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SINTERED ALUMINA AS A PUMP BEARING AND JOURNAL MATERIAL

1. SUMMARY

In the ORNL Homogeneous Reactor Project a number of ORNL 5-gpm canned-rotor pumps used in the in-pile loops for radiation-corrosion studies and three Westinghouse model 100A canned-rotor pumps used in the dynamic out-of-pile corrosion test loops have been equipped with bearings and journals of pure sintered alumina to improve bearing and journal performance.

Two of the first four in-pile loop pumps equipped with Graphitar No. 14 bearings and Stellite 98M2 or hardened 17-4 PH stainless steel failed because of excessive bearing wear. No pump failure has occurred as a result of bearing wear and/or corrosion in the eight in-pile loop pumps with aluminum oxide bearings and journals during a total cumulative in-pile operating time of approximately 10,000 hr. However, five of these eight pumps have failed as a result of bearing displacement (slippage) and/or electrical breakdown of the stator insulation. Design modifications have been made to eliminate these two causes of pump failure.

Two of the Westinghouse model 100A pumps equipped with aluminum oxide bearings and journals have pumped uranyl sulfate solution at 300°C for more than 7,000 hr with no evidence of bearing wear. A third model 100A pump with aluminum oxide bearings and journals will be tested in a loop circulating thorium oxide slurry.

Design criteria and operating experience with the aluminum oxide bearing and journal combination as installed in these pumps are presented.

2. INTRODUCTION

In the ORNL Homogeneous Reactor Project, in-pile loops are used to study radiation-corrosion effects on materials exposed to a variety of environmental conditions that approximate those in an operating homogeneous reactor. The initial design of the ORNL 5-gpm pump for use in the in-pile loops specified Stellite 98M2 journal bushings and Graphitar No. 14 bearings, primarily because these materials had served quite acceptably in the out-of-pile dynamic corrosion test loops. The first four in-pile pumps were therefore equipped with Graphitar No. 14 bearings, and three of the four contained Stellite 98M2 journal bushings (one contained journal bushings of partially hardened 17-4 PH stainless steel).

Several considerations pointed up the desirability of a different bearing and journal material:

1. Two of the first four in-pile loop pumps (loops GG¹ and EE^{2,3,4}) failed, after 1218 and 897 hr of operation, respectively, because of excessive wear of the Graphitar No. 14 bearings. The journal bushings in the pumps in loops GG and EE were, respectively, Stellite 98M2 and hardened 17-4 PH stainless steel.

2. Although the Stellite 98M2 and Graphitar No. 14 had given satisfactory service in pumps in out-of-pile loops, where the bearing and journal temperatures are normally less than 100°C, it was believed that temperatures up to ~150°C might be required in the pump bearing region of the in-pile pumps.

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(At the higher temperature the buildup of hydrogen peroxide, from fission-product radiation in the aqueous fuel solution, would be minimized. Too high a concentration of hydrogen peroxide would cause uranium peroxide precipitation in the pump bearing region and thus loss of uranium from the circulating fuel solution). The corrosion resistance of Stellite 98M2 in uranyl sulfate solution at temperatures above $\sim 100^{\circ}\text{C}$ was considered unsatisfactory both from the bearing-reliability standpoint and the introduction of cobalt (an alloying element in Stellite 98M2) into the circulating fuel solution. It had been observed in the 100A pump loops that cobalt (from bearing wear or corrosion) formed a complex compound with uranium, which precipitated, with a resultant loss of uranium from solution.

3. The Graphitar No. 14 material is, of course, subject to oxidation by the oxygen used in the loops to maintain solution stability. Any such loss of oxygen would mask the overall in-pile loop metal corrosion rate as calculated from the oxygen consumption.

The excellent properties of alumina as a bearing and journal material with water lubrication had been demonstrated by others;⁵ so it appeared to be a logical choice to try in the canned-rotor pumps. The corrosion resistance of pure alumina is comparable to that of Stellite 98M2 in oxygenated uranyl sulfate solutions at 100°C (maximum pump temperature used in experiments to date); at temperatures $> 100^{\circ}\text{C}$ the alumina is more corrosion-resistant than Stellite 98M2 or Graphitar No. 14. Also, the inertness of alumina to oxidation was an important factor in its selection.

It is the purpose of this report to set forth the design considerations and operating experiences with aluminum oxide as a bearing and journal bushing material in the Westinghouse model 100A pumps and the 5-gpm in-pile loop pumps.

3. CORROSION TEST RESULTS

Corrosion tests have been made on materials of interest for pump bearings and journal bushings. Included in these tests have been Stellite 98M2, 17-4 PH stainless steel, Graphitar No. 14, and aluminum oxide. Test results^{9,10,12,13,14} on these materials in uranyl sulfate solution of various concentrations and at temperatures up to 300°C and in 5% nitric acid solution at 100°C are shown in Table I. Both static and dynamic corrosion tests are included in Table I. One dynamic corrosion test was made in which a number of proposed pump bearing materials were simultaneously exposed to a circulating fuel solution;⁷ results of that test are given in Table II.

From Tables I and II it can be seen that in uranyl sulfate solutions up to a concentration of approximately $0.17\text{ }m$ containing varying amounts of excess sulfuric acid and copper sulfate the corrosion rates of Stellite 98M2, 17-4 PH stainless steel (partially hardened to Rockwell C 30-35), Graphitar No. 14, and aluminum oxide are small ($< 2\text{ mpy}$) at a temperature of 100°C or less. The pump bearings are estimated to be at approximately this temperature during normal pump operation with loop temperatures to 300°C .

One exception to the low corrosion rate at 100°C is a rate of 10 mpy obtained for Stellite 98M2 in $1.33\text{ }m$ uranyl sulfate solution.

At temperatures of 150°C and above the corrosion rates of the materials tested were quite different. In addition, different results were

obtained in static and dynamic conditions. The 150°C temperature is of interest for future operating conditions as mentioned in Sec. 2. A brief summary of the corrosion test results of each pump bearing material tested is given below. More detailed information may be obtained from Tables I and II.

(a) Aluminum Oxide. -- With one exception the maximum corrosion rate obtained for the pure sintered aluminum oxide was 12 mpy. This includes both static and dynamic (~ 12 fps) tests at temperatures up to 300°C. The exception is a corrosion rate of 27 mpy obtained in 1.33 m uranyl sulfate solution at 250°C. Most other corrosion rates were less than ~ 3 mpy.

(b) Stellite 98M2. -- The corrosion rate of Stellite 98M2 increases rather rapidly with increasing temperatures. While the rate was < 2 mpy at 100°C, rates of 200 and 290 mpy were obtained at 200°C in uranyl sulfate solutions of 0.06 m and 0.11 m concentration, respectively. In both cases some excess sulfuric acid was added to the solutions. At 150°C in a solution containing 0.04 m UO_2SO_4 , 0.02 m H_2SO_4 , and 0.005 m CuSO_4 at a flow velocity of 13 fps, the corrosion rate was 40 mpy as compared to 12 mpy for aluminum oxide.

(c) 17-4 PH Stainless Steel. -- The partially hardened 17-4 PH stainless steel (Rockwell C 30-35) gave corrosion rates up to a maximum of 18 mpy. This maximum rate was obtained at 200°C with a solution containing 0.06 m UO_2SO_4 and 0.006 m H_2SO_4 . No tests were made at temperatures above 200°C. At 150°C the corrosion resistance of partially hardened 17-4 PH stainless steel was equal to or better than the aluminum oxide.

The fully hardened 17-4 PH stainless steel (Rockwell C-44) was less corrosion resistant than the partially hardened material. A rate of 30 mpy at 100°C in a 0.17 m uranyl sulfate solution was obtained. In addition, the fully hardened material cracked and blistered in some of the tests. Thus, from the standpoint of corrosion resistance, extreme care is required in the heat-treating procedure when hardening 17-4 PH stainless steel for use as a bearing or journal bushing.

(d) Graphitar No. 14. -- Graphitar No. 14 exhibited excellent corrosion resistance, with corrosion rates essentially zero, at temperatures of 100°C or less. However, in oxygenated solutions at temperatures of 150°C and above, the corrosion resistance of Graphitar No. 14 was poor. A rate of > 200 mpy was obtained in oxygenated water at 300°C at a flow rate of 12 fps. At 150°C in a 0.04 m UO_2SO_4 solution containing 0.02 m H_2SO_4 and 0.005 m CuSO_4 at a flow rate of 13 fps, the corrosion rate was 81 mpy.

Since the Graphitar is porous, it probably retains some of the solution to which it is exposed even after repeated washing and drying. Thus the weight changes, normally used to measure corrosion, may not indicate a true corrosion rate. In one test¹⁵, conducted in a static autoclave at 100, 125, and 150°C, analysis of the carbon dioxide produced by oxidation of the Graphitar was used to determine the amount of corrosion. The test solution was 1.34 m uranyl sulfate to which 100 psi overpressure of oxygen was added. A standard Graphitar No. 14 bearing as used in the Westinghouse model 100A pumps was used as the test specimen. Based on the carbon dioxide analysis and using the plane surface area as the exposed surface, corrosion rates of 1-4 mpy at 100°C and 5-10 mpy at 120 and 150°C were obtained.

In addition to the over-all corrosion of the Graphitar No. 14 bearing, measurements of surface finish were obtained in the test described above. The initial surface finish of the Graphitar No. 14 bearing varied between 10 and 20 μ in. After approximately 1300 hr exposure in the 1.34 M uranyl sulfate solution (~ 700 hr at 100°C, ~ 400 hr at 125°C, and ~ 200 hr at 150°C), the surface-finish measurements had increased to 80 to 120 μ in. An increase in the over-all length of the bearing of ~ 0.015 in. (2.010 in to 2.025 in.) was also noted after the test.

4. BEARING AND JOURNAL DESIGN

The aluminum oxide bearings and journals in use on both the Westinghouse model 100A pump and the ORNL 5-gpm pump were designed to be interchangeable with, and identical to, the Stellite 98M2 journal bushings and Graphitar No. 14 bearings currently in use, so that existing pump rotors and bearing housings could be used. The aluminum oxide material used in all bearing applications to date has been obtained from the Kearfott Company, Clifton, New Jersey. Formal specifications have not been used, and the material is identified as "pure sintered alumina, fine-grained." Spectrographic analyses of samples of the aluminum oxide bearing material obtained from the Kearfott Co. have indicated approximately 99% Al_2O_3 .

The bearings and journals for both the Westinghouse model 100A pump and the ORNL 5-gpm pump are of the sleeve type and are lubricated by the loop circulating solution. In the present application, this solution is either water, 5 wt % nitric acid solution, 3 wt % trisodium phosphate solution, or various concentrations of aqueous solutions of uranyl sulfate. The uranyl sulfate solution may, in some cases, contain copper sulfate and excess sulfuric acid. These pumps are designed to operate at pressures up to 2000 psia with the circulating solution at temperatures up to 300°C. However, the liquid in the pump bearing region is normally at a temperature below 125°C.

4.1 Westinghouse Model 100A Pump

The aluminum oxide journal bushings are installed on the Westinghouse model 100A pump rotor shafts as shown in Fig. 1. The bushing is purchased in the form of a cylindrical blank with a flange on one end. The dimensions of this blank are such that approximately 0.010 in. is allowed for final grinding and finishing. The bushing is finished to final dimensions such that the ID of the bushing is approximately 0.001 in. larger than the pump rotor shaft. This is done to allow for thermal expansion of the shaft during operation without overstressing the aluminum oxide bushing; the coefficient of thermal expansion of the alumina is reported as 5×10^{-6} °F. This allows for a temperature rise of the pump shaft and journal of ~ 200°C before any stress is applied to the bushing from expansion of the rotor shaft. The bushing is held in place by means of two clamp rings as shown in Fig. 1. These clamp rings are of the same material as the rotor shaft and are machined to produce an interference fit on the shaft and journal bushing. A relief groove is cut in both ends of the alumina to accommodate the clamp rings. The OD of the clamp ring is below the bearing surface. Figure 2 is a photograph of the aluminum oxide bushing as installed on the rotor shaft.

The aluminum oxide bearings are of the same material as the journal bushings, and they are also purchased as cylindrical blanks with approximately

0.010 in. allowance for finish grinding of the ID and OD. The bearings are installed in bearing housings as shown in Fig. 3. The aluminum oxide bearings are held in place in the housing by means of a 0.001 to 0.002 in. interference fit. This allows for a temperature rise of 100 to 200°C (depending on the interference) of the bearing assembly before the aluminum oxide becomes loose enough for possible slippage in the housing. Figure 4 is a photograph of an aluminum oxide bearing as installed in its stainless steel housing.

The lengths of the journal bushings and bearings are approximately 2 in. The diametrical clearance between the journal bushings and bearing is approximately 0.002 in. The surface finish of both bearings and journals is specified as $< 5 \mu\text{in.}$

4.2 ORNL 5-gpm In-Pile Pump

The ORNL 5-gpm pump used to circulate solution in the in-pile loops is a canned-rotor type centrifugal pump. Figure 5 is an assembly drawing of the pump. This pump has a capacity of approximately 5 gpm at 40 ft head. Speed is $\sim 3450 \text{ rpm.}$

The aluminum oxide journal bushings and bearings are similar to the ones previously described for the Westinghouse model 100A pump except the bearing and journal lengths are approximately 1 in. instead of 2 in. Journal bushings and bearings are purchased as cylindrical blanks with $\sim 0.010 \text{ in.}$ allowance for final grinding and finishing.

Figure 6 is a drawing of the rotor showing the installation of the aluminum oxide. Figure 7 is a drawing of the bearing assembly. Again, clamp rings are used to attach the aluminum oxide journal bushing to the rotor shaft, and an interference fit of $\sim 0.0015 \text{ in.}$ is used to hold the aluminum oxide bearing in the bearing housing. A recent modification incorporates "locking" pins in the bearing housing to prevent the aluminum oxide bearing from slipping in the housing. Figure 8 is a photograph of a pump rotor with aluminum oxide bushings installed.

5. OPERATING TEST RESULTS

5.1 Out-of-Pile Results

To date, aluminum oxide bearings have been installed on three Westinghouse model 100A pumps. One of these pumps was operated for 200 hr while circulating water at 200°C. An inspection of the aluminum oxide bearings at this time revealed no measurable or visible wear. The pump was then reassembled and operated for an additional 1300 hr circulating a 0.04 M uranyl sulfate - light water solution containing 0.02 M sulfuric acid and 0.03 M copper sulfate at 300°C. Operation of the pump was entirely satisfactory and again no measurable or visible wear of the aluminum oxide bearings was observed. An additional 4500 hr of operation on this pump with uranyl sulfate solution has been accumulated since this inspection and no evidence of excessive bearing wear has been observed, although the pump has not been disassembled for inspection. Operation of this pump is continuing. A second pump has accumulated more than 1200 hr of operation while circulating a 0.04 M uranyl sulfate - heavy water solution containing 0.025 M sulfuric acid and 0.01 M copper sulfate at

300°C. One model 100A pump equipped with aluminum oxide bearings and journals is being tested in the thorium oxide slurry test loops to evaluate the aluminum oxide bearings in loops circulating thorium oxide slurries. The Graphitar No. 14 bearings and Stellite 98M2 journal bushings used in the pumps in thorium oxide slurry loops have given relatively poor service as compared to service in solution loops.⁸ Graphitar bearing replacement, particularly the front bearing, is normally required in less than 300 hr. To date, insufficient operating time has been accumulated to determine any possible improvement in bearing life with the aluminum oxide in Westinghouse model 100A pumps circulating thorium oxide slurries.

5.2 In-Pile Results

All in-pile loop pumps are now equipped with aluminum oxide bearings and journal bushings. To date, eight of the loops in which pumps were equipped with aluminum oxide bearings have been operated in the LITR. A summary of the pump operation of all in-pile loops operated to date is given in Table III.

The pumps from loops EE, L-4-8, L-4-11, L-2-15, and L-4-16 have been disassembled and examined remotely in the corrosion examination facility and the findings on three of these have been reported by A. R. Olsen.⁴ As noted by Olsen, the pump in loop EE, which contained Graphitar bearings and a hardened 17-4 PH journal bushing, apparently failed by seizure between the rotor can and the pump stator can. Wear as observed on the Graphitar bearing could account for this seizure. The pump in loop L-4-11, containing aluminum oxide bearings and journals, operated satisfactorily throughout the in-pile operating period, and no measurable bearing wear was observed.

The pump in loop L-4-8 containing aluminum oxide bearings and journals apparently failed because the rear bearing slipped forward and reduced the rotor end-play; thus seizure occurred between the front and rear bearing thrust surfaces. As noted in disassembly of the loop after in-pile operation,³ tapping the rotor assembly backward released it and allowed free rotation. However, no appreciable bearing wear could be observed. The pumps in loops L-2-10, L-2-15, and L-4-16 containing aluminum oxide bearings and journals have also been examined remotely in an effort to determine the cause of failure. The pump from loop L-2-10 appeared to be locked as a result of bearing slippage. The rotor could be rotated after tapping the rotor as in the L-4-8 pump. No direct bearing inspection of this pump was made. The cause of pump failure of the pumps removed from loops L-2-14, L-2-15, and L-4-16 is believed to be due to electrical breakdowns in the stator windings, either coil-to-coil or winding-to-winding short circuits.¹¹ The pump stator windings have recently been redesigned to minimize this type of pump failure. In three of these pumps, no direct evidence of bearing slippage was observed when the pumps were disassembled in the remote-handling facility. Measurements of the bearings and journals in loop L-2-15 indicated no wear. The diameters of the bearings and journals were not measured on the pumps from loops L-2-14 and L-4-16; however, no significant wear was observed from a visual examination.

The rear bearing housing assemblies of all pumps in loops subsequent to L-4-8 have been pinned to the rear of the can housing in an attempt to eliminate the type of failure (bearing slippage) noted above. However, the aluminum oxide bearing itself has not been pinned into the stainless steel housing. In view of a second failure of an Al₂O₃-equipped pump, in loop L-2-10, the aluminum oxide bearing will be mechanically pinned to the housing

as well as securing the housing to the pump can on future pumps. In one recent pump in use in an experimental loop, the aluminum oxide bearing moved forward in the rear bearing housing, indicating this possibility. This had not been observed on any of the previous pumps.

6. DISCUSSION

The extreme hardness and excellent anti-galling tendencies⁵ of pure sintered aluminum oxide are desirable properties for a bearing and journal bushing material. The aluminum oxide has a corrosion resistance in homogeneous reactor fuel solutions (uranyl sulfate) which makes it satisfactory for use in the canned-rotor pumps used to circulate these solutions and its corrosion resistance is in fact superior to the Stellite 98M2 bushings and Graphitar No. 14 bearings previously used.

Eight in-pile loop pumps which have been operated in the LITER were equipped with aluminum oxide bearings and journal bushings. The use of aluminum oxide has eliminated pump failures resulting from bearing wear and its chemical composition precludes the introduction of known undesirable corrosion products (such as cobalt) into the fuel solution. Although five of these eight pumps failed during in-pile operation (operating time before failure varied from 663 to 1672 hr), none of these failures are attributed to bearing or journal bushing wear and/or corrosion, but are believed to be the result of:

- (1) mechanical displacement of the bearings (pumps in loops L-4-8 and L-2-10) or
 - (2) electrical short circuits in the stator windings caused by thermal breakdown of the insulation (pumps in loops L-2-14, L-2-15, and L-4-16).
- Design modifications have been made to eliminate the pump failures resulting from mechanical displacement of the bearings and a change to class H electrical insulation for the pump stator windings (present insulation is class A) is being made to minimize failures resulting from thermal breakdown of the stator insulation. Since two of the four in-pile loop pumps equipped with Graphitar No. 14 bearings and Stellite 98M2 or hardened 17-4 PH stainless steel journal bushings failed as a result of excessive bearing wear, the aluminum oxide has been superior from the standpoint of bearing wear as compared to these materials. However, it should be pointed out that the in-pile loop pump was changed from the original single bearing model⁽¹⁶⁾ to the present double bearing design at the same time the aluminum oxide bearings and journals were installed in the pumps (loop L-4-8 and subsequent). Some improvement in bearing wear, therefore, may be attributed to the design change. No direct comparison of bearing and journal materials between the two pump models has been made.

Additional operating time is required to evaluate the aluminum oxide as a bearing and journal material in the Westinghouse model 100A pumps. However, preliminary results of more than 7,000 hr of operation on two model 100A pumps in uranyl sulfate solution are encouraging. No wear has been observed to date.

The relatively low coefficient of thermal expansion ($5 \times 10^{-6}/^{\circ}\text{F}$)⁶ and high modulus of elasticity (52×10^6 psi at 25°C)⁶ of sintered aluminum oxide must be taken into account in any bearing and journal design. The

slippage of the aluminum oxide in the stainless steel housings, probably due to insufficient allowance for the greater thermal expansion of the stainless steel, resulted in a locked rotor condition in at least one of the in-pile loop pumps. Since an increased interference fit between the bearing and housing to eliminate this slippage would probably have cracked the aluminum oxide during the initial assembly, the bearings in all in-pile loop pumps are now held in position by means of set screws in the bearing housing which projects into recessed holes in the outer surface of the bearing.

TABLE I

CORROSION TEST RESULTS OF PUMP BEARING MATERIALS

Material	Solution	Temp (°C)	Time (hr)	Corrosion Rate (mpy)	Flow Vel. (fps)
Stellite 98M2	0.02 m UO_2SO_4 + 0.005 m H_2SO_4 ~ 500 ppm O_2	100	200	1.3	12
	0.17 m UO_2SO_4	100	1000	0.5	Static
	1.33 m UO_2SO_4	100	1800	10.0	Static
	0.02 m UO_2SO_4 + 0.005 m H_2SO_4 ~ 500 ppm O_2	150	200	12	12
		200	200	51	12
	0.06 m UO_2SO_4 + 0.006 m H_2SO_4 500-1000 ppm O_2	200	200	200	12
	0.11 m UO_2SO_4 0.016 m H_2SO_4 500-1000 ppm O_2	200	200	290	12
	5 wt % HNO_3	100	100	4.2	Static
Stellite 6	5 wt % HNO_3	100	500	15	Static
17-4 PH SS	0.02 m UO_2SO_4	100	5000	11.3	Static
Fully Hardened To Rockwell C-44	0.005 m H_2SO_4			(Cracks and Blisters)	
	0.17 m UO_2SO_4	100	5000	30.0 (Cracks)	Static

TABLE I (CONTINUED)

Material	Solution	Temp (°C)	Time (hr)	Corrosion Rate (mpy)	Flow Vel. (fps)
17-4 PH SS Hardened To Rockwell C-35	0.02 m UO_2SO_4 + 0.005 m H_2SO_4 ~ 500 ppm O_2	100	200	~ 0.4	12
	0.02 m UO_2SO_4 0.002 m H_2SO_4 ~ 500 ppm O_2	150	200	~ 1.4	12
	0.2 m UO_2SO_4 0.005 m H_2SO_4 500-1000 ppm O_2	200	200	8.5	12
	0.06 m UO_2SO_4 0.006 m H_2SO_4 500-1000 ppm O_2	200	200	18	12
	5 wt % HNO_3	100	2000	1.7	Static
Al_2O_3	5 wt % HNO_3	100	2500	1.6	Static
	0.04 m UO_2SO_4 0.02 m H_2SO_4 0.005 m CuSO_4	100	2000	0.4	Static
	0.17 m UO_2SO_4 0.4 m H_2SO_4 0.15 m CuSO_4	100	160	0	Static
	1.34 m UO_2SO_4 150 psi O_2	250	1000	27	Static
	0.17 m UO_2SO_4 150 psi O_2	150	520	1.6	Static
		300	4580	3.4	Static

TABLE I (CONTINUED)

Material	Solution	Temp (°C)	Time (hr)	Corrosion Rate (mpy)	Flow Vel. (fps)
Al ₂ O ₃	0.17 m UO ₂ SO ₄	200	200	3.2	Static
	0.01 m CuSO ₄	300	2500	7.0	Static
	150 psi O ₂				
Graphitar No. 14	0.02 m UO ₂ SO ₄ + 0.005 m H ₂ SO ₄	100	3600	0	20
	H ₂ O + O ₂	300	100	> 200	12
	wt % HNO ₃	100	320	0	Static
	0.17 m UO ₂ SO ₄	100	1960	0	Static

TABLE IICORROSION TEST RESULTS OF PUMP BEARING MATERIALS

Conditions: Solution: 0.04 *m* UO_2SO_4
0.02 *m* H_2SO_4
0.005 *m* CuSO_4
(1000-2000 ppm O_2)
Temperature: 150°C
Time: 200 hr
Flow Velocity: 13 fps

<u>Material</u>	<u>Corrosion Rate (mpy)</u>
Stellite 6	5.9
Stellite 1	6.1
Stellite 98M2	40
17-4 PH (Annealed) Rockwell B-72	4.1
17-4 PH (Partially Hardened) Rockwell C-35	8.1
Al_2O_3 Sintered (Kearfott Co. fine grained pure alumina)	12
Graphitar No. 14	81

TABLE III
SUMMARY OF IN-PILE LOOP PUMP OPERATION

Loop Number	In-Pile Operation (hr)	Loop Temp (°C)	LITR Beam Hole	Loop Fission and Gamma Heat (watts)*	Bearing Material	Journal Material	Pump Failure
DD	465	250	HB-4	550	Graphitar No. 14	Stellite 98M2	No
EE	630	250	HB-4	830	Graphitar No. 14	17-4 PH SS	Yes
FF	692	250	HB-4	865	Graphitar No. 14	Stellite 98M2	No
GG	1064	250	HB-4	1080	Graphitar No. 14	Stellite 98M2	Yes
L-4-8**	1676	250	HB-4	920	Al ₂ O ₃	Al ₂ O ₃	Yes
L-2-10	1672	280	HB-2	1255	Al ₂ O ₃	Al ₂ O ₃	Yes
L-4-11	1130	250	HB-4	1065	Al ₂ O ₃	Al ₂ O ₃	No
L-4-12	2020	250	HB-4	1195	Al ₂ O ₃	Al ₂ O ₃	No
L-14-13	1042	250	HB-4	950	Al ₂ O ₃	Al ₂ O ₃	No
L-2-14	663	280	HB-2	3100	Al ₂ O ₃	Al ₂ O ₃	Yes
L-2-15	792	278	HB-2	2800	Al ₂ O ₃	Al ₂ O ₃	Yes
L-4-16	898	280	HB-4	830	Al ₂ O ₃	Al ₂ O ₃	Yes

* As determined from difference in the loop heater power requirements with reactor on and off.

** Pump bearing and journal design was modified at the same time bearing and journal material was changed to the aluminum oxide.

ASSEMBLY - 100A PUMP ROTOR WITH ALUMINUM OXIDE JOURNAL BUSHINGS

Fig. 1. Westinghouse Model 100A Pump Rotor with Aluminum Oxide Journal Bushings.

Fig. 2. Photograph of Aluminum Oxide Journal Bushing Installed on a Westinghouse Model 100A Pump Rotor.

Fig. 3. Aluminum Oxide Bearing Assembly - Westinghouse Model 100A Pump.

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Fig. 4. Photograph of Aluminum Oxide Bearing Installed in Westinghouse Model 100A Bearing Housing.

Fig. 5. In-Pile Loop Pump

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Fig. 6. ORNL 5gpm In-Pile Pump Rotor with Aluminum Oxide Journal Bushings.

Fig.7. Aluminum Oxide Bearing Assembly - In-Pile 5gpm Pump.

Fig.8. Photograph of ORNL 5 gpm In-Pile Loop Pump Rotor with Aluminum Oxide Journal Bushings.

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