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SODIUM REMOVAL DISASSEMBLY
AND EXAMINATION OF THE FERMI
SECONDARY SODIUM PUMP

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AUGUST 1, 1974

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SODIUM REMOVAL DISASSEMBLY AND EXAMINATION OF THE FERMI SECONDARY SODIUM PUMP

INTRODUCTION

In developing the water-vapor-nitrogen sodium removal process demonstration on actual plant components provides useful experience and information.

Several plant-scale components including Fermi 3-in. bellows seals valves have been successfully cleaned. Recently, a 13,000 gpm Fermi secondary pump was processed and the results are described in this report.

SUMMARY

The Fermi secondary pump is a centrifugal single stage design. The pump had been operated more than 42,000 hours between 450 and 800°F. Sodium was drained from the pump in 1973 and the system was back filled with carbon dioxide. The pump was fabricated for 2.25 Cr - 1 Mo Croloy steel.

Prior to cleaning the pump was inerted and heated with 150°F nitrogen using the pump casing as the containment vessel. The water-vapor-nitrogen process was used in three increasing stages of water concentration. The hydrogen concentration in the discharge line was followed as an indicator of the sodium-water reaction rate. Upon completion of the hydrogen evolution, the pump was rinsed several times with hot water.

Six pounds of sodium were removed from the pump during a process cycle of 79 hours including rinsing. The maximum pump temperature recorded was 175°F with no variation exceeding 10°F. The hydrogen concentration in the effluent provided a very satisfactory index for control of the reaction by adjustment of the water-vapor concentration feed to the system. Rinsing effectiveness was limited by a pool of water in the volute that was not drainable with the available system hook up.

Sodium and its compounds were removed from all internal surfaces that could be observed by the first stage of disassembly. All such surfaces were coated with a black deposit. Areas above the sodium liquid level were coated with a vermillion colored oxide. Sodium was found on the 1) threads of the impeller nut lock screw, 2) impeller nut-tapered shaft interface, and 3) vapor deposited sodium was found in the oil seal.

Conclusions drawn from this experience are as follows:

- A mechanical plant-scale pump can be cleaned of sodium in its own housing with no prior disassembly using the water-vapor-nitrogen process.

- Hydrogen concentration in the discharge provides a responsive indication of the sodium reaction rate that can be controlled by throttling the water vapor concentration in the nitrogen feed. Increments of increased water vapor concentration provide a positive method to control the sodium reaction rate. Step increments of less than 5 vol% could refine this degree of control.
- Process modifications to improve removal of sodium frost from vapor space surfaces and other areas should consider 1) intentional delivery of water vapor and rinse water through the oil seal, 2) local water vapor feed lines directing vapor access to the impeller interfaces, and 3) longer vapor processing times for greater crevice penetration.
- Rinse effectiveness can be improved by draining or siphoning water from cavities such as seen in the volute.

REMOVAL PREPARATION

The pump had been operated in excess of 42,000 hours at temperatures between 450 and 800°F. A large portion of the operating time was at a zero power condition in which the sodium temperature was 450°F and the sodium flow rates were 1.2×10^6 lb/hr to 3×10^6 lb/hr at a maximum temperature of 800°F.⁽¹⁾ Sodium was drained from the secondary system pump during the third quarter of 1973; the system was then backfilled with carbon dioxide (CO₂) gas. The purpose of the CO₂ gas was to form a sodium carbonate film on the residual sodium and minimize aqueous sodium hydroxide formation during subsequent exposure to air.

Prior to cutting the pump out of the Fermi Secondary System in February 1974, the pump was purged with argon; this condition was maintained during the entire removal operation. The connecting lines from the pump to the secondary system (both sodium and cover gas) were severed one at a time, and immediately seal welded with steel plates. Piping included the 16-in.

1. "Operating Experience with Major Components of the Enrico Fermi Atomic Power Plant," IAEA-SM-127/40.

discharge line, the 18-in. inlet line, the 6-in. sodium overflow line, and the 3-in. cover gas line. Prior to seal welding the 18-in. sodium inlet line, a steel spider support was welded to the inside of the pump to prevent vibration damage of the pump bearing during shipment. A cross sectional drawing of the pump is shown in Figure 1.

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FIGURE 1. Details of Fermi Secondary Sodium Pump Subassemblies

PROCESSING PLAN AND EQUIPMENT

The sodium removal process to be qualified at HEDL was the water-vapor-nitrogen process which included a water rinse. Since the large physical size of the pump did not allow the use of the Sodium Removal Development Apparatus (SRDA) vessel, the pump's own outer case was used as the cleaning vessel by connecting it to the SRDA piping, utilizing the SRDA control instrumentation. A schematic of the pump processing system connected to the SRDA is shown in Figure 2.

FIGURE 2. Schematic of Fermi Secondary Pump Mounted with SRDA for Sodium Removal Processing.

Two additional openings were made in the pump prior to processing the pump, to allow more efficient water rinsing and recirculation later in the process and to insure a good sample for hydrogen monitoring during the cleaning process. A 2-in. hole was made in the inner pump adjacent to the original 3-in. hole in the cover gas nozzle. This new hole was used to introduce the water rinse to the internal areas of the pump. Another 0.5-in. hole was made just below the pump case flange in the outer pump case to supply a gas sample to the continuous hydrogen monitor and to act as a gas vent during subsequent water rinsing operations.

Seven thermocouples (TC) were attached to the pump for monitoring temperatures during processing. Two TC monitored the outer skin temperature of the pump case while the remaining TC were used for internal pump temperatures at the impeller (2 TC), the inner pump case (1 TC) and the internal gas temperatures (2 TC). The pump was then inerted by purging with nitrogen to less than 1 vol% O_2 .

As shown in the system schematic (Figure 2) moist gas was introduced into the pump at equal pressure through three openings: 1) the pump intake, 2) the pump discharge, and 3) the pump sodium overflow nozzle. The gas was then vented from the cover gas line to the outside of the building through a 2-in. vent line.

Following this moist gas cleaning cycle, the pump was rinsed successively with demineralized water which was recirculated through the pump for periods of up to 2 hours. The water was then pumped from the bottom of the pump and reintroduced within the inner pump barrel (Figure 2); the cleaning procedure and results are presented in Appendix A.

Available drawings of the Fermi Secondary Pump made it difficult to accurately determine the internal surface area of the pump. Since the drawings indicated that no pools of undrained sodium should exist in the pump, the best calculations indicated that approximately 175 square feet (ft^2) of wetted steel surface and an additional 150 ft^2 of steel were exposed to the

argon cover gas and sodium vapor. Based on the wetted steel surface area of 175 ft² and a sodium retention value of 1 lb of sodium per 100 ft² of wetted surface, the minimum amount of sodium in the pump was estimated to be 1.7 lb.

It was not possible to accurately determine the amount of sodium in the remainder of the pump because the thermal history of that portion of the pump was not available. Similarly, it was not possible to determine the presence of sodium frost, condensed sodium, or sodium wetted surfaces. However, based on the assumption that these surfaces were wetted and drained, the total amount of sodium in the pump was estimated to be 3 to 4 lb.

The amount of sodium reacted during processing was determined by two methods. The first method integrated the evolved hydrogen over the elapsed processing time to calculate the amount of sodium reacted. The second method measured the total sodium hydroxide ion removed from the pump by the water rinses.

PROCESSING

Prior to processing with water-vapor-nitrogen, it was necessary to preheat the pump to prevent water condensation. This was accomplished by applying 600 watts of heat to the upper pump case and also by purging the pump with 6 SCFM of hot, dry nitrogen. The external heat was supplied by four calrods which were original equipment and still attached to the pump (Figure 3). After 24 hours of preheating, the outer skin of the pump was 100°F and sufficiently warm to start processing with moist gas.

Pump processing was started with the addition of 5% water vapor to the nitrogen gas stream. The water vapor was supplied by a steam generator and the water vapor concentration in the gas stream was measured with a dew point measuring instrument. Water concentration was controlled by a needle valve while the extent of the water-vapor-sodium reaction was determined by monitoring the hydrogen concentration in the effluent gas.

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FIGURE 3. Fermi Pump Attached to SRDA

Approximately 6 lb of sodium were removed from the pump in 79 hours of total processing time, including water rinsing. Hydrogen evolution estimated 5.8 lb of sodium and the rinse water analysis indicated 6.4 lb of sodium, data are shown in Table 1

After processing the the Fermi pump for 4 hours at 5% H_2O vapor, the hydrogen evolution concentration was less than 0.5 vol% (5 SCFM) (see Figure 4). The concentration was then increased to 10 vol% H_2O vapor and the hydrogen evolution started to increase. When the hydrogen approached 4 vol%, the addition of the water vapor was terminated temporarily, which caused the hydrogen rate to respond

TABLE 1. Water-Vapor-Nitrogen Processing of Fermi Pump

SODIUM REACTION

<u>H₂O Concentration vol% in Sodium</u>	<u>Total Gas Flow (SCFM)</u>	<u>Temperature, °F</u>	<u>Time, Hours</u>
5	6	140-160	4.5
10	6	140-160	18.0
15	6	140-160	22.5

WATER RINSE

<u>Rinse Number</u>	<u>Time Hours</u>	<u>Volume (ℓ)</u>	<u>Sodium Concentration (g/ℓ)</u>	<u>Total Sodium (gm)</u>	<u>pH</u>
1(a)	--	8	35.2	281	11.9
2(b)	--	38	32.8	1240	12.1
3	4	983	0.74	727	11.5
4	4	963	0.09	88	10.7
5	4	983	0.07	69	10.4
6	2	983	0.06	60	10.2
7	1	423	0.10	42	10.3
8	1	423	0.25	106	10.6
9	1	423	0.18	76	10.5
10	1	423	0.03	13	9.7
11	4	983	0.01	10	9.3
12	4	983	0.07	69	10.1
13	1	423	0.04	17	9.8
14	2	983	0.03	25	9.7
15	1	423	0.07	29	10.1
16	2	983	0.04	39	9.8
17	3	983	0.04	39	9.8

SODIUM REMOVED

<u>Sodium, lb</u>	<u>Method</u>
6.4	Calculated from Water Rinse Analysis
5.8	Calculated from H ₂ Evolution ^(b)

(a) Caustic solution drained from pump.

(b) Hydrogen evolved was not measured during water rinsing; the difference of 0.6 lb partly represents the sodium removal during water rinsing.

FIGURE 4. Fermi Pump Cleaning H₂ Evolution Record

immediately by falling rapidly. The water vapor addition was then resumed at 10 vol% and the hydrogen evolution was again increased, but did not exceed 2 vol%. After 22 hours the hydrogen evolution rate had fallen to nearly 0.15 vol%, so the water vapor was increased to 15 vol%. Hydrogen evolution again rose immediately and reached 0.25 vol%, then fell to 0.02 vol% after 40 hours and did not change subsequently. The temperatures being monitored throughout the pump did not change by more than 10°F throughout the processing. However, the mean temperature gradually rose after each increase in steaming rate in response to the warmer gas temperature produced by the higher steam contents.

It must be emphasized that the rise in hydrogen evolution noted when the H₂O vapor concentration was increased was controllable unlike those observed in development testing with confined pools of bulk sodium. Such a spike of bulk sodium does not respond to changes in the water vapor concentration since it involves reaction with the liquid caustic solution confined above the pool in a pot. The constancy of measured temperatures can confirm that thermal spikes were not involved in the Fermi pump processing. All temperatures throughout the component were maintained well below any possible stress corrosion cracking threshold, since no temperature exceeded 175°F (Table 2).

TABLE 2. Maximum Temperatures Observed During Fermi Pump Cleaning by WVN

<u>Location</u>	<u>°F</u>
Pump Impeller	170
Pump Inner Barrel	175
Pump Volute Exterior	120
Outer Barrel Exterior	130
Maximum Rinsing Fluid	160

After the hydrogen evolution had fallen to 0.02 vol% (lower detectable limit of instrument) and had not subsequently changed for 5 hours, the decision was made to proceed with the water rinse. The pump was rinsed with a total of 15 rinses of deionized water, six of which were partial volume flushes aimed at removing liquid trapped in the pump inlet and outlet piping. (The bottom of the volute could not be reached readily because of the cover plates which were welded in place when the pump was removed from the Fermi reactor system.) The rinses and resulting sodium concentrations are shown in Table 1. The first three or four rinses appeared to clean the pump internals. The pH of the rinses ranged from approximately 9.3 for Rinse 11 to 11.5 for Rinse 3. The final resistivity of the rinse water was never greater than 2000 ohms when rinsing was terminated. The residual sodium in the remaining rinses was probably due to undrained water remaining in the pump volute.

DISASSEMBLY AND INSPECTION

After processing for sodium removal the initial disassembly of the pump was easily and rapidly accomplished. The entire inner pump assembly was removed from the outer pump case and supported in a temporary fixture for examination and further disassembly (Figures 5 and 6). The metal surfaces of both the outer case and the inner pump assembly were completely free of sodium or caustic. Except for reddish rust deposits on surfaces above the liquid interface, all of the surfaces were coated with a black deposit. This black deposit was magnetic and more heavily concentrated in regions of the pump that saw very low sodium flow velocities during

FIGURE 5. Fermi Pump Removed from Outer Housing Following WVN Processing

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FIGURE 6. Fermi Pump Outer Housing Interior

operation. Figure 7 shows a typical deposit in the area of the pump bearing sodium inlet hole, while the location and pictures of additional deposits and debris found in the pump are shown in Figure 8. The black, powder-like deposit was analyzed by emission spectroscopy which showed it to be 97% iron. X-ray diffraction showed that 2/3 of the iron was metallic and 1/3 was Fe_3O_4 oxide, while X-ray Fluorescence analysis determined the composition (see Table 3).

Chips of glass as large as 0.3 in. were found in the bottom of the purge housing and bearing case. The source of these white, transparent, glass chips was not identified, although speculation leads to extraneous material or possibly a sight glass plate in the oil seal housing.

FIGURE 7. Accumulated Debris in Bearing Pocket Na Inlet Hole

TABLE 3. Deposits and Debris Found in Fermi Pump

Vermilion Deposit	Surfaces above liquid Na
Black Deposits	All wetted surfaces ^(a)
Glass Chips	Bottom of housing, top of bearing inside bearing pocket

(a) X-ray diffraction 2/3 metallic

1/3 Fe_3O_4

X-ray fluorescence 70 wt% Fe

5 wt% Cr

1 wt% Mo

0.5 wt% Ni

SLAG TYPE CHIPS

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Following the preliminary inspection, further disassembly of the pump was accomplished without mechanical problems. The shaft assembly (pump shaft, bearing journal and impeller) was removed from the inner case prior to removing the impeller from the shaft. This required hand cleaning after the second stage of disassembling the pump vertical thrust bearing and oil seal unit at the top of the pump. The oil seal subassembly had not been exposed to water immersion because it was above the rinse water level. The oil weir above the rinse water level contained oxidized sodium (Figure 9).

FIGURE 9. Fermi Pump Shaft Oil Seal and Bearing Area

The sodium frost was deposited by argon cover gas flowing upward through the oil seal during service and was easily removed with an alcohol-moistened cloth. The remainder of the subassembly was completely free of sodium or sodium products on all of the exposed surfaces. Similarly, the sodium-lubricated pump bearing and journal were completely free of any sodium products or bleedout, and demonstrated extremely little mechanical wear. The same was true of the pump impeller.

Removal of the impeller nut required a substantial amount of torch heating to 500°F and force. The 3.25-in. nut would not turn with an air impact wrench and was only removed by the use of a 15-in. wrench and an 8-lb hammer. Removal of the impeller from the tapered shaft spindle required a specially fabricated gear-type puller. The impeller was removed by applying torch heating to <500°F and force to the puller fixture and then heating the impeller hub with a torch. The bearing journal was removed from the shaft by lightly heating the ends, then forcing it off of the shaft.

The pump, impeller hub area, shaft spindle and bearing journal are shown in Figures 10, 11 and 12. Note that some residual sodium remained in the threaded impeller nut as well as in the <1 mil crevice formed by the impeller and shaft. The total amount of sodium was less than 1 g with the majority being in the threaded area. These sodium-coated surfaces were easily cleaned with an alcohol-moistened cloth. It is interesting to note that the water-vapor-nitrogen process removed the sodium from the top 1 to 1.5 in. of the crevice and also from the 1-in. long bearing journal seats on the shaft (<1 mil gas crevices). The sodium deposits found on the impeller hub were consistent with those found on the shaft.

Visual examination of the completely disassembled pump revealed no evidence of excessive mechanical wear during operation and no detrimental effects from the water-vapor-nitrogen cleaning process. Further examination of the pump shaft, impeller, and bearing journal by dye-penetrant inspection revealed no caustic stress cracking. One defect was found (Figure 13) which was determined to be a stringer in the original forging for the pump shaft.

FIGURE 10. Fermi Pump Impeller-Shaft Interface Area

FIGURE 11. Fermi Pump Shaft Bottom End

COMPLETELY FREE OF SODIUM FOLLOWING VN
PROCESSING
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FIGURE 12. Fermi Pump Bearing Subassembly

FIGURE 13. Defects Detected by Dye Penetrant Inspection

The elastomer "O-ring" seal was examined after disassembly of the oil inlet flange from the pump case flange. This seal was reported to be fabricated from neoprene and not to have been changed during the service-life of the pump. Since the original hardness and strength of the material was not available, it was not possible to quantify any change in properties. However, the seal exhibited good elasticity. The compression of the 0.25-in. "O-ring" was 12% with a gland depth of 0.22 in., and the permanent set of the elastomer was estimated to be 9 to 10% by measurement of the thickness of the seal.

APPENDIX A

CLEANING PROCEDURE FOR FERMI SECONDARY PUMPS

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CLEANING PROCEDURE FOR FERMI SECONDARY PUMPS

The Fermi pump is presently attached to the SRDA in a bypass mode. The SRDA cleaning vessel is blocked off from the piping system and the process lines (gas, vent and water rinse) are connected to the pump; a piping schematic is shown in Figure 2. The present system allows the use of all of the SRDA equipment and instrumentation.

The pump will be cleaned by reacting the residual sodium in the pump with moist nitrogen gas. After the completion of the moist gas sodium reaction, the pump will be rinsed with deionized water and then dried with hot gas. The pump will be disassembled and inspected after it has been cleaned using the following stepwise procedures:

1. Connect all attached thermocouples to the appropriate recorder.
2. Open Valves 1, 2 and 3, and close Valves 4, 5 and 6.
3. Preheat the pump to 120 to 150°F by purging with hot nitrogen gas at a flow rate of 10 SCFM.
4. Introduce 5 vol% water vapor into nitrogen gas stream.
5. Monitor hydrogen concentration in vent gas and internal pump temperatures.
6. If hydrogen level exceeds 4% or pump internal temperatures exceed 200°F, turn off water vapor source and continue gas purge.
7. When hydrogen level is less than 0.5% and internal pump temperatures are less than 180°F repeat Step 4.
8. Continue the moist gas for a minimum of 4 hours or until hydrogen concentration is less than 0.5%.
9. Increase moisture concentration to 10%.
10. If hydrogen level exceeds 4% or pump internal temperature exceeds 200°F, turn off water vapor source and continue gas purge.
11. When hydrogen level is less than 0.5% and internal pump temperatures less than 180°F repeat Step 9.
12. Maintain a stepwise increase of moisture remaining at each level for a minimum of 4 hours. Moisture will be increased to 20, 30 and 50%.

NOTE: DO NOT INCREASE MOISTURE LEVEL IF HYDROGEN EVOLUTION IS GREATER THAN 0.5%.

13. When moisture level has been at 50% for 4 hours and hydrogen evolution is less than 0.02% above background, proceed to step 14.
14. Turn off moist gas flow and close Valves 1, 2 and 3.
15. Open Valve 4 and start adding rinse water to pump.
16. If internal pump temperatures increase to 200°F, turn off water and wait for temperatures to cool to less than 180°F.
17. Repeat Step 15.
18. When pump is full of water, open Valve 1 and start recirculation pump.
19. Recirculate for 4 hours then stop pump.
20. Close Valves 1 and 4, and open Valve 5 to drain.
21. Close Valve 5 and open Valve 1.
22. Refill pump with 180°F deionized.
23. Repeat Step 19.
24. Continue rinsing pump with successive batches of 180°F water until the resistivity of the water remains above 25,000 Ω cm after 2 hours of recirculation.
25. Purge the pump with dry nitrogen gas at 150°F for 24 hours.