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A PROTOTYPE PORTABLE PUMP AND OXIDE-CLEANUP SYSTEM FOR EBR-II ROTATING SHIELD PLUG SEALS

by

P. Elias and G. Goldfuss

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Reactor Engineering Division

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TABLE OF CONTENTS

	<u>Page</u>
I. INTRODUCTION.	5
II. DESCRIPTION OF ROTATING SHIELD PLUGS AND ROTARY SEALS.	7
A. Rotating Shield Plugs	7
B. Rotary Freeze Seals	8
C. Temperature Control of Seal Alloy	10
D. Secondary Mechanical Seals	11
III. CHRONOLOGY OF OPERATIONAL DIFFICULTIES AND CORRECTIVE MEASURES	11
A. Recurrence of Plug Sticking	11
B. Initial Detection of Seal-alloy Oxides	12
C. Vacuum Removal of Oxides	12
D. Subsequent Operations, Inspections, and Changes	14
E. Wire-brushing Technique	15
F. Combined Vacuum and Brushing Operations	15
IV. PROTOTYPE OXIDE-CLEANUP SYSTEM.	16
A. Component Description.	17
B. Out-of-pile Tests	21
V. DISCUSSION: PAST AND FUTURE EFFORTS	23
ACKNOWLEDGMENT	23

LIST OF FIGURES

<u>No.</u>	<u>Title</u>	<u>Page</u>
1.	Principal Components of EBR-II Fuel-handling System.	6
2.	Rotating-shield-plug Assembly.	7
3.	Seal Blade-trough Design and Secondary Seals for Large Rotating Plug	9
4.	Partial Cross Section of Seal Blade on Large Plug, Showing Arrangement of "Fire Rod" Heaters	10
5.	Typical Deposits Vacuumed from Small and Large Rotating-plug-seal Troughs	13
6.	Prototype Oxide-cleanup System Proposed for EBR-II Rotating-plug Seals	16
7.	Exploded Assembly of Oxide-cleanup System Components	18
8.	Cross Section of System Showing Principle of Oxide Removal .	19
9.	Closeup View of Skimmer-trough Internals	21

A PROTOTYPE PORTABLE PUMP AND OXIDE-CLEANUP SYSTEM FOR EBR-II ROTATING SHIELD PLUG SEALS

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P. Elias and G. Goldfuss

I. INTRODUCTION

On September 13, 1965, principal responsibility for EBR-II was formally transferred from the Reactor Engineering Division at Argonne, Illinois, to the Idaho Division at NRTS, Idaho. Since that time, personnel from both Divisions have collaborated in reviewing plant performance, effecting system repairs and improvements, and developing experimental equipment. The objective here is to increase plant reliability, reduce operational complexities and costs, and enhance irradiation test capability of the reactor.

One post-shutdown operational problem that has persisted since July 1963, is occasional sticking of two, motor-driven, rotating shield plugs preparatory to exchange of fuel and/or special subassemblies containing irradiation test specimens. On some occasions, the plugs have been readily dislodged by motor-induced "jogging." On others, plug dislodgement has necessitated disengagement of the motor drives, substitution of a manually operated gear train, and application of considerable force.

This malfunction is significant because, as shown in Fig. 1, both plugs are subsequently rotated to position supported mechanisms (gripper holddown) involved in effecting these exchanges. In addition, the plugs support other reactor components (vessel cover and 12 control subassembly drives) that are disengaged to facilitate plug rotation. Thus if not resolved, the sticking problem could become progressively worse and impose a severe penalty (in terms of reactor downtime) on economy of operation and use of EBR-II for irradiation studies.

Continued investigation and analysis have narrowed the potential sources of plug sticking to accumulation of oxidic material in the bismuth-tin alloy rotary freeze seal on each plug. Accordingly, this report describes: (1) the measures employed to reduce oxidation of the seal alloy; (2) the time-consuming, manual techniques used periodically for batch-type removal of oxidic material that does accumulate; and (3) the prototype, portable pump and cleanup system that is designed to expedite removal of this material. Also included are the results of out-of-pile feasibility tests performed successfully on the prototype system under simulated operating conditions.

112-1998 Rev. 2

Fig. 1. Principal Components of EBR-II Fuel-handling System. Reactor has been shut down; reactor cover hold-down clamps have been released; freeze seals on both rotating plugs have been heated to the completely molten state; control subassembly drive shafts have been disconnected; and the reactor cover has been raised clear of the transfer arm. In this view, the manually operated transfer arm has removed a fresh subassembly from the refueling-machine coffin grapple to gripper mechanism-holddown assembly for ultimate positioning and insertion into reactor. Positioning is accomplished by relative rotation of large and small rotating plugs. All operations are performed by remote control from an adjacent console (not shown), with the subassembly completely submerged in the primary sodium coolant.

II. DESCRIPTION OF ROTATING SHIELD PLUGS AND ROTARY SEALS

The following design descriptions include modifications that were made upon removal of both plugs after initial installation checkout tests, in July 1962, and prior to filling the primary tank with sodium.

A. Rotating Shield Plugs

The rotating-shield-plug assembly (see Fig. 2) consists of two stepped plugs, each 8 ft thick and fabricated of Type 304 stainless steel plate (2.50-3.25 in. thick). The smaller plug (of 83.75-in. OD) rotates on a

Fig. 2. Rotating-shield-plug Assembly

ball-bearing ring which is eccentrically located in and supported by the larger plug (of 125.25-in. OD). The latter, in turn, rotates on a similar ring which is mounted on the primary-tank support structure. Both plugs are equipped with a rotary freeze seal which, when completely molten, permits plug rotation while maintaining gastight integrity of the primary tank. Both plugs are rotated independently by electric motors mounted on the large plug and tank cover, respectively.

Each plug is partially filled with shielding material (a 3-ft-thick layer of steel shot topped by a 4-ft-thick layer of high-density concrete). The small plug is pierced by 17 vertical sleeves to accommodate two reactor-vessel cover-lifting shafts (of 4.5-in. OD), one subassembly-holddown shaft (of 6-in. OD), one subassembly-gripper shaft and a spare nozzle (each of 3.75-in. OD), and twelve control-rod drive shafts (each of 2.5-in. OD). In addition, both plugs are penetrated vertically near the periphery by numerous 0.625-in.-dia holes: 120 in the large plug and 80 in the small plug. Each hole contains a Type 304 stainless steel-clad, "Fire Rod" heater for melting the freeze seal.

B. Rotary Freeze Seals

Figure 3 shows the seal installed on the large plug. A similar seal but of smaller diameter is installed on the small plug. Each seal consists of a vertical, cylindrical blade welded in alignment with the heater holes and a mating trough attached to the plug stationary support.

As shown in the partial cross section of Fig. 4, the seal blade for the large plug is a welded and bolted assembly of two Type 304 stainless steel rings which is of 124.125-in. ID, 14.75 in. high, and of 1.125-in. wall thickness. Except for the inside diameter (82.625 in.), the blade for the small plug is of identical construction.

The trough for the large plug seal measures 128.875 in. in OD, 10.500 in. in height, and 3 in. in width; the trough is fabricated of Type 304 stainless steel plate, 0.188 in. thick. It contains 2100 lb of low-melting-point alloy (58% bismuth-42% tin; M.P. 281°F), in which the blade is immersed. Constructed of similar material, the trough for the small plug seal (of 87.25-in. OD, 11 in. high, and 2.50 in. wide) contains 1300 lb of alloy.

During reactor operation, the alloy in the upper half of each trough is allowed to freeze while that in the lower half is maintained in the molten state. The frozen region prevents loss of seal alloy in the event of a large pressure differential across the seal; the molten region prevents outleakage of argon blanket gas from the primary tank. Preparatory to plug rotation for fuel handling, the alloy is heated to the completely molten state.

112-2300 Rev. 1

Fig. 3. Seal Blade-trough Design and Secondary Seals for Large Rotating Plug. Inset shows single secondary seal employed on small rotating plug.

Fig. 4 Partial Cross Section of Seal Blade on Large Plug, Showing Arrangement of "Fire Rod" Heaters

Two "windows" are provided for viewing the seal alloy on either side of each blade during fuel-handling operations. On the building atmosphere side, the window consists of a lateral, rectangular slot (0.75 in. wide) cut through the blade to one of the upper heater holes. The slot extends from an elevation equivalent to the trough top to about 3 in. below the alloy surface. For viewing, the heater in this hole is removed and a boroscope is inserted. Similar viewing of the alloy on the primary-system argon side is accomplished through a hole drilled vertically through the plug body. Later on, additional access holes were drilled as described on p. 13.

C. Temperature Control of Seal Alloy

The half-frozen or the completely molten state of the seal alloy is achieved by controlling current input to the heaters whose active sections are spaced 6 in. apart at the corresponding levels in the seal blades (see Fig. 4).

In the original installation, Type 304 stainless steel-clad, Chromel-Alumel thermocouples were spaced circumferentially about 15 in. apart for measuring seal-alloy temperatures at four levels. These temperatures were regulated by scanning-type controllers that monitored individual thermocouple outputs sequentially and effected "ON-OFF" operation of the heaters.

As a result of the installation checkout tests, the upper and lower heaters were grouped electrically into six sectors, each sector being controlled individually. The upper heaters are constantly energized at lower power and the power level may be varied from sector to sector around the seal. On-off control of the lower heaters was retained, but applied to each sector.

All thermocouples were repositioned consistent with the new heater system and mounted so they could be readily replaced. Some nonreplaceable units also were installed. One thermocouple in each sector of the seal blade is used for control-temperature sensing. During plug rotation, each of these thermocouples bears a constant spatial relationship to the sector of heaters which it controls, irrespective of plug position.

This mode of control, coupled with the revised heater arrangement, is designed to maintain an almost uniform temperature around the seal periphery at the molten alloy surface. This uniformity, in turn, should result in the lowest maximum (local) seal-alloy temperature consistent with assurance that the alloy is completely molten. Calculations indicated that the seal should be operable at a maximum temperature of less than 400°F.

D. Secondary Mechanical Seals

As shown in Figs. 1 and 2, the manner in which the large plug and seal trough are supported results in some lateral and vertical movement of both components during plug rotation. Therefore, as shown in the enlarged view of Fig. 3, two sliding-bearing seals are installed to accommodate both motions and minimize inleakage of shield-cooling air, particularly when the seal alloy is in the molten state and most susceptible to oxidation. In addition, provisions are made for flushing the area above the seal alloy prior to melting the alloy and then maintaining a low-flow purge while it is in the molten state.

By comparison, the small plug and seal trough are supported, in effect, by the large plug. Hence, neither is subject to significant vertical motion. Therefore, as shown in the inset of Fig. 3, a single sliding seal is installed to accommodate lateral movement. Similar provisions are made for initial flushing and continuous low-flow purging of the region above the seal alloy.

Laboratory experiments indicated that oxygen concentrations well below 1% were achievable with this seal arrangement.

III. CHRONOLOGY OF OPERATIONAL DIFFICULTIES AND CORRECTIVE MEASURES

A. Recurrence of Plug Sticking

Sticking of the large rotating plug was first encountered during sodium-cleanup operations in July and August 1963. On both occasions, the plug was freed by altering temperature distributions in the seal trough.

Similar sticking also occurred in November 1963, during loading of subassemblies for the wet critical experiments. At that time, one seal-trough thermocouple was found to be defective and was replaced. In addition, a check of the seal-heater circuitry revealed one circuit was open. Ammeters were installed for detecting future heater failures.

No further difficulties were experienced with plug rotation until late June and during July 1965. On these occasions, manual assistance was required to effect dislodgement. Attention was then focused on the seal alloy.

B. Initial Detection of Seal-alloy Oxides

Wire probes, inserted through the "windows" in each seal blade, revealed the presence of spongy or crusty layers of deposits in the outer annulus of the respective troughs. Most of these deposits were submerged 1 or 2 in. below the molten alloy surface.

Five samples were removed through a vacated heater hole with the aid of a metal syringe (0.375-in. tubing with an internal plunger). These samples consisted of molten metal, black powdery oxide, and porous black clinkers or nodules (see Fig. 5). Chemical analysis of the powdery and nodular samples revealed they were predominantly oxides of bismuth, tin, and sodium. Sodium content of the oxide ranged from 12.5 w/o in sample No. 1, 10 w/o in each of samples No. 2 and No. 3, to 3-4 w/o in samples No. 4 and No. 5. In all samples, the iron content was less than 0.25%.

The significance of finding these oxide deposits (or metal-oxide mixtures) was twofold: they could account for the plug sticking and the apparent poor temperature distribution in the troughs. In the latter case, for example, the oxide could blanket some of the upper-level thermocouples, interfere with heat transfer from the molten alloy to the thermocouple, and result in low indicated temperatures. This was substantiated by probing locations which registered low temperatures, apparently disturbing the oxide deposits, bringing molten alloy in contact with the thermocouples, and thereby obtaining increased temperature readings.

These findings prompted efforts to develop techniques and equipment for removing substantial amounts of oxide from the troughs in order to improve heat distribution and thus eliminate plug sticking.

C. Vacuum Removal of Oxides

During August and September 1965, approximately 23.5 lb of black powdery oxide, nodules, and metal were removed from the large plug seal; 2.5 lb of the same material were removed from the small plug seal. In both instances, the deposits were removed through a length of steel tubing (of 0.500-in. ID) leading from the viewing hole in the plug to a vacuum

Powdery oxide from above seal alloy. About 96 gm filtered through duck cloth of vacuum cleaner bag.

Mixture of powdery oxide, nodules, and metal. Material plugged the vacuum tubing which required reheating to effect release.

High metal-content deposit which also plugged the vacuum tubing.

Fig. 5 Typical Deposits Vacuumed from Small and Large Rotating-plug-seal Troughs

cleaner. As a result of these cleanup operations, less seal heating time was required (40 hr vs. 56 hr) before the large plug could be rotated. Vertical temperature profiles at several large plug locations showed maximum temperatures of 355°F at the seal alloy surface, and 528°F near the bottom of the trough.

Two samples of nodular oxides from the large plug-seal trough were chemically analyzed and found to contain the equivalent of 6 and 13 w/o sodium, respectively.

D. Subsequent Operations, Inspections, and Changes

Both seals were melted and the plugs rotated a number of times during January 1966 without any significant changes in operation of either plug. Toward the end of the month and continuing through February, each of the 200 austenitic Type 304 stainless steel-clad heaters was replaced with a unit clad in ferritic Type 405 stainless steel. The latter is more compatible with the bismuth-tin alloy.

Early in March 1966, the transfer arm was removed for repair, and advantage was taken of the vacated nozzle to inspect the plug annuli exposed to the bulk sodium coolant. The objective here was to determine whether plug sticking might be caused by deposition of sodium and/or sodium oxide in these annuli.

Because of space limitations on the offset viewing device and light source, inspection was confined to a few degrees of the small-plug annulus, and an arc of about 60° on the large-plug annulus. Some small globules of sodium oxide were observed near the bottom of the large annulus, but there was no visible evidence of blockage in either annulus. Improbability of sodium blockage in the balance of either annulus was affirmed by temperature measurements above the offset in the large annulus. Measured values were above the melting point of sodium, even with a bulk sodium temperature of 280°F.

To facilitate future inspection, one vertical hole (of 0.875-in. ID) was drilled to the area of the offset and lower annulus of each plug. A similar hole was drilled through the small plug to permit sampling of seal alloy from the air side of the seal trough. Access to the large plug-seal trough was provided by enlarging the "window" heater hole and penetrating the gas seal above the trough.

All access holes were completed and used to vacuum clean the seal troughs in September 1966. About 26 lb of powdery oxide were removed from the small plug and 50 lb from the large plug troughs. Subsequent probing with a 0.5-in.-dia tube revealed moderately compacted deposits of oxide-like material. This material extended several inches down into the

troughs and, except for discontinuities, apparently continued around the trough circumference. A considerable amount of the "scaly" material was removed by "coring" with the tubular probe.

E. Wire-brushing Technique

This simple technique was particularly effective in removing the "scaly" material. It consisted of inserting, rotating, and oscillating a steel-bristled, condenser-tube cleaning brush (of 0.75-in. diameter) into the molten alloy. By these actions, the compacted oxide is worked into the bristles, largely remains there when the brush is withdrawn, and then is tapped out of the brush into a container.

Approximately 68 lb of a gray and light-colored material were removed from both seal troughs by combined coring and brushing operations. Chemical analyses for bismuth and sodium contents revealed 42.8 w/o Bi-5.5 w/o Na in the light-colored and 42.3 w/o Bi-4.5 w/o Na in the gray-colored "oxide." The equivalent sodium contents were 7.5 and 6.1%, respectively. Some of the initially gray oxide removed by coring turned white after several hours of exposure to air. Hence, the sodium content of the lighter-colored material is more representative of the compacted oxide.

After completion of the cleaning operations, the alloy levels were measured to be 8 in. in the small trough and 6.75 in. in the large trough. Makeup alloy was added to restore the specified operating levels of 9 and 8.25 in., respectively.

F. Combined Vacuum and Brushing Operations

Prior to these operations in October 1966, the vacuum cleaner was replaced with a large, mechanical vacuum pump. An alloy-melting and -charging apparatus was fabricated for adding makeup alloy to the seal troughs, and longer condenser-tube cleaning brushes were procured to entrap more oxide.

Two days of vacuum cleaning were unproductive. Boroscope examination revealed very little powdery oxide on the seal alloy surface. Upon application of the brushing technique, some oxide-like material was removed from the trough walls, seal blades, and the bulk alloy. Brush cleaning was continued until the molten alloy contained well in excess of 50% metal (excluding the unoxidized metallic component of the oxide). About 32 lb of material were removed from the small trough, lowering the alloy level from 8 to 7.75 in., and 130 lb were removed from the large trough, with a corresponding alloy level decrease from 6.75 to 5.75 in.

Again, makeup alloy was added to each seal trough: 127 lb in the small-plug trough, and 350 lb in the large-plug trough. Subsequent checks on the argon side of each trough showed alloy levels of 8.75 in. in the small plug trough and of 8.125 in. in the large plug trough.

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Fig. 6. Prototype Oxide-cleanup System Proposed for EBR-II Rotating-plug Seals

with plug rotation for a complete traverse of each trough. Upon completion of cleanup operations, the system is removed and makeup alloy is added, as necessary, to ensure a gastight plug assembly during postfueling operations.

Preparatory to fuel-handling operations on December 3, 1966, the alloy in each trough was heated and maintained in molten state for about 4 hr. At that time, and during the ensuing four days of fueling operations, both plugs were rotated without difficulty.

On December 6, samples were taken from each trough to check the alloy composition. The results of this analysis showed an insignificant deviation from the original average composition of the alloy (58 w/o Bi-42 w/o Sn).

Further vacuum-brushing cleanup operations were suspended indefinitely, and both seals were returned to the half-molten state on December 7, 1966. Since that time, effort has been directed toward development and testing of a portable cleanup system which can be used periodically to prevent oxide buildup and consequent plug sticking.

IV. PROTOTYPE OXIDE-CLEANUP SYSTEM

Figure 6 shows the most promising portable oxide-cleanup system evolved thus far. The system which weighs 20 lb, is designed to agitate and pump continuously the oxide-containing seal alloy from each trough, through special inspection holes, to a motorized skimmer bowl atop the respective rotating plug. Here, the surface oxide is skimmed into a separate container, and the "purified" alloy returns by gravity to the trough through an adjacent heater hole. Pumping and skimming operations are carried out simultaneously

Long-term out-of-pile tests of the prototype system have been performed under simulated prefueling conditions and with alloy containing a known amount of "deposits." The results show that the system delivers 1.2-1.5 gpm of seal alloy at a 34-in. outlet head, with a cleanup efficiency of 100% of the floating deposits entrained to the skimmer trough. Subject to actual in-reactor tests, the projected pumping operations would last 30 min for the large rotating-plug seal and 20 min for the small-plug seal. The cleanup efficiency will depend upon the degree of mixing effected in the trough.

A. Component Description

The following component descriptions are made with reference to the exploded and cross-sectional views of the pump assembly (see Figs. 7 and 8, respectively), starting with the strainer at the lower end of the pump tube.

Fabricated of Type 304 stainless steel, the louvered strainer is of 1-in. overall height and tapers from 0.375 in. at the extreme bottom to 0.625 in. at the top. Here, the strainer is threaded onto the pump tube. At high rotational speeds, the pump impeller creates a high-pressure-fluid region in the surrounding space because of the centrifugal forces and swirling in the fluid. The stationary louvers act as stator nozzles and guide the swirling fluid into the impeller. In addition, the strainer prevents the rotating impeller from contacting the bottom of the seal troughs.

Also fabricated of Type 304 stainless steel, the pump tube is 32.25 in. long, of 0.625-in. OD, with the nominal 0.500-in. ID reamed to 0.505 in. As shown in Fig. 8, the pump tube houses a 33.25-in.-long, 0.25-in.-dia impeller drive shaft of hardened drill steel. On this shaft are mounted two impellers, one at the bottom and the other about 21 in. from the bottom. Both impellers are fabricated of tool steel and measure 0.50 in. in diameter and overall height. The impeller drive shaft is centrally located and supported by three bearings spaced 1.25 in., 10.50 in., and 20.50 in. above the strainer. Each bearing consists of a journal (of 0.253-in. ID and 0.312-in. OD) and three radial webs of hardened tool steel. Each web is plug-welded to the tube wall. At the upper end, the pump tube is threaded (left hand) into the pump body.

The pump body, fabricated of Type 304 stainless steel, is 18 in. long, 1.25 in. in OD, and 1.0625 in. in ID. It is threaded at the upper end to accommodate the air-motor support housing and contains three Oilite bushings (of 1-in. OD and 0.50 in. thick) spaced vertically on 5-in. centers. These bushings provide lateral support and vertical alignment of a 0.375-in.-OD, 15-in.-long extension of the impeller shaft which interconnects the air-motor-drive collet.

112-8439-A

Fig. 7. Exploded Assembly of Oxide-cleanup System Components

Fig. 8. Cross Section of System Showing Principle of Oxide Removal

The air motor is a commercially available, multivane, nonreversible unit, having the following specifications:

Length, in.	6.75	
Outside diameter, in.	~2.00	
Weight, lb	1.50	
	<u>Air Pressure, psi</u>	
	<u>60</u>	<u>90</u>
Rated horsepower, hp	0.27	0.47
Speed at rated horsepower, rpm	11,000	12,500
Free speed, rpm	22,000	25,000
Maximum torque, ft-lb	0.268	0.40
Size hose connection pipe tap, in.	0.125	
Recommended hose size, in.	0.250	

The sidewall of the pump body (below the first Oilite bushing) is pierced by a rectangular opening (1.25 in. high and 0.75 in. wide). Effluent from the pump body discharges through this opening onto a ramp leading into the skimmer trough, which is attached to the pump body.

The skimmer trough (also see Fig. 9) measures 12.75 in. in length, 3 in. in width, and 5 in. in depth, and is fabricated of Type 304 stainless steel sheet, 0.0312 in. thick. Inside the trough, the ramp terminates in a vertical baffle that extends to within 0.25 in. of the trough bottom. Approximately 1 in. behind the baffle, the trough bottom is penetrated by a 0.50-in.-ID, 31.25-in.-long standpipe. This standpipe maintains a constant liquid-level height extending from the bottom of the ramp across the trough to an incline at the opposite end. In addition, two 0.312-in.-dia, 1.75-in.-long vent tubes are installed in the ramp to prevent syphoning under the baffle, or a back pressure from changing the liquid-level height.

The surface of the liquid is skimmed by four Type 304 stainless steel blades (2.875 in. wide, 0.500 in. high, and 0.0625 in. thick) which span the width of the trough. These blades, spaced 4 in. apart, are attached to an electric motor-driven, sprocket-and-chain assembly which traverses the length of the trough.

In operation, the seal alloy and oxides are pumped up from the seal trough, and discharged through the pump body opening and down the ramp into the skimmer trough. Being less dense than the parent metal, the dross and oxide float to the surface which is traversed by the skimmer blades to a depth of about 0.125 in. Each blade travels at a rate of 0.5 in./sec, pushing the surfaced material toward and up the incline. Here, the lighter material discharges through an opening (3 in. long and 0.50 in. wide) into a separate container. The heavier parent metal flows back under the baffle, down the standpipe, and into the seal trough to complete the cycle.

112-8441-A

Fig. 9. Closeup View of Skimmer-trough Internals

The skimmer trough has provisions for introducing and maintaining an inert gas blanket above the seal alloy to minimize oxidation during the skimming process. Throughout this process, the alloy is maintained in the molten state by resistance heater wires and tapes which are wrapped around the pump tube, skimmer trough, and standpipe. Current input is controlled by a variable transformer. Seal-alloy temperature is indicated by thermocouples affixed to the walls of the aforementioned components.

B. Out-of-pile Tests

In these tests, the prototype system was positioned above, and used to pump and clean up bismuth-tin alloy from, a mock-up section of the EBR-II seal trough. The trough measured 7 in. long, 1 in. wide, 9 in. deep, and was fabricated of Type 304 stainless steel. At the outset

of the test runs, the trough was loaded with 15 lb of seal alloy, including about 1.5 lb of dross and oxides (see Fig. 5). Makeup mixture was added, as necessary, prior to each successive test run. During each test, the mixture was heated to the molten state and maintained at a temperature of 300°F by resistance-heater wires wrapped around the mock-up trough, pump tube, and skimmer trough. The alloy temperature was monitored by thermocouples attached to the walls of these components.

Approximately 40 hr of successful testing were accumulated along with the following observations and measurements:

(1) Pumping efficiency is affected significantly by the depth to which the pump tube is submerged in the seal trough. The strainer-impeller assembly must be immersed below the surfaced oxide and dross to ensure their mixing with, and entrainment by, the bulk alloy. Otherwise, the powdery dross will not enter the pump. In operation, the mixing-entrainment process is enhanced by the clean alloy which discharges from the standpipe above the surfaced deposits.

(2) With the pump tube submerged 2 in. below the alloy surface, and the air motor operating at 12,000 rpm, the mixture discharged at a rate of 120-125 lb/min into the skimmer trough. Within the trough, the surfaced deposits were skimmed at a rate of 0.3 lb/min.

(3) The mixture discharge rate decreased proportionally with the air-motor speed, and ceased flowing at a motor speed of 6,000 rpm.

At the conclusion of the tests, the system was dismantled for inspection. There was no evidence of excessive wear on the impeller shaft, bearings, or bushings.

The skimmed-off deposits were heated in a separate container at successively increased temperatures to determine the metal content. This was found to average 15-20% at 600°F; the balance was of a foamlike consistency.

No chemical analysis was made of the deposits or the metal yield. The primary objectives of the out-of-pile tests were to pump the alloy continuously from the mock-up trough and remove the entrained deposits. Both objectives were accomplished successfully.

In July 1967, the prototype pump-skimmer assembly, along with sketches and specifications, were transferred to Idaho personnel for their review, modification (as necessary), construction, and testing on both rotating-shield-plug seals in the EBR-II.

V. DISCUSSION: PAST AND FUTURE EFFORTS

Since termination of extensive oxide-cleanup activities in December 1966, experience with seal melting and plug rotation has instilled confidence that reliable operation has been restored. As of June 30, 1967, both plug seals have accumulated 476 hr in the molten condition and 202 hr in the heating phase without major malfunction of either plug. Approximately 3 to 4 hr of seal heating has been required to release the plugs for rotation.

As a precaution against future plug malfunction due to oxide buildup, the seal alloy will be surveyed periodically by manual sampling and probing. Cleaning operations will be implemented upon detection of oxide buildup or if seal performance begins to deteriorate. Whether such cleaning and/or purification is performed continuously or batch-wise will depend upon in-reactor tests of the prototype pump system and the character of the impurities to be removed. In any event, it is not anticipated that cleaning operations will be as extensive as those performed in late 1966, since the latter cleanup represented removal of several years' accumulation of oxidic material.

In summary, normal plug rotation has been achieved by identifying and developing methods for expeditious removal of the obstructing oxidic materials. However, the origin of these materials and/or the mechanisms which have or may promote their buildup in the future is, at present, confined to theories. Of these theories, only the segregation phenomenon has been investigated to the extent that results merit further study.

Budget allocations have been provided for programmatic studies of the segregation, oxidation, and corrosion theories that have been advanced. The findings of such a program could provide information of immeasurable value in the design of similar seals for future reactors.

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