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Argonne National Laboratory

FABRICATION OF EBR-II, CORE-I FUEL PINS

by

H. F. Jelinek, N. J. Carson, Jr., and A. B. Shuck

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

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ABSTRACT

A total of 11,117 enriched uranium-5 w/o fissium alloy fuel pins were manufactured for EBR-II, Core I. These were made from a synthetic fission product alloy of nonradioactive elements, natural uranium, and enriched uranium. The material was supplied as precast billets. The manufacturing methods were developed for the EBR-II Fuel Cycle Facility. Experimental refabrication equipment was used to production test both the methods and the equipment.

The billets were induction melted and pressure cast into precision-bore, high-silica glass molds in batches of 90 to 160. The number of molds used was adjusted according to batch weight. After casting, the molds were broken away and the castings were fed into a pin-process and inspection machine. Both ends were sheared from the castings to produce finished pins measuring 0.144 in. in diameter by 14.22 in. long. The pins were inspected for diameter, porosity, weight, and length. Rejected pins and sheared ends were broken into short lengths and returned for consolidation. Acceptable fuel pins were sealed and sodium bonded in stainless steel jackets, and assembled into Core-I fuel elements.

INTRODUCTION

Purpose

The purposes of the work described in this report were as follows:

1. to manufacture fuel for EBR-II, Core I, and additional fuel for dry critical experiments and reactor plant startup;
2. to produce natural uranium pins to be used in the EBR-II Fuel Cycle Plant startup tests;
3. to test gas-pressure injection-casting methods and experimental refabrication equipment in a sustained operation.

Only the production of fuel pins is covered in this report. Preparation of the fissium alloys is described in ANL-6290.[1] The jacketing, bonding, and welding of the fuel rods and assembly into multiple-rod fuel elements is described in ANL-6276.[2] Development of the methods and equipment employed for this fuel loading and for fuel refabrication is described in ANL-6272.[3]

Fissium Alloy

Continuously recycled fuel tends to reach an equilibrium composition determined by fission product generation and efficiency of refining. The alloy used for the first core loading approximates an equilibrium of fuel and fission elements predicted for repeated EBR-II fuel recycle. These equilibrium alloys, termed "fissium alloys," have been predicted to have the compositions shown in Table I. Because natural elements were used in place of fission products, the alloy was not highly radioactive.

Table I

PREDICTED EQUILIBRIUM COMPOSITION
AND CORE I COMPOSITIONS

Elements	Predicted Fissium Range 3.7-8.8 w/o Fs	Core I Nominal Composition 5 w/o Fs	Core I Analytical[a] Composition w/o
Molybdenum	1.6-3.4	2.46	2.56 ± 0.12[b]
Ruthenium	1.2-2.6	1.96	2.14 ± 0.07
Technetium	0.5-1.0	-	-
Rhodium	0.2-0.5	0.28	0.27 ± 0.03
Palladium	0.1-0.3	0.19	0.19 ± 0.02
Zirconium	0.1-1.0	0.10	0.11 ± 0.03
Niobium	0.01	0.01	0.01[c]

[a] Emission spectrographic data on cast fuel pins.

[b] All deviations were determined from the averages by

$$\sigma = \sqrt{\frac{\Sigma X^2}{n} - \bar{X}^2}$$

[c] No analysis was obtained for niobium; quantitative alloying assumed.

Fuel Pins, Rods, and Elements

The EBR-II, Core-I fuel is in the form of cylindrical pins. The specified dimensions of the fuel pins are 0.144 ± 0.001 in. in diameter by

14.22 ± 0.03 in. long, with masses of 65 to 70 gm each. Each pin is jacketed and sodium bonded in a 0.156 ± 0.0005-in.-ID x 0.009 ±0.0005-in. wall, Type 304L, stainless steel tube. The jacketed pins, termed fuel rods, are shown in Figure 1.

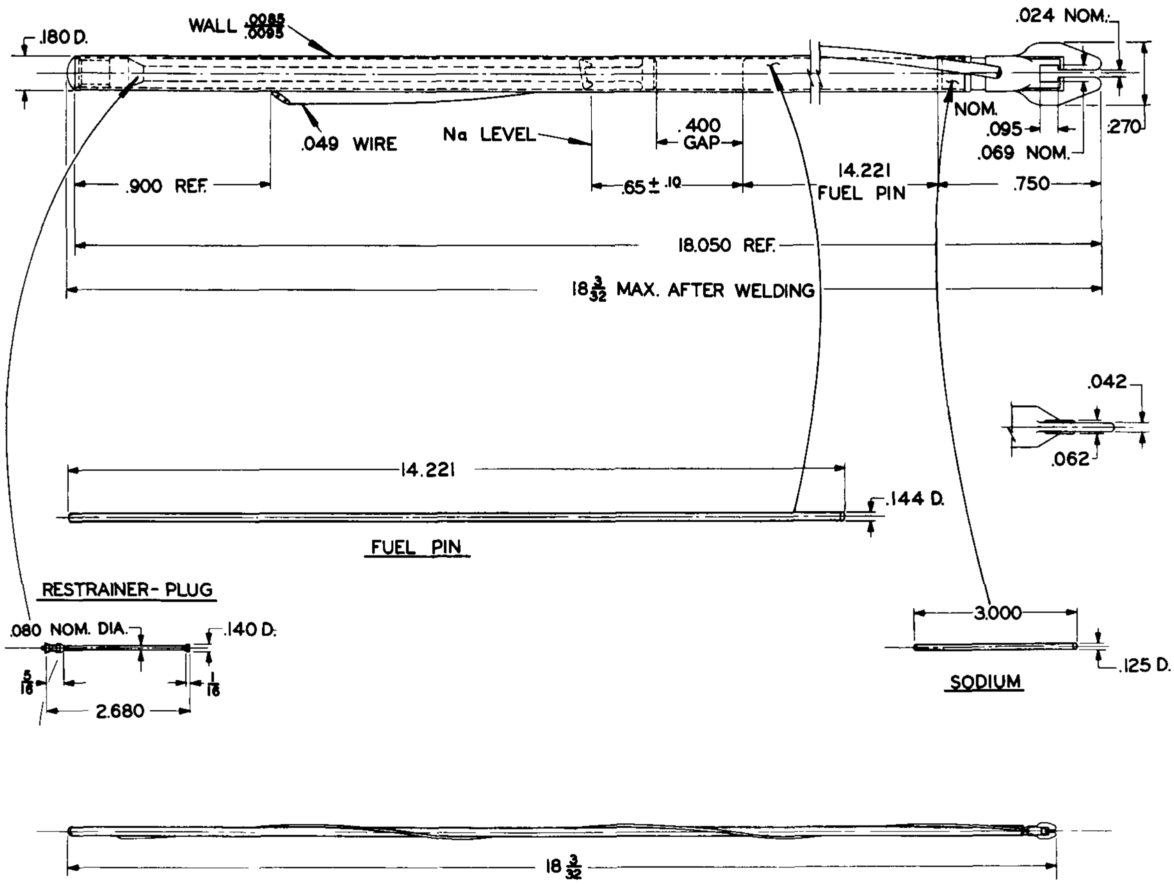

Figure 1. EBR-II Fuel Rod

The T-slot tip welded to the bottom of the fuel tube attaches to a grid in the fuel element. The spiral wire separates adjacent fuel rods and provides channels for sodium flow between fuel rods. The top plug is provided with a strut which "restrains" the fuel from rising in the tube. The sodium level is adjusted to provide an expansion space in the annulus around the restrainer.

Ninety-one fuel rods and 36 depleted uranium blanket rods are assembled in hexagonal tubes, as shown in Figure 2. These have been termed fuel elements and are the basic loading units of the reactor. Each control and safety element contains 61 fuel rods in moveable assemblies. Details of the construction of the fuel elements, blanket elements, and safety elements are given in ANL-6276. The total numbers of each type of element produced and the number of fuel pins in each are shown in Table II.

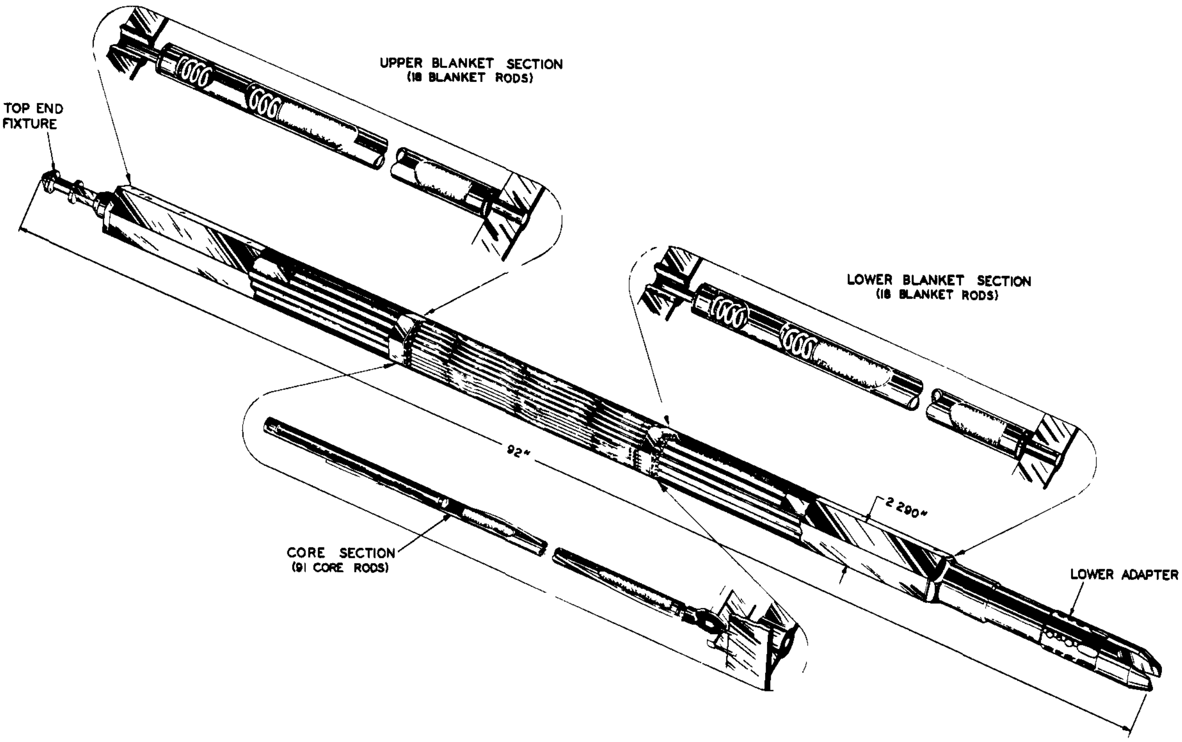

Figure 2. EBR-II Fuel Element

Table II

NUMBER AND TYPE OF ELEMENTS PRODUCED

Element Type	Number Produced	Fuel Rods Each	Total Rods
Fuel	97	91	8,827
Control	17	61	1,037
Safety	3	61	183
Dummy	24	91	2,184
	141		12,231

Manufacturing Operations

The operations comprising fuel pin manufacture are illustrated in Figure 3. Prealloyed 5 w/o fissium billets are induction melted in coated graphite crucibles and injection cast into coated Vycor molds. Crucible heels are recycled. Castings are stripped and sheared to form fuel pins which are inspected for diameter, internal flaws, weight, and length. Rejected pins are "chopped" into short lengths and sent, with sheared ends and short castings, to be consolidated into billets.

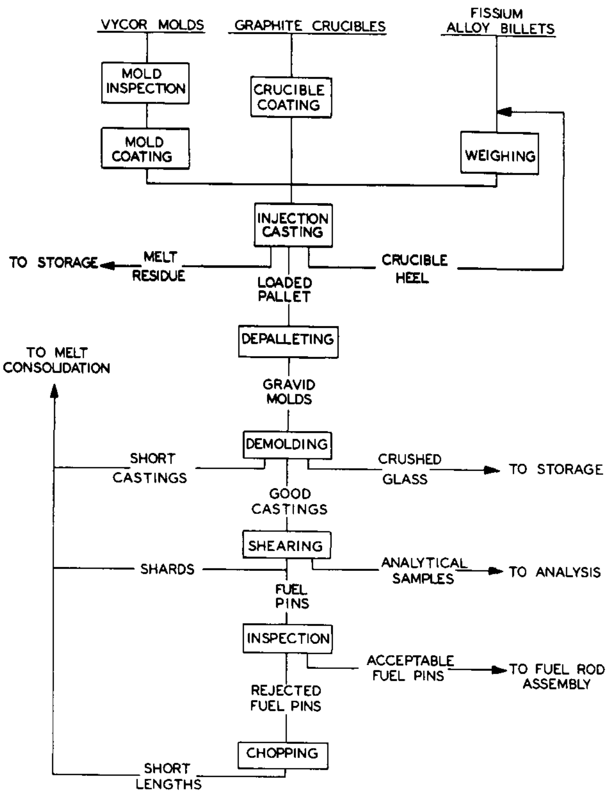

Figure 3. Operations Comprising Fuel Pin Manufacture

Equipment developed for the EBR-II fuel-cycle process was employed for production of Core I. It was installed in a special facility in Building 6 at ANL. The facility is described in ANL-6092.(4)

Nuclear Hazard Control

Since the total amount of fuel alloy in the work area at one time can be greater than the "always-safe mass," manufacturing procedures were carefully reviewed for nuclear safety. The work area was divided into zones by means of bright colored tape applied to the floor. The amount of fuel alloy per zone was limited in such a way as to make safe, not only the amount of fuel alloy in each zone, but also the merging of fuel alloy in adjacent zones. Interzone transfers were made the responsibility of the engineer-in-charge, who kept a continuously current record of the amount and distribution of fuel alloy within the work area. No liquids were allowed in the work area except in containers of "always-safe geometry." Fuel alloy was not placed on the floor. All fuel alloy containers were either sealed to prevent liquid from entering or made incapable of retaining liquids. These procedures, plus a preliminary indoctrination period for the operating personnel, proved sufficient to achieve safe practice in operation.

PIN CASTING

Injection casting into Vycor* glass molds was developed for fabrication of EBR-II fuel. In this process the precision-bore molds are suspended, open end down, above the crucible. The metal is melted and heated to a predetermined superheat. The furnace is evacuated and the crucible is raised, immersing the open mold tips. The furnace is then pressurized, forcing molten metal into the evacuated mold cavities. After the castings have solidified, the crucible is lowered.

*Vycor is a trade name for high-silica glass from Corning Glass Works.

This method of making castings was preferred because: (1) the castings produced have the desired diameter and random grain structure, and (2) the process is amenable to remote operation.

Injection-casting Furnace

The casting furnace, shown in Figure 4, is an induction-heated, bell-type jar having the induction coil inside the removable bell. Power is supplied by a 30-kw, 440-v, 10,000-cycle motor-generator set. The furnace is located on an elevated stage, and the vacuum pumping system, pressure accumulator tank, and the extension of the crucible actuator are located beneath.

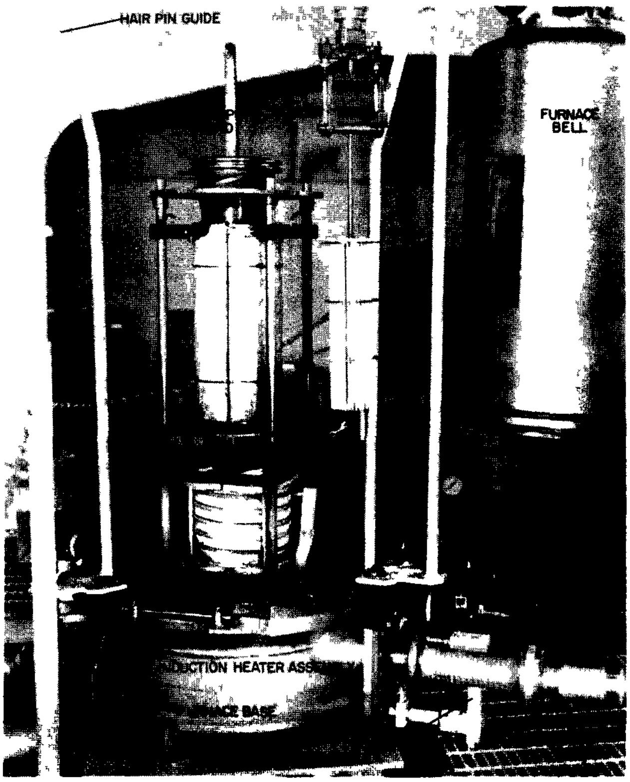

Figure 4. Injection-casting Furnace

Important furnace components are the base, bell, pan, crucible actuator, mold-support stand, and induction heater assembly. The furnace base and bell are made from $\frac{1}{2}$-in.-thick, low-carbon steel with an electroless nickel protective coat. The 28-in.-diameter bell is sealed to the base by an O-ring. An expandable metal ring holds the 2 parts together against casting pressures which can reach 90 psi before breaking the safety rupture disc. Three "hairpins" guide the bell into place and prevent damaging of the internal components during assembly.

The crucible actuator is a pneumatic cylinder which imparts a 10-in. vertical motion to the crucible. The furnace pan is used to position and support the mold stand with respect to the heater assembly. The mold-support stand aligns the molds vertically over the crucible.

A molybdenum induction coil heater assembly was used during most of the production run (see Figure 5). The coil is made from $\frac{3}{8}$-in.-diameter rod which has been wound to $7\frac{1}{2}$ turns with a 9-in. OD. The reflector shield, coil spacers, and coil fit into a Lava* cylinder supported on the top and bottom by re-enforced Lava plates. Four tie-rods through the plates fasten the assembly together. This heater assembly was used

*Aluminum Silicate - American Lava Company

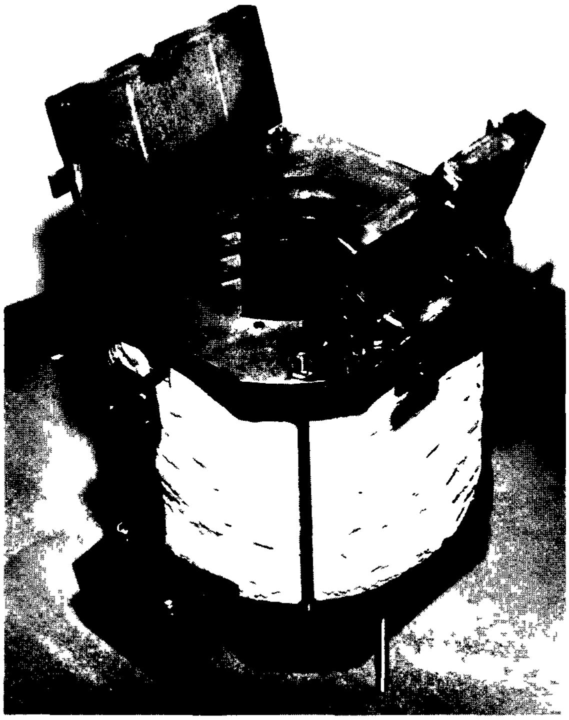

Figure 5. Molybdenum Induction Coil Heater

successfully to temperatures of 1340°C over 90 times before the support structure failed. The same coil was placed in a new form and is still being used.

The pumping system incorporates 2 Stokes Microvac-Model 148G mechanical pumps connected in parallel. The system is capable of maintaining a pressure of 50-70 μ. This is suitable because an inert atmosphere (argon gas) can be used during melting, and a partial vacuum is needed for only a short time prior to casting. Isolation of the furnace from its mechanical pumps is by means of pneumatically operated, solenoid-controlled, 2-in. gate-type vacuum valves. The exhaust from both pumps is discharged through Briggs filters and a ventilation duct to the atmosphere.

A 4-in.-diameter, 15-ft-long duct with six 90° bends connects the pumping system to the furnace. Connected to this duct is an accumulator tank with proper valving to prevent pressurizing the vacuum pumps. When the vacuum valves are closed, pressurized argon gas from the accumulator tank can be admitted to the furnace chamber through a 3-way, pneumatically operated, rotary plug valve. The flow rate is controlled by a parabolically characterized valve connected in series with the plug valve.

The volume of the accumulator tank is approximately the same as the furnace chamber so that the effective casting pressure can be easily determined from the tank pressure. Argon gas from commercial cylinders is used to fill the accumulator tank which is constantly kept at a positive pressure.

Molds

A casting longer than $15\frac{1}{2}$ in. is needed to make a 14.22-in. fuel pin, inasmuch as some defective material must be removed from each end. The top of the casting usually contains a small shrinkage pipes, while the gate end is generally too large. Molds for the production of pin castings are shown in Figure 6. They are made from precision-bore Vycor glass tubes. One end is pinched closed to form a vacuum-tight seal and provide

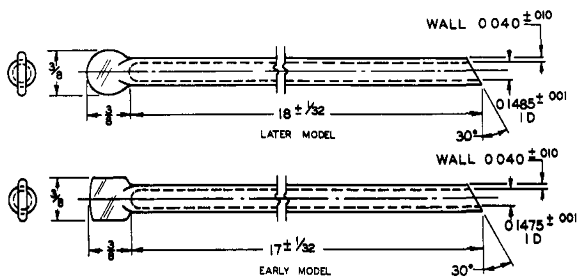

Figure 6. EBR-II Vycor Molds

a shoulder by which the mold is suspended in the pallet. The other end is open and cut on a 30° angle from the perpendicular cross section, to increase the entry area and furnish a point for penetration through the oxide crust on the metal bath.

A total of 12,500 molds, 17 in. long and 0.1475 ± 0.001 in. in ID were supplied at the beginning of the production run. Too many short or under-diameter castings were produced with these molds. A second group of 8000 larger molds, 18 in. long and 0.1480 ± 0.001 in. in ID were later ordered to increase the production yield. All molds were cleaned by the suppliers and individually wrapped for shipment. Approximately 10% of the molds were inspected, with an air gauge, for proper diameter. The per cent defective was usually less than one. Most defects occurred at the extreme ends of the molds.

The glass-metal contact area, which includes the cavity and the lower outside surface of the mold, was coated to minimize a glass-metal reaction and to improve the surface quality of the casting. A coating of 7-10-μ thoria powder in an alcohol suspension was swabbed into the mold bore with a 3-mm pipe cleaner. A $1\frac{1}{2}$-in. section of pipe cleaner attached to a $\frac{1}{8}$-in.-diameter by 19-in.-long rod was dipped into the mixed slurry and passed into the bore. This coating was allowed to air dry for several hours before the molds were placed in an oven and baked for 4-6 hr at 800°C. The bottom outside diameter of the molds was brushed with the same coating after the molds were placed in the furnace pallet.

Crucibles

The fuel alloy was melted in high-density graphite crucibles which were shaped like deep bowls. To prevent graphite-metal interactions, crucibles were sprayed with a water suspension of 95% thoria-5% zirconia powder (-325 mesh particle size). A single spray coat provided the necessary protection to temperatures above 1350°C. This coat also simplified the removal of the metal splashed on the crucible wall. Spraying and cleaning was done in a ventilated hood. The sprayed crucibles were allowed to air dry at room temperature before use. The crucible coating lasted for only one heat and was reapplied each time the crucible was used.

Charging

The charge to the injection furnace consisted of 5 w/o fissium alloy billets and heels. Billets were prepared from uranium biscuits, enriched uranium buttons, and pressed alloy powders in the melt-refining furnace.(1)

Heels are the excess metal remaining in the crucible after casting. A total of 85 virgin metal billets were used. An additional 47 billets were prepared from remeltable scrap generated in processing the castings.

Since heels accumulated faster than they could be recycled, some melts had to be made entirely from heels. The success of these melts was determined by the cleanliness of the metal and the amount of dross produced. A heavy dross impeded the flow of metal into the molds and occasionally prevented a mold from entering the metal bath.

A precasting operation was performed with the aid of a perforated crucible and mold to separate the dross (see Figure 7). This crucible served as a strainer. The molten metal dripped into the mold and the dross remained in the crucible. The billet produced was recharged directly into the casting furnace. Both the crucible and mold were sprayed with the thoria-zirconia coating previously described.

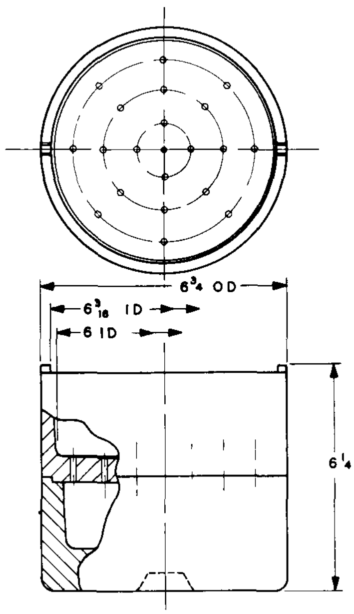

Figure 7. Perforated Crucible and Mold

The weight of alloy charged was between 11.5 to 12.5 kg per melt. Charges were calculated on the basis that 80.0 and 85.5 gm were required to fill the 17-in. and 18-in. mold, respectively. A minimum heel weight of 1500 gm was needed to submerge the gate ends of the molds. An additional 500 gm was usually added as a safety factor.

Mechanics of Melting and Casting

The crucible was supported on stabilized zirconia insulators atop the pedestal on the crucible actuator. The insulators were contoured to hold the crucible in the center of the induction coil. Crucible height was adjustable by screwing the pedestal up or down the actuator ram. The molds were positioned so that, with the crucible in the raised position, their gated ends came within $\frac{1}{16}$ in. of the crucible bottom. The height of the molds above the crucible bottom was critical for 2 reasons; (1) if the molds were too far from the bottom, gas could enter the mold cavity, a result of which was the production of castings which were either too short or formed of pellets; (2) if the molds were allowed to contact the crucible bottom, they would often be broken. A break near the bottom of a mold can result in a short or pelletized casting. A break near the top of a mold will cause it to fall into the molten metal heel.

The first operation in the preparation of a melt was to raise the actuator pedestal and place the coated graphite crucible on the insulators. The crucible was lowered into the induction heater assembly and the charge loaded into the crucible. The 2 counterbalance doors of the heater assembly were closed and the inductive load of the furnace coil balanced with the variable capacitance bank of the power supply.

The coated molds were loaded into the pallet and positioned in the support stand. The pallet handle was detached and the furnace bell was placed on the base. The vacuum pumps were opened to the furnace chamber and the bell locked in place with the clamping ring. Air was removed by alternately evacuating and purging with argon gas. A slight positive pressure of argon was maintained throughout the melting cycle to minimize inleakage. The furnace was evacuated just prior to casting, at which time the power to the coil was reduced to prevent arcing. As the pressure decreased, the power was increased until the casting temperature was again reached with the furnace pressure between 50 and 100 μ.

The casting cycle was initiated by closing the vacuum valves, turning off the power to the induction coil, and raising the crucible with the actuator. Furnace pressurization was delayed 4 sec by a timer. The delay allowed the submerged mold ends to preheat and the molten metal to become quiescent in the crucible. A second timer on the actuator controlled the time that the crucible was held in the raised position.

Two different ranges of holding time produced good castings: (1) between 12 and 14 sec, and (2) between 260 and 280 sec. The first required accurate control of casting temperature and produced rapid quenching of the metal in the molds. The second required an indication of phase transformations so that the crucible could be lowered when the heel was between the liquidus and solidus temperature.

When the shorter holding times were used, metal temperatures were measured with an optical pyrometer. Measurements were taken through a quartz sight glass and prism mounted on the furnace cover. Both the mold pallet and the heater-assembly top covers contained small central holes to permit sighting directly into the crucible.

A platinum-platinum-10 per cent rhodium immersion thermocouple was used for the method involving the longer holding times. It was contained in a coated graphite protection tube mounted in the mold pallet. When the crucible was raised, the thermocouple was immersed in the metal heel. The drop in heel temperature was observed on a high-speed recorder. A change in the cooling rate indicated the liquidus temperature of the alloy. The crucible was lowered while the heel was below the liquidus temperature (~1080°C) but above the solidus temperature (~1000°C).

The furnace was allowed to cool for at least 4 hr and usually overnight. It was then opened and disassembled in steps in reverse of the loading sequence. The gravid molds were taken from the furnace pallet and stripped by breaking the sealed end of the mold and sliding the casting out the top. No special attention was given to cleaning the castings. Each casting was given a visual examination and measured for length. The type of defects, which included pitted surfaces, shrinkage pipe, and hot tears, were recorded in the order of their importance on an inspection sheet. Figure 8 shows castings from a typical melt.

The crucible heel was cleaned of glass and thoria. If thin, it was broken with a hammer into 3 to 5 pieces. The larger heels were broken with a 250-ton press. The acceptable castings and broken heels were marked and stored in birdcages until needed. Rejected castings and recoverable scrap were returned to melt refining for consolidation.

Mold-cooling System

A forced-gas-cooling system was added to the furnace late in the production run to improve the uniformity of solidification and cooling. The system contained a turbo-blower to circulate gas from the accumulator tank through the mold pallet immediately after the molds were filled with molten metal. The effect of the cooling gas was to increase the solidification rate of the metal near the bottom of the molds where the normal rate was often too slow to give full-length castings.

The cooling system was especially important when the short-holding-time casting cycle was used. In this cycle the metal superheat was very critical. Metal cast too cold froze before it could fill the mold completely, and short castings resulted. Metal cast too hot was not solid when the crucible was lowered and dripped from the molds. This too could cause short castings. The range of suitable casting temperatures for a given pair of timer settings was very narrow, and small deviations significantly reduced casting yield. The major effect of mold cooling was to widen the range of suitable superheats and make casting yields less dependent on measurement of melt temperature.

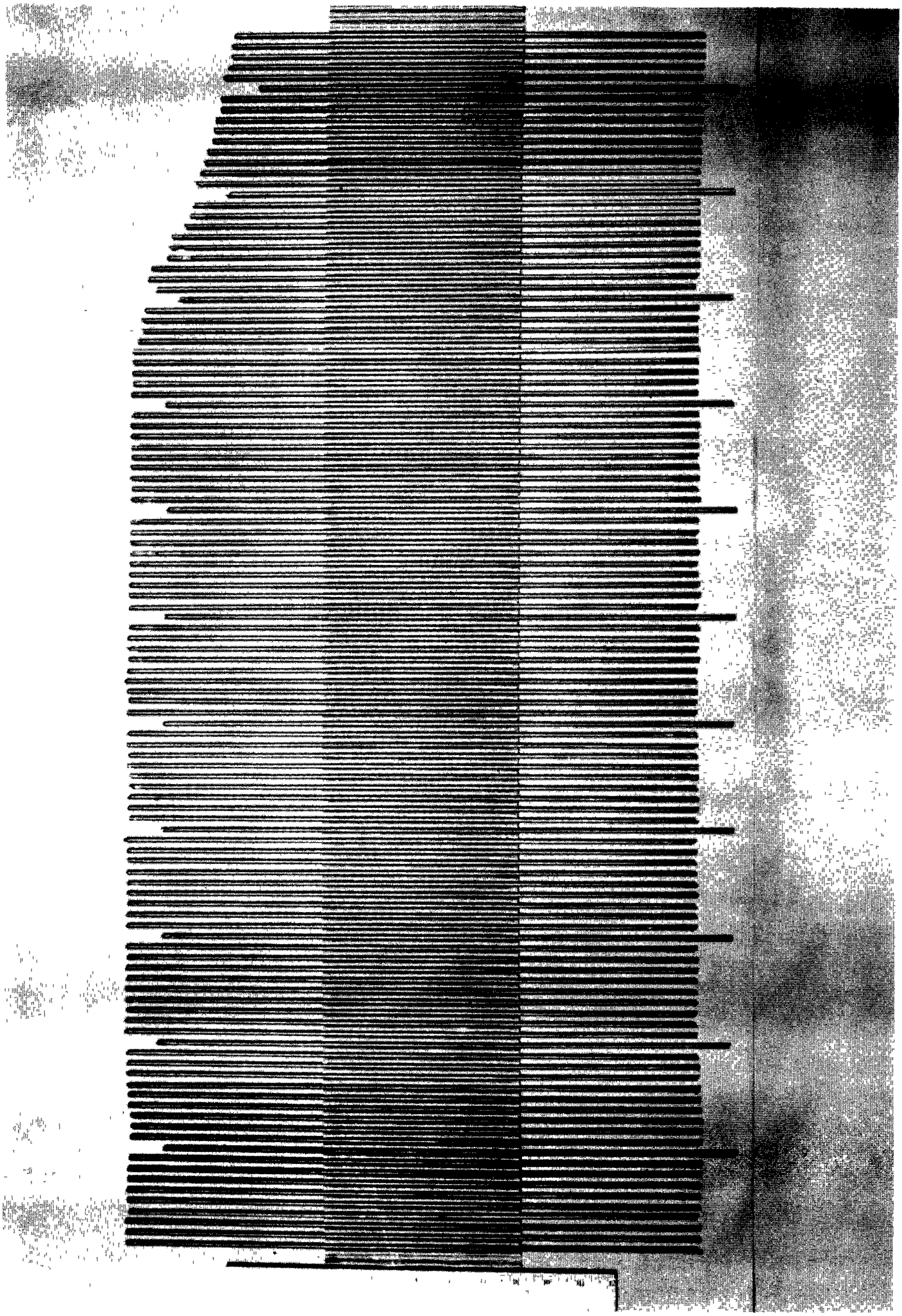

Figure 8. EBR-II Castings

FUEL PIN PROCESSING AND INSPECTION

Pin processing is that group of operations which make fuel pins from the product of the injection-casting furnace. Acceptable fuel pins are right cylinders, 0.144 ± 0.001 in. in diameter by 14.22 ± 0.03 in. long. They weigh between 65 and 70 gm, and vary in density from 17.9 to 18.2 gm/cc. Their surfaces must be suitable for sodium bonding. Slight internal porosity is acceptable, provided that (1) the cavities do not penetrate to the surface, (2) the maximum sized cavity is $\frac{1}{16}$ in. or less in diameter, (3) no cavity or cluster of cavities occupy more than $\frac{1}{4}$ of the area of any cross section, and (4) the weight of the pin is 65 gm or more.

Processing Equipment

The Core-I pin processing and inspection equipment was a developmental model of the integrated machine designed for hot-cell operation. Four complementary machines were grouped around a transfer table on a single 63$\frac{1}{2}$ x 66-in. base plate (see Figure 9).

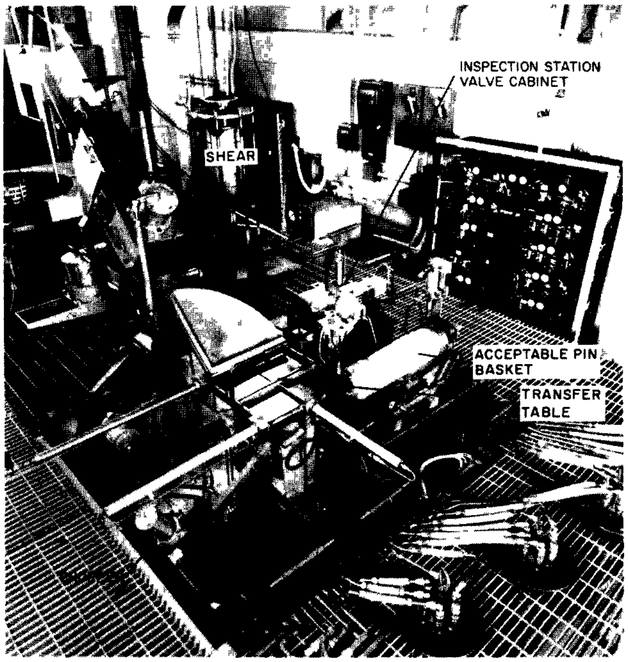

Figure 9. Model I Pin Processing Equipment

A pallet unloader, a demolder, and a shear constituted the first machine. These were mounted on a single 4-in. channel iron frame inclined at 45°. An inspection station, a basket for acceptable pins, and a chopper were located off the other 3 corners of the transfer table. The pallet unloader and demolder did not develop to a usable state in time to be used in the Core-I production run. All other equipment was operable remotely.

Remote processing started with shearing. The shear was a double-bladed, guillotine type in which the casting was positioned by a cylinder-operated shutter. A 4-in.-diameter, one-way cylinder drives down a hammer-bar that depresses both blades simultaneously, cutting out a section of casting nominally 14.22 in. long. The cropped ends, termed shards, drop through the bottom of the shear and are guided through the frame to a suitable receptacle. When the shutter is withdrawn, the fuel pin falls onto an inclined chute. As the pin falls, it rotates 90° about its lead end and drops onto the transfer table shuttle.

The pin is pushed from the transfer table shuttle into the inspection station by means of a drive cylinder mounted on the transfer table. After being inspected for diameter, internal quality, weight and length, the pin is returned to the transfer table shuttle. The shuttle is moved to the opposite end of the table where the pin, if acceptable, can be pushed into the pin basket. If the pin is not acceptable, the shuttle is tilted, causing the pin to slide into the chopper, where it is broken into remelt stock.

Inspection Equipment

All equipment necessary to measure the diameter, length, and weight of a fuel pin, and to indicate its internal quality, was mounted on a single machine called an inspection station (see Figure 10). Its frame was a welded, open steel box. The lower level had a set of guide ways which positioned a balance. The pan, which was installed after the balance was in place, extended above the top of the frame. It was enclosed on 3 sides by a V-shaped lifting bar capable of raising a pin from the balance pan into a spring-loaded, flat-anvil comparator used to measure length. The lifting bar and comparator, with their actuating and indicating devices, were supported on an L-shaped bracket atop the station. On the top left of the station was a cubical housing containing a ring jet and an eddy current flaw detection coil. The ring jet indicated pin diameter and the coil indicated pin diameter and the coil indicated internal quality.

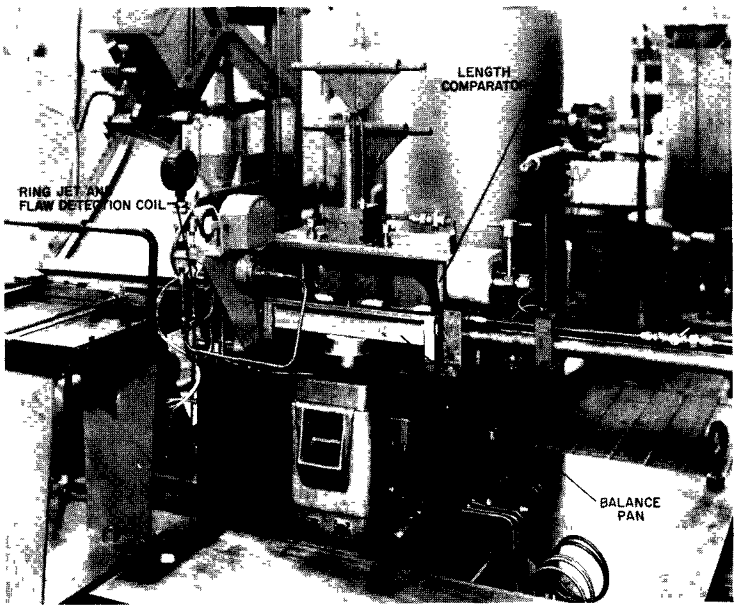

Figure 10. Inspection Station

Pins entering the inspection station passed through both the ring jet and the coil. Travel must be uniform and less than one inch per second to produce meaningful indications. To obtain uniformity at low speeds, the drive-to-inspection cylinder was replaced with a motor-driven screw feeder.

Fuel-pin-diameter Measurements

Measurements of fuel-pin diameter were made remotely by means of a 3-jet, ring-type air gauge. The ring jet was used with an adjustable orifice, a pressure regulator, and a pressure transducer. Changes in fuel-pin diameter were reflected as back pressure at the jets, which caused a change in flow through the orifice. This flow change produced a change in pressure downstream of the orifice that was sensed and converted to an electrical signal by the transducer. The signal was recorded as a continuous trace by one pen of a dual-channel recorder. The system was zeroed by means of 2 centerless-ground steel specimens whose diameter had been measured to the nearest 0.0001 in.

The average diameter of a fuel pin was obtained by visually averaging each trace using a specially designed tape reader. To test the accuracy of the overall technique for measuring the average diameter, a group of 54 fuel pins was taken from the process after their average diameters were measured. The volume of each pin was calculated from its weight in air and in carbon tetrachloride. The average diameter was calculated from the volume with the use of the measured length. The difference between measured and calculated diameters averaged less than 0.0001 in. with a standard deviation of approximately 0.0001 in.

Evaluation of Internal Quality

The internal quality of a fuel pin was evaluated by means of an eddy current flaw-detection coil mounted in the same fixture and coaxial with the ring jet. The coil, which was supported on a Lava coil form, measured $\frac{3}{16}$ in. in ID by $\frac{1}{8}$ in. long. It consisted of 5 layers of Formvar*-insulated AWG Size 40 wire. The coil was operated as part of a modified Owen bridge circuit developed by Renken, Myers, and McGonnagle (see Figure 11).[5] The operating frequency and circuit constants were selected to bring the test situation to a point on the impedance plane where internal and external flaws produced voltage changes of opposite polarity. These changes were modified, amplified, rectified, and indicated as a continuous trace on the second channel of a Sanborn recorder.

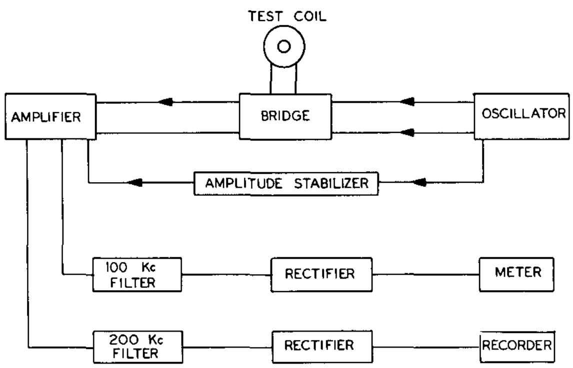

Figure 11. Block Diagram of Eddy Current Flaw Detector

The significance of traces was established by comparing them with negatives obtained by gamma radiography. It has not been possible to make the eddy current test quantitative. The test has been developed to a point, however, at which an experienced observer can recognize an unacceptable fuel pin from the trace.

*Formvar is a trade name owned by the General Electric Company.

Weight Measurements

Fuel-pin weight was measured by means of a Mettler, Type K7 balance adapted for remote weighing (see Figure 12). Adaptation consisted of adding a cylinder to lock and unlock the balance pan, and installing a linear differential transformer to indicate pan position. The armature of the transformer was hung from the counterbalance arm while the coil was attached to an adjustable fixture bolted to the balance case. The balance was zeroed by placing a pin of known weight on the pan and moving the transformer coil until the indication was correct.

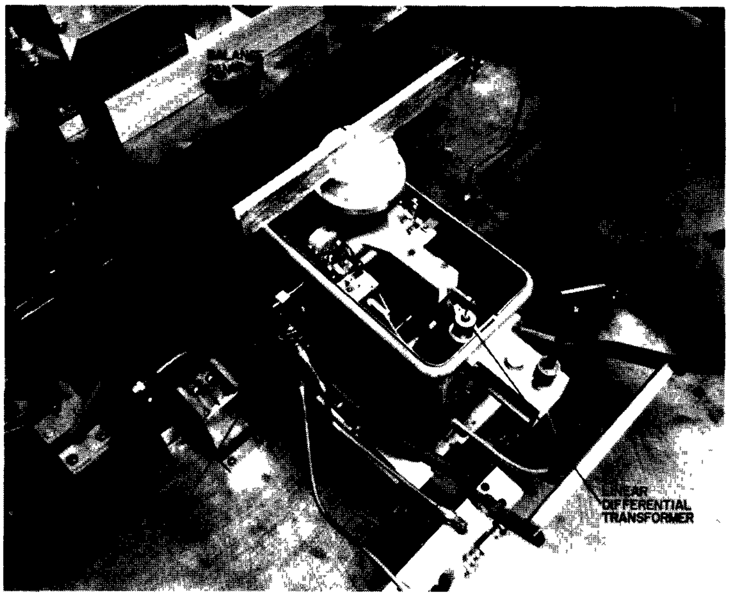

Figure 12. Remotely Operable Balance with Cover Removed

The performance of the remotely operable balance was checked by making comparison weighings. A portion of the fuel pins weighed remotely were also weighed by hand with a conventional Mettler, Type K7 balance and the weights compared. For the 2598 comparisons made, the error averaged 0.002 gm, with a standard deviation of 0.046 gm.

Length Measurements

Fuel-pin length was measured with the flat-anvil comparator above the balance pan. On entering the inspection station, the fuel pin passed through clearance holes in a U-shaped lifting bar and came to rest on the balance pan. After weighing, the pin was lifted onto the length gauge by raising the lifting bar pneumatically. The moveable anvil of the length gauge connected to the armature of a linear differential transformer. When a pin entered the gauge, the moveable anvil was forced back against its spring and its position signaled by the transformer. The electrical signal was indicated on a second channel of the Schaevitz indicator. The gauge was zeroed by means of a pin of known length.

Length-gauge performance was checked by a conventional comparator incorporating a dial indicator. Lengths obtained remotely were compared with those obtained conventionally. For 294 comparisons, the difference between remote and conventional measurement averaged 0.001 in. with a standard deviation of 0.003 in.

Auxiliary Equipment

The auxiliary pin-processing equipment, which was set up near the end of the run to increase the rate of production, consisted of conventional hand equipment. Castings were sheared using a Di-Acro Rod Parter and pins weighed on a conventional Mettler, Type K7, balance. The internal quality of a fuel pin was evaluated by cobalt radiography, and the length was measured using a dial-indicator comparator gauge. The diameter of a fuel pin was measured by means of an air gauge similar to the one described but mounted in the feeding device shown in Figure 13.

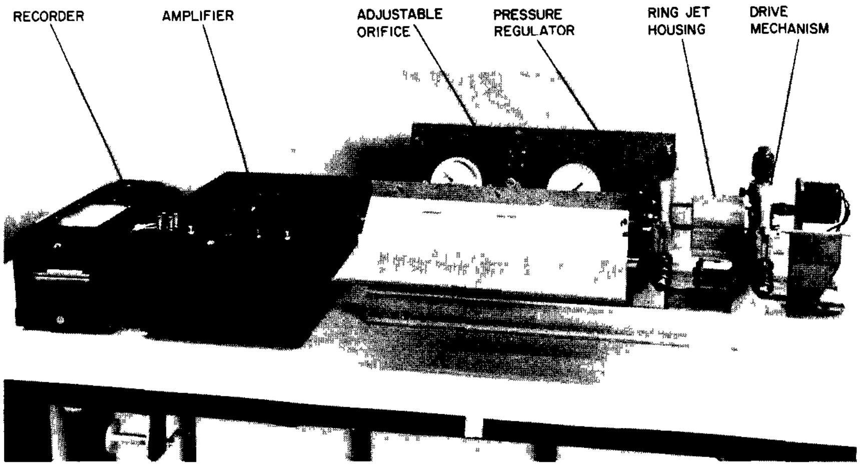

Figure 13. Air Gauge Feeding Device

RESULTS

A summary of production data by melts is given in Tables III and IV. From the 16,723 molds used, 12,296 acceptable castings were produced and 11,117 fuel pins were accepted for construction of fuel rods. The common causes of casting rejection and their frequency of occurrence are given in Table V. The frequency of fuel-pin defects appears in Table VI.

Table III

SUMMARY OF PRODUCTION OF EBR-II, CORE-I, SIMULATED(a) FUEL PINS

Melt No	Date Cast	Molds Loaded	Pins Processed	Date Processed	Pins Accepted	Cause for Rejection					Disposition	
						Improper Diameter	Improper Length	Poor Surface	Pipe	Unsoundness*	Canning	Other**
DL-15	9-30-59	120	60	10-19-59	48	1	0	7	1	3	28	22
DL-21	10- 5-59	90	61	10-28-59	60	1	0	0	0	0	60	0
DL-16	10- 7-59	96	81	10-31-59	54	1	1	25	0	0	54	0
DL-13	10- 9-59	100	86	11- 4-59	43	0	2	23	18	0	43	0
DL-30	10-13-59	100	69	11-18-59	62	0	1	5	1	0	62	0
DL-29	10-16-59	100	66	11-19-59	51	0	5	8	2	0	51	0
DL-25	10-21-59	120	101	12- 1-59	96	0	0	3	2	0	96	0
DL-18	10-26-59	120	41	12-11-59	34	1	3	3	0	0	34	0
DL-20	10-30-59	120	31	11-11-59	21	0	7	3	0	0	21	0
DL-18A	11-10-59	120	83	11-13-59	55	0	4	20	4	0	55	0
DL-31	11-17-59	120	40	12-12-59	32	2	2	3	1	0	32	0
DL-17	11-19-59	112	60	11-21-59	38	7	7	8	0	0	38	0
DL-19	11-21-59	110	31	12-11-59	16	0	4	11	0	0	16	0
DL-27	12- 1-59	70	23	12- 3-59	14	0	4	4	1	0	14	0
DL-12	12- 4-59	80	44	12-12-59	25	2	1	8	8	0	25	0
DL-5003	12- 8-59	120	59	12-22-59	39	0	6	12	2	0	39	0
DL-27A	12-11-59	120	62	12-16-59	46	4	5	6	1	0	46	0
DL-23	12-15-59	105	28	12-21-59	22	0	2	4	0	0	22	0
DL-26	12-22-59	110	55	1- 4-60	17	5	4	19	10	0	15	8
DL-2	12-28-59	110	76	1- 4-60	41	7	4	6	18	0	40	1
DL-1	12-30-59	105	43	1- 6-60	20	0	1	0	22	0	15	5
DL-3	1- 7-60	120	17	1-15-60	11	1	2	3	0	0	11	0
DL-8	1- 8-60	120	5	1-16-60	3	1	0	0	1	0	3	0
DL-5	1-11-60	110	12	1-16-60	7	1	2	1	1	0	7	0
DL-4	1-13-60	120	3	1-19-60	0	0	0	0	3	0	0	0
DL-9A	1-14-60	119	35	1-23-60	24	1	1	0	9	0	24	0
DL-14A	1-15-60	119	60	1-19-60	54	0	2	0	4	0	50	4
DL-11	1-16-60	118	76	1-19-60	67	0	3	0	6	0	67	0
DLP-401	1-18-60	119	71	1-26-60	54	0	7	0	10	0	54	0
DLP-502	1-19-60	110	24	1-26-60	11	0	2	0	11	0	11	1
DL-503	1-20-60	100	83	1-26-60	76	0	3	0	4	0	76	0
DL-11A	1-21-60	119	56	2- 1-60	48	0	7	0	1	0	36	12
DLP-407	1-22-60	112	62	1-30-60	48	0	11	1	2	0	48	0
DLP-508	1-23-60	113	80	2- 1-60	56	0	19	4	1	0	56	0
DLP-506	1-25-60	100	7	2- 1-60	6	0	1	0	0	0	6	0
DLP-409	1-26-60	99	95	1-29-60	86	0	7	0	2	0	86	0
DLP-510	1-27-60	100	74	1-30-60	68	0	3	2	1	0	68	0
DLP-404	1-28-60	119	114	2- 1-60	105	2	6	1	0	0	105	0
DLC-1989	1-29-60	119	94	2- 1-60	81	0	9	0	4	0	81	0
DLP-505	2- 1-60	119	93	2-11-60	79	2	11	1	0	0	79	0
DL-11A-1	2- 2-60	119	101	2-11-60	73	1	26	1	0	0	73	0
DLP-511	2- 3-60	119	99	2-17-60	84	0	12	0	3	0	84	0
DLP-412	2- 4-60	119	83	2-24-60	72	0	11	0	0	0	72	0
DLP-413	2- 5-60	119	74	2-25-60	61	0	12	1	0	0	61	0
DL-32	2- 8-60	118	101	2-18-60	93	0	8	0	0	0	93	0
DL-33	2- 9-60	119	77	2-27-60	71	0	4	0	2	0	71	0
DL-34	2-10-60	119	73	2-28-60	63	0	7	0	3	0	63	0
DL-35	2-11-60	119	69	3- 1-60	58	0	5	6	0	0	58	0
DL-37	2-13-60	119	77	3- 2-60	66	0	7	3	1	0	66	0
DL-38	2-15-60	119	80	3- 3-60	69	0	9	2	0	0	69	0
DL-39	2-16-60	119	83	3- 5-60	73	1	9	0	0	0	73	0
DL-41	2-18-60	118	83	2-26-60	76	0	7	0	0	0	76	0
DLP-514	2-19-60	118	71	3- 6-60	62	0	7	0	0	0	62	2(b)
DLP-515	2-23-60	119	46	3-11-60	41	0	1	0	0	0	41	4(b)
DL-41A	2-24-60	119	29	3- 8-60	21	0	2	0	0	0	21	6(b)
DLP-516A	3- 2-60	119	85	3-11-60	66	1	18	0	0	0	66	0
DLP-517	3- 3-60	110	89	3-16-60	62	3	24	0	0	0	62	0
DL-36	3- 5-60	120	88	3-14-60	62	0	21	0	0	0	62	5(b)
DLP-518	3-19-60	174	64	3-23-60	54	1	9	0	0	0	54	0
	Total	6,708	3,733		2,945	46	358	204	160	3	2,901	70

(a)Natural uranium

(b)Removed from process prior to inspection

*Rejection based on X-ray and visual observations

**Includes accepted and rejected castings used as process standards and experimental specimens

Table IV

SUMMARY OF PRODUCTION OF EBR-II, CORE-I, ENRICHED FUEL PINS

Melt No.	Date Cast	Molds Loaded	Pins Processed	Date Processed	Pins Accepted	Cause for Rejection					Disposition	
						Improper Diameter	Improper Length	Poor Surface	Pipe	Unsoundness*	Canning	Other**
EBR-1	4- 4-60	100	34	4-13-60	24	0	2	0	4	4	24	0
2	4- 6-60	95	33	4-19-60	27	0	5	0	1	0	27	0
7	4- 7-60	90	67	4- 8-60	65	0	1	0	1	0	65	0
3	4- 9-60	119	69	4-14-60	43	0	18	0	7	1	43	0
4	4-12-60	119	80	-	0	0	0	0	0	0	0	80[(a)]
5	4-14-60	119	103	6- 9-60	80	3	1	12	4	3	70	10
6	4-18-60	119	91	4-22-60	72	0	11	1	7	0	72	0
9	4-30-60	119	73	5- 3-60	58	0	10	0	0	5	58	0
9A	5- 4-60	119	95	5- 6-60	81	0	13	1	0	0	81	0
10	5- 5-60	119	80	5- 9-60	56	0	13	1	6	4	56	0
11	5- 6-60	119	106	5-12-60	93	1	3	0	7	2	93	0
12	5- 9-60	120	108	5-18-60	104	0	3	0	0	1	104	0
13	5- 9-60	110	72	7-11-60	70	0	1	0	0	1	70	0
14	5-10-60	120	105	5-12-60	83	0	2	0	4	16	83	0
15	5-11-60	120	81	5-16-60	79	0	1	0	1	0	79	0
16	5-12-60	119	92	6- 7-60	78	2	2	0	6	4	78	0
17	5-12-60	120	102	5-20-60	90	0	3	0	8	1	90	0
18	5-13-60	119	97	5-23-60	92	1	1	0	1	2	92	1
19	5-16-60	110	97	6-10-60	84	0	3	0	3	7	84	0
19A	5-17-60	120	58	6- 9-60	53	1	0	1	3	0	53	0
20	5-17-60	119	60	5-19-60	52	0	2	0	2	4	52	0
21	5-18-60	111	108	8-19-60	105	0	0	0	3	0	105	3
22	5-19-60	115	103	6-14-60	100	0	1	0	0	2	100	0
23	5-20-60	115	106	5-25-60	87	0	2	0	5	12	87	1
24	5-23-60	119	112	5-26-60	104	0	0	1	1	6	104	0
25	5-24-60	120	76	5-26-60	57	0	1	0	18	0	57	2
26	5-24-60	119	104	6- 2-60	99	0	0	0	5	0	99	0
27	5-25-60	120	96	6- 8-60	73	0	0	0	23	0	73	0
28	5-26-60	119	102	6- 1-60	87	0	0	1	14	0	87	0
29	5-26-60	119	95	6- 2-60	84	0	1	0	10	0	84	0
8	5-27-60	120	96	6- 6-60	84	0	2	0	8	2	84	0
31	6- 8-60	119	89	6-16-60	85	0	1	0	3	0	85	0
32	6- 9-60	120	86	6-13-60	84	1	0	0	1	0	84	0
33	6- 9-60	120	89	6-17-60	79	4	3	0	3	0	79	0
34	6-10-60	119	93	6-21-60	88	3	2	0	0	0	88	0
35	6-13-60	119	87	7- 5-60	82	0	1	0	4	0	82	0
36	6-14-60	120	92	7- 8-60	87	0	0	0	4	1	87	0
37	6-14-60	120	104	7- 6-60	95	4	3	0	2	0	95	0
38	6-15-60	120	98	6-23-60	96	0	0	0	2	0	96	0
39	6-16-60	120	98	6-24-60	95	2	0	0	1	0	95	0
40	6-17-60	120	91	6-28-60	89	1	0	0	1	0	89	0
41	6-17-60	120	102	7- 7-60	99	0	1	0	2	0	99	0
30	6-20-60	120	71	6-28-60	69	0	2	0	0	0	69	0
38A	6-21-60	120	80	6-29-60	78	0	0	0	2	0	78	0
42	6-21-60	120	95	6-30-60	92	2	0	0	1	0	92	0
43	6-23-60	120	88	7-12-60	86	0	2	0	0	0	86	0
44	7-11-60	120	100	7-14-60	97	0	1	1	1	0	97	0
45	7-12-60	120	99	7-14-60	99	0	0	0	0	0	99	0
22A	7-13-60	120	81	7-15-60	79	0	0	1	0	1	79	0
46	7-14-60	120	78	7-18-60	78	0	0	0	0	0	78	0
47	7-15-60	120	94	7-20-60	91	0	1	0	2	0	91	0
48	7-18-60	120	95	7-21-60	86	0	1	0	2	6	86	0
47A	7-19-60	120	102	7-22-60	99	0	1	0	2	0	99	0
49	7-20-60	120	83	7-25-60	79	0	2	0	1	1	79	0
50	7-21-60	120	90	7-26-60	87	0	1	1	0	1	87	0
51	7-22-60	120	95	7-27-60	90	0	2	0	1	2	90	0
52	7-25-60	120	102	7-28-60	90	0	4	0	7	1	90	0
53	7-26-60	120	87	7-29-60	72	0	0	0	13	2	72	0
54	7-27-60	120	105	8- 1-60	80	0	4	0	19	2	80	0
56	7-28-60	120	101	8- 3-60	93	0	2	0	6	0	93	0
57	7-29-60	120	84	8- 3-60	73	0	2	0	8	1	73	0
58	8- 1-60	130	101	8- 5-60	100	0	1	0	0	0	100	0
59	8- 2-60	134	100	8- 8-60	98	0	0	1	1	0	98	0
60	8- 3-60	134	32	8- 8-60	31	1	0	0	0	0	31	0
61	8- 4-60	116	16	8- 8-60	13	1	1	0	0	1	13	0
62	8- 5-60	120	88	8- 9-60	77	0	0	0	10	1	77	0
63	8- 8-60	120	101	8-10-60	90	2	0	0	6	3	90	0
50A	8- 9-60	120	80	8-10-60	69	5	4	2	0	0	69	0
64	8- 9-60	120	55	8-10-60	50	0	0	0	5	0	50	0
65	8-10-60	115	102	8-11-60	98	0	1	0	2	1	98	0
64A	8-11-60	120	12	8-15-60	8	4	0	0	0	0	8	0
66	8-11-60	118	91	8-15-60	85	3	0	0	3	0	85	0

Table IV (Cont'd.)

Melt No	Date Cast	Molds Loaded	Pins Processed	Date Processed	Pins Accepted	Cause for Rejection					Disposition	
						Improper Diameter	Improper Length	Poor Surface	Pipe	Unsoundness*	Canning	Other**
EBR-67	8-12-60	118	100	8-15-60	90	7	3	0	0	0	90	0
68	8-13-60	118	98	8-16-60	96	0	1	0	1	0	96	0
69	8-15-60	118	101	8-16-60	100	0	0	0	0	1	100	0
70	8-16-60	118	26	8-17-60	26	0	0	0	0	0	26	0
71	8-16-60	118	88	8-18-60	87	0	0	0	1	0	87	0
67A	8-17-60	118	83	8-18-60	79	0	2	0	0	2	79	0
72	8-18-60	118	93	8-22-60	89	0	0	2	1	1	89	0
73	8-18-60	118	90	8-23-60	88	0	0	0	0	1	88	0
74	8-19-60	118	94	8-23-60	94	0	0	0	0	0	94	0
75	8-22-60	118	86	8-24-60	84	0	1	0	1	0	84	0
76	8-23-60	118	76	8-25-60	76	0	0	0	0	0	76	0
71A	8-23-60	118	64	8-25-60	64	0	0	0	0	0	64	0
77	8-24-60	118	106	8-25-60	102	0	1	0	3	0	102	0
78	8-25-60	118	103	8-26-60	92	2	5	0	3	1	92	0
79	8-26-60	118	65	8-30-60	55	9	0	0	1	0	55	0
76A	8-29-60	118	11	8-31-60	8	2	1	0	0	0	8	0
80	8-30-60	117	109	8-31-60	93	0	5	0	1	10	93	0
81	8-30-60	119	109	9- 1-60	99	0	3	1	0	6	99	0
82	8-31-60	117	46	9- 1-60	45	0	1	0	0	0	45	0
50B	9- 1-60	10	3	9- 6-60	0	0	0	0	0	3	0	0
55	9- 1-60	118	93	9- 6-60	87	2	1	0	2	1	87	0
83	9- 2-60	117	105	9- 6-60	76	1	3	3	13	9	76	0
84	9- 6-60	117	109	9- 7-60	105	0	1	0	1	2	105	0
85	9- 6-60	117	105	9- 8-60	92	0	1	5	1	6	92	0
86	9 7-60	118	86	9- 8-60	81	0	1	1	3	0	81	0
87	9- 8-60	118	104	9- 9-60	98	1	1	4	0	0	98	0
88	9- 8-60	118	113	9-12-60	92	0	5	0	3	13	92	0
89	9- 9-60	117	68	9-13-60	66	0	0	0	1	1	66	0
90	9-12-60	118	97	9-13-60	90	0	0	0	1	6	90	0
91	9-13-60	117	112	9-14-60	105	0	0	1	1	5	105	0
92	9-13-60	117	102	9-15-60	93	0	1	1	2	5	93	0
93	9-15-60	118	88	9-15-60	79	0	0	1	0	8	79	0
94	9-16-60	117	105	9-20-60	94	0	0	1	3	7	94	0
95	9-19-60	120	85	9-20-60	75	4	4	0	0	2	75	0
87B	9-20-60	10	7	9-20-60	5	0	0	0	0	2	5	0
97	9-20-60	120	101	9-22-60	85	0	0	6	2	8	85	0
98	9-21-60	120	107	9-22-60	105	0	0	2	0	0	105	0
99	9-22-60	120	94	9-26-60	84	0	1	3	0	6	84	0
100	9-22-60	120	101	9-29-60	82	0	4	0	0	15	82	0
101	9-26-60	120	109	9-30-60	83	3	1	1	0	21	83	0
102	9-27-60	120	88	10- 4-60	77	0	1	2	0	8	77	0
103	10- 3-60	120	109	10- 5-60	102	0	1	3	0	3	102	0
104	10- 5-60	120	58	10- 6-60	53	0	3	2	0	0	53	0
105	10- 4-60	120	53	10- 7-60	51	1	0	1	0	0	51	0
106	10- 6-60	120	101	10-10-60	91	0	2	4	3	1	91	0
107	10- 7-60	120	117	10-11-60	111	0	0	2	0	3	111	0
108	10-10-60	120	95	10-12-60	90	0	0	4	1	0	90	0
109	11-18-60	120	117	11-21-60	116	0	1	0	0	0	116	0
110	11-21-60	120	99	11-23-60	97	0	0	0	0	2	97	0
111	11-23-60	120	101	11-25-60	100	0	1	0	0	0	100	0
112	11-25-60	120	94	12- 2-60	87	0	4	3	0	0	87	0
113	12- 5-60	120	99	12- 8-60	97	0	0	0	1	1	97	0
114	12- 6-60	120	50	12- 8-60	46	0	3	1	0	0	46	0
115	12- 7-60	120	93	12- 9-60	88	0	5	0	0	0	88	0
116	12- 8-60	120	54	12-13-60	51	2	0	0	0	1	51	0
79AA	12-20-60	120	92	12-22-60	81	0	9	0	1	1	81	0
117	12-21-60	120	21	1- 3-61	20	0	1	0	0	0	20	0
118	12-29-60	120	39	1- 4-61	37	0	2	0	0	0	37	0
119	1- 3-61	120	68	1- 6-61	65	0	1	0	0	2	65	0
120	1- 4-61	120	65	1- 5-61	32	0	4	2	1	26	32	0
121	1- 5-61	120	81	1- 8-61	64	0	4	0	0	13	64	0
122	1-10-61	120	87	1-12-61	84	0	1	0	0	2	84	0
123	1-11-61	120	79	1-13-61	75	0	1	0	1	2	75	0
96	9-20-60	120	69	11- 4-60	56	0	8	3	2	0	56	0
124	1-13-61	110	90	1-16-61	89	0	0	0	0	1	89	0
125	1-18-61	90	71	1-19-61	71	0	0	0	0	0	71	0
126	1-19-61	120	115	1-20-61	103	1	2	5	2	2	103	0
128	1-30-61	120	95	1-31-61	84	0	1	2	8	0	84	0
129	1-31-61	120	102	2- 1-61	97	0	0	0	5	0	97	0
130	2- 1-61	120	105	2- 3-61	94	1	4	0	4	2	94	0
131	2- 7-61	120	109	2- 9-61	84	0	2	3	13	7	84	0
		16,723	12,296		11,117	77	254	93	355	320	11,107	97

*Rejection based on X-ray and visual observations

**Includes accepted and rejected castings used as process standards and experimental specimens

(a) Removed from process prior to inspection

Table V

FREQUENCY OF OCCURRENCE OF CASTING DEFECTS

Type of Defect	Occurrence[a] (%)
Hot Tears	4.30
Drip Back	10.88
Bad Surface	0.01
Short Castings	9.47
No Casting in Molds	1.48
Miscellaneous	0.18

[a]The occurrence was obtained by dividing the defects by the total number of molds and multiplying by 100.

Table VI

FREQUENCY OF OCCURRENCE OF OF FUEL-PIN DEFECTS

Type of Defect	Occurrence[a] (%)
Pipe	3.2
Unsoundness	2.0
Improper Length	3.8
Poor Surface	1.8
Undersize Diameter	.08
Other[b]	.05

[a]Number of pins having given defect divided by total castings processed times 100.

[b]Oxidized in experimental heat treatment.

An overall materials balance is given in Table VII. Of the total weight of fuel alloy produced, 84.5% was made into acceptable fuel pins. Only 8.9% was lost in the process as alloy-preparation residues, drosses, and samples. The excess billets and castings will be used in future production or directly in hot-cell operations.

Table VII

FUEL PIN MANUFACTURING MATERIALS BALANCE

Item	Weight (kg)	Item	Weight (kg)
Uranium	850 9	Acceptable Fuel Pins	756 8
Molybdenum	22 0	Consolidation Losses	58 7
Ruthenium	17.6	Injection-casting Residue	18.2
Rhodium	2 5	Samples	2 6
Palladium	1 7	Excess Billets and Castings	59.4
Zirconium	0 9	Total Product	895 7
Niobium	0 1		
Total Raw Material	895 7		

Complete production data is given in Appendices A and B. Since these appendices are bulky, they are issued separately with a more restricted distribution, as shown in Table VIII.

Table VIII

APPENDICES AND DISTRIBUTION

Appendix	Titles	Distribution
A-1	Summary of Calculated Compositions and Analysis	Programs 7 103/7.10.6 (1) ANL R E Macherey (1) ANL
A-2	Charge Calculations and Analysis	A. B. Shuck (1) ANL H Kittel (1) ANL
A-3	Furnace Operation Data	H Jelinek/N. Carson (1) ANL L. J. Koch (1) ANL
A-4	Casting Description Data	Project Files 733 (1) ANL W. Loewenstein (1) ANL
B, Vol I	Fuel Pin Inspection	H. O. Monson (1) ANL M. Novick (2) Idaho
B, Vol II	Fuel Pin Inspection	C. E. Stevenson (1) Idaho S. Lawroski/M. Levenson (1) ANL
B, Vol III	Fuel Pin Inspection	L. K. Hurst (1) ANL

DISCUSSION

A problem which arose during the manufacture of fuel pins was the achievement of structural uniformity within and between castings. Because of irregular cooling, some castings were predominantly of the alpha phase while others were predominantly gamma. The metastable gamma phase differs in density from the alpha phase.(6) Therefore, fuel pins containing retained gamma tend to shrink when they are heated. Since fuel rods are bonded at 525°C, shrinkage can occur during bonding. This results in fuel pins with low sodium levels.

The investigation of fuel-pin shrinkage proceeded along two lines: (1) the volume of 50 pins was measured by an immersion weighing technique before and after bonding, and (2) length measurements were made of a group of short-length pins before and after a high-alpha heat treatment. Data obtained from the 50-pin control group showed a diameter change of 0.0003 in. with a standard deviation of 0.0001 in. Although these figures are small, they should be viewed with the knowledge that a 0.00025-in.-diameter change causes a 0.06-in. change in sodium level (assuming a constant length). The results of the second investigation showed: (1) there was a significant change in fuel-pin volume during bonding, (2) the degree of change varied from pin to pin, and (3) the degree of change varied between sections of the same pin.

The first corrective attempt was to give the pins an alpha heat treatment prior to inspection. This did achieve dimensional stability, but it also increased the pin hardness to 55 Rc equivalent. The hardened pin was susceptible to secondary cracking during shearing and reduced the life of the shear blades.

Installation of a forced-gas-cooling system into the furnace was the second corrective measure. This did not eliminate shrinkage, but it led to a more reliable and uniform shrinkage. The volume of 55 fuel pins made from forced-cooled castings were measured by immersion. These pins were then heat treated at 500°C for 1 hr and their volumes remeasured. This group showed an average diameter decrease of 0.0003 in. which was not appreciably different. However, the standard deviation of this change was only 4.7×10^{5} in., which is less than half of the standard deviation of the first group. This meant that a more uniform casting structure was obtained with forced-gas cooling.

LABOR

The 12,296 acceptable castings and 11,117 acceptable fuel pins were produced over a period of 11 months. This production required 2 supervisors and 6 technicians full time. The labor per 100 acceptable castings comprised 17.3 man hours of supervision, 3.3 specialized man hours, and 20.1 man hours of technicians. The labor per 100 acceptable fuel pins was 19.1 man hours of supervision, 3.6 specialized man hours, and 79.6 man hours of technicians. In the last category, 18.4 man hours were required to process recorded data.

The monthly production rates are plotted in Figure 14. The furnace and pin-processing operation reached a maximum rate during August and September, when 9000 pins were cast and processed. During this period, one melt was made per day with a 6-day work week.

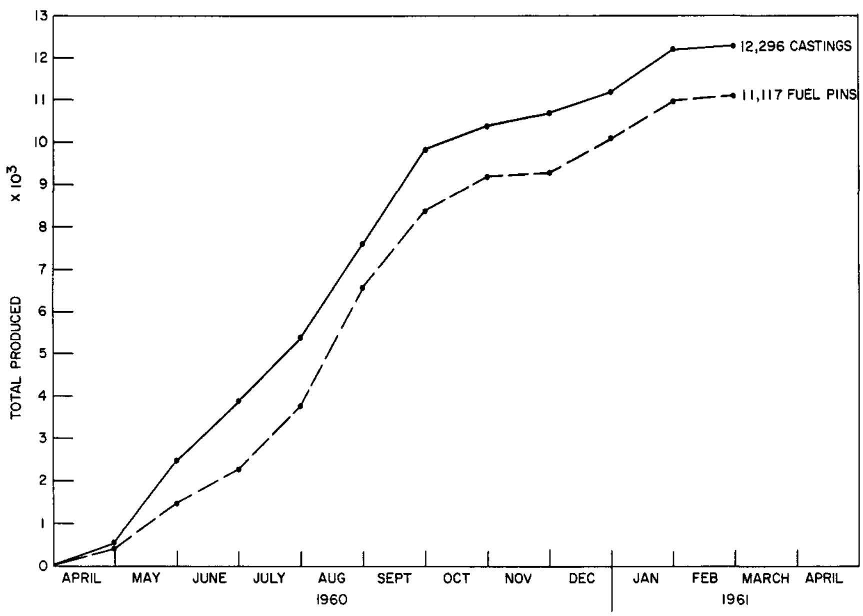

Figure 14. Production Rate of EBR-II Castings and Fuel Pins

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REFERENCES

1. Hampson, D. C., Preparation of Alloy for First Core Loading of EBR-II, ANL-6290 (Aug 1961).

2. Carson, N. J., Olp, R. H., Jelinek, H. F., Grant, N. R., Walker, D. E., Hessler, N. F., and Shuck, A. B., Fabrication of EBR-II Core I Fuel Elements, ANL-6276 (to be published).

3. Shuck, A. B., Ayer, J. E., Cameron, T. C., Carson, N. J., Grunwald, A. P., Jelinek, H. F., Olp, R. H., and Stone, C., Development of Methods and Equipment for Production of EBR-II Fuel Rods, ANL-6272 (to be published).

4. Ayer, J. E., and Shuck, A. B., The Design and Construction of the EBR-II Initial Fuel Loading Facility, ANL-6092 (June 1961).

5. Renken, C. J., Myers, R. G., and McGonnagle, W. J., Status Report in Eddy Current Theory and Application, ANL-5861 (Nov 1958).

6. Zegler, S. T., and Nevitt, M. V., Structure and Properties of Uranium-Fissium Alloy, ANL-6116 (July 1961).