ANL-6550
Metals, Ceramics,
and Materials
(TID-4500, 24th Ed.)
AEC Research and
Development Report

ARGONNE NATIONAL LABORATORY
9700 South Cass Avenue
Argonne, Illinois 60440

THE MANUFACTURE OF SUPPLEMENTAL DEPLETED FUEL RODS FOR FCF STARTUP

by

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

Metallurgy Division

Program 7.10.13

September 1963

Operated by The University of Chicago
under
Contract W-31-109-eng-38
with the
U. S. Atomic Energy Commission

DISCLAIMER

TABLE OF CONTENTS

LIST OF FIGURES

THE MANUFACTURE OF SUPPLEMENTAL DEPLETED FUEL RODS FOR FCF STARTUP

by

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

ABSTRACT

Approximately 2000 supplemental rods were made for use in EBR-II Fuel Cycle Facility startup tests. They were made in the same manner as Core-I fuel rods but using partially depleted pins instead of fuel pins. For production details the reader is referred to the publications covering Core-I production.[1,2]

A "duplex" or double melting operation was used for Core-I production. The alloys were first melted together and cast in an ingot mold. The ingot was then remelted and injection cast to produce fuel pins. In order to simplify the operation, a single melt, or "simplex" operation, alloying and injection casting in one step was tried. This operation was unsatisfactory because of uncontrollable gas evolution from the ingredients of the charge. The interior parts of the furnace became coated with condensed metal to an extent that threatened mechanical and electrical failure of the furnace.

A thermocouple head was developed for use in the injection casting furnace. It had increased accuracy and reliability, and was more easily remotely replaced. The improvememts were due to unit construction and improved cold-junction contacts.

A statistical analysis was made of a sample of 412 rods. The analysis produced (1) an equation for predicting sodium levels through the selection of sodium loads, and (2) evidence that jacket-preassembly classification is necessary under existing specifications for sodium level.

INTRODUCTION

The purposes of this work were: (1) to manufacture supplemental rods for EBR-II Fuel Cycle Facility startup tests, (2) to determine the feasibility of alloying and injection casting in a simplex operation, (3) to improve crucible temperature measurements, and (4) to study statistically the effect of pin and jacket dimensions on sodium-level height. A total of 2007 rods, 449 pins, and 430 gravid molds[a] were produced. The production techniques were those used during Core-I manufacture and are reported in ANL-6274[1] and ANL-6276.[2] Quality control was less rigid since the supplemental material was not intended for reactor use.

The typical EBR-II fuel rod, shown in Figure 1, differed from a supplemental rod only in the composition of its fuel pin. Each fuel rod contained an enriched uranium-5 w/o fissium alloy pin whereas each supplemental rod contained a partially depleted uranium-5 w/o fissium alloy pin. In most cases the pin alloy was prepared in a separate furnace; however, some alloying was done in the injection casting furnace.

Representative process data covering Core-I production was given in the publications and will not be repeated here. Complementary data is presented in the discussion section.

PIN MANUFACTURE

The sequence of operations comprising pin manufacturing are illustrated in Figure 2. The major operations were casting, shearing, and inspection. Manufacturing took place in a special facility described in ANL-6092.[3]

Injection Casting

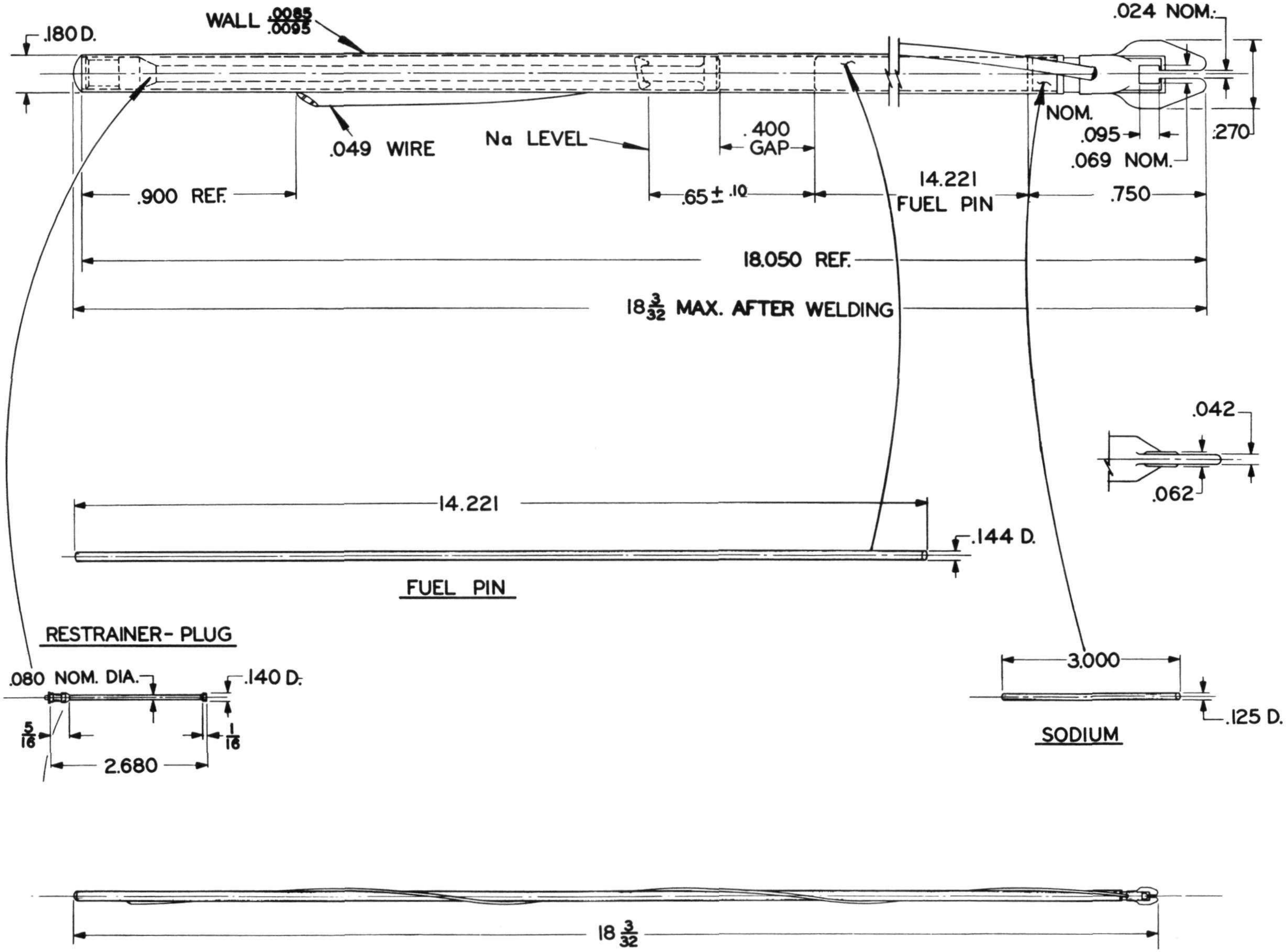
The fuel-fabrication process is based on the injection casting operation. Tubular Vycor[b] molds, closed at one end, were hung open end down over the crucible. The charge was melted by induction heating in a coated graphite crucible. Injection casting consisted of raising the crucible to submerge the open mold ends and changing the furnace atmosphere from a vacuum to a positive pressure. The furnace is shown in Figure 3.

Besides the graphite crucible, which was reusable, the main supplies for the casting operation were: (1) the simulated fuel alloy, and (2) the precision-bore Vycor molds. The crucible was coated by hand with a mixture of thoria and zirconia powders suspended in alcohol, oven dried at 150°C, and placed in the casting furnace. The billet or alloy metals were weighed and charged with sufficient remelt material (remelt crucible heels) to fill approximately 120 molds and leave a $\frac{1}{4}$- to $\frac{3}{8}$-in.-thick heel. The Vycor molds of 0.1475-in., ID and 17-in. length, were inspected and coated with a suspension of 5- to 10-μ thoria powder in alcohol.

---

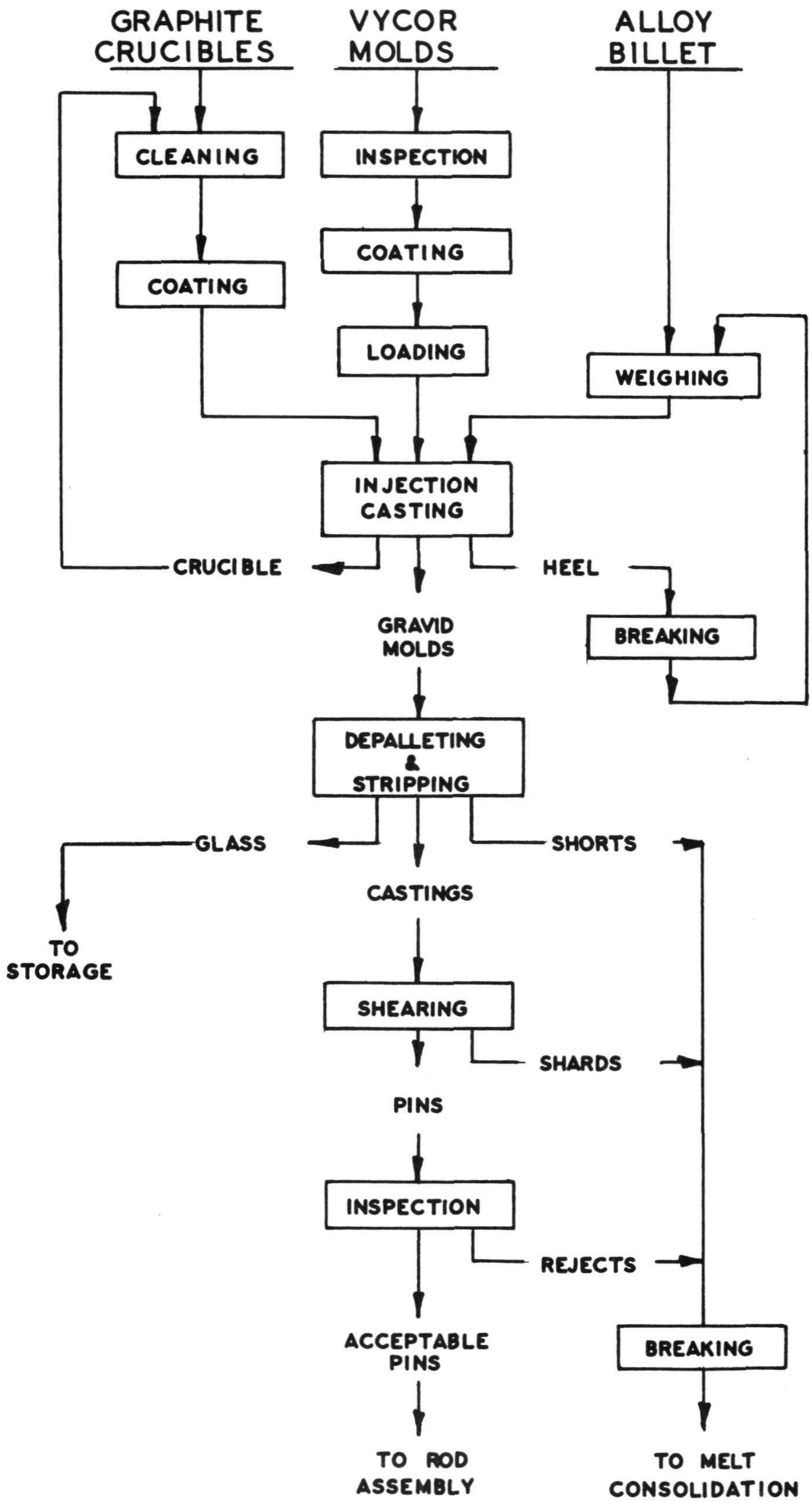
[a]A gravid mold is one which contains a casting.

[b]Vycor is a trade name for high-silica glass from Corning Glass Works.



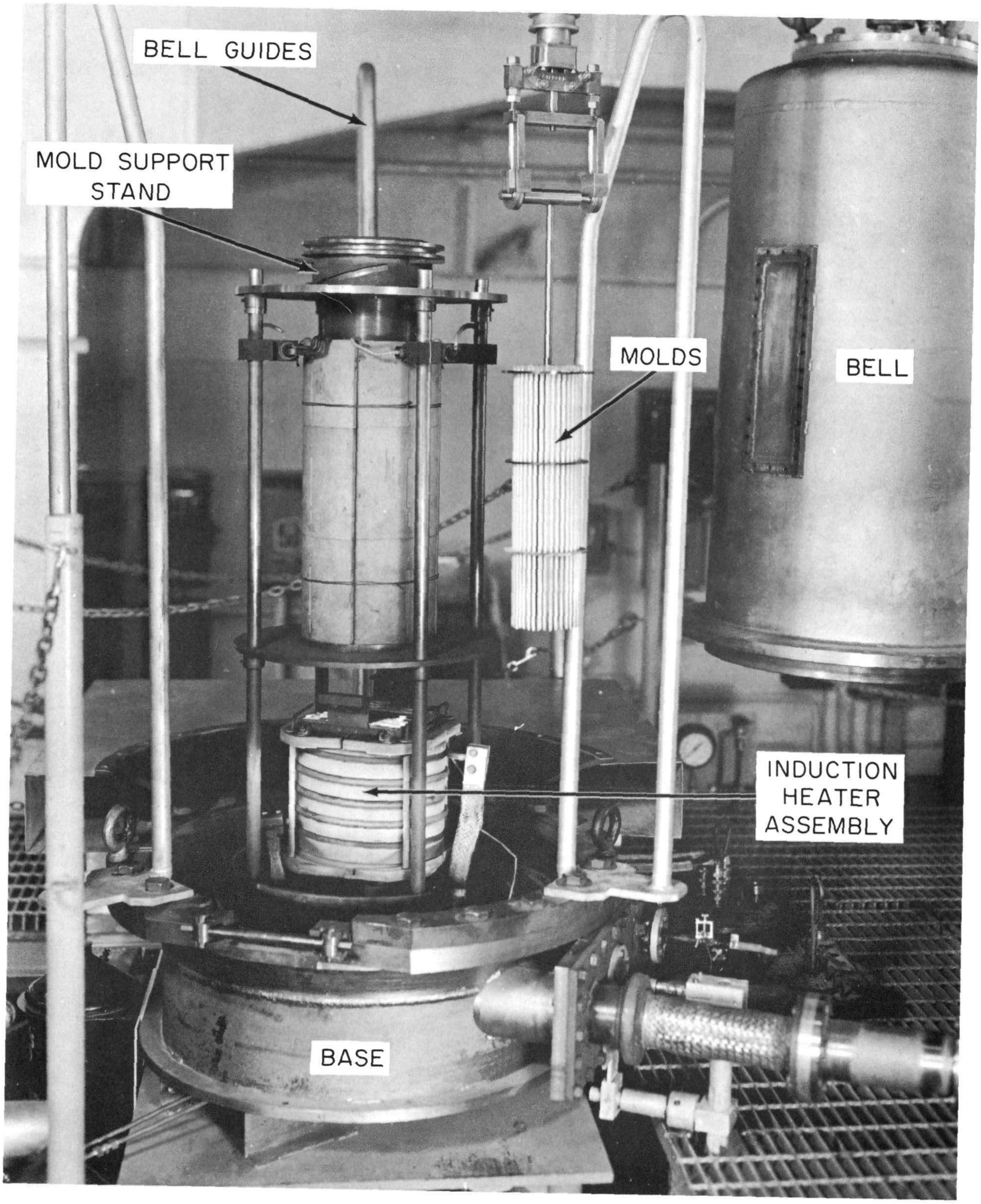
106-6618

Figure 1. EBR-II Fuel Rod (dimensions in in.)



106-7129

Figure 2. Operations Comprising Pin Manufacture



106-4827-B

Figure 3. Injection Casting Furnace with Bell Removed

Molds were dried at 600°C for 6 hr and placed in a supporting jig known as "the furnace pallet." The exact number of molds loaded was adjusted to the charge weight. The pallet was hung in the mold support stand and the furnace bell put in place.

The charge was heated to 1300°C in an atmosphere of argon gas at a slightly positive pressure. The furnace was then evacuated to less than 70μ and the temperature increased to 1340°C. The crucible was next raised to immerse the ends of the Vycor molds in the melt, and the furnace pressure was increased to 27 psia in order to cast. After a 14-sec delay, the crucible was lowered. Argon was circulated through the mold pallet after casting to chill the gravid molds.

The products of the casting furnace were gravid molds and a crucible containing the heel. The gravid molds were taken from the pallet in a ventilated hood. Castings were hand stripped and wiped to remove the excess thoria. The castings, longer than $14\frac{1}{4}$ in., were processed to make pins. The crucible was emptied, brush cleaned, and recoated. The crucible heel and short pins were broken, weighed, and set aside for addition to subsequent charges or remelting into billets.

Pin Processing

Pins were sheared from castings by a modified Di-Acro Rod Parter. Modification included the addition of a set of 0.148-in.-diameter dies, a can for collecting sheared ends, and a positioning fixture. The top of the casting was sheared first to remove the shrinkage cavity. The trimmed casting was turned end for end and sheared to length. Acceptable pins were from 14.190 to 14.250 in. long.

Each pin was inspected for average diameter, weight, length, and internal quality. The average diameter was estimated from a continuous trace produced by a three-jet, ring-type air gauge. Pin weight was measured on a Mettler, Type K7, balance. Length measurements were made with a dial indicator comparator. Internal quality was ascertained by gamma radiography. A nominal pin had an average diameter of 0.1440 in. and a length of 14.22 in., and weighed between 66 and 69 g.

Acceptable pins were batched in groups of 50 for assembly into rods. Rejected pins were broken into $1\frac{1}{2}$-in. lengths and stored for consolidation into billets.

ROD ASSEMBLY AND INSPECTION

The operations which comprise rod assembly are shown in Figure 4. The raw materials to the process were jacket preassemblies,

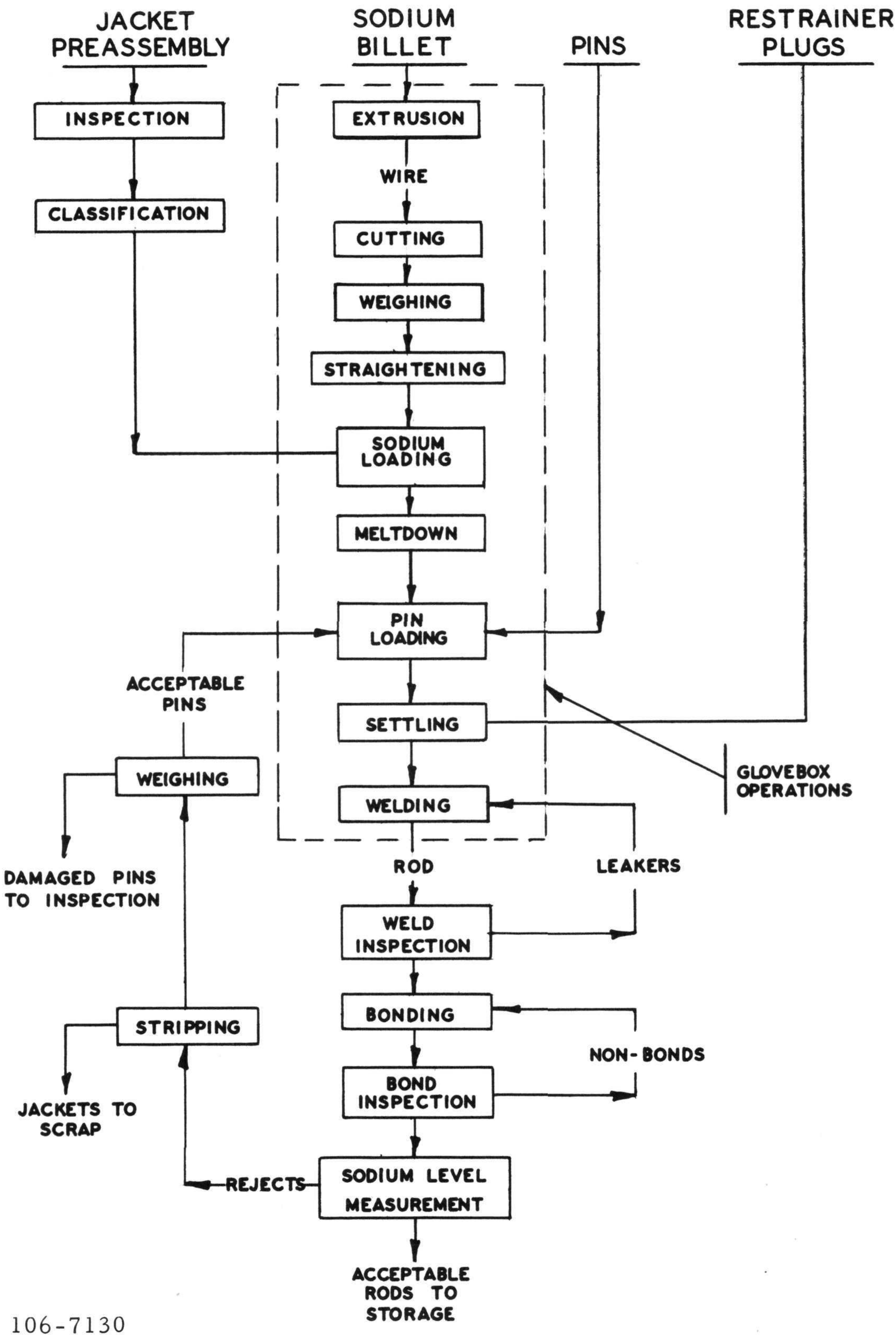


Figure 4. Operations Comprising Rod Manufacture

sodium extrusion billets, pins, and restrainer plugs. The end product was a leak-tight, sodium-bonded rod similar to that shown in Figure 1.

A jacket preassembly was a length of stainless steel tubing having an attachment tip welded into the bottom and a spacer wire spiraled around the outside. The average bore diameter of each was measured by a wand-type air gauge. Those accepted were grouped into classes according to their average diameter with the range of each class being 0.0001 in.

Sodium was received in the form of cast billets. The billets were extruded to produce $\frac{1}{8}$-in.-diameter wires, which were cut roughly to length. The wires were weighed, trimmed, and straightened, and were placed in the jackets by means of a special tweezers that prevented the sodium from rubbing on the top of the tube.

The jacket preassemblies containing sodium were heated to 150°C in an evacuated furnace. Furnace pressure was increased to atmospheric and the temperature increased to 450°C. The sodium melted and wetted the bottom of the jacket wall.

Each sodium-containing jacket received a pin. As loaded, the pins extended above their jackets. They were "settled" into position by re-melting the sodium in a vibratory furnace. When the pins were positioned, restrainer plugs were added and settled. Assembly was completed by welding the restrainer plugs to the jacket tube by means of a stored-energy-arc welder.

To compare techniques, the closure welds were tested by two different leak tests. In the first test, proposed by Grunwald,[4] the upper end of the fuel rod was inserted through an elastomer gasket into a close-fitting test chamber. A measured quantity of high-pressure gas was admitted to the test chamber by momentarily opening a valve to a metered antechamber. The pressure decay was then recorded for about 4 min. If the weld did not leak, the pressure remained constant. If the weld leaked, a fraction of the gas passed into the void space of the fuel element, resulting in a pressure decay to a reduced but predictable level. The size of the leak could be estimated from the rate of pressure decay. If the system leaked, the resulting pressure dropped below that determined by the chamber volume plus the void volume of the fuel element.

In the second test, the fuel rod was placed in a chamber which was pressurized with helium. After helium impregnation, the fuel rod was transferred to a vacuum sampling chamber attached to a helium leak detector. If the leaks were small enough, the helium in the void was retained; if not, leaks were detected by the mass spectrometer leak detector.

The leak-tight rods were thermally bonded in a vibratory furnace. They were heated to 525°C, vibrated for 2 hr, and cooled by blowing room air upward through the rod magazine. The quality of the bond was verified by means of an eddy-current, flaw-detection probe connected to a DuMont Cyclograph. The height of the sodium level was measured by X-radiography.

DISCUSSION

Simplex Operation

Simplex furnace operation was tested during production of the supplemental castings. A simplex operation is one in which both the alloy and the pin castings are produced in a single heat. During Core-I manufacture, the raw materials were alloyed in a separate vacuum induction melting and casting operation. The alloy ingots produced, plus some alloyed remelt stock, made up the charge to the injection casting furnace. Although this duplex melting technique gave excellent results, the obvious advantages of simplex operation demanded that it be tried.

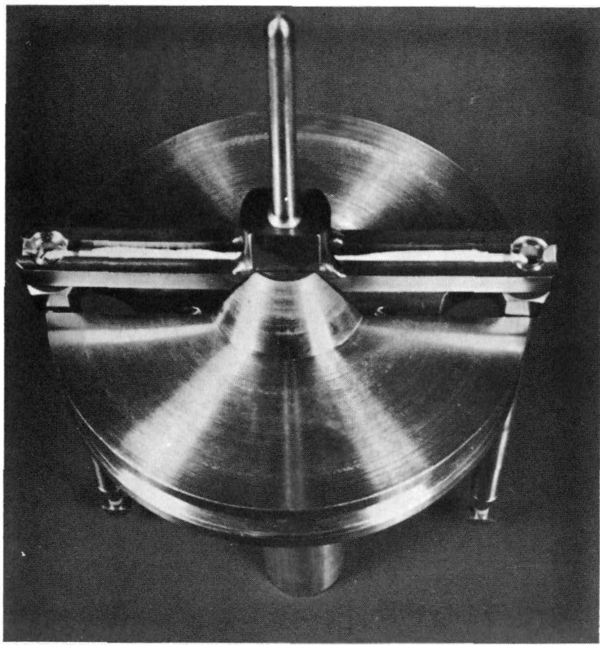
Eight simplex melts were made. The materials charged were uranium biscuit segments, zirconium wire, and pressed molybdenum, ruthenium, rhodium, palladium, and niobium powders. The charge was heated slowly to approximately 1360°C, held for 30 min, and poured. The results of the simplex melts were satisfactory from the standpoint of casting yields.

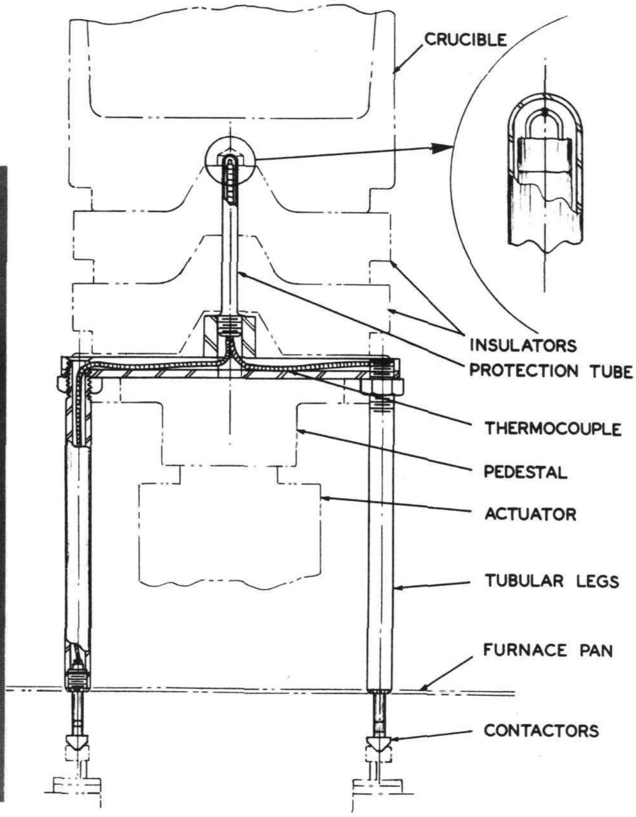
When the furnace was opened, evidence was found of uncontrolled gas evolution. Much of the interior of the furnace, including the movable parts beneath the furnace pan and the thermocouple connectors, was coated with condensed vapors. Metal had splashed onto the internal parts of the heater assembly and had dripped down onto the furnace pan. The furnace had to be cleaned after each melt to prevent impurity buildups which might interfere with the operation or control of the furnace. Because this cleanup could not be made remotely, simplex operation was abandoned.

Measurement of Crucible Temperature

The temperature of the injection casting furnace crucible was measured by means of a platinum-platinum 10 w/o rhodium thermocouple. Previously, the hot junction had been housed in a molybdenum protection tube which screwed into the top of the furnace pedestal. The wires ran through the pedestal to copper contacts attached to the underside. The remainder of the thermocouple circuit was copper; therefore, the thermocouple cold junction was on the underside of the furnace pedestal where the temperature at casting was between 500 and 600°C.

The new thermocouple fitting, shown in Figures 5 and 6, incorporates a similar thermocouple and protection tube. The protection tube is





ABS-243

Figure 5. Unit Thermocouple Head on Furnace Pedestal

106-7132

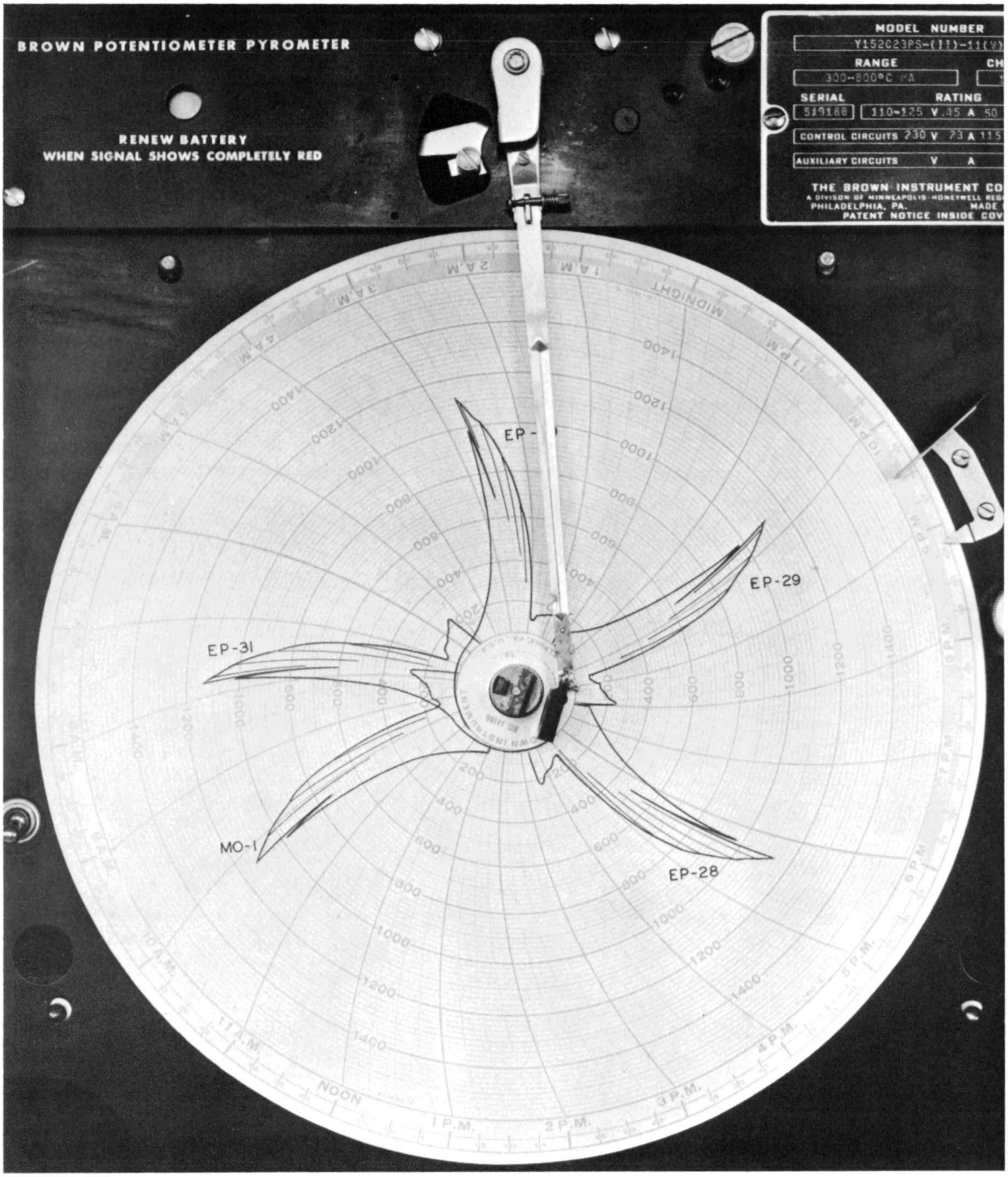
Figure 6. Unit Thermocouple Head

threaded into the top of a slotted crossarm, which has two $7\frac{1}{2}$-in.-long tubular legs extending out the bottom. The thermocouple wires run from the protection tube out the crossarm and down the legs to a set of spring-loaded, copper contacts. The assembly fits into the top of the furnace pedestal and is replaceable by manipulator. The length of the legs is such that the copper contacts are below the furnace pan where the temperature is approximately 200°C.

The lower and more constant cold junction temperature resulted in more accurate temperature measurements. Accuracy and reliability were checked by comparing thermocouple readings with optical readings. Reproducibility is illustrated by the chart in Figure 7 which shows the thermocouple indications for five successive programmed melts.

Study of Sodium Level

The height of the sodium level was studied because of the difficulties experienced in meeting the specification for sodium level in Core-I rods. During Core-I manufacture, 3881 rods were rejected. Of these, 1750, or almost half, were rejected for improper height of the sodium level.



106-7133

Figure 7. Thermocouple Indications for Five Successive Programmed Melts

The height of the sodium level is determined by the weight of sodium loaded into the jacket preassembly. It was thought that loads could be accurately calculated. The measured diameter and length of both the fuel pin and the jacket cavity were used along with 0.968 g/cm^3 for the density of sodium. Although the load calculations were straightforward, the resulting heights of the sodium levels were found to be in error by as much as $\frac{1}{4}$ in. It was obvious that theoretical calculations were inadequate and an empirical estimate was needed.

A statistical study was performed in which 11 batches of 50 rods each were prepared by Core-I production techniques. The jacket preassemblies used covered the entire range of permissible sizes. Pins were used in the order in which they were produced and should be representative of the process. Sodium loads were varied to produce levels from the top of the restrainer knob to more than one-half inch above it. From these 11 batches, 412 defect-free rods were obtained. The pertinent data taken during their production appears in Appendix A to this report.

The experimental data were fitted to a quadratic expression to give the equation

$$H = 2.6040 - 40.599D + 123.29V - 0.53654W - 234.38D^2 - 1000.2DV + 117.32DW + 451.96V^2 - 158.24VW + 13.218W^2 \quad .(1)$$

Here the sodium height in inches above the pin (H) is expressed as a function of the jacket preassembly average diameter in inches (D), the pin volume in cubic inches (V), and the sodium weight in grams (W). Pin volume was calculated by the equation

$$V = \frac{\pi}{4}d^2L \quad ,$$

where d is the measured average diameter and L is the measured length. Volume was used instead of diameter because (1) an extra term, pin length, was included in the analysis, and (2) the volume will be obtained by mechanical integration in future operations. The equation should serve as a guide in selecting sodium loads for future fuel rods.

Equation (1) can also be used to estimate the number of level rejects to be expected. The differences between the observed and calculated values of H have a standard deviation of 0.0505 in. This corresponds to a probability of rejection of 4.8% for a level tolerance of ±0.1 in. An acceptance probability of only 95.2% can be expected when the sodium load is tailored for each rod.

Tailoring the sodium load to each rod-jacket combination is time-consuming. Assembling a group of 50 fuel rods by this technique requires 50 unique sodium extrusions. A less laborious situation would be that in which 50 similar extrusions could be used. For this to be the case, the 50 fuel pins must be represented by a batch-average volume and the 50 jacket preassemblies by a batch-average cavity volume.

Fuel pins must be used in the order in which they are produced. The volume of each may be measured and the measurements averaged to obtain a batch-average pin volume. The jacket preassemblies need not be used in any predetermined order. During Core-I manufacture each batch of jackets was selected so as to have cavity diameters within a range of 0.0001 in. The jackets were considered to have the same volume, and sodium loads were calculated from a batch-average pin volume.[a]

The data in Appendix A were refitted in order to obtain an equation applicable to Core-I manufacturing conditions. When an average V for all 412 rods ($\overline{V}$) was used, the equation

$$H = 8.4154 - 56.760D + 96.371\overline{V} - 11.591W - 830.79D^2 + 284.67D\overline{V} + 15.944DW + 95.248\overline{V}^2 - 138.31\overline{V}W + 25.857W^2 \qquad (2)$$

was obtained. The differences between the observed values of H and those calculated from equation (2) have a standard deviation of 0.0576 in. This corresponds to a probability of rejection of 8.3% when the tolerance is ±0.1 in. The use of a batch-average volume for the pins reduces the labor burden but almost doubles the number of probable rejects.

Equation (1) can be used to estimate the sodium load for an individual rod from the pin volume and the jacket preassembly cavity diameter. Equation (2) can be used to estimate a common sodium load for a batch of rods. The use of this equation requires that a batch-average pin volume be used and the jacket preassemblies have nearly equal cavity diameters. The use of both equations require that the jacket preassembly cavity diameters be known. The equations can be applied only when 100% inspection of the jacket preassemblies is made. Complete inspection is not needed for acceptance, but for classifying or sizing the jackets. Without classification a sampling technique could be used for acceptance and an appreciable amount of labor saved. Approximately one man-day is required to classify 100 jacket preassemblies. Jacket cavity diameters are known to approximate a normal population whose mean could be used to represent a random sample of 50 with negligible error.

The data in Appendix A were again fitted to obtain an expression for the sodium-level height as a function of the batch-average pin volume ($\overline{V}$) and the batch-average jacket cavity diameter ($\overline{D}$):

$$H = -1.4944 - 47.864\overline{D} + 145.58\overline{V} - 41.864W + 468.62\overline{D}^2 - 330.25\overline{D}\overline{V} - 106.36\overline{D}W + 67.647\overline{V}^2 - 31.503\overline{V}W + 39.936W^2 \quad . \qquad (3)$$

---

[a] All jacket preassemblies were assumed to have nominal cavity depth.

The differences between the observed levels and those predicted by equation (3) have a standard deviation of 0.0736 in. This corresponds to a probability of rejection of 17.4% for a level tolerance of ±0.1 in.

It is obvious that the suggested steps save labor but increase the probability of producing a reject. Since a reject represents wasted labor, some operational compromise must be made to achieve maximum efficiency under the existing level specification of 0.65 ±0.1 in. If, however, the specification for sodium level could be changed to 0.65 ±0.15 in., the rejection probability predicted from equation (3) would be only 4.2%.

LEAK-DETECTION RESULTS

The somewhat crude and elementary pressure leak-detection equipment was found to be more reliable than the helium leak-detection method for large leaks. The sensitivities to small leaks of pressure appeared about equal when a short sensing line was used to the mass spectrometer. When a long sensing line was required to the mass spectrometer leak detector, pressure leak detection appeared clearly superior. From these tests, the decision was made to develop more refined pressure leak detecting equipment.[4]

ACKNOWLEDGMENTS

The authors wish to acknowledge the assistance of Donald Kraft (MET) in operating the injection casting furnace; Charles Konicek (MET) and Fred Soppet (MET) in producing pins from the castings; Walter Grajek (RE), William Roeda (RE), and Robert Rutkowski (RE) in assembling and inspecting the rods. Robert McGowan (MET) fabricated most of the fissium alloy. James Butler (AMD) performed the statistical calculations. All fuel-rod hardware was supplied by Norbert Grant (RE) and David Walker (MET).

REFERENCES

1. Jelinek, H. F., Carson, N. J., and Shuck, A. B., Fabrication of EBR-II Core-I Fuel Pins, ANL-6274 (June 1962).

2. Carson, N. J., Grant, N. R., Hessler, N. F., Jelinek, H. F., Olp, R. H., and Shuck, A. B., Fabrication of EBR-II Core-I Fuel Elements, ANL-6276 (December 1962).

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

4. Grunwald, A. P., Leak Testing of EBR-II Fuel Rods, Nuclear Science and Engineering, 12(3), 419-423 (1962).

APPENDIX A

Control Group Production Data

Rod Designation		Height of Sodium Level above Pin (in.) H	Average Jacket Diameter (in.) D	Average Fuel Pin Diameter (in.) d	Weight of Sodium Added (g) W	Fuel-pin Length (in.) L
Batch	No.					
213	1	1.03	0.15555	0.1432	0.900	14.229
	2	0.94	0.15565	0.1434	0.900	14.227
	3	0.99	0.15565	0.1427	0.900	14.234
	5	0.99	0.15575	0.1430	0.898	14.227
	6	0.84	0.15575	0.1428	0.900	14.232
	7	0.81	0.15575	0.1432	0.901	14.230
	10	0.91	0.15585	0.1435	0.901	14.231
	11	0.79	0.15585	0.1434	0.901	14.232
	12	0.95	0.15585	0.1430	0.900	14.244
	13	0.90	0.15585	0.1434	0.901	14.232
	14	0.89	0.15595	0.1432	0.901	14.234
	15	0.96	0.15595	0.1433	0.900	14.228
	16	0.96	0.15595	0.1431	0.901	14.230
	17	0.84	0.15595	0.1432	0.901	14.228
	18	0.86	0.15595	0.1433	0.900	14.247
	19	0.88	0.15595	0.1433	0.900	14.228
	20	0.94	0.15595	0.1429	0.902	14.239
	21	0.81	0.15605	0.1433	0.900	14.228
	22	0.84	0.15605	0.1430	0.900	14.230
	23	0.78	0.15605	0.1433	0.901	14.226
	24	0.89	0.15605	0.1433	0.901	14.230
	26	0.75	0.15605	0.1426	0.900	14.234
	27	0.75	0.15605	0.1431	0.900	14.228
	28	0.89	0.15605	0.1434	0.901	14.226
	29	0.89	0.15605	0.1428	0.901	14.232
	30	0.79	0.15605	0.1433	0.899	14.229
	31	0.88	0.15615	0.1433	0.899	14.230
	32	0.79	0.15615	0.1433	0.900	14.232
	33	0.81	0.15615	0.1430	0.900	14.230
	34	0.83	0.15615	0.1433	0.901	14.228
	36	0.80	0.15615	0.1433	0.900	14.227
	38	0.81	0.15625	0.1433	0.899	14.233
	40	0.92	0.15625	0.1437	0.901	14.229
	41	0.85	0.15625	0.1433	0.901	14.227
	42	0.78	0.15625	0.1431	0.900	14.228
	43	0.88	0.15625	0.1433	0.900	14.228
	45	0.81	0.15635	0.1433	0.901	14.227
	46	0.87	0.15635	0.1433	0.899	14.227

Rod Designation		Height of Sodium Level above Pin (in.) H	Average Jacket Diameter (in.) D	Average Fuel Pin Diameter (in.) d	Weight of Sodium Added (g) W	Fuel-pin Length (in.) L
Batch	No.					
213	47	0.72	0.15635	0.1431	0.899	14.229
	48	0.79	0.15635	0.1434	0.901	14.226
	49	0.77	0.15635	0.1432	0.900	14.231
	50	0.76	0.15645	0.1433	0.899	14.231
214	19	0.78	0.15595	0.1435	0.875	14.229
	20	0.71	0.15595	0.1431	0.875	14.227
	21	0.66	0.15605	0.1430	0.876	14.232
	22	0.69	0.15605	0.1433	0.875	14.228
	23	0.77	0.15605	0.1435	0.875	14.225
	24	0.72	0.15605	0.1434	0.876	14.227
	25	0.67	0.15605	0.1430	0.875	14.227
	26	0.68	0.15605	0.1431	0.876	14.230
	27	0.69	0.15605	0.1433	0.876	14.235
	28	0.72	0.15605	0.1432	0.874	14.227
	29	0.77	0.15605	0.1433	0.874	14.225
	30	0.67	0.15605	0.1432	0.876	14.228
	31	0.64	0.15615	0.1432	0.875	14.229
	32	0.68	0.15615	0.1433	0.875	14.226
	33	0.65	0.15615	0.1432	0.875	14.237
	35	0.76	0.15615	0.1435	0.873	14.227
	36	0.67	0.15615	0.1435	0.874	14.231
	37	0.70	0.15615	0.1433	0.875	14.228
	38	0.65	0.15625	0.1430	0.876	14.232
	39	0.69	0.15625	0.1435	0.876	14.228
	40	0.72	0.15625	0.1433	0.876	14.229
	41	0.70	0.15625	0.1432	0.876	14.227
	42	0.66	0.15625	0.1432	0.875	14.228
	43	0.73	0.15625	0.1435	0.875	14.227
	44	0.70	0.15625	0.1435	0.875	14.229
	46	0.61	0.15635	0.1433	0.874	14.235
	49	0.68	0.15635	0.1433	0.876	14.228
	50	0.63	0.15645	0.1432	0.876	14.227
215	1	1.11	0.15555	0.1432	0.924	14.227
	2	1.00	0.15565	0.1433	0.925	14.227
	3	1.04	0.15565	0.1435	0.925	14.229
	4	1.05	0.15575	0.1433	0.926	14.230
	5	1.06	0.15575	0.1432	0.926	14.230
	6	1.10	0.15575	0.1432	0.926	14.227
	7	1.09	0.15575	0.1432	0.925	14.226
	8	1.11	0.15585	0.1433	0.926	14.225
	9	1.11	0.15585	0.1435	0.926	14.229
	10	1.08	0.15585	0.1434	0.925	14.232
	11	0.93	0.15585	0.1432	0.925	14.239
	12	1.01	0.15585	0.1431	0.924	14.233
	13	1.01	0.15585	0.1435	0.925	14.229

Rod Designation		Height of Sodium Level above Pin (in.) H	Average Jacket Diameter (in.) D	Average Fuel Pin Diameter (in.) d	Weight of Sodium Added (g) W	Fuel-pin Length (in.) L
Batch	No.					
215	14	1.04	0.15595	0.1435	0.926	14.227
	15	1.05	0.15595	0.1432	0.926	14.229
	17	1.06	0.15595	0.1432	0.926	14.227
	18	1.03	0.15595	0.1432	0.926	14.226
	19	0.91	0.15595	0.1430	0.925	14.228
	20	1.06	0.15595	0.1435	0.925	14.226
	21	1.07	0.15605	0.1435	0.926	14.229
	22	1.04	0.15605	0.1432	0.926	14.231
	25	1.02	0.15605	0.1434	0.926	14.229
	26	1.00	0.15605	0.1435	0.926	14.227
	27	0.88	0.15605	0.1435	0.924	14.231
	28	1.06	0.15605	0.1436	0.925	14.226
	29	1.10	0.15605	0.1439	0.925	14.227
	30	1.00	0.15605	0.1433	0.926	14.230
	32	0.98	0.15615	0.1437	0.924	14.229
	33	1.04	0.15615	0.1435	0.926	14.226
	34	1.05	0.15615	0.1437	0.925	14.229
	35	1.08	0.15615	0.1436	0.926	14.229
	36	1.12	0.15615	0.1438	0.926	14.227
	40	0.87	0.15625	0.1432	0.926	14.226
	42	0.94	0.15625	0.1435	0.926	14.229
	44	1.00	0.15625	0.1437	0.925	14.228
	46	0.88	0.15635	0.1436	0.925	14.230
	47	0.89	0.15635	0.1432	0.925	14,227
	48	1.06	0.15635	0.1433	0.926	14.227
	49	0.90	0.15635	0.1435	0.925	14.227
	50	0.99	0.15645	0.1436	0.925	14.226
218	1	0.81	0.15555	0.1435	0.851	14.227
	2	0.73	0.15565	0.1434	0.850	14.228
	3	0.73	0.15565	0.1435	0.851	14.227
	4	0.82	0.15575	0.1436	0.851	14.228
	6	0.79	0.15575	0.1436	0.850	14.226
	7	0.71	0.15575	0.1433	0.850	14.229
	8	0.67	0.15585	0.1435	0.851	14.227
	9	0.69	0.15585	0.1434	0.851	14.228
	10	0.68	0.15585	0.1434	0.850	14.228
	11	0.68	0.15585	0.1434	0.850	14.228
	12	0.63	0.15585	0.1436	0.850	14.225
	13	0.72	0.15585	0.1433	0.850	13.227
	14	0.63	0.15595	0.1436	0.851	14.229
	15	0.72	0.15595	0.1439	0.851	14.227
	16	0.66	0.15595	0.1435	0.851	14.230
	17	0.59	0.15595	0.1436	0.851	14.228
	18	0.62	0.15595	0.1430	0.851	14.226

Rod Designation		Height of Sodium Level above Pin (in.) H	Average Jacket Diameter (in.) D	Average Fuel Pin Diameter (in.) d	Weight of Sodium Added (g) W	Fuel-pin Length (in.) L
Batch	No.					
218	19	0.64	0.15595	0.1432	0.851	14.230
	20	0.73	0.15595	0.1437	0.850	14.229
	21	0.66	0.15605	0.1436	0.851	14.227
	22	0.62	0.15605	0.1435	0.850	14.226
	23	0.62	0.15605	0.1435	0.851	14.229
	24	0.61	0.15605	0.1436	0.851	14.229
	25	0.58	0.15605	0.1435	0.850	14.220
	26	0.68	0.15605	0.1436	0.850	14.227
	28	0.80	0.15605	0.1435	0.849	14.229
	29	0.72	0.15605	0.1437	0.850	14.227
	30	0.66	0.15605	0.1435	0.850	14.226
	31	0.57	0.15615	0.1433	0.850	14.228
	32	0.62	0.15615	0.1435	0.851	14.229
	33	0.65	0.15615	0.1435	0.851	14.222
	34	0.67	0.15615	0.1436	0.850	14.229
	35	0.62	0.15615	0.1432	0.850	14.227
	36	0.61	0.15615	0.1435	0.851	14.227
	37	0.61	0.15615	0.1433	0.851	14.228
	38	0.55	0.15625	0.1432	0.851	14.225
	40	0.60	0.15625	0.1433	0.851	14.229
	41	0.63	0.15625	0.1437	0.851	14.228
	42	0.62	0.15625	0.1436	0.851	14.229
	44	0.56	0.15625	0.1432	0.851	14.230
	45	0.61	0.15635	0.1433	0.850	14.228
	46	0.57	0.15635	0.1434	0.850	14.228
	48	0.59	0.15635	0.1433	0.851	14.228
	49	0.60	0.15635	0.1436	0.851	14.229
	50	0.63	0.15645	0.1437	0.850	14.229
219	1	0.57	0.15555	0.1435	0.825	14.228
	2	0.73	0.15565	0.1436	0.825	14.230
	3	0.67	0.15565	0.1434	0.825	14.224
	4	0.65	0.15575	0.1432	0.826	14.226
	5	0.69	0.15575	0.1437	0.826	14.228
	6	0.68	0.15575	0.1437	0.825	14.232
	7	0.68	0.15575	0.1429	0.825	14.228
	9	0.61	0.15585	0.1435	0.826	14.227
	10	0.58	0.15585	0.1434	0.826	14.226
	11	0.61	0.15585	0.1434	0.825	14.225
	13	0.58	0.15585	0.1434	0.825	14.225
	16	0.62	0.15595	0.1430	0.826	14.229
	17	0.61	0.15595	0.1433	0.825	14.229
	18	0.59	0.15595	0.1434	0.826	14.229
	20	0.59	0.15595	0.1435	0.826	14.232
	21	0.59	0.15605	0.1436	0.825	14.228

Rod Designation		Height of Sodium Level above Pin (in.) H	Average Jacket Diameter (in.) D	Average Fuel Pin Diameter (in.) d	Weight of Sodium Added (g) W	Fuel-pin Length (in.) L
Batch	No.					
219	22	0.58	0.15605	0.1435	0.825	14.226
	23	0.58	0.15605	0.1435	0.825	14.227
	24	0.59	0.15605	0.1435	0.825	14.226
	25	0.55	0.15605	0.1434	0.825	14.229
	26	0.61	0.15605	0.1434	0.825	14.228
	27	0.58	0.15605	0.1433	0.825	14.227
	28	0.64	0.15605	0.1434	0.825	14.226
	30	0.61	0.15605	0.1433	0.825	14.227
	32	0.61	0.15615	0.1435	0.825	14.231
	34	0.57	0.15615	0.1434	0.825	14.228
	35	0.53	0.15615	0.1435	0.825	14.230
	36	0.57	0.15615	0.1435	0.825	14.227
	37	0.53	0.15615	0.1436	0.826	14.227
	41	0.52	0.15625	0.1436	0.825	14.229
	43	0.54	0.15625	0.1434	0.826	14.229
	44	0.53	0.15625	0.1435	0.825	14.227
220	2	0.82	0.15565	0.1435	0.860	14.227
	3	0.83	0.15565	0.1434	0.859	14.226
	4	0.70	0.15575	0.1434	0.861	14.227
	6	0.75	0.15575	0.1437	0.860	14.228
	7	0.76	0.15575	0.1436	0.861	14.226
	8	0.72	0.15585	0.1434	0.861	14.211
	9	0.68	0.15585	0.1434	0.860	14.231
	10	0.66	0.15585	0.1436	0.860	14.227
	12	0.68	0.15585	0.1435	0.861	14.228
	13	0.73	0.15585	0.1435	0.861	14.229
	14	0.67	0.15595	0.1435	0.860	14.227
	16	0.74	0.15595	0.1436	0.861	14.228
	17	0.72	0.15595	0.1435	0.861	14.227
	18	0.66	0.15595	0.1432	0.861	14.230
	19	0.73	0.15595	0.1436	0.860	14.228
	20	0.66	0.15595	0.1434	0.860	14.226
	22	0.72	0.15605	0.1437	0.860	14.227
	23	0.70	0.15605	0.1437	0.861	14.227
	24	0.67	0.15605	0.1435	0.860	14.227
	25	0.70	0.15605	0.1433	0.861	14.229
	26	0.57	0.15605	0.1433	0.861	14.230
	27	0.58	0.15605	0.1433	0.860	14.226
	29	0.68	0.15605	0.1435	0.861	14.226
	30	0.71	0.15605	0.1435	0.860	14.225
	32	0.57	0.15615	0.1430	0.861	14.227
	33	0.63	0.15615	0.1434	0.861	14.227
	34	0.66	0.15615	0.1435	0.861	14.228
	35	0.68	0.15615	0.1436	0.861	14.228

Rod Designation		Height of Sodium Level above Pin (in.) H	Average Jacket Diameter (in.) D	Average Fuel Pin Diameter (in.) d	Weight of Sodium Added (g) W	Fuel-pin Length (in.) L
Batch	No.					
220	37	0.66	0.15615	0.1433	0.861	14.227
	38	0.56	0.15625	0.1430	0.861	14.229
	40	0.62	0.15625	0.1434	0.861	14.229
	41	0.56	0.15625	0.1433	0.859	14.227
	42	0.74	0.15625	0.1431	0.859	14.228
	43	0.61	0.15625	0.1433	0.861	14.227
	44	0.62	0.15625	0.1434	0.861	14.229
	46	0.56	0.15635	0.1433	0.860	14.225
	47	0.58	0.15635	0.1434	0.861	14.228
	48	0.59	0.15635	0.1435	0.861	14.228
	49	0.61	0.15635	0.1435	0.860	14.231
221	1	0.69	0.15555	0.1435	0.839	14.225
	2	0.62	0.15565	0.1430	0.839	14.227
	4	0.71	0.15575	0.1437	0.838	14.230
	5	0.73	0.15575	0.1435	0.837	14.229
	6	0.57	0.15575	0.1432	0.838	14.227
	7	0.75	0.15575	0.1435	0.838	14.229
	8	0.79	0.15585	0.1435	0.838	14.228
	9	0.55	0.15585	0.1431	0.838	14.234
	10	0.59	0.15585	0.1432	0.838	14.228
	11	0.68	0.15585	0.1435	0.838	14.228
	13	0.59	0.15585	0.1437	0.838	14.228
	18	0.54	0.15595	0.1432	0.837	14.228
	22	0.56	0.15605	0.1434	0.839	14.229
	25	0.67	0.15605	0.1437	0.838	14.231
	26	0.71	0.15605	0.1437	0.839	14.230
	29	0.54	0.15605	0.1436	0.838	14.228
	30	0.63	0.15605	0.1435	0.838	14.228
	31	0.63	0.15615	0.1434	0.839	14.227
	32	0.57	0.15615	0.1432	0.839	14.226
	33	0.68	0.15615	0.1438	0.839	14.227
	34	0.55	0.15615	0.1437	0.839	14.227
	35	0.58	0.15615	0.1433	0.839	14.231
	37	0.57	0.15615	0.1434	0.839	14.228
	38	0.53	0.15625	0.1434	0.839	14.228
	41	0.53	0.15625	0.1432	0.839	14.240
	42	0.63	0.15625	0.1437	0.839	14.227
	44	0.61	0.15625	0.1437	0.839	14.229
	50	0.53	0.15645	0.1436	0.839	14.228
222	1	1.09	0.15555	0.1437	0.889	14.229
	3	0.90	0.15565	0.1433	0.888	14.227
	4	0.89	0.15575	0.1436	0.888	14.229
	5	0.96	0.15575	0.1437	0.888	14.227
	6	0.94	0.15575	0.1434	0.887	14.228

Rod Designation		Height of Sodium Level above Pin (in.) H	Average Jacket Diameter (in.) D	Average Fuel Pin Diameter (in.) d	Weight of Sodium Added (g) W	Fuel-pin Length (in.) L
Batch	No.					
222	7	0.84	0.15575	0.1430	0.887	14.228
	9	0.87	0.15585	0.1432	0.889	14.230
	10	0.88	0.15585	0.1433	0.888	14.224
	11	0.96	0.15585	0.1435	0.888	14.227
	13	0.86	0.15585	0.1435	0.888	14.235
	14	0.98	0.15595	0.1436	0.887	14.237
	15	0.82	0.15595	0.1433	0.888	14.229
	16	0.90	0.15595	0.1436	0.889	14.227
	17	0.85	0.15595	0.1433	0.888	14.227
	18	0.94	0.15595	0.1436	0.889	14.228
	19	0.87	0.15595	0.1433	0.889	14.244
	20	0.88	0.15595	0.1435	0.889	14.229
	21	0.91	0.15605	0.1436	0.888	14.227
	23	0.80	0.15605	0.1432	0.888	14.228
	24	0.88	0.15605	0.1433	0.889	14.227
	25	0.60	0.15605	0.1435	0.887	14.229
	26	0.75	0.15605	0.1432	0.887	14.228
	27	0.92	0.15605	0.1432	0.888	14.232
	28	0.89	0.15605	0.1437	0.888	14.229
	29	0.87	0.15605	0.1437	0.887	14.228
	30	0.87	0.15605	0.1436	0.887	14.229
	31	0.83	0.15615	0.1436	0.887	14.228
	32	0.78	0.15615	0.1435	0.889	14.227
	33	0.80	0.15615	0.1435	0.888	14.228
	34	0.81	0.15615	0.1436	0.888	14.225
	35	0.76	0.15615	0.1434	0.888	14.229
	36	0.60	0.15615	0.1432	0.888	14.228
	37	0.87	0.15615	0.1436	0.889	14.226
	38	0.86	0.15625	0.1435	0.889	14.229
	39	0.64	0.15625	0.1433	0.887	14.229
	40	0.74	0.15625	0.1441	0.887	14.225
	42	0.74	0.15625	0.1436	0.888	14.229
	43	0.73	0.15625	0.1433	0.887	14.229
	44	0.75	0.15625	0.1434	0.889	14.228
	45	0.72	0.15635	0.1434	0.889	14.227
	47	0.68	0.15635	0.1439	0.888	14.228
	48	0.71	0.15635	0.1433	0.887	14.230
	49	0.64	0.15635	0.1433	0.887	14.230
	50	0.86	0.15645	0.1433	0.888	14.227
223	1	0.57	0.15555	0.1434	0.811	14.230
	2	0.62	0.15565	0.1435	0.811	14.227
	3	0.68	0.15565	0.1438	0.812	14.230
	4	0.56	0.15575	0.1433	0.812	14.228

Rod Designation		Height of Sodium Level above Pin (in.) H	Average Jacket Diameter (in.) D	Average Fuel Pin Diameter (in.) d	Weight of Sodium Added (g) W	Fuel-pin Length (in.) L
Batch	No.					
223	6	0.54	0.15575	0.1436	0.812	14.228
	9	0.61	0.15585	0.1434	0.811	14.228
	11	0.61	0.15585	0.1437	0.812	14.230
	16	0.56	0.15595	0.1436	0.812	14.227
	19	0.70	0.15595	0.1443	0.812	14.238
	22	0.54	0.15605	0.1437	0.812	14.229
	24	0.57	0.15605	0.1435	0.813	14.228
224	2	0.81	0.15565	0.1433	0.861	14.228
	3	0.82	0.15565	0.1435	0.861	14.228
	4	0.73	0.15575	0.1433	0.860	14.229
	5	0.69	0.15575	0.1432	0.860	14.229
	9	0.61	0.15585	0.1428	0.860	14.227
	10	0.78	0.15585	0.1435	0.861	14.233
	11	0.63	0.15585	0.1430	0.861	14.231
	12	0.69	0.15585	0.1431	0.860	14.227
	13	0.79	0.15585	0.1435	0.860	14.230
	14	0.82	0.15595	0.1436	0.860	14.230
	15	0.67	0.15595	0.1434	0.860	14.246
	16	0.76	0.15595	0.1435	0.859	14.231
	17	0.68	0.15595	0.1432	0.860	14.227
	18	0.66	0.15595	0.1430	0.860	14.227
	19	0.79	0.15595	0.1436	0.861	14.228
	20	0.75	0.15595	0.1433	0.861	14.228
	21	0.65	0.15605	0.1431	0.859	14.227
	22	0.67	0.15605	0.1432	0.859	14.230
	23	0.66	0.15605	0.1430	0.860	14.227
	24	0.72	0.15605	0.1436	0.860	14.229
	25	0.63	0.15605	0.1430	0.861	14.228
	26	0.66	0.15605	0.1434	0.861	14.226
	27	0.70	0.15605	0.1434	0.861	14.237
	28	0.69	0.15605	0.1434	0.860	14.231
	29	0.71	0.15605	0.1436	0.860	14.228
	30	0.68	0.15605	0.1433	0.860	14.227
	31	0.71	0.15615	0.1434	0.861	14.231
	34	0.77	0.15615	0.1433	0.861	14.228
	36	0.70	0.15615	0.1436	0.861	14.227
	37	0.64	0.15615	0.1436	0.860	14.228
	38	0.66	0.15625	0.1435	0.859	14.233
	39	0.71	0.15625	0.1437	0.860	14.230
	40	0.68	0.15625	0.1436	0.860	14.231
	42	0.68	0.15625	0.1435	0.861	14.229
	43	0.68	0.15625	0.1437	0.861	14.228
	44	0.67	0.15625	0.1437	0.861	14.227
	45	0.63	0.15635	0.1435	0.859	14.228
	47	0.55	0.15635	0.1434	0.860	14.234
	50	0.61	0.15645	0.1437	0.861	14.228

Rod Designation: Batch	Rod Designation: No.	Height of Sodium Level above Pin (in.) H	Average Jacket Diameter (in.) D	Average Fuel Pin Diameter (in.) d	Weight of Sodium Added (g) W	Fuel-pin Length (in.) L
225	2	0.73	0.15565	0.1434	0.860	14.229
	4	0.78	0.15575	0.1436	0.859	14.230
	5	0.80	0.15575	0.1436	0.859	14.232
	6	0.68	0.15575	0.1436	0.860	14.230
	7	0.72	0.15575	0.1435	0.860	14.228
	8	0.65	0.15585	0.1432	0.859	14.229
	9	0.73	0.15585	0.1436	0.859	14.227
	10	0.71	0.15585	0.1434	0.860	14.230
	11	0.81	0.15585	0.1436	0.860	14.229
	12	0.68	0.15585	0.1435	0.860	14.228
	13	0.73	0.15585	0.1437	0.861	14.229
	14	0.97	0.15595	0.1453	0.861	14.230
	15	0.71	0.15595	0.1437	0.861	14.230
	16	0.76	0.15595	0.1437	0.860	14.228
	17	0.66	0.15595	0.1434	0.860	14.238
	18	0.70	0.15595	0.1435	0.860	14.228
	19	0.71	0.15595	0.1437	0.860	14.230
	21	0.73	0.15605	0.1436	0.860	14.229
	23	0.66	0.15605	0.1435	0.860	14.225
	24	0.73	0.15605	0.1437	0.861	14.231
	26	0.58	0.15605	0.1435	0.860	14.233
	27	0.70	0.15605	0.1436	0.860	14.227
	29	0.68	0.15605	0.1436	0.861	14.227
	30	0.68	0.15605	0.1435	0.861	14.229
	31	0.60	0.15615	0.1433	0.861	14.224
	32	0.66	0.15615	0.1434	0.859	14.231
	33	0.68	0.15615	0.1437	0.860	14.229
	34	0.60	0.15615	0.1432	0.860	14.230
	35	0.65	0.15615	0.1434	0.860	14.225
	37	0.70	0.15615	0.1436	0.861	14.228
	38	0.58	0.15625	0.1430	0.861	14.226
	39	0.65	0.15625	0.1437	0.859	14.229
	40	0.65	0.15625	0.1436	0.859	14.228
	41	0.56	0.15625	0.1430	0.859	14.229
	43	0.59	0.15625	0.1437	0.859	14.231
	47	0.59	0.15635	0.1436	0.860	14.227
	49	0.54	0.15635	0.1433	0.860	14.229
	50	0.63	0.15645	0.1436	0.860	14.227
226	1	0.72	0.15555	0.1436	0.839	14.227
	2	0.77	0.15565	0.1437	0.839	14.225
	3	0.62	0.15565	0.1430	0.841	14.227
	4	0.73	0.15575	0.1436	0.841	14.227
	5	0.73	0.15575	0.1437	0.840	14.239
	6	0.73	0.15575	0.1432	0.840	14.227
	7	0.69	0.15575	0.1435	0.840	14.227

Rod Designation		Height of Sodium Level above Pin (in.) H	Average Jacket Diameter (in.) D	Average Fuel Pin Diameter (in.) d	Weight of Sodium Added (g) W	Fuel-pin Length (in.) L
Batch	No.					
226	8	0.59	0.15585	0.1435	0.839	14.226
	9	0.64	0.15585	0.1435	0.838	14.229
	13	0.56	0.15585	0.1431	0.840	14.225
	14	0.67	0.15595	0.1436	0.841	14.227
	16	0.68	0.15595	0.1436	0.840	14.228
	17	0.62	0.15595	0.1436	0.839	14.228
	18	0.68	0.15595	0.1435	0.840	14.229
	19	0.64	0.15595	0.1436	0.840	14.229
	21	0.62	0.15605	0.1437	0.840	14.226
	22	0.63	0.15605	0.1431	0.841	14.231
	23	0.67	0.15605	0.1438	0.839	14.229
	25	0.59	0.15605	0.1432	0.840	14.224
	26	0.55	0.15605	0.1434	0.840	14.231
	28	0.57	0.15605	0.1434	0.841	14.229
	30	0.70	0.15605	0.1437	0.841	14.230
	32	0.63	0.15615	0.1435	0.841	14.226
	41	0.56	0.15625	0.1434	0.840	14.232
	42	0.57	0.15625	0.1436	0.841	14.229
	50	0.57	0.15645	0.1435	0.840	14.232