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THE ASSEMBLY, SODIUM BONDING AND INSPECTION OF
EBR-II BLANKET RODS

MASTER

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The Experimental Power Breeder Reactor, EBR-II, is a heterogeneous, unmoderated, sodium-cooled reactor to provide engineering and operational information applicable to full scale central-station nuclear power plants. The enriched uranium-fissium alloy fuel is blanketed with depleted unalloyed uranium in type 304 stainless steel tubes. An elevation through the reactor core, Figure 1, shows the relative location of fuel and blanket components. The maximum calculated center temperature for blanket slugs adjacent to the fuel is 600°C and the surface temperature is 520°C. Sodium metal is utilized as a heat transfer medium in the annulus between the uranium and the tube wall. To insure adequate heat transfer via the sodium, no voids, unbonded, or non-wetted areas greater than 1/16" in any direction can be tolerated. An exacting sodium fill height must also be maintained to insure complete coverage of the uranium in the event that radiation damage to the slug material should cause dimensional changes with a resultant length increase and to allow space for the expansion of the sodium and the collection of released fission gases. Two different types of blanket rods were produced as described in Table I and shown in Figures 2 and 3.

All loading operations were performed in an atmosphere of 90 v/o argon-10 v/o helium, which was also the atmosphere surrounding the compression spring above the sodium at the top of each rod. The work was performed in a glove box, shown in Figure 4, which was designed to permit four operators working simultaneously to extrude the necessary sodium, load, and cap 216 rods per day. The box was fabricated with an extruded and welded aluminum angle frame, safety glass windows on two sides and on top, transfer locks at each end and a 3/4" thick stainless steel base containing three 9" diameter ports for inserting tubular bundles

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containing the blanket tubes. Each port opening had its own individual cover to seal the box while transferring tube bundles to and from the underside of the glove box. The glove box was mounted on a steel frame 7 feet above floor level to allow passage of the 61" long tube bundles containing the inner and outer rods beneath the box. Operators platforms were located on either side of the box with separate control stations at the ends of the platform for each operator. Equipment for evacuating and purging the transfer locks and the tube bundles via the ports were located beneath the operators' platforms.

Three portable tank-type oil baths heated with external electric resistance band type elements were located in a 6 foot deep pit beneath the box. Each bath was positioned directly beneath one of the loading ports on the underside of the glove box so that it could be raised to surround the tube bundle suspended from the port. The bath of silicone oil was used to melt the sodium inside the blanket tubes. A view of the oil baths in two different raised positions may be seen in Figure 5.

Each of the operators' control stations, shown in Figure 6, contained the necessary controls to raise and lower the oil bath, temperature controller for the oil bath, and switches for operating solenoid operated vacuum and purging valves for evacuating and purging the tube bundle and transfer lock. Also in the station was a vacuum gage and channel selector for obtaining vacuum readings at various places in the system.

A horizontal direct pump hydraulic extruder was used to extrude solid sodium slugs inside the glove box. This extruder, shown in Figure 7, consisted of a 6" bore x 17-1/4" stroke, 1500 psi, double acting hydraulic cylinder which was coupled to a vacuum tight container opening to the inside of the glovebox at one end of the box. A 17" long, 3-1/2" O.D. x 2-1/2" I.D. steel liner filled with sodium was inserted in the container, and a steel die in a die holder was locked in position in front of the container and liner. These component parts can be

seen in Figure 8. The hydraulic ram then extruded the sodium through the die and onto a run-out table. When the extruded sodium reached its proper length, it tripped a limit switch which actuated a flying shear that cut the sodium to length without interrupting the smooth flow of sodium from the extruder. In this way sodium of uniform length and diameter was produced for loading into the blanket tubes. The sodium slugs were extruded in two sizes: 0.250" diameter x 3-7/8" long for the upper and lower blanket rods, and 0.375" diameter by 10" long for the inner and outer rods. The sodium was extruded at a rate of approximately 20"/minute and the extrusion ratio for the two sizes was approximately 100:1 and 45:1 respectively.

Since there were two types of blanket rods and since the loading, bonding and inspection of the two types was basically identical, the information presented will pertain only to the upper and lower rods.

The casting, fabrication, beta-treating, and machining of the unalloyed uranium slugs was performed outside the laboratory. When received by ANL, the uranium slugs had a coating of paraffin base oil to prevent excessive oxidation. The slugs were then vapor degreased, weighed, visually inspected and tested for internal defects by an ultrasonic through transmission technique, as shown in Figures 9 and 10. The sonic test was also used for checking the grain size of the slugs. Slugs which were improperly heat treated had an abnormally large grain size as shown in Figure 11. Slugs were also spot-checked for length and diameter using go-no go gauges. Upon the completion of testing, acceptable slugs were again coated with the paraffin base oil and stored. Before being used, the slugs were vapor degreased, and rinsed in hot distilled water and ethyl alcohol.

Prior to loading, the stainless steel tubes were cut, machined to length, rolled and cleaned in soapy water, and rinsed in distilled water and alcohol. The I.D. of the tubes was then checked with an air gauge. Following this, acceptable tubes had the bottom end-plug welded in place and the welds leak checked with a

helium mass spectrometer.

The tubes were placed in a tube bundle which was capable of holding 36 tubes as shown in Figure 12. The tube bundle was then inserted and sealed in a loading port on the underside of the glove box. The bundle was then evacuated to 25 microns of Hg, purged with the inert gas mixture, evacuated, and purged again before opening to the glove box.

Polyethylene ferrules were inserted at the top of each tube and sodium slugs inserted as shown in Figure 13. The ferrules serve a twofold purpose: (1) prevent contamination of the top portion of the tube with sodium, which would result in a poor or defective weld; and (2) prevent the possibility of inserting two slugs of sodium in the same tube. This was accomplished by immediately removing the ferrule from the tube after inserting the sodium slug.

When all of the tubes in the bundle had been loaded with sodium, the port cover was secured in place and the bundle was evacuated to 25 microns of Hg. The oil bath was then raised until the bottom six inches of the tube bundle were submerged in oil. The sodium melted and thereby freed any entrapped gases. The oil bath was then lowered and the sodium allowed to solidify before purging with the inert gas mixture and removal of the port cover.

The uranium slugs were then loaded into the tubes as shown in Figure 14. To prevent contamination of the uranium, clean nylon gloves were worn over the rubber gloves. The chief source of contamination to the rubber gloves was vacuum grease which could be picked up from the "O" rings of the port and bundle covers. After the uranium had been loaded in all of the tubes, the oil bath was raised until all but 2" of the tubes of the tube bundle were submerged in oil. The sodium then melted thereby allowing the uranium to settle to the bottom of the tubes.

The compression springs were then inserted in the tubes as illustrated in Figure 15. The springs, when completely settled in the molten sodium, were even

with the top edge of the tube. When all of the springs had settled, the oil bath was lowered and the top end-plugs were snapped in place. This was accomplished by placing a support guide over two tubes at a time, inserting end-plugs in the openings in the guide, and snapping the plugs in the tube with the aid of a punch and hammer. The plug was held in place by a rolled groove in the tube which matched a corresponding groove in the plug. The compression spring was compressed $1/4$ " at a load of 10 pounds.

After all of the plugs had been inserted, the bundle and port covers were positioned securely in place and the bundle removed from the glove box. The end-plugs were then inert-gas shielded-arc welded as shown in Figure 16, and the welds leak checked with a helium mass spectrometer. Thirty-six rods were checked simultaneously by placing the tubes in a tube bundle and evacuating the bundle with the pumps of the leak test station. A leak in a tube was readily detected since the atmosphere in the top of the sealed tubes contained 10 v/o helium.

Upon completion of the leak testing, the rods were loading into racks for further loading into the bonding furnace as shown in Figure 17. Each rack held 6 rods, the furnace accomodated 36 racks. The rods were heated in air for 4 hours at 475°C and vibrated at 1800 cycles per minute. The resultant amplitude was approximately $1/16$ ". At the end of 4 hours, the rods were removed from the furnace, shown in Figure 18, one rack at a time and differentially quenched to eliminate shrinkage voids by lowering them vertically into a circulating water bath at the rate of 3 feet per minute.

The rods were then inspected by passing them through an encircling differential eddy-current coil for determining bond integrity and measuring the sodium fill height, shown in Figure 19. This equipment had adequate sensitivity to detect non-bonded areas or voids as small as $1/32$ " in any direction and height of sodium above the uranium within $\pm 1/16$ ". Amplified signals from the coil were recorded on a continuous strip chart traveling at the same speed as the rod

through the coil. A permanent record with a 1:1 ratio to rod length was obtained. Rods which were not adequately bonded or contained voids in the sodium filled annulus were recycled through the sodium bonding process. Acceptable rods were assembled into blanket elements for loading into the reactor core.

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TABLE I

SUMMARY OF DATA OF BLANKET RODS FOR E.B.R. II

	TYPE OF BLANKET ROD	
	UPPER & LOWER	INNER & OUTER
NUMBER REQUIRED FOR REACTOR LOADING	2,394	11,250
TOTAL NUMBER PRODUCED	7,000	14,950
LENGTH (INCHES)	$21\frac{5}{8}$	$62\frac{7}{16}$
DIAMETER (INCHES)	0.376	0.493
NUMBER OF URANIUM SLUGS PER ROD	2	5
URANIUM SLUG DIMENSIONS		
LENGTH (INCHES)	9.000 ± 0.005	11.000 ± 0.005
DIAMETER (INCHES)	0.316 ± 0.0005	0.433 ± 0.0005
SODIUM ANNULUS (INCHES)	0.008	0.012
SODIUM FILL HEIGHT ABOVE URANIUM (INCHES)	0.450 ± 0.200	1.200 ± 0.500

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EBR-II REACTOR ELEVATION

276 008

Figure 1.

Figure 2.,

Upper and Lower Blanket Rod. Top; Machined, rolled and cleaned stainless steel tube. Center; Bottom end plug, two uranium slugs, Inconel-x compression spring and top end plug (L to R). Bottom; Assembled rod containing sodium.

Figure 3.

Inner and Outer Blanket Rod. (Top to bottom). Machined, rolled and cleaned stainless steel tube. Top end plug, Inconel-x compression spring and uranium slugs. Assembled rod containing sodium. Miniature display model. Length of assembled rod is $62\frac{7}{16}$ ".

Figure 4.

Glove Box Facility for Loading EBR-II Mark I Blanket Rods. Shown in this view are the elevated inert atmosphere glove box, operators' platform, control stations, and vacuum pumping systems under the platform.

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012

Figure 5.

Portable Tank-Type Oil Baths. Bath on left in high intermediate position with bottom six inches of tube bundle submerged in oil. Bath on right in high position with all but 2" of tubes of tube bundle submerged in oil. In foreground are gear motors for raising and lowering baths.

Figure 6.

Operator's Control Station Mounted at End of Platform.

Figure 7.

Sodium Extruder Before Assembly to the Glove Box. Shown in this photo is the hydraulic cylinder at the left which is sealed to the container in the center. A flange in the center is used to seal the extruder to the glove box. On the right is the die holder clamp ring, flying shear, and sodium run-out table.

Figure 8.

Loading End of Extruder. Shown in this view is an empty liner in loaded position, clamp ring, die and die holder.

Figure 9.

Ultrasonic Through Transmission Test Equipment Showing Rod Being Driven Between the Sending and Receiving Crystals. The recorder is in the center and electronic equipment in the rear.

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Figure 10. Ultrasonic Test Trace of a Uranium Slug Indicating a Defect and Macro of Same Slug Containing a Small Crack

Figure 11. Ultrasonic Through Transmission Trace of Uranium Slug Rejected for Abnormally Large Grain Size. Photomicrographs show area of large grain size and also an area of alpha recrystallized material.

Figure 12.

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Stainless Steel Blanket Tubes being Placed in Tubular Bundle for
Transfer to Glove Box Loading Station.

Figure 13. Inserting Extruded Sodium Slug in Blanket Tube with End Protected by Polyethylene Ferrule.

Figure 14. Inserting Depleted Unalloyed Uranium Slugs in Blanket Tubes.

Figure 15: Loading Inconel-x Compression Springs in Filled Blanket Tubes.

100 020

Figure 16. View of Inert-Gas Shielded-Arc Welding Equipment for Welding Bottom and Top End Plugs.

Figure 17. View of Rods Being Loaded Onto Racks for Further Loading Into Bonding Furnace.

Figure 18.

View of Loaded Rack, Containing Six Rods, Being Differentially
Quenched in Circulating Water Bath After Removal from Bonding
Dumaco

Figure 19. View of Eddy Current Test Equipment. The trace from this test was used for determining bond integrity and sodium fill height.