000-7000 grams). This necessarily meant batch-type operations with the additional requisite that the issuing of each new batch of material be dependent upon the return to the vault of a previous batch properly accounted for. The melting, rolling and machining operations were staggered in point of time to limit the amount of material being received or issued at any moment to the size of a melting charge. The areas in the immediate vicinity of these operations were roped off to exclude unauthorized personnel. Operations resulting in an extensive subdivision of the enriched material (deburring, machining, etc.) were performed under water containing boric acid in the interests of accountability, criticality and health considerations. It is felt that without the above-mentioned precautions the progress of the fabrication might have been adversely affected.

Although the specifications as a whole were much more strict than those ordinarily encountered in a fabrication of this type, the two most restrictive were found to be the flatness and the weight specifications.

The required flatness was obtained only by close adherence to the rolling schedule outlined in Figure 1 and described in the body of this report. Elimination of the 3-minute reheat following the final hot rolling pass was found to affect the obtainable flatness, as did the use of rolls 11 in. in diameter or less in the cold-finishing operation. The abnormally high impurity content of the majority of the raw material (reduction-buttons) exerted an additional adverse influence.

The 1% maximum weight variation between fuel plates in effect reduced the tolerable variation in thickness from the stated 0.002 in. (0.120 in.-0.122 in.) to a value of the order of 0.0012 in. This is easily shown by calculating the weight of a 3.000 in. x 1.990 in. x 0.120 in. fuel plate (minimum permissible dimensions) using an average density of 18.70 g/cc and comparing this value with the calculated weight of a similar plate 0.122 in. thick.

$$L_{\min} \times W_{\min} \times T_{\min} \times k \times \rho = \text{Weight in grams}$$

$$3.000 \text{ in.} \times 1.990 \text{ in.} \times 0.120 \text{ in.} \times 16.38 \times 18.70 = 219.315 \text{ grams}$$

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Thus, the calculated weight of a fuel plate having the minimum allowable dimensions is 219.315 grams, which fixes the upper value at 221.508 grams when the 1% maximum weight variation is applied. The calculated weight of the same plate at 0.122 in. is 222.991 grams, or 1.483 grams heavy; the weight increases 1.838 grams for each 0.001 in. increase in plate thickness. The maximum thickness corresponding to the upper weight limit of 221.508 grams is

$$\frac{221.508}{219.315} \times 0.120 \text{ in.} = 0.1212 \text{ in.} ,$$

if the fuel plates are to fall within the specified limits in weight as fabricated. Extension of the length and width dimensions to 3.005 in. and 1.995 in., respectively, further aggravates the situation by adding an estimated 0.918 gram to the weight of each fuel plate. Upon completion of the fabrication less than 10% of the fuel plates were adjusted in weight by drilling.

Table IX is a summary of the completed fabrication indicating the nature of the residues produced and their respective amounts referred to the individual charge weights. Certain trends are immediately detectable, as for example the increase in the amount of remeltable scrap produced (in the form of "picture frames") with the introduction of the stamping operation.

The over-all fabrication was set up to produce the necessary fuel plates in the shortest possible time and in a manner consistent with the established safety and accountability requirements. Although efforts were made to obtain maximum yield from each melt, such efforts were governed largely by the need for safety and accountability precautions.

ACKNOWLEDGEMENTS

The successful completion of the ZPR-III fabrication is the net result of the cooperative efforts of personnel from the Metallurgy Division, Central Shops, Special Materials Division and the Chemistry Division.

Persons contributing to this operation include the following: W. H. Morris and D. L. Hoffman, both of whom shared in the responsibility for assembling each melting charge and performing the melting and casting within the 16F area; M. Dimenn and J. A. Zic who performed the additional melting and casting outside the 16F area; F. J. Karasek, A. C. Carr and C. A. Bogenschneider for their assistance in rolling and shearing; J. Hollister, J. R. Fessett, Jr., and C. Munter for their assistance in performing the necessary stamping and machining operations;

The work was carried through under the direction of F. G. Foote and J. F. Schumar, Director and Associate Director, respectively, of the Metallurgy Division, both of whom displayed a greatly appreciated understanding of the problems inherently associated with such a fabrication, especially in the face of a greatly shortened delivery date.

[illegible]

Table I

A COMPARISON OF THE CALCULATED U^{235} CONTENT OF THE
CAST BILLETS WITH ANL REPORTED VALUES

Casting No.	S.M. Batch No.	Percent U^{235}		Casting No.	S.M. Batch No.	Percent U^{235}	
		SM-8 (Sylvania)	ANL (± 0.05)			SM-8 (Y-12)	ANL (± 0.05)
1-16F	142-1023	93.15	93.23	9-16F	142-1032	93.16	93.22
2-16B	-1024	93.11	93.28	10-16B	-1033	93.15	93.25
3-16F	-1025	93.14	93.15	11-16F	-1034	93.16	93.26
4-16B	-1026	93.15	93.32	12-16B	-1035	93.17	93.19
5-16F	-1027	93.23	93.32	13-16F	-1036	93.14	93.25
6-16B	-1028	93.17	93.33	14-16B	-1037	93.13	93.17
7-16F	-1029	93.16	93.34	15-16F	-1038	93.12	93.23
8-16B	-1030	93.21	93.24	16-16B	-1039	93.12	93.20
Note: The SM-8 values are calculated from the reported net shipping weight of the enriched material; the ANL values are the reported results of isotopic analyses.				17-16F	-1040	93.13	93.20
				18-16B	-1041	93.20	93.23
				19-16F	-1042	93.16	93.19
				20-16B	-1043	93.13	93.20
				21-16F	-1058	93.17	93.24
				22-16B	-1059	93.16	93.20
				23-16F	-1060	93.15	93.20
				24-16B	-1061	93.18	93.20
				25-16F	-1062	93.20	93.20
				26-16B	-1063	93.19	93.24
				27-16F	-1064	93.16	93.22
				28-16B	-1065	93.17	93.23
				29-16B	-1066	93.17	93.17
				30-16F	-1074	93.14	93.18
				31-16F	-1075	93.18	93.22
				32-16B	-1076	93.18	93.23
				33-16B	-1077	93.18	93.23
				34-16F	-1078	93.16	93.26
				35-16B	-1079	93.16	93.24
				36-16B	-1080	93.13	93.22
				37-16F	-1081	93.16	93.20
				38-16B	-1082	93.16	93.20
				39-16F	-1083	93.18	93.23
				40-16B	-1084	93.17	93.23
Numerical Average		93.16	93.28	Numerical Average		93.16	93.22

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Table II
NOTCHING AND BREAKING OF REDUCTION BUTTONS RECEIVED FROM SYLVANIA

Button No.	Rec'd Wt. (grams)	Pieces to Melt Charge (grams)	% of Rec'd. Wt.	Notch Turnings	% of Rec'd. Wt.	History of Sample (grams)	% of Rec'd. Wt.	Clean-up (grams)	% of Rec'd. Wt.
6182	2995.68	2995.25	99.996	None	-	None	-	0.42	0.014
6183	3001.31	3001.18	99.996	None	-	None	-	0.13	0.004
6184	3001.67	3001.11	99.981	None	-	None	-	0.56	0.019
9354	2098.55	2098.11	99.979	None	-	0.25	0.012	0.19	0.009
6185	3006.60	3006.26	99.989	None	-	None	-	0.34	0.011
6186	1838.07	1837.85	99.988	None	-	0.18	0.010	0.04	0.002
6187	1837.21	1836.86	99.981	None	-	0.25	0.014	0.10	0.005
5816	2254.40	2253.79	99.793	None	-	0.23	0.010	0.38	0.017
5823	2247.20	2246.81	99.983	None	-	0.24	0.011	0.15	0.006
5825	2252.40	2251.93	99.979	None	-	0.29	0.013	0.18	0.008
5824	2254.70	2254.18	99.977	None	-	0.36	0.016	0.16	0.007
5819	2251.58	2251.19	99.983	None	-	0.21	0.009	0.18	0.008
5817	2436.88	2436.30	99.976	None	-	0.16	0.007	0.42	0.017
5841	2247.04	2246.45	99.974	None	-	0.23	0.010	0.36	0.016
5847	2256.70	2256.37	99.985	None	-	0.17	0.008	0.16	0.007
5848	3264.19	3263.83	99.989	None	-	0.25	0.008	0.11	0.003
5861	2978.87	2978.20	99.978	None	-	0.19	0.006	0.48	0.016
5859	2980.35	2980.04	99.990	None	-	0.18	0.006	0.13	0.004
5853	2255.56	2255.12	99.980	None	-	0.29	0.013	0.15	0.007
5871	2252.74	2252.40	99.985	None	-	0.22	0.010	0.12	0.005
5813	3027.06	3026.32	99.976	None	-	0.26	0.008	0.48	0.016
142 1011-22	6177.93	6177.93	100.00			Scrap Pressed-Powder Plates			
TOTALS	58,916.69	58,907.49	99.984	-	-	3.96	0.007	5.24	0.009

Note: Buttons are of the smaller size which do not require notching prior to freezing and breaking.

END OF REPORT

NOTCHING AND BREAKING OF REDUCTION BUTTONS RECEIVED
DIRECT FROM OAK RIDGE (Y-12)

0 3 7 1 2 3 4 1 0 7 0

Table IV

DISTRIBUTION OF MATERIAL DURING MELTING AND CASTING

Raw Material Received from Sylvania								
Melt No.	Charge Wt. (grams)	Wt. of Casting (grams)	w/o of Charge	Shot & Skull (grams)	w/o of Charge	Remelt (grams)	w/o of Charge	Remarks
* 1-16F	6636.95	6500.32	97.94	136.63	2.06	None	-	Shot & skull contains 409 g remelt.
* 2-16B	6624.10	6465.00	97.60	159.10	2.40	None	-	
* 3-16F	6944.86	6796.00	97.86	148.86	2.14	None	-	
* 4-16B	6933.42	6747.00	97.31	186.42	2.69	None	-	
* 5-16F	6939.12	6360.00	91.65	579.12	8.35			
* 6-16B	6693.02	6570.00	98.16	123.02	1.84	None	-	Charge-compressed powder plates.
* 7-16F	6720.03	6546.00	97.41	174.03	2.59	None	-	
* 8-16B	6177.93	5124.00	82.94	1053.93	17.06	None	-	
Raw Material Received from Oak Ridge								
* 9-16F	6706.60	6585.00	98.19	121.60	1.81	None	-	Drip melt. Material remelted. Heavy Casting Sprue.
* 10-16B	6701.90	6590.00	98.33	111.90	1.67	None	-	
* 11-16F	6612.29	6502.00	98.33	110.29	1.67	None	-	
* 12-16B	6606.38	6465.00	97.86	141.38	2.14	None	-	
* 13-16F	6655.46	6452.00	96.94	203.46	3.06	None	-	
* 14-16B	6647.44	6500.00	97.78	147.44	2.22	None	-	
* 15-16F	6636.72	6480.00	97.64	156.72	2.36	None	-	
* 16-16B	6678.83	6588.00	98.64	90.83	1.36	None	-	
* 17-16F	6562.91	6433.00	98.02	129.91	1.98	None	-	
* 18-16B	6666.37	6572.00	98.58	94.37	1.42	None	-	
* 19-16F	6712.74	6577.00	97.98	135.74	2.02	None	-	
* 20-16B	6710.66	6561.00	97.77	149.66	2.23	None	-	
* 21-16F	6679.16			38.01	0.57	6641.15	99.43	
* 22-16B	6744.36	6105.00	90.52	72.92	1.08	566.44	8.40	
* 23-16F	6674.85	6581.00	98.59	93.85	1.41	None	-	
* 24-16B	6638.66	6562.00	98.84	76.66	1.16	None	-	
* 25-16F	6676.68	6579.00	98.54	97.68	1.46	None	-	
* 26-16B	6669.09	5396.00	80.91	55.29	0.83	1217.80	18.26	
* 27-16F	6673.88	6576.00	98.53	97.88	1.47	None	-	
* 28-16B	6747.33	4524.00	67.05	124.89	1.85	2098.44	31.10	
* 29-16B	6703.10	6599.00	98.45	104.10	1.55	None	-	Heavy Casting Sprue.
** 30-16F	8021.70	6870.50	85.65	296.52	3.70	854.68	10.65	
* 31-16F	6663.45	6580.00	98.75	83.45	1.25	None	-	
* 32-16B	6634.57	6541.00	98.59	93.57	1.41	None	-	Heavy Casting Sprue.
** 33-16B	6946.57	6610.00	95.15	336.57	4.85	None	-	
** 34-16F	6974.61	6577.00	94.30	397.61	5.70	None	-	
** 35-16B	7115.82	6410.00	90.08	418.96	5.89	286.86	4.03	Heavy Casting Sprue.
** 36-16B	6972.61	6426.00	92.16	546.61	7.84	None	-	
** 37-16F	7028.07	6686.00	95.13	342.07	4.87	None	-	
** 38-16B	6951.80	6359.00	91.47	533.17	7.67	59.63	0.86	Heavy Casting Sprue.
** 39-16F	7041.69	6314.00	89.66	356.77	5.07	370.92	5.27	
** 40-16B	7642.33	7525.00	98.46	117.33	1.54	None	-	
TOTALS		271,768.06	251,233.82	92.44	8438.32	3.11	12,095.92	4.45

Note: *Melts containing only virgin reduction button.

**Melts containing 60% or more of remelt scrap in the form of rejected fuel plates, sprues and shearing and stamping scrap.

Table V

CROPPING OF CAST BILLETS PRIOR TO ROLLING

Melt No.	Wt. of Casting (grams)	Wt. of Cropped Casting (grams)	% of Cast Wt.	Wt. of Cropped Top (grams)	% of Cast Wt.	Wt. of Turnings (grams)	% of Cast Wt.
1-16F	6500.32	6500.32	100.00	None	-	None	-
2-16B	6465.00	5675.00	87.78	719.55	11.13	70.45	1.09
3-16F	6796.00	6184.00	91.00	547.35	8.05	64.65	0.95
4-16B	6747.00	6107.00	90.52	581.82	8.62	58.18	0.86
5-16F	6360.00	5491.00	86.34	816.62	12.84	52.38	0.82
6-16B	6570.00	6389.00	97.24	127.35	1.94	53.65	0.82
7-16F	6546.00	6318.00	96.52	177.07	2.70	50.93	0.78
8-16B	5124.00	4724.00	92.19	347.84	6.79	52.16	1.02
9-16F	6585.00	6379.00	96.87	131.02	1.99	74.98	2.14
10-16B	6590.00	5989.00	90.88	523.92	7.95	77.08	1.17
11-16F	6502.00	6299.00	96.88	133.07	2.05	69.93	1.07
12-16B	6465.00	6278.00	97.11	113.62	1.76	73.38	1.13
13-16F	6452.00	6220.00	96.40	162.67	2.52	69.33	1.08
14-16B	6500.00	6152.00	94.65	275.24	4.23	72.76	1.12
15-16F	6480.00	6176.00	95.31	228.80	3.53	75.20	1.16
16-16B	6588.00	6256.00	94.96	258.08	3.92	73.92	1.02
17-16F	6433.00	6204.00	96.44	147.64	2.30	81.36	1.26
18-16B	6572.00	6290.00	95.71	200.04	3.04	81.96	1.25
19-16F	6577.00	6264.00	95.24	234.82	3.57	78.18	1.19
20-16B	6561.00	6370.00	97.09	114.38	1.74	76.62	1.17
21-16F	Drip Melt - Casting Remelted						
22-16B	6105.00	5652.00	92.58	397.42	6.51	55.58	0.91
23-16F	6581.00	6319.00	96.02	192.82	2.93	69.18	1.05
24-16B	6562.00	6376.00	97.16	116.66	1.78	69.34	1.06
25-16F	6579.00	6124.00	93.08	383.47	5.83	71.53	1.09
26-16B	5396.00	5059.00	93.75	266.98	4.95	70.02	1.30
27-16F	6576.00	6276.41	95.45	227.74	3.46	71.85	1.09
28-16B	4524.00	4259.00	94.14	197.33	4.36	67.67	1.50
29-16B	6599.00	6185.17	93.73	342.76	5.19	71.07	1.08
30-16F	6870.50	6135.00	89.30	608.31	8.85	127.19	1.85
31-16F	6580.00	6112.00	92.89	394.29	5.99	73.71	1.12
32-16B	6541.00	6171.00	94.34	299.36	4.58	70.64	1.08
33-16B	6610.00	6289.00	95.14	249.78	3.78	71.22	1.08
34-16F	6577.00	6217.00	94.53	292.73	4.45	67.27	1.02
35-16B	6410.00	6019.00	93.90	322.00	5.02	69.00	1.08
36-16B	6426.00	6068.00	94.43	292.80	4.56	65.20	1.01
37-16F	6686.00	6345.00	94.90	271.73	4.06	69.27	1.04
38-16B	6359.00	6047.00	95.09	243.76	3.84	68.24	1.07
39-16F	6314.00	5979.00	94.70	268.54	4.25	66.46	1.05
40-16B	7525.00	4903.00	65.16	777.92	10.34	1844.08	24.50
TOTALS	251,233.82	234,800.90	93.46	11,987.30	4.77	4445.62	1.77

Note: Billet 1-16F was rolled without cropping.

Billet 40-16B was scalped to remove surface cold shuts.

Table VI

DISTRIBUTION OF MATERIAL DURING ROLLING, SHEARING AND STAMPING

Melt No.	Wt. of Cropped Billet (grams)	Wt. Fuel Plate Blanks (grams)	% of Billet Wt.	Residues (grams)	% of Billet Wt.	Scrap (grams)	% of Billet Wt.
Fuel Plates Sheared and Machined to Size							
1-16F	6500.32	5624.40	86.52	*	-	875.92	13.48
2-16B	5675.00	5076.99	89.46	9.67	0.17	588.34	10.37
3-16F	6184.00	5511.51	89.12	15.38	0.25	657.11	10.63
4-16B	6107.00	5426.81	88.86	14.52	0.24	665.67	10.90
5-16F	5491.00	4992.93	90.93	15.62	0.28	482.45	8.79
6-16B	6389.00	5657.05	88.55	19.42	0.30	712.53	11.15
7-16F	6318.00	5606.06	88.73	11.90	0.19	700.04	11.08
8-16B	4724.00	4073.03	86.22	27.08	0.57	623.89	13.21
9-16F	6379.00	5659.60	88.72	17.60	0.28	701.80	11.00
10-16B	5989.00	5422.27	90.54	25.06	0.42	541.67	9.04
Fuel Plates Stamped to Size							
11-16F	6299.00	4887.31	77.59	*	-	1411.69	22.41
12-16B	6278.00	4874.62	77.65	*	-	1403.38	22.35
13-16F	6220.00	4879.65	78.45	*	-	1340.35	21.55
14-16B	6152.00	4893.14	79.54	*	-	1258.86	20.46
15-16F	6176.00	4898.43	79.31	*	-	1277.57	20.69
16-16B	6256.00	4913.47	78.54	*	-	1342.53	21.46
17-16F	6204.00	4695.15	75.68	*	-	1508.85	24.32
18-16B	6290.00	4915.24	78.14	*	-	1374.76	21.86
19-16F	6264.00	4890.61	78.07	*	-	1373.39	21.93
20-16B	6370.00	5084.46	79.82	*	-	1285.54	20.18
21-16F	Drip Melt - Casting Remelted						
22-16B	5652.00	4413.69	78.09	15.46	0.27	1222.85	21.64
23-16F	6319.00	4899.36	77.53	20.79	0.33	1398.85	22.14
24-16B	6376.00	5067.99	79.48	25.46	0.40	1282.55	20.12
25-16F	6124.00	4862.67	79.40	24.72	0.41	1236.61	20.19
26-16B	5059.00	4006.09	79.19	19.71	0.39	1033.20	20.42
27-16F	6276.41	4896.00	78.01	11.40	0.18	1369.01	21.81
28-16B	4259.00	3332.84	78.25	18.59	0.44	907.57	21.31
29-16B	6185.17	4888.81	79.04	20.15	0.33	1276.21	20.63
30-16F	6135.00	4702.56	76.65	36.90	0.60	1395.54	22.75
31-16F	6112.00	4690.39	76.74	32.72	0.54	1388.89	22.72
32-16B	6171.00	4912.53	79.61	30.67	0.49	1227.80	19.90
33-16B	6289.00	4939.93	78.55	19.36	0.31	1329.71	21.14
34-16F	6217.00	4708.28	75.73	12.83	0.21	1495.89	24.06
35-16B	6019.00	4700.18	78.09	6.31	0.10	1312.51	21.81
36-16B	6068.00	4698.15	77.43	18.82	0.31	1351.03	22.26
37-16F	6345.00	4937.95	77.82	20.13	0.32	1386.92	21.86
38-16B	6047.00	4740.31	78.39	10.64	0.18	1296.05	21.43
39-16F	5979.00	4727.64	79.07	11.67	0.20	1239.69	20.73
40-16B	4903.00	3575.95	72.93	17.33	0.36	1309.72	26.71
TOTALS	234,800.90	189,684.05	80.78	529.91	0.23	44,586.94	18.99

Note: Increase in the weight of scrap, commencing with Melt 11-16F, is due to the nature of the stamping operation.

* Included in the Melting Residue.

Table VII

DISTRIBUTION OF MATERIAL DURING FINAL MACHINING OPERATION

Melt No.	Wt. Fuel Plate Blanks (grams)	Wt. Accepted Fuel Plates (grams)	w/o of Fuel Plate Blanks	Wt. Rejected Fuel Plates (grams)	w/o of Fuel Plate Blanks	Mach, Turnings (grams)	w/o of Fuel Plate Blanks
1-16F	5624.40	2649.92	47.12	2646.23	47.05	328.25	5.84
2-16B	5076.99	3311.09	65.22	1540.36	30.34	225.54	4.44
3-16F	5511.51	5074.13	92.06	219.16	3.98	218.22	3.96
4-16B	5426.81	4873.98	89.81	444.06	8.18	108.77	2.00
5-16F	4992.93	4205.36	84.23	675.59	13.53	111.98	2.24
6-16B	5657.05	3100.30	54.80	2446.23	43.24	110.52	1.95
7-16F	5606.06	4206.59	75.04	1328.60	23.70	70.87	1.26
8-16B	4073.03	3988.92	97.94	None	-	84.11	2.06
9-16F	5659.60	5537.58	97.84	None	-	122.02	2.16
10-16B	5422.27	4869.47	89.80	443.21	8.17	109.59	2.02
11-16F	4887.31	3314.82	67.83	1544.41	31.60	28.08	0.58
12-16B	4874.62	2650.85	54.38	2189.24	44.91	34.53	0.71
13-16F	4879.65	4637.87	95.04	219.63	4.50	22.15	0.45
14-16B	4893.14	4417.46	90.28	439.17	8.98	36.51	0.75
15-16F	4898.43	4641.39	94.75	219.22	4.48	37.82	0.77
16-16B	4913.47	4872.70	99.17	None	-	40.77	0.83
17-16F	4695.15	4199.99	89.45	439.53	9.36	55.63	1.18
18-16B	4915.24	4863.74	98.95	None	-	51.50	1.05
19-16F	4890.61	3755.51	76.79	1094.03	22.37	41.07	0.84
20-16B	5084.46	2870.36	56.45	2182.75	42.93	31.35	0.62
21-16F	Drip Melt - Produced no fuel plates						
22-16B	4413.69	3530.64	79.99	876.51	19.86	6.54	0.15
23-16F	4899.36	4415.66	90.13	438.91	8.96	44.79	0.91
24-16B	5067.99	3311.06	65.33	1745.70	34.45	11.23	0.22
25-16F	4862.67	3094.90	63.65	1751.61	36.02	16.16	0.33
26-16B	4006.09	3756.79	93.78	221.18	5.52	28.12	0.70
27-16F	4896.00	3763.14	76.86	1095.38	22.37	37.48	0.76
28-16B	3332.84	3320.63	99.63	None	-	12.21	0.37
29-16B	4888.81	4637.09	94.85	219.51	4.49	32.21	0.66
30-16F	4702.56	3977.52	84.58	663.52	14.11	61.52	1.31
31-16F	4690.39	4637.87	98.88	None	-	52.52	1.12
32-16B	4912.53	4640.13	94.46	219.46	4.47	52.94	1.08
33-16B	4939.93	4865.06	98.48	None	-	74.87	1.52
34-16F	4708.28	4427.81	94.04	220.44	4.68	60.03	1.28
35-16B	4700.18	4648.99	98.91	None	-	51.19	1.09
36-16B	4698.15	4423.62	94.16	218.94	4.66	55.59	1.18
37-16F	4937.95	4871.17	98.65	None	-	66.78	1.35
38-16B	4740.31	4425.79	93.37	221.93	4.68	92.59	1.95
39-16F	4727.64	3544.58	74.98	1107.25	23.42	75.81	1.60
40-16B	3575.95	3540.55	99.01	None	-	35.40	0.99
TOTALS	189,684.05	159,875.03	84.29	27,071.76	14.27	2,737.26	1.44

Note: The amount of machine turnings produced in the final machining operation is noticeably reduced, commencing with melt 11-16F, upon introduction of the stamping operation.

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Table VIII

RECORD OF FUEL PLATE REJECTIONS AND CAUSES

Melt No.	No. Fuel Plate Blanks	No. Accepted Fuel Plates	No. of Rejects				
			Edge Cracking	Warp	Out-of Square	Bad Surface	Under-Weight
Fuel Plates Sheared and Machined to Size							
1- 16F	24	12			12		1
2- 16B	22	15			7		
3- 16F	24	23					
4- 16B	24	22			2		
5- 16F	22	19	2		1		
6- 16B	25	14	9		2		
7- 16F	25	19			6		
8- 16B	18	18					
9- 16F	25	25					
10- 16B	24	22			2		
Fuel Plates Stamped to Size							
11- 16F	22	15	6	1			8
12- 16B	22	12	2				
13- 16F	22	21					
14- 16B	22	20	1				
15- 16F	22	21					
16- 16B	22	22					
17- 16F	21	19		1			
18- 16B	22	22					
19- 16F	22	17					
20- 16B	23	13	2				
21- 16F		Drip Melt - Produced no fuel plates					
22- 16B	20	16					4
23- 16F	22	20					2
24- 16B	23	15	1				7
25- 16F	22	14					8
26- 16B	18	17	1				
27- 16F	22	17					5
28- 16B	15	15					
29- 16B	22	21					1
30- 16F	21	18			1		2
31- 16F	21	21					
32- 16B	22	21					1
33- 16B	22	22					
34- 16F	21	20			1		
35- 16B	21	21					
36- 16B	21	20					1
37- 16F	22	22					
38- 16B	21	20				1	
39- 16F	21	16				5	
40- 16B	16	16					
TOTALS	846	723	24	2	34	6	57

Note: Three acceptable fuel plates from melt 40-16B returned to vault as extras.

NO. 44777

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Table IX

SUMMARY OF MATERIAL DISTRIBUTION WITH RESPECT TO INDIVIDUAL SELTS

Melt No.	S.M. Batch	Charge Wt. (grams)	Accepted Fuel Plates (grams)	% of Charge Wt.	Remeltable Scrap			Nonremeltable Scrap			Spectro Sample		Remarks		
					Billet Top (grams)	Overcharge & Drip Melt (grams)	Shear & Stamp Scrap (grams)	Rejected Plates (grams)	% of Charge Wt.	Shot & Skull (grams)	Turnings (grams)	Roll, Shear & Punch Residue (grams)		(grams)	% of Charge Wt.
1-16F	142-1023	6636.95	2649.92	39.93	None		875.92	2646.23	53.07	*	326.16	136.63	2.09	0.03	Fuel Plates sheared to approximate dimensions and machined to final size.
2-16B	-1024	6624.10	3311.09	49.98	719.55		588.34	1540.36	43.00	159.10	295.35	9.67	0.64	0.01	
3-16F	-1025	6944.86	5074.13	73.06	547.35		657.11	219.16	20.50	148.86	281.08	15.38	1.79	0.03	
4-16B	-1026	6933.42	4873.98	70.30	581.82		665.67	444.06	24.40	186.42	166.28	14.52	0.67	0.01	
5-16F	-1027	6939.12	4205.36	60.60	816.62		482.55	675.59	28.46	579.12	163.82	15.62	0.54	0.01	
6-16B	-1028	6693.02	3100.30	46.32	127.35		712.53	2446.23	49.10	123.02	163.48	19.42	0.69	0.01	
7-16F	-1029	6720.03	4206.59	62.60	177.07		700.04	1328.60	32.82	174.03	121.21	11.90	0.59	0.01	
8-16B	-1030	6177.93	3988.92	64.57	347.84		623.89	None	15.73	1053.93	135.61	27.08	0.66	0.01	
9-16F	-1032	6706.60	5537.58	82.57	131.02		701.80	None	12.42	121.60	196.16	17.60	0.84	0.01	
10-16B	-1033	6701.90	4869.47	72.66	523.92		541.67	443.21	22.51	111.90	185.12	25.06	1.55	0.02	
11-16F	-1034	6612.29	3314.82	50.13	133.07		1411.69	1544.41	46.72	110.29	96.98	**	1.03	0.02	
12-16B	-1035	6606.38	2650.85	40.13	113.62		1403.38	2189.24	56.10	141.38	107.03	**	0.88	0.01	
13-16F	-1036	6655.46	4637.87	69.69	162.67		1340.35	219.63	25.88	203.46	90.26	**	1.22	0.02	
14-16B	-1037	6647.44	4417.46	66.45	275.24		1258.86	439.17	29.68	147.44	108.44	**	0.83	0.01	
15-16F	-1038	6636.72	4641.39	69.93	228.80		1277.57	219.22	26.00	156.72	111.94	**	1.08	0.02	
16-16B	-1039	6678.83	4872.70	72.96	258.08		1342.53	None	23.96	90.83	113.56	**	1.13	0.02	
17-16F	-1040	6562.91	4199.99	64.00	147.64		1508.85	439.53	31.94	129.91	136.02	**	0.97	0.01	
18-16B	-1041	6666.37	4863.74	72.96	200.04		1374.76	None	23.63	94.37	132.51	**	0.95	0.01	
19-16F	-1042	6712.74	3755.51	55.95	234.82		1373.39	1094.03	40.26	135.74	118.28	**	0.97	0.01	
20-16B	-1043	6710.66	2870.36	42.77	114.38		1285.54	2182.75	53.39	149.66	107.30	**	0.67	0.01	
21-16F	-1058	6679.16	None			6340.37			94.93	38.01	300.78		5.07		
22-16B	-1059	6744.36	3530.64	52.35	397.42	566.44	1222.85	876.51	45.42	72.92	60.70	15.46	1.42	0.02	
23-16F	-1060	6674.85	4415.66	66.15	192.82		1398.85	438.91	30.42	93.85	113.23	20.79	0.74	0.01	
24-16B	-1061	6638.66	3311.06	49.88	116.66		1282.55	1745.70	47.37	76.66	78.79	25.46	1.78	0.03	
25-16F	-1062	6676.68	3094.90	46.35	383.47		1236.61	1751.61	50.50	97.68	85.61	24.72	2.08	0.03	
26-16B	-1063	6669.09	3756.79	56.33	266.98		1033.20	221.18	41.07	55.29	95.80	19.71	2.34	0.03	
27-16F	-1064	6673.88	3763.14	56.39	227.74		1369.01	1095.38	40.34	97.88	107.22	11.40	2.11	0.03	
28-16B	-1065	6747.33	3320.63	49.21	197.33	2098.44	907.57	None	47.48	124.89	78.47	18.59	3.29	0.02	
29-16B	-1066	6703.10	4637.09	69.8	342.76		1276.21	219.51	27.43	104.10	101.63	20.15	1.65	0.02	
30-16F	-1074	8021.70	3977.52	49.58	608.31	854.68	1395.54	663.52	43.91	296.52	186.76	36.90	1.95	0.02	
31-16F	-1075	6663.45	4637.87	69.60	394.29		1388.89	None	26.76	83.45	124.40	32.72	1.83	0.03	
32-16B	-1076	6634.57	4640.13	69.94	299.36		1227.80	219.46	26.33	93.57	121.78	30.67	1.80	0.02	
33-16B	-1077	6946.57	4865.06	70.04	249.78		1329.71	None	22.74	336.57	145.01	19.36	1.08	0.01	
34-16F	-1078	6974.81	4427.81	63.48	292.73		1495.89	220.44	28.81	397.61	126.27	12.83	1.03	0.01	
35-16B	-1079	7115.82	4648.99	65.33	322.00	286.86	1312.51	None	27.00	418.96	118.69	6.31	1.50	0.03	
36-16B	-1080	6972.61	4423.62	63.44	292.80		1351.03	218.94	26.72	546.61	119.56	18.82	1.23	0.02	
37-16F	-1081	7028.07	4871.17	69.31	271.73		1386.92	None	23.60	342.07	134.96	20.13	1.09	0.02	
38-16B	-1082	6951.80	4425.79	63.66	243.76	59.63	1296.05	221.93	26.20	533.17	159.13	10.64	1.70	0.03	
39-16F	-1083	7041.69	3544.58	50.34	268.54	370.92	1239.69	1107.25	42.41	356.77	140.80	11.67	1.47	0.02	
40-16B	-1084	7642.33	3540.55	46.33	777.92		1309.72	None	27.32	117.33	1878.73	17.33	0.75	0.01	
TOTALS		271,768.06	159,875.03	58.83						8,301.69	7,434.91	666.54	48.75	0.02	

*Included in Poll Residue.

**Included in Melting Residue.

Figure 1. Flow Diagram of Operations for the Manufacture of ZPR-III Fuel Plates

32

Figure 2. Broken Pieces of Two Small Reduction Buttons.

AS-24

0717270 071

33

Figure 3. Enriched Uranium Reduction Button. The button as pictured shows some residual calcium on its surface.

ANL-106-1993

Approx. 1X

000 000000

Figure 4. Portable Billet Casting Furnace Showing Furnace Arrangement and Accompanying Vacuum System.

ANL-106-1997

037776 070

35

Figure 5. Close-up View of Vacuum Melting Furnace Showing the Mold and Crucible Arrangement.

ANL-106-1991

PDF GENERATED

Figure 6. Split Graphite Billet Mold Coated with MgZrO_4

ANL-106-1996

Approx. 1/3X

037727 077

37

Figure 7. Cast Billet Prior to Hot Rolling Out of Salt at 600°C.
The billet is cropped under water containing H_3BO_3 .

ANL-106-1994

Approx. 2/3X

38
Figure 8. Rolling Mill Setup for Hot Rolling Cast Billets Out of Salt at 600°C.

ANL-106-2001

Figure 9. Cold Finishing of Rolled Plates Prior to Shearing Into Fuel Plate Blanks.

ANL-106-2000

NOT REPRODUCED

40

Figure 10. Uranium Plate After Cold Finishing to Final Thickness.

ANL-106-1998

Approx. 1/7X

41
Figure 11. Setup Used to Shear the Rolled Plates After Cold Finishing to Final Thickness.

ANL-106-1992

Figure 12. End-Milling Setup for Finish Machining ZPR-III
Fuel Plates Under Water Containing H_3BO_3 .

ANL-106-1999

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Figure 13. Indicator Arrangement Used to Measure the Length of Finished ZPR-III Fuel Plates. The indicator as pictured registers a length 0.004" over 3.00".

ANL-106-2288

000 000000

Figure 14. Comparator Used to Measure the Width of Finished ZPR-III Fuel Plates. The indicator as pictured registers a width of 0.0012" over 1.990".

ANL-106-2285

071779 077

45
Figure 15. A Push-Through Type Gage Used to Measure the Combined Value of Thickness and Warp of Finished ZPR-III Fuel Plates.

ANL-106-2287

Approx. 2/3X

070 877177

Figure 16. Gage Used to Measure the Corner Squareness of Finished ZPR-III Fuel Plates.

ANL-106-2286

071779 0711

47

Figure 17. Finished ZPR-III Fuel Plate

ANL-106-1995

Approx. 4/3X

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