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Argonne National Laboratory

FABRICATION OF THE FUEL AND BLANKET
FOR THE
ARGONNE FAST SOURCE REACTOR (AFSR)

by

W. R. Burt, Jr.

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FABRICATION OF THE FUEL AND BLANKET FOR THE ARGONNE FAST SOURCE REACTOR (AFSR)

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ABSTRACT

This report describes the development and the manufacture of the core and the manufacture of the blanket for the Argonne Fast Source Reactor (AFSR). It includes a detailed account of the operations of casting, rolling, machining, and jacketing.

The core consists of 4.5-in.-diameter uranium discs enriched to 93 w/o U^{235} . These discs were vacuum sealed in 0.005-in.-thick nickel cans. Two cans contained a 1.302-in.-thick disc in each and the remaining can contained a series of 0.050- to 0.565-in.-thick discs.

The blanket is a thick-walled, right circular cylinder of bare, depleted uranium. This cylinder is $20\frac{5}{8}$ in. in O. D. x $20\frac{5}{8}$ in. high with an 8-in. wall thickness. It was made up of five individual rings stacked upon each other. Top and bottom plugs of depleted uranium completed the blanket after positioning of the core in the reactor.

INTRODUCTION

The Argonne Fast Source Reactor (AFSR) is a laboratory reactor to supplement the existing facilities of the Idaho Division of Argonne National Laboratory. It was designed as a readily available source of both fast and thermal neutrons for use as follows:

- 1) developing, testing, calibrating, and standardizing various neutron counters;
- 2) irradiation of foils;
- 3) checking out complex experimental systems before operation in other reactors; and
- 4) development of potential experiments in the fast reactor field.

The design of AFSR is summarized in Table I. The reactor core consists of a right circular cylinder of enriched uranium, 93 w/o U^{235} , 4.53 in. in diameter and approximately 4.53 in. high. The uranium is in the form of three discs stacked one on top of another, each disc being vacuum sealed in a 0.005-in.-thick nickel can. The purpose of the nickel can is to prevent oxidation of the uranium in hot air, to prevent release of fission products into the coolant (air) stream, and to prevent contamination when handling the fuel.

Table I

SUMMARY OF DESIGN DATA - AFSR

Core

Geometry	Solid right circular cylinder
Diameter	4.53 in.
Length	4.53 in.
Material	U, enriched to 93 w/o U^{235} , canned in Ni.

Blanket

Geometry	Hollow right circular cylinder
OD	$20\frac{5}{8}$ in.
Wall thickness	8 in.
Height	$20\frac{5}{8}$ in.
Material	Depleted U

Reactor Cooling System

Max reactor power	1000 w
Cooling air flow	55 cfm
Air temp rise across core	56°C
Max metal temp	70°C
% of power produced in core	80
% of power produced in blanket	20

Nuclear

Critical mass	21 kg
Neutron energy	Fast
Max neutron flux	$5.7 \times 10^{11} \text{ n}/(\text{cm}^2)(\text{sec})$

Biological Shield

Material	Magnetite aggregate concrete (226 lb/ft ³)
Nominal Thickness	$4\frac{1}{2}$ ft

Two of the three discs of the uranium core were machined directly from castings and are about $1 \frac{5}{16}$ in. thick. The third section is comprised of uranium discs ranging from 0.050 to 0.565 in. in thickness with the total thickness adjusted for the desired core loading. The thinner core discs were cut from plates rolled from cast slabs.

The blanket or reflector of the AFSR consists of depleted uranium in a stack of five rings and two end plugs which form a thick-walled right cylinder. The dimensions of this cylinder are $20 \frac{5}{8}$ in. in outside diameter by $20 \frac{5}{8}$ in. high. Figure 1 shows the core and blanket components as assembled.

The development of casting and rolling techniques for the uranium core, and fabrication of the nickel cans posed no serious problems. Normal uranium was used to perfect methods that would result in minimum scrap generation during later production of the enriched uranium components.

Initially, castings of normal uranium were made in a disc-shaped mold designed with the disc in a vertical plane. The riser was placed on the edge of the disc at the top. This mold was also designed such that a graphite core rod could be added later to core a $\frac{1}{2}$ -in.-diameter x $4 \frac{1}{2}$ -in.-long hole through one of the enriched uranium discs. This mold with the disc in a vertical plane did not produce sound castings. A mold was then designed with the disc in a horizontal plane. The riser for this mold was placed at the center of the top face of the new disc. Sound castings were produced in this mold.

It was difficult to form a vacuum-tight joint between the two halves of evacuated thin-walled nickel cans during the final sealing. On all cans the silver brazed joint was resealed at localized spots to insure a continuous, impermeable joint between can segments.

Depleted uranium for the blanket components was commercially procured from the National Lead Co. of Albany, New York, as rough machined castings. These were finish machined to final tolerances at Argonne National Laboratory. The blanket components were assembled prior to shipment to the Idaho site.

This report covers development work and production of the enriched core and finishing of the depleted blanket components. An overall flowsheet of the manufacturing operations is shown in Figure 2.

Figure 1. Assembly Drawing of Argonne Fast Source Reactor Showing Location of Major Components

Figure 2. Flowsheet for Fabrication of AFSR Core and Blanket Components

CORE DEVELOPMENT

Initial development work was directed toward making a casting with the disc cast in a vertical plane. The disc was approximately 1.5 in. thick and $4\frac{3}{4}$ in. in diameter. With this type of mold, a graphite core rod could be placed in the mold so as to cast a disc with a $\frac{1}{2}$ -in.-diameter "glory" hole across its diameter. This would eliminate drilling of the hole and increase the yield of good metal.

The first casting was made in a split graphite mold. The mold cavity was in the shape of a disc, 1.5 in. thick and $4\frac{3}{4}$ in. in diameter. After shrinkage on solidification and cooling, about $\frac{1}{16} - \frac{1}{8}$ in. of metal over final dimensions was left for finish machining. Two feed gates, each $\frac{9}{32}$ in. in diameter, distributed molten metal (approximately 725 cc) from the pouring gate and riser to the mold cavity. The mold cavity was coated with mullite ($3\text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2$) by flame spraying prior to use.

24866

Figure 3

Development Casting, $4\frac{5}{8}$ in. in Diameter, Using Graphite Mold with Disc Cast in Vertical Position.

Melting was done in a vacuum induction furnace using a graphite stopper rod and bottom pour crucible. The crucible had a $\frac{3}{8}$ -in.-diameter pouring hole. Both the stopper rod and crucible were coated with a duplex ceramic coating consisting of a ThO_2 slurry applied over a MgO-ZrO_2 base. Normal uranium biscuit charge material was used to simulate material to be used in enriched uranium melts. The melt cycle consisted of heating to 1300°C for one hour, freezing the melt in the crucible, reheating to 1250°C and holding for 10 min before pouring at 1250°C . The intermediate freezing step was used to reduce the gaseous impurity content of the cast material.

The first casting (see Figure 3) made under these conditions completely filled the mold and had an excellent surface appearance. The cast disc was 4.635-4.645 in. in diameter and 1.465-1.485 in. thick, which provided adequate stock for machining to the final dimensions of 4.500 in. in diameter and 1.302 in. thick.

After machining to final dimensions and drilling a 0.147-in.-diameter thermocouple hole, the disc was radiographed by

means of a Co^{60} source. As shown in Figure 4, this radiograph revealed severe porosity at the top of the disc with a large cavity extending to a depth of $1\frac{1}{2}$ in. There also was scattered porosity near the center of the casting, below the large cavity, and a series of internal voids around the top just below the surface.

26722

3/4 X

Figure 4. Radiograph of Machined Disc Cast in Vertical Position.
Dark circle in left portion is a hole drilled through the disc.

While this casting was being machined, a second casting was made with the same mold with a graphite core rod placed vertically in the mold. The core rod was also coated with a duplex ceramic wash of ThO_2 over MgO-ZrO_2 . The melt was taken to 1300°C , held for $\frac{1}{2}$ hr, frozen, remelted, and held at 1215°C for 10 min prior to pouring at that temperature. The metal did not completely fill the mold cavity. The two $\frac{9}{32}$ -in.-diameter feed gates froze prematurely and the top $\frac{1}{2}$ in. of the mold cavity was not filled. A Co^{60} radiograph of the casting is shown in Figure 5. The deep areas of pipe directly below the feed gates are readily apparent. The bottom half of the casting was sound.

26723

3/4 X

Figure 5. Radiograph of Disc Cast in Vertical Position with a Graphite Core Rod. The core rod is represented by the dark vertical band.

Following this unsuccessful attempt to cast a disc with a $\frac{1}{2}$ -in.-diameter hole along its diameter, further castings were made in an effort to produce a solid disc free from internal porosity. Initially, the feed gates were enlarged to increase the rate of metal flowing into the mold and reduce premature freezing of the gates. Premature freezing of the gates was eliminated, but porosity still existed. Following this, the pouring temperature and mold temperature were increased, but porosity still occurred at the top of the casting. Finally, the feed gates were eliminated by extending the hot top or riser down to the mold cavity. This mold and a typical casting are shown in Figure 6. A total of 12 development castings were made in an attempt to cast a sound vertical disc. As none of these castings was free from internal porosity, this method was abandoned in favor of casting the material in a mold with the disc in a horizontal plane.

The graphite mold used in casting the disc in a horizontal plane is illustrated in Figure 7. The mold cavity measured $4\frac{3}{4}$ in. in diameter and $1\frac{3}{8}$ in. high. A hot top in the form of a frustum of a cone $1\frac{1}{2}$ in. high was used. Cone diameters were $1\frac{1}{8}$ in. at the base and 1 in. at the top. The

hot top was tapered to facilitate removal of the graphite core. All crucibles, stopper rods and molds used for these development castings were coated with the ThO_2 , MgO-ZrO_2 duplex ceramic coating previously mentioned. The diameter of the crucible pouring hole was reduced from $\frac{3}{8}$ to $\frac{1}{4}$ in.

106-4704

Approx. 1/3X

Figure 6. Coated Graphite Mold with Enlarged Hot Top and a Typical Casting.

106-4703-A

1/2X

Figure 7. Coated Graphite Mold for Casting Disc in Horizontal Plane.

The first melt for casting a disc in the horizontal plane was made with the mold 1 in. inside the induction coil. This was done to heat the mold hot top. The melt cycle consisted of holding at 1300°C for $\frac{1}{2}$ hr, freezing at 1075°C , reheating to 1200°C , and pouring. The first casting made in this manner showed an excellent surface and was sound internally with the exception of one small $\frac{1}{8}$ -in.-diameter hole in the body of the casting.

A second casting was made with the same melt cycle but with the mold placed 2 in. inside the induction coil to increase the heating of the mold hot top. The charge consisted entirely of biscuit uranium to simulate the enriched uranium charge. This casting showed no evidence of internal defects. This mold design and melt cycle were deemed acceptable for casting of the enriched uranium discs.

In addition to the above development casting, one casting was made from briquetted chips from machining. Because of the large amount of chips generated in machining the discs to final dimensions, a significant reduction in the amount of virgin material needed could be realized if the machining chips could be reclaimed in a simple manner.

Material in the form of machining chips was used for the chip remelt development casting. Heavily oxidized chips from machining operations involving heavy cuts and high speeds were used to simulate the poorest material formed on machining of the enriched uranium discs. No pretreatment of the chips, such as pickling, was used other than a rinsing operation with alcohol to remove any soluble dirt or grease on the surfaces of the chips.

The chips were hand loaded into a hardened steel die and compacted on a Greenerd arbor press at a ram pressure of approximately 20,000 psi. Compacted briquettes were $\frac{3}{4}$ in. in diameter and ranged from $\frac{1}{4}$ to $\frac{1}{2}$ in. in height. The briquettes were stored under vacuum in a desiccator prior to charging into the furnace.

Standard vacuum induction melting techniques were employed in reclaiming the chips from machining. A graphite slab mold, $\frac{5}{16} \times 1\frac{3}{8} \times 7$ in. with a flame-sprayed mullite coating was used. A MgO bottom-pour crucible and stopper rod were used with a charge of 630 gm. The melt reached a temperature of 1220°C after $1\frac{1}{2}$ hr and was poured at 1205°C. The vacuum prior to pouring was 2×10^{-4} mm Hg.

The resulting casting from reclaimed chips had an excellent surface. A Co⁶⁰ gamma-ray radiograph showed no secondary pipe or evidence of porosity. The casting weight constituted an 88.8% recovery of the charge weight. The remaining 11.2% stayed in the skull which contained heavily oxidized chips not melted during the cycle.

Analyses were made for gases and impurities which may have been introduced by the heavily oxidized chips or other foreign matter. The results of these analyses are shown in Table II together with analyses of typical biscuit uranium for comparison purposes.

One slab casting was made from normal uranium biscuit material to insure proper melting and casting techniques and to furnish stock for establishing a suitable rolling schedule. Melting and casting of this slab utilized the same techniques and materials as were used for the disc casting, with the exception of the dimensions of the graphite mold. The slab mold had a $\frac{7}{8} \times 4\frac{1}{8} \times 9\frac{1}{2}$ -in. cavity. The resultant casting was slab milled to a thickness of 0.594 in. in preparation for rolling on a 9 x 16-in. 2-high mill.

Table II

ANALYSES OF TYPICAL BISCUIT URANIUM
AND REMELT CASTING MADE FROM
BRIQUETTED MACHINING CHIPS*

Element	Minor Element Analyses, ppm	
	Typical Biscuit Uranium	Cast Metal from Briquetted Chips
C	120	$\left\{ \begin{array}{l} 228 \\ 174 \end{array} \right.$
N ₂	NA	11
H ₂	NA	0.85
O ₂	NA	35
Ag	<1	<1
Al	<5	30
As	<10	<10
B	0.1	0.1
Ba	-	-
Be	<0.5	<0.5
Bi	<1	<1
Ca	<20	<50
Co	<5	15
Cr	1	2
Cu	15	8
Fe	20	80
K	<50	<50
Li	<1	<1
Mg	40	1
Mn	1	4
Mo	<20	<20
Na	<10	<10
Ni	10	20
P	<50	<50
Pb	<1	<1
Sb	<1	<1
Si	30	100
Sn	<5	<5
Ti	<50	<50
Zn	<50	<50

* C, N₂, O₂, and H₂ from chemical analyses.
Balance of elements from spectrographic
analyses.

NA - Not available.

The initial rolling schedule called for hot rolling to a width of 5 in. (from $4\frac{1}{8}$ in.), and a thickness of 0.450 in., followed by warm rolling to the desired final thickness. The billet was cross rolled from a 625° C carbonate salt bath to 0.487-in. thickness, which gave the required 5-in. width. The cross rolling was done in four passes for a total reduction in thickness of 18%. Following this, the slab was rolled parallel to the longitudinal axis. It was reduced in one pass to a thickness of 0.450 in. The piece was then cooled and the adhering salt removed.

The 0.450-in.-thick plate was heated to 325° C in oil and rolled to a final thickness of 0.170 in. in 19 passes. The plate was reheated for 5 min between passes. The total reduction in thickness was 62%.

No difficulty was encountered in the rolling operations. Flatness of the plate was adequate for final cleanup by machining provided about 0.010 in. per side was left for machining stock. On this basis the combination of hot and warm rolling was acceptable for rolling billets of enriched uranium.

ENRICHED URANIUM PROCESSING

Crucibles

The enriched uranium biscuit was melted in a graphite bottom-pour crucible. The crucible was protected from attack by the molten metal by a duplex ceramic coating. The crucible (see Figure 8) measured $8\frac{1}{2}$ in. in outside diameter, 8 in. in overall height, and $\frac{3}{4}$ in. in wall thickness. The interior was designed with a slight draft to facilitate skull removal. The bottom was pitched to the pouring hole to assist in draining.

106-4719

Figure 8

Graphite Crucible and Stopper
Rod Coated with Duplex Ce-
ramic Coating.

The $\frac{5}{8}$ -in.-diameter, ceramic-coated, graphite stopper rod, also shown in Figure 8, fitted into the pouring hole of the $\frac{1}{4}$ -in.-diameter crucible by means of a tapered tip. This tip was designed to allow for a slight movement of the stopper rod, either vertically or horizontally, without leakage of molten metal. The stopper rod was manipulated by a $\frac{1}{4}$ -in.-diameter tantalum pull rod fastened to the stopper rod. The tantalum rod extended through the furnace cover with compression-type vacuum seal. The crucible and stopper rod were fabricated from ATZ-grade graphite.

The graphite crucible and stopper rod were protected from attack by the molten uranium by a duplex ceramic coating. The base coating consisted of two layers of a magnesium zirconate slurry applied by brushing. The first coating was allowed to dry prior to application of the second layer. The third or top layer consisted of a suspension of thoria in water applied by spraying. Both crucible and stopper rod were air dried prior to use in the furnace.

After casting, the crucible was removed from the furnace and the melt residue or skull salvaged. The ceramic coating was scraped from the crucible and stopper rod, and these surfaces cleaned and recoated prior to re-use.

Molds

Two types of graphite molds were used in production of enriched uranium castings. The molds were designed for flat disc castings and for rectangular slab castings.

The design of the flat disc mold is shown in Figure 7. The drag portion of the mold was $6\frac{1}{2}$ in. in diameter and 3 in. in height. The internal cavity was $4\frac{3}{4}$ in. in diameter with a height of $1\frac{3}{8}$ in. The $5\frac{1}{4}$ -in.-diameter, $1\frac{1}{2}$ -in.-thick cope rested on a $\frac{1}{4}$ -in. lip in the drag section. After completing two $1\frac{3}{8}$ -in.-thick castings, a mating $\frac{1}{4}$ -in. lip was cut into the cope. This was done to allow deeper penetration of the cope into the drag in order to cast one disc $\frac{3}{4}$ in. in height. The cope included a centrally located sprue in the form of a frustum of a cone, $1\frac{1}{8}$ in. in diameter at the base, 1 in. in diameter at the top, and $1\frac{1}{2}$ in. in height.

106-4710

1/4X

Figure 9. Coated Split Graphite Mold for Casting Slabs of Enriched Uranium.

All portions of the internal mold cavity and cope were flame sprayed with a mullite coating ($3\text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2$). Flame spraying was done with an oxy-hydrogen torch. The coating was removed after each casting and the mold recoated prior to the next casting operation.

The second type of mold was a conventional, split, graphite slab mold, illustrated in Figure 9. When assembled, the mold formed a cylinder $6\frac{7}{8}$ in. in OD and $12\frac{1}{2}$ in. high. The internal cavity measured $\frac{11}{16} \times 4\frac{1}{8} \times 11\frac{1}{2}$ in. The mold sections were held together by two tapered graphite rings serving as compression rings. As with the disc mold, all internal mold surfaces were flame sprayed with mullite.

Vacuum Induction Furnace

Melting and casting of the enriched uranium biscuit material was performed in a vacuum induction furnace. The furnace proper was a 13-in.-OD, $12\frac{1}{2}$ -in.-ID, 36-in.-high quartz tube with an external induction

106-4176

Figure 10. Top Cover, Quartz Tube, and Heating Coil of 13-in.-OD Vacuum Induction Furnace.

coil. The furnace was located on a balcony with the tube, coil, and controls above the balcony floor, and the furnace bottom and vacuum pumping system beneath the balcony. A view of the furnace showing top cover, quartz tube, and induction coil may be seen in Figure 10. The quartz tube was insulated with a 1-in.-thick layer of high-density, stabilized zirconia brick.

A 50-kw, 440-v, 3000-cycle motor-generator unit supplied the power for melting via the induction coil surrounding the quartz tube. The coil consisted of twelve turns of two parallel strands of $\frac{1}{2}$ -in.-OD copper tubing with the turn spacing approximately $\frac{1}{4}$ in. The water-cooled coil was 15 in. high and 14 in. in ID, leaving a $\frac{1}{2}$ -in. gap between the coil and quartz tube.

Power from the generator was cable fed to a variable capacitance condenser bank, and from the condenser bank to the coil by water-cooled bus bars.

The furnace pumping system was capable of maintaining a vacuum of 3×10^{-4} torr during melting and 3×10^{-5} torr during superheating periods. The vacuum system consisted of two independent pumping units connected in parallel. Each unit had a 10-in. diffusion pump with a pumping speed of 3000 cfm at 5×10^{-4} torr and a mechanical pump with a pumping speed of 115 cfm. The furnace was equipped with chevron-type water-cooled baffles and a cold trap located between the furnace and diffusion pumps to impede the diffusion of pump oil into the furnace.

Charge Material

The charge material consisted of broken buttons of 93 w/o U^{235} enriched uranium, each button broken into quarters. As the surface of the

broken segments were free from entrapped or adherent slag from the reduction process, no pretreatment of the material, such as mechanical cleaning, pickling, or premelting, was needed. The segments were charged in the as-received condition. Typical as-received broken buttons are shown in Figure 11.

Figure 11

Typical As-received Broken Buttons of Enriched Uranium.

106-5038

Melting and Casting

Preparation of a melt cycle began by placing the graphite mold on a graphite pedestal in the mold well. This pedestal served to position the mold at the proper height in the furnace. The mold well was then raised to the furnace base by a portable lift truck, and the well bolted to the bottom flange on the base. The mold was located such that the upper 2 in. were within the induction coil.

With the mold and well in place, the graphite crucible (whether disc or slab type) was placed on top of the mold. After inserting the stopper rod and loading the broken chunks of enriched biscuit uranium into the crucible, a $\frac{3}{4}$ -in.-thick graphite cover was placed on top of the crucible. The tantalum pull rod was passed through the compression fitting in the furnace cover and connected to the stopper rod. The cover was then lowered onto the quartz tube. Cooling water lines were connected to the furnace cover and the furnace evacuated to 1×10^{-3} torr prior to melting.

Charges for the slab castings were heated to 1350°C and held for 30 min, followed by cooling to 1225°C and holding for 30 min prior to pouring. Metal temperatures during heating were measured with a Leeds and Northrup optical pyrometer sighted on the metal surface. The melting cycle for the disc castings consisted of heating to 1300°C and holding for 30 min, followed by cooling to 1075°C to allow solidification of the melt. The metal was then reheated to 1215°C and held for 10 min, to assure uniform temperature of the molten metal, and then poured. This cycle was identical to that used in obtaining sound development castings. A summary of melting and casting data for individual heats is presented in Table III. Two typical castings, one a disc and the other a slab, are shown in Figure 12.

Table III

SUMMARY OF MELTING AND CASTING DATA

Melt No.	Type of Casting	Melt-cycle Time		Vacuum (1×10^{-4} torr)		Pouring Temp (°C)	Charge Wt (gm)	% Remelt Material in Charge	Casting Wt (gm)	Recovery (% U)
		(hr)	(min)	(minimum)	(at pour)					
AFSR-1	Slab	3	4	0.6	1.0	1265	5963.63	0	5488.46	92.0
2	Slab	3	5	0.4	0.4	1230	5967.74	91	5420.65	90.8
3	Slab	3	5	0.4	0.5	1239	5973.78	0	5472.82	91.6
4	Slab	3	1	0.3	0.4	1238	8242.86	0	7636.02	92.6
5	Disc	3	23	0.4	0.8	1215	8486.10	21	7787.49	91.7
6	Disc	3	25	0.3	0.5	1215	8482.11	18	7981.42	94.2
7	Disc	3	2	1.2	1.3	1195	4740.14	27	4162.90	87.8

106-4711

1/2X

Figure 12. Typical Disc and Slab Castings of Enriched Uranium.

The mold and casting were removed from the furnace by unloading in the reverse order of loading. The mold was disassembled, the casting removed, and melt residues from the crucible and stopper rod were consolidated. These operations were carried out in a ventilated hood equipped with filters to minimize air contamination. Following this operation, the stopper rod and internal cavities of the mold and crucible were lightly sanded to remove the duplex ceramic coating and adherent particles of metal. Prior to re-use, ceramic coatings were re-applied to the mold, crucible, and stopper rod.

Conditioning of Castings

The disc castings were conditioned by removing the heavy sprue (approximately 1 in. in diameter and 1 to $1\frac{1}{2}$ in. in height) to present a uniform casting thickness for radiography. A $\frac{1}{8}$ -in.-wide x $\frac{1}{4}$ -in.-deep circumferential groove was machined in the sprue slightly above its junction with the casting body. After notching, the casting was chilled in liquid nitrogen and the sprue broken off in a protective hood with the hydraulic ram of a 10-ton Greenerd arbor press. After the casting had reached room temperature, the broken surface was machined flush with the face of the cast disc. All machining was done on a 12-in. Monarch lathe with a ventilated protective hood around the work. Carboloy-tipped tools were used for all cutting operations.

The slab castings were not conditioned, as the cast surfaces were free from cold shuts and other defects. The top of the castings, representing the last material to flow from the crucible, were free from pipe, and no conditioning of the top surface was necessary prior to rolling.

Casting Evaluation

Upon completing the weight balance of the casting process for U^{235} accountability, each casting was radiographed to determine the extent of internal porosity, if any. Radiography was done with a gamma-emitting Co^{60} source and Type AA film, with a 0.010-in. lead screen on both sides of the film.

Each radiograph was evaluated to determine the presence and extent of internal porosity. None of the seven castings exhibited internal porosity by radiography. Typical radiographs of disc and slab castings are shown in Figure 13.

Rolling

A detailed schedule of rolling operations performed on the four cast slabs is given in Table IV. Sufficient rolled plate and sheet were required to machine 5 discs 0.300 in. thick, 2 discs 0.150 in. thick, 1 disc 0.100 in. thick, and 2 discs 0.050 in. thick. All discs were to be $4\frac{1}{2}$ in. in diameter.

13a. Radiograph of Disc Casting

106-4750

3/4X

13b. Radiograph of Slab Casting

106-4751

3/4X

Figure 13. Radiographs of Acceptable Enriched Uranium Castings.

Table IV
ROLLING HISTORY OF CAST SLABS AND DISPOSITION OF ROLLED PRODUCTS

Casting or Segment #	Dimensions at Beginning of Rolling Operation (in.)	Direction ⁽¹⁾ of Rolling	Rolling ⁽²⁾ Temp (°C)	Heating Media	No. of Passes	Final Size (in.)	Disposition
AFSR-1	5/8 x 4-1/8 x 6-5/8	Transverse	600	Salt ⁽³⁾	3	0.560 x 4-7/8 x 6-5/8	To be further reduced by rolling in the longitudinal direction.
	0.560 x 4-7/8 x 6-5/8	Longitudinal	600	Salt	4	0.377 x 4-7/8 x 9-7/8	To be finished by rolling at 325°C.
	0.377 x 4-7/8 x 9-7/8	Longitudinal	325	Oil	5	0.333 x 5 x 11	Plate too warped for further use. Broken up for remelting.
AFSR-2	5/8 x 4-1/16 x 6-11/16	Transverse	600	Salt	3	0.559 x 4-5/8 x 6-11/16	To be further reduced by rolling in the longitudinal direction.
	0.559 x 4-5/8 x 6-11/16	Longitudinal	600	Salt	4	0.357 x 4-7/8 x 10-1/4	Sheared into two nominal 5-in. squares for machining.
AFSR-3	5/8 x 4-1/16 x 6-5/8	Transverse	600	Salt	2	0.563 x 4-7/8 x 6-5/8	To be further reduced by rolling in the longitudinal direction.
	0.563 x 4-7/8 x 6-5/8	Longitudinal	600	Salt	9	0.218 x 4-7/8 x 16-1/2 to 17	Sheared into 3A: 9 in. long - for further rolling. 3B: 8 in. long - for further rolling.
AFSR-3A	0.218 x 4-7/8 x 9	Longitudinal	600	Salt	2	0.186 x 4-7/8 x 10-1/4 to 10-1/2	Sheared into two nominal 5-in. squares for machining.
AFSR-3B	0.218 x 4-7/8 x 8	Longitudinal	600	Salt	5	0.136 x 4-7/8 x 13	Sheared into 3B-1: 5 in. long-for further rolling. 3B-2: 5 in. long-for machining. Remainder, 3 in. long, remelted.
AFSR-3B-1	0.136 x 4-7/8 x 5	Longitudinal	600	Salt	8	0.060 x 5 x 12-1/8	To be finished by cold rolling.
	0.060 x 5 x 12-1/8	Longitudinal	Cold	--	18 ⁽⁴⁾	0.050 x 5-1/16 x 13	Sheared into two nominal 5 in.-squares for machining. Remainder, 3 in. long, remelted.
AFSR-4	5/8 x 4-1/16 x 9-1/4	Transverse	600	Salt	2	0.562 x 4-7/8 x 9-1/4	To be further reduced by rolling in the longitudinal direction.
	0.562 x 4-7/8 x 9-1/4	Longitudinal	600	Salt	4	0.349 x 4-7/8 x 14-5/8	Sheared into three nominal 5 in.-squares for machining.

⁽¹⁾Relative to original casting dimensions.

⁽²⁾All hot rolling consisted of a 30-min preheat with a 5-min reheat per pass.

⁽³⁾Houghton 235 neutral carbonate salt.

⁽⁴⁾A total of 4 passes per mill setting required for each of the last 4 settings.

The first enriched slab casting, AFSR-1, 0.657-0.670 x 4 $\frac{1}{8}$ x 6 $\frac{5}{8}$ in., was rolled according to the procedure developed with normal uranium. The billet was preheated to 600°C and cross rolled to a width of 4 $\frac{7}{8}$ in. This was done in three passes, and the final thickness was 0.563 in. The plate was then rolled in the longitudinal direction at 600°C to a thickness of 0.383 in. in four passes. Following a cleaning operation to remove adherent salt products, the plate was warm rolled from 325°C oil to a thickness of 0.349 in. in five passes. At this stage the plate was severely rippled, and further rolling only increased the degree of rippling. Attempts were made to straighten the plate by heating and pressing between flat plates on a 50-ton hydraulic straightening press. Even after pressing at a temperature of 850°C the plate was not sufficiently flat to continue rolling or to allow cleanup of both surfaces by machining to a final thickness of 0.300 in.

As a result of the rippling which developed during warm rolling at 325°C, this operation was abandoned for the fabrication of subsequent slab castings in favor of hot rolling at 600°C directly to the final thickness. All subsequent slab castings rolled in this manner did not ripple.

As noted in Table IV, warm rolling operations performed on billet AFSR-1 resulted in severe warping and rippling of the plate such that the

plate had to be broken up and remelted. The remaining three slabs were all hot rolled to size, allowing a nominal 0.030 in. over the finished thickness for machining stock. In hot rolling these three slabs, no rippling or warping occurred that was of sufficient severity to reject the plate. Any slight variation in flatness was removed by hot pressing at 600°C with a 50-ton hydraulic straightening press or by hand straightening on an arbor press. The segment of AFSR-3 which was cold rolled to the final thickness of 0.050 in. exhibited a slight amount of warping which was removed by hand straightening.

Hot and cold rolling was done on a United 17 x 24-in. two-high rolling mill. Roll spacing was controlled through 5-in.-diameter, Acme thread screws driven by a 5-hp, shunt-wound, DC motor through a gear reduction and worm and pinion. The roll bearings were of the Timken tapered roller type and were mounted in cast steel chocks. The top roll and chocks were balanced by means of hydraulic cylinders. The flat rolls were chill-cast, alloy cast iron and were ground without crown. The rolls were driven by a 150/200-hp, shunt-wound, DC motor through a combination drive and pinion stand with a 15.56 to 1 reduction. Rolling speed was maintained at 75 ft/min for all rolling operations.

For all hot rolling the billets were preheated in a portable resistance heating furnace. The heating medium was Houghton 235 salt, a 28 w/o Li_2CO_3 , 33 w/o Na_2CO_3 , 39 w/o K_2CO_3 mixture. Billets were preheated for 30 min prior to rolling and were reheated for 5 min between passes. The Houghton 235 salt was reclaimed at the end of the rolling operations to recover the 87 gm of enriched uranium remaining in the salt solution.

Shearing

After the hot-rolled, enriched uranium plates had been cleaned by washing in dilute NaOH solution to remove adhering salt products, they were sheared into squares approximately 5 in. on an edge. Following this, a $4\frac{3}{4}$ -in.-diameter circle was lightly scribed onto the surface to assure sufficient stock from which to machine the required 4.500-in.-diameter discs. The squares were then sheared into octagons with a maximum inside circle diameter of $4\frac{3}{4}$ in. This shearing operation served a two-fold purpose: (1) to reduce the time required for machining and the amount of machining scrap generated, and (2) to yield the maximum amount of remeltable shearing scrap and reduce the total amount of material necessary for completion of the job.

Shearing was done on a 6-ft Cincinnati shear rated for $\frac{1}{2}$ -in. mild steel. The shearing table and rear scrap chute were covered with Kraft paper to prevent contamination of the shear and to facilitate recovery of uranium fines.

Heat Treatment

Although the maximum operating temperature of the uranium in the reactor core was estimated to be not more than 70°C, which would probably not cause excessive growth due to radiation damage, the sheared octagons were given a beta heat treatment followed by a water quench to minimize the degree of preferred orientation remaining in the rolled discs.

The heat treatment consisted of immersing the discs, one at a time, into molten lead at 735°C and holding for 10 min. The discs were then removed and quenched in room-temperature water. All transfer times between the lead bath and water quench were less than 5 sec. All but the 0.050-in.-thick discs were spray coated with graphite prior to immersion in the lead to prevent contamination and adherence of lead to the uranium. The 0.050-in.-thick sections were sealed in a $\frac{1}{8}$ -in.-thick, welded copper jacket. This jacket, or can, was provided with a $\frac{1}{4}$ -in. copper evacuation tube. After evacuating the can to 10^{-5} torr or less, the copper tubing was permanently sealed. This evacuated can containing the 0.050-in.-thick discs was beta heat treated in a manner similar to that used for the other discs. The copper can protected the finished uranium surface from lead contamination and minimized warping of the uranium in the heating and quenching cycle.

Following the heat treatment and quenching operation, the disc surfaces were wire brushed to remove adherent particles of lead and residual graphite. This brushing was done in a filtered, ventilated hood to prevent air contamination. After cleaning, the discs were hand straightened on an arbor press to insure sufficient flatness for cleanup of both faces by machining.

Machining

Machining of the enriched uranium discs consisted of turning the final diameter, facing both sides, finishing to the desired thickness, and drilling holes in two of the disc castings. The flatness of the discs had to be maintained within 0.002-in. total indicator runoff.

All turning and facing operations were performed on two Monarch lathes, and the "glory" hole and thermocouple holes were drilled on a Kearney and Trecker Model H horizontal milling machine equipped with a Bridgeport drilling head.

All material was machined without the use of a lubricant or coolant to minimize criticality considerations. Although this made the machining operations more difficult, no serious problems were encountered other than excessive regrinding of tools, necessary because of the rapidity with which they became dull. In addition, all machining operations were conducted

inside protective hoods equipped with a closed exhaust system and filter to avoid loss of material and prevent contamination of the air. Repeated air samples were taken during the course of machining operations to determine the extent of air contamination and avoid any possible hazard to personnel working in the area.

106-4702

Figure 14. Machining 4.5-in.-diameter, 1.3-in.-thick Disc. Note exhaust filter in upper left section of the hood, and the copper tube for feeding argon gas.

Argon gas was fed into the protective hoods at the point of the cutting tool. This helped to cool the tool and prevented ignition of uranium chips by forming a blanket of inert gas. Lathe cutting, with carbide tool bits, was done at extremely low speeds, 100 sfm or less, to reduce tool overheating and chip ignition. Roughing cuts were taken with a 0.010-in. feed. Finishing cuts were made with a light 0.001-in. feed to obtain a fine surface finish and to hold dimensional tolerances within ± 0.001 in. Figure 14 shows one of the disc castings in the final stages of machining.

The 0.050-in.-thick discs were rolled to the final thickness and only required machining to the proper diameter. For this, the sheared disc was held between two steel pads. One pad was clamped in the lathe chuck to impart rotational movement to the disc, and the other pad was held against the work piece by the tailstock. Sufficient force was imparted by the tailstock to prevent movement of the disc during machining. A photograph of this setup is shown in Figure 15.

Figure 15
Machining the Diameter of
0.050-in.-thick Discs Sup-
ported by Steel Pads.

106-4701

Two of the disc castings required thermocouple and test holes, which had to be drilled in the finished piece. In one, a 0.146-in.-diameter thermo-

106-4718

Figure 16. Drilling the Thermocouple Hole in a 4.5-in.-diameter, 1.3-in.-thick Disc. Note hood exhaust filter at the left.

couple hole extended through the disc normal to the face. The second disc had a similar 0.146-in.-diameter thermocouple hole extending half way through the disc and a 0.531-in.-diameter "glory" hole passing through the disc along a diameter. These holes were drilled on the horizontal milling machine with a Bridgeport drilling head attachment. The 0.531-in.-diameter hole was drilled by holding the work piece in a Hartford chuck. A $\frac{1}{2}$ -in.-diameter, high-speed tool steel drill was used to rough the hole to a depth of half the diameter. The disc was then rotated 180° and the remaining portion of the hole drilled. The final operation consisted of reaming the hole to its final size. Following this, the thermocouple hole was drilled with the Bridgeport head as shown in Figure 16. This hole was then reamed to size and undercut according to specifications. Figure 17 shows various $4\frac{1}{2}$ -in.-diameter, enriched uranium discs finish machined from castings and from hot rolled plate stock.

Chip Remelting

In order to conserve material and utilize enriched uranium scrap generated by machining, machining chips were compacted into briquettes and vacuum melted to recover the uranium. This casting was then used as charge stock for melting and casting the $4\frac{5}{8}$ -in.-diameter discs.

The chips received no pretreatment other than an alcohol rinse to remove adherent oil or foreign matter. The chips were compacted in a $\frac{3}{4}$ -in.-diameter, hardened steel split die at a pressure of 22.6 tsi. After compacting, the briquettes were stored under vacuum in a desiccator prior to use. The compacted briquettes were $\frac{3}{4}$ in. in diameter and from $\frac{1}{4}$ to $\frac{1}{2}$ in. in height.

17a. Fuel Disc Machined from Casting Showing 0.531-in.-diameter Hole through Casting.

106-5128

17b. Fuel Disc Machined from Casting Showing Cavity in One Face for Foil Irradiation.

106-5128

17c. Fuel Discs Machined from Rolled Plate Stock.

106-5128

Figure 17. Finish Machined 4.5-in.-diameter, Enriched Uranium Discs.

The enriched uranium briquettes were vacuum induction melted and cast into a coated graphite mold in the portable furnace shown in Figure 18.

106-1997

Figure 18. Portable Vacuum Induction Furnace for Remelting Enriched Uranium Briquettes.

This furnace is a $5\frac{5}{8}$ -in.-diameter x 26-in.-long, Vycor tube vacuum induction furnace powered by a 15-kw 10,000-cycle Tocco motor-generator set. Power was induced into the furnace by means of an external water-cooled coil surrounding the Vycor tube. The induction coil is 7 in. high x $6\frac{3}{4}$ in. in OD, and consists of 13 turns of $\frac{3}{8}$ -in.-OD copper tubing.

The furnace vacuum system consists of a 6-in. coil fractionating diffusion pump backed by a 6-in. booster pump and two two-stage mechanical pumps, operated either individually or in parallel. With this vacuum system, the furnace was capable of operating at a vacuum of 10^{-6} torr.

The briquettes were charged into a $3\frac{1}{8}$ -in.-ID, $7\frac{1}{2}$ -in.-deep, high purity MgO bottom-pour crucible. A $\frac{5}{8}$ -in.-diameter, high-purity MgO stopper rod with a tapered point was fitted into the $\frac{3}{8}$ -in.-diameter crucible pouring hole. A $3\frac{1}{2}$ -in.-diameter, $\frac{3}{8}$ -in.-thick, high-purity MgO cover with a $\frac{3}{4}$ -in.-diameter

sight hole was placed over the crucible after loading. A 0.030-in.-thick tantalum heater encased the loaded crucible and cover which was, in turn, surrounded by a $\frac{3}{8}$ -in.-thick, 10-in.-high zirconia insulator. An insulating magnesia spacer was placed between the crucible and mold to support the crucible and minimize heat loss from the crucible to the mold. A tantalum pull rod was fastened to a tantalum wire loop at the top of the stopper rod. The pull rod extended through the top cover of the furnace to enable the operator to manipulate the stopper rod for pouring the melt.

The metal was cast into a split graphite mold held together with tapered graphite compression rings. The $\frac{5}{8}$ -in.-diameter, $9\frac{1}{2}$ -in.-long mold cavity was coated with a MgO-ZrO₂ wash. The coating was oven dried prior to use.

Two castings were made with briquettes as charge material, one being charged with 1143 gm and the second with 1427 gm. The casting yields were 83.8 and 88.4 w/o, respectively. The first casting was poured at 1240°C and the second at 1310°C. The metal temperature was measured with an optical pyrometer by sighting into the crucible through a right-angled prism placed over the glass port in the top of the furnace. The higher temperature of the second melt resulted in a higher recovery of metal in the casting. The vacuum in the furnace prior to pouring was less than 2×10^{-4} torr in both cases.

Removal of the casting from the mold and recovery of the heavy residual skull was performed in a ventilated and filtered hood to prevent air contamination and possible injury to the operator. The casting was wire brushed to remove adhering mold wash and then used as charge material for the disc melts.

NICKEL CANNING OF ENRICHED URANIUM DISCS

Fabrication of Cans and Components

The enriched uranium discs were sealed in 0.005-in. thick nickel cans to prevent oxidation of the uranium and to prevent contamination of the coolant stream with released fission products.

The nickel cans were made in two sections with overlapping circumferential joints around the uranium disc. This joint was silver brazed, hand filed to finished size, and leak checked. The can was then evacuated and sealed under vacuum.

As the number of cans needed was not large, all forming dies were of a temporary type. With the exception of punches, all draw rings and

pressure pads were made of cold-rolled steel and not hardened. All of the forming punches were made of Micarta. A typical punch and die are shown in Figure 19, together with a formed can segment. This can had a counter-bored lip or step which was formed by spinning after drawing.

106-4716

Figure 19. Typical Forming Punch and Die with a Finished Nickel Can Segment Shown at Lower Right

The 0.005-in. nickel sheet stock was received in a fully annealed state. Because of the rapid work hardening which took place in the drawing operation, the cans could be drawn only half way without intermediate annealing. They

were placed in a sealed steel container for annealing and the container evacuated. This assembly was then heated to 900°C (1650°F) to fully anneal the cans. The half-drawn annealed cans were again placed in the dies and redrawn to their full depth. The full-drawn cans were put on a Micarta mandrel and cut to their finished length on a lathe.

The counter-bored lip or step in the bottom of one of the can segments was spun on a lathe using a $\frac{5}{8}$ -in.-OD $\times$ $\frac{1}{4}$ -in.-ID $\times$ $\frac{3}{16}$ -in.-wide ball bearing as the spinning tool. An edge lip, also spun by a ball bearing, formed the circumferential overlapping joint with the top section of the can. A series of can segments, as drawn and finished, is illustrated in Figure 20.

106-4705

Figure 20. A Series of Nickel Can Segments As Drawn and As Finish Machined

The 0.531-in.-diameter "glory" hole in one of the uranium discs was sealed after assembly in the nickel can with a duplex tube of nickel inside Zircaloy-2. The nickel tube, of 0.005-in.-thick wall, was shrunk fit inside a 0.020-in.-wall Zircaloy-2 tube. The Zircaloy-2 tube was slightly shorter than the nickel tube, and the exposed nickel ends together with nickel bushings were joined to the nickel can by silver brazing. The thermocouple holes in the discs were protected by small nickel tube inserts which were also joined to the nickel cans with a nickel bushing by silver brazing. These 0.005-in.-wall nickel thermocouple tubes were machined to final size from bar stock and the nickel and Zircaloy-2

segments of the "glory" hole tube were machined from tube stock. The duplex "glory" hole tube and two thermocouple tubes can be seen in Figure 21.

106-4713

Figure 21. Nickel Can Segments and an Uranium Disc Completely Sealed in a Nickel Can

A - Assembled Can Prior to Silver Brazing
B - Loaded Can after Complete Sealing
C - Duplex "Glory" Hole Tube

D - Machined Ni Thermocouple Hole Tubes
E - Foil-retainer Ring
F - Segment of a Ni Can

All can segments, tubes, and bushings used in a can assembly were washed in ethyl alcohol prior to use to insure clean mating surfaces and joints for soldering.

Sealing of Cans

After loading the nickel can with enriched uranium, the can was placed in a lavite block which was bored to confine the counter-bored edge of the bottom can. The can rested in this block to a depth allowing the circumferential joint to extend approximately $\frac{1}{8}$ in. above the block to insure proper heating of the joint. A $\frac{3}{8}$ -in.-thick copper disc was placed on the top of the can to aid in heat removal. A 0.015-in.-diameter hole in the top face, which was drilled prior to assembly of the can, served as a purge hole for argon gas during the silver brazing operation. This purge hole was centered in a $\frac{1}{8}$ -in.-diameter, $\frac{1}{64}$ -in.-deep depression in the nickel can, which matched a similar depression in the enriched uranium disc. The purge hole and depression were later sealed and filled during the final vacuum sealing operation. After applying a liquid flux, Easy-Flo silver solder with a melting point of 635°C (1175°F) was used to braze the joint.

After brazing all joints, each can was leak tested by means of a mass spectrometer helium leak detector. If any leaks were detected, the location was identified and the defective area rebrazed. The excess silver solder was removed by hand filing from all leak-proof joints until the can dimensions were within specifications. Following this filing operation, the can was again leak checked in the same manner as before. If a leak was located, the joint was rebrazed.

Final sealing of the can was accomplished by evacuating the can through the 0.015-in.-diameter purge hole and sealing this hole by silver brazing. A special Lucite adapter was made for evacuating and sealing the cans. Lucite enabled the operator to observe the vacuum brazing operation.

The Lucite adapter measured 2 in. in diameter and $2\frac{1}{2}$ in. in length. A $\frac{3}{16}$ -in.-diameter axial hole containing an internal "O" ring was used to guide a sealed $\frac{1}{8}$ -in.-diameter tungsten electrode through the adapter. A $1\frac{3}{16}$ -in.-diameter $\times$ $1\frac{1}{4}$ -in.-deep cavity was drilled on the adapter bottom face. On this same surface, a groove was machined to accommodate a $1\frac{1}{2}$ -in.-ID "O" ring and to provide a vacuum seal between the nickel can and adapter. The adapter and nickel can were evacuated through a $\frac{1}{8}$ -in.-ID connection sealed to the side of the adapter.

A $\frac{1}{8}$ -in.-diameter Easy-Flo silver alloy disc was placed in the $\frac{1}{32}$ -in.-deep depression in the nickel can covering the purge hole. Over this disc was placed a $\frac{1}{8}$ -in.-diameter nickel disc. The tungsten electrode was then pushed through the "O" ring in the top of the Lucite adapter and placed on these discs, allowing the adapter to slide down and seat on the surface of the can.

After evacuating the system to a pressure of 10^{-5} torr or less, as measured at a manifold between the adapter and vacuum system, power from a DC welder was applied to the electrode. The operator regulated the heat generated by means of a foot control for the welder output. After the desired temperature was reached and flow of silver alloy braze metal was complete, the power was shut off and the braze metal allowed to cool and solidify. This completed the sealing operation.

The brazed joint was then hand filed such that the joint was flush with the can surface. A finished can, loaded and sealed, can be seen at the top of Figure 21.

The final seal was leak checked by means of a helium mass spectrometer leak detector. As the can had been flushed with helium immediately prior to evacuation and sealing of the purge hole, a leak in the seal should allow residual helium in the can to escape if the vacuum drawn on the can after sealing was greater than the vacuum drawn during the sealing operation. As the leak detector was capable of drawing a better vacuum than the system for can evacuation, this procedure afforded a test for the integrity of the final seal. If a seal leaked, the can was again resealed by repeating the initial sealing operation.

Two completed cans containing the two large discs machined directly from castings were shipped to the Idaho Division. The series of thin uranium discs was also delivered to Idaho along with two mating nickel can segments. After a series of critical experiments to determine proper core size, a total of seven uranium discs comprising a stack height of 1.965 in. were returned to ANL with the can segments. These discs were then permanently vacuum sealed in the nickel can by the silver brazing operation previously described.

MANUFACTURE OF DEPLETED URANIUM COMPONENTS

The AFSR blanket components were fabricated from depleted uranium. These components consisted of five rings stacked one on top of the other, a top plug, a bottom plug, two safety rods, two shim rods, and one control rod. All depleted uranium was procured as rough machined castings from the National Lead Company of Albany, New York. Conventional melting, casting, and machining techniques were used in the manufacture of these items.

Final machining of the components was done at ANL. This presented some difficult problems as there was no jig borer at the machine shop's disposal with which to hold the close tolerances required. All machining was done on conventional Cincinnati milling machines, a Lucas horizontal mill, and a King vertical boring mill. None of these machines was intended for holding the close tolerances required of this job. An added difficulty was the handling of the heavy pieces. The 21-in.-diameter x $4\frac{1}{2}$ -in.-thick rings weighed over 1000 lb each.

The first operations consisted of facing one side, turning the OD, and boring out the ID on a King boring mill. The boring was started by drilling, with the use of a succession of chip-breaker type drills progressing from a 1-in. through a 2-in. drill. These drills were considerably heavier than conventional drills, resulting in less chatter. A 1-in. drill could penetrate 5 in. of uranium in $4\frac{1}{2}$ min. Each drill was used until its margin became abraded, and excessive chatter and drag ended its useful life.

Following drilling of the 2-in.-diameter hole, the ID was bored to its final 4.71-in. size by carbide tool bits on the boring bar. The coolant used for these operations and all succeeding ones was White and Bagley's #1500 concentrate cut with water to a 50 to 1 ratio. After boring, the piece was inverted and the second side faced to the final thickness. The two faces were parallel within 0.002 in. T.I.R.

While machining the outside diameter on three of the 21-in.-diameter castings, a deep cavity was exposed under the surface. These cavities had been packed with chunks of uranium and puddled over with weld deposited uranium on the top. A typical cavity is shown in Figure 22 together with pieces of uranium metal extracted from the cavity prior to finish machining the outside diameter. These holes were drilled out and plugged with machined mating pieces of cast depleted uranium.

After machining to the final OD, ID, and thickness dimensions, the uranium ring was transferred to a Cincinnati milling machine where the holes corresponding to location of safety, shim, and control rods were rough drilled and bored to final size. This operation is shown in Figure 23, in which a safety rod hole is being drilled prior to boring to final size. Two semi-finished blanket rings are shown in Figure 24.

26724

Figure 22. Defective Area Found in a Cast and Rough-machined Depleted Uranium Blanket Ring

Figure 23

Drilling a Safety Rod Hole in a Depleted Uranium Blanket Ring

106-4706

Figure 24. Two Semifinished Depleted Uranium Blanket Rings. These rings are $20\frac{5}{8}$ in. in diameter.

The middle blanket ring was segmented and consisted of three wedge-shaped pieces. These pieces were assembled into a ring of the same overall dimensions as the other four rings. This was done by sawing through half the thickness of the cast uranium with a 10-in.-diameter milling cutter. The casting was then inverted and finish cut from the other side. The exposed cut surfaces were finished to the required angle by setting up with a 10-in. sine bar and indicator and machining on a Cincinnati horizontal mill.

The three pieces were then assembled and bolted to a holding jig for turning the final OD and ID and for completion of the remaining holes.

Specifications called for two $\frac{1}{2}$ -in.-diameter locating holes through each ring to allow proper alignment of the five finished rings. In addition, a $\frac{1}{8}$ -in.-diameter thermocouple hole extended vertically into the blanket to a depth of approximately $10\frac{1}{4}$ in. The thermocouple hole passed through two rings and bottomed in the third ring. The holes were first bored to $\frac{3}{4}$ -in. diameter to insure straightness and alignment between the discs. A series of 1-in.-long sleeves were machined to the locating or thermocouple hole ID and the OD finished to allow for a shrink fit in the $\frac{3}{4}$ -in. holes. The sleeves were chilled in liquid nitrogen and dropped into the $\frac{3}{4}$ -in.-diameter holes in the rings. This permitted accurate alignment of these holes and insured straightness.

Additional holes ranging from $\frac{1}{2}$ to 3 in. in diameter (the "glory," grazing, source, and beam holes shown in Figure 1) were made in a plane perpendicular to the vertical axis of the blanket assembly. The $\frac{1}{2}$ -in.-diameter "glory" hole was machined on the Lucas horizontal boring mill. The operation consisted of drilling through the ring from both sides. These drilled holes were then sleeved with short plugs having the desired ID dimension. The larger-diameter grazing, source, and beam holes were rough drilled and finish bored to size. In machining these holes, a bar support was used on the mill, which added greatly to the rigidity of the boring tool, permitting a better finish with less deflection and increased accuracy of the finished hole.

Other blanket components consisting of the top and bottom plugs, the safety rod, shim rod, and control rods were machined from rough-machined castings, also received from the National Lead Company. The

beam hole plug was machined from a depleted uranium casting made at ANL. Machining was done on standard lathes by conventional machining practices. The finish-machined components are shown in Figure 25.

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Figure 25. Finish-machined Depleted Uranium Blanket Components

A - Top plug	D - 1-in.-diameter control rod
B - Beam hole plug	E - Bottom plug
C - 2-in.-diameter safety and shim rods	

After completing all machining operations, the five blanket rings were assembled for dimensional inspection. The assembled blanket is shown in Figure 26. The care taken to insure alignment and straightness of holes and overall dimensions by checking and rechecking during machining operations resulted in perfect alignment of all vertical and horizontal holes. No remachining was necessary. A mockup of the core assembly was used to check the fit of the core and alignment of the "glory" hole.

Figure 26

Depleted Uranium Blanket Assembly with the Top Plug Suspended above Its Location in the Blanket

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A simplified account of the enriched uranium is given below:

<u>Operation</u>	<u>Weight of Enriched Uranium Processed (gm)</u>	<u>Per Cent of Charged Metal</u>
Disc and Slab Melt Charges	47,856.36	100.0
Disc and Slab Castings	42,949.76	89.7
Machining Stock (Castings and rolled plates)	34,771.95	72.6
Finish Machined Discs	24,688.58	51.6

One of the slab castings (of 5488.46-gm mass) developed severe rippling during rolling and was broken up for remelt stock. The total charge weight of 47,856.36 gm included 11,519.80 gm of remelted material in the form of casting sprues, shearing scrap, and castings from remelting of machining chips. The yield of material as finished discs from virgin biscuit uranium charged to the melts (36,336.56 gm) was 68.0%. Of the total amount of scrap generated, 12.3% (4,484.71 gm) was not considered re-usable. This scrap consisted of melt residues, fines, and material lost in rolling and heat-treating media. Re-usable scrap from shearing, machining chips recoverable through remelting, and scrap from castings in the form of sprues accounted for the balance of the scrap material and weighed 7,163.27 gm. This is equivalent to 19.7% of the virgin biscuit uranium used.

To increase the yield of acceptable material it would be necessary to cast discs to closer tolerances in order to reduce the amount of machining chips generated. Similarly, rolling plate stock to the desired final thicknesses could reduce machining scrap. However, these operations would require closer control over mold dimensions and casting surface quality, and much finer rolling practices to insure the final degree of surface flatness required for discs machined from rolled stock. With additional time for development work this might be possible, but such development could not be justified for the small number of components required for AFSR.

A better yield could have been achieved through recovery of more of the machining chips. Approximately 6500 gm of chips remained upon completion of the job. Assuming an 85% recovery of chips through melting and casting, the necessary amount of enriched uranium could have been reduced by approximately 5500 gm. The yield of acceptable material from virgin charge material would then increase to approximately 80%. Increases in yield, therefore, could best be derived through increased recovery of machining scrap rather than through closer control of processing operations.

Depleted Uranium Components

Machining of the depleted uranium blanket components consumed approximately 2,100 man hours of machining time. A total of 2,805 kg of depleted uranium in the form of rough machined castings was received for final machining. The finish-machined components weighed a total of 2,083 kg, representing a yield of 74.3%.

The dimensions of the blanket components required exacting control over work piece set-up and machining operations. Although the care taken in these operations may seem to be overly cautious, the precise alignment obtained during the initial assembly of the components justified these precautions. This was particularly true considering the limitations of the equipment available for use.

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The photographs in this report were taken by C. L. Long of Graphic Arts. The metallography was done by A. P. Baudino, Jr., of the Metallurgy Division.

APPENDIX

Examination of the nickel-clad, enriched uranium fuel discs after several months of operation in the reactor revealed defects in the cladding material of two of the nickel cans. Subsequent exposure to the air coolant of the reactor system resulted in small areas of localized oxidation on the enriched uranium disc in one of these cans.

The three core sections were returned to the Central Shops division of Argonne National Laboratory where the cans were removed and the discs reclad in 304 stainless steel. The cladding thickness was increased from 0.005 to 0.015 in. to provide a more substantial jacket. All the uranium fuel discs were reduced in diameter by machining to compensate for the increased cladding thickness. The circumferential can joints were sealed by electron beam welding rather than by brazing. The welded joints were leak checked in the manner described earlier in the report.

The enriched uranium disc exhibiting areas of oxidation was recast by the Metallurgy Division and remachined into a new disc. The techniques employed were identical with those used in producing the initial disc and described in the main body of the report.