LMEC-68-5

Volume II

General, Miscellaneous
and Progress Reports

Mechanical Elements Operating in Sodium and Other Alkali Metals Volume II Experience Survey

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ABSTRACT

The operating history of sodium service mechanisms used in the following sodium-cooled reactors is presented: the Sodium Reactor Experiment, the Experimental Breeder Reactor II, the Enrico Fermi Atomic Power Plant, and the Hallam Nuclear Power Facility. Included are mechanism component design characteristics, operating conditions, their operability and maintainability, and the history of component malfunctions with the subsequent repairs or modifications required. It is concluded that, as yet, an adequate design basis does not exist.

I. INTRODUCTION

Liquid sodium has found application as the heat transfer fluid in graphite moderated reactors and fast breeder reactors. Sodium has a liquidus range of 208 to 1630°F, which includes the 1200°F reference coolant temperature for near-future Liquid Metal Fast Breeder Reactor (LMFBR) plants. Sodium is a low viscosity, high heat capacity, high thermal conductivity liquid and is low in cost. To utilize its desirable heat transfer and economic characteristics, many of the control and fuel handling operations must be performed in sodium liquid or vapor. If these mechanisms are isolated from the sodium, present engineering knowledge can be applied; however, plant costs are increased because of the greater mechanical complexity. Operating and maintenance procedures also become more involved; and with complexity the propensity to component failure increases. Locating the mechanisms as close to the operation as possible introduces a sodium-sodium vapor environment with its inherent problems. Sodium has a high chemical reactivity and, as mentioned, a low viscosity. Protective surface films normally realized with high-temperature materials are continuously removed because of the high reducing nature of sodium. This, along with the inherent thin fluid films present with low viscosity fluids, permits intimate interaction of operating material surfaces which are in contact. Selection of materials and subsequent loads, speeds, and geometries becomes a challenging responsibility.

Experience gained with mechanisms operating in nuclear reactor sodium can be the most important contribution to future sodium mechanism design efforts. The experience survey presented herein is Volume II of the report, "Mechanical Elements Operating in Sodium and Other Alkali Metals." It reports the operating history of sodium service mechanisms in four sodium cooled reactors:

- 1) Sodium Reactor Experiment (SRE)
- 2) Experimental Breeder Reactor-II (EBR-II)
- 3) Enrico Fermi Atomic Power Plant (EFAPP)
- 4) Hallam Nuclear Power Facility (HNPF).

Volume I* is a literature survey which reports on the more significant mechanical element development and experimental programs conducted since 1950, grouping the data under material selection or under element performance.

The experience survey reflects a detailed, but not exhaustive, review of information available from the sources referenced. The intention of the survey is to provide the reader with sufficient information to become aware of problems facing designers of mechanical components for sodium service. It is not intended to be a design handbook. It is suggested that by use of the references and information provided, a designer will be able to perform a more quantitative evaluation of specific mechanism-in-sodium design conditions. The reader can determine for himself such things as ranges of loading conditions, materials pairs, clearances which have caused difficulty in the operation of such mechanisms, and which types of mechanisms to avoid.

All design data presented in the tables were obtained from available original design drawings. Modifications made, but not represented by drawing revision, are not included. Significant design changes are discussed in the text.

Material designations are provided as called out on design drawings and not necessarily by the procurement specification designation. The terms SS (stainless steel) and CRES (corrosion resistant steel) are used interchangeably in the tables.

Blank spaces in the tables reflect a lack of information for the column noted.

General illustrations (selected from reference reports) of the reactor components reviewed are provided to introduce the reader to the reactor plant and component overall design. Because these figures have been copied from a variety of sources, figure callouts may not, in certain cases, agree with the tables; however, this should not detract from an understanding of the material presented. Table callouts reflect design drawing terminology.

*J. K. Balkwill, "Mechanical Elements Operating in Sodium and Other Alkali Metals, Volume I Literature Survey," LMEC-68-5 (December 31, 1968)

II. SUMMARY

A survey has been made of mechanical components which have been, or are presently being operated in the sodium environments of four sodium-cooled nuclear power reactors: SRE, EBR-II, EFAPP, and HNPF. The experience survey provides a record of mechanism component design characteristics, operating conditions, operability and maintainability, and a history of component malfunction with subsequent repairs or modifications made. Information for the survey was obtained from manufacturing specifications, fabrication drawings, design files, progress reports, maintenance reports, hazards summary reports, as well as personal communication with plant personnel.

Information for components common to all plants, journal bearings and bellows, is summarized in Tables A-1 and A-2 in the Appendix.

The mechanical elements reviewed have operated in reactor-grade sodium for periods up to 49,000 hr. Temperatures of exposure ranged from 100 to 1000°F in both sodium vapor and sodium liquid. Component operating loads were minimized where possible, with contact surface relative velocities in general being reduced to a practical minimum; two exceptions being mechanical pumps, and oscillator rod shaft supports and seals. Austenitic, corrosion-resistant steels were used extensively in fabricating the mechanisms reviewed, wear surfaces were generally hard chrome plating, Colmonoy and Stellite hard facing, or Haynes alloy and Inconel. Aluminum-bronze alloy found extensive use at EBR-II for journal bearings.

The SRE and HNPF designs made minimal use of sodium-exposed mechanical components; consequently, conventional engineering knowledge and practices were applicable. In contrast, EBR-II and EFAPP designs make extensive use of in-sodium handling and control mechanisms, requiring careful selection of interacting materials, clearances, and loads. In general, operation of the mechanisms in the sodium environments has been very satisfactory. Major problem areas defined by the review are: operation of mechanisms which resulted in binding and clogging; interaction of materials in high-purity reactor sodium, resulting in galling or seizure; and the sealing of the reactor atmosphere (sodium vapor) from the outer air atmosphere at rotating or oscillating shaft penetrations.

It can be concluded from the reported experience with sodium mechanisms at the plants reviewed that an adequate design basis does not as yet exist. The applicability of sodium as a medium in which materials will interact satisfactorily under load with relative surface velocities for limited periods of time has definitely been established. Available information will permit evaluation of basic mechanical configurations, design clearances, loads, speeds, and, to a certain degree, materials for sodium service. One limitation immediately apparent is the temperature range of future LMFBR's, requiring further test programs.

The reader is referred to the LMEC "Failure Data Handbook for Nuclear Power Facilities," LMEC-Memo-69-7, Volumes I and II, which is a guide for the design construction and maintenance of nuclear power plants from a reliability improvement standpoint. The Failure Data Handbook will be kept in an up-to-date condition providing the reader with the most recent information available on events affecting the construction schedule or cost, safety, availability, or the maintainability of a nuclear power plant or test facility. The initial scope has been limited to liquid metal facilities emphasizing mechanical components.

III. HALLAM NUCLEAR POWER FACILITY

A. DESCRIPTION

The HNPF, located at Hallam, Nebraska, utilized a sodium-cooled, graphite-moderated thermal reactor which operated with moderate power densities and relatively low levels of fuel burnup. Conventional engineering knowledge and practices were followed in the design of the reactor and fuel handling systems. Use of "in-sodium" mechanisms for moving fuel, actuation and guidance of control rods, etc., was avoided. The reactor was designed for an output of 254 Mwt, producing 75 Mwe through a conventional steam cycle.

The outer core tank, fabricated of Type 304 CRES, was 32 ft high and 20 ft in diameter. The primary sodium coolant entered the lower end of the reactor at 607°F and exited at 945°F (design). The coolant system consisted of six separate loops: three primary and three secondary. The two principal types of mechanisms at the HNPF which operated in sodium environments were centrifugal sodium pumps and fuel element variable-orifice devices.

B. DISCUSSION OF MECHANISMS REVIEWED

1. Reactor Core Clamp Mechanism (Table 1)

The core clamp assemblies positioned and restrained the moderator cans at their tops. There were six core clamp assemblies arranged in a hexagonal pattern around the moderator cans. The clamp assemblies were mounted on a centering ring which was mounted on a support ledge located on the inside wall of the reactor vessel. Both the clamps and the ring were made from Type 405 CRES to match the thermal coefficient of expansion of the can spacers. The clamps had a built-in locking device such that when the clamps were in a closed position the linkage was past dead center and force exerted by the moderator can tops could not loosen the clamps. Locating pins and lugs were welded to the centering ring and support ledge to allow for radial expansion but prevent gross movement of the core with respect to the reactor vessel. A nominal radial clearance (0.035 in.) between the six clamping mechanisms and the adjacent moderator can head spacer assemblies ensured that there would be no clamping loads under design operating conditions.

TABLE 1
HNPF CORE CLAMP AND REACTOR VESSEL BELLOWS

Mechanism	Design Information					Operating Conditions				
	Component (Drawing No.)	No. per Mechanism	Material of Construction	Dimensions and Manufacturing Tolerances	Clearances, Loading, and Speed	Operating Medium	Temperature, Velocity, and Pressure	Exposure to Environment (hr)	Operating Cycles or Hours	Operating Medium Impurities Range/Average
Core Clamp Number in Plant 1 Primary Material of Construction 405 CRES Assembly Drawing (7518-D71103)	Mounting Ring (7518-D71103)	1	405 CRES	Refer to Drawings where necessary	Stress, maximum com- bined stress estimated at 31,000 psi	Sodium Liquid	945° F max	≈ 22,000	Not available	Sodium Liquid C (ppm) 22 to 26/24
	5-Can Clamp (7518-D71101)	3 each	405 CRES	Refer to Drawings where necessary	Clearance, nominal radial 0.035 in. at room temperature be- tween clamping mecha- nism and adjacent mod- erator can heads. Speed, very slow, manually operated.	Sodium Liquid	945° F max	≈ 22,000	Not available	
	6-Can Clamp (7518-D71102)									
	Pivot Pins (7518-D71103)	6	304 CRES Nitrided surface	2-1/2 in. length; 1 in. diam. 1 in. - 14 threads; 1/16-in. thread relief	Speed, very slow surface speed	Sodium Liquid	945° F max	≈ 22,000	Not available	
	Core Linkage Pins Bushing Washers (7518-D71104)	24	304 CRES Nitrided surfaces	Refer to Drawings where necessary	Speed, very slow relative surface speeds	Sodium Liquid	945° F max	≈ 22,000	Not available	
	Bell Crank Assembly (7518-D71105)	6	304 CRES Nitrided Bearing Pin Surfaces	Hexagonal turning head, 2-in. diam.; 8-in. length; 30° chamfer at top; 1.250-in. diam. bearing pin after nitriding	Clearance, bearing pin 0.010 in./0.020	Sodium Liquid	945° F max	≈ 22,000	Not available	
Reactor Vessel Bellows	Bellows (Uniflex 1007-XD-1005 and AI 7518- D971274)	1	321 CRES ASTM A-240	228-7/8 in. -OD max 222-3/4 in. -ID min 0.050-in. wall thickness 20-3/4-in. installed length at 70° F (expanded 2-3/4 in.) 21-3/4-in. length at design conditions 22-1/4-in. length at 1000° F isothermal	Speed, slow linear movement as tempera- ture varies	Sodium Vapor	150 to 1000° F	Not available	Not available	Not available

a. Statement of Operability

The core clamp assemblies became difficult to operate.

b. Statement of Maintainability

The core clamp assemblies were extremely inaccessible, making maintenance difficult.

c. History of Malfunction and/or Modification

In the spring of 1964,^(1,2) the core clamps had to be loosened to enable the removal of damaged moderator cans in the HNPF core. Torques exceeding 1250 ft-lb on the bell crank assembly were required to loosen the clamps which had been designed to loosen with a 500 ft-lb torque. Excessive pressure exerted on the clamps by swollen graphite, resulting from sodium in-leakage into the damaged cans, caused this increase in release torque.

2. Reactor Vessel Bellows (Table 1)

The gas seal from the HNPF reactor vessel to the upper cavity liner was made by a flexible bellows which also took care of differential thermal expansion between the reactor vessel and the cavity liner. The axial movement of the bellows was estimated at approximately 4 in. The normal operating conditions showed that the internal gas pressure acting on the bellows would not be greater than 0.5 psi. The design pressure for the bellows was 5 psi. The bellows was fabricated from Type 321 CRES, which has considerable corrosion resistance, creep strength at high temperatures, formability and weldability. Bending stresses in the convolutions due to pressure loading were limited to the allowable value of 14,600 psi at 1050°F, as given in the ASME Boiler and Pressure Vessel Code, Section VIII, Unfired Pressure Vessels, 1956. Membrane stresses in the bellows were limited to the code allowable value of 13,100 psi at 1050°F. To conform to this restriction the bellows was subjected to an extension cold spring of 2.75 in. at the time of installation.

a. Statement of Operability

There were no operating difficulties with the reactor vessel bellows.

b. Statement of Maintainability

No maintenance was required on the reactor vessel bellows.

c. History of Malfunction and/or Modification

There was no history of failure or modification for the reactor vessel bellows.

TABLE 2
HNPf UPPER SHIELD ROLLER ASSEMBLY

[illegible]

3. Upper Shield Roller Assembly (Table 2)

The HNPF reactor loading face shield rested on 40 horizontal roller assemblies which supported it at all times and allowed rotation. Four guide rollers were provided to maintain shield alignment and concentricity during rotation. The roller assemblies were isolated from the reactor sodium atmosphere by a "dip-type" seal of a low-temperature melting alloy. Information on this mechanism has been included because future reactor concepts may locate these mechanisms in a sodium vapor environment. The shield was supported by a side shell framed into a ring girder which, in turn, rested on a total of 40 rollers. The maximum bending stress in the ring girder was 14,600 psi, compression. The maximum static bearing stress on the rollers was 142,000 psi; the dynamic stress when rolling was 98,000 psi.

a. Statement of Operability

Difficulty was encountered with operation of the guide roller system, indicating that the operational loads had been underestimated. No operating difficulties were encountered with the support roller system.

b. Statement of Maintainability

No maintenance was required on the roller assembly.

c. History of Malfunction and/or Modification

Early problems with loading face shield rotation⁽³⁾ were attributed to distortion in the side shell as installed. Before the loading face shield was grouted, it rotated freely on the rollers provided. After grouting, the first rotation caused a seizure between the face shield and the side shell face. Severe galling resulted from intimate material contact during this rotation. It was necessary to fill-weld all gouged areas and rebore the side shell ID. Adequate clearance was obtained, permitting face-shield rotation.

Later problems with face-shield rotation indicated insufficient lateral guide roller support. Adding four additional guide rollers⁽⁴⁾ and reinforcing the mounts did not improve the condition appreciably. However, the face shield could be driven from side to side within the side shell, indicating some annular clearance. A system of peripheral hydraulic rams was installed around the side shell, acting radially inward against the face shield. By exerting a progressive radial force the hydraulic rams were able to roll the face shield within the side shell;

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in effect, slowly rotating the shield relative to the side shell in the reverse direction, proportional to the differences in their contacting diameters. Initially, a rotation of about 8 deg/hr was obtained with the pulsing force; however, as the rolling continued, rotation increased to about 15 deg/hr. This increase in rotation without an increase in ram action pulse rate indicated a change in the effective diameter of either the face shield, the side shell, or both. It was concluded that deposited oxides and bulk sodium had been removed from the annulus as the face shield rolled.

4. Fuel Channel Orifices (Table 3)

The HNPF Mark I orifice mechanism⁽⁵⁾ was designed to provide precise flow control with adjustment increments limited to 1/64-in. vertical movement of an orifice bulb per wrench placement, corresponding to a change of about 2°F in the fuel channel coolant outlet temperature. The loads on the mechanism were: the weight of the bulb and drive shaft of approximately 20 lb; the frictional resistance developed by the system; and the hydraulic uplift on the orifice bulb. Design adjustment torque was about 25 in.-lb, due mainly to friction between components of the drive mechanism. The objectives of this design were precision in adjustment and avoidance of inadvertent large adjustment increments. Emphasis on radiation shielding integrity resulted in the use of a Teleflex cable actuator which penetrated the shield plug through a helical conduit. There was no barrier to prevent sodium vapor from entering the lower end of the conduit.

a. Statement of Operability

The orifice plug and drive tube assembly offered no operating difficulties. The drive tube actuator mechanism experienced excessive binding, hindering operation.

b. Statement of Maintainability

The orifice plug and drive tube assembly required no maintenance. Reactor shutdown would be required if maintenance or cleaning were performed on the actuator assembly.

c. History of Malfunction and/or Modification

Major orifice adjustment problems were first experienced in late 1963,⁽⁶⁾ after about 16 weeks exposure to reactor design temperature. The problems became progressively worse with longer exposures. An intensive investigation to determine the source of the "sticking" problem was then initiated. It was finally determined that the sticking was a binding between the lower shaft and conduit

which resulted from an accumulation of solidified sodium vapors. The Teleflex cable was found to be free in its conduit with no sign of galling. At this time it was recommended that the mechanism be modified to include a bellows seal which would exclude the reactor cover atmosphere from the annulus between the Teleflex assembly and its conduit, thus precluding the accumulation of sodium crud in this critical region. The bellows was never added; however, the modification would have satisfied the need. A modified rigid rod system was designed for the second core loading.

5. Free Surface Pumps (Table 4)

The HNPF sodium coolant system consisted of six separate loops: three primary and three secondary. Each loop utilized a vertically mounted, centrifugal, overhung, free-surface-type pump to circulate sodium. These pumps were designed to enable removal of internal parts (including impeller, shaft, pump barrel, gas seals, and bearings) through the top without disturbing the pump case or piping. This design feature allowed ready access for maintenance to the pump driver assembly without radiation considerations. The primary and secondary pumps were identical except that the primary pump drive shaft was 5 ft longer because of radiation shielding considerations.

a. Statement of Operability

The primary and secondary pumps operated well under the design conditions.

b. Statement of Maintainability

The pumps were designed for easy accessibility.

c. History of Malfunction and/or Modification

Performance of the six heat transfer system sodium pumps at the HNPF was quite satisfactory. No problems inherent to the design were encountered, except for the primary pump impeller modifications⁽⁷⁾ required to reduce gas entrainment potential during operation at less than design head conditions. The only plant down-time required for corrective action was caused by extraneous items such as foreign material, case flooding, and improper assembly. All these were items not related to design of the pump mechanisms.⁽⁷⁾ During start-up, testing, and operation of the HNPF, the primary pumps accumulated an average operating time of 21,585 hr per pump, while the secondary pumps accumulated an average of 17,481 hr per pump.⁽⁸⁾

TABLE 4
HNPF SODIUM PUMPS
(Sheet 1 of 2)

Mechanism	Design Information					Operating Conditions				
	Component (Drawing No.)	No. per Mech- anism	Material of Construction	Dimensions and Manufacturing Tolerances	Clearances, Loading, and Speed	Operating Medium	Temperature, Velocity, and Pressure	Exposure to Environment (hr)	Operating Cycles or Hours	Operating Medium Impurities Range/Average
Primary Pump Byron Jackson Number in Plant 3 Primary Material of Construction 304 CRES Specification Number 7518-S-78104	Hydrostatic Bearing Journal (3F-5328 and 3B-10330)	1	304 CRES Hard-faced Colmonoy 5	11.980-in./11.979 diam 13-1/2-in. length	Speed, 0 to 850 rpm	Sodium Liquid	300 to 945°F Sodium velo- city to 15.5 ft/sec	≈22,000	No.1- 21,198 No.2- 21,677 No.3- 21,897 hours	Sodium Liquid C (ppm) 22 to 26 /24 O ₂ (ppm) 5 to 95 /≈14
	Hydrostatic Bearing Pad (1F-4456)	1	304 CRES Hard-faced Colmonoy 6	12.000-in./12.002 diam	Clearance, 0.020 in./0.021	Sodium Liquid	300 to 945°F Sodium velo- city to 15.5 ft/sec	≈22,000	No.1- 21,198 No.2- 21,677 No.3- 21,897 hours	
	Upper Wear Ring-Impeller (3F-5328)	1	304 CRES	16.062-in./16.060 diam 1-1/2-in. length	Speed, 0 to 850 rpm	Sodium Liquid	300 to 945°F Sodium velo- city to 15.5 ft/sec	≈22,000	No.1- 21,198 No.2- 21,677 No.3- 21,897 hours	
	Upper Wear Ring Surface Pump Case (1F-4456)	1	304 CRES	16.125-in./16.127 diam	Clearance, 0.063 in./0.067	Sodium Liquid	300 to 945°F Sodium velo- city to 15.5 ft/sec	≈22,000	No.1- 21,198 No.2- 21,677 No.3- 21,897 hours	
	Lower Wear Ring-Impeller (1F-4456 and 1F-5328)	1	304 CRES	15.250-in./15.248 diam 1-3/4-in. length	Speed, 0 to 850 rpm	Sodium Liquid	300 to 945°F Sodium velo- city to 15.5 ft/sec	≈22,000	No.1- 21,198 No.2- 21,677 No.3- 21,897 hours	
	Lower Wear Ring Surface - Pump Case (1F-4456)	1	304 CRES	15.310-in./15.312 diam	Clearance, 0.060 in./0.074	Sodium Liquid	300 to 945°F Sodium velo- city to 15.5 ft/sec	≈22,000	No.1- 21,198 No.2- 21,677 No.3- 21,897 hours	
Secondary Pump Byron Jackson Number in Plant 3 Primary Material of Construction 304 CRES Specification Number 7518-S78105	Hydrostatic Bearing Journal (3F-5360 and 1F-4457)	1	304 CRES Hard-faced Colmonoy 5	11.980-in./11.978 diam 13-1/2-in. length	Speed, 0 to 850 rpm	Sodium Liquid	300 to 900°F Sodium velocity to 15.5 ft/sec	≈19,000	No.1- 17,375 No.2- 18,470 No.3- 16,597	Sodium Liquid O ₂ (ppm) 5 to 95/≈14 H ₂ (ppm) Traces
	Hydrostatic Bearing Pad (1F-4457)	1	304 CRES Hard-faced Colmonoy 6	12.000-in./12.002 diam	Clearance, 0.020 in./0.024	Sodium Liquid	300 to 900°F Sodium velocity to 15.5 ft/sec	≈19,000	No.1- 17,375 No.2- 18,470 No.3- 16,597	
	Upper Wear Ring Impeller (3F-5360)	1	304 CRES	16.062-in./16.060 diam 1-3/4-in. length	Speed, 0 to 850 rpm	Sodium Liquid	300 to 900°F Sodium velocity to 15.5 ft/sec	≈19,000	No.1- 17,375 No.2- 18,470 No.3- 16,597	
	Upper Wear Ring Surface - Pump Case (3F-5309)	1	304 CRES	16.125-in./16.127 diam	Clearance, 0.063 in./0.067	Sodium Liquid	300 to 900°F Sodium velocity to 15.5 ft/sec	≈19,000	No.1- 17,375 No.2- 18,470 No.3- 16,597	

TABLE 4
HNPF SODIUM PUMPS
(Sheet 2 of 2)

[illegible]

6. Valves, General

Austenitic stainless steel, in the cast (CF-8), forged, or wrought equivalent of Type 304, was designated as the basic material for construction of all valve components contacting molten sodium. This material (ASTM-A-362 or RDT-MA-182) was selected for its high heat strength, weldability, resistance to thermal shock, corrosion resistance, and commercial availability. The quality standards established for the material for use in the various valves, were in accordance with the radiographic standards as outlined in ASTM E71: Class I for wall thicknesses less than 1/2 in.; Class II for wall thicknesses 1/2 in. and greater.⁽⁹⁾

Hard facing materials, as applied to the valve trim, were cobalt base alloys such as Stellite No. 6 and Stellite No. 12. Although the phenomenon of self-welding of valve seats was not anticipated in the HNPF, the hard facing materials were specified to prevent galling of the moving parts of the valve and to provide wear resistance of the valve seats. The heliarc or neutral oxy-acetylene methods of deposition of these alloys were specified to prevent excessive carburization of the deposit, which may result in embrittlement. Following finish-machining, all hard-faced surfaces were subjected to a high-sensitivity penetrant inspection test to establish quality control requirements.

The heliarc welding process was used in making all joints and seals employed in the primary containment of the molten sodium: e.g., body-to-bonnet joint, stem freeze seal, and bellows stem seal. An exception was the stem freeze seal, used on certain of the valves, which used frozen sodium as the sealing element. Quality control of all welded joints was established by radiographic and penetrant inspection requirements.

Stem packing, employed as a secondary stem seal of the molten sodium, was high-temperature graphitized asbestos reinforced with Inconel wire. This material was selected for its high-temperature properties, resistance to "setting," and freedom from organic lubricants.

Carbon steel was used in the construction of the valve yokes; bearing materials in the actuating structures were bronze or treated steels. Organic-free lubricants such as molybdenum disulphide were employed in the actuating structures.

Fig. 1. HNPf Primary Sodium Throttling Valve

a. Throttle Valves (Table 5)

Figure 1 illustrates the design of the HNPF primary throttling valves; the secondary throttling valves were identical, except that no double containment jacket was provided. The valves were supplied by the General Kinetics Corporation; their operation is described in the following paragraphs.

In the full-open position, the valve ball was supported on four inclined surfaces of the cage and was completely out of the flow path of the valve; the cage was held in the full-open position by the valve stem; the bottom of the cage bridged the space in the body. When the valve was actuated in the closing direction, the cage carried the ball into the flow path of the valve until the ball made contact with the ball pin guide; further downward movement of the stem and cage caused the wedging surface of the cage to contact the ball and to roll it towards the valve seat for tight shutoff. In the fully closed position, the ball was wedged into the valve seat by the wedging surface of the cage; no other surfaces contacted the ball. When the valve was actuated in the opening direction, the cage was moved by the stem in an upward direction, which released the wedging action of the cage and brought two of the four inclined surfaces (which previously supported the ball) into contact with the ball. Further upward movement of the stem and cage rolled the ball out of the valve seat and onto the four inclined surfaces of the cage.

The throttling valves were provided with forced-convection-cooled stem freeze seals designed by Atomics International (AI). The stem seal was accomplished by solidifying sodium in an annulus which communicated with the valve interior. This annulus was formed by the inside diameter of the finned sleeve and the outside diameter of the valve stem. Ducted coolant gas directed across the finned surface provided the means of heat dissipation which resulted in the freeze. The valve stem was hollow to reduce the heat load. Above the freeze section a lantern ring and packing arrangement were provided to maintain an inert gas atmosphere over the seal to minimize the formation of sodium oxides. The packing used could provide an effective sodium seal in the event of complete loss of the frozen seal; and it was spring loaded to compensate for subsequent set.

(1) Statement of Operability. Complex actuating mechanisms not exposed to the sodium environment caused operating difficulties.

TABLE 5
HNPf THROTTLING VALVE

Mechanism	Design Information					Operating Conditions				
	Component (Drawing No.)	No. per Mech- anism	Material of Construction	Dimensions and Manufacturing Tolerances	Clearances, Loading, and Speed	Operating Medium	Temperature, Velocity, and Pressure	Exposure to Environment (hr)	Operating Cycles or Hours	Operating Medium Impurities Range/Average
Throttling Valve General Kinetic Corp. Number in Plant 1 - 6-in. 6 - 14-in. Primary Material of Construction 304 CRES Assembly Drawings 6-in. 7518-D73405 14-in. 7518-D73405 Specification Number 7518-S73401				Dimensions Provided for 14-in. Valve						Sodium Liquid O ₂ (ppm) 5 to 95/14
	Ball Pin Guide (L-0366, L-0424, A-4170)	1	304 CRES Stellite 6 Tip	1.500-in./1.498 diam 13-1/8-in. length		Sodium Liquid	300 to 600° F Sodium velocity to 15.5 ft/sec	22,000	Unavailable	
	Valve Seat (L-0366 and L-0424)	1	304 CRES Stellite 6 Faced	Refer to Drawing where necessary		Sodium Liquid	300 to 600° F Sodium velocity to 15.5 ft/sec	22,000	Unavailable	
	Cage Guide (L-0366 and L-0424)	1	304 CRES Stellite 6 Faced	Refer to Drawing where necessary	Surface velocity, 1 in./sec	Sodium Liquid	300 to 600° F Sodium velocity to 15.5 ft/sec	22,000	Unavailable	
	Ball Cam Surface (L-0366 and L-0424)	1	304 CRES Stellite 6 Faced	Dimensions not provided		Sodium Liquid	300 to 600° F Sodium velocity to 15.5 ft/sec	22,000	Unavailable	
	Back Seat Surface Guide (L-0366 and L-0424)	1	Stellite 6	Dimensions not provided	Surface velocity, 1 in./sec	Sodium Liquid	300 to 600° F Sodium velocity to 15.5 ft/sec	22,000	Unavailable	
	Lantern Ring (L-0366, L-0424, and A-4172)	1	12% Cr Steel	2.744-in./2.742 OD 2.021-in./2.026 ID 1-3/8-in. length	Surface velocity, 1 in./sec	Sodium Liquid	300 to 600° F Sodium velocity to 15.5 ft/sec	22,000	Unavailable	
	Stem Shaft (L-0366, L-0424, A-4182, and A-4180)	1	304 CRES	2.000-in./1.997 OD 1-1/4-in. principal ID	Clearance, 0.021 in./0.029 Surface velocity, 1 in./sec	Sodium Liquid	300 to 600° F Sodium velocity to 15.5 ft/sec	22,000	Unavailable	

(2) Statement of Maintainability. There were no unusual maintenance problems with the throttling valve.

(3) History of Malfunction and/or Modification. All throttle valve mechanisms exposed to sodium liquid or vapor exhibited satisfactory operation except for the stem packing, which had to be replaced occasionally when sodium oxide accumulated on the valve stem in a sufficient amount to push the packing out of place when the valve was operated.⁽¹⁰⁾ However, the drive mechanisms which were not exposed to a sodium environment caused considerable operational difficulties (Refs 11, 12). Categories encompassing these operational difficulties included: (1) failure of the clutch assembly in the EIM valve operator; (2) failure of the key between the helical gear and the jack screw spindle of the yoke assembly; (3) failure of the bronze bushing which held the yoke to the jack screw spindle; and (4) bent valve stems. Modifications to overcome these difficulties included increasing the bearing contact surface between the thrust washer and shaft, modification of the keyway to eliminate friction with the thrust washer, and installation of shims to prevent vertical movement when changing direction of travel.

b. Blocking Valves (Table 6)

The design of the primary blocking valves is illustrated in Figure 2. In operation, with the valve fully open, the wedge disk was clear of the flow path of the valve. At closing, the wedge made contact with the seating surface of the valve and further downward movement of the stem caused the wedge to deflect to accomplish contact over the entire seating surface. By deflecting, it was considered that the wedge compensated for valve seat distortion (if such occurred) and so accomplished tight shutoff.

Valve construction was similar to that of the primary throttling valves as regards stem freeze seal, double containment jacket, and valve body drain line. Power actuation was also similarly accomplished except that no positioning instrumentation was required; the valves were normally fully open or fully closed.

(1) Statement of Operability. Slight binding was experienced, otherwise there were no operating difficulties.

(2) Statement of Maintainability. No maintenance difficulties were encountered.

Fig. 2. HNPF Primary Sodium Blocking Valve

HNPF BLOCKING VALVE

[illegible]

Fig. 3. HNPF Primary Sodium Check Valve

(3) History of Malfunction and/or Modification. Slight binding of the stem hindered valve operation. The binding tendency was caused by an accumulation of sodium oxide in the stem freeze seal.

c. Check Valves (Table 7)

The function of the primary sodium check valves was to prevent a flow reversal in a primary heat transfer system if loss of pumping head occurred while sodium was circulated in the remaining systems at rated heat pressure. The valves were located in the reactor return line of each of the three primary heat transfer systems downstream of the intermediate heat exchanger (IHX). Location of the valves was intended to prevent a gross thermal shock of the heat exchanger due to a flow reversal. During convection flow conditions, the allowable pressure drop across the valve was in the order of 0.05 psi, dependent upon flow rate. The pressure drop at various flow rates was determined by the supplier after completion of manufacture of the prototype valve. The data so obtained were within the HNPF system requirements.

The HNPF primary sodium check valve is illustrated in Figure 3. By utilizing a knife-edge bearing rather than a pin-in-sleeve type journal, it was considered that the hinge structure would remain operative when exposed to system "dirt" and/or a relatively high oxide level of the flowing sodium. The open area surrounding the knife edge was intended to provide a washing action of the hinge due to free communication with the flow stream. A pin-in-sleeve type journal, it was considered, would probably be more subject to seizing due to a buildup of sodium oxide in the relatively close fitting journal.

The knife-edge bearing also provided the advantage that rolling friction was encountered at the initial movement of the disk, resulting in a lower head loss at extremely low flows. Sliding friction occurred in a pin-in-sleeve type journal for all disk movement.

The negative seat angle, as illustrated, was intended to provide through-drainage of the sodium at a negligible driving head. In the prototype, this negative angle was 5 deg and was intended to provide lower heat loss at the low convection flow rates, in addition to good drainage. It was determined, during preliminary hydraulic flow testing of the prototype, that this large angle did not

TABLE 7
HNPF CHECK VALVE

[illegible]

materially improve the low flow head loss. Therefore, in the final units this angle was reduced to nominally 1 deg to improve disk closure at reverse flow conditions while maintaining the through-drainage requirement.

- (1) Statement of Operability. Check valves operation was satisfactory.
- (2) Statement of Maintainability. No maintenance was required on the check valves.
- (3) History of Malfunction and/or Modification. There was no history of check valve malfunction.

d. Gate Valve (Table 8)

The small stem freeze seal (gate type) blocking valves were located in lines between the primary or secondary heat transfer system and the related sodium service system, and functioned to isolate the respective systems.

The design features of these valves are illustrated in Figure 4. The stem freeze seal device, as designed by AI, employed natural convection cooling to establish the seal; thus eliminating the requirement of directed forced convection cooling as employed in the primary blocking valves.

- (1) Statement of Operability. Operation of the small stem freeze seal gate valves was satisfactory.
- (2) Statement of Maintainability. No maintenance difficulties were encountered.
- (3) History of Malfunction and/or Modification. There was no history of gate valve malfunction.

e. Bellows Seal Valves (Table 9)

The function of the bellows stem-seal valves was to block or divert the flow of sodium to the various components (i.e., cold trap, plugging meter, service pump, drain, and fill tanks) of the sodium service system. The sodium service systems could be isolated from the heat transfer system and access for repair or replacement of equipment could be more readily attained.

Figure 5 illustrates a typical bellows stem-seal valve used in HNPF. The offset pattern body is illustrated; angle pattern body valves were also used in the system. Note that a conventional packed-stem seal was incorporated on the valve

Fig. 4. Small Blocking Valve
(Stem Freeze Seal)

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Fig. 5. HNPF Small Blocking and Diverting Valve (Bellows Stem Seal)

HNPF BELLOWS VALVES

[illegible]

as a secondary stem seal. The bellows stem seal had the advantage that no auxiliary services (i.e., coolant source or inert gas connection) were required to maintain the seal. A seamless, single ply, convoluted style bellows was employed and was protected by a flow impingement shield. As in the primary throttling valves, the valve seat was "free standing" to minimize seat distortion.

(1) Statement of Operability. Operation of the valves was satisfactory with seal bellows intact.

(2) Statement of Maintainability. Bellows replacement was difficult in radioactive areas.

(3) History of Malfunction and/or Modification. Approximately 12% of the bellows seal valves installed in the sodium circulating portion of the HNPF heat transfer system suffered bellows failures.⁽¹³⁾ The failures were generally associated with throttling of the valve for extended periods of time. Under these conditions the bellows vibrated to the extent that audible indications were evident in the vicinity of the valve during high flow and high pressure drop conditions. After repeated bellows replacement it was recommended that certain critical bellows seal valves be modified to replace the bellows with ambient-cooled stem freeze seals. Six valves, one on the vent line from the top of each IHX to the expansion tanks and one from each loop high point to the expansion tanks, were removed and replaced with orifices. The remaining bellows seal valves were operated with extreme care, putting limits on their use as throttling valves.

It has been recommended that the use of bellows seal valves be kept to an absolute minimum. When they are required, care must be taken to select a valve which will operate in any position and with high pressure drops without responding in a vibratory mode.

7. Fuel and Moderator Handling Machine (Table 10)

The fuel and moderator handling machine consisted of a shielded cylinder with a hoist and grapple mechanism to raise and lower components, a gas lock, and indexing devices. The machine was supported and transported by a trolley, which in turn rode on a gantry crane. Fuel handling machine design is shown in Figures 6 and 7.

7508-52174

Fig. 6. HNPF Fuel Handling Machine

7508-52175

Fig. 7. Top of HNPF Fuel Handling Machine

TABLE 10
HNPF FUEL HANDLING MACHINE
(Sheet 1 of 4)

Mechanism	Design Information					Operating Conditions				
	Component (Drawing No.)	No. per Mech- anism	Material of Construction	Dimensions and Manufacturing Tolerances	Clearances, Loading, and Speed	Operating Medium	Temperature, Velocity, and Pressure	Exposure to Environment (hr)	Operating Cycles or Hours	Operating Medium Impurities Range/Average
Fuel Handling Machine	Grapple Assembly	2								
Number in Plant 1	Grapple Head Upper Chain Attachment (7508-D741115)	2	304 CRES Chrome Plate	8-1/8-in. OD taper, 15' from upper and lower surfaces; 0.750-in./0.752 ID pin seat; surf. fin. - 125 rms chrome plate thickness - 0.001 in./0.002	Clearance, grapple head with guide tube 0.282-in. nominal pin seat with pin 0.001-in./0.004	Sodium vapor and condensate		Unavailable	Unavailable	Sodium Vapor Unavailable
Primary Material of Construction 304 CRES	Head Pin (7508-D741115)	2	4130 Steel	7-5/8-in. length; 0.749-in./0.748 OD; surf. fin. - 125 rms	Clearance, pin with pin seat 0.001-in./0.004 pin with bushing 0.126-in. nominal	Sodium vapor and condensate		Unavailable	Unavailable	
Assembly Drawing 7508-D741177	Upper Tube - Body Assembly (7508-D741113)	2	304 CRES	0.875-in. ID pin bushing 3.500-in./3.498 OD tube; surf. fin. - 125 rms	Clearance, upper tube with lower head 0.002-in./0.005; head pin in bushing 0.126-in. nominal	Sodium vapor and condensate		Unavailable	Unavailable	
	Lower Head Chain Tension- ing Unit (7508-D741117)	2	304 CRES Chrome Plate	3.502-in./3.503 ID - body upper tube seat; 9/32-in./1/4 guide web thickness; chrome plate thickness 0.001-in./0.002; surf. fin. - 125 rms	Clearance, lower head with upper tube 0.002-in./0.005; web in guide tube slots 0.74-in./0.125	Sodium vapor and condensate		Unavailable	Unavailable	
	Tensioning Springs (7508-D741117)	16	Inconel X	5-1/2 active coils 4-9/16-in./4-1/2 ID; 7-1/2-in./7-1/4 free length 5/8-in. wire OD		Sodium vapor and condensate		Unavailable	Unavailable	
	Spring Spacer Sleeve (7508-D741117)	14	304 CRES Chrome Plate	4-3/32-in. ID; chrome plate thickness 0.001-in./0.002; surf. fin. - 125 rms		Sodium vapor and condensate		Unavailable	Unavailable	
	Guide Tube - Spring Spacer (7508-D741117)	2	304 CRES	4-in. OD nominal 0.120 in. wall; surf. fin. - 125 rms		Sodium vapor and condensate		Unavailable	Unavailable	
	Guide Tube - Grapples (7508-D741118)	2	304 CRES Chrome Plate	8-in. Sched 5 tube 8.407-in. ID; guide slots - vertical 0.355-in./0.375 width; chrome plate thickness 0.002-in./0.003; surf. fin. - 125 rms	Clearance, grapple head in guide tube 0.282-in. nominal; lower and upper heads in guide tube slots 0.74-in./0.125	Sodium vapor and condensate		Unavailable	Unavailable	

TABLE 10
HNPF FUEL HANDLING MACHINE
(Sheet 2 of 4)

Mechanism	Design Information					Operating Conditions				
	Component (Drawing No.)	No. per Mech- anism	Material of Construction	Dimensions and Manufacturing Tolerances	Clearances, Loading, and Speed	Operating Medium	Temperature, Velocity, and Pressure	Exposure to Environment (hr)	Operating Cycles or Hours	Operating Medium Impurities Range/Average
	Chain Guides (7508-D741118)	72	304 CRES	1/16-in. plate 2-in.x 6-in.		Sodium vapor and condensate		Unavailable	Unavailable	
	Chain (Mfg number 100 HHS Chain Belt Co.)	4	CRES	1-1/4-in. pitch; 99-ft length		Sodium vapor and condensate		Unavailable	Unavailable	
	Universal Joint (Mfg number C-654 Curtis Universal Joint Co.)	2	Steel (solid hub)	3-in. OD; 9-in. length		Sodium vapor and condensate		Unavailable	Unavailable	
	Grapple - Main Piston (7508-D741112)	2	304 CRES	6.489 in./6.487 OD at cylinder region; surf. fin. - 125 rms	Clearance, piston with cylinder at seal region (O-ring seal) 0.013-in./0.017	Sodium vapor and condensate		Unavailable	Unavailable	
	Cylinder (7508-D741112)	2	304 CRES	6.502-in./6.504 ID at piston seal region; surf. fin. 16 rms inner seal surface, 32 rms outer seal surface	Clearance, cylinder with piston 0.013-in./0.017	Sodium vapor and condensate		Unavailable	Unavailable	
	Grapple - Lower Body Extension (7508-D741111)	2	304 CRES	4.251-in./4.253 ID inner piston region; 3.250-in./ 3.252 ID guide region; surf. fin. - 125 rms	Clearance, body exten- sion with inner piston 0.003-in./0.007; body extension with guide 0.002-in./0.005	Sodium vapor and condensate		Unavailable	Unavailable	
	Inner Piston - Lower Body (7508-D741116)	2	304 CRES	4.248-in./4.246 OD adjacent to quad ring seat; surf. fin. - 32 rms	Clearance, piston with body extension 0.003-in./0.007	Sodium vapor and condensate		Unavailable	Unavailable	
	Inner Guide - Lower Body Extension (7508-D741116)	2	Bronze	3.248-in./3.247 OD; surf. fin. - 125 rms	Clearance, guide with body extension 0.002-in./0.005	Sodium vapor and condensate		Unavailable	Unavailable	
	Grapple Latch Housing (7508-D741111)	2	304 CRES	3.125-in./3.128 ID at inner housing region; surf. fin. - 125 rms	Clearance, latch housing with inner housing 0.002-in./0.008	Sodium vapor and condensate		Unavailable	Unavailable	
	Inner Housing - Latch Housing (7508-D741116)	2	304 CRES	3.123-in./3.120 OD main body; 1.625-in./1.627 ID spool seat	Clearance, inner housing with latch housing 0.002- in./0.008; spool seat with spool 0.002-in./0.006	Sodium vapor and condensate		Unavailable	Unavailable	

TABLE 10
HNPf FUEL HANDLING MACHINE
(Sheet 3 of 4)

Mechanism	Design Information					Operating Conditions				
	Component (Drawing No.)	No. per Mech- anism	Material of Construction	Dimensions and Manufacturing Tolerances	Clearances, Loading, and Speed	Operating Medium	Temperature, Velocity, and Pressure	Exposure to Environment (hr)	Operating Cycles or Hours	Operating Medium Impurities Range/Average
	Spool (7508-D741116)	2	KETOS Tool Steel Electro- film Solid Film Lubri- cant	1.623-in./1.621 OD main body region, hardened Rc 58-60; surf. fin. - 125 rms	Clearance, spool with spool seat latch housing 0.002-in./0.006	Sodium vapor and condensate		Unavailable	Unavailable	
	Latch Finger (7508-D741116)	6	304 CRES	0.5005-in./0.5015 ID pin seat 0.750-in. width	Clearance, pin with latch finger 0.0005-in./0.0015	Sodium vapor and condensate		Unavailable	Unavailable	
	Latch Pin (7508-D741108)	6	Commercial	0.500-in. pin OD nominal	Clearance, pin with latch finger 0.0005-in./0.0015	Sodium vapor and condensate		Unavailable	Unavailable	
	Drive Assembly									
	Sprocket Bear- ings - Upper (Mfg number 5208 U-TM Hyatt Co.)	4	Commercial	Refer to Drawings where necessary		Sodium vapor and condensate		Unavailable	Unavailable	
	Sprocket Bear- ings - Lower (Mfg number 5208 U-TM Hyatt Co.)	4	Commercial	Refer to Drawings where necessary		Sodium vapor and condensate		Unavailable	Unavailable	
	Lower Sprocket Bearing - Lower (9113 P)	1	Commercial	Refer to Drawings where necessary		Sodium vapor and condensate		Unavailable	Unavailable	
	Lower Sprocket Bushing - Upper (7508-D741129)	1	Bronze	2.563-in./2.565 ID; 3.930-in./3.928 OD; 0.700-in./0.695 width; surf. fin. - 32 rms ID - 63 rms OD	Clearance, bushing with seat ID 0.0070-in./0.0099; bushing width with seat 0.009-in./0.019; loads, negligible	Sodium vapor and condensate		Unavailable	Unavailable	
	Lower Sprocket Bushing Seat (7508-D741129)	1	304 CRES	3.9370-in./3.9379 ID; 0.709-in./0.714 depth; surf. fin. - 63 rms	Clearance, bushing with seat ID 0.0070-in./0.0099; bushing seat depth with bushing 0.009-in./0.019; loads, negligible	Sodium vapor and condensate		Unavailable	Unavailable	

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The machine shielding consisted of lead shot confined between steel walls of the machine body. The greatest shield thickness surrounded the lower section of the machine. Upper section shielding was tapered. A movable lead-shot-filled skirt provided shielding when an element was entering or leaving the machine. The skirt was raised and lowered by four hydraulic cylinders. Protection against free-fall was provided by flow control valves on the cylinder inlet connections. When the machine was moved, the skirt was locked in the "up" position by manually inserted pins.

There were two internal grapples, each suspended between two continuous roller chains. Each grapple was capable of picking up fuel elements (and similar items) when it was rotated into the pickup position directly above the port in the bottom of the machine. When the machine was traveling, the fuel element was carried in the position 180 deg away from the pickup position, and the grapple was kept in the pickup position in the port at the bottom of the machine to seal the machine atmosphere. As a safety measure, grapples could be released only when they were in the port at the bottom of the machine. Each grapple operated in a guide tube which ran the full height of the machine. The tubes were continuous except for two lengthwise slots. The chains which supported the grapples were outside the guide tubes, and a bar between the chains passed through the slots in the guide tube to support the grapple inside the tube.

Two hoists, one for each grapple, were located at the top of the machine. Each hoist mechanism was outside the machine, and the chain sprocket drive shaft passed through a seal in the machine body. A variable speed electric motor supplied power for the hoist mechanism. The motor was equipped with a brake for quick stopping. Power was transmitted through a slip clutch, gearbox, and torque load cell. A hand crank could be attached to the input side of the gearbox in case of motor failure. A limit switch assembly with a selsyn and counter was driven from the output side of the gearbox. The limit switches stopped the grapple at various predetermined positions. The selsyn and its mate on the control panel were used to drive a counter which indicated the grapple position. The hoist mechanism counter was mechanically driven, and it was used to check the operation of the selsyn-driven counter on the control panel. A torque load cell was connected to the slow speed shaft of the gearbox to indicate grapple load to the operator. The cell was interlocked to stop the hoist motor if safe loads in either direction were exceeded.

At the bottom of the machine body were the television cameras, gas lock, helium blower, photoelectric cell, and drip pan. As the machine was positioned near a given station, the downward facing television cameras transmitted a picture which showed the operator how accurately the machine was positioned. The gas lock sleeve was normally carried about 6 in. above the floor. When the machine was positioned, this sleeve could be driven down to make a seal between the machine and the index ring. (The index ring was previously positioned and sealed to the reactor face.) A vacuum pump and helium supply were provided to evacuate the gas lock and fill it with helium. A helium blower, located outside the machine body, had a nozzle protruding upward into the machine. After fuel elements had been raised into the machine and rotated 180 deg from the pickup position, they could be lowered a few inches into the blower nozzle. Helium was drawn from the machine body and was blown upward through the fuel element. A photoelectric cell at the bottom of the gas lock sleeve was interlocked so that the gas lock could not be evacuated nor the machine moved if anything was left attached to the grapple when in the travel position. The drip pan swung in a horizontal plane underneath the (raised) gas lock sleeve to catch any debris.

All the mechanisms from the inside and bottom end of the machine were removed to convert the fuel handling machine for moderator handling. After these were removed, the top half of the machine body could be unbolted and removed. Only the bottom end of the machine body and the movable shield were left in place. Then the conversion equipment could be added. This consisted of the machine top plug and grapple assembly.

The machine top plug and grapple assembly consisted of a shield plug designed to fit inside the machine body with a flange on the top for mounting. Six holes penetrated the plug, spaced the same as the fuel channels in the reactor. Solid steel rods which supported the moderator can spreader were located in three of the holes. The other three holes were for the moderator can grapple. Both the spreader and the grapple were raised and lowered by the overhead building crane. Seals were provided for each rod which passed through the machine top plug. Grapple extension rods could be coupled into the original lengths to permit the grapple to reach down to the lower grid plate of the reactor.

a. Statement of Operability

The fuel handling machine required extensive servicing, making operation difficult.

b. Statement of Maintainability

The fuel handling machine was designed for ease of maintenance. Not being in constant use provided ample time for maintenance and modification after each period of usage.

c. History of Malfunction and/or Modification

Some modifications of the fuel handling machine were made to improve its performance.⁽¹⁴⁾ The first of these was a relocation of the vacuum connection for purging the gas back from the top of the drip pan housing to a light port on the gas lock. This was done to facilitate purging of the gas lock and to prevent damage to the drip pan gate. Following shortly after this the gas control system for operation of the drip pan was modified by replacing the check valves with needle valves to enable better control of the gate closing rate. This change reduced the maintenance requirements on the gate by about 80%. Mirrors were added at both sides of the operator cab to allow the operator to see the area ahead of the cask without moving from the console. Two modifications were made on the basis of AEC requests. The first of these was the installation of a deadman switch in the grapple drive circuit so arranged that if this switch contact were broken the speed controls would have to be reset to zero before grapple operation could be resumed. This was done so that the operator would be required to stay at the console when the grapples were in operation. The second was the installation of a source range short period alarm in the fuel handling machine annunciator circuit. Along with this, telephone communication with the control room was also set up. This work allowed the fuel handling machine operator and the control operator to coordinate efforts and gave the fuel handling machine operator immediate knowledge of nuclear system trouble.

Possibly the greatest maintenance requirement on the fuel handling machine was the drip pan gate. Until the gas lock and control system modifications were completed almost daily repair of the gate was required. After these modifications, maintenance was largely on the basis of usage hours basically to replace

the O-ring seal, and to remove collected sodium which had dripped off fuel elements during transfer.

The indexing bar was damaged a couple of times due to striking improperly inserted index rings. Functionally, this repair work is attributed to operator error rather than defective design. Also, due to some misalignment between the loading face, sleeves and thimbles, most of the index rings required milling to enable a fit into reactor plug positions.

As expected, the quad rings on the grapple mechanisms required frequent replacement.

During preliminary operation, the sleeve provided inside the gas lock as a guide and sodium scraper would not stay in place, but slipped down, interfering with TV viewing. The sleeve was removed as an expedient and was never replaced.

C. SUMMARY OF HNPF RESULTS

Since the HNPF was designed with a minimum number of mechanisms required to function in a sodium environment, information involving mechanical elements operating in a sodium environment is limited. Information on some mechanisms which were not exposed to sodium at HNPF, but may be exposed to sodium in future designs, is included here.

Extensive problems with the HNPF fuel channel orifice drives can be attributed to lack of consideration of the propensity of sodium vapors to migrate to, and congeal on, colder areas. This propensity should be considered in future design of mechanisms in similar environments.

Valve problems at the HNPF were increased by the complicated drive mechanisms employed. There were no failures involving mechanisms in a sodium environment other than bellows seal failures. These failures usually occurred when the bellows seal valve was used for throttling with consequent flow-induced vibration.

The HNPF free-surface sodium pumps were well designed. Problems occurred when foreign matter, inadvertently left in the system during system maintenance or construction, migrated to the bearing area of the pump.

The HNPF fuel handling machine required many minor modifications to reduce maintenance problems. These may be attributed to the complexity of the machine.

HNPF REFERENCES

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Supplemental Source Material (Not Specifically Cited in Text)

- a. Personal communication with D. K. Darley, Atomics International HNPF Operations Analysis Program Site Representative
- b. Personal communication with R. E. Durand, Atomics International Manager HNPF Evaluation Unit

TABLE 11
SRE CORE CLAMPS AND CORE TANK BELLOWS

Mechanism	Design Information					Operating Conditions				
	Component (Drawing No.)	No. per Mech- anism	Material of Construction	Dimensions and Manufacturing Tolerances	Clearances, Loading, and Speed	Operating Medium	Temperature, Velocity, and Pressure	Exposure to Environment (hr)	Operating Cycles or Hours	Operating Medium Impurities Range/Average
Core Clamps Number in Plant: 12 Primary Material of Construction: 405 CRES	Worm (9693-792159 9693-792155 9693-97268)	2	440C - CRES	Dimensions are difficult to present. Refer to drawings where necessary	Speed, very slow Manually operated Clearances, 0.0025 in. top bushings 0.002 in. bottom bush- ings	Air	≈ 70°F	Mechanism failed prior to system fill and was not operated fol- lowing the failure	1 cycle	Not applicable
	Worm Gear (9693-792158 9693-97260 9693-792155)	2	304 CRES	Dimensions are difficult to present. Refer to drawings where necessary	Speed, very slow Manually operated	Air	≈ 70°F	Mechanism failed prior to system fill	1 cycle	
	"T" Screw (9693-792152)	2	440C - CRES	Dimensions are difficult to present. Refer to drawings where necessary	Speed, very slow Manually operated	Air	≈ 70°F	Mechanism failed prior to system fill	1 cycle	
Core Tank Bellows	Core Tank Bellows (C-12606-S)	1	321 CRES	132 in. ID minimum 140-1/4 in. OD ma 10-11/16 in. /10-5/16 length		Sodium Vapor and Condensate	300 to 1030°F	93,600	93,600 hr	Information not available

IV. SODIUM REACTOR EXPERIMENT

A. DESCRIPTION

The SRE utilized an experimental sodium-cooled graphite-moderated power reactor, located at Santa Susana, California. The SRE was a thermal reactor and operated with moderate power densities and relative low levels of fuel burn-up. Conventional engineering knowledge and practices were followed in designing the reactor and fuel handling systems. Use of "in-sodium" type mechanisms for fuel handling actuation and guidance of control rods, etc., was avoided. The reactor was designed for an output of 20 Mwt, producing 6 Mwe through a conventional steam cycle, or dissipating heat with an air blast heat exchanger.

The outer core tank, fabricated of steel plate 1/2-in.-thick, was 19 ft high and 12-1/2 ft in diameter. The reactor vessel was fabricated of 1-1/2-in. Type 304 CRES, was 19 ft high and 11 ft in diameter. The primary sodium coolant entered the reactor at 500°F leaving at 960°F (design). The two principal types of mechanisms operating in the coolant were centrifugal sodium pumps and variable orifice devices on the fuel elements. The coolant system consisted of four separate loops: (1) main primary, (2) main secondary, (3) auxiliary primary, and (4) auxiliary secondary. The primary loops and reactor were filled and circulation was started on April 19, 1957.

B. DISCUSSION OF MECHANISMS REVIEWED

1. Reactor Core Clamp Mechanism (Table 11)

Core clamps were utilized to control horizontal clearances between the zirconium clad graphite moderator elements. A separate, self-centering cylinder was provided around the top edge of the core to center and support the top ends of the graphite assembly. This band was fabricated of Type 405 CRES, 1/4-in.-thick by 6 in. high. It was supported and centered with a 1/4-in. Type 304 CRES vessel liner by means of dowels welded to its inside surface projecting into holes drilled in the liner. Spacer plates on top of the moderator and reflector cans were clamped in position by 12 straight bars of Type 405 CRES mounted on the band. Two worm gears attached to the band with threaded studs

TABLE 12
SRE UPPER SHIELD ROLLER ASSEMBLY

[illegible]

were provided on each bar so that the bars could be adjusted radially to bear against the entire top of the core and properly align its position beneath the top shield.

a. Statement of Operability

The mechanisms failed during their initial setting. They were not operated thereafter.

b. Statement of Maintainability

No attempt was made to maintain these mechanisms.

c. History of Malfunction and/or Modification

The worm and worm gear galled during their initial operation prior to filling the primary system with sodium. Since later adjustments of moderator element spacing was not anticipated, repair operations were not attempted.⁽¹⁾

2. Upper Shield Roller Mechanism (Table 12)

Three upper shield rollers were used to center the reactor loading face shield (140-in. diameter) in the ring shield, and to provide lateral roller bearings for rotating the loading face shield. The loading face shield was rotated numerous times during the Core I recovery program in 1960 and during the SRE-PEP modification program in 1964/1965. Rotation was accomplished by lifting the shield approximately 1 in. with a bridge crane, and applying a tangential force with come-alongs. The required tangential force usually was substantial (several thousand pounds).

a. Statement of Operability

The roller mechanism operated satisfactorily. Because the rollers could not be observed during the shield rotation, doubt concerning their operation existed. The loading face shield consistently returned to a centered position satisfying the roller mechanisms operational function.

b. Statement of Maintainability

The roller mechanism required no maintenance.

c. History of Malfunction and/or Modification

There was no history of roller mechanism malfunction.⁽¹⁻³⁾

a. SRE Main Sodium Pump
(cutaway of lower portion of
pump, showing freeze seals)

Fig. 8. SRE Centrifugal Pumps

b. SRE Secondary Sodium Pump

3. Sodium Pumps (Table 13)

Centrifugal pumps (Fig. 8) were used to circulate sodium through the reactor and secondary systems. The pumps were mounted vertically within a casing. By unbolting a flange at the reactor floor and melting a casing freeze seal, the entire pump could be removed from the casing for maintenance. Impellers for the two pumps were located in volutes within the main and auxiliary galleries, respectively. The main secondary and auxiliary secondary pumps were located above ground level.

The primary pumps were similar to the secondary pumps except that the casing and drive shaft were lengthened to accommodate the required shielding. The pumps were modified, hot oil process pumps with the impeller and shaft made of Type 316 CRES. Other portions of the pump in contact with sodium were Type 304 CRES. Freeze-type seals were used instead of packings to prevent leakage of sodium past the pump drive shaft into the pump casing. The pump was driven by dc motors having variable speed control from 0 to 1500 rpm. Impeller wear rings were the only parts in mechanical contact with a mating surface operating in a sodium environment. The original pumps were used through the Core II period.

The power expansion program (PEP) utilized free-surface-type centrifugal pumps as reported in Table 13. The original pumps are not documented due to unavailability of drawings.

a. Statement of Operability

The Core I and II pumps operated satisfactorily for approximately 44,000 hr at temperatures to 1030°F. The PEP main primary pump operated satisfactorily except for level control difficulties. The PEP main secondary pump operated satisfactorily except for oil seal difficulties. The PEP auxiliary primary pump operated satisfactorily except for some difficulty with sodium level control and the oil seal. The PEP auxiliary secondary pump operated satisfactorily.

b. Statement of Maintainability

No unusual maintenance was required for any of the pumps.

c. History of Malfunction and/or Modification^(1, 2, 4-8)

After 44,000 hr at temperatures to 1030°F the Core I and II pumps were removed for PEP modification. Examination of the impeller wear rings revealed

TABLE 13
SRE MAIN AND AUXILIARY SODIUM PUMPS
(Sheet 1 of 4)

Mechanism	Design Information					Operating Conditions				
	Component (Drawing No.)	No. per Mech- anism	Material of Construction	Dimensions and Manufacturing Tolerances	Clearances, Loading, and Speed	Operating Medium	Temperature, Velocity, and Pressure	Exposure to Environment (hr)	Operating Cycles or Hours	Operating Medium Impurities Range/Average
Main Sodium Pumps	Primary Pump (PEP)									Sodium Liquid
Number in Plant: 1 primary 1 secondary	Hydrostatic Bearing - Impeller Shaft (307436)	1	304 CRES Colmonoy 5 plated	9.985 in. /9.984 Diameter 1/32 in. Colmonoy plate thickness	Speed, 0 to 1050 rpm Clearance, 0.016 in.	Sodium Liquid	300 to 690°F 690 to 700°F	19,306 2,141	17,582 hr	O ₂ (ppm) 1.6 to 30/<10
Primary Material of Construction:	Hydrostatic Bearing Pad (307443)	1	304 CRES Colmonoy 6 plated	10.000 in. /10.002 Diameter 1/32 in. Colmonoy plate thickness		Sodium Liquid	300 to 690°F 690 to 700°F	19,306 2,141	17,582 hr	
304 CRES	Upper Wear Ring - Impeller (307436)	1	304 CRES	13.475 in. /13.473 Diameter	Speed, 0 to 1050 rpm Clearance, 0.027 in.	Sodium Liquid	300 to 690°F 690 to 700°F	19,306 2,141	17,582 hr	
	Lower Wear Ring - Impeller (307436)	1	304 CRES	11.965 in. /11.963 Diameter	Speed, 0 to 1050 rpm Clearance, 0.037 in.	Sodium Liquid	300 to 690°F 690 to 700°F	19,306 2,141	17,582 hr	
	Lower Wear Ring Pad - Diffuser Assembly (405825)	1	304 CRES	12.000 in. /12.002 Diameter		Sodium Liquid	300 to 690°F 690 to 700°F	19,306 2,141	17,582 hr	
	Upper Wear Ring Pad (506299)	1	304 CRES	13.500 in. /13.502 Diameter		Sodium Liquid	300 to 690°F 690 to 700°F	19,306	17,582 hr	
	Secondary Pump (PEP)									Information not available
	Hydrostatic Bearing Pad (307523)	1	304 CRES Colmonoy 6 plated	8.000 in. /8.002 Diameter 1/32 in. Colmonoy plate thickness	Clearance, 0.016 in.	Sodium Liquid	300 to 690°F 690 to 700°F	19,802 1,645	11,442 hr	
	Lower Wear Ring Pad (506365)	1	304 CRES	9.500 in. /9.505 Diameter	Clearance, 0.028 in.	Sodium Liquid	300 to 690°F 690 to 700°F	19,802 1,645	11,442 hr	
	Upper Wear Ring Pad (214121)	1	304 CRES	9.500 in. /9.501 Diameter	Clearance, 0.028 in.	Sodium Liquid	300 to 690°F 690 to 700°F	19,802 1,645	11,442 hr	
	Hydrostatic Bearing - Impeller (307522)	1	304 CRES Colmonoy 5 plated	7.985 in. /7.984 Diameter	Speed, 0 to 1500 rpm	Sodium Liquid	300 to 690°F 690 to 700°F	19,802 1,645	11,442 hr	

TABLE 13
SRE MAIN AND AUXILIARY SODIUM PUMPS
(Sheet 2 of 4)

Mechanism	Design Information					Operating Conditions				
	Component (Drawing No.)	No. per Mech- anism	Material of Construction	Dimensions and Manufacturing Tolerances	Clearances, Loading, and Speed	Operating Medium	Temperature, Velocity, and Pressure	Exposure to Environment (hr)	Operating Cycles or Hours	Operating Medium Impurities Range/Average
	Upper Wear Ring - Impeller (307522)	1	304 CRES	9.465 in. /9.464 Diameter	Speed, 0 to 1500 rpm	Sodium Liquid	300 to 690°F 690 to 700°F	19,802 1,645	11,442 hr	
	Lower Wear Ring Impeller (307522)	1	304 CRES	9.475 in. /9.474 Diameter	Speed, 0 to 1500 rpm	Sodium Liquid	300 to 690°F 690 to 700°F	19,802 1,645	11,442 hr	
Auxiliary Sodium Pumps	Primary Pump (PEP)									Sodium Liquid
Number in Plant:	Hydrostatic Bearing Pad ()	1				Sodium Liquid	300 to 690°F 690 to 700°F	19,202 2,245	15,241 hr	O ₂ (ppm) 1.6 to 30/<10
1 primary 1 secondary	Hydrostatic Bearing Shaft ()	1				Sodium Liquid	300 to 690°F 690 to 700°F	19,202 2,245	15,241 hr	
Primary Material of Construction:	Upper Wear Ring - Upper Impeller ()	1				Sodium Liquid	300 to 690°F 690 to 700°F	19,202 2,245	15,241 hr	
304 CRES	Lower Wear Ring - Upper Impeller ()	1				Sodium Liquid	300 to 690°F 690 to 700°F	19,202 2,245	15,241 hr	
	Upper Wear Ring - Lower Impeller ()	1				Sodium Liquid	300 to 690°F 690 to 700°F	19,202 2,245	15,241 hr	
	Impeller Drive Shaft at Upper Wear Ring - Upper Impeller (;)	1				Sodium Liquid	300 to 690°F 690 to 700°F	19,202 2,245	15,241 hr	
	Lower Wear Ring Pad - Upper Impeller ()	1				Sodium Liquid	300 to 690°F 690 to 700°F	19,202 2,245	15,241 hr	
	Impeller Drive Shaft at Upper Wear Ring - Lower Impeller ()	1				Sodium Liquid	300 to 690°F 690 to 700°F	19,202 2,245	15,241 hr	

TABLE 13
SRE MAIN AND AUXILIARY SODIUM PUMPS
(Sheet 3 of 4)

Mechanism	Design Information					Operating Conditions				
	Component (Drawing No.)	No. per Mech- anism	Material of Construction	Dimensions and Manufacturing Tolerances	Clearances, Loading, and Speed	Operating Medium	Temperature, Velocity, and Pressure	Exposure to Environment (hr)	Operating Cycles or Hours	Operating Medium Impurities Range/Average
	Impeller Drive Shaft at Upper Wear Ring - Lower Impeller ()	1				Sodium Liquid	300 to 690°F 690 to 700°F	19,202 2,245	15,241 hr	
	Lower Wear Ring Pad - Lower Impeller ()	1				Sodium Liquid	300 to 690°F 690 to 700°F	19,202 2,245	15,241 hr	
	Secondary Pump (PEP)									Information not available
	Hydrostatic Bearing Pad ()	1				Sodium Liquid	300 to 690°F 690 to 700°F	19,194 2,253	17,881 hr	
	Hydrostatic Bearing Shaft ()	1				Sodium Liquid	300 to 690°F 690 to 700°F	19,194 2,253	17,881 hr	
	Upper Wear Ring - Upper Impeller ()	1				Sodium Liquid	300 to 690°F 690 to 700°F	19,194 2,253	17,881 hr	
	Lower Wear Ring - Upper Impeller ()	1				Sodium Liquid	300 to 690°F 690 to 700°F	19,194 2,253	17,881 hr	
	Upper Wear Ring - Lower Impeller ()	1				Sodium Liquid	300 to 690°F 690 to 700°F	19,194 2,253	17,881 hr	
	Impeller Drive Shaft at Upper Wear Ring - Upper Impeller ()	1				Sodium Liquid	300 to 690°F 690 to 700°F	19,194 2,253	17,881 hr	
	Lower Wear Ring Pad - Upper Impeller ()	1				Sodium Liquid	300 to 690°F 690 to 700°F	19,194 2,253	17,881 hr	

SRE MAIN AND AUXILIARY SODIUM PUMPS
(Sheet 4 of 4)

[illegible]

TABLE 14
SRE VARIABLE ORIFICE

Mechanism	Design Information					Operating Conditions				
	Component (Drawing No.)	No. per Mech- anism	Material of Construction	Dimensions and Manufacturing Tolerances	Clearances, Loading, and Speed	Operating Medium	Temperature, Velocity, and Pressure	Exposure to Environment (hr)	Operating Cycles or Hours	Operating Medium Impurities Range/Average
Variable Orifice Number in Plant: 1 Primary Material of Construction: 304 CRES	Hanger Tube (7602-18035)	1	304 CRES	2.51 in. ID 2.75 in. OD		Sodium Liquid	650 to 700°F 600 to 650°F 350 to 600°F	1,816 360 2,144	13 cycles	Sodium Liquid O ₂ (ppm) <5
	Guide Tube (7602-18034)	1	304 CRES	1.748 in. ID 1.878 in. OD		Sodium Vapor	650 to 700°F 600 to 650°F 350 to 600°F	1,816 360 2,144	13 cycles	Sodium Vapor Not available
	Guide Tube (7602-18034)	1	304 CRES	1.084 in. ID 1.25 in. OD		Sodium Vapor	650 to 700°F 600 to 650°F 350 to 600°F	1,816 360 2,144	13 cycles	
	Guide (7602-18039)	3	304 CRES	2.460 in. / 2.455 Diameter	Clearance, 0.050 in.	Sodium Liquid	650 to 700°F 600 to 650°F 350 to 600°F	1,816 360 2,144	13 cycles	
	Orifice Shaft - Shield Section (7602-18039)	1	304 CRES	1.628 in. OD	Clearance, 0.120 in.	Sodium Vapor	650 to 700°F 600 to 650°F 350 to 600°F	1,816 360 2,144	13 cycles	
	Orifice Shaft - Seal Section (7602-18039)	1	304 CRES	0.9661 in. / 0.9616 Diameter	Clearance, 0.018 in.	Sodium Vapor	650 to 700°F 600 to 650°F 350 to 600°F	1,816 360 2,144	13 cycles	
	Orifice Shaft - Below Orifice (7602-18039)	1	304 CRES	0.612 in. / 0.610 Diameter	Clearance, 0.011 in.	Sodium Liquid	650 to 700°F 600 to 650°F 350 to 600°F	1,816 360 2,144	13 cycles	
	Guide (7602-18037)	1	304 CRES	0.626 in. / 0.624 ID		Sodium Liquid	650 to 700°F 600 to 650°F 350 to 600°F	1,816 360 2,144	13 cycles	

the rubbing contact surfaces to be in good condition. The wear rings were Type 316 CRES and the pump bowl Type 304 CRES.

PEP pump operation for over 17,000 hr indicated satisfactory service for the hydrostatic bearings and wear rings. The PEP main primary pump was modified to correct cover gas entrainment and oil seal leakage which occurred shortly after initial startup operation. The PEP main secondary pump developed oil seal leakage, requiring seal modification. Both PEP auxiliary pump oil seals were modified as a precautionary measure. The PEP auxiliary primary pump experienced difficulty with gas entrainment at high flow rates.

4. Variable Orifice Mechanism (Table 14)

The Core 1 and 2 fuel elements utilized an orifice plate at the lower end of the element below the lower guide vanes. The PEP fuel elements (Core III) utilized a variable orifice on each element. The orifice consisted of a plug-type throttle valve designed to control the fuel channel sodium coolant flow range from 3.5 to 10.5 lb/sec by vertical plug motion. The Core III elements were never used due to the decision to deactivate the SRE. A test was conducted on one orifice assembly. The orifice was installed in the reactor vessel and periodically cycled between the full-open and full-closed position throughout the 6-mo test period. Total exposure time and number of operating cycles are reported in Table 14.

a. Statement of Operability

The test orifice operated very well.

b. Statement of Maintainability

The test orifice required no maintenance.

c. History of Malfunction and/or Modification

There was no history of failure or modification for the variable orifice assembly.

5. Core Tank Bellows (Table 11)

The core tank bellows were designed to provide a gas seal between the reactor vessel and the outer vessel.

TABLE 15
SRE FUEL HANDLING MACHINE

Mechanism	Design Information					Operating Conditions				
	Component (Drawing No.)	No. per Mech- anism	Material of Construction	Dimensions and Manufacturing Tolerances	Clearances, Loading, and Speed	Operating Medium	Temperature, Velocity, and Pressure	Exposure to Environment (hr)	Operating Cycles or Hours	Operating Medium Impurities Range/Average
Fuel Handling Machine	Mark I Fuel Handling Machine									
Number in Plant: 1	Grapple Plug (9693-78243)	1	304 CRES	5.245 in. /5.247 Diameter 10-5/16 in. length		Sodium Vapor	70 to $\approx$ 150°F	$\approx$ 24,480	$\approx$ 1200 cycles	Information not available
Primary Material of Construction:	Sleeve Seal -- Lower Outlet	1	304 CRES	5.252 in. /5.254 Diameter	0.007 in Quad Ring seal between plug and sleeve	Sodium Vapor	70 to $\approx$ 150°F	$\approx$ 24,480	$\approx$ 1200 cycles	
304 CRES	Mark II Fuel Handling Machine									
	6 in. Vacuum Gate Valve -- Plug Seat (9693-9782358 9693-9782174)	1	304 CRES	Refer to drawing where necessary		Sodium Vapor	70 to $\approx$ 150°F	$\approx$ 33,120	$\approx$ 2400 cycles	
	6 in. Vacuum Gate Valve -- Plug (9693-9782358 9693-9782174)	1	304 CRES	Refer to drawing where necessary		Sodium Vapor	70 to $\approx$ 150°F	$\approx$ 33,120	$\approx$ 2400 cycles	
	6 in. Vacuum Gate Valve -- Plug O-Ring (9693-782177 9693-9782174)	1	PR-408-70 Styrene			Sodium Vapor	70 to $\approx$ 150°F	$\approx$ 33,120	$\approx$ 2400 cycles	

a. Statement of Operability

There were no operating difficulties with the core tank bellows.

b. Statement of Maintainability

The core tank bellows required no maintenance.

c. History of Malfunction and/or Modification

A small gas leak was discovered during initial system checkout. The gas leak persisted throughout operation of the plant.⁽¹⁾

6. Fuel Handling Machine (Table 15)

To remove any element from the reactor core it was necessary to use the shielded cask or fuel handling machine. The fuel cask was located over the plug of the element to be handled and a pneumatic mechanism within the cask forced a cylinder downward, making an O-ring seal at the top of the plug casing. The lead skirt (shield) was also pneumatically lowered to the shield surface. A gas lock at the lower end of the cask where the O-ring seal had been made was evacuated and backfilled with helium to a pressure equal to the core tank pressure.

The latch mechanism was lowered until it engaged the top of the plug of the element to be removed. The element was raised into the cask. A separate mechanism then rotated the entire lifting assembly to bring the new element into position over the center of the casing. After installing the new element, the irradiated unit was transported to the cleaning or storage facilities. Cask cooling was accomplished through a 3/4-in. annulus between the steel cask body and the lead shield. the circulating air dissipated the heat transferred to the body from the hot fuel element. The hoist consisted of a pair of endless, stainless steel roller chains mounted on sprockets driven by a self-locking worm and gear unit. The entire unit was mounted on an upper and lower turntable, permitting 180 deg rotation about the vertical axis. Two hoists were used for the new element, and one to remove the irradiated element. The grapple was designed to engage a lifting ring on the inside of the top of each fuel plug. Spring-loaded fingers were automatically engaged as the grapple was pushed into the top of the plug. The pneumatically actuated fingers could be released only when the grapple was in the down position or in the gas lock cylinder.

The machine bearings were of conventional manufacture (52100 alloy steel) and were lubricated with either oil or grease. The machine was subjected to limited contact with sodium liquid and vapor.

a. Statement of Operability

The Mark I fuel handling machine was too complex for reliable operation. The Mark II machine operated satisfactorily.

b. Statement of Maintainability

The Mark I fuel handling machine required frequent periodic cleaning of seal surfaces and changes of quad-rings. The Mark II machine was not difficult to maintain.

c. History of Malfunction and/or Modification^(1, 2, 6 and 9)

Problems were encountered with the lower seal on the Mark I cask as a result of sodium oxide buildup. The sleeve surface required cleaning and the quad-rings were replaced 12 times during the 3 years of machine operation. This maintenance was required to maintain integrity of the lower seal separating the machine atmosphere from that of the reactor building. This problem was corrected in the Mark II fuel handling cask by using a 6-in. vacuum gate valve. Little difficulty was experienced during the 4 years this machine was in operation. The valve plug required preventative maintenance consisting of replacement of O-rings and general cleaning.

C. SUMMARY OF SRE RESULTS

The SRE was designed with a minimum number of mechanisms required to function in a sodium environment. Consequently, this facility provided only limited information involving mechanical elements which operated in sodium.

Continuous difficulty was experienced with shaft freeze seals on the original freeze-seal-type sodium pumps. Little difficulty was experienced with the SRE-PEP free-surface pumps which were equipped with gas seals. These pumps did not, however, operate at full design temperature (to 1200°F).

Failure of the core clamps probably resulted from the use of Type 300 series austenitic steel against similar material and can in no way be attributed to the effects of a sodium environment.

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5. H. D. May, "Carbon Removal From the SRE Sodium Following PEP Modifications," NAA-SR-12410 (November 1, 1967)
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7. R. W. Woodruff to R. O. Williams, Jr., "SRE Operations Unit Schedule for Week Ending 9-19-67," Internal letter (September 12, 1967)
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Supplemental Source Material (Not Specifically Cited in Text)

- a. "Sodium Reactor Experiment Power Expansion Program Reactor Safety Analysis Report," NAA-SR-9516 (November 2, 1964)
- b. Sodium Reactor Experiment Check-Out Test No. 1104
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V. EXPERIMENTAL BREEDER REACTOR

A. DESCRIPTION

The EBR-II is an experimental fast power reactor located at the National Reactor Testing Station (NRTS) in Idaho. The EBR-II complex comprises an unmoderated heterogeneous, sodium-cooled reactor and powerplant with a power output of 62.5 Mwt, producing 20 Mwe through a conventional steam cycle. Major emphasis has been placed on achieving high thermal performance at high temperatures, and high fuel burnup with a fast and economical fuel processing system.

The reactor is contained within a primary tank that is 26 ft in diameter and 26 ft high. The volume encompassed by this vessel includes the entire primary coolant system, excluding the sodium service system (Fig. 9, 10). The sodium service lines and all other necessary penetrations are made through the top shield. The primary tank houses the following system components: (1) the two primary sodium pumps which take suction from the sodium plenum, (2) a single IHX in which primary sodium transfers heat to the secondary sodium, (3) nuclear instruments, (4) an independent safety rod drive structure permitting continuous use of two safety rods during fuel handling, and (5) a fuel storage rotor from which insertions and withdrawals can be made during reactor operation.

Fuel handling processes utilize a double rotating plug, a gripper and transfer mechanisms operating beneath the top shield in the sodium pool (Fig. 11).

Sodium enters the reactor from the lower plenum (Fig. 12) at approximately 700°F, reaching a temperature of approximately 883°F as it leaves the reactor. The primary flow through the reactor reaches 9000 gal/min with flow velocities within the core reaching 23.8 ft/min. The primary sodium system inventories 89,000 gal.

The primary system was filled with sodium on February 26, 1963.

B. SODIUM SERVICE SYSTEM

A recirculating cold trap system is used for continuous primary sodium purification. This system maintains impurity concentrations at or near the solubility limits for temperatures just above the melting point of sodium. The cold trap consists of a 500-gal tank filled with Type 304 CRES wire mesh; this

Fig. 9. EBR-II Primary System

NOTE: FOR PLAN VIEW SEE FIG. 4

Fig. 10. EBR-II Reactor Vessel Assembly

Fig. 11. Principal Components of EBR-II Fuel Handling and Unloading Systems

Fig. 12. EBR-II Simplified Flow Diagram

Fig. 13. EBR-II Reactor Cover Holddown

provides supplementary surface area to enhance sodium crystallization and deposition. The cold trap is operated at 350°F.

Sodium impurity concentration is determined by two types of analytical devices. Two plugging indicators are mounted on the cold trap inlet and discharge lines to monitor the oxygen concentration in the primary tank sodium. Two vacuum cup samplers are used to physically remove sodium samples for chemical or radiological analysis. Samples may be taken from either the cold trap inlet or discharge line.

C. DISCUSSION OF MECHANISMS REVIEWED

1. Reactor Vessel Cover Holddown (Table 16)

The reactor vessel cover holddown devices (Figs. 10, 11, and 13) operate entirely in the primary tank sodium pool and cover gas regions.

Three reactor cover holddown clamps are equally spaced about the circumference of the cover. Clamping is accomplished by a tube which slides over a fixed rod. Sliding the clamping tubes upward provides clearance between the flange and the tubes permitting the cover to be raised.

a. Statement of Operability

The holddown devices performed well.

b. Statement of Maintainability

The holddowns were relatively easy to maintain.

c. History of Malfunction and/or Modification ⁽¹⁻¹²⁾

The upper tie rod bushings of holddowns No. 3 and 2 failed in March and July of 1963, respectively, due to material interactions which caused galling of the tie rod shafts. The bushing material was changed to aluminum-bronze (Ampco 18 HT 13), with the diametral clearance increased from 0.003/0.010 in. to 0.030 in. No further problems have been encountered with this mechanism. The No. 1 upper bushing, and the three lower bushings were replaced at the same time as the No. 2 upper bushing as a precautionary measure. It must be noted that the failed bushings operated in the sodium vapor environment above the sodium pool.

2. Fuel Holddown Mechanism (Table 17)

The fuel holddown mechanism (Fig. 10) has an aluminum-bronze bearing located in a sleeve attached to the primary tank cover and an aluminum-bronze labyrinth seal.

TABLE 16

EBR-II REACTOR VESSEL COVER HOLDDOWN MECHANISM

Mechanism	Design Information					Operating Conditions				
	Component (Drawing No.)	No. per Mech- anism	Material of Construction	Dimensions and Manufacturing Tolerances	Clearances, Loading, and Speed	Operating Medium	Temperature, Velocity, and Pressure	Exposure to Environment (hr)	Operating Cycles or Hours	Operating Medium Impurities Range/Average
Reactor Vessel Cover Holddown Mechanism	Tie Rod (EB-1-25498D)	1	304 CRES Hard chrome plate - lower 20 in.	Lower Guide Section 3.497 in. /3.493 OD Shield Plug Section 3.055 in. /3.050 OD Chrome Plate Thickness 0.0005 in. /0.001	32,000 lb Tensile load when cover is locked	Sodium Liquid Lower Sect. Sodium Vapor Upper Sect.	700°F 300 to 700°F	≈ 35,478 ≈ 3,942	≈ 70 cycles	<u>Sodium Vapor</u> N ₂ (%) 1.0 to 5.3/1.9 H ₂ (ppm) 10 to <100/35.5 O ₂ (ppm) 3.2 to 11.5/5.8
Number in Plant: 3										
Primary Material of Construction: 304 CRES	Tie Rod Bushing - Lower Guide	1	1) 304 CRES 1/16 in. Haynes Overlay 2) Aluminum Bronze (Ampco 18-13)	1) Drawing unavailable 2) 3.559 in. /3.564 ID Length 2-3/4 in.	Load, negligible Speed, 10 in. /min linear 1) Drawing unavailable 2) Clearance, Tie Rod 0.062 in. /0.071	Sodium Liquid	700°F	1) No. 3 ≈ 720 No. 1, 2 ≈ 3,600 2) No. 3 ≈ 38,700 No. 1, 2 ≈ 35,820	1) ≈ 4 cycles ≈ 10 cycles 2) ≈ 66 cycles ≈ 60 cycles	<u>Sodium Liquid</u> O ₂ (ppm) 3.2 to 11.5/5.8
Assembly Drawing: EB-1 254-78-F	1) Original (Unavailable) 2) Replacement (EB-1-25490-B)									
Primary System Filled: February 26, 1963	Tie Rod Bushing - Shield Plug 1) Original (EB-1-25489-A) 2) Replacement (Not available)	1	1) 304 CRES 1/16 in. Haynes Overlay 2) Aluminum Bronze (Ampco 18-13)	1) 3.058 in. /3.060 ID Length 2-3/4 in. 2) Drawing unavailable	Load, negligible Speed, 10 in. /min linear 1) Clearance, Tie Rod 0.003 in. /0.010 2) Clearance, Tie Rod ~0.030 in.	Sodium Vapor	700°F	1) No. 3 ≈ 720 No. 1, 2 ≈ 3,600 2) No. 3 ≈ 38,700 No. 1, 2 ≈ 35,820	1) ≈ 4 cycles ≈ 10 cycles 2) ≈ 66 cycles ≈ 60 cycles	
	Inner Bellows (Welded nested type) (EB-1-25480-B)	1	304 CRES	Diameter, 8-3/4 in. Length, 15 in. compressed 30 in. extended	Speed, 10 in. /min linear	Sodium Vapor Inner Surface Air Outer	700°F 300 to 700°F	≈ 35,478 ≈ 3,442	≈ 70 cycles	
	Outer Bellows (Welded nested type) (EB-1-25479-C)	1	304 CRES	Diameter, 15-3/4 in. Length, 15 in. compressed 30 in. extended	Speed, 10 in. /min linear	Sodium Vapor Outer Surface Air Inner	700°F 300 to 700°F	≈ 35,478 ≈ 3,442	≈ 70 cycles	

TABLE 17
EBR-II FUEL HOLDDOWN MECHANISM
(Sheet 1 of 2)

Mechanism	Design Information					Operating Conditions				
	Component (Drawing No.)	No. per Mech- anism	Material of Construction	Dimensions and Manufacturing Tolerances	Clearances, Loading, and Speed	Operating Medium	Temperature, Velocity, and Pressure	Exposure to Environment (hr)	Operating Cycles or Hours	Operating Medium Impurities Range/Average
Fuel Holddown Mechanism Number in Plant: 1 Primary Material of Construction: 304 CRES Assembly Drawing (EB-1-26109- F) Primary System Filled February 26, 1963	Holddown Tube (EB-1-27192-C)	1	304 CRES Hard chrome plate - where contact is made with the subassemblies	3.000 in. ID 4.500 in. OD Chrome Plate Thickness 0.0002 in. / 0.0004	Load, 500 to 600 lb compression	Sodium Liquid	700 to 845°F (Neutron flux) 700°F 300 to 700°F	≈ 8,055 ≈ 27,423 ≈ 3,942	≈ 2,255 cycles	Sodium Vapor N ₂ (%) 1.0 to 5.3/1.9 H ₂ (ppm) 10 to <100/35.5
	Tube Weldment (EB-1-26940-D)	1	304 CRES Hard chrome plate - at packing gland (60 in.)	6.000 in. / 5.996 OD 4-3/4 in. ID 10-ft 9-in. length 4.753 in. / 4.747 OD at pack- ing gland Chrome Plate Thickness 0.0002 in. / 0.0004	Load, 60 lb radial	Sodium Liquid (Sodium vapor pack- ing gland)	700°F 300 to 700°F	≈ 35,478 ≈ 3,942	≈ 2,255 cycles	O ₂ (ppm) 3.2 to 11.5/5.8 Sodium Liquid O ₂ (ppm) 3.2 to 11.5/5.8
	Guide Tube; Holddown Rod (EB-1-27570-C)	1	304 CRES Stellite 6B Bearing surface	6.032 in. / 6.024 OD Stellite 6B Section 12-in. length 6-7/32 in. ID 6-23/32 in. OD 304 CRES Section 27-3/4-in. length	Load, negligible Clearance, ≈ 0.062 in.	Sodium Liquid	700 to 845°F 700°F 300 to 700°F Velocity, 2.27 ft/sec. ΔP, 9.6 psi	≈ 8,055 ≈ 27,423 ≈ 3,942	≈ 2,255 cycles	
	Labyrinth Seal; Holddown Rod (EB-1-26949-C)	1	Aluminum Bronze (Ampco 18-13)	6.000 in. / 5.996 OD 12-in. length 23 Circumferential Grooves 1/4 in. wide, 3/32 in. deep	Load, negligible Speed, 6 in. /min linear Clearance, 0.030 in.	Sodium Liquid	700 to 845°F 700°F 300 to 700°F Velocity, 2.27 ft/sec ΔP, 9.6 psi	≈ 8,055 ≈ 27,423 ≈ 3,942	≈ 2,255 cycles	
	Bushing: Lower Side Inner Rotating Plug With Tube Weldment (EB-1-26942-A)	1	Aluminum Bronze (Ampco 18-13)	6.024 in. / 6.032 ID 6.498 in. / 6.496 OD 1-in. length	Load, negligible Speed, 6 in. /min linear Clearance, 0.024 in. / 0.036	Sodium Liquid	700°F 300 to 700°F	≈ 35,478 ≈ 3,942	≈ 2,255 cycles	
	Packing Gland (Motorized) (EB-1-26416-E)	4 Above 4 Below Spacer	Asbestos and Graphite (John Crane Style 177J)	4-3/4 in. ID 5-3/4 in. OD 1/2-in. length	Load, 60 lb radial Speed, 6 in. /min linear	Sodium Condensate and Vapor	≈ 150°F	≈ 39,420	≈ 2,255 cycles	

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a. Statement of Operability

The mechanism performed well overall; some minor difficulty was encountered with packing gland seals.

b. Statement of Maintainability

Except for the packing glands, no maintenance has been required.

c. History of Malfunction and/or Modification

There has been no indication of sodium-related malfunction. (4-12)

3. Fuel Storage Basket (Table 18)

The storage basket (Fig. 11) provides temporary storage for new and spent fuel and for blanket subassemblies. The basket is suspended from the primary tank cover and is fully submerged in the tank sodium at all times to permit natural convection cooling of spent subassemblies within it. The rack is cylindrical with a capacity of 75 subassemblies. The drive mechanism imparts vertical and rotational movement of the basket to permit insertion or removal of a subassembly from the basket by the transfer arm. The fuel basket sensing rods were removed to permit alignment improvement between the transfer arm and basket at elevated temperatures.

a. Statement of Operability

The drive assembly equipment has operated well with the exception of some packing gland and outside alignment difficulties. The fuel sensing rod operated well without difficulty.

b. Statement of Maintainability

No maintenance has been performed on components within the primary vessel; maintenance on these components would be extremely difficult.

c. History of Malfunction and/or Modification (4-15)

Some difficulty has been experienced with basket drive alignment but this was corrected by external adjustments and apparently was not associated with the bearing.

The packing gland spacer in the drive assembly was found to be galling the storage basket support shaft due to material interaction (August 1963). A new spacer was installed with the material changed from CRES to aluminum-bronze. The diametral clearance between spacer and shaft was increased from 0.011 to 0.058 in.

TABLE 18
EBR-II FUEL STORAGE BASKET
(Sheet 1 of 2)

Mechanism	Design Information					Operating Conditions				
	Component (Drawing No.)	No. per Mechanism	Material of Construction	Dimensions and Manufacturing Tolerances	Clearances, Loading, and Speed	Operating Medium	Temperature, Velocity, and Pressure	Exposure to Environment (hr)	Operating Cycles or Hours	Operating Medium Impurities Range/Average
Fuel Storage Basket Number in Plant: 1 Primary Material of Construction: 304 CRES Assembly Drawings A. Drive Assembly EB-1-26930-F B. Sensing Rod EB-1-27358-D Primary System Filled February 26, 1963	A. Drive Assembly									
	Lower Main Shaft (EB-1-27374 EB-1-27370-D)	1	304 CRES	6.000 in. / 5.998 OD 19 ft 5-1/8 in. length		Sodium Liquid	700°F 300 to 700°F	≈35,478 ≈3,942	≈2,255 cycles	Sodium Vapor N ₂ (%) 1.0 to 5.3/1.9
	Lower Bearing Main Shaft (EB-1-27402-B)	1	Aluminum Bronze (Ampco 18-23)	6.007 in. / 6.009 ID 8.5008 in. / 8.5000 OD 1.510 in. / 1.515 length	Load, negligible Speed, 20 in./min rotational Clearance, 0.007 in. / 0.011	Sodium Liquid	700°F 300 to 700°F	≈35,478 ≈3,942	≈2,255 cycles	H ₂ (ppm) 10 to <100/35.5 O ₂ (ppm) 3.2 to 11.5/5.8
	Intermediate Main Shaft (EB-1-27371-C)	1	304 CRES	7.000 in. / 6.998 OD 14 ft 6-19/32 in. length		Sodium Vapor	700°F 300 to 700°F	≈35,478 ≈3,942	≈2,255 cycles	Sodium Liquid O ₂ (ppm) 3.2 to 11.5/5.8
	Lower Packing Support and Shoulder (EB-1-27174-B)	1	Aluminum Bronze Centrifugal Cast (Ampco 18-23)	7.007 in. / 7.008 ID	Load, none Clearance, 0.007 in. / 0.010	Sodium Condensate and Vapor	≈150°F	≈39,420	≈2,255 cycles	
	Packing Spacer 1) Original (EB-1-26662-B) 2) Replacement (EB-1-38436-B)	1 1	1) 304 CRES 2) Aluminum Bronze (Grade not specified)	1) 7.055 in. / 7.060 ID Two 5/16 in. shoulders 2) 7.055 in. / 7.060 ID 1 in. length	Load, none 1) Clearance, 0.055 in. / 0.062 2) Clearance, 0.055 in. / 0.062	Sodium Condensate and Vapor	≈150°F	1) 5116 2) ≈34,304	1) ≈290 cycles 2) ≈1,965 cycles	
	Packing Gland Packing (EB-1-26656-E)	4 Above 4 Below Spacer	Asbestos and Graphite		Load, normal packing surface friction	Sodium Condensate and vapor	≈150°F	≈34,304	≈2,255 cycles	
	B. Sensing Rod									
	Lower Guide Bushing (EB-1-29399-A)	1	17-4 PH CRES	1.280 in. ID 3-3/4 in. OD 1-1/2 in. length	Load, negligible Clearance, 0.030 in.	Sodium Liquid	700°F 300 to 700°F	≈35,478 ≈3,942	≈800 cycles	
	Sensing Rod at Lower Guide Bushing (EB-1-27362-B EB-1-27358-D)	1	304 CRES	1.250 in. / 1.248 OD	Clearance, 0.030 in.	Sodium Liquid	700°F 300 to 700°F	≈35,478 ≈3,942	≈800 cycles	

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Fig. 14. EBR-II Primary System Mechanical Sodium Pump

4. Flexible Ball Joint — Primary Pump Discharge Piping (Table 19)

The primary coolant pumps can be removed from the primary tank by incorporating a ball seal disconnect between the pump discharge and reactor lower plenum piping. Contacts between the pump discharge extensions, and the reactor inlet lines are maintained by bellows-mechanical spring holddowns which are removable with the pump. Aside from providing a quick disconnect feature, the joint provides for thermal expansion and reduces the concern for precise alignment of pump to piping.

a. Statement of Operability

No operating problems have been encountered with these components.

b. Statement of Maintainability

No maintenance has been required on this equipment.

c. History of Malfunction and/or Modification

No failures or operating difficulties have been experienced with this equipment. (4-11)

5. Primary Pumps (Table 20)

The primary system contains two vertically mounted, single-stage centrifugal mechanical pumps (Fig. 14). Maximum capacity of each pump is 5000 gpm at 85 psi. The pumps are supported from the primary tank cover via primary tank nozzles which penetrate the top biological shield. A labyrinth-type shaft seal is used to minimize diffusion of sodium vapor into the motor enclosure. The pump shaft connects at the top of the shield plug to the motor shaft, projects downward through the shield plug, then down through the spacing baffle assembly and into the pump case where it is located radially by a hydrostatic bearing. The pump impeller is overhung on the shaft immediately below this bearing. A 9.5 in. shaft diameter was selected to insure vibrational stability. Sodium is supplied to the bearing by means of a flow passage from the discharge region. The hydrostatic pressure thus produced in the bearing shell acts to center the journal. Pads within the hydrostatic bearing pockets provide an additional centering action during startup. Colmonoy hard facing is provided to reduce wear and surface interaction.

a. Statement of Operability

Operation of the pumps has been very satisfactory.

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TABLE 20
EBR-II PRIMARY PUMPS
(Sheet 1 of 2)

Mechanism	Design Information					Operating Conditions				
	Component (Drawing No.)	No. per Mech- anism	Material of Construction	Dimensions and Manufacturing Tolerances	Clearances, Loading, and Speed	Operating Medium	Temperature, Velocity, and Pressure	Exposure to Environment (hr)	Operating Cycles or Hours	Operating Medium Impurities Range/Average
Primary Pumps Number in Plant: 2 Primary Material of Construction 304 CRES Assembly Drawing 6-768-416 Primary System Filled February 26, 1963 Manufactured Byron Jackson	Pump Case Lower Wear Ring (6-768-416)	1	304 CRES Faced with Stellite	14.000 in. /13.958 Diameter	Load, none Speed, stationary Clearance, 0.042 in./0.044	Sodium Liquid	700°F 300 to 700°F	≈ 35,478 ≈ 3,946	≈ 10,080 hr	Sodium Vapor N ₂ (%) 1.0 to 5.3/1.9
	Pump Case Upper Wear Ring (6-768-416)	1	304 CRES Faced with Stellite	18.000 in. /17.958 Diameter	Load, none Speed, stationary Clearance, 0.042 in./0.044	Sodium Liquid	700°F 300 to 700°F	≈ 35,478 ≈ 3,946	≈ 10,080 hr	H ₂ (ppm) 10 to <100/35.5 O ₂ (ppm) 3.2 to 11.5/5.8
	Impeller Assembly - Hydrostatic Bearing Pad (6-768-420, RC-3339-1)	1	304 CRES Faced with Colmonoy [0.6 Ni 0.16 Cr 0.04 B 0.10 Fe]	11.983 in. /11.982 Diameter	Load, mechanical and hydraulic imbalance Speed, 108 to 1075 rpm rotational Discharge Pressure, 80 psi at 5000 gpm Clearance, 0.018 in./0.020	Sodium Liquid	700°F 300 to 700°F	≈ 27,216 ≈ 3,024	≈ 10,080 hr	Sodium Liquid O ₂ (ppm) 3.2 to 11.5/5.8
	Impeller Assembly - Upper Wear Ring Surface (6-768-420 RC-3339-1)	1	304 CRES	17.958 in. /17.957 Diameter	Load, none Speed 108 to 1075 rpm rotational Clearance, 0.042 in./0.044	Sodium Liquid	700°F 300 to 700°F	≈ 27,216 ≈ 3,024	≈ 10,080 hr	
	Impeller Assembly - Lower Wear Ring Surface (6-768-420 RC-3339-1)	1	304 CRES	13.958 in. /13.957 Diameter	Load, none Speed 108 to 1075 rpm rotational Clearance, 0.042 in./0.044	Sodium Liquid	700°F 300 to 700°F	≈ 27,216 ≈ 3,024	≈ 10,080 hr	
	Pump Case Hydrostatic Bearing Pad (6-768-416)	1	304 CRES Faced with Colmonoy	12.000 in. /11.982 Diameter	Load, mechanical and hydraulic imbalance Speed, stationary Clearance, 0.018 in. /0.020	Sodium Liquid	700°F 300 to 700°F	≈ 27,216 ≈ 3,024	≈ 10,080 hr	
	Impeller Drive Shaft at Lower Labyrinth Seal (6-768-416)	1	304 CRES	9.498 in. Diameter	Load, none Speed, 108 to 1075 rpm rotational Clearance, 0.2475 in. diam- etral after modification	Sodium Vapor	700°F 300 to 700°F	≈ 27,216 ≈ 3,024	≈ 10,080 hr	
	Lower Labyrinth Seal (6-768-416)	1	Aluminum Bronze (Ampco 18-13)	9.746 in. /9.745 Diameter after modification	Load, none Speed, stationary Clearance, 0.2475 in. diametral after modification	Sodium Vapor	700°F 300 to 700°F	≈ 27,216 ≈ 3,024	≈ 10,080 hr	

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b. Statement of Maintainability

The pumps are difficult to remove from the system. No maintenance has been required since an initial shaft bowing problem was corrected.

c. History of Malfunction and/or Modification (Refs 2-13, 16-20)

Pump No. 1 failed during initial operation due to a bowed drive shaft which results in damage to the lower labyrinth seals and baffles. After about 150 hr of operation, Pump No. 2 failed for the same reasons. The pump shaft bowed principally due to high temperature caused by its rubbing on the aluminum-bronze labyrinth bushing.⁽³⁾ It is presumed that the situation became progressively worse as increasing temperature caused the bushing to expand inward due to the constraint offered by its relatively cool mounting support. This resulted in severe galling of the shaft and damage to the bushing. Figure 15 shows the damaged shaft. New shafts were fabricated and the radial clearance at the lower labyrinth seal increased to 0.120 in. Baffle clearance was also increased.

After 4442 hr of operation, Pump No. 1 failed to rotate during startup. The impeller drive shaft was raised and lowered freeing the shaft. One week later the shaft again froze, and was freed by the same procedure. It was postulated that sticking of the shaft was caused by condensed sodium on the upper shaft, which was sheared by the vertical motion of the shaft. No additional difficulties were reported concerning the pumps.

6. Throttle Valves (Table 21)

The flow from the primary pumps separates into two streams before entering the high- and low-pressure reactor inlet plenum chambers (Fig. 12). The main pump outlet lines supply the high-pressure core region inlet plenum chamber. Smaller lines connected to the outlet lines supply the low pressure plenum chamber through two throttle valves. The valves are angle type bellows sealed at the upper end of the shaft just below the operator assembly. The shaft and plug are removable through the cover for maintenance. A labyrinth seal isolates the valve chamber from the main sodium pool.

a. Statement of Operability

The throttle valves have not been operated since initially set. No problems have occurred.

b. Statement of Maintainability

The throttle valves have not required maintenance.

Fig. 15. EBR-II Primary Pump Impeller Drive Shaft

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TABLE 22
EBR-II REACTOR VESSEL COVER LIFTING MECHANISM

Mechanism	Design Information					Operating Conditions				
	Component (Drawing No.)	No. per Mech- anism	Material of Construction	Dimensions and Manufacturing Tolerances	Clearances, Loading, and Speed	Operating Medium	Temperature, Velocity, and Pressure	Exposure to Environment (hr)	Operating Cycles or Hours	Operating Medium Impurities Range/Average
Reactor Vessel Cover Lifting Mechanism Number in Plant: 1 Primary Material of Construction: 304 CRES Assembly Drawing EB-1-26396-F EB-1-26434-E Primary System Filled February 26, 1963	Lifting Column (EB-1-26446-D)	2	304 CRES	3.668 in. OD	Speed, 5 in./min linear	Sodium Liquid and Vapor	700°F 300 to 700°F	≈ 35,478 ≈ 3,942	≈ 70 cycles	Sodium Vapor
	Lifting Column Split Bushing (EB-1-26445-B)	2	Aluminum Bronze (Ampco 18-13)	3.720 in. ID 1-1/8 in. length	Load, negligible Clearance, 0.052 in.	Sodium Liquid	700°F 300 to 700°F	≈ 35,478 ≈ 3,942	≈ 70 cycles	N ₂ (%) 1.3 to 5.3/1.9
	Lifting Column Shield Sleeve (EB-1-26449-C)	2	304 CRES Hard chrome plate	4.750 in./4.748 OD 12 ft 4-1/8 in. length	Load, none Clearance, 0.0125 in.	Sodium Vapor	≈ 150°F	≈ 39,420	≈ 70 cycles	H ₂ (ppm) 10 to <100/35.5
	Lower Packing Support Shoulder (EB-1-26413-D)	2	304 CRES	4.760 in./4.765 ID 1/2 in. length	Load, none Clearance, 0.0125 in.	Sodium Condensate and Vapor	≈ 150°F	≈ 39,420	≈ 70 cycles	O ₂ (ppm) 3.2 to 11.5/5.8
	Packing Spacer (EB-1-26465-B)	2	304 CRES	4.760 in./4.765 ID Two shoulders 5/16 in. width	Load, none Clearance, 0.0125 in.	Argon	≈ 150°F	≈ 39,420	≈ 70 cycles	Sodium Liquid
	Packing Gland Packing (EB-1-26416-E)	4 above 4 below spacer	Asbestos and Graphite		Load, normal packing surface friction	Sodium Condensate and Vapor	≈ 150°F	≈ 39,420	≈ 70 cycles	O ₂ (ppm) 3.2 to 11.5/5.8

c. History of Malfunction and/or Modification

There has been no history of malfunction or modification.⁽⁴⁻¹¹⁾

7. Reactor Vessel Cover Lifting Mechanism (Table 22)

The vessel assembly consists of three major units: the grid-plenum assembly (Figs. 16 and 17), the vessel, and the top cover (Fig. 10). The cover when closed forms the upper reactor coolant plenum chamber from which the sodium flows to the heat exchanger. When fuel or blanket subassemblies are to be unloaded, the cover holddown clamps are released and the cover is elevated to the top of the primary tank by two elevating columns (Fig. 9) to allow the fuel handling system to unload and transfer fuel to the storage basket. The columns are raised by two synchronized electric motor-driven lifting mechanisms located on the small rotating plug. In the raised position the reactor cover engages pins extending from the underside of the rotating plug to prevent swinging of the mass (approximately 17 tons) during plug rotation. The cover is raised 9 ft 8 in., providing the required clearances. Two aluminum-bronze bearings support the CRES lifting columns operating in sodium.

a. Statement of Operability

The mechanism has operated very well; there have been no problems.

b. Statement of Maintainability

No maintenance has been required; however, it would be extremely difficult to perform maintenance on this piece of equipment.

c. History of Malfunction and/or Modification

The two aluminum-bronze bearings which support the lifting columns have performed well. No difficulty has been experienced with this mechanism.⁽⁴⁻¹²⁾

8. Core Gripper (Table 23)

The fuel handling system consists of the reactor core gripper mechanism, the holddown mechanism, the transfer arm, and the storage rack. The core gripper mechanism (Fig. 11) is located in the small rotating plug which in turn is eccentrically located in the large rotating plug. The gripper is positioned over the desired location in the reactor by rotation of the two plugs. The gripper unit must also be rotated about its centerline to provide the correct angular orientation of the gripper head. A holddown sleeve, a funnel-shaped unit, is lowered by an electrically driven screw over the subassembly to be removed.

Fig. 16. EBR-II Reactor Vessel Grid Assembly

Fig. 17. Section of EBR-II Reactor Grid Plenum

TABLE 23
EBR-II CORE GRIPPER
(Sheet 1 of 2)

Mechanism	Design Information					Operating Conditions				
	Component (Drawing No.)	No. per Mech- anism	Material of Construction	Dimensions and Manufacturing Tolerances	Clearances, Loading, and Speed	Operating Medium	Temperature, Velocity, and Pressure	Exposure to Environment (hr)	Operating Cycles or Hours	Operating Medium Impurities Range/Average
Core Gripper	Upper Guide Bearing - Inner Rotating Plug (EB-1-25930-A)	1	Aluminum- Bronze (Ampco 18-13)	2.915 in./2.919 ID 1-in. length 4.372 in./4.370 OD (4 slots to aid flush of particles)	Load, negligible		700°F 300 to 700°F	≈ 35,478 ≈ 3,942	≈ 2,255 cycles	Sodium Vapor N ₂ (%) 1.0 to 5.3/1.9
Primary Material of Construction: 304 CRES	Gripper Main Shaft at Upper Guide Bearing (EB-1-25928-B EB-1-25945-C)	1	304 CRES Hard chrome plate	2.893 in./2.890 OD (Major) 2.624 in./2.622 OD (Minor) Chrome plate thickness, 0.0002 in./0.0004	Load, negligible Speed, 6 in./min	Sodium Liquid	700°F 300 to 700°F	≈ 35,478 ≈ 3,942	≈ 2,255 cycles	H ₂ (ppm) 10 to <100/35.5 O ₂ (ppm) 3.2 to 11.5/5.8
Assembly Drawing EB-1-25917- F	Gripper Main Shaft at Packing Gland (EB-1-25927-C)	1	304 CRES Hard chrome plate	4.753 in./4.747 OD chrome plate thickness, 0.0002 in./0.0004	Load, packing gland surface friction Speed, 6 in./min linear	Sodium Condensate and Vapor	≈ 150°F	≈ 39,420	≈ 2,255 cycles	Sodium Liquid O ₂ (ppm) 3.2 to 11.5/5.8
Primary System Filled February 26, 1963	Gripper Main Shaft at Labyrinth Section (EB-1-26786-C)	1	Aluminum Bronze (Ampco 18-13)	2.875 in. OD	Load, negligible Speed, 6 in./min linear Clearance, 0.030 in.	Sodium Liquid	Velocity, 2.27 ft/sec ΔP, 9.6 psi 700 to 845°F (Neutron flux) 700°F 300 to 700°F	≈ 8,055 ≈ 27,423 ≈ 3,942	≈ 2,255 cycles	
	Bellows - Jaw Actuator to Sensing Rod (Convolute Type - EB-1- 26420)	2	347 CRES Two ply	0.010 in. Wall thickness total 9.991 in. Free length 8.866 in. Compressed 9.991 in. Extended 1-11/64 in. OD 13/64 in. ID 89-1/2 Convolutions	Load, negligible Pressure, 5 psig	Sodium Liquid	700°F 300 to 700°F	≈ 35,478 ≈ 3,942	≈ 2,255 cycles	
	Bellows - Main Shaft to Jaw Actuator (Convolute Type - EB-1- 26423)	2	347 CRES Two ply	0.010 in. Wall thickness total 7.772 in. Free length 7.022 in. Compressed 7.772 in. Extended 1-9/16 in. OD 1-7/64 in. ID 53-1/2 Convolutions	Load, negligible Pressure, 5 psig	Sodium Liquid	700°F 300 to 700°F	≈ 35,478 ≈ 3,942	≈ 2,255 cycles	
	Packing Gland Packing (Unavailable)	1			Load, normal packing surface friction	Sodium Vapor	≈ 150°F	≈ 39,420	≈ 2,255 cycles	
	Packing Spacer and Lower Support (Unavailable)	1 each			Load, none	Sodium Vapor	≈ 150°F	≈ 39,420	≈ 2,255 cycles	

TABLE 23
EBR-II CORE GRIPPER
(Sheet 2 of 2)

Mechanism	Design Information					Operating Conditions				
	Component (Drawing No.)	No. per Mech- anism	Material of Construction	Dimensions and Manufacturing Tolerances	Clearances, Loadings, and Speed	Operating Medium	Temperature, Velocity, and Pressure	Exposure to Environment (hr)	Operating Cycles or Hours	Operating Medium Impurities Range/Average
Lower Core Gripper Subassembly Mark II Number in Plant: 13 Primary Material of Construction: 420 CRES Assembly Drawing EB-1-38625- B	Lower Guide Assembly (EB-1-38620-C)	1	304 CRES	Dimensions difficult to present - Drawing should be referred to if necessary	Load, negligible	Sodium Liquid	(Neutron flux) 700 to 845°F 700°F 300 to 700°F	≈ 8,055 ≈ 27,423 ≈ 3,942	≈ 2,255 cycles	
	Bearing - Fused in Guide for Clamp to Ride on (EB-1-38620-C)	6	Stellite	1/4 in. Diameter of each bearing 2,240 in. / 2,235 OD Total bearing unit	Load, negligible	Sodium Liquid	(Neutron flux) 700 to 845°F 700°F 300 to 700°F	≈ 8,055 ≈ 27,423 ≈ 3,942	≈ 2,255 cycles	
	Clamp - Gripper (EB-1-38696-B)	1	304 CRES Original chrome plated	2,260 in. / 2,265 ID		Sodium Liquid	(Neutron flux) 700 to 845°F 700°F 300 to 700°F	≈ 8,055 ≈ 27,423 ≈ 3,942	≈ 2,255 cycles	
	Jaw Actuator Cams (EB-1-38696-B)	2	Stellite 6B	0.250 in. Diameter cam surface 1,770 in. / 1,772 surface spacing	Load, negligible	Sodium Liquid	(Neutron flux) 700 to 845°F 700°F 300 to 700°F	≈ 8,055 ≈ 27,423 ≈ 3,942	≈ 2,255 cycles	
	Guide-Mark II (EB-1-38619-C)	1	420 CRES Chrome plated	20° Lead in surface 1,024 in. ID Main body 0,687 in. ID Tip indicator 0,505 in. / 0,495 OD Guide Pin (not chromed) 0,095 in. / 0,093 Orientation bar width Chrome plate thickness 0,0002 in. / 0,0004	Load, negligible	Sodium Liquid	(Neutron flux) 700 to 845°F 700°F 300 to 700°F	≈ 8,055 ≈ 27,423 ≈ 3,942	≈ 2,255 cycles	
	Gripper Jaw Mark II (EB-1-38431-C)	2	420 CRES Chrome plated	0,375 in. / 0,376 ID Pivot pin Chrome plate thickness 0,0002 in. / 0,0004		Sodium Liquid	(Neutron flux) 700 to 845°F 700°F 300 to 700°F	≈ 8,055 ≈ 27,423 ≈ 3,942	≈ 2,255 cycles	
	Jaw Pivot Pin (EB-1-25212A)	1	Tool Steel Type 18-4-1 or Type 18-4-2 Chrome plated	0,365 in. / 0,363 OD after plating 2,187 in. length Chrome plate thickness 0,001 in. Hardened RC 50-55	Load, negligible Clearance, 0,010 in. / 0,013	Sodium Liquid	(Neutron flux) 700 to 845°F 700°F 300 to 700°F	≈ 8,055 ≈ 27,423 ≈ 3,942	≈ 2,255 cycles	
	Tip Indicator (EB-1-25022)	1	420 CRES	0,195 in. Radius pin slot 90° Included contact angle Hardened RC 40-45	Load, negligible	Sodium Liquid	(Neutron flux) 700 to 845°F 700°F 300 to 700°F	≈ 8,055 ≈ 27,423 ≈ 3,942	≈ 2,255 cycles	

This holddown sleeve secures the six adjacent subassemblies, spreading them slightly, and acts as a guide for the centrally located gripper mechanism (Fig. 18). The gripper head is lowered through the holddown sleeve, gripping the subassembly adapter in the same manner as the control rod drive gripper. The two jaws engage the adapter, and operate by means of a cam incorporated in a sliding sleeve. The jaws are positive operating and are cammed both open and closed, locking by cam action. A sensing rod is elevated when adapter head contact is made acting against a spring. This provides a check on proper engagement of the gripper. An electrically driven screw drive (Fig. 19) moves the gripper mechanism vertically.

a. Statement of Operability

The mechanisms have operated satisfactorily except for some minor difficulty with packing gland packing.

b. Statement of Maintainability

Maintainability is considered about average as compared to other sodium mechanisms. Neutron activation of the lower portion of the gripper, which extends into the reactor, complicates maintenance once the mechanism is removed. A removable lower section, once the gripper is removed from the vessel, would improve its maintainability.

c. History of Malfunction and/or Modification (Refs 4-12, 14, 17-19, 21, 22)

The gripper stuck during linear motion experienced after approximately 5040 hr of exposure to the sodium environments. It was freed by raising and lowering the gripper while manually rotating it. The same difficulty was encountered after approximately 6480 hr. In this case, the gripper was freed by slight motion of the reactor vessel cover, indicating that the interference probably occurred between the shaft and some element of the cover. After about 7200 hr, the gripper was removed and inspected to determine the cause of binding. Sodium and sodium oxide were found on the shaft at a point just above the sodium level in the tank and the lower bearing position when the gripper was at the operating level. In addition, sodium-oxide-type deposits were found at the center of the labyrinth seal. No damage to the labyrinth seal or reactor cover guide sleeve was evident. It was postulated that the sticking resulted from the sodium-oxide-type buildup in the labyrinth seal area and that the buildup resulted from the low sodium flowrate through the seal during startup when the main sodium pumps were not operating. (Note: During this period, both main pumps were inoperative due to the shaft bowing problems previously discussed. Sodium was circulated

Fig. 18. EBR-II Gripper Mechanism

Fig. 19. EBR-II Control Gripper Actuating Device and Mechanical Interlock for Support Platform

by the EM pump at a reduced rate. The 12 control rod drives and the fuel hold-down mechanism, all of which have similar labyrinth seals and were subjected to the same low flow conditions, were apparently unaffected by similar problems.)

The following gripper modifications were made while it was removed for inspection:

- 1) The stand pipe was modified to provide for insertion of a split aluminum-bronze bearing at the top.
- 2) Three 3/4-in. holes were drilled in the outer gripper tube, about 23 in. from its lower end, to provide argon gas balancing during vertical shaft movement.
- 3) Four 1/2-in. holes were drilled just above the lower bearing in the tube to promote mixing of the bulk sodium with the sodium in and above the bearing.

After these modifications no further difficulties of the nature described were encountered.

After approximately 13,680 hr of exposure, the gripper funnel was damaged by contacting the fuel holddown at a velocity of 6 in./min (Fig. 20). The funnel was twisted through approximately 6 deg, and the jaws could not be closed. It was deduced that the gripper shaft bowed due to thermal distortion which resulted from temperature gradients produced by rapid insertion of the gripper. The damage was repaired and the gripper returned to service.

9. Control Rods and Control Rod Drives (Table 24)

Twelve identical control rods (Fig. 21) are employed to provide the required operational control for the reactor. The control rods operate on the fuel-void principle, the control being dependent on the amount of fuel or void in the core region. The upper end of the control rod is equipped with an adapter section identical to the subassemblies which are accepted by the control rod drive or fuel gripper unit for unloading. Bearings on this lower section provide a guide between the control rod and the hexagonal guide thimble.

The control rod drives (Fig. 22) are also identical and are arranged so that only one drive may be operated at a time, except when "scrammed" when all 12

Fig. 20.
Lower Section of EBR-II
Core Gripper

Fig. 21. EBR-II Control Subassembly

TABLE 24
EBR-II CONTROL ROD AND CONTROL ROD DRIVE
(Sheet 1 of 2)

Mechanism	Design Information					Operating Conditions				
	Component (Drawing No.)	No. per Mech- anism	Material of Construction	Dimensions and Manufacturing Tolerances	Clearances, Loading, and Speed	Operating Medium	Temperature, Velocity, and Pressure	Exposure to Environment (hr)	Operating Cycles or Hours	Operating Medium Impurities Range/Average
Control Rod Number in Plant: 12 Primary Material of Construction: 304 CRES Assembly Drawing EB-1-25496-C Primary System Filled February 26, 1963	Upper Bushing - Top (EB-1-26433-D EB-1-25737-A)	4	Beryllium Copper (Berylko 25) on 416 CRES carrier	2.190 in. /2.187 OD 0.0461 in. length Surface fin. 32 rms Hardened RC 43	Load, negligible Speed, maximum 8.5 ft/sec linear Clearance, 0.009 in.	Sodium Liquid	700°F Max	Variable dependent on burnup rates		Sodium Vapor N ₂ (%) 1.0 to 5.3/1.9
	Lower Bushing - Bottom (EB-1-25808-B)	4	Beryllium Copper (Berylko 25) on 416 CRES carrier	1.783 in. /1.781 OD 0.0461 in. length Surface fin. 32 rms Hardened, RC 43	Load, negligible Speed, maximum 8.5 ft/sec linear Clearance, 0.010 in.	Sodium Liquid	700°F Max	Variable dependent on burnup rates		H ₂ (ppm) 10 to <100/35.5 O ₂ (ppm) 3.2 to 11.5/5.8
	Guide Tube (EB-1-25740-D)	1	347 CRES Hard chrome plated	2.198 in. /2.200 ID Upper region 1.791 in. /1.793 ID Lower region 39-1/3 in. length Chrome plate thickness 0.0005 in. /0.003 Surface fin. 20 rms Hardened, Brinnell 700-800	Load, negligible Clearance, 0.009 in. Upper region 0.010 in. Lower region	Sodium Liquid	700°F Max	Variable dependent on burnup rates		Sodium Liquid O ₂ (ppm) 3.2 to 11.5/5.8
	Cap (EB-1-26022-B)	1	304 CRES	0.312 in. ID 0.8751 in. /0.8755 ID socket Surface fin. 20 rms	Load, none Clearance, 0.062 in.	Sodium Liquid	700°F Max	Variable dependent on burnup rates		
	Pin (EB-1-27275-B)	1	304 CRES	0.250 in. OD Surface fin. 20 rms	Load, none Clearance, 0.062 in.	Sodium Liquid	700°F Max	Variable dependent on burnup rates		
	Compression Spring (EB-1-27274-A)	1	Inconel X	0.500 in. Mean Diameter 8.187 in. Free length 0.250 in. Stroke 34 Active coils 0.177 in. OD wire	Preload, 60 lb Spring rate, 34 lb/in.	Sodium Liquid	700°F Max	Variable dependent on burnup rates		
Control Rod Rod Drive	The portion of the Control Rod Drive Assembly operating in a sodium environment is the same as the core gripper (Table 8) with the exception of the components listed below.									
Assembly Drawing EB-1-25006-F	Reactor Vessel Cover Sleeve (EB-1-25006-F)	1	Wrought Stellite 6B	2.559 in. /2.567 ID 29-1/8 in. length	Load, negligible Clearance, 0.030 in.	Sodium Liquid	Velocity, 2.27 ft/sec ΔP, 9.6 psi (Neutron flux) 700 to 845°F 700°F 300 to 700°F	≈ 8,055 ≈ 27,423 ≈ 3,942	≈ 8,470 hr	

TABLE 24
EBR-II CONTROL ROD AND CONTROL ROD DRIVE
(Sheet 2 of 2)

Mechanism	Design Information					Operating Conditions				
	Component (Drawing No.)	No. per Mech- anism	Material of Construction	Dimensions and Manufacturing Tolerances	Clearances, Loading, and Speed	Operating Medium	Temperature, Velocity, and Pressure	Exposure to Environment (hr)	Operating Cycles or Hours	Operating Medium Impurities Range/Average
	Labyrinth Seal — Main Shaft to Reactor Vessel Cover (EB-1-26625-C)	1	Aluminum Bronze (Ampco 18-13)	2.535 in. / 2.531 OD 12 in. length 23 Circumferential grooves 1/4 in. wide 0.076 in. deep	Load, negligible Speed, maximum 8.5 ft/sec linear Clearance, 0.030 in.	Sodium Liquid	Velocity, 2.27 ft/sec ΔP , 9.6 psi 700 to 845°F (Neutron flux) 700°F 300 to 700°F	 ≈ 8,055 ≈ 27,423 ≈ 3,942	 ≈ 8,470 hr	
	Tube — Lower Guide Region (EB-1-26674-D)	1	304 CRES Hard chrome plate at sec- tion in contact with guide ring		Load, negligible Speed, maximum 8.5 ft/sec linear Clearance, 0.045 in.	Sodium Liquid	700°F 300 to 700°F	≈ 35,478 ≈ 3,942	≈ 8,470 hr	
	Lower Guide Ring (EB-1-25157-B)	1	304 CRES Stellite overlay	2.575 in. / 2.580 ID at Stellite section	Load, negligible Clearance, 0.045 in.	Sodium Liquid	700°F 300 to 700°F	≈ 35,478 ≈ 3,942	≈ 8,470 hr	
	Bellows Seal — Welded Type (EB-1-25177-C)	1	347 CRES	4-1/2 in. OD 2-9/16 in. ID 9-15/16 in. Compressed length 24-13/16 in. Extended length Wall thickness 0.010 in.		Sodium Vapor	≈ 150°F	≈ 39,420	≈ 8,470 hr

Fig. 22. EBR-II Control Rod Drive Mechanism

function simultaneously. The operation stroke is 14 in. vertical, which is provided by a rack and pinion type drive with a constant-speed electrical motor having a constant rack output velocity.

The control rod drive mechanism performs three major functions: (1) the connection between the drive and the control rod; (2) the low-speed vertical motion, up and down; and (3) the high-speed downward motion for "scram." The gripper is identical to that of the core gripper previously described. The control rod is actuated by a long shaft which extends through the upper biological shield to the drive mechanism rack and pinion system driven at 5 in./min. The rack consists of a tube with gear teeth on the exterior surface. A magnetic clutch releases the shaft from the rack allowing a pneumatic cylinder to drive the rod down (out of the reactor core). A hydraulic shock absorber connected to the air cylinder acts to arrest the downward "scram" motion during the lower 5 in. of travel.

a. Statement of Operability

With the exception of the difficulty described in section c. below, the drive units have operated satisfactorily. The control rods have operated satisfactorily.

b. Statement of Maintainability

The control rods have only required normal fuel rod replacement due to burnup. The drive mechanism is not difficult to remove from the system; however, repairs after removal are difficult. New drives are currently being installed as required.

c. History of Malfunction and/or Modification (Refs 4-12, 20, 22-29)

Though no failures have been encountered, an examination of a control rod which had been in the reactor for a period of approximately 1 year revealed the upper and lower beryllium-copper guide bearings (or bushings) were severely corroded and/or eroded (Figs. 23, 24). The upper seal (Fig. 23) was more severely affected than the lower. This is noteworthy because the temperature of the sodium passing both seals was approximately the same (700°F), and sodium velocities at the lower labyrinth seal were somewhat greater than at the upper seal. The upper seal was exposed to a higher neutron flux than the lower, this factor apparently weighing heavily as a cause of the damage.

Figure 25 depicts a lower guide bearing from a control rod which had been in the storage basket for approximately 1 year. Sodium velocity through this

Fig. 23. EBR-II Control Rod Upper Guide Bearing

Fig. 24. EBR-II Control Rod Lower Guide Bearing

Fig. 25.
EBR-II Control
Rod Lower
Guide Bearing
After 1-yr
Storage

seal was very low (convective flow), and the sodium temperature was 700°F with essentially no neutron flux present. Etching of the beryllium-copper surface is evident in the photograph. Plans to replace the current beryllium-copper seals with aluminum-bronze are in progress.

Control rod drives Nos. 7 and 9 failed to drop after approximately 5760 hr of exposure to the environment. Investigation revealed carbon steel balls had fallen out of the oscillator drive mechanism bearing and lodged in the labyrinth seals of these drives.

After approximately 1200 hr of operation, difficulty was encountered, releasing control rod drives Nos. 8 and 11. The drives were removed and an inspection revealed one jaw-actuating cam was missing from drive No. 8. The cam was found in the drive jaws. Burnishing of the contact surface of one cam was noted on drive No. 11 and the gripper sleeve showed evidence of galling. Drive No. 11 was repaired and the screws holding the jaw-actuating cams were butt-welded. A new drive was inserted in the No. 8 position.

Control rod drive No. 9 sensing rod failed to drop under its own weight after approximately 2386 hr of operation. The sensing rod was manually freed.

After approximately 2796 hr of operation, control rod drive No. 9 was removed because of persistent sensing rod sticking. Subsequent investigation revealed the upper bellows had ruptured, allowing sodium to migrate above the bellows. The drive was replaced.

The jaw actuator for drive No. 7 failed in March 1966. There was evidence that the bellows sealing the jaw-actuating shaft had failed, permitting entrance of sodium to the upper portion of the shaft with subsequent freezing.

During the investigation of copper loss from various bearings in the primary tank, an aluminum-bronze labyrinth seal from a control rod drive which had been in the reactor for approximately 2 years was removed and examined (Fig. 26). As shown in the photograph there is no indication of wear or dissolution. This seal was subjected to some fast neutron flux, maximum sodium temperatures of 845°F, and sodium flow velocities of approximately 2.27 ft/sec.

Fig. 26. EBR-II Control Rod Drive Labyrinth Seal

10. Safety Rods and Safety Rod Drive (Table 25)

The safety rod and thimble (Fig. 27) are essentially identical to the control subassembly except for modifications at the lower end. Two safety rods are utilized in the reactor. The safety rods are attached to a common drive unit extending below the reactor structure. The unit is driven by two shaft extensions outside the fuel transfer system and therefore unaffected by fuel transfer operations. The safety rod is engaged to the driving mechanism by a rotational locking mechanism. A hexagonal collar on the upper end of the safety rod must be raised 1 in. above its normal "up" position to allow disengagement of the rod from its drive.

The safety rods are connected beneath the reactor to a horizontal bar which is connected to two vertical shafts which extend upward through the biological shield. Each shaft is coupled to a rack tube by a magnetic clutch latch arrangement similar to that used on the control rod drive. When released from the "up" or cocked position, the rod assembly drops 14 in. by gravitational attraction, decelerating by means of a pneumatic shock absorber during the last 5 in. of travel.

a. Statement of Operability

The safety rods and the safety rod drives operated satisfactorily.

b. Statement of Maintainability

The safety rods are replaced with new rods periodically because of fuel burnup. No maintenance has been required. The safety rod drives are considered unmaintainable. No malfunctions have been encountered.

c. History of Malfunction and/or Modification (4-12)

There has been no malfunction with either the safety rod or drive systems. The existing beryllium-copper labyrinth seals at the lower end of the safety rods show no record of examination; however, it would be expected that deterioration would have occurred as in the control rod seals.

The drive mechanism clearances reflected in Table 25 were obtained from the drawings referenced. Reference 22 reported that bearing clearances had been increased during installation with as-built drawings not made.

11. Transfer Arm (Table 26)

The transfer arm (Fig. 11) is the portion of the subassembly movement process which interconnects the fuel handling and fuel unloading systems. After the subassembly has been raised out of the reactor, the holddown tube is raised around the

Fig. 27. EBR-II Safety Subassembly

TABLE 25
EBR-II SAFETY ROD AND SAFETY ROD DRIVE

Mechanism	Design Information					Operating Conditions				
	Component (Drawing No.)	No. per Mech- anism	Material of Construction	Dimensions and Manufacturing Tolerances	Clearances, Loading, and Speed	Operating Medium	Temperature, Velocity, and Pressure	Exposure to Environment (hr)	Operating Cycles or Hours	Operating Medium Impurities Range/Average
Safety Rod and Drive Number in Plant: 2 Primary Material of Construction: 304 CRES Assembly Drawings EB-1-25791-F EB-1-25381-F Primary System Filled February 26, 1963	Safety Rod									
	Upper and Lower Bushings (EB-1-25797-B EB-1-25773-D)	4 each	Beryllium Copper (Berylko 25) on 416 CRES carrier	1.866 in. /1.864 OD 0.0461 in. length Surface fin. 32 rms Hardened, Berylko RC 43 416 CRES RC 30-34	Load, negligible Speed, maximum 7 ft/sec linear Clearance, 0.010 in.*	Sodium Liquid	700°F	Variable dependent on burnup rates		Sodium Vapor N ₂ (%) 1.0 to 5.3/1.9 H ₂ (ppm) 10 to <100/35.5
	Guide Tube (EB-1-25801-D)	1	347 CRES Hard chrome plated	1.874 in. /1.876 ID 33.344 in. length Chrome plate thickness 0.0005 in. /0.003 Hardened, Brinell 700-800	Clearance, 0.010 in.*	Sodium Liquid	700°F 300 to 700°F	≈ 35,478 ≈ 3,942	≈ 8,055 hr	O ₂ (ppm) 3.2 to 11.5/5.8 Sodium Liquid
	Safety Rod Drive									O ₂ (ppm) 3.2 to 11.5/5.8
	Bellows Seal Welded Opposed Type (EB-1-25395-D)	1	304 CRES	9 in. OD 4 in. ID Length 9-in. compressed 23-5/8 in. extended Wall thickness, 0.010 in.	Pressure, 1 psi	Sodium Vapor	≈ 150°F	≈ 39,420	8,055 hr	
	Lower Bearing (EB-1-25389-A)	1	Aluminum Bronze (Ampco 18)	3.502 in. /3.503 ID 5.998 in. /6.000 OD 3/4 in. Length	Load, negligible Clearance, 0.002 in. /0.003*	Sodium Liquid	700°F 300 to 700°F	≈ 35,478 ≈ 3,942	8,055 hr	
	Upper Solid Shaft at Lower Bearings (EB-1-25382-E)	1	304 CRES	3.500 in. OD	Speed, 7 ft/sec Max linear	Sodium Liquid	700°F 300 to 700°F	≈ 35,478 ≈ 3,942	8,055 hr	
	Lower Guide Bearing (EB-1-25393-B)	1	Aluminum Bronze (Ampco 18)	3.501 in. /3.502 ID 8 in. OD 1 in. length	Load, negligible Clearance, 0.001 in. /0.002*	Sodium Liquid	700°F 300 to 700°F	≈ 35,478 ≈ 3,942	8,055 hr	
*As-built clearances unavailable										

TABLE 26
EBR-II TRANSFER ARM

Mechanism	Design Information					Operating Conditions				
	Component (Drawing No.)	No. per Mech- anism	Material of Construction	Dimensions and Manufacturing Tolerances	Clearances, Loading, and Speed	Operating Medium	Temperature, Velocity, and Pressure	Exposure to Environment (hr)	Operating Cycles or Hours	Operating Medium Impurities Range/Average
Transfer Arm Number in Plant: 1 Primary Material of Construction 304 CRES Assembly Drawing EB-1-25665 Primary System Filled February 26, 1963	Lower Main Shaft (EB-1-25729)	1	304 CRES	4-1/4 in. OD 1/2 in. wall	Speed, very low rotational Clearance, 0.030 in.	Sodium Liquid	700°F 300 to 700°F	≈ 35,478 ≈ 3,942	≈ 2,255 cycles	<u>Sodium Vapor</u> N ₂ (%) 1.0 to 5.3/1.9
	Lower Bearing Main Shaft (EB-1-28556-B)	1	Aluminum Bronze (Ampco 18-13)	4.275 in. /4.280 ID 3 in. length Surface fin. 32 rms	Load, small alternating radial load ≈ 21 lb Clearance, 0.030 in.	Sodium Liquid	700°F 300 to 700°F	≈ 35,478 ≈ 3,942	≈ 2,255 cycles	H ₂ (ppm) 10 to <100/35.5
	Sensing Rod (EB-1-25727-A)	1	17-4 PH CRES		Load, negligible Clearance, 0.030 in.	Sodium Liquid	700°F 300 to 700°F	≈ 35,478 ≈ 3,942	≈ 2,255 cycles	O ₂ (ppm) 3.2 to 11.5/5.8
	Carrier Block (EB-1-28557-C)	1	Inconel X	0.535 in. /0.540 seat slot 1.004 in. /1.006 seat diameter 0.750 in. spherical rad Surface fin. 20 rms	Load, 130 lb Clearance, 0.030 in.	Sodium Liquid	700°F 300 to 700°F	≈ 35,478 ≈ 3,942	≈ 2,255 cycles	<u>Sodium Liquid</u> O ₂ (ppm) 3.2 to 11.5/5.8
	Bellows - Convolute Type (EB-1-25725-B)	1	321 CRES	2.085 in. OD 1-1/2 in. ID 11 in. free length 1.938 in. stroke 0.006 in. wall thickness		Sodium	700°F 300 to 700°F	≈ 35,478 ≈ 3,942	≈ 2,255 cycles	
	Packing Gland Packing (Unavailable)				Load, normal packing surface friction	Sodium Condensate and Vapor	≈ 150°F	≈ 39,420	≈ 2,255 cycles	
	Packing Spacer and Support Shoulder (Unavailable)	1 each			Load, none	Sodium Condensate and Vapor	≈ 150°F	≈ 39,420	≈ 2,255 cycles	

suspended subassembly acting as lateral support during movement to the transfer point. The core gripper head is rotated to the transfer angle with the collar on the subassembly adapter fitting into the U-shaped transfer arm holding device. The locking bar of the transfer arm holding device locks the subassembly positively to the transfer arm. After being released by the core gripper the arm is rotated through an arc of 80 deg to position the subassembly above any one of three concentric rows of storage locations in the storage basket. The arm is manually operated.

a. Statement of Operability

Operation of the transfer arm has been satisfactory after an initial failure of the bell crank, which does not operate in sodium.

b. Statement of Maintainability

The transfer arm assembly is difficult to remove and replace.

c. History of Malfunction and/or Modification (Refs 4-12, 22, 29-31)

One failure is recorded for the transfer arm: the bell crank, a component not operating in a sodium environment, failed. When the mechanism was removed, the lower main shaft bearing was inspected (February 1966). The aluminum-bronze bearing showed no deterioration at that time (3 years exposure).

12. Fuel Unloading Machine Gripper and Ports

The fuel unloading machine (Fig. 28) consists of a 14-ft-high shielding cask resting on a self-propelled carriage. The carriage moves between a position above the primary tank transfer port to a position above the pit of the interbuilding coffin.

The shielding cask supports a fuel-subassembly gripper (Fig. 29) and its drive assembly. The gripper can be lowered through the vertical storage tube of the cask and past a rotary shielding valve (Figure 30). Horizontal clearance between the bottom of the shielding cask and the top of the transfer port (Fig. 31) is sealed by a bottom ring seal during vertical gripper motion. The 5-in.-diameter ring seal piston has a basic T-shaped cross section fitting into the closed-off groove of its housing. Thirty-three coil springs act to force the O-ring-type seal against the mating seal surface.

A shielding valve seals off the lower end of the hexagonal storage tube inside the shielding cask. The valve consists of a 7-in.-wide, 13.5-in.-diameter, lead-filled cylindrical plug. A 3.5-in.-diameter hole lined with a hexagonal tube is located, perpendicular to the rotating axis. Plug rotation of 90 deg fully closes the valve. A gap of 0.010 in. between the valve cylinder and housing is

Fig. 28. EBR-II Fuel Unloading Machine

Fig. 29.
 EBR-II Gripper
 Mechanism

Fig. 30. EBR-II Bottom Ring Seal and Shielding Valve

Fig. 31. EBR-II Fuel-Transfer Port

sealed by special 1/4-in.-diameter elastomer O-rings. A wire ring in the center of each O-ring keeps it in the saddle-shaped circular grooves cut into the cylindrical periphery of the shielding cylinder.

A removable drip cup catches sodium drippage from spent fuel subassemblies. A tilted lip prevents spilling during plug rotation. The cup requires periodic cleaning.

The gripper consists of an outer shell, a core and a sensing device. The outer shell is a 5-ft-long tubular member surrounding the other components. Its main function is to act as the gripper jaw-actuating device. Spacers and guides maintain a concentric annulus between the outer shell and the core. The lower end of the shell surrounds the gripper jaws closely as it pivots them on 3/8-in.-diameter Stellite balls. Movement of the outer shell relative to the core, pivots the jaws about 5 deg. The outer shell moves 1-1/2 in., applying cam pressure on the upper and lower ends of the jaws to either open or close them. The function of the core is to support the jaws that carry the fuel subassembly weight. The core outer surface seats 3/16-in. balls which act as jaw pivots. The sensing device, about 5 ft long with longitudinal grooves for sodium and argon flow, is housed in the center of the core.

Table 27 is a review of the Mark II gripper. Prints of the Mark I and III grippers were not available.

a. Statement of Operability

A great deal of difficulty has been experienced with both the Mark I and II grippers. Sticking resulted from internal and external sodium-sodium oxide buildup during normal operation. Periodic operating difficulties with the fuel unloading machine port were encountered because of sodium-sodium oxide buildup on plug surfaces.

b. Statement of Maintainability

Maintenance was not difficult to perform on the fuel unloading machine gripper or port. These mechanisms required frequent maintenance; continuous cleaning was necessary.

c. History of Malfunction and/or Modification

(1) Mark I Gripper. The gripper was subject to continual sticking caused by internal and/or external sodium-sodium oxide buildup; it required cleaning six times.

TABLE 27
EBR-II FUEL UNLOADING MACHINE
(Sheet 1 of 3)

Mechanism	Design Information					Operating Conditions				
	Component (Drawing No.)	No. per Mech- anism	Material of Construction	Dimensions and Manufacturing Tolerances	Clearances, Loading, and Speed	Operating Medium	Temperature, Velocity, and Pressure	Exposure to Environment (hr)	Operating Cycles or Hours	Operating Medium Impurities Range/Average
Fuel Unloading Machine Number in Plant: 1 Primary Material of Construction: 304 CRES Assembly Drawing: EB-1-38296 Primary System Filled: February 26, 1963	Gripper Mark II							Installed 6-65 Replaced 5-67		Continually changing environments Impurity levels unknown
	Sensing Rod Wear Buttons and Surfaces (EB-1-38312-C)	6	Stellite 6 weld Upper end Inconel	0.985 in. OD maximum 0.190 in. / 0.195 Rad. ball seat 0.180 in. / 0.179 Rad. 0.012 in. / 0.015 Tip Rad.	Load, negligible Clearance, 0.047 in.	Sodium Condensate, Vapor, Drip-pings and Dips into Sodium Liquid	70 to 700°F	≈17,280	≈1,040 cycles	
	Inner Tube (EB-1-38310-D)	1	304 CRES	1.031 in. ID one end 0.198 in. / 0.208 slot width	Load, negligible	Sodium Condensate Vapor, Drip-pings and Dips into Sodium Liquid	70 to 700°F	≈17,280	≈1,040 cycles	
	Sensing Rod Extension (EB-1-38300-B)	1	304 CRES	0.468 in. per side 6-15/16 in. length	Load, negligible Clearance, 0.032 in.	Sodium Condensate, Vapor, Drip-pings and Dips into Sodium Liquid	70 to 700°F	≈17,280	≈1,040 cycles	
	Inner Tube Upper Section (EB-1-38310-D)	1	304 CRES	Cross section, 0.994 x 1.093 in. 4-3/16 in. length	Load, negligible Clearance, 0.037 in. / 0.032	Sodium Condensate, Vapor, Drip-pings and Dips into Sodium Liquid	70 to 700°F	≈17,280	≈1,040 cycles	
	Guide Cap for Upper Section Inner Tube (EB-1-38306-B)	1	Inconel Two Stellite 6 Weld wear buttons	1.125 x 1.031 in. 1.25 in. length	Load, negligible	Sodium Condensate, Vapor, Drip-pings and Dips into Sodium Liquid	70 to 700°F	≈17,280	≈1,040 cycles	
	Gripper Jaw (EB-1-38309-C)	1	Inconel cam wear Regions built up with Stellite weld	Contact center pivot point - weld surface Stellite 6 Dimensions are difficult to describe. Refer to drawing if necessary	Load, negligible	Sodium Condensate, Vapor, Drip-pings, and Dips into Sodium Liquid	70 to 700°F	≈17,280	≈1,040 cycles	
	Cooling Shell (EB-1-38311-D)	1	304 CRES with 12 Stellite guide balls	0.250 in. / 0.249 Ball OD 2.834 in. / 2.830 Seat depth Lower end 2.900 in. / 2.895 OD 2.745 in. / 2.755 ID	Load, negligible	Sodium Condensate, Vapor, Drip-pings and Dips into Sodium Liquid	70 to 700°F	≈17,280	≈1,040 cycles	

TABLE 27
EBR-II FUEL UNLOADING MACHINE
(Sheet 2 of 3)

Mechanism	Design Information					Operating Conditions				
	Component (Drawing No.)	No. per Mech- anism	Material of Construction	Dimensions and Manufacturing Tolerances	Clearances, Loading, and Speed	Operating Medium	Temperature, Velocity, and Pressure	Exposure to Environment (hr)	Operating Cycles or Hours	Operating Medium Impurities Range/Average
	Compression Spring (EB-1-38297-A)	1	Inconel X	2.540 in. ID 16 in. free length 13-3/4 in. Extended 9-1/2 in. Compressed	Preload, 14 lb Spring rate, 5 lb/in.	Sodium Condensate, Vapor, Drip- pings, and Dips into Sodium Liquid	70 to 700°F	≈17,280	≈1,040 cycles	
	Collar (EB-1-38308-C)	1	Inconel	2.812 in. flat to flat hexago- nal section 1 in. length	Load, negligible	Sodium Condensate, Vapor, Drip- pings, and Dips into Sodium Liquid	70 to 700°F	≈17,280	≈1,040 cycles	
	Sensing Rod Chain Link (EB-1-38390-A)	64	304 CRES	0.425 in. length 0.032 in. /0.031 thickness 0.096 in. /0.097 ID	Load, 15 lb tension	Sodium Condensate and Vapor	70 to 700°F	≈17,280	≈1,040 cycles	
	Guide Pin in Cover and Inner Tube Slots (EB-1-38476-A)	2	Inconel	0.190 in. Diameter 3/8 in. length	Load, negligible	Sodium Condensate and Vapor	70 to 700°F	≈17,280	≈1,040 cycles	
	Sensing Rod Chain Pulley (EB-1-38299-A)	1	17-4 PH H900 CRES	0.500 in. Diameter 0.718 in length	Torque, 31.5 in. lb	Sodium Condensate and Vapor	70 to 700°F	≈17,280	≈1,040 cycles	
	Sensing Rod Chain Retaining Guide (EB-1-38298-A)	1	304 CRES	0.750 in. /0.749 length 5/32 in. thickness	Load, negligible	Sodium Condensate and Vapor	70 to 700°F	≈17,280	≈1,040 cycles	
Rotating Port Fuel Unload- ing Machine	Rotating Plug (EB-1-27737-D)	1	304 CRES	13.500 in. /13.497 Diameter 6-7/8 in. width	Load, none	Sodium Vapor	70 to ≈600°F	≈39,420	≈2,255 cycles	
	Hexagon Tube (EB-1-27737-D)	1	304 CRES	2.962 in. flat to flat	Load, none	Sodium Vapor	70 to ≈600°F	≈39,420	≈2,255 cycles	
	Rotating Plug Drive Shaft (EB-1-27737-D)	1	304 CRES	2.164 in. /2.1635 Diameter Surface fin. 5-15 rms	Ball bearing radial load, 140 lb	Sodium Vapor	70 to ≈600°F	≈39,420	≈2,255 cycles	
	Rotating Plug Shell (EB-1-27741-E)	1	304 CRES	13.505 in. /13.510 Diameter 7-5/16 in. width Surface fin. 100 rms	Load, none Clearance, 0.005 in. / 0.013	Sodium Vapor	70 to ≈600°F	≈39,420	≈2,255 cycles	
	Pillow Block Left Side (EB-1-28173-A)	1	Bronze	11/32 in. ID 1 in. OD 3/4 in. length	Load, negligible	Sodium Vapor	70 to ≈600°F	≈39,420	≈2,255 cycles	

TABLE 27
EBR-II FUEL UNLOADING MACHINE
(Sheet 3 of 3)

Mechanism	Design Information					Operating Conditions				
	Component (Drawing No.)	No. per Mech- anism	Material of Construction	Dimensions and Manufacturing Tolerances	Clearances, Loading, and Speed	Operating Medium	Temperature, Velocity, and Pressure	Exposure to Environment (hr)	Operating Cycles or Hours	Operating Medium Impurities Range/Average
	Pillow Block Right Side (EB-1-28172-A)	1	Inconel	9/16 in. ID 1 in. OD 3/4 in. length	Load, negligible	Sodium Vapor	70 to $\approx 600^{\circ}\text{F}$	$\approx 39,420$	$\approx 2,255$ cycles	
Primary Tank Fuel Transfer Port	Transfer Port Housing (EB-1-28622-E)	1	304 CRES	13.505 in. /13.510 ID	Load, none Clearance, 0.008 in. /0.010	Sodium Vapor	$\approx 650^{\circ}\text{F}$ 300 to 650°F	$\approx 35,478$ $\approx 3,942$	$\approx 2,255$ cycles	
	Rotating Port (EB-1-28621-D)	1	304 CRES	13.500 in. /13.497 OD	Load, none	Sodium Vapor	$\approx 650^{\circ}\text{F}$ 300 to 650°F	$\approx 35,478$ $\approx 3,942$	$\approx 2,255$	
	Rotating Port Shaft (EB-1-28621-D)	1	304 CRES	2.1640 in. /2.1635 OD	Ball bearing radial load, 140 lb	Sodium Vapor	$\approx 650^{\circ}\text{F}$ 300 to 650°F	$\approx 35,478$ $\approx 3,942$	$\approx 2,255$	

The gripper caught on the leading edge of the lower port of the fuel unloading machine. The edge was chamfered to prevent recurrence of the incident (September 1963).

Mark I was replaced by the Mark II gripper in June 1965.

(2) Mark II Gripper (Refs 4-14, 22, 32-53). This gripper also stuck repeatedly because of internal and/or external sodium-sodium oxide buildup; it required cleaning 19 times.

The gripper jaws on Mark II did not operate properly; a weld had failed on the main gripper drive shaft. Mark I was used while repairs were made. The Mark II was returned to service in November 1965.

The gripper jaw cam actuator was modified in January 1967 to provide greater closing force.

The gripper was inspected after difficult operation and several screws were found working loose. Repairs were made.

(3) Fuel Unloading Machine Rotating Port (Refs 4, 5, 7-12, 22, 33, 35, 38, 41, 43, 46, 51-61). The port became inoperable 17 times due to sodium-sodium oxide buildup on the rotating surfaces. The unit was disassembled, cleaned, reassembled and returned to service.

The O-rings were replaced 11 times because of the difficulty in maintaining a gas seal in the fuel unloading machine. Inspection revealed O-ring deterioration in each case.

A drip pan was installed in the rotating plug in March 1964 to catch sodium drippings from the gripper and subassemblies. A new pan was installed in April 1967.

(4) Fuel Transfer Port - Primary Tank (Refs 4-2, 19, 22, 32, 33, 36, 44, 46, 47, 62-66). The port became inoperable eight times due to sodium-sodium oxide buildup on the plug rotating surfaces. The unit was disassembled, cleaned, reassembled, and returned to service.

O-ring deterioration repair was required seven times.

Sodium-sodium oxide was cleaned from the transfer port hexagonal tube 10 times to eliminate sticking of the fuel unloading machine gripper.

13. Oscillator Rod and Drive (Table 28)

The drawings for the Mark I oscillator rod drive were not available. The Mark II drive is the only one described in Table 28.

The reactivity generator (Fig. 32) is a specially designed device to sinusoidally perturb the critical reactor system. The complete reactivity generator assembly consists of three separate units: (1) the oscillator rod; (2) the mechanical actuator; and (3) the drive mechanism.

The mechanical actuator provides the link between the oscillator rod and the drive mechanism. The Mark I drive consists of a suitably supported long extension rod and a scotch yoke which translates rotary motion into vertical oscillatory motion. The reactivity generator permits a maximum stroke of 8 in. for frequencies less than 1 cps, or a shorter stroke of 4 in. for all frequencies up to 2 cps. The Mark II drive is designed for rotary oscillatory motion, eliminating the use of ball bushings.

a. Statement of Operability

The Mark II boron-carbide oscillator rod operated well except at the lower speeds and higher temperature differentials. The Mark I drive system operated well until failure of the lower linear ball bushing occurred. It would be a recommended practice to provide safety retainers to prevent release of balls in similar items for future service. The Mark II drive system operated well with the exception of a failed sensing rod bellows.

b. Statement of Maintainability

The oscillator rod required no maintenance. The Mark I drive was very difficult to repair. The Mark II drive compared well with control rod drive maintenance.

c. History of Malfunction and/or Modification (Refs 4, 10-12, 22-24, 67-73)

During routine transfer function measurements of the EBR-II, the effort required to turn the Mark II oscillator rod increased markedly at very slow speeds and high reactor temperature differentials. When the rod was removed and inspected, rubbing marks were found on one side. It was concluded that these marks were caused by a combination of rod and thimble bowing at the lower speeds and higher temperature differentials.

Fig. 32. EBR-II Reactivity Generator Assembly
(Mark I only)

TABLE 28
EBR-II OSCILLATOR ROD AND DRIVE
(Sheet 1 of 3)

Mechanism	Design Information					Operating Conditions				
	Component (Drawing No.)	No. per Mech- anism	Material of Construction	Dimensions and Manufacturing Tolerances	Clearances, Loading, and Speed	Operating Medium	Temperature, Velocity, and Pressure	Exposure to Environment (hr)	Operating Cycles or Hours	Operating Medium Impurities Range/Average
Boron Carbide Rod Mark II and Drive Number in Plant: 1 Primary Material of Construction 304 CRES Assembly Drawing EB-1-38806- F Primary System Filled February 26, 1963	Shaft Oscillator Rod Extension (EB-1-38746-C)	1	304 CRES Colmonoy 4 Welded Inlay Hard Facing	1.4955 in. / 1.4950 OD 1/8 x 1/8 in. Helical Slots 30° Orientation Chrome plated section Thickness 0.0002 in. / 0.0005 Surf. Fin. 8-16 RMS	Speed, 480 rpm Max. rotational	Sodium Liquid	700°F 300 to 700°F (Neutron Flux)	≈ 3,168 ≈ 192	≈ 52 Hours	Sodium Liquid O ₂ (ppm) 4 to 20/11.2 H ₂ (ppm) 1.6 to 8.2/4.1
	Lower Bearing (EB-1-38755-B)	1	Stellite 6B	1.4900 in. / 1.5005 ID	Clearance, 0.0045 in. / 0.0055	Sodium Liquid	700°F 300 to 700°F (Neutron Flux)	≈ 3,168 ≈ 192	≈ 52 Hours	Sodium Vapor N ₂ (%) 0.3 to 4.0/1.0 H ₂ (ppm) 0 to 400/61
	Seal Ring (EB-1-38748-A)	1	Aluminum Bronze (Ampco 18-13)	1.783 in. / 1.781 OD with 3 Circumferential Grooves 1/4 in. wide 13/16 in. length Surf. Fin. 30 RMS		Sodium Liquid	700°F 300 to 700°F (Neutron Flux)	≈ 3,168 ≈ 192	≈ 52 Hours	O ₂ (ppm) 4 to 20/11.2
	Compression Spring (EB-1-38758)	1	Inconel X	1.125 in. OC 10-1/4 in. Free Length 9-3/16 in. Extended Length 8-15/16 in. Compressed Length	Spring Rate, 230 lb/in.	Sodium Liquid	700°F 300 to 700°F (Neutron Flux)	≈ 3,168 ≈ 192	≈ 52 Hours	
	Mark II Drive Unit									
	Guide Tube Bearing (EB-1-38820)	1	Aluminum Bronze (Ampco 18-13)	2.250 in. / 2.252 ID 3.249 in. / 3.248 OD 5/8 in. Length	Clearance, 0.0015 in. / 0.0050	Sodium Vapor	≈ 150°F	≈ 3,360	≈ 52 Hours	
	Bearing Carrier — Upper (EB-1-38826-C)	1	304 CRES Chrome Plated	2.2485 in. / 2.2470 Diameter Chrome plate thickness 0.0002 in. / 0.0005 Surf. Fin. 63 RMS	Speed, 6 in. / min	Sodium Vapor	≈ 150°F	≈ 3,360	≈ 52 Hours	
	Bearing No. 2 — Drive Shaft Upper Section (EB-1-38812-A)	1	Aluminum Bronze (Ampco 22)	1.3780 in. / 1.3785 ID 2.374 in. / 2.373 OD 0.625 in. Length Surf. Fin. 8-16 RMS	Clearance, 0.0045 in. / 0.0055	Air	≈ 150°F	≈ 3,360	≈ 52 Hours	
	Drive Shaft Upper Section (EB-1-38829-B)	1	304 CRES Welded Inlay Colmonoy 5 Hard Facing	1.3735 in. / 1.3730 OD Chrome Plate (Threaded Joint) Thickness, 0.0002 in. / 0.0005 Surf. Fin. 8-16 RMS	Speed, 450 rpm Max. rotational	Air	≈ 150°F	≈ 3,360	≈ 52 Hours	

TABLE 28
EBR-II OSCILLATOR ROD AND DRIVE
(Sheet 2 of 3)

Mechanism	Design Information					Operating Conditions				
	Component (Drawing No.)	No. per Mech- anism	Material of Construction	Dimensions and Manufacturing Tolerances	Clearances, Loading, and Speed	Operating Medium	Temperature, Velocity, and Pressure	Exposure to Environment (hr)	Operating Cycles or Hours	Operating Medium Impurities Range/Average
	Bearing No. 3 - Drive Shaft Intermediate (EB-1-38832-B)	1	Aluminum Bronze (Ampco-22)	1.6875 in. / 1.6880 ID 1/2 in. Length; Surf. Fin. 8-16 RMS	Clearance, 0.0045 in. / 0.0055	Sodium Vapor	≈650°F 300 to 650°F	≈3,168 ≈ 192	≈52 Hours	
	Drive Shaft - Intermediate Section No. 2 (EB-1-38830-C)	1	304 CRES Welded Inlay Colmonoy 5 Hard Facing Upper Region Colmonoy 4 Hard Facing Lower Region Chrome Plate Threaded Joint	1.6830 in. / 1.6825 OD Upper Region 1.6805 in. / 1.6800 OD Lower Region 1/8 x 1/8 in. Helical Slots 30° Angle Colmonoy 4 Thickness, 0.040 in. Chrome plate (Threaded Joint) Thickness, 0.0002 in. / 0.0005 Surf. Fin. 8 RMS	Speed, 450 rpm Max. rotational	Sodium Vapor	≈650°F 300 to 650°F	≈3,168 ≈ 192	≈52 Hours	
	Bearing No. 4 (EB-1-38833-B)	1	Stellite-6B	1.6850 in. / 1.6855 ID 1/2 in. Length Surf. Fin. 8 RMS	Clearance, 0.0045 in. / 0.0055	Sodium Liquid	700°F 300 to 700°F	≈3,168 ≈ 192	≈52 Hours	
	Reactor Vessel Cover Sleeve (EB-1-27113-C)	1	Wrought Stellite-6B	2.567 ID nominal	Clearance, 0.004 in. / 0.006 measured values	Sodium Liquid	700 to 845°F 700°F 300 to 700°F (Neutron Flux)	≈1,272 ≈1,896 ≈ 192	≈52 Hours	
	Bearing Carrier - Lower (EB-1-38828-C)	1	Colmonoy 4 Hard Facing Welded Inlay	2.563 in. / 2.561 OD Surf. Fin. 8-16 RMS	Speed, 6 in. / min linear	Sodium Liquid	700 to 845°F 700°F 300 to 700°F (Neutron Flux)	≈1,272 ≈1,896 ≈ 192	≈52 Hours	
	Bearing Carrier - Intermediate (EB-1-38827-D)	1	304 CRES Welded Inlay Colmonoy 4 Hard Facing Chrome Plate External Threads	2.576 in. / 2.574 OD 1/4 in. Contact Radius Chrome Plate (External Threads) Thickness, 0.0002 in. / 0.0005 Surf. Fin. 8-16 RMS	Speed, 6 in. / min linear	Sodium Liquid	700°F 300 to 700°F	≈3,168 ≈ 192	≈52 Hours	
	Ring - Lower Guide (EB-1-25157-B)	1	304 CRES Stellite Overlay	2.575 in. / 2.580 ID	Clearance, 0.004 in. / 0.006 measured values	Sodium Liquid	700°F 300 to 700°F	≈3,168 ≈ 192	≈52 Hours	
	Bearing No. 5 (EB-1-38834-B)	1	Stellite 6B	1.9645 in. / 1.9650 ID 1/2 in. Length Surf. Fin. 8 RMS	Clearance, 0.0045 in. / 0.0055	Sodium Liquid	700 to 845°F 700°F 300 to 700°F (Neutron Flux)	≈1,272 ≈1,896 ≈ 192	≈52 Hours	

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TABLE 28
EBR-II OSCILLATOR ROD AND DRIVE
(Sheet 3 of 3)

Mechanism	Design Information					Operating Conditions				
	Component (Drawing No.)	No. per Mech- anism	Material of Construction	Dimensions and Manufacturing Tolerances	Clearances, Loading, and Speed	Operating Medium	Temperature, Velocity, and Pressure	Exposure to Environment (hr)	Operating Cycles or Hours	Operating Medium Impurities Range/Average
	Drive Shaft - Lower Section (EB-1-38843-C)	1	304 CRES Welded Inlay Colmonoy 4 Hard Facing	1.9600 in. / 1.9595 ID	Speed, 450 rpm Max. rotational	Sodium Liquid	700 to 845°F 700°F 300 to 700°F (Neutron Flux)	≈1,272 ≈1,896 ≈ 192	≈52 Hours	
	Gripper Jaw (EB-1-38814-D)	1	410 CRES Hard Chrome Plated	0.375 in. / 0.376 pivot ID Chrome Plate Thickness, 0.0002 in. / 0.0004		Sodium Liquid	700 to 845°F 700°F 300 to 700°F (Neutron Flux)	≈1,272 ≈1,896 ≈ 192	≈52 Hours	
	Clamp-Gripper (EB-1-38696-B)	1	304 CRES Stellite 6B Cams	2.260 in. / 2.265 ID 2.495 in. OD 1.770 in. / 1.772 Separation of Cam Surfaces 0.250 in. OD Cam	Load, Negligible	Sodium Liquid	700 to 845°F 700°F 300 to 700°F (Neutron Flux)	≈1,272 ≈1,896 ≈ 192	≈52 Hours	
	Pin (EB-1-38693-A)	1	Rex AA Tool Steel Hard Chrome Plate	0.372 in. / 0.371 OD 2-3/16 in. Length Chrome Plate Thickness, 0.0002 in. / 0.0004	Load, Negligible Clearance, 0.018 in.	Sodium Liquid	700 to 845°F 700°F 300 to 700°F (Neutron Flux)	≈1,272 ≈1,896 ≈ 192	≈52 Hours	
	Sensing Tip (EB-1-38697-B)	1	410 CRES	0.625 in. OD 3/16 in. Length		Sodium Liquid	700 to 845°F 700°F 300 to 700°F (Neutron Flux)	≈1,272 ≈1,896 ≈ 192	≈52 Hours	
	Bellows Sensing Rod Seal Primary (EB-1-38740-C) Backup (EB-1-387741)	3 5		Drawings Not Available						

The lower linear ball bushing of the Mark I oscillator rod drive shaft failed, permitting the balls to work down the shaft and out the sodium vent holes into the labyrinth seals of the adjacent control rod drive shaft. This resulted in the failure of control rods No. 7 and 9 to drop during a scram on October 19, 1964. Both the oscillator rod and drive were subsequently discarded and the Mark II system was designed.

The Mark II operated for approximately 52 hr. The sensing rod and gripper jaw bound up during rotating fuel handling operations just before the removal of the oscillator drive shaft on February 22, 1967. Inspection revealed that the sensing rod bellows had failed. The Colmonoy-Stellite journal bearings on the drive shaft and the bearing carrier were also inspected at this time. The bearing that ran in an argon atmosphere was highly polished and in good condition. The two sodium bearings were also in good condition with only slight wear marks evident.

D. SUMMARY OF EBR-II RESULTS

A large number of aluminum-bronze bearings and seals are utilized in the EBR-II mechanisms. These components have operated in a sodium environment at temperatures up to 845°F; no failures have been reported. In addition, inspection of both the transfer arm bearing and a control-rod-drive labyrinth seal, after extensive exposure to the sodium environment, revealed no indication of deterioration. Diametral clearances associated with these components have been maintained uniformly quite large at 0.030 in.

Inspection of control-rod, beryllium-copper labyrinth-seal guide bearings has revealed severe deterioration. These bearings are being redesigned.

Difficulty has been experienced with mechanisms involved in the transfer of fuel in and out of the primary vessel, i.e. the fuel unloading machine gripper, and rotating port, and the primary tank transfer port. The problem results from sodium-sodium oxide buildup on sliding surfaces, which causes sticking. The problem apparently has been difficult to resolve.

Thermally-induced bowing problems have been experienced with primary pump impeller drive shafts, the main core gripper shaft, and the oscillator rod.

Difficulty has been experienced with control-rod drive bellows failures, and with malfunctions of the gripper actuating mechanism.

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VI. ENRICO FERMI ATOMIC POWER PLANT

A. DESCRIPTION⁽¹⁻³⁾

The EFAPP is presented in Figures 33 through 36. The plant was designed for a reactor power level of 300 Mwt producing 100 Mwe. The present operating license covers operation to 200 Mwt.

The reactor sodium systems (Fig. 37) are designed with three primary and three secondary loops, each with a sodium pump. Each system is serviced by a 100-gpm cold trap, a 1-gpm plugging loop, a sampling station and the required valving, and sodium storage facilities. The primary system contains a 10-gpm hot trap facility. The primary system has an inventory of 45,000 gal and the secondary system, 36,000 gal. The primary system is designed to operate at 1000°F, 125 psig, and the secondary system at 900°F, 175 psig, with the containment material Type 304 CRES in all cases. Argon cover gas is pressurized to 4 in. water gage on primary sodium free surfaces and 25 to 40 psig on secondary sodium free surfaces. Design temperatures with the core "A" fuel loading are: reactor inlet 550°F, outlet 800°F, steam generator inlet (secondary) 767°F, outlet 517°F, at a flow of 8.85×10^6 lb/hr.

The reactor core is cooled by upflow of sodium from a high-pressure plenum (Fig. 36). Approximately 13% of the flow is diverted through throttle valves to the low-pressure plenum, cooling the blanket subassemblies and hardware. The core subassemblies are mechanically held down in the core support plate, against forces from the coolant flow, by fingers of the holddown mechanism. Subassemblies are handled within the reactor by the offset handling mechanism (OHM), the rotating plug, and the transfer rotor. A sweep arm mechanism (not shown in previously cited figures) now is used to ensure that there are no partially raised subassemblies or other obstructions to the movement of the OHM or the raised holddown fingers.

Beyond the reactor, subassemblies are raised in finned pots from the core transfer rotor through a vertical exit pipe. A track-mounted cask car receives the subassemblies in finned pots (sodium filled) through the exit port and valve assembly. The cask-car hoist, in turn, places subassembly finned pot units into the fuel and repair building (FARB), Figs. 38-40, sodium-filled transfer

1. STEAM GENERATOR HOUSE
2. GASTIGHT BUILDING
3. TRANSFER CASK CAR
4. PRIMARY SODIUM OVERFLOW TANK
5. REACTOR
6. PRIMARY SODIUM PUMP
7. INTERMEDIATE HEAT EXCHANGER
8. SECONDARY SODIUM PUMP
9. STEAM GENERATOR
10. SECONDARY SODIUM DUMP TANK
11. CONTROL ROOM
12. TURBINE-GENERATOR

Fig. 33. Location of Equipment in EFAPP

Fig. 34. Perspective of Fermi Reactor

Fig. 35. Elevation of EFAPP

Fig. 36. EFAPP Reactor Vessel (Elevation)

Fig. 37. Flow Diagram of EFAPP

Fig. 38. EFAPP Fuel Cleaning and Decay Facility (Sectional Elevation)

Fig. 39. EFAPP Fuel Decay and Radioactive Equipment Repair Building

Fig. 40. EFAPP Fuel and Repair Building Irradiated Subassembly Decay Storage Pool

tank. Steam-cleaning equipment is positioned above a second tank port which receives the subassembly itself from its finned pot and positions it for steam cleaning.

Primary system pumps are located (Fig. 37) in the cold leg of the loop between the IHX and the reactor inlet plenum. A 30-in. exit pipe from the reactor supplies sodium to the shell side of the IHX and then to the pump inlet. The outlet of each primary pump incorporates a check valve, allowing the plant to operate with one loop shut down. The 6-in. bypass throttle valves to the low-pressure plenum, along with the primary pumps and IHX tube bundles, are installed in vertical containers, permitting them to be accessible at operating floor level for maintenance without draining the system.

1. Operating Milestones

Construction of the EFAPP was begun in 1956. The primary sodium system was filled in December 1960. A program of reactor components testing⁽²⁾ within the core was conducted during the first half of 1961, and continued as a preoperational test program of all plant systems. Criticality was achieved in August 1963, with operation at power levels in excess of 1 Mwt initiated in December 1965. Power levels were increased, reaching 100 Mwt by October 1966⁽⁴⁻⁸⁾ when operation was interrupted by a fuel meltdown incident. Figure 41 summarizes plant operation through 1966.

2. Thermal History

Figure 41 and References 9 through 14 provide a complete thermal history of the primary sodium system from 1961 through 1966. An average temperature has been 493°F with extremes at 1000°F and 300°F. The excursion to 1000°F in May of 1961 was a part of the reactor components test program and was held for approximately 1 week. The average temperature figure is only useful in evaluating a component which performed for the entire period referenced. Service encompassing lesser periods may be obtained from Figure 41.

3. Sodium and Cover Gas Impurity History

Sodium sampling originally was accomplished by "grab" or "dip" sampling. A more reliable sampling system is presently in use. A sample coil now is installed in parallel with the cold trap. The nonmetallic impurities are determined

Fig. 41. EFAPP Operating History (1961)

Fig. 41. EFAPP Operating History (1962)

Fig. 41. EFAPP Operating History (1963)

Fig. 41. EFAPP Operating History (1964)

Fig. 41. EFAPP Operating History (1965)

Fig. 41. EFAPP Operating History (1966)

as the average of three analytical runs taken from a sample coil. Carbon is presented as sodium carbonate as well as elemental carbon. Hydrogen is reported as hydroxide and nonhydroxide forms. Hydrogen results were known to be high prior to May 1965. This abrupt change in results reflects use of an improved analytical technique. The techniques used in analyzing sodium impurities are: atomic absorption for iron, nickel, and chromium; mercury amalgamation for equivalent oxide; water solution-carbon dioxide evolution for carbonate carbon; and, vacuum reflux (mercury medium) gas chromatograph for hydrogen. Table 29 presents a history of sodium impurity analyses as well as plugging temperatures.⁽¹⁵⁻²⁰⁾

Argon cover gas sampling is performed continuously, analyzing for oxygen, hydrogen, nitrogen, methane, and carbon monoxide. Each analysis is performed on a commercial gas chromatograph. An analysis is made every 12 min with periodic "grab" samples taken to provide a check on the accuracy of the chromatograph. Prior to 1965, the "grab" sampling technique was the only source of cover gas impurity data. Present data indicates certain readings as off scale. It is believed that the off-scale readings (with the exception of nitrogen) are not representative of actual cover gas impurity levels. Table 30 presents a history of cover gas impurity analyses.

B. DISCUSSION OF MECHANISMS REVIEWED

The following section provides a more detailed component description where operability and maintainability of the particular component are discussed.⁽²¹⁾ A summary of operational malfunctions is given with a description of subsequent modifications and repairs.

1. Core Subassemblies (Table 31)

The core subassemblies consist of an upper and lower axial blanket section, 18 in. long, and a 31.2-in. fuel section, central to the assembly. Figure 42 provides details of a complete unit, including the handling head, self-orienting device, and support system. The support system is critical to reactor operation and received special care in handling and heat treating. Alignment of the subassembly support holes is required to maintain the upper end of the subassembly within 0.050 in. of its theoretical location to facilitate handling accuracy.

TABLE 29
EFAPP PRIMARY SODIUM IMPURITIES (ppm)
(Sheet 1 of 2)

Date	O (Sodium Monoxide)	C Total	H Total	Fe	Ni	Cr	Plugging Temperature (°F)	References
1-61	-	-	-	-	-	-	<250	22
2-61	-	-	-	-	-	-	<240	23
3-61	-	-	-	-	-	-	<240	24
9-61	-	-	-	-	-	-	<230	25
2-62	-	-	-	-	-	-	<225	26
4-62	-	-	-	-	-	-	<230	27
1-63	-	-	-	-	-	-	250-335	-
							303 Avg	28, 29
2-63	-	-	-	-	-	-	220	30
5-63	-	-	-	-	-	-	230	31
9-63	-	-	-	-	-	-	<240	32
10-63	-	-	-	-	-	-	<230	33
11-63	-	-	-	-	-	-	<240	33
12-63	25	37	-	-	-	-	<240	33
1-64	-	-	-	-	-	-	<240	34
2-64	-	-	-	-	-	-	<240	35
3-64	27	41	-	-	-	-	<240	33
4-64	-	-	-	-	-	-	<240	36
5-64	-	-	-	-	-	-	<240	37
6-64	-	43	11	-	-	-	<240	38, 33
7-64	12	38	3	-	-	-	<240	39, 33
8-64	10	59	7	-	-	-	<240	40, 33
9-64	15	43	2	-	-	-	<240	40, 33
10-64	21	31	3	-	-	-	<240	41, 33
11-64	-	-	-	-	-	-	<240	42
12-64	-	-	-	-	-	-	<240	43
1-65	16	50	4	-	-	-	<240	44, 33
2-65	14	40	8	-	-	-	<240	45, 33
3-65	12	48	3	-	-	-	<200	46, 15, 33
4-65	12	48	3	-	-	-	<240	15
5-65	18	33	1.3	1-5	-	-	<240	47, 15, 33
6-65	27	44	3.9	-	-	-	<240	48, 33
7-65	-	-	-	-	-	-	<240	49
8-65	10	38-82	2.07	-	-	-	<240	47, 33
9-65	-	-	-	-	-	-	<240	-
10-65	11	47	0.75	-	-	-	<240	50, 33
11-65	9	64	0.71	-	-	-	<240	51, 33
12-65	9	47-105	1.3	2.6	-	-	205-450	-
							232 Avg	52, 33
1-66	-	-	-	-	-	-	210-250	-
							219 Avg	53
2-66	8-11	42-82	0.8-0.9	2.9-3.0	-	-	210-220	-
							216 Avg	9, 33

TABLE 29
EFAPP PRIMARY SODIUM IMPURITIES (ppm)
(Sheet 2 of 2)

Date	O (Sodium Monoxide)	C Total	H Total	Fe	Ni	Cr	Plugging Temperature (°F)	References
3-66	9	36	1.1	-	-	-	-	10, 33
4-66	14	40-77	1.2	3.2	0.1	<0.3	210-230 211 Avg	11, 33
5-66	8	73	0.7	1.9	0.2	<0.3	210	12, 33
6-66	13	-	-	8.9	1.3	2.0	210-225 214 Avg	13, 33
7-66	-	-	-	-	-	-	210-230 216 Avg	54
8-66	6	61	1.1	0.8	<0.3	<0.1	210-240 214 Avg	33, 55
9-66	7	37-95	1.4	-	-	-	210-260 232 Avg	56
10-66	7	74-93	1.4	0.2	<0.2	<0.2	210-230 216 Avg	33, 57
11-66	10	48-200	1.7	0.1-0.9	0.1-0.3	<0.1-0.6	210	58
12-66	15	41-69	1.1	1.4	<0.2	<0.2	210	15, 59
1-67	6	40-153 83 Avg	1.2	0.4	<0.1	<0.2	<210	60, 61
2-67	-	-	-	-	-	-	<220	62
3-67	6	65-127 94 Avg	1.4	0.4	<0.1	<0.1	<220	60, 63
4-67	12	85-231 130 Avg	1.5	0.5	<0.1	<0.1	<220	60, 64
5-67	12	19-205 59 Avg	1.9	2.4	1.0	<0.4	<220	60, 65
6-67	5-9	46-185 97 Avg	0.9-2.9	0.6-3.4	0.05-0.4	0.5-1.6	220	66, 67
7-67	6	19-72 40 Avg	1.2	3.4	0.4	0.9	<220	60
8-67	9	48-76 66 Avg	1.8	3.0	0.4	1.6	<220	60, 67
9-67	10-17	20-60 40 Avg	1.5	1.1	0.7	1.8	-	60, 68
11-67	6	47-92 68 Avg	1.6	6.7	3.4	1.6	<220	60
1-68	6	47-92 68 Avg	1.6	6.7	3.4	1.6	-	69
Min	6	19	0.7	0.1	0.05	0.1	-	-
Max	27	231	11	6.7	3.4	2.0	-	-
Avg	12	62	2.4	2.5	0.7	0.7	-	-

TABLE 30
EFAPP PRIMARY COVER GAS IMPURITIES (ppm)
(Sheet 1 of 2)

Date	O	CO	CO ₂	H ₂	He	Meth	N	References
8-66	<25	<10	<10	<8	<4	<10	2350	55
9-66	<25	<10	<10	4	<4	<10	1900	56
11-66	<25	<10	10	<4	<4	<10	1300	58
12-66	<25	<10	<10	<4	<4	<10	1080	59
1-67	<25	<10	10	<4	<4	<10	1440	61
2-67	<25	<10	<10	4	<4	<10	1650	62
3-67	<25	<10	<10	<4	<4	10	940	63
4-67	<25	<10	<10	4	<4	<10	1920	64
5-67	<25	<10	10	<4	<4	<10	2400	65
6-67	<25	<10	<10	<4	<4	<10	1600	66
9-67	<25	<10	<10	4	<4	<10	600	68
1-68	<25	<10	<10	<4	<4	<10	1000	69
3-68	<25	<10	<10	4	<4	<10	2450	70
4-68	<25	<10	<10	4	<4	<10	4800	71
5-68	<25	<10	<10	4	<4	<10	4860	72
6-68	<25	<10	<10	4	<4	<10	824	73, 74
9-63	<30*	<200*	<200*	25	-	-*	390	75
10-63	<30*	<50*	50	23	-	<50*	260	76
11-63	60	<50*	<40*	29	-	<50*	520	77
12-63	60	<50*	<40*	2.5	-	<50*	390	78
1-64	60	<40*	-*	2.5	-	-*	260	34
2-64	90	<50*	13	<2.5*	-	-	520	35
3-64	30	<50*	4	5	-	-	390	79
4-64	30	<15*	7	<2.5*	-	-	650	36
5-64	<30	<15*	7	<2.5*	-	<10	715	37
6-64	<30	<15*	13	<2.5*	-	<10	280	38
6-64	<30	<20*	-	500	-	520	3680	38
7-64	<30	<20*	<7	50	-	10	2000	39

*Not detectable

TABLE 30
EFAPP PRIMARY COVER GAS IMPURITIES (ppm)
(Sheet 2 of 2)

Date	O	CO	CO ₂	H ₂	He	Meth	N	References
9-64	<30	<50	<7	2	<4	<10	845	40
10-64	<30	<12	<15	<2	-	<10	3260	41
11-64	60	<10	<12	<2	-	<10	1720	42
12-64	30	<10	14	24	-	<10	3240	43
1-65	30	<10	<14	2	20	<10	2420	44
2-65	<30	<10	<14	146	680	<10	3960	45
3-65	<30	<10	10	1230	<4	560	3910	46
4-65	<30	<10	<12	985	<4	270	2880	-
5-65	<30	<10	<12	46	<4	10	4960	47
6-65	<30	<10	<12	4	<4	<10	1200	48
7-65	<30	<10	<12	15	<4	<10	1300	49
8-65	<30	10	100	12	<4	<10	1550	80
9-65	<30	<10	70	8	<4	<10	3000	-
10-65	<30	<10	10	<4	<4	<10	3450	50
11-65	<30	<10	80	4	<4	<10	1250	51
12-65	<45	<10	<10	16	<4	<10	2950	52
1-66	<45	<10	<10	<2	<4	<10	2440	53
2-66	<25	<10	<20	4	<4	<10	650	9
3-66	<25	<10	20	6	<4	<10	3150	10
4-66	<25	<10	25	4	<10	<10	3000	11
5-66	<25	<10	10	6	<4	<10	3000	12
6-66	<25	<10	<10	2.5	<4	16	2400	13
7-66	<25	<10	20	7.5	<4	<10	1800	54
Min	<25	<10	4	2	<4	<10	260	-
Max	90	<50	100	1230	680	560	4960	-
Avg	<32	<11	<17	<69	<24	<40	1958	-

Fig. 42. Isometric View of Fermi Reactor Core Subassembly

TABLE 31
EFAPP CORE SUBASSEMBLIES
(Sheet 1 of 5)

Mechanism	No. in Plant	Design Information							Operating Environment			
		Primary Material of Construction	Component	No. per Mechanism	Material of Construction	Dimensions and Manufacturing Tolerances	Clearances, Loading, and Speed	Drawing No.	Operating Medium	Operating Medium Impurities (ppm)	Temperature, Velocity and Pressure	Exposure to Environment (hr)
Core Subassembly (Ass'y Dwg. 6XN-1716M)	91	304 SS	Wrapper Tube Spacer Pads	364 (4 per each of 91 ass'y's)	347 SS Colmonoy 4 overlay on corners	2.693 ± 0.0005 in. OD Length: 1 in.	Clearance: Compression fit with adjacent sub-assemblies	5XN-2930 6XN-1716M	Liquid Sodium	<u>Range</u> <u>Avg.</u> <u>Sodium Liquid</u> Oxygen (sodium monoxide) 6 to 27, 12 Carbon 19 to 231, 62 Hydrogen 0.7 to 11, 2.4 Iron 0.1 to 6.7, 2.5 Nickel 0.05 to 3.4, 0.7 Chromium 0.1 to 2.0, 0.7	<u>Oper. Temp.</u> Sodium Liquid 300° to 1000° F 493° F ave. <u>Flow Velocity</u> Core Region (max) 15.7 ft/sec Axial Blanket (max) 14.1 ft/sec.	<u>Hr of Exposure</u> ≈ 29,160 max. possible period each sub-assembly must be treated separately.
			Lower Outer Subassembly - Nozzle Bearing	91	304 SS Nitrided	1.993 + 0.0000 in. - 0.0015 OD Length: 1/8 in. Tapered edge. 1.500 + 0.001 in. - 0.000 ID Length: 2 in.	Clearance: Tapered fit into opening in lower support plate.	5XN-3363A				
			Lower Outer Subassembly - Upper Bearing	91	304 SS Nitrided	2.125 + 0.0015 in. - 0.0000 ID Length: 2-1/4 in.	Clearance: 0.005 in. (Between lower outer subass'y. Upper bearing and lower inner sub-ass'y. Upper bearing)	6XN-1716N				
			Lower Inner Subassembly - Bearing Ring	91	304 SS	2.646 in. OD 2.600 in. ID Tapered to 2.100 + 0.000 in. - 0.005 OD	Clearance: Tapered fit into opening in upper support plate.	5XN-3383B 6XN-3361D				
			Lower Inner Subassembly - Bottom Bearing	91	304 SS Colmonoy 4 overlay	1.495 + 0.000 in. - 0.001 OD Length: 2-3/8 ± 1/8 in	Clearance: 0.005 in. (Between bottom bearing and no)	5XN-3363A 6XN-1716M 6XN-3361D				
			Lower Inner Subassembly - Upper Bearing	91	304 SS Colmonoy 4 overlay	2.120 + 0.000 in. - 0.001 OD Length: 1-7/8 ± 1/8 in.	Clearance: 0.005 in. (Between inner upper bearing and outer upper bearing)	6XN-3361D 5XN-3363A				
			Nozzle Spring	91	Inconel "X"	Wire: 0.283 dia. No. 1 temper wire No. of Coils: 13 active 2 inactive Length: 5.31 in at 390 lb.	Load: Shall not exceed 490 lb nor be less than 430 lb. Spring: To work in 2.120 dia. hole and over 1.495 in dia shaft	3XN-3362 6XN-1716M				
			Handling Lug Retaining Ring	91	304 SS	1-1/8 in OD Length: 1/4 in.		6XN-1721M	Liquid Sodium			

TABLE 31
EFAPP CORE SUBASSEMBLIES
(Sheet 2 of 5)

Mechanism	No. in Plant	Design Information							Operating Environment			
		Primary Material of Construction	Component	No. per Mechanism	Material of Construction	Dimensions and Manufacturing Tolerances	Clearances, Loading, and Speed	Drawing No.	Operating Medium	Operating Medium Impurities (ppm)	Temperature, Velocity and Pressure	Exposure to Environment (hr)
Core Subassembly (Ass'y Dwg. 6XN-1716M) Inner Row Radial Blanket Subassembly (Ass'y Dwg. 6XN-1729)	48	304 SS	Handling Lug Ring (or Collar)	91	304 SS	1.0 in. ID Length: 0.600 in.	Clearance: 5/16 in. (Between pin shaft and handling lug collar)	6XN-1721M	Liquid Sodium ↑ Liquid Sodium			
			Handling Lug Pin	91	304 SS Nitrided	1 1/16 in. OD (Shaft) Length: 0.656 in. 1-3/8 in. OD (Head) Conical Shaped	See Drawing	6XN-1721M				
			Wrapper Tube Spacer Pads	144 (4 per each of 48 assy's)	347 SS Colmonoy 4 overlay on corners	2.693 ± 0.0005 in. OD Length: 1 in.	Clearance: Compression fit with adjacent sub-assemblies	6XN-1727 6XN-1728				
			Lower Outer Subassembly - Nozzle Bearing	48	304 SS	1.993 + 0.0000 in. - 0.0015 OD Length: 1/8 in. Tapered edge 1.500 + 0.001 in. - 0.000 ID Length: 2 in.	Clearance: Tapered fit into opening in lower support plate.	6XN-1729				
			Lower Outer Subassembly - Upper Bearing	48	304 SS Nitrided	2.125 + 0.0015 ID - 0.000 Length: 2-1/4 in.	Clearance: 0.005 in. (Between lower outer subass'y. Upper bearing and lower inner sub-ass'y. Upper bearing)	6XN-1729				
			Lower Inner Subassembly - Bearing Ring	48	304 SS	2.646 in. OD 2.600 Tapered to: 2.100 + 0.000 in. - 0.005 OD	Clearance: Tapered fit into opening in upper support plate.	6XN-1729				
			Lower Inner Subassembly - Bottom Bearing	48	304 SS Colmonoy 4 overlay	1.495 + 0.000 in. - 0.001 OD Length: 2-3/8 ± 1/8 in.	Clearance: 0.005 in. (Between bottom bearing and nozzle bearing ID)	6XN-1729				
			Lower Inner Subassembly - Upper Bearing	48	304 SS Colmonoy 4 overlay	2.120 + 0.000 OD - 0.001 Length: 1-7/8 ± 1/8 in.	Clearance: 0.005 in. (Between inner upper bearing and outer upper brg.)	6XN-1729				

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Mechanism	No. in Plant	Design Information							Operating Environment			
		Primary Material of Construction	Component	No. per Mechanism	Material of Construction	Dimensions and Manufacturing Tolerances	Clearances, Loading, and Speed	Drawing No.	Operating Medium	Operating Medium Impurities	Temperature, Velocity and Pressure	Exposure to Environment (hr)
Neutron Source No.7 (Shreve Walker and Associates)	1	304 SS	Wrapper Tube - Corner Spacer Pads	4	Colmonoy No. 4	2.693 ± 0.005 in. OD Length: 1 in.	Contact fit with adjacent sub-assemblies Pads are located 30-7/64 in below top of lower guide tube	B-300	Liquid Sodium 			

TABLE 31
EFAPP CORE SUBASSEMBLIES
(Sheet 5 of 5)

Mechanism	No. in Plant	Design Information							Operating Environment			
		Primary Material of Construction	Component	No. per Mechanism	Material of Construction	Dimensions and Manufacturing Tolerances	Clearances, Loadings, and Speed	Drawing No.	Operating Medium	Operating Medium Impurities (ppm)	Temperature, Velocity and Pressure	Exposure to Environment (hr)
			Pickup Head - Washer	1	Stellite No. 6	0.9375 in. ID Length: 0.600 in. 1.625 in. OD	Clearance: 0.050 in. (Between washer and pickup head shaft head)	6XN-5580	Liquid Sodium ↑ ↓			
			Orifice Plug	1	304 SS	1.587 +0.000 in. - 0.001 OD Length of Surface 1/8 in.	Clearance: 0.163 in. (Between orifice plug and lower orifice sleeve)	B-201				

a. Statement of Operability

The original chevron-wire support structure for the fuel pin disintegrated as a result of sodium endurance testing. Replacement with a grid-type design, currently in use, imposed a limitation on the core power to 200 Mwt, whereas the original design value was 300 Mwt. This limitation was the result of an increase in pressure drop across the core due to the higher pressure drop for the grid-type pin spacer and the fixed outlet pressure of the pump.

The subassemblies have been satisfactory for fuel handling. Upon insertion into the core, the camming characteristic is such that the subassembly aligns into the square matrix as it is being lowered into the core region. Some difficulty has been experienced in loading fuel subassemblies in areas adjacent to the lower guide tubes for the control and safety rods. This is because these rod subassemblies do not have camming surfaces that are characteristic of the fuel and blanket subassembly. However, it has been found that the camming operation can be performed successfully by reducing the sodium flow to zero and, in some cases, by precamming the subassembly by lowering it into a known orientation position and then putting it into the desired position.

Dimensional tolerances for subassemblies have been satisfactory with respect to their insertion into the core matrixes and also for the provision of a sufficiently close tolerance between the subassembly pads. Nozzle tolerances have generally been satisfactory as the nozzle slides down through the upper support plate and seats into the lower support plate. Some difficulty has been experienced with a small number of subassemblies having nozzles with manufacturing tolerances on the high side. These required matching with support plate holes also having tolerances on the high side. In the Fermi design, the requirement of a close clearance between the nozzle and the support plate could result in the hangup and scraping of a subassembly due to the presence of burrs.

The coefficient of reactivity which was measured during the early stages of power operation was found to be in good agreement with the predicted value.

b. Statement of Maintainability

On-site maintenance of subassemblies has been minor; however, it would be desirable to have a hot cell available for on-site inspection.

Prior to insertion into the reactor, it was found that the spring characteristics of the inner and outer sleeve and spring assembly of some of the lower nozzles were not completely within specifications. Consequently, in some cases, the inner nozzles have been deflared so that the outer sleeve can be slipped off to make the nozzle spring accessible for repair or replacement. In reassembling the nozzles, difficulty has been encountered in reflaring the inner nozzle sleeve because of the work-hardening caused by the deflaring operation.

c. History of Malfunction and/or Modification

During precriticality testing, several dummy subassembly nozzle sleeves became distorted and wedged in the core support plate structure (Refs. 2, 3, 20, 26, 81-83). The distortion was believed to be caused by residual stresses introduced by improper nitriding of the nozzle sleeves. The subassemblies also were subjected to dropping which resulted from sticking hold-down sleeves; a failure to delatch retained a subassembly in a partially raised position. Indexing the rotating plug bent the OHM structure and several subassemblies. The conical handling heads were found damaged as a result of sticking of the head in the conical socket of the holddown finger.

When personnel were sent down into the reactor to make repairs to the damage mentioned previously, erosion damage was found at the seating surfaces at some of the lower support plate openings.^(2,3) Stellite inserts were installed in all openings to resist the suspected cavitation damage.

2. Safety Rods (Table 32)

Safety rod drives⁽⁸⁴⁾ are electromechanically actuated, ball nut and screw type reciprocating mechanisms (Fig. 43). A drive extension penetrates the shield plug and extends down to the top of the reactor lattice. The extension carries a gripper which latches to the safety rod for motion. The scram mechanism latch is located at the upper end of the extension and is electromagnetically actuated. The safety rod (Fig. 44) consists of the poison section, the dash pot ram, the extension rod and pickup head. The dash pot ram is the

Fig. 43. EFAPP Safety Rod Drive Extension

Fig. 44.
EFAPP Safety Rod
Assembly

TABLE 32
EFAPP SAFETY RODS AND DRIVE MECHANISMS
(Sheet 1 of 3)

Mechanism	No. in Plant	Design Information							Operating Environment			
		Primary Material of Construction	Component	No. per Mechanism	Material of Construction	Dimensions and Manufacturing Tolerances	Clearances, Loading, and Speed	Drawing No.	Operating Medium	Operating Medium Impurities	Temperature, Velocity and Pressure	Exposure to Environment (hr)
Safety Rod Drive Mechanism (Full Scale Ass'y Dwg. 7177E74 APDA)	7	304 SS	Cocking Tube Lower Section	7	321 SS	1.75 in. ID Length: 7.56 in. 2.00 in. OD		218B617	Liquid Sodium	(ppm) Range Avg. Sodium Liquid Oxygen (Sodium Monoxide) 6 to 27, 12 Carbon 19 to 231, 62 Hydrogen 0.7 to 11, 2.4 Iron 0.1 to 6.7, 2.5 Nickel 0.05 to 3.4, 0.7 Chromium 0.1 to 2.0, 0.7 Sodium Vapor Range Avg. Oxygen <25 to 90, <32 Carbon Monoxide <10 to 50, <11 Carbon Dioxide 4 to 100, <17 Hydrogen 2 to 1230, <69 Methane <10 to 560, <40 Nitrogen 260 to 4960, 1958	Operating Temperature 300 to 1000°F 493°F Average Latch Load 200 pounds Scram Bellows Pressure 30 psi Cam Shaft Load 50 pounds Drive Speed 1.6 in./min normal drive 10.0 ft/min fast drive Stroke 54 in. Drive System-Operating Load 400 pounds Motor Stall 1000 pounds (Ref. 181)	Hours operated 2,039 Startups 406 Scrams 774 Hours of Exposure ~49,200
			Cocking Tube Upper Section	7	321 SS	2.163 in. ID 2.166 in. ID Length: 6.10 in. 2.375 in. OD		218B617				
			Latch Finger Activator	7	Stellite-6B	2.156 in. OD 2.153 in. ID Length: 3.00 in. 1.595 in. ID (Finger Activator Pads) Length: 0.474 in.	See Dwg.	2XN-4761				
			Latch Finger	21	Stellite-6B	See Dwg. (Unusual Configuration)	See Dwg.	5XN-4754B				
			Latch Finger Retainer	7	Inconel-X	Shaft Bearing: 0.505 in. ID 0.500 in. ID 8 slots equally spaced around ID Length: 1.25 in. Finger Retainer: 0.360 in. Socket 0.355 in. Socket Bellows Guide: 1.94 in. ID Length: 1.81 in. 2.375 in. OD	See Dwg.	218B537				
			Latch Shaft	7	Inconel-X	0.496 in. OD 0.495 in. OD 12 thd. ACME Form 6 pitch R. H.	Clearance: 0.009 in. 0.005 in. (Between Shaft and Retainer Bearing) Note: As the threaded section of shaft moves back and forth through the slotted bearing, any accumulation of crud is scrapped out.	218B597				
			Latch Bellows Shaft	7	Inconel-X	0.812 in. OD	Clearance: 0.228 (Between Bellows and Shaft)	218B597				

TABLE 32
EFAPP SAFETY RODS AND DRIVE MECHANISMS
(Sheet 2 of 3)

Mechanism	No. in Plant	Design Information							Operating Environment			
		Primary Material of Construction	Component	No. per Mechanism	Material of Construction	Dimensions and Manufacturing Tolerances	Clearances, Loading, and Speed	Drawing No.	Operating Medium	Operating Medium Impurities (ppm)	Temperature, Velocity and Pressure	Exposure to Environment (hr)
Safety Rods (Allis-Chalmers)	8	304 SS	Latch Bellows	7	316 SS	1.080 in. ID 1.040 1.740 in. OD 1.700 Stroke: 0.750 in. No. of Convolutions: 20 Max. thickness: 0.006 in.	Spring Rate: 50 lb/in. $\pm$ 10 lb/in.	218B471	Liquid Sodium to Argon			
			Support Tube	7	304 SS Hard Chrome plate outer diameter	1.910 in. OD 1.900 Length: 104.65 in.	Clearance: 0.360 in. 0.330 in. (Between Support Tube and Reciprocating Bellows)	855B321	Sodium Vapor and Argon			
			Reciprocating Bellows	7	316 SS	2.270 in. ID 2.230 3.770 in. OD 3.730 Stroke: 60 in. No. of Convolutions: 700 Thickness: 0.010 in.		192C133	Sodium Vapor and Argon to Argon			
			Dash Pot Stem Seat	8	304 SS	1.662 in. OD Length: 3 in.		E-201-200-8 Combustion Engr.	Liquid Sodium			
			Dash Pot Stem	8	304 SS	1.125 +0.000 in. -0.002 OD Length: Slight vertical movement because of thermal expansion of lower support	Clearance: 0.115 in. (Between Dash Pot Spring and Stem)	E-201-200-8				
			Dash Pot	8	304 SS	1.816 $\pm$ 0.001 in. ID Length: 1 in. 2.000 in. OD Length: 7-3/4 in.	Clearance: 0.277 in. (Between Lower Guide Tube and Dash Pot)	E-201-200-8				
			Dash Ram Bearing Pads (or wear pads)	64 8 pads on each of 8 rams	Colmonoy-4	2.362 +0.000 in. -0.005 OD Length: 1-1/16 in.	Speed: 9 ft/sec during Reactor Scram	43-500-614 Allis-Chalmers 43-400-873				

TABLE 32
EFAPP SAFETY RODS AND DRIVE MECHANISMS
(Sheet 3 of 3)

Mechanism	No. in Plant	Design Information							Operating Environment			
		Primary Material of Construction	Component	No. per Mechanism	Material of Construction	Dimensions and Manufacturing Tolerances	Clearances, Loading, and Speed	Drawing No.	Operating Medium	Operating Medium Impurities (ppm)	Temperature, Velocity and Pressure	Exposure to Environment (hr)
			Upper Shell (Outer)	8	304 SS	2.120 ± 0.017 ID	Clearance: 0.125 in. (between accelerator spring and upper shell)	43-300-993	Liquid Sodium			
			Acceleration Spring (or Cocking Spring)	8	Inconel-X Copper Electroplated	1.537 in. ID 1.995 OD Wire: 0.229 dia. Length: 18.0 free length Compressed Hot: 10.0 in. Spring Constant Hot: 14.1 lb/in. Load at Compressed length Hot: 113 lb	This permits differential expansion between the guide tubes and reactor vessel, and also maintains a constant force between the upper and lower guide tubes during reactor operation.	43-400-726				
			Support Tube (Middle Section)	8	304 SS Nitrided	1-25/64 in. OD Length: 7-1/16 in.	Clearance: 0.147 in.	43-201-396 43-400-725				
			Support Tube (Upper Section)	8	304 SS Nitrided	0.900 +0.000 in. -0.002 OD Length: 7-3/4 in.		43-201-395 43-400-725				
			Latch Adapter	8	304 SS Nitrided	0.900 +0.000 in. -0.002 OD Length: 2-5/8 in.		43-201-394 43-400-725				
			Spring Retainer	8	Inconel-X	0.912 ± 0.001 ID Length: 1-3/16 in. 2.090 ± 0.002 OD Lip - 1-3/8 in. ID Width of Lip: 3/8 in.	Acceleration Spring rides on one side of the lip - Cocking tube pushes down from other side of lip	43-101-033 Cocking Tube 218B617 G. E. dwg.				
			Handling Lug Washer	8	304 SS	1-1/8 ± 1/64 in. OD Length: 1 in.	May be of importance in SR Mech. grapple clearances	2XN-4995B APDA				
			Handling Lug Ring (or collar)	8	Inconel-X	0.645 in. ID 0.641 in. ID 1.180 in. length	Clearance: 0.098 in. 0.096 in. (Between pin shaft and handling lug ring)	5XN-5045				
			Handling Lug Pin	8	304 SS	0.547 in. O.D. (Shaft) 0.545 in. O.D. (Head) Length: 1.531 in. 1.000 in. OD (head) Conical shape	See Dwg.	5XN-4992B				

piston of the hydraulic shock absorber which is used to absorb and dissipate the kinetic energy of the safety rod after its free fall. The ram is a double-tapered piston with a 6-in. effective length. An approximate 3-g deceleration load is applied to the safety rod.

a. Statement of Operability

A major problem with the safety rod drives was that the rods dropped off when operating. Such drops resulted from the inability of the latch magnet-armature combination to hold the latch rod and still provide a rapid drop time when required to release the rod. No provision is included in the latch magnets and armatures for allowing the forces to come into parallel alignment. The magnets are rigidly held by guide bushings; if they are slightly out of alignment, they are not free to align themselves with the armature.

Another problem related to latch magnets and armatures is the air gap; it is difficult to work with and modify to provide uniformity of air-gap thickness on all rods. This is expected to be overcome, but has not yet been accomplished.

Originally, there were design problems. Cable take-up pulleys tended to become misaligned, causing slack; or the cables became caught on associated components. This problem was eliminated by using coiled wires.

It was found highly desirable to include strain gages on the safety rod drives for use in adjusting and for trouble-shooting; this was done and is recommended in future designs.

Difficulty continues to be experienced with the latch stroke immediately after lowering the rod extensions down into the handling heads. This is thought to be due to the differential thermal expansion of the rod drive extension, since the latch stroke is usually completed successfully following a soak period to allow the extension to heat up to the sodium ambient temperature.

b. Statement of Maintainability

Though the overall performance of the equipment has been satisfactory, drive components not in contact with a sodium environment have required excessive maintenance.

Maintenance work on the safety rod itself is practically impossible after it has been withdrawn from the primary system because the rod is extremely radioactive.

Since the rod drives are located on top of the shield plug, they are directly accessible for maintenance, although the area is quite crowded due to the closely clustered arrangement.

The design of the latch magnet housing is such that there is insufficient accessibility to the latch magnet and armature.

Another component of the Fermi safety rod drive mechanisms, which might be expected to present a remote maintenance problem, are the grippers. Endurance tests of the Fermi safety rod grippers in 750 to 1000°F sodium, followed by more than 3 years of operation in the reactor, indicate that maintenance requirements should be minimal over a 10-year life.

c. History of Malfunction and/or Modification

During a 10-psig pressure coefficient of reactivity check, a rod failed to drop when the reactor was scrammed manually (Refs. 75, 76, 84-87). A leak had developed in the latch rod bellows, allowing sodium to enter the extension, freeze around the latch rod, and thereby prohibit delatching. The bellows apparently had become sensitized and exhibited severe corrosion from a pre-service exposure. All latching rod bellows were replaced at this time as a safety precaution.^(38,85,88) A positive argon inner chamber pressure was established to minimize sodium entry if such a leak might reoccur.^(80,89) The welded, nested, reciprocating bellows generally have performed well at EFAPP.⁽³⁾

Based on experience to date, it appears that a minimum amount of research and development work would be required to adapt the Fermi safety rod drive design for 1000-Mw applications. The basic concept appears sound although improvement in details can and should be made. If temperatures much in excess of 1000°F are encountered, a review of materials applications, and appropriate sodium testing should be conducted. In all cases, thorough sodium testing of prototype components is strongly urged, because most of the serious operational difficulties experienced during preoperational testing of the Fermi drives did not show up until the machines were operated in 500 to 700°F sodium. Also recommended for serious consideration in future designs of this type of equipment is a modular and/or subcomponent approach to design and testing (as discussed in Reference 87, pp 84 to 98).

3. Control Rods (Table 33)

The two operating control rod systems^(90,91) (Figs. 45 and 46) have two basic differences from the safety rod system. Variable speed drives are used for the "regulating-rod" drive, and a special safety latch is added to both drive extensions. The safety latch (Fig. 47) is intended to protect each guide tube from inadvertent dropping from a height greater than 1 in. from its seat. There are no dash pots or rams in this system. Design of the control rod drive gripper, though similar to the safety rod drive gripper previously mentioned, was more difficult because of size restrictions. Maximum gripper diameter is 2 in. rather than 2-3/8 in. for the safety rod.⁽³⁾

a. Statement of Operability

No major operating problems have been encountered. Minor difficulties were experienced with the operation of the latch fingers, cam, and rod handling head during preoperational testing. It was necessary, through cut and try operations, to develop a latch finger cam configuration which provided adequate clearance and positive action, and compensated for thermal expansion during the latch stroke. The drives have performed satisfactorily. One minor change was made by replacing the rigid coupling, which coupled the rod positioning potentiometer to its drive shaft, with a flexible coupling.

Scales were added to the contact rods to permit close reading of rod elevation. The automatic action of the shim rod is quite satisfactory; however, it would be better to make a fast accountability of rod positions without it.

b. Statement of Maintainability

Very little maintenance has been necessary. However, it is difficult to perform a major overhaul because of rod drive clustering at the top of the shield plug.

c. History of Malfunction and/or Modification

Operational difficulties experienced with the grippers during early preoperational testing in the reactor sodium were due to improper implementation of the design rather than the basic design concept.^(2,3) Although no basic design changes were required, operating clearances were found to be critical.

Fig. 45. EFAPP Control Rod Guide Tubes

Fig. 46. EFAPP Operating Control Rod

Fig. 47. EFAPP Operating Control Rod Latch Mechanism

TABLE 33
EFAPP CONTROL RODS
(Sheet 1 of 4)

Mechanism	No. in Plant	Design Information						Operating Environment				
		Primary Material of Construction	Component	No. per Mechanism	Material of Construction	Dimensions and Manufacturing Tolerances	Clearances, Loading, and Speed	Drawing No.	Operating Medium	Operating Medium Impurities (ppm)	Temperature, Velocity and Pressure	Exposure to Environment (hr)
Control Rod Drive Mechanism (Snyder Corp. "Details Control Rod Drive" 59-47 Sheet 6)	2		Lower Latch Cylinder	2	310 SS Nitrided Inconel-X Overlay	ID 1.814 in./1.810 OD 2.375 in./2.365 (Inconel-X pads) 12 pads	Clearance 0.034 in./0.030 (Between pads on latch cylinder and lower guide tube)	Snyder Corp. 59-47 Sheet 25 "Details control rod drive"	Liquid Sodium	Range Avg. Sodium Liquid	Oper. Temp. Liquid Sodium	≈ 33,480
			Gripper Cam	2	Inconel-X	OD 1.782 in./1.772 ID 1.440 in./1.438 (Finger retainer ring) See Drawing	Clearance 0.032 in./0.038 (Between gripper cam and lower latch cylinder)	Sheet 25		Oxygen (sodium monoxide) 6 to 27, 12 carbon 19 to 231, 62 hydrogen 0.7 to 11, 2.4 iron 0.1 to 6.7, 2.5 nickel 0.05 to 3.4, 0.7 chromium 0.1 to 2.0, 0.7	300 to 1000°F 493°F Avg. Vapor Sodium ≈ 175°F minimum 300 to 1000°F 493°F Avg. maximum	
			Gripper Finger Retainer	2	Inconel-X	ID 0.505 in./0.500 Length 0.316 in./0.312 Notch for finger 0.315 in./0.312 See Drawing	Clearance 0.006 in./0.002 (Between retainer shaft bearing and shaft) Clearance 0.004 in./0.003 (Between notch for finger and finger)	Sheet 25		Sodium Vapor	Shim Rod Speed 0.4 in./min	
			Gripper Finger	12	310 SS Nitrided	See Drawing (Unusual configuration)	See Drawing	Sheet 25		Oxygen <25 to 90, <32 Carbon Monoxide <10 to <50, <11 Carbon Dioxide 4 to 100, <17 Hydrogen 2 to 1230, <69 Helium <4 to 680, <24 Methane <10 to 560, <40 Nitrogen 260 to 4960, 1958	Regulating Rod Speed Range 1 to 10 in./min (Ref. 3)	
			Drive Shaft Extension	2	304 SS	OD 0.499 in./0.498 (Area of gripper finger retainer) Length 4-1/8 in. OD 0.937 in./0.935	Clearance 0.078 in./0.070 (Between shaft and gripper bellows)	Sheet 24				
			Gripper Bellows	2	316 SS	ID 1.015 in./1.005 OD 1.605 in./1.595 Compressed Length: 2.87 in. Free Length 3.62 in. Extended Length 3.87 in. Convolutions 77 Thickness 0.004 in.	Spring Rate 5 to 10 lb/in.	Sheet 23	Liquid Sodium Argon			

TABLE 33
EFAPP CONTROL RODS
(Sheet 2 of 4)

Mechanism	No. in Plant	Design Information							Operating Environment			
		Primary Material of Construction	Component	No. per Mechanism	Material of Construction	Dimensions and Manufacturing Tolerances	Clearances, Loading, and Speed	Drawing No.	Operating Medium	Operating Medium Impurities (ppm)	Temperature, Velocity and Pressure	Exposure to Environment (hr)
Control (Shim) Rods (Allis-Chalmers) (Weight = 13 lb in Na)	2	304 SS	Reciprocating Bellows Guide Tube	2	304 SS Chrome-Plated OD	1.982 in. OD	Clearance 0.273 in. (Between guide tube and bellows)	Sheet 24	Sodium Vapor and Argon	<div>↑ Sodium Vapor and Argon/Argon ↓ Liquid Sodium ↓</div>		
			Reciprocating Bellows	2	316 SS	ID 2.255 in./2.245 in. OD 3.755 in./3.745 in. Thickness 0.010 in. Convolutions 389 Compressed Length 13.37 in. Free Length 38.87 in. Extended Length 47.37 in.	Spring Rate 2 to 4 lb/in.	Sheet 23				
			Shim Rod Seat Stem Seat	2	304 SS	OD 1.662 in. Length 3 in.		E-201-200-8 Combustion Engr.				
			Shim Rod Seat Stem	2	304 SS	OD 1.125 ^{+0.000} _{-0.002} in. Length Slight vertical movement because of thermal expansion of lower support	Clearance 0.115 in. (Between shim rod seat spring and stem)	E-201-200-8				
			Shim Rod Seat	2	304 SS	OD 2.375 in. Length 18-1/8 in.	Clearance 0.027 in. (Between shim rod seat and lower guide tube)	E-201-200-8 3XN-4810				
			Poison Rod Support Grid Wear Rings	4 (2 on each of 2 control rods)	Colmonoy 4	OD 2.362 ^{+0.000} _{-0.005} in. Length 1/16 in.		43-500-813 Allis-Chalmers 43-201-979				

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EFAPP CONTROL RODS
(Sheet 3 of 4)

Mechanism	No. in Plant	Design Information							Operating Environment			
		Primary Material of Construction	Component	No. per Mechanism	Material of Construction	Dimensions and Manufacturing Tolerances	Clearances, Loading, and Speed	Drawing No.	Operating Medium	Operating Medium Impurities (ppm)	Temperature, Velocity and Pressure	Exposure to Environment (hr)
			Delatching Spring	2	Inconel-X	ID 1.306 in. OD 1.594 $\pm$ 1/64 in. Wire 0.144 in. dia Length 6.833 in. Free length 3.500 in. Compressed Hot Spring Constant-Hot 7.5 lb/in. Load at Compressed Length Hot: 25 lb	Speed This permits differential expansion between the guide tubes and reactor vessel, and also maintains a constant force between the upper and lower guide tubes during reactor operation.	43-201-521	Liquid Sodium			
			Delatching Spring Lower Housing	2	304 SS	OD 1.840 $^{+0.002}_{-0.000}$ in. ID 1.750 $\pm$ 0.004 in.	Clearance 0.156 in. (Between spring and lower housing) 0.086 in. (Between upper housing and lower housing)	43-201-986 43-201-995				
			Delatching Spring Upper Housing	2	304 SS	OD 2.000 $^{+0.015}_{-0.000}$ in. ID 1.926 $^{+0.000}_{-0.002}$ in.	Clearance 0.332 in. (Between spring and upper housing)	43-201-985 43-101-329				
			Support Tube	2	304 SS Nitrided	Upper Shaft Section (OD) 0.687 $^{+0.000}_{-0.002}$ in. Lower Shaft Section 1.125 in. OD	Clearance 0.181 in. (Between spring and lower shaft section) 0.012 (Between spring retainer and upper shaft section)	43-201-995 43-101-329				
			Spring Retainer	2	Inconel-X	ID 0.699 $\pm$ 0.001 OD 2.000 $^{+0.015}_{-0.000}$ in. Length 1-1/16 in.		43-101-329				

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Mechanism	No. in Plant	Design Information						Operating Environment				
		Primary Material of Construction	Component	No. per Mechanism	Material of Construction	Dimensions and Manufacturing Tolerances	Clearances, Loading, and Speed	Drawing No.	Operating Medium	Operating Medium Impurities	Temperature, Velocity and Pressure	Exposure to Environment (hr)
			Spring Retainer (Continued)	2	Inconel-X	(Lip) ID 0.676 in. OD 1.926 in. Width of lip 1/4 in.	Detatching spring rides on one side of the lip – spring compression tube pushes down from other side of lip.	Snyder Corp. Sheet 25 "Details Control rod drive"	Liquid Sodium ↑ ↓	(ppm)		
			Handling Lug Washer	2	304 SS	OD 1-1/8 ± 1/64 in. Length 1 in.	May be of importance in C. R. Mech. grapple clearances	2XN-4994B APDA				
			Handling Lug Ring (or Collar)	2	Inconel-X	ID 0.645 in./0.641 Length 1.180 in.	Clearance 0.098 in. /0.096 (Between pin shaft and handling lug ring)	5XN-4993A				
			Handling Lug Pin	2	304 SS	OD (Shaft) 0.547 in./0.545 Length 1.531 in. OD (Head) 1.000 in. Conical shape	See Drawing	5XN-4992B				

4. Oscillator Rod (Table 34)

The oscillator rod was designed for limited service in testing the stability of the reactor during startup and early operation. The equipment consists of the oscillator rod, a drive extension, and a variable speed power unit. A rotating rod with an eccentric poison section comprises the basic mechanism. The rod is supported on a spherical thrust bearing (previously a conical thrust bearing) and is stabilized laterally by journal and sleeve bearings. The oscillator drive extension shaft is supported at the upper end by a thrust-radial ball bearing. Along its length, the shaft is supported by a needle bearing and four journal sleeve bearings. The upper two journal sleeve bearings operate in sodium vapor-argon and the lower two bearings operate in sodium. Critical areas of design were found to be vibrational response of the long slender drive shaft and journal sleeve bearings, material selection, and operating clearances in the bearings. Since 1961, the materials tested and found to be satisfactory as bearing surfaces included: Colmonoy 4, 5, and 70, Ampco 22, Kentanium, and Kenametal K-95.^(92,93)

a. Statement of Operability

The oscillator rod, extension, and drive system have functioned quite satisfactorily during low-power and high-power operations. However, the design does not provide for withdrawal of the rod extension when preparing for fuel handling and the subsequent reinsertion of the extension following fuel handling. This operation must be done manually.

A redesign of this system should incorporate remote withdrawal and reinsertion of the oscillator rod drive extension.

b. Statement of Maintainability

It has not been necessary to remove the oscillator rod or extension because of bearing or seal difficulties subsequent to operation of the oscillator rod assembly in the reactor.

A high worth low-power rod was removed and replaced with a low worth high-power rod prior to operation at power levels in excess of 1 Mwt. This was part of a planned program and was conducted satisfactorily.

TABLE 34
EFAPP OSCILLATOR ROD
(Sheet 1 of 4)

Mechanism	No. in Plant	Design Information							Operating Environment			
		Primary Material of Construction	Component	No. per Mechanism	Material of Construction	Dimensions and Manufacturing Tolerances	Clearances, Loading, and Speed	Drawing No.	Operating Medium	Operating Medium Impurities (ppm)	Temperature, Velocity and Pressure	Exposure to Environment (hr)
Oscillator Rod Drive Mechanism 77XN-1980D 77XN-1981A 66XN-1991B	1	304 SS	Housing - Lower Section	1	304 SS	1.970 + 0.005 in. ID - 0.000 in.	Clearance: 0.230 in. (Between lower bearing and housing - lower section.) Clearance: 0.220 in. (Between upper bearing and housing - lower section.)	66XN-1991B	Liquid Sodium	Range Sodium Oxygen (sodium monoxide) 6 to 27, 12 Carbon 19 to 231, 62 Hydrogen 0.7 to 11, 2.4 Iron 0.1 to 6.7, 2.5 Nickel 0.05 to 3.4, 0.7 Chromium 0.1 to 2.0, 0.7	Operating Temp Liquid Sodium 300° to 750°F 490°F Ave. Drive Speed Range 0.06 to 600 rpm Drive Torque 140 in.-lb max	Hr of Expos.
			Outer Bearing (Housing - lower section)	1	304 SS Stellite 6 Overlay at bottom	2.400 in. OD 2.395 in. Length: 1.00 in.	Clearance: 0.002 in. (Between housing OD and lower guide tube)	66XN-1991B 5XN-5284A		Avg. Sodium Vapor Oxygen <25 to 90, <32 Carbon monoxide <10 to <50, <11 Carbon dioxide 4 to 100, <17 Hydrogen 2 to 1230, <69 Helium <4 to 680, <24 Methane <10 to 560, <40 Nitrogen 260 to 4960, 1958		
			Bottom Drive (Drive shaft - lower section)	1	Nitrided 304 SS Stellite 6B Overlay	1.687 in. ID 1.955 in. 1 line has 90° arc 1 line has 60° arc	Speed: 0 to 600 rpm	66XN-1991B				
			Lower Bushing (Drive shaft - lower section)	1	Stellite 6B Overlay	1.7590 in. OD 1.7600 in. Length: 1-1/4 in.	Speed: 0 to 600 rpm	66XN-1991B 5XN-1983A				
			Upper Bushing (Drive shaft - lower section)	1	Stellite 6B Overlay	1.7485 in. OD 1.7495 in. Length: 2-1/2 in.	Speed: 0 to 600 rpm	66XN-1991B 5XN-1983A	Sodium Vapor and Argon			
			Neutron Shield Bushing	1	304 Boron Stainless Ampco 22 inlay	1.025 in. ID 1.026 in. Length: 1/4 in.	Clearance: 0.009 in. (Between bushing and drive shaft)	5XN-1983A 77XN-1980D				
			Bearing (Drive shaft - middle section)	1	304 Boron Stainless Colmonoy 5 Overlay	1.015 in. OD 1.016 in. Length: 2 in.	Speed: 0 to 600 rpm	5XN-1983A 77XN-1980D				
			Bellows	1	321 SS	4-1/2 in. OD 3-9/16 in. ID (Note: Internal guides 0.031 SS Type 304 are installed every 45 diaphragms and are the bearing surface.) 732 Nesting Tape diaphragms 0.007 SS Type 321.	Must be able to be compressed 11.0 in.	5XN-1990A 77XN-1980D				

TABLE 34
EFAPP OSCILLATOR ROD
(Sheet 2 of 4)

Mechanism	No. in Plant	Design Information							Operating Environment			
		Primary Material of Construction	Component	No. per Mechanism	Material of Construction	Dimensions and Manufacturing Tolerances	Clearances, Loading, and Speed	Drawing No.	Operating Medium	Operating Medium Impurities (ppm)	Temperature, Velocity and Pressure	Exposure to Environment (hr)
Oscillator Rod	1	304 SS	Nozzle	1	304 SS Nitrided	1.584 in. ID 1.587 in. ID Length: 3-3/4 in. 1.751 in. OD 1.749 in. OD Length: 5-3/16 in.	Clearance: 0.020 in. (Between nozzle bearing pads and nozzle) Clearance: 0.065 in. (Between nozzle and dash pot)	6XN-5263D	Liquid Sodium			
			Stationary Housing Intermediate Subassembly - Nozzle Bearing Pads	12 (6 ea. in two rows of pads)	Colmonoy 4	1.564 in. OD 1.562 in. OD Length of Pads: 5/16 in.	Remains in dash pot during operation of oscillator	6XN-5264D				
			Stationary Housing Intermediate Subassembly - Dash Pot Bearing Pads	4	Colmonoy 4	1.811 in. OD 1.809 in. OD Length: 1 ± 1/64 in.	Clearance: 0.005 in. (Between dash pot bearing and dash pot)	6XN-5264D				
			Stationary Housing Subassembly - Lower Radial Bearing	1	Colmonoy 4	2.0500 in. ID 2.0505 in. ID Length: 1 ± 1/64 in.	Clearance: 0.007 in. (Between oscillator rotating rod lower bearing and lower radial bearing)	6XN-5260D				
			Plunger Bearing Pads	6 (3 on each of two rings)	Colmonoy 4	0.323 in. OD 0.321 in. OD Length: 7/32 in.	Clearance: 0.023 in. (Between retainer and plunger bearing pads)	6XN-5265D				
			Retainer	1	304 SS	0.343 in. ID 0.346 in. ID Length: 4-3/16 in. 1/2 in. OD	Clearance: 0.031 in. (Between retainer and inner spring)	6XN-5265D				
			Spring - Nozzle, Outer	1	Inconel "X"	1.218 in. OD 0.844 in. ID Free length: 7-1/2 in. Wire: 0.187 dia. Coils: 26	Clearance: 0.063 (Between Housing and outer spring)	6XN-5265D				
									Liquid Sodium			

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Mechanism	No. in Plant	Design Information						Operating Environment			
		Primary Material of Construction	Component	No. per Mechanism	Material of Construction	Dimensions and Manufacturing Tolerances	Clearances, Loading, and Speed	Drawing No.	Operating Medium	Operating Medium Impurities	Temperature, Velocity and Pressure
Oscillator Rod (Continued)			Spring - Nozzle, Inner	1	Inconel "X"	0.791 in. OD 0.531 In. ID Free length: 7-1/2 in. Wire: 0.130 in. diam. Coils: 37	Clearance: 0.053 in. (Between outer spring and inner spring)	6XN-5265D	Liquid Sodium <		

(Sheet 4 of 4)

Mechanism	No. in Plant	Design Information							Operating Environment			
		Primary Material of Construction	Component	No. per Mechanism	Material of Construction	Dimensions and Manufacturing Tolerances	Clearances, Loading, and Speed	Drawing No.	Operating Medium	Operating Medium Impurities	Temperature, Velocity and Pressure	Exposure to Environment (hr)
Oscillator Rod (Continued)			Thrust Bearing 304 SS	1	Kentanium K-162-B Spherical Surface	1.420 in. ID Concave Radius	Clearance: Spring tension fit	6XN-5260D 6XN-5261D	Liquid Sodium ↑	(ppm)		
			Extension Lower Bearing 304 SS	1	Stellite 6 Overlay	2.0430 in. OD 2.0435 in. Length: 3/4 in.	Clearance: 0.007 in. (Between lower radial bearing and lower bearing)	6XN-5260D 6XN-5261D				
			Extension Upper Bearing 304 SS	1	Stellite 6 Overlay	2.0935 in. OD 2.0940 in. Length: 1 in.	Clearance: 0.0007 in. (Between upper radial bearing and upper bearing)	6XN-5262A 6XN-5260D				
			Driver Collar 304 SS	1	Stellite 6 Overlay 4 places 1/16 in. thick	1 notch for male fitting: 90° arc 1 notch for male fitting: 60° arc 1.906 in. OD 1.900 in. Length: 3/8 in.	Clearance: (Between the male drive unit and female driver collar)	6XN-5262A 6XN-5260D				
			Spacer	1	304 SS	0.515 in. ID 0.937 ± 0.002 OD Length: 0.964 in.	Clearance: 0.015 in. (Between spacer and handling head shaft)	6XN-5262A				
			Washer 304 SS	1	Stellite 6-B Inlay	15/16 in. ID Length: 0.600	Clearance: 1/4 in. (Between washer and handling head shaft)	6XN-5262A				
			Handling Head 304 SS	1	Stellite 6 Overlay	Conical shaped head 1-3/8 in OD Length: 0.875 in.		6XN-5262A				
					304 SS	Shaft for washer 11/16 in. OD Length: 0.661 in.						
					Hard Chrome Plate	Shaft for spacer 0.500 in. OD Length: 1 in.						
									Liquid Sodium ↓			

c. History of Malfunction and/or Modification

During preoperational testing, certain modifications were found necessary. The conical support bearing was replaced by a spherical bearing of Kennametal K-95, tungsten carbide.⁽⁹³⁾ The socket was made of Kennametal 138-A, titanium carbide cermet. The socket and sphere were provided with sodium circulation holes.

Serrations in the lower housing on the oscillator rod adapter piece were modified to include a larger gage tooth and a new material.^(36,92,94) the original nitrided Type 304 CRES serrations were found to be partially spalled on the extension housing. A Stellite 6B overlay was added to the new serrations, and the bearing plunger also was modified. The Colmonoy bearing had three 0.250-in.-diameter flats and eight 1.500-in.-diameter flats ground on each of the two 5/16-in. Colmonoy bearing rings on the lower inner nozzle assembly to provide for sodium drainage.

After 16 hr in the sodium endurance test tank, the third from the top journal bearing (Stellite 6B, Colmonoy No. 4 journal) galled and was replaced with Ampco 22 aluminum-bronze.^(37,95) This bearing initially was aluminum-bronze⁽⁹³⁾ but had been removed in favor of the Stellite 6B, Colmonoy 4 combination (explanation not found).

After 18 hr in 500 to 750°F sodium at 500 rpm, the upper Colmonoy No. 4 journal and Stellite 6B bearing were found scored, although all other bearings remained in good condition. Two replacement Ampco 22 aluminum-bronze bushings were fabricated, having a 0.0045/0.0055-in. diametral clearance, with the cleaned up Colmonoy No. 4 overlay. The new bushings had a surface finish of 8 RMS. The upper end of the top journal bearing had short hairline cracks without signs of spalling.^(95,96)

The poison section bearing sleeve was Colmonoy No. 70 overlay on Type 304 CRES (32 RMS surface finish) with a Colmonoy No. 4 journal (65 RMS surface finish). Four grooves were provided for sodium flow, with diametral clearances from 0.005 to 0.007 in. The drive section lower two bearings were made from Stellite 6B and the journals had Colmonoy No. 4 overlays (125 RMS surface finish). Diametral clearances of 0.007 to 0.009 in. were provided for the two lower bearings and 0.004 to 0.005 in. and 0.009 to 0.010 in. for the two

upper bearings previously modified. These five sleeve bearings, after a total test exposure of 75 hr at speeds from 300 to 600 rpm and temperatures of 500 and 750°F, showed only surface burnishing as did the socket bearings.⁽⁹⁷⁾

Following resolution of the bearing problems, the oscillator rod was installed in the reactor in the spring of 1963 and has performed entirely satisfactorily since that time at power levels up to approximately 100 Mwt. Although the Fermi plant experience has shown that the rotating oscillator of relatively simple mechanical design can be made to work, application of this design to other and larger reactors may be expected to require a significant amount of developmental testing of the particular mechanical arrangement chosen to ensure proper operation.

5. Core Support Plate (Table 35)

The core support plates rest on the core support structure. They are fabricated from Type 347 CRES and reflect precision in assembly, care in handling, and complete heat treatment during states of fabrication. The two support plates are 2 in. thick and spaced 14 in. apart by ribs welded between the plates. The square fuel section in the center of the radial section supports the core subassemblies and is removable, providing core flexibility. Subassembly openings are accurately machined to provide very close alignment tolerances. Each of the openings for subassemblies in the lower plate has a groove located 1/4 in. from the lower plate surface. These grooves hold the nozzles or orifice holders which distribute flow in the blanket area.

a. Statement of Operability

The core support plate has adequately supported the core and blanket subassemblies and it has functioned satisfactorily for inserting and removing subassemblies.

An adverse operational factor was the occurrence of bulging of the subassembly lower sleeves in the area between the upper and lower support plates. The cause of this phenomenon has not been resolved and it has not been observed to recur since the initial period of nonnuclear operation and testing.

TABLE 35
EFAPP CORE SUPPORT PLATE
(Sheet 1 of 3)

Mechanism	No. in Plant	Design Information							Operating Environment			
		Primary Material of Construction	Component	No. per Mechanism	Material of Construction	Dimensions and Manufacturing Tolerances	Clearances, Loading, and Speed	Drawing No.	Operating Medium	Operating Medium Impurities	Temperature, Velocity and Pressure	Exposure to Environment (hr)
Support Plates (Combustion Engineering)	2 (1 upper) (1 lower)	347 SS	CR & SR Upper Support Ring	10	347 SS	2.311 $\frac{+0.002 \text{ in.}}{-0.000 \text{ ID}}$		E-200-605OA Sheets 1 & 2, Detail T	Sodium Liquid	(ppm) Range Avg. Liquid Sodium	Operating Temperature 300 to 1000°F 493°F Ave. Flow Rate Through Region 14.1 ft/sec maximum (Ref. 3)	Hours of Exposure ≈49,200
			CR & SR Orientation Slots (Upper Plate)	40 (4 for each of 10 holes)	347 SS Nitrided	13/32 in Wide Depth: 7/8 in.		Detail T		Oxygen (Sodium Monoxide) 6 to 27, 12		
			CR & SR Lower Support	10	347 SS	2-11/32 in. ID Length: 0.250 in. 1.778 in. ID Length: 1.750 in.				Carbon 19 to 231, 62		
			Upper Support (Core Subassemblies and Inner Radial Blanket Subassemblies)	139	347 SS	2.250 ± 0.002 in. ID Length: 2 in.				Hydrogen 0.7 to 11, 2.4		
			Lower Support (Core Subassemblies and Inner Radial Blanket Subassemblies), Nozzle End	139	347 SS	1.778 $\frac{+0.000 \text{ in.}}{-0.002 \text{ ID}}$ Length: 1.750 in. 2-11/32 in. ID Length: 0.250 in.		Detail S		Iron 0.1 to 6.7, 2.5		
			Upper Support (Outer Radial Blanket Subassemblies and Storage and Thermal Shielding Subassemblies)	722	347 SS	2.000 $\frac{+0.002 \text{ in.}}{-0.000 \text{ ID}}$		Detail Z		Nickel 0.05 to 3.4, 0.7		
			Lower Support (Outer Radial Blanket Subassemblies, Storage and Thermal Shielding Subassemblies), Nozzles	722	347 SS	1.750 $\frac{+0.001 \text{ in.}}{-0.000 \text{ ID}}$ Length: 2 in.		Detail Y		Chromium 0.1 to 2.0, 0.7		

TABLE 35
EFAPP CORE SUPPORT PLATE
(Sheet 2 of 3)

Mechanism	No. in Plant	Design Information							Operating Environment			
		Primary Material of Construction	Component	No. per Mechanism	Material of Construction	Dimensions and Manufacturing Tolerances	Clearances, Loading, and Speed	Drawing No.	Operating Medium	Operating Medium Impurities	Temperature, Velocity and Pressure	Exposure to Environment (hr)
Lower Guide Tubes (Safety and Control) (Combustion Engineering)	10	304 SS	Square Lower Guide Tube Corner Spacer Pads	40 (4 pads on each of 10 tubes)	Colmonoy-4	2.693 ± 0.0005 OD Square Length: 1 in.	Contact fit with adjacent subassemblies Pads are located 30-7/64 in. below top of Lower Guide Tube, 4-1/4 in. below core centerline.	E-201-394-7B (Comb. Engr)	Liquid Sodium	(ppm) Range Avg. Liquid Sodium	Operating Temperature 300 to 1000°F Drop Velocity 3.9 ft/sec-max (Ref. 181)	Hours of Exposure =49,200 Operational Scrams (To October 1966) 774
			Round Lower Guide Tube (Journal)	10	347 SS	2.402 ± 0.007 in. ID Length: 70-5/8 in.	Clearance: 0.040 in., Safety Rod 0.033 in., Control Rod (Between SR & CR wear pads and guide tube)	E-201-394-7B E-200-698-6 E-201-200-8 6XN-4350 3XN-4810		Oxygen (Sodium Monoxide) 6 to 27, 12 Carbon 19 to 231, 62 Hydrogen 0.7 to 11, 2.4 Iron 0.1 to 6.7, 2.5 Nickel 0.05 to 3.4, 0.7 Chromium 0.1 to 2.0, 0.7		
			Stem - Transition Piece	10	304 SS	1.127 ^{+0.002 in.} _{-0.000 ID} Length: 1/2 in. (2 places) 2.311 ^{+0.000 in.} _{-0.002 OD} Length: -1 in.		E-201-394-7B				
			Alignment Tube	10	304 SS (Lower 2 in. Nitrided)	1.687 in. ID Length: 13-1/4 in. 1.751 ^{+0.002 in.} _{-0.000 ID} 2-1/32 in. OD		E-201-394-7B				
			Dash Pot and Shim Rod Seat Spring	10	Inconel-X	1.604 in. OD 1.240 in. ID Wire: 0.182 in. diameter Length: 9-3/4 in. free length No. Coils: 22		E-201-200-8				
			Guide Tube Sleeve	10		2.065 in. ID 2.063 in. ID Length: 14-23/32 in.		E-200-643-14				
			Lower Orifice Sleeve	10		1.662 in. OD Length: 3-3/8 in. 1.750 ^{+0.000 in.} _{-0.002 OD} Length: 2-3/8 in.		E-200-653-14				

TABLE 35
EFAPP CORE SUPPORT PLATE
(Sheet 3 of 3)

Mechanism	No. in Plant	Design Information							Operating Environment			
		Primary Material of Construction	Component	No. per Mech- anism	Material of Construction	Dimensions and Manufacturing Tolerances	Clearances, Loading, and Speed	Drawing No.	Operating Medium	Operating Medium Impurities	Temperature, Velocity and Pressure	Exposure to Environment (hr)
			Guide Tube Sleeve Orienta- tion Pins	20 (2 pins on each of the 10 sleeves)	304 SS	3/8 in. OD Length:		E-201-200-8	Liquid Sodium			

b. Statement of Maintainability

Removal of the core support plate prior to nuclear operation was conducted by men working in an atmosphere of inert gas and equipped with sealed suits. This operation was extremely difficult but it was successfully completed.

The design of the internals of the reactor vessel is such that the core-blanket support structures are removable; however, since such an operation would be very involved and costly, it may not be practical to undertake it following extended nuclear operation.

c. History of Malfunction and/or Modification

During initial operations, flow damage developed on the subassembly support plates in some lower plate openings apparently from cavitation. During early core maintenance operations, the core support plate was removed and Stellite inserts were installed in all lower support plate openings (Refs. 3, 98).

6. Core Holddown Assembly (Table 36)

The core subassemblies must be restrained from rising due to coolant flow from the high-pressure plenum. This is accomplished by holding the handling lug of each subassembly with a female knob (finger) which is attached to the holddown assembly (Fig. 48). The finger compresses a spring in the inlet nozzle of the subassembly, providing for thermal expansion as well as firmly locating the subassembly. The spacing of the fingers which engage the handling heads are such that the heads are drawn in slightly toward the core centerline, producing a tight configuration. Three ball screws actuate the holddown assembly. The holddown force is transmitted first through a spring plate assembly, and then through three short actuator shafts to the actuator column, at the bottom of which are the fingers. Bellows are used to seal the actuator shafts to the top plate of the rotating plug. All components below this plug are in a sodium/sodium-vapor environment. A three-arm alignment spider on the lower end of the actuator column positions the holddown fingers with respect to the subassembly lattice. The 600-deg conical sockets are on the ends of the spider seat on the mating conical heads of three support columns. The free hanging alignment of the spider must be maintained accurately to avoid galling between engaging surfaces as the spider assembly is lowered into place.

Fig. 48. EFAPP Holddown Assembly

TABLE 36
EFAPP HOLDDOWN MECHANISM
(Sheet 1 of 2)

Mechanism	No. in Plant	Design Information							Operating Environment				
		Primary Material of Construction	Component	No. per Mechanism	Material of Construction	Dimensions and Manufacturing Tolerances	Clearances, Loading, and Speed	Drawing No.	Operating Medium	Operating Medium Impurities	Temperature, Velocity and Pressure	Exposure to Environment (hr)	
Hold-Down Mechanism (Ass'y Dwg 7177E84) Less Spider	1	304 SS	Hold-Down Spider Support Column (Caps) (Journal)	3	304 SS Inconel-X Overlay in caps	2.880 + 0.000 in. - 0.001 OD Length: 3.00 in.	Clearance: Due to difference in materials used in Cap overlay and Socket, there is a difference in expansion allowing for clearance.	E-201-280-5B. Comb. Engr.	Liquid Sodium	(ppm) Range Avg. Sodium Liquid	Operating Temperature 300 to 1000°F 493°F Oxygen (Sodium Monoxide) 6 to 27, 12 Carbon 19 to 231, 62 Hydrogen 0.7 to 11, 2.4 Iron 0.1 to 6.7, 2.5 Nickel 0.05 to 3.4, 0.7 Chromium 0.1 to 2.0 Sodium Vapor Oxygen <25 to 90, <32 Carbon Mon-oxide <10 to <50, <11 Carbon Dioxide 4 to 100, <17 Hydrogen 2 to 1230; <69 Helium <4 to 680, <24 Methane <10 to 560, <40 Nitrogen 260 to 4960, 1958	Compression Spring Rate - Total 38,000 lb/in. Total Hold-Down Load 273,000 lb Total Upward Force of Sub-Assembly Handling Heads on Fingers (300 Mw power level) Steady State 71,200 lb Cold No-Flow 43,800 lb Startup 78,000 lb (There are 139 finger sockets) (Ref 156)	Hours of Exposure =49,200 Number of Complete Moves, Up and Down (to July 1967, Ref 154) 539 to June 1968 540 (Ref. 135)
			Hold-Down Spider Sockets (Bearing)	3	304 SS	Width of Opening: 2.880 + 0.002 in. - 0.001 ID	See Note Above. Travels 9 in. Constant downward pressure.	E-201-286-4B E-201-287-7B SKD-D-5702 5XN-3850					
			Subassembly Hold-Down Finger Sockets (Journal)	139	304 SS Stellite-6 Overlays in Sockets	1.115 + 0.002 in. - 0.000 ID (Opening of socket) Depth: 0.498 + 0.000 in. - 0.002	Clearance: See Subass'y Lifting Lug. Constant downward pressure.	6XN-4352 6XN-4353					
			Safety Rod Upper Guide Tube (Journal)	8	347 SS Bottom 2 in. Nitrided.	2.454 ± 0.0025 ID Length: 67-1/8 in. (61-7/8 in. per Comb. Engr.)	Clearance: See Safety Rod Dwg.	6XN-4349 E-200-698 Comb. Engr.					
			Control Rod Upper Guide Tube (Journal)	2	347 SS Bottom 2 in. Nitrided.	2.402 ± 0.007 ID Length: 67-1/8 in. (61-7/8 in. per Comb. Engr.)	Clearance: See Control Rod Dwg.	6XN-4350 E-200-698 Comb. Engr.					
			Safety and Control Rod Upper Guide Tube Mitered Joints	40 (4 on each of 10 Tubes)	347 SS Stellite-6 Overlay on Conical Lips.	See Dwg. 2.646 ± 0.0035 OD Machined to 80° Conical Shape.	See Dwg. Clearance: Press fit with mating surface on lower guide tubes. 100 lb force from spring at bottom.	6XN-4350 E-200-698 Comb. Engr.					
			Safety and Control Rod Guide Tube Bearing Sleeves (Pads)	80 (8 on each of 10 Tubes)	347 SS Stellite-6 Pads.	Pads: 2.670 + 0.005 ID - 0.000 Length: 1-1/8 in.		6XN-4347					

TABLE 36
EFAPP HOLDDOWN MECHANISM
(Sheet 2 of 2)

Mechanism	No. in Plant	Design Information							Operating Environment			
		Primary Material of Construction	Component	No. per Mechanism	Material of Construction	Dimensions and Manufacturing Tolerances	Clearances, Loading, and Speed	Drawing No.	Operating Medium	Operating Medium Impurities	Temperature, Velocity and Pressure	Exposure to Environment (hr)
			Actuator Shaft Bellows (Reciprocating)	3	304 SS	3.625 min. ID 6.000 max. OD Length: 20.88 in. min. extended. 8.88 max. compressed. Thickness:		855B387	Sodium Vapor and Argon to Argon			
			Actuator Shaft (Bearing)	3	CRE Steel G. E. Specs. B50A146A	3.545 in. OD 3.540 in. ID Length: 9.75 + 1/16 in.		856B149				
			Actuator Shaft Thimble (Journal)	3	304 SS	3.64 in. ID 3.62 in. ID Length: 7.26 in.	Clearance: 0.095 in. 0.080 in.	855B956 192C883	Argon (Backup Seal in Case Bellows Ruptures)			
			Actuator Shaft Packing Gland (Journal)	3	304 SS	3.64 in. ID 3.62 in. ID Length: 2.28 in. Chevron Packing used in packing gland.	Clearance: 0.095 in. 0.080 in.	856B152				

a. Statement of Operability

Repeated operation has shown that this mechanism provides adequate alignment and support of the fuel subassemblies.

Operation of the holddown mechanism, remotely conducted from the control room, has been satisfactory for many hundreds of cycles. The mechanism has been raised and lowered without difficulty and the readout mechanism has been found adequate to indicate position.

b. Statement of Maintainability

During initial operations, it was necessary to cut holes in the side of the holddown column above the rotating shield plug for maintenance of the safety rod drives.

It is expected that removal and reinstallation of the holddown would be very difficult. Repair of damaged fingers resulting from holddown finger-handling head interference and subsequent plug rotation was extremely difficult. It was necessary for personnel to enter the reactor vessel under inert gas conditions to obtain access to the holddown plate. Fortunately, nuclear operation had not yet begun and this work could be accomplished without radiation shielding.

Strain gages were added to the mechanism to aid in checking the alignment and to measure the side motion and twisting of the holddown plate as it is lowered onto the core.

c. History of Malfunction and/or Modification

During the preoperational testing phase, several fingers of the holddown were bent. The damage was caused when several subassembly heads stuck to the holddown fingers when the holddown was raised and the plug rotated. A locking angle developed in the conical head geometry of the handling head and holddown finger due to high frictional loads.^(3,98-100) The tight cone-to-cone engagement was redesigned, and a core sweeping mechanism was designed and installed to monitor the core for obstructions when the holddown is raised. Galling has been attributed to a soft Inco A weld metal buildup or a section of the support column Inconel X ball. An Inconel X column end was fabricated using a cylindrical configuration with a frustrum of a cone, upper end. This made the holddown fingers more rugged and less vulnerable to operational interaction damage.

7. Core Sweep Mechanism (Table 37)

The sweep mechanism was developed to ensure that no subassemblies or other obstructions project above the subassembly handling head elevation or below the raised holddown finger elevation prior to fuel handling, or before lowering of the holddown mechanism.⁽¹⁰¹⁾ The requirement for this safety procedure was demonstrated by the incident described above regarding the core holddown and subassembly sections which involved holddown finger and handling head interaction.

The sweep mechanism has been in service since 1962 and is permanently installed in the rotating plug in one of the lower guide tube access holes. The mechanism consists of a rotating and reciprocating column with an arm pivoted at its lower end. When not in use, the arm is folded into the column, and the column is raised to a position 1-3/8 in. above the subassembly handling head elevation. In operation, when the sweep arm is lowered to a horizontal position, the column is lowered to within 3/8 in. of the subassembly handling head elevation. The sweep arm is passed over the core between the holddown and handling heads to ensure that no subassembly remains attached to a holddown finger and that all subassemblies are properly seated following a refueling procedure.

The arm folding system consists of a nut and traveling screw system, which actuates a link connected to the sweep arm. The sweep arm is provided with a breakaway joint which functions when the arm actuating system jams, leaving the arm extended at an angle greater than 35 or 40 deg. When the sweep column is raised, the arm contacts the rotating plug at the breakaway joint, severing the joint, causing the arm to drop to a vertical position as the column is withdrawn for maintenance. The azimuth drive, excluding the nut screw and linkage, is located above the rotating plug. Originally, the sweep arm was to be used only during nonnuclear operation; however, remote operation now is possible.

a. Statement of Operability

The core sweep mechanism, installed subsequent to the period of difficulties with the holddown fingers and core damage, has provided satisfactory service following modifications prior to nuclear operation to eliminate high torque and shear screw failures. It can be operated remotely from the control room and readout is available to indicate if any obstructions exist between the handling heads of the subassemblies and the raised structures of the holddown mechanism.

TABLE 37
EFAPP CORE SWEEPING MECHANISM
(Sheet 1 of 4)

Mechanism	No. in Plant	Design Information						Operating Environment				
		Primary Material of Construction	Component	No. per Mechanism	Material of Construction	Dimensions and Manufacturing Tolerances	Clearances, Loading, and Speed	Drawing No.	Operating Medium	Operating Medium Impurities	Temperature, Velocity and Pressure	Exposure to Environment (hr)
Core and Blanket Sweeping Mechanism Assy. Dwgs. 220XN5347G 220XN5348	1	304 SS	Support Column	1	321 SS Colmonoy Hard facing on OD	213-7/8 in. length OD dimensions irregular See Ref. Dwg. 3-3/4 in. ID	Clearance Support column ID to guide clevis OD 1/16 in.	88XN4525	Critical Areas Sodium Liquid	Range Avg. Sodium Liquid	Oper. Temp. 300 to 1000° F 493° F Avg.	Hr of Exposure ≈ 33,480 Oper. Sweeps 539 to July 67 (Ref. 154)
			Guide Plug	7	304 SS Colmonoy-5 facing in guide region	1-1/8 in. length Guide region 9/16 in. length Final OD with Colmonoy-5 facing 0.747 in./0.744 Surf fin-16	Clearance Guide plug to clevis guide way 0.041 in./0.033	6XN5287G	Upper Area Sodium Vapor	Oxygen (Sodium monoxide) 6 to 27, 12 Carbon 19 to 231, 62 Hydrogen 0.7 to 11, 2.4 Iron 0.1 to 6.7, 2.5 Nickel 0.05 to 3.4, 0.7 Chromium 0.1 to 2.0, 0.7 Sodium Vapor	Arm Travel at pivot 90° Fold Time (nonlinear) 7 min Unfold Time (nonlinear) 6 min Pivot Loads 110 lb horiz 19.4 lb vert	
			Guide Clevis (Within support column)	1	304 SS Colmonoy-5 facing in guide plug way	Total length 14-1/8 in. 3-5/8 in. OD Guide plug way 0.780 in./0.785 width Clevis pin seat 0.8750 in./0.8755 OD Width between faces 1.62 in.	Clearance Guide clevis seat to bushing OD 0.0005 in./-0.0005 (P. F.) Guide way to guide plug 0.041 in./0.033	6XN4529D	Sodium Liquid	Oxygen <25 to 90, <32 Carbon Monoxide <10 to <50, <11 Carbon Dioxide 4 to 100, <17 Hydrogen 2 to 1230, <69 Helium <4 to 680, <24 Methane <10 to 560, <40 Nitrogen 260 to 4960, 1958	Arm Weight 70 lb Cam Pin Sliding Distance 41 in. Pin Loads in Slot (Hertz loads) 49,000 psi Torque to Stall Arm 28 in. lb (Ref. 160, 161)	
			Clevis Pin	1	304 SS Colmonoy-5 facing in from ends	2.6 length Colmonoy faced in 0.76 in. from each end Final OD 0.6250 in./0.6245	Clearance Clevis pin to bushing 0.0150 in./0.0165 Clevis pin to rod end 0.0010 in./-0.0005 (P. F.)	6XN4536L				
			Flanged Bushing (Clevis pin to guide clevis)	2	Colmonoy-5	OD 0.8755 in./0.8750 ID 0.640 in./0.641 Length 0.45 in. Flange 0.035 0.94 OD	Clearance Guide clevis seat to bushing OD 0.0005 in./-0.0005 (Press fit) Clevis pin to bushing 0.0150 in./0.0165	6XN4536L				
			Actuating Rod End	1	304 SS	Length 5 in. Clevis pin seat 0.6245 in./0.6255 ID Face width between guide clevis bushings 1.500 in./1.495	Clearance Clevis pin to rod end 0.0010 in./-0.0005 (P. F.) Face of bushing and rod end face 0.027 in./0.025	6XN4536L				

TABLE 37
EFAPP CORE SWEEPING MECHANISM
(Sheet 2 of 4)

Mechanism	No. in Plant	Design Information							Operating Environment			
		Primary Material of Construction	Component	No. per Mechanism	Material of Construction	Dimensions and Manufacturing Tolerances	Clearances, Loading, and Speed	Drawing No.	Operating Medium	Operating Medium Impurities	Temperature, Velocity and Pressure	Exposure to Environment (hr)
			Arm Actuating Screw	1	AISI No. T1 Tool steel	1-1/2-4 Acme thread P.D. 1.3750 in./1.350 Minor diameter 1.2175 in./1.2300 Lead angle 3° 19 ft Surf fin 16 maximum Major diameter 1.5000 in./1.4875 Hardness R-C 15-20	P.D. Clearance 0.062 in./0.015	6XN4529D	Sodium Vapor			
			Arm Actuator Nut	1	AISI No. T1 Tool steel	1-1/2-4 Acme thread P.D. 1.4120-1.3900 Major diameter 1.530 min Surf fin - 16 Minor diameter 1.260 in./1.272 Height 2 in. Hardness R-C 60-64	P.D. Clearance 0.062 in./0.015	6XN4526E				
			Cleaner Block	1	304 SS Colmonoy-5 facing in select areas on sides	Length 9-7/8 in. Height max 3-7/8 Width final after hard facing 1.562 in./1.560 Inner slot width 0.880 in./0.890 Pin hole 1.125 in./1.126	Clearance Cleaning surface to cam way surface 0.030 in./0.038 Bushings to block 0.001 in./-0.001 (P.F.) Breakaway brace sides bushing flange surface and block slot 0.050 in./0.025	6XN4535D 88XN4525W				
			Cam Follower Pin Bushing	2	Colmonoy-5	OD 1.126 in./1.125 ID 0.890 in./0.891 Flange width 0.035 in./0.030 Flange diameter 1.16 Total width 3/8 in.	Clearance Pin in bushing 0.0150 in./0.0165	6XN4536L				

TABLE 37
EFAPP CORE SWEEPING MECHANISM
(Sheet 3 of 4)

Mechanism	No. in Plant	Design Information							Operating Environment			
		Primary Material of Construction	Component	No. per Mechanism	Material of Construction	Dimensions and Manufacturing Tolerances	Clearances, Loading, and Speed	Drawing No.	Operating Medium	Operating Medium Impurities	Temperature, Velocity and Pressure	Exposure to Environment (hr)
			Cam Follower Pin	1	304 SS Colmonoy-5 facing in from ends	2.6 in. length Colmonoy faced in 1 in. from end Final OD after facing with Colmonoy 0.8750 in. / 0.8745	Clearance Bushing to pin 0.0150 in. / 0.0165	6XN4536L	Sodium Liquid			
			Breakaway Brace Upper Section	1	304 SS Colmonoy-5 facing in select areas on sides	Length 7-3/8 in. Height 2 in. Width after hard facing in bushing region 0.785 in. / 0.780 Follower pin seat 0.8750 in. / 0.8755	Clearance Brace sides bushing flange surface and cleaner block slot 0.050 in. / 0.025 Follower pin in seat 0.0000 in. / 0.0010	6XN4535D				
			Lower Column Left hand half Right hand half (Cam way)	1 1	304 SS Colmonoy-5 in select areas - cam way sides and surface regions	Colmonoy facing on sides of each half 0.015 in. / 0.025 Face to face width 1.592 in. / 1.598 Cam way slot after Colmonoy facing 0.906 in. Other details, see Ref. Dwg. 34B and 35D	Clearance Cam follower pin to cam way width 0.0310 in. / 0.0315 Opposite faces of column halves with cleaning block 0.030 in. / 0.038	6XN4535D 6XN4534B 88XN4525W				
			Track Inserts Left Side Right Side (Cam way insert)	1 1	304 SS Colmonoy facing on track surface and adjacent side	Colmonoy hard facing 0.025 in. / 0.015 Length 9.000 in. / 8.995 Maximum height 5-1/4 in.	Opposite faces of track insert and column halves with cleaning block 0.030 in. / 0.038	6XN4534B 88XN4525W				
			Hard Facing Inserts Left Side Right Side	1 1	304 SS Colmonoy facing on one side	Colmonoy hard facing 0.025 in. / 0.015 Length 17-3/8	Opposite faces of inserts and column halves with cleaning block 0.030 in. / 0.038	88XN4525				

TABLE 37
EFAPP CORE SWEEPING MECHANISM
(Sheet 4 of 4)

Mechanism	No. in Plant	Design Information							Operating Environment			
		Primary Material of Construction	Component	No. per Mechanism	Material of Construction	Dimensions and Manufacturing Tolerances	Clearances, Loading, and Speed	Drawing No.	Operating Medium	Operating Medium Impurities	Temperature, Velocity and Pressure	Exposure to Environment (hr)
			Sweep Arm	1	304 SS Colmonoy-5 facing in select areas	68-5/8 length Face of pivot area faced with Colmonoy 4-3/4 OD Ring 3-1/4 in. ID Width 1.562 in./1.560 Pivot bore 1.500 in./1.501 Brace arm slot 0.650 in./0.8750 Brace pivot bore 0.8750/0.8755	Clearance Opposite faces of column halves with arm faces 0.030 in./0.038 Arm with bushing 0.0006 in./0.0000	6XN4536L 88XN4525W	Sodium Liquid			
			King Pin Bushing	1	Colmonoy-5	1-1/2 in. length ID 1.270 in./1.274 OD 1.5000/1.4995	Clearance Bushing with king pin 0.025 in./0.020 Bushing with arm 0.0006 in./0.0000	6XN4536L				
			King Pin	1	304 SS Colmonoy-5 facing in center of pin	3-1/4 in. length OD 1.250 in./1.249 Colmonoy facing over 2 in. length in center of pin	Clearance King pin with bushing 0.025 in./0.020	6XN4536L				
			Breakaway Brace Lower	1	304 SS Colmonoy-5 facing at swing arm pivot	32-3/8 length Width at pivot 0.500 in./0.495 Pivot bore 0.6250/0.6255	Clearance Brace arm and pin 0.0010 in./0.0000 Between bushing faces and brace arm faces 0.080 in./0.085	6XN4536L				
			Arm Link Pin	1	304 SS Colmonoy-5 facing in from ends of pin	Length 1-1/2 in. OD 0.6250 in. / 0.6245 Colmonoy facing 9/16 in. in from ends	Clearance Bushing and pin 0.0150 in./0.0165 Pin and brace arm 0.0010 in./0.0000	6XN4536L				
			Flanged Bushing	2	Colmonoy-5	Length 0.45 OD 0.8755/0.8750 ID 0.640/0.641 Flange width 0.035 in.	Clearance Between bushing faces and brace arm faces 0.080 in./0.085 Pin and bushing 0.0150 in./0.0165	6XN4536L				

b. Statement of Maintainability

Maintainability is fairly complex. During high-power nuclear operation, the mechanism becomes intensely radioactive and contact maintenance following removal from the reactor is not possible.

In 1968 it was demonstrated that the mechanism can be removed from the reactor in its radioactive condition and can be stored in an inert gas atmosphere. To gain access to the mechanism, reactor plug top shielding must be disassembled and removed and the drive must be disconnected and removed before the sweep mechanism can be withdrawn from the rotating shield plug into an inerted container.

c. History of Malfunction and/or Modification

In general, mechanical difficulties were limited to the nonsodium portions of the system (Refs. 35, 48, 50, 75, 102-104). During early operation, the arm folding nut and screw developed operating difficulties. These components operated in sodium vapor between 200 and 500°F. The nut and screw threads are Acme-type 4-pitch, 1-1/4-in. nominal pitch diameter. The T-1 tool steel (annealed), surface hardness Rockwell 15-20C, screw exhibited excess wear. The T-1 tool steel nut was hardened to Rockwell 50-55C. The screw was then hardened to Rockwell 50-55C and reground with a new nut fabricated from M-2 tool steel hardened to Rockwell 62-64C. This combination has performed well for hundreds of operations. In the liquid sodium environment, the principal difficulty encountered was with shear of safety shear screws⁽¹⁰⁵⁾ at the break-away connection in the arm linkage. Higher operating torques than those anticipated were also realized.

8. Rotating Shield Plug and Bearing (Table 38)

The shield plug (Fig. 49) serves as a portion of the biological shield, as a gas-tight seal, and as a part essential to the fuel handling cycle. It constitutes the mount for the OHM; the core holddown mechanism, in turn, supports the control rod drives. The shield plug rotates within a full-length skirt at the top of the reactor vessel, with a nominal 1/4-in. clearance around the plug. An intentional 1/16-in. eccentricity was provided within the annulus to optimize the as-built plumbness of the system. The 150-ton system total weight is supported on a double-row ball bearing (Fig. 50). Differential thermal expansion

Fig. 49. EFAPP Rotating Shield Plug (Sectional Elevation)

Fig. 50. EFAPP Rotating Shield Plug Bearing and Seal

TABLE 38
EFAPP ROTATING SHIELD PLUG AND BEARING

Mechanism	No. in Plant	Design Information							Operating Environment			
		Primary Material of Construction	Component	No. per Mechanism	Material of Construction	Dimensions and Manufacturing Tolerances	Clearances, Loading, and Speed	Drawing No.	Operating Medium	Operating Medium Impurities	Temperature, Velocity and Pressure	Exposure to Environment (hr)
Rotating Plug Bearing (Supplied by Kaydon Corp.) Combustion Engineering Dwg. E-201-229-5C E-200-600	1	8660 Steel	Outer Races	2	8660 Steel	Pitch Diameter 120.750 in. Ball contact points 30° from vertical both directions. Hardness ball paths Rockwell C-58, 63.		E200-640	Questionable. Argon Cover Gas with Some In-Leakage of Sodium Vapor	(ppm) Range Unknown	Operating Temperature ≈175°F	Hours of Exposure ≈49,200
			Center Race	1	8660 Steel	Pitch Diameter 120.750 in. Ball contact points 30° from vertical both directions. Hardness ball paths Rockwell C-58, 63		E200-640			Total Bearing Load = 120 tons	Total Move-ments 5561 to June 1968 (Ref 135)
			Balls	238	SAE 50100 or 51100 or 52100 Steel	2.000015 OD 1.999985 in groups of six 2.0001 1.9999 per total lot Rockwell C63, 66		E200-640				
			Retainer Segments	34	SAE 64 Leaded Bronze	Pitch Diameter 120.750 in. Hole Diameter for balls 2.077 in. / 2.062 Bearing surface on lower side of retainer 3-11/16 in. long. Three per segment. Ball separation ϕ to ϕ from edge to edge 1-25/32, 2-27/32, 3-23/64, 3-7/64, 3-7/64, 3-23/64, 2-27/32, 1-25/32 in.		E-200-640				

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of the bearing races is provided for in this design without overloading the balls. The bearing, located external to a rotating dam-type dip seal designed to use NaK as the seal fluid, lies internal to a rotating flexible mechanical seal. The mechanical seal, a two-ring design type, is supplied with argon cover gas between the two rings (at 1-1/2 psig), limiting leakage to that of back diffusion. The NaK dip seal was never utilized.

Maintenance of the plug bearing is facilitated by a bayonet engagement between the plug shell and the load ring riding the bearing. The weight of the plug is transferred from the load ring to a reactor step; this permits the load ring to be raised, providing for access to the bearing with the plug in place. The seal rings can be reached for maintenance by raising the rotating seal skirt. In this operation, the dome is used to maintain an inert atmosphere.

a. Statement of Operability

The rotating shield plug has operated very well; however, its operation is somewhat complex, requiring a high degree of precision in positioning the plug.

Problems related to positioning the shield plug have been associated primarily with the amplidyne-cervical motor control system. The shield plug itself has demonstrated generally good performance from the standpoint of rotation. The control system has occasionally produced a null-out with excessive error in the requested positions. This has necessitated direct operator surveillance at the plug for verification.

The original design for the shield plug included a NaK dip-seal; however, this seal has not yet been needed. The silicone-rubber, double-lip backup seal has been consistently adequate, allowing free plug rotation while retaining a positive gas seal. This silicone-rubber seal is lubricated with Dow-Corning 400 lubricant.

b. Statement of Maintainability

Maintainability is reasonably good. Replacement of the silicone rubber seal, if required, would require jacking-up the 150-ton shield plug to provide access to the seal and the double-race ring (ball) bearing.

Cables extending from the machinery deck to the shield plug are so numerous that they overcrowd the cable bend (flexible housing); this limits accessibility and makes cable replacement difficult.

ENLARGED VIEW OF "A"

Fig. 51. EFAPP Offset Handling Mechanism

Reactor repair and maintenance experience indicates the need for greater accessibility to the core and internals; provision of more holes in the design of the shield plug would have accomplished this.

c. History of Malfunction and/or Modification

There have been some minor problems with the rotating plug. In initial operations, and during a nonnuclear test at 1000°F, the rotating plug became inoperative due to an accumulation of sodium-sodium oxide "crud" in the plug annulus.^(4,106-110) The first incident was eased by raising the sodium level 2 in. above the deposit as determined by observations at the alignment port and at one of the lower guide tube access penetrations (the shielding plug was freed by use of chain-fall come-alongs). This level was periodically cycled to bring fresh sodium to the area. Eventually, the plug was freed by using four 5-ton chain falls pulling tangentially to the periphery of the plug. Five years later a similar binding occurred. In later incidents, frequent rotation of the plug appeared to reduce the binding effect, indicating a grinding away of debris.

The ball bearings associated with the plug have operated satisfactorily; however, observations were made of deposited material resembling sodium oxide on the balls and races.^(106,110) A deposit of bronze material, apparently picked up from the spacer bars, also was observed on the balls. The center race did not rotate at this point in its operating history. The overall reliability of the present rotating plug bearings and seal is evidenced by the extended service life without significant malfunctions.

9. Offset Handling Mechanism (Table 39)

The OHM (Fig. 51), the rotating plug, and the core transfer rotor are used for in-core handling. Combined motions of the OHM and the rotating plug enable withdrawal of subassemblies, etc., from any position in the reactor lattice, and placement of the core transfer rotor in the finned transfer pot. The OHM is designed so that an operating malfunction will not introduce a hazardous condition. A locking worm in the vertical drive prevents motion in the event of power failure. The gripper is a positive action device. The lock and unlock action is provided by a cam member actuated by a probe. As the handling mechanism moves down over the subassembly, the latch cam probe contacts the subassembly handling lug. The handling mechanism continues down, and the probe

TABLE 39
EFAPP OFFSET HANDLING MECHANISM
(Sheet 1 of 4)

Mechanism	No. in Plant	Design Information							Operating Environment			
		Primary Material of Construction	Component	No. per Mechanism	Material of Construction	Dimensions and Manufacturing Tolerances	Clearances, Loading, and Speed	Drawing No.	Operating Medium	Operating Medium Impurities	Temperature, Velocity and Pressure	Exposure to Environment (hr)
Offset Handling Mechanism (Ass'y. Dwg. No. 7177E66) General Electric Co.	1	304 SS	Housing Pipe Tail Bearing (Journal)	1	304 SS Plated with Colmonoy-6	14.737 in. ID 14.736 in. ID Length: 2.62 in.	Clearance: 0.052 in. 0.051 in.	172D673 5XN-4397-A	Liquid Sodium	(ppm) Range Avg. Sodium Liquid Oxygen (Sodium Monoxide) 6 to 27, 12 Carbon 19 to 231, 62 Hydrogen 0.7 to 11, 2.4 Iron 0.1 to 6.7, 2.5 Nickel 0.05 to 3.4, 0.7 Chromium 0.1 to 2.0, 0.7 Sodium Vapor Oxygen <25 to 90, <32 Carbon Monoxide <10 to <50, <11	Sodium Liquid 300 to 1000°F 493°F Ave. Buoyancy Force on Arm in Down Position 440 lb Force on Latch Rod at Elevation Where Latch Plate Slides Under Latch Rod Bearing 150 lb Face Seal Contact Load 300 lb Subassembly Weight = 2000 in (Ref 56)	Azimuth Cycles to 6/68 7669 (Ref 135) Elevation Cycles 8392 (Ref 135) Units Handled 766 (Ref 154) Hours of Exposure ±49,200
			Azimuth Bearing Pipe Tail Bearing (Bearing)	1	304 SS Insert Material:	14.6845 diam Length: 3.250 Spiral grooves cut across length of bearing insert. 90 grooves 4.5" apart 3.5" (See Dwg.)		189C969 189C992 5XN-4401 5XN-4398 534E481				
			Elevation Bearing Pipe (Journal)	1	304 SS Plated with Colmonoy-6	11.699 in. ID 11.698 in. ID	Clearance: 0.079 in.	189C970 192C105				
			Lower Reciprocating Shaft (Bearing)	1	304 SS Plated with Colmonoy-6	11.620 in. OD 11.619 in. OD Length of Bearing Surface: 110.06 in. 110.00 in.		189C972				
			Bellows (Reciprocating)	1	304 SS Thickness: 0.047 in. 0.027 in.	8.75 in. ID 11.00 in. OD Compressed: 8.688 in. ID 10.900 in. OD	Length: -1/2 in. 137.00 -0 in. Extended 13.7 in. Extended length, 10 Sections 65 Convolutions per Section	189C953	Sodium Vapor and Argon to Argon	Carbon Dioxide 4 to 100, <17 Hydrogen 2 to 1230, <69 Helium <4 to 680, <24 Methane <10 to 560, <40 Nitrogen 260 to 4960, 1958		
			Grapple Crane Arm Guide Ribs (Journal)	2	Stellite-6	Rib Surface Length: 108.30 in. 108.25 in.	Clearance: 0.010 in. 0.015 in. Distance between ribs on the two stabilizer bars: Lower ribs (26 in.) 6.562/6.589 in. Upper ribs 6.616/6.655 in.	189C959 189C960 8-1/2 x 11 Dwg. by V. V. McClure 2/9/60 5XN-4589-1	Liquid Sodium			

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TABLE 39
EFAPP OFFSET HANDLING MECHANISM
(Sheet 2 of 4)

Mechanism	No. in Plant	Design Information							Operating Environment			
		Primary Material of Construction	Component	No. per Mechanism	Material of Construction	Dimensions and Manufacturing Tolerances	Clearances, Loading, and Speed	Drawing No.	Operating Medium	Operating Medium Impurities	Temperature, Velocity and Pressure	Exposure to Environment (hr)
			Grapple Crane Arm Pads (Bearing)	2	304 SS Stellite-6 Filler Mat'l.	Distance between pads: 6.552 in. 6.640 in.	Adjust to 0.010 in. to 0.015 in. total clearance with actual distance between guides. Speed:	218B664 172D666 172D676 217B385	Liquid Sodium			
			Finger Retainer Bearing Pads (Journal)	4	304 SS Pad Mat'l. Stellite-3	3.213 in. ID 3.211 in. Length: 0.315 in. 0.370 in.	Clearance: Sliding surface	5XN-4574 855B324 855B323				
			Grapple Fingers (Bearings)	4	Stellite-6	See Dwg. (Unusual Configuration)	Negligible load	217B400 66XN-4600				
			Grapple Slide Pin Track (Journal)	1	304 SS	1.51 in. Length 1.50 in. 0.38 in. Wide 0.37 in.	Clearance: 0.063 in.	217B385				
			Grapple Slide Pin (Bearing)	1	302 SS Hard Chrome Plated	0.317 in. diam 0.307 in. of Pin Head	Negligible load	217B396 2XN-4588				
			Lower Latch Bellows (Reciprocating)	1	304 SS	1.050 in. ID 0.950 in. 2.070 in. OD 2.050 in.	Length (Extended): 5.25 in. Length (Compressed): 4.12 in.	217B399 5XN-4586 2XN-4593	Liquid Sodium to Argon			
			Grapple Shaft (Journal)	1	304 SS	0.624 in. OD 0.623 in.	Clearance: 0.379 in. 0.378 in.	217B397 5XN-4584				
			Grapple Flange (Bearing)	1	304 SS	1.003 in. ID 1.001 in. Length: 1.36 in.		217B398	Liquid Sodium			
			Grapple Cam Fitting	1	416 SS Nitrided	2.568 in. ID 2.564 in. 3.192 in. OD 3.182 in.		217B395 5XN-4583				
			Grapple Flange Socket (For Grapple Finger Pivot)	4	304 SS Plated with Stellite-6			217B398				

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TABLE 39
EFAPP OFFSET HANDLING MECHANISM
 (Sheet 3 of 4)

Mechanism	No. in Plant	Design Information							Operating Environment			
		Primary Material of Construction	Component	No. per Mechanism	Material of Construction	Dimensions and Manufacturing Tolerances	Clearances, Loading, and Speed	Drawing No.	Operating Medium	Operating Medium Impurities	Temperature, Velocity and Pressure	Exposure to Environment (hr)
			Bellows (Face Seal)	1	304 SS Thickness: Unavailable	16.00 in. ID 19.00 in. OD	Will not be subject to expansion and contraction.	189C955	Sodium Vapor to Argon			
			Stabilizer Foot Bearing (Snap Open)	1	304 SS Colmonoy-6 Insert (2 halves)	3.875 in. ID 3.865 in. ID		189C956 5XN-4548A 66XN-4562	Liquid Sodium ↑			
			Pivot Bearing (Lower Plate on Stabilizer)	1	304 SS Colmonoy-5 Inserts	1.771 in. ID 1.770 in. ID Length: Top Insert: 0.63 in. 0.61 in. Bottom Insert: 0.63 in. 0.61 in.		5XN-4549A 66XN-4562				
			Torsion Bar	1	347 SS	0.625 in. OD 0.624 in. OD Length: 114.97 in.	Clearance: 0.135 in. (Between Torsion Bar and Spacer Tube) 0.035 in. (Between Torsion Bar and Spacers)	2XN-4546A 66XN-4562				
			Actuator Lever Position Track	1	304 SS Colmonoy-5 Insert	1.020 in. ID 0.980 in. ID Depth: 0.630 in. 0.610 in.		6XN-4550A				
			Actuator Lever	1	347 SS Stellite-6 Insert	0.755 in. OD 0.750 in. OD Length: 0.56 in.	Clearance: 0.265 in. (Between Lever and Track)	2XN-4409A 66XN-4562				
			Pivot Pin	1	347 SS Stellite-6 Inserts	1.750 in. OD 1.749 in. OD Length: Top Insert: 0.76 in. 0.74 in. Bottom Insert: 0.76 in. 0.74 in.	Clearance: 0.021 in. (Between Pivot Pin and Pivot Bearing)	2XN-4410 66XN-4562				

TABLE 39
EFAPP OFFSET HANDLING MECHANISM
(Sheet 4 of 4)

Mechanism	No. in Plant	Design Information							Operating Environment			
		Primary Material of Construction	Component	No. per Mechanism	Material of Construction	Dimensions and Manufacturing Tolerances	Clearances, Loading, and Speed	Drawing No.	Operating Medium	Operating Medium Impurities	Temperature, Velocity and Pressure	Exposure to Environment (hr)
			Actuator Lever Bearing	1	347 SS Colmonoy-6 Inserts	1.125 in. OD 1.124 in. ID Length: Top Insert: 0.31 in. Bottom Insert: 0.31 in.	Clearance: 0.15 in. (Between Actuator Lever Brg. and Bushing)	2XN-4409A 66XN-4562	Liquid Sodium ↑ ↓			
			Bushing - For Torsion Bar Lever	1	304 SS	1.140 in. ID 1.142 in. ID Length: 1.88 in.		2XN-4590 66XN-4562				
			Spacer Tube - Torsion Bar	1	304 SS	0.76 in. ID Length: 112.00 in.	Slight movement between Torsion Bar and Spacer Tube as Torsion Bar twists.	2XN-4406 66XN-4562				
			Spacer - Torsion Bar	4	304 SS	0.660 ± 0.010 in. ID Length: 0.38 in. 0.36 in.	Slight movement between Torsion Bar and Spacer as Torsion Bar twists.	2XN-4408 66XN-4562				

actuates the gripper fingers to the closed position. This action stops downward motion by actuating a limit switch. A spring-loaded plate locks the probe rod in the up position, fixing the relative position of the cam member and fingers in the locked position. Interlocks require completion of all motions prior to withdrawal. The lock release can be operated only when the subassembly is in a seated position and the control function is changed. A two-speed drive control slows the travel from 20 ft/min to 1 ft/min as the fuel enters the core.

Although the OHM is located permanently in sodium, it does not experience insertions and withdrawals with accompanying crud and contamination. The gripper latch linkage is located within a sealed argon chamber with the main reciprocating bellows seal located above the sodium surface.

a. Statement of Operability

The OHM has operated very well since its initial installation in 1959. The original readout instrumentation was insufficient, and supplementary instrumentation was required.

The complexity of the OHM operation requires an experienced operator. Strict administrative control is required when handling objects such as control rods, safety rods, oscillator rods, or a neutron source.

The azimuth mode has nulled-out with excessive error in the azimuth position. Overload "trips" in the "raise" mode have occurred with no apparent reason, with an action similar to a stiff bellows in that repeated lowering and raising would result in successfully attaining a "full-up" position.

The stabilizer is particularly vulnerable to damage and hang up because the lower plate is located about 1 in. above the tops of the subassembly handling heads. Improvement of the gripper contact force feedback system would greatly enhance the capability of the OHM for reactor inspection and maintenance operations.

The number of OHM operating cycles have far exceeded its design lifetime, without any apparent loss in inert gas sealability or positioning accuracy. It is estimated that the OHM must be positioned to within $\pm 1/4$ in. at the subassembly handling head to achieve a latch stroke prior to removal of the subassembly.

b. Statement of Maintainability

Those portions of the OHM which are located above the rotating shield plug are comparatively easy to maintain. However, the design incorporates a gas-filled tube with bellows providing for flexibility down through the OHM to the latch. The gas-filled tube and its associated bellows must remain intact so as to exclude sodium from this area. Under normal operating conditions, no difficulty would be expected if sodium did enter the area. However, should excessive pressures be required on the argon cover gas, sodium inside the latch rod tube would be forced upward into regions in and above the rotating shield plug where it could freeze and prevent operation of the OHM latch. Maintenance of this gas-filled space is extremely difficult without the complete removal of the OHM from the reactor vessel. This implies sealed gas-filled containers and remote operation to remove this large component from the high-temperature, sodium-argon atmosphere. Even then it is anticipated that the radiation levels resulting from induced radioactivity in the lower portions of the OHM would be such that it would be practically impossible to perform contact maintenance on this equipment. Semi-remote or full-remote maintenance procedures would be required.

c. History of Malfunction and/or Modification

Operating malfunctions with the OHM were minimal and in no way related to sodium environmental effects. While handling dummy subassemblies (1961), the OHM was bent when an attempt was made to move laterally while a number of subassemblies were displaced from seated positions. Following the delatching of the gripper from the stuck subassembly, the handling machine was partially raised to save handling time. The interlock override permitted the rotating plug to be rotated prematurely. The gripper did not fully release due to misalignment with the subassembly. As the rotating plug was actuated, while the subassembly was partially raised, the OHM foot was forced into the subassembly (partially inserted) and damaged both components. ^(25,98) Redesign strengthened the gripper linkage, permitting shock loading, if required, to free a stuck gripper. A "snap open foot" (lower plate) was provided to permit release of the subassembly when lateral resistance develops.

The rotating mechanical seal (Fig. 52) also has required attention. ^(36,111) The assembly now consists of a rubber lip seal outside of a gas-buffered,

Fig. 52. EFAPP OHM Face Seal Modifications

teflon, double-lip face seal. The outer lip seal is effective; however, the ineffective face seal is located in such a position that maintenance or modification is a major problem.

The asbestos elevation seal packing became ineffective due to heat hardening. Teflon chevron-type packing was installed, increasing integrity and ease of maintenance.^(36,111)

The latch rod cavity is pressurized to 10 psig, exerting a force equal to the weight of the latch rod less the counter spring force, tending to move the latch rod upward. The counterbalance spring needed to be shortened to compensate for this load. The 10-psig pressure will inhibit in-leakage of sodium into the cavity in the event of a bellows failure.⁽¹¹²⁾

10. Transfer Rotor (Table 40)

The transfer rotor (Fig. 53) receives subassemblies from the OHM, and stores them under sodium in finned pots during the thermal stabilization period. The rotor rotates and positions each subassembly under the vertical exit port. These are removed by the cask car hoist grapple into the cask car rotor assembly through the exit port. The reactor vessel rotor disk provides storage for eleven subassemblies prior to removal from the reactor vessel.

The rotor plate is suspended at the end of a long actuator shaft (Fig. 54), at the upper end of which is a drive and indexing system. All components with the exception of the rotor plate, are removable for replacement or maintenance. A special tapered spline, which replaced the pin-bayonet latch shown in Figure 54, is located at the lower end of the drive shaft, permitting remote disassembly. When the shaft first is lowered, the rotor plate is caused to rest on a support plate. Further lowering frees the shaft spline from the plate. A rotation of 45 deg aligns the spline with relieved slots in the plate, allowing the shaft to be removed vertically. A tail bearing, operating in sodium, supports the shaft at the lower end.

a. Statement of Operability

Operation has been satisfactory. The drive has been overloaded occasionally with an unbalanced load. Due to increased momentum, the rotor would overshoot its mark, preventing the shot pin from going into proper position.

Fig. 53. EFAPP Transfer Rotor Assembly

Fig. 54. EFAPP Transfer Rotor Plate, Tail Bearing, and Drive Shaft End

TABLE 40
EFAPP TRANSFER ROTOR
(Sheet 1 of 3)

Mechanism	No. in Plant	Design Information							Operating Environment			
		Primary Material of Construction	Component	No. per Mechanism	Material of Construction	Dimensions and Manufacturing Tolerances	Clearances, Loading, and Speed	Drawing No.	Operating Medium	Operating Medium Impurities (ppm)	Temperature, Velocity and Pressure	Exposure to Environment (hr)
Transfer Rotor Cross Co. Fabr. Snyder Co. Assy Dwg. A-110500 (Cross Co.)	1	304 SS	Leveling Plate	1	304 SS	44.505 in. OD 44.495 in. (Partial circumference) pilot hole bore 4.720 in. 4.725 in. Transverse Slot 1.75 in. width 0.60 deep. Chamfer all edges dimensioned.	Clearance Rotor Plate with Level Plate OD 0.105 in. on radius 0.095 in. on radius	110522B	Sodium Liquid ↑ ↓	Range Avg. Sodium Liquid Oxygen (Sodium Monoxide) 6 to 27, 12 Carbon 19 to 231, 62 Hydrogen 0.7 to 11, 2.4 Iron 0.1 to 6.7, 2.5 Nickel 0.05 to 3.4, 0.7 Chromium 0.1 to 2.0, 0.7 Sodium Vapor Oxygen <25 to 90, <32 Carbon Monoxide <10 to <50, <11 Carbon Dioxide 4 to 100, <17 Hydrogen 2 to 1230, <69 Helium <4 to 680, <24 Methane <10 to 560, <40 Nitrogen 260 to 4960, 1958	Sodium Liquid 300 to 1000 °F 493 °F Avg.	Hours of Exposure =49,200 Operating Movements 657 to July 67 (Ref 154)
			Rotor Plate	1	304 SS	Level Plate Seat 44.705 in. 44.695 in. Positioning Bar Width 0.87 Depth 0.80 Finned Pot Port 7.750 in. ID	Clearance Rotor Plate with Level Plate OD 0.105 in. on radius 0.095 in. on radius	110549N				
			Bushing (Rotor Tapered Spline Drive)	1	304 SS (Malcomize)	Upward Exit Port Diameter for Shaft End 4.002 in. 4.003 in. Spline Seat 0.493 in. 0.495 in. at full depth 30° Included Angle 5° Face Angle 1.986 in. 1.988 in. Radius (max.) From Sphere Tooling Pin T-7288	Clearance Exit Port with Spline OD 0.095 in. on radius 0.093 in. on radius Bushing to Shaft 0.003 in. on radius 0.001 in. on radius	110549N				

TABLE 40
EFAPP TRANSFER ROTOR
(Sheet 2 of 3)

Mechanism	No. in Plant	Design Information							Operating Environment			
		Primary Material of Construction	Component	No. per Mechanism	Material of Construction	Dimensions and Manufacturing Tolerances	Clearances, Loading, and Speed	Drawing No.	Operating Medium	Operating Medium Impurities	Temperature, Velocity and Pressure	Exposure to Environment (hr)
			Shaft Assembly 1) Spline End	1	347 SS (Forging) Colmonoy-4 Facing in Select Areas	1) 3.816 in. 3.812 in. Major Diameter of Tapered Spline 30° Included Angle 5° Face Angle 0.500 Face Width Minimum 2) OD After Colmonoy-4 Facing (0.06 in. thick) 4.000 in. 3.997 in.	Bushing to Shaft 0.003 in. on radius 0.001 in.	110647F	Sodium Liquid			
			2) Upper Section Tail Bearing Region and Above									
			Tail Bearing Column	1	304 SS Colmonoy-4 Facing in Select Areas	1) Tail Bearing ID (0.060 in. facing) 4.004 in. 4.005 in. 3 in. brg length 2) Nozzle Bearing OD (0.060 in. facing) 5.785 in. 5.780 in. 3 in. brg length 3) Upper Shoulder OD (0.060 in. facing) 5.785 in. 5.780 in. 2-3/4 in. brg length	Nozzle to Housing 0.010 in. on radius 0.005 in. Housing to Upper Shoulder 0.012 in. on radius 0.005 in.	110548D	Sodium Liquid			
			Outer Housing	1	304 SS	1) Nozzle Section 5.800 in. ID 5.795 in. 3.4 in. brg length 2) Upper Shoulder Seat 5.805 in. ID 5.795 in. 2.3 in. brg length	Nozzle to Housing 0.010 in. on radius 0.005 in. Upper Shoulder to Housing 0.012 in. on radius 0.005 in.	110681-A	Sodium Liquid			
									Sodium Vapor			

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TABLE 40
EFAPP TRANSFER ROTOR
(Sheet 3 of 3)

Mechanism	No. in Plant	Design Information							Operating Environment			
		Primary Material of Construction	Component	No. per Mech- anism	Material of Construction	Dimensions and Manufacturing Tolerances	Clearances, Loading, and Speed	Drawing No.	Operating Medium	Operating Medium Impurities	Temperature, Velocity and Pressure	Exposure to Environment (hr)
			Neutron Shields		Boron Carbon Steel	ID of Shield Adaptor Mating with Shaft 4.020 in. 4.025 in. 1 in. length one end ID of Upper Shield Bearing with Shaft 4.011 4.013 3 in. length both ends	Shield Adaptor with Shaft 0.014 in. on radius 0.005 in. on radius Shield Bearing with Shaft 0.008 in. on radius 0.005 in. on radius	110540-E 110543-B	Sodium Vapor ↑ ↓			
			Upper Shield Bearing	1								
			Seal Adaptor Shield	1								
			Seal (Packing)	1	Not Available	Not Available	Not Available	110542				

This occurred only when fully loaded and a large azimuth change was being made. The difficulty was overcome by actuating the start pushbutton again to bring the rotor into proper position. No design change was made to correct this minor operating inconvenience.

b. Statement of Maintainability

Removal of the transfer rotor plate would be a very complex undertaking, requiring access to the rotating shield plug and the removal of grapple plates in the transition deck. Therefore, it is unlikely that removal of the rotor plate would be attempted.

Replacement of the lower bearing of the transfer rotor shaft would require disconnecting the bayonet-type shaft from the circular rotor plate, and the vertical removal of the shaft out of the standpipe; then the lower bearing guide tube, on the bottom of which the lower bearing is mounted, would have to be removed. This lower bearing is partially self-locating with a large clearance.

c. History of Malfunction and/or Modification

During hot-gas testing, the tail bearing developed scoring damage. It was necessary to increase the diametral clearance from 0.004/0.008 in. to 0.031/0.034 in. with the addition of a 0.005-in. crowned cross section.⁽¹¹⁰⁾ Subsequently, no further difficulty was experienced with the tail bearing.

An accidental dropping of a 520-lb finned pot subassembly unit, resulting from a hoist cable fitting separation, caused damage to the No. 12 position on the rotor plate. Shaft operation continued unaffected.^(113,114)

The drive shaft primary seal required rework. The asbestos braided packing had become heat hardened; it was replaced by two teflon chevron seals, separated by a lantern ring. The space between the seals was buffered with a positive cover gas pressure.^(37,75,115)

The vertical exit port plug, originally sealed by silicone lip seals, was difficult to remove and occasionally seized.^(110,116) A new O-ring-type seal was installed, replacing the deteriorated assembly.

11. Transport Cask Car

The transport cask car (Fig. 55) is a mobile facility for transferring core and blanket components from the reactor transfer rotor port. The facility

PLAN

ELEVATION

Fig. 55. EFAPP Transport Cask Car

consists of a cask car, an exit port seal with ball valve assembly, a finned pot gripper suspended from a wire rope hoist assembly, an argon cover gas system with axial blower for forcing circulation through an air-to-argon heat exchanger, a storage rotor within a cask, a rotor latch and positioning system, and finned-pot latch assemblies at each rotor position. The gripper is supported on two cables actuated by a hoist driven by two grooved drums. These lock together after an initial latching or unlatching motion between cables. Differential motion between cables at a fixed gripper elevation occurs either at the reactor vessel transfer rotor level, or as the cask car rotor level activates the gripper fingers. Component details are included in separate subsections.

During the initial loading to criticality (106 core subassemblies), the transport cask car was shown to be basically acceptable in design function. Actual service was hindered by repeated malfunction and operational deficiencies. An unusually large amount of downtime was required throughout its history. Repairs and modification did not significantly improve performance. The original design did not provide adequately for the difficult operating environments within the cask car which resulted from handling sodium components at 300 to 350°F. The spilling and dripping of sodium and eventual distribution of sodium throughout the cask car by the cover gas (argon) forced circulation was not fully anticipated at the time of its conceptual design. Sodium-sodium oxide deposits accumulated in mechanisms, bearings, ball valve, and throughout the argon blowers, dampers, and heat exchangers. Other difficulties resulted from design deficiencies in the cask itself. The cask consisted of an inner wall of Type 304 CRES and an outer wall of carbon steel, with the annulus filled with cast lead, plus a thin section filled with a stack of depleted uranium. This configuration proved to be dimensionally unstable, resulting in continual warping and gross distortion, leading to misalignments of mechanisms, binding, and complete inoperability. Other design deficiencies were resolved by conceptual revision.

Because this unit became radioactive, it was not easily maintained thereafter.

A brief review is included regarding the original fuel transport cask car even though an entirely new fuel transport facility was fabricated and installed. Information provided will serve to assist in design efforts for future similar units.

Fig. 56. EFAPP-Cask Car Ball Valve and Seal Flange

a. Ball Valve (Fig. 56 - Table 41)

The ball valve depleted-uranium ball is sealed by O-rings carried in plates that are pneumatically operated. The mechanism for the seal action utilizes small springs and close operating tolerances with numerous cavities which are vulnerable to contamination. The ball actuation shaft is supported on ball bearings.

- (1) Statement of Operability. The ball valve operated satisfactorily for only about 1/2 hr when it was new (clean) and not affected by sodium.
- (2) Statement of Maintainability. The ball valve was extremely difficult to maintain because it required the disassembly of cask car components. No provision was made for the disposal of radioactive sodium in the cask car or for its decontamination.

The internals of the cask had to be opened to the atmosphere for maintenance, and maintenance personnel working below the sealing flange were exposed to some low-level radioactivity from the uranium components of the sealing flange and the ball valve.

- (3) History of Malfunction and/or Modification. The original rigid gas line, which operated the valve seal plate lifting system, was replaced by a flex hose to allow removal of the valve without removing the port seal flange.⁽⁷⁷⁾

The uranium ball section deteriorated due to surface oxidation and flaking, making sealing difficult.⁽¹¹⁷⁾ The ball was first metal plated with a copper base and nickel outer layer. Within 6 weeks after operation, this coating started to peel off.⁽¹¹⁸⁾ Next, a layer of epoxy sealant was applied to the ball.⁽¹¹⁹⁾ Within 9 months this sealant began peeling. No further attempt has been made to seal the ball.

The ball operating shaft seals and ball surface seals required continuous maintenance (five times in 4 years) and resulted in modification to the seals. The tiny springs also were removed from the ball seals (Refs. 13, 25, 41, 43, 79, 80, 120).

The thrust bearings were replaced after two seizures.^(34,43)

The original carbon steel shaft support bearings required replacement with units of corrosion-resistant steel.⁽¹¹⁷⁾

TABLE 41
EFAPP TRANSPORT CASK CAR BALL VALVE AND FLOOR SEAL
(Sheet 1 of 3)

Mechanism	No. in Plant	Design Information							Operating Environment			
		Primary Material of Construction	Component	No. per Mechanism	Material of Construction	Dimensions and Manufacturing Tolerances	Clearances, Loading, and Speed	Drawing No.	Operating Medium	Operating Medium Impurities	Temperature, Velocity and Pressure	Exposure to Environment (hr)
Cask Car										(ppm) Range Avg.	Oper. Temp.	Hr of Exposure
Ball valve and operator assembly	1	Depleted Uranium and Corrosion Resistant Steel	Retainer		SS	Sleeve seat ID 12.255 in. / 12.250 in.	Retainer to sleeve sliding surfaces 0.0015 in. / 0.005 in.	20ZH004	Argon and Sodium Vapor (Sodium Drippings)	Not available	≈ 175 to 350°F ≈ 325°F Avg. (Ref. 3)	Not available Total Moves Not available
Hydramatics Corp. Assy. Dwg. B-401-X1			Sleeve		SS	Retainer surface OD 12.247 in. / 12.245 Back plate surface 10.997 in. / 10.995 Insert sleeve seat ID 10.001 in. / 9.999	Sleeve to retainer 0.0015 in. / 0.005 in. Sleeve to back plate 0.0015 in. / 0.005	17VH001 100-4-1130 100-4-1150				
Baldwin Lima Hamilton Assy. Dwg. 100-4-1140			Back plate		SS	Sleeve seat ID 11.005 in. / 11.000	Back plate to sleeve 0.0015 in. / 0.005	38ZH002				
			Insert Sleeve		SS			100-3-2030 100-3-2031				
			Ball	1	Spent Uranium 2 to 3% Molybdenum							
Floor Seal and Actuator Assembly	1	304 SS	Actuator pivot pin	1	304 SS	OD 0.250 in. / 0.248 in. Length: 2 in.	Clearance pivot pin in support block 0.000 in. / 0.004 in.	100-1-660 (100-1-661)				
Baldwin Lima Hamilton Assy. Dwgs. 100-7-1500 100-7-1510			Pivot pin support block		304 SS	Pivot pin seat ID 0.252 in. / 0.250 in.	Clearance support block to pivot pin 0.000 in. / 0.004 and pinned	100-3-1100				
			Actuator Drive pin	1	304 SS	OD 0.250 in. / 0.248 in. Length: 1 in.	Clearance drive pin to actuator arm 0.000 in. / 0.004 in. and pinned	100-1-660				
			Actuator Arm	1	304 SS	Shaft Seat ID 1.002 in. / 1.000 Drive pin seat ID 0.252 in. / 0.250	Clearance actuator to drive pin 0.000 in. / 0.004	100-1-650				

TABLE 41
EFAPP TRANSPORT CASK CAR BALL VALVE AND FLOOR SEAL
(Sheet 2 of 3)

Mechanism	No. in Plant	Design Information							Operating Environment			
		Primary Material of Construction	Component	No. per Mechanism	Material of Construction	Dimensions and Manufacturing Tolerances	Clearances, Loading, and Speed	Drawing No.	Operating Medium	Operating Medium Impurities	Temperature, Velocity and Pressure	Exposure to Environment (hr)
			Actuator Arm Shaft	1	304 SS	OD 1.000 in./0.998 Length: 4-1/4 in.	Clearance Arm shaft to bushing 0.003 in./0.006 Arm shaft to arm 0.000 in./0.004 and pinned	100-1-640	Argon and Sodium Vapor (Sodium Drippings)			
			Actuator Shaft Bushings	2	440C SS	Rockwell C-60,62 OD 1.247 in./1.246 ID 1.004 in./1.003 Length outer bushing 1 in. Length inner bushing 1-1/2 in.	Clearance Bushings to arm shaft 0.003 in./0.006 Bushings to support block 0.003 in./0.006	100-2-760 (100-2-766) (100-2-767)				
			Shaft Bushing Support Blocks	2	304 SS	Shaft bushing Seat ID 1.252 in./1.250 Actuator Arm operating slot 1.020 in./1.000	Clearance Support block to shaft bushing 0.003 in./0.006	100-3-1100				
			Actuator Lift Arm	3	304 SS	Shaft seat ID two holes 1.002 in./1.000	Clearance Lift arm to actuator shaft 0.000 in./0.004 and pinned Lift arm to roller shaft 0.002 in./0.006 not pinned	100-1-620				
			Actuator Roller Shaft	3	304 SS	Lift Arm end OD 0.998 in./0.996 Roller end OD 0.748 in./0.746 Roller seat length 1.010 in./1.000	Clearance Roller shaft to roller 0.002 in./0.006 Roller shaft to lift arm 0.002 in./0.006 not pinned	100-1-670				
			Actuator Lift Roller	3	304 SS surfkote M-1280	ID 0.752 in./0.750 OD 1-1/4 in. Length: 0.990 in./0.980	Clearance Roller to roller shaft 0.002 in./0.006 Roller to Flange Slot width 1/8 in. centered	100-1-630				

TABLE 41
EFAPP TRANSPORT CASK CAR BALL VALVE AND FLOOR SEAL
(Sheet 3 of 3)

Mechanism	No. in Plant	Design Information							Operating Environment			
		Primary Material of Construction	Component	No. per Mech- anism	Material of Construction	Dimensions and Manufacturing Tolerances	Clearances, Loading, and Speed	Drawing No.	Operating Medium	Operating Medium Impurities	Temperature, Velocity and Pressure	Exposure to Environment (hr)
			Floor Sealing Flange	1	Spent uranium 2 to 3% molybdenum	Actuator roller Operating slot width 1-1/2 in.	Clearance Flange slot with roller 1/8 in. centered	100-7-1360	Argon and Sodium Vapor (Sodium Drippings) ↑ ↓			
			Seal Valve Bellows with End Flanges	1	304 SS	Bellows ID 17-5/8 in. 3/4 in. stroke		100-3-1240				

The shaft bellows of the ball valve damper operator developed a leak requiring repair.⁽⁶⁾

b. Seal Flange (Fig. 56 - Table 41)

The seal flange forms the gas-tight seal between the cask car and the exit ports in both the reactor building and fuel and repair building. The sealing flange is raised and lowered by three actuators, each operating independently by means of three synchronous motors. The operating mechanism is not directly in contact with sodium environments, but represents a typical sodium vapor seal system.

(1) Statement of Operability. The sealing flange failed in service about five times. The three actuator motors failed to raise the flange off the exit port due to malfunction of the three actuators.

(2) Statement of Maintainability. No provision for maintenance was made in the design of the sealing flange. Sealing flange failure at the exit port prevents travel of the cask car. In one instance, the cask car had to be jacked up off the exit port and the sealing flange was lowered onto a piece of sheet metal.

(3) History of Malfunction and/or Modification. The seal flange actuators operated irregularly, requiring continuous attention. Five incidents of actuator failure due to overloading resulted from nonuniform actuator motion causing seal flange tilting. Separate control switches eventually were provided to permit independent actuation, if required.^(117,120-123)

The exit port and plug were redesigned to a simple O-ring concept.^(74,122)

c. Finned Pot Gripper (Table 42)

The gripper is a cable-suspended and cable-operated mechanism. Operation of the gripper fingers is totally dependent upon the relative position of the two support cables which actuate a linkage train, working the fingers. The gripper will fail to operate if it twists as it travels, if slack develops in either cable, or if the gripper linkage binds due to sodium crud accumulation. It is essential to know the gripper position, as indicated by early operational difficulties.

TABLE 42
EFAPP CASK CAR FINNED POT GRIPPER
(Sheet 1 of 5)

Mechanism	No. in Plant	Design Information							Operating Environment			
		Primary Material of Construction	Component	No. per Mechanism	Material of Construction	Dimensions and Manufacturing Tolerances	Clearances, Loading, and Speed	Drawing No.	Operating Medium	Operating Medium Impurities (ppm) Range Avg.	Temperature, Velocity and Pressure	Exposure to Environment (hr)
Cask Car Gripper Assembly Baldwin Lima Hamilton Assy. Dwg. 100-7-1370	1	SS	Cable Link	2	304 SS	ID Cable end shaft seat 0.3135 in./0.3130 ID actuator end shaft seat 0.5005 in./0.5000 actuator slot width 7/16 in.	Clearance Link shaft seat to shaft 0.0000 in./0.0015 Actuator shaft seat ID to shaft 0.0000 in./0.0015 Actuator to slot 1/32 in.	100-2-2240	Reactor Transfer Tank Sodium and Cask Car Argon Sodium Vapor	Sodium Vapor Not available Sodium Liquid Oxygen (sodium monoxide) 6 to 27, 12 Carbon 19 to 231, 62 Hydrogen 0.7 to 11, 2.4 Iron 0.1 to 6.7, 2.5 Nickel 0.05 to 3.4, 0.7 Chromium 0.1 to 2.0, 0.7	Sodium Liquid 300 to $\approx$ 550°F Sodium Vapor $\approx$ 175 to 350°F 325°F Avg. (Ref.3) Subassembly Finned Pot Weight $\approx$ 520 lb	Not available Total Moves to Aug. 65 $\approx$ 315
			Link Shaft (Cable end)	2	304 SS	Length: 1 in./63/64 OD 0.313 in./0.312 Set screw lock	Clearance Link shaft to link seat 0.0000 in./0.0015	100-2-770 (100-2-776)				
			Link Shaft (Actuator end)	2	304 SS	Length: 1 in./63/64 OD 0.500 in./0.499 Set screw lock	Clearance Link shaft to actuator bushing ID 0.003 in./0.005 Link shaft seat ID to shaft OD 0.0000 in./0.0015	100-2-770 (100-2-772)				
			Shaft Bushing (Actuator end)	2	440 C SS	Length: 0.375 in./0.370 ID 0.504 in./0.503 OD 0.622 in./0.621 Rockwell C-60-62	Clearance Link shaft to actuator bushing ID 0.003 in./0.005 Bushing OD to Actuator ID 0.003 in./0.005	100-2-760 (100-2-761)				
			Actuating Arm	1	304 SS	Main shaft Bushing seat ID 1.001 in./1.000 Cable link bushing seat ID 0.626 in./0.625 Plunger link shaft seat ID 0.5005 in./0.5000 Max width 1-1/16 in. arm width 3/8 in.	Clearance Actuator bushing OD to actuator ID 0.003 in./0.005 Main shaft bushing OD to actuator ID 0.003 in./0.005 Plunger link shaft OD to actuator ID 0.0005 in./0.0015	100-2-810				
			Main shaft	1	304 SS	Length 4 in./3-63/64 OD 0.750 in./0.749 Set screw lock	Clearance Main shaft to main shaft bushing 0.003 in./0.005 main shaft to housing seat ID 0.000 in./0.004	100-2-770 (100-2-773)				

TABLE 42
EFAPP CASK CAR FINNED POT GRIPPER
(Sheet 2 of 5)

Mechanism	No. in Plant	Design Information							Operating Environment			
		Primary Material of Construction	Component	No. per Mechanism	Material of Construction	Dimensions and Manufacturing Tolerances	Clearances, Loading, and Speed	Drawing No.	Operating Medium	Operating Medium Impurities	Temperature, Velocity and Pressure	Exposure to Environment (hr)
			Main Shaft Bushing	1	440 C SS	Length 1.062 in./1.057 OD 0.997 in./0.996 ID 0.754 in./0.753 Rockwell C-60-62	Clearance Bushings OD to actuator ID 0.003 in./0.005 Main shaft bushing to shaft 0.003 in./0.005	100-2-760 (100-2-762)	Reactor Transfer Tank Sodium and Cask Car Argon Sodium Vapor			
			Plunger Link	1	304 SS	Plunger shaft and actuator shaft bushing seat ID 0.6255 in./0.6250 Width 1 in. Actuator slot width 7/16 in.	Clearance Link with actuator shaft bushing OD 0.003 in./0.0045 Link with plunger shaft bushing OD 0.003 in./0.0045	100-2-800				
			Plunger Link Actuator Bushings	2	440 C SS	Length OD 0.622 in./0.621 ID 0.504 in./0.503 Rockwell C-60-62	Clearance Bushings OD with link ID 0.003 in./0.0045 Bushings ID with shaft 0.003 in./0.005	100-2-760 (100-2-764)				
			Plunger Link Plunger Bushing	1	440 C SS	Length OD 0.622 in./0.621 ID 0.504 in./0.503 Rockwell C-60-62	Clearance Bushings OD with Link ID 0.003 in./0.0045 Bushings ID with shaft 0.003 in./0.005	100-2-760 (100-2-763)				
			Plunger Link Actuator End Shaft	1	304 SS	Length 1 in./63/64 OD 0.500 in./0.499 Set screw lock	Clearance Shaft in actuator arm ID 0.0000 in./0.0015 Shaft with bushing ID 0.003 in./0.005	100-2-770 (100-2-772)				
			Plunger Shaft	1	304 SS	Length 4 in./3-63/64 OD 0.500 in./0.499 setscrew lock	Clearance Shaft with Bushing ID 0.003 in./0.005 Shaft in plunger body ID 0.000 in./0.002	100-2-770 (100-2-774)				
			Plunger	1	304 SS	Finger Link Shaft seat ID 0.500 in./0.501 Plunger shaft Seat ID 0.500 in./0.501	Clearance Plunger ID with Plunger shaft OD 0.000 in./0.002 Finger link shaft with housing ID 0.000 in./0.002	100-3-740				

TABLE 42

EFAPP CASK CAR FINNED POT GRIPPER
(Sheet 3 of 5)

Mechanism	No. in Plant	Design Information							Operating Environment			
		Primary Material of Construction	Component	No. per Mechanism	Material of Construction	Dimensions and Manufacturing Tolerances	Clearances, Loading, and Speed	Drawing No.	Operating Medium	Operating Medium Impurities	Temperature, Velocity and Pressure	Exposure to Environment (hr)
			Plunger-finger Link Shaft	4	304 SS	OD 0.500 in./0.499 Length: 2-3/16 in./2-11/64 Set screw lock	Clearance Link shaft with plunger ID 0.000 in./0.002 Link shaft with link slot width 0.008 in./0.011	100-2-770 (100-2-771)	Reactor Transfer Tank Sodium and Cask Car Argon Sodium Vapor			
			Finger Link	4	304 SS	Pressure pad chamber ID 0.687 in./0.688 Finger link Shaft seat ID 0.510 in./0.508 Finger Slot 13/16 in. Finger shaft bushing seat ID 0.6250 in./0.6255	Clearance Link slot with plunger finger shaft 0.008 in./0.011 Finger link with drive shaft bushing 0.003 in./0.0045 Pressure pad OD to link cylinder ID 0.002 in./0.006	100-2-830 100-2-820				
			Finger Link Spring	4	302 SS Cold drawn	Coil OD 1/2 in. Wire diameter 0.056 in. Free length 31/32 in. Solid length 0.40 Active coils 5 31 lb/in. L. H. coiling	Spring OD within link cylinder ID clearance not critical	100-1-320 100-2-820				
			Finger Link Pressure Pad	4	304 SS	Spring seat ID 37/64 in. OD 0.685 in./0.682 1/2 in. length	Clearance Pressure pad OD with link cylinder ID 0.002 in./0.006	100-1-310 100-2-820				
			Spring Retainer	4	304 SS	Spring Recess OD 17/32 in. ID 3/8 in. 1/8 in. deep	Clearances not critical	100-1-410 100-2-820				
			Finger Drive Shaft Bushings	8	440 C SS	Length 0.250 in./0.245 OD 0.622 in./0.621 ID 0.504 in./0.503	Clearance Bushing OD with link 0.003 in./0.0045 Bushing ID with drive shaft 0.003 in./0.005	100-2-760				

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Gripper
Assembly
(Modifi-
cations)
Aug. 1965
Assy. Dwg.
6XN-5730-A

Original
1. Plunger
2. Fingers
3. Linkage

TABLE 42
EFAPP CASK CAR FINNED POT GRIPPER
(Sheet 5 of 5)

Mechanism	No. in Plant	Design Information							Operating Environment			
		Primary Material of Construction	Component	No. per Mechanism	Material of Construction	Dimensions and Manufacturing Tolerances	Clearances, Loading, and Speed	Drawing No.	Operating Medium	Operating Medium Impurities	Temperature, Velocity and Pressure	Exposure to Environment (hr)
1	304 SS		Cam Shaft Spacer	2	410 SS	1-1/8 in. OD 49/64 in. ID 1/8 in. thick	Clearance Not critical	5XN5732A	Reactor Transfer Tank Sodium and Cask Car Argon Sodium Vapor			
			Follower Yoke	1	304 SS	Follower Shaft Seat ID 0.500 in./0.501 Follower Stud Seat ID 0.500 in./0.501 Plunger Pin Seat ID 0.506 in./0.508	Yoke to follower clearance when centered 0.005 in./0.023 Innerface distance 2.005 in./2.015	5XN5733A				
			Cam	1	410 SS	ID 0.758 in./0.760	Clearance Cam ID to Cam Shaft OD 0.0085 in./0.0120	5XN5733A				
			Follower Shaft	1	410 SS	OD 0.499 in./0.498	Clearance Follower ID to Shaft OD 0.006 in./0.009	5XN5733A				
			Upper Follower	2	Stellite-6B	Shaft Seat ID 0.505 in./0.507 Follower to Yoke face distance 1.969 in./1.995	Clearance Follower ID to Shaft OD 0.006 in./0.009 Follower to yoke clearance when centered 0.005 in./0.023	5XN5733A				
			Lower Follower	2	Stellite-6B	Stud Seat ID 0.505 in./0.507 Yoke and follower width 0.927 in./0.937	Clearance Follower ID to Stud OD 0.006 in./0.009 Follower to Yoke clearance 0.006 in./0.029	5XN5733A				
			Follower Stud	2	410 SS	OD 0.499 in./0.498 Follower to Yoke outerface stud length 0.943 in./0.956	Clearance Stud to Follower 0.006 in./0.009 clearance 0.006 in./0.029	5XN5733A				
			Roller Chain Components 1. Block Link 2. Conn Link	2 4	SS SS	No. 60SS Roller Chain Standard Components		6XN5730A				

(1) Statement of Operability. The finned pot gripper was potentially hazardous to use, and erratic in operation. Malfunctions resulted in serious consequences. The cask car could not be moved from the exit port when the gripper failed to release from the shield plug. Grappling and delatching operations from the finned fuel transfer pots were unreliable because of malfunctioning of the gripper. Proper functioning was dependent on the load-sensing system.

A major design fault was the use of two cables to operate the gripper. The original design permitted accidental gripper lock-on to the edge of the finned pot. This was corrected.

Because of frozen sodium, the gripper would not operate unless it was hot; consequently it was necessary to install a heater.

(2) Statement of Maintainability. The gripper could be maintained only with the cask car empty. It was difficult to decontaminate.

(3) History of Malfunction and/or Modification. In general, modifications which were not required by the sodium environment were as follows: gripper finger spring material was changed from Inconel X to Type 302 CRES, with the wire diameter increased to avoid nesting of the spring sections in the event of a spring wire fracture; and tapering of the gripper fingers to improve gripping reliability.⁽³⁸⁾

Operational difficulties and modifications, which were sodium-related, are presented in the following sequential order. Early in the operating history of the gripper, sodium accumulation became a problem. Fouling with sodium and sodium oxide necessitated hot operation. Spring-operated finger actuation became difficult, and in cases inoperative, due to buildup of crud within the spring cavities. These problems caused other problems, including the dropping of a finned pot assembly; this damaged a latch position in the rotor. When the damage was repaired and the gripper cleaned, the internal dash ram assembly was eliminated. Cleaning became a routine requirement causing significant downtime.^(42,123,124) After a failure to release while lowering a finned pot assembly into the reactor, the gripper was removed and the Inconel 600 stem was replaced with a Stellite 6B stem to avoid galling.

d. Hoisting Assembly (Table 43)

The hoist assembly, as described in the introductory section, is a two-cable system operated in relative motion to latch and unlatch the gripper.

(1) Statement of Operability. The original hoist assembly, as received, would not operate. When operated initially, the cables jammed on the drum. This was attributed to the design of the hoist control. Also, the bearings failed because of incompatible materials (freezing up of bearings on the shaft).

(2) Statement of Maintainability. No provision was made for accessibility without violating the cask car atmosphere. Failure of the hoist immobilized the cask car.

The results of a malfunction, such as the cables becoming disarranged on the drum, had serious consequences. On one occasion, the shield plug jammed when it was halfway out of the exit port and the cables were unwound from the hoist drum. This was due to the cables going out of proper relative length adjustment.

(3) History of Malfunction and/or Modification. Hoist difficulties center around the incompatibility of materials and basic design inadequacy.

Hoist bearings which were initially carbon steel required replacing due to galling and scoring. Tungsten carbide sleeves keyed to the sheaves and tungsten carbide shaft bushing keyed to a Type 400 C-CRES shaft were used as replacements. A more sensitive gripper load sensing arm was installed as a result of a failure to stop when the gripper contacted the lifting lug. Incidents such as this repeatedly caused cable fouling and cross-winding.^(39,122,123) Pretwisting and preloading the cables was tried to avoid cable fouling.^(47,117,122) Damage resulted when the seal plug was being lifted by fouled cables and became wedged in the port due to the canted gripper. A 6000-lb force was required to break the plug loose. The overload damaged the cable, but the drive shaft bearing only required repolishing.⁽¹²²⁾ Hoist shaft journals and bushings of the drum later were found scored two additional times. The shaft was grooved at the drive pinion bearing. Hoist bearing brackets were provided with removable holddown caps to improve maintainability. Also, bearing surfaces were provided

TABLE 43
EFAPP CASK CAR HOISTING ASSEMBLY
(Sheet 1 of 6)

Mechanism	No. in Plant	Design Information							Operating Environment			
		Primary Material of Construction	Component	No. per Mechanism	Material of Construction	Dimensions and Manufacturing Tolerances	Clearances, Loadings, and Speed	Drawing No.	Operating Medium	Operating Medium Impurities	Temperature, Velocity and Pressure	Exposure to Environment (hr)
Cask Car									Argon (Sodium Vapor)	Range (ppm) Avg.	Oper. Temp.	Hr of Exposure
Cable Hoisting Assembly	1	SS	Hoisting Shaft	1	304 SS	Clutch, bushing, and R. H. cable drum region shaft OD 2.000 in. / 1.994	Clearance Shaft with clutch and drum 0.002 in. / 0.009 Shaft with bushing support brackets 0.003 in. / 0.010	100-2-1370		Not available	≈ 175 to 350°F	Not available
Baldwin Lima Hamilton			V. Tooth Drive Clutch	1	304 SS	ID Shaft Seat 2.002 in. / 2.003 Keyed to shaft Tooth angle 45° Face angle 2° 24' Tooth Height 0.299 Face Width 1-3/16 in.		100-2-1420			Hoist Load ≈ 520 lb	Total Moves ≈ 555
Assy. Dwg. 100-7-1550			Cable Drum at Clutch	1	304 SS	ID Shaft Seat 2.002 in. / 2.003	Clearance Drum with shaft 0.002 in. / 0.009	100-3-1150 (100-3-1151)				
			Support Bushings	2	440 C SS	ID 2.004 in. / 2.003 OD 2.374 in. / 2.373	Clearance Bushing with shaft 0.003 in. / 0.010 Bushing in bracket 0.001 in. / 0.003	100-2-960 (100-2-964) (100-2-965)				
			Support Bracket	2	304 SS	ID Bushing Seat 2.375 in. / 2.376	Clearance Bracket with bushing 0.001 in. / 0.003	100-3-1120				
			Hoisting Shaft Entry Bushings (Intermediate Drive Shaft)	2	440 C SS Surf-kote M1280	ID 1.756 in. / 1.755	Clearance Bushings with shaft 0.005 in. / 0.008	100-2-960 (100-2-963)				
			Intermediate Drive Shaft	1	304 SS	OD 1.750 in. / 1.748	Clearance Shaft with entry bushings 0.005 in. / 0.008	100-3-1140				
			Actuator Shaft	1	304 SS	OD 1.500 in. / 1.499	Clearance Shaft with entry bushings 0.005 in. / 0.007	100-2-1260				

TABLE 43
EFAPP CASK CAR HOISTING ASSEMBLY
(Sheet 2 of 6)

Mechanism	No. in Plant	Design Information							Operating Environment			
		Primary Material of Construction	Component	No. per Mechanism	Material of Construction	Dimensions and Manufacturing Tolerances	Clearances, Loading, and Speed	Drawing No.	Operating Medium	Operating Medium Impurities	Temperature, Velocity and Pressure	Exposure to Environment (hr)
			Actuator Shaft Entry Bushings	2	440 C SS	ID 1.506 in./1.505	Clearance Bushings with actuator shaft 0.005 in./0.007	100-2-960 100-2-962	Argon (Sodium Vapor)			
			Sheave Mounting Bracket	1	304 SS	ID Bushing seat press fit with bushing Spacing between bracket faces fixed sheave 4.496 in./4.494 ID Fixed sheave shaft seat 1.501 in./1.502	Clearance Total end play of sheaves and spacer on shaft 0.002 in./0.010 in. Fixed sheave shaft seat with shaft 0.001 in./0.003	100-4-530				
			Actuator Shaft Mounting Bracket Bushings	2	440 C SS Surfkote M1280	ID 1.506 in./1.505 OD Press fit in mounting bracket Rockwell C-60, 62	Clearance Mounting bracket bushing with actuator shaft 0.005 in./0.007	100-2-880 (100-2-881)				
			Shaft (Fixed Sheave)	1	304 SS	OD 1.500 in./1.499 Pinned to bracket	Clearance Shaft with sheave bushing 0.003 in./0.005 Shaft with spacer 0.005 in./0.007	100-2-1340				
			Fixed Sheaves	2	304 SS	Bushing Seat ID 1.755 in./1.756 Hub Width 0.998 in./0.996	Clearance Sheave with bushing 0.001 in./0.003	100-2-1320 100-1-700				
			Fixed Sheave Bushings	2	440 C SS Surfkote M1280	ID 1.503 in./1.504 OD 1.754 in./1.753 Rockwell C-60, 62	Clearance Fixed sheave shaft with sheave bushing 0.003 in./0.005 Bushings with sheave 0.001 in./0.003	100-1-710				
			Fixed Sheave Spacer	1	304 SS	ID 1.505 in./1.506 Length 2.496 in./2.494	Clearance Spacer with shaft 0.005 in./0.007	100-1-690				

TABLE 43
EFAPP CASK CAR HOISTING ASSEMBLY
(Sheet 3 of 6)

Mechanism	No. in Plant	Design Information							Operating Environment				
		Primary Material of Construction	Component	No. per Mechanism	Material of Construction	Dimensions and Manufacturing Tolerances	Clearances, Loading, and Speed	Drawing No.	Operating Medium	Operating Medium Impurities	Temperature, Velocity and Pressure	Exposure to Environment (hr)	
Cask Car Modification Cable Winder Mechanism Detroit Edison Co. Design Assy. Dwg. 6M-721-232			Cam Lever (Actuator Shaft)	2	304 SS	Actuator Shaft Bushing press fit in cam lever Floating Shaft Seat ID 1.501 in./1.502 Keyed to shaft	Clearance Floating shaft with cam lever 0.001 in./0.003 Keyed to shaft	100-3-1160	Argon (Sodium Vapor)				
			Cam Lever Actuator Shaft Bushings	2	440C SS Surfkote M1280	ID 1.505 in./1.506 OD Press fit in cam lever Rockwell C-60, 62	Clearance Bushing with actuator shaft 0.005 in./0.007	100-1-680					
			Guide Roller	2	304 SS	3/4 IPS Sch 40 0.113 in. wall		100-2-1300 100-2-1301					
			Floating Shaft	1	440C SS Surfkote M1280	OD 1.500 in./1.499	Clearance Shaft with sheave bushing 0.003 in./0.005	100-2-1310					
			Floating Sheave	2	304 SS	ID Bushing press fit in seat Hub width 1-3/4		100-2-1330 100-1-770					
			Sheave Bushing	2	440C SS	ID 1.503 in./1.504 OD Press fit in sheave	Clearance Bushing with shaft 0.003 in./0.005	100-1-710 (100-1-711)					
			Frame Assembly	1	304 SS	Shaft Seat ID 1.379 in./1.377		5M721-228 6M721-229	Argon (Sodium Vapor)		(ppm) Range Avg. Not available	Oper. Temp. ≈ 175 to 350° F	Hr of Exposure Not available
			Main shaft and idler shaft outer support bracket										
			Primary Support Brackets (Left)	1	304 SS	Main drive bushing seat ID 2.379 in./2.377 Idler shaft bushing seat ID 1.379 in./1.377 Cam drum bushing seat ID 2.004 in./2.002		6M721-229					

TABLE 43
EFAPP CASK CAR HOISTING ASSEMBLY
(Sheet 4 of 6)

Mechanism	No. in Plant	Design Information							Operating Environment			
		Primary Material of Construction	Component	No. per Mech- anism	Material of Construction	Dimensions and Manufacturing Tolerances	Clearances, Loading, and Speed	Drawing No.	Operating Medium	Operating Medium Impurities	Temperature, Velocity and Pressure	Exposure to Environment (hr)
			Primary Support Brackets (Contd) Right	1	304 SS	Main drive bush- ing seat ID 2.379 in./2.377 Cam drum bush- ing seat ID 2.004 in./2.002		6M721-229	Argon (Sodium Vapor)			
			Main Drive Shaft Extension	1	440C SS	Outer OD 0.874 in./0.872 Main OD 2.000 in./1.994 Rockwell C-43, 45		5M721-228 6M721-229				
			Outer Drive and Idler Shaft Bushings	3	440C SS	OD 1.375 in./1.373 ID 0.879 in./0.877 Rockwell C-48, 50		5M721-228				
			Inner Drive Bushing	1	440C SS	OD 2.374 in./2.373 ID 2.004 in./2.003		5M721-228				
			Idler Shaft	1	440C SS	OD 0.874 in./0.872 Rockwell C43,45		5M721-228				
			Cam Drum Bushings	2	440C SS	OD 2.000 in./2.998 ID 1.505 in./1.503		5M721-228 6M721-229				
			Gears Pinions	2 2	440C SS	12 pitch 14-1/2° P. A. 24 and 96 teeth P. D. 2 and 8 in. Keyed to shafts Rockwell C-50, 52		5M721-228				
			Cam Drum Shaft	1	440C SS	OD 1.501 in./1.499		5M721-227				
			Cam Drum Helix	2	440C SS	Cam width 0.505 in./0.500 Cam height 1/2 in.		5M721-227				

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TABLE 43
EFAPP CASK CAR HOISTING ASSEMBLY
(Sheet 5 of 6)

Mechanism	No. in Plant	Design Information							Operating Environment			
		Primary Material of Construction	Component	No. per Mechanism	Material of Construction	Dimensions and Manufacturing Tolerances	Clearances, Loading, and Speed	Drawing No.	Operating Medium	Operating Medium Impurities	Temperature, Velocity and Pressure	Exposure to Environment (hr)
			Support Arm for Guide Roller Assembly	1	440C SS	OD 0.748 in./0.746 Rockwell C-48, 50		6M721-229	Argon (Sodium Vapor)			
			Follower Bracket at Rollers	2	304 SS	Support arm slot height 0.754 in./0.752 Roller shaft seat ID 0.502 in./0.500 G _L to G _L of roller shaft seats 2.017 in./2.013		5M721-230 5M721-231				
			Cam Drum Followers	4	440C SS	Roller height 0.502 in./0.500 Roller diameter 1.500 in./1.498 Roller shaft OD 0.498 in./0.496 Distance roller surface 0.519 in./0.513 Rockwell C-48, 50 End play of shaft 1/16 in.		5M721-234				
			Follower Bracket Guide Pulleys	4	440C SS	Pulley cable seat radius 0.1426 in./0.1386 Pulley diameter 2.002 in./1.998 Pulley shaft OD 0.498 in./0.496 Effective cable seat diameter 0.3202 in./0.3042 Rockwell C-48, 50	End play of shaft 1/16 in.	5M721-234				
			Follower Bracket Pulley Mount Plate	2	304 SS	Pulley shaft seat ID 0.502 in./0.500 G _L to G _L of pulley shaft seats 2.033 in./2.029		5M721-230 5M721-231				
			Follower Arm Pivot Bushing	2	440C SS	ID 0.504 in./0.502 Height 1-31/32 in. Rockwell C-43, 45		5M721-230				

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Mechanism	No. in Plant	Design Information						Operating Environment				
		Primary Material of Construction	Component	No. per Mechanism	Material of Construction	Dimensions and Manufacturing Tolerances	Clearances, Loading, and Speed	Drawing No.	Operating Medium	Operating Medium Impurities	Temperature, Velocity and Pressure	Exposure to Environment (hr)
			Pivot Pin	2	440C SS	OD 0.498 in./0.496 Rockwell C-48, 50		5M721-230	Argon (Sodium Vapor)			
			Pivot Bushing Mount Bracket	2	304 SS	Bushing seat height 2 in.		5M721-230				
			Actuator and Load Cable Guide Pulleys	2	440C SS	OD pulley shaft 0.498 in./0.496 Pulley end play of shaft 1/16 in. Rockwell C-43, 45		5M721-233				
			Actuator and Load Cable Pulley Brackets	2	304 SS	ID shaft seat pulleys 0.504 in./0.502		5M721-233				

with removable holddown caps to improve maintainability. Also, bearing surfaces were repolished during each maintenance disassembly because of roughness, apparently caused by interaction between sodium and the bearing materials.^(80,117,118)

e. Rotor Plate and Latch Assembly (Table 44)

The rotor was driven by a pinion-circular ring gear assembly supported by a ball-bearing unit. The rotor plate originally provided storage for 11 finned pot subassembly units and the seal plug. Each station was equipped with horizontally actuated latching fingers on which the rim of the finned pot rested.

(1) Statement of Operability. The rotor and pot latch assembly were highly undependable due to a combination of structural failures in the cask. Progressive distortion of the cask finally caused the cask car to be scrapped.

(2) Statement of Maintainability. Essentially continuous maintenance was required to keep the rotor free within the cask. A point was reached where the original rotor was scrapped and a circular plate was substituted to avoid interference between the rotor and cask.

(3) History of Malfunction and/or Modification. Rotor malfunction originated with cask deformation and distortion which caused binding or bearing seat distortion. Grinding was used to eliminate most of these clearance problems for a period of time until continued rework proved futile (Refs. 32, 41, 42, 76, 117, 120-123, 125). A new rotor was designed and fabricated which held only three finned pot subassembly units and the shield plug (Refs. 44, 47).

Rotor drive shaft malfunctions were mechanical in nature. The shield seal was replaced once.^(39,122) Drive pinion and support bearings required resetting after working loose. Galling and wear were observed on the pinion and shaft at the pinion support bearing.^(31,120) All components were cleaned, repositioned, and firmly anchored.

The support latches which were used originally served with a low degree of reliability. Several times the latches failed to fully close, partially supporting the finned pots. The design was susceptible to binding due to sodium-sodium oxide crud accumulation (Refs. 42, 117, 120, 122). New latch assemblies, which were rotated from a vertical to a horizontal position, were provided for

TABLE 44
EFAPP CASK CAR ROTOR PLATE AND LATCH ASSEMBLY
(Sheet 1 of 9)

Mechanism	No. in Plant	Design Information							Operating Environment			
		Primary Material of Construction	Component	No. per Mechanism	Material of Construction	Dimensions and Manufacturing Tolerances	Clearances, Loading, and Speed	Drawing No.	Operating Medium	Operating Medium Impurities	Temperature, Velocity and Pressure	Exposure to Environment (hr)
Cask Car												
Rotor Drive and Positioning Assembly	1	SS	Ring Gear (Bevel)	1	4140 Chrome plated 0.005 in./0.006	60.005 in./59.995 Pitch diameter and outside diameter G _L pinion to G _L P.D. 1.501 in./1.499 Base surface to G _L P.D. 3.063 in./3.061 Pitch cone angle 2°-51'-45" D.P. -6-20° P. A. 360 teeth Shot pin seats at 30° spacing on O.D. 1-1/8 drill, 5/8 deep 1-3/8 from base surface		100-4-430	Argon and Sodium vapor (Sodium Drippings)	Range (ppm) Avg. Not available	Oper. Temp. ≈ 175 to 350° F ≈ 325° F Avg. (Ref. 3)	Not available Total Moves to July 1967 555 (Ref. 154)
Baldwin Lima Hamilton			Pinion and Drive Shaft	1	304 SS	3.005 in./2.995 Pitch diameter with shaft G _L 60.005 in./59.995 Pitch diameter with mating ring gear D.P. -6-20° P. A. 18 teeth Pitch cone angle 2°-51'-45" Shoulder bushing Shaft diameter 1.375 in./1.374 Outer bushing Shaft diameter 1.250 in./1.249	Clearance Shaft with shoulder bushing ID 0.003 in./0.005 Shaft with outer bushing ID 0.004 in./0.006	100-3-770				
Assy. Dwgs. 100-7-1380 100-7-1440			Shoulder Bushing	1	440 C SS Surf Kote M-1280	ID 1.379 in./1.378 OD 1.877 in./1.876 Rockwell C 60, 62	Clearance Shoulder bushing ID with shaft 0.003 in./0.005 Shoulder bushing OD with housing press fit	100-2-880				

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Mechanism	No. in Plant	Design Information						Operating Environment				
		Primary Material of Construction	Component	No. per Mechanism	Material of Construction	Dimensions and Manufacturing Tolerances	Clearances, Loading, and Speed	Drawing No.	Operating Medium	Operating Medium Impurities	Temperature, Velocity and Pressure	Exposure to Environment (hr)
			Outer Bushing	1	440 C SS Surf Kote M-1280	ID 1.255 in. / 1.254 OD 1.627 in. / 1.626 Rockwell C 60, 62	Clearance Outer bushing ID with shaft 0.004 in. / 0.006 Outer bushing OD with housing press fit	100-2-960 (100-2-961)	Argon and Sodium Vapor (Sodium Drippings)	Range ^(ppm) Not available	Avg. ≈ 175 to 350°F (Ref. 3)	Hr. of Exposure Not available
			Shaft Housing	1	304 SS	Shoulder bushing seat ID 1.874 in. / 1.875 Outer bushing seat ID 1.624 in. / 1.625	Clearance Bushings with housing press fit	100-2-870		<u>Total Moves</u> to Jan 1965 ≈ 315 (Ref. 154)		
			Rotor Bearing (Ball thrust)	1	SS	56 in. ID 60 in. OD 2 in. thick Kaydon A-6153	Commercial bearing standard clearances	100-7-1380				
			Shot Pin (Positioning pin)	1	304 SS	End of pin 1/2 in. radius sphere Main body OD 1.125 in. / 1.123	Clearance Pin body OD with block bushing 0.005 in. / 0.009	100-1-440				
			Pin Block (Bearing)	1	304 SS	Bushing seat ID 1.5000 in. / 1.5007 1-1/2 in. seat length Spring retainer pin seat 0.5005 in. / 0.5000	Clearance Bushing seat ID with bushing OD press fit Spring retainer pin with pin block press fit	100-4-460 100-2-1110				
			Block Bushings	2	440 C SS Surf Kote M1280	OD bushing 1.5015 in. / 1.5009 ID 1.130 in. / 1.132 Rockwell C-60, 62	Clearance Block bushing with pin body OD 0.005 in. / 0.009 Bushing OD with bushing seat ID press fit	100-4-460 100-1-420				
			Spring Retainer Pin	8	304 SS	Pin stem OD 0.5008 in. / 0.5003 Pin head OD 0.810 in. / 0.780	Clearance Spring retainer pin with pin block press fit	100-4-460 100-1-450				

TABLE 44
EFAPP CASK CAR ROTOR PLATE AND LATCH ASSEMBLY
(Sheet 3 of 9)

Mechanism	No. in Plant	Design Information							Operating Environment			
		Primary Material of Construction	Component	No. per Mechanism	Material of Construction	Dimensions and Manufacturing Tolerances	Clearances, Loading, and Speed	Drawing No.	Operating Medium	Operating Medium Impurities	Temperature, Velocity and Pressure	Exposure to Environment (hr)
Cask Car	11		Spring	4	Inconel-X	5.00-in. Free length Coil OD 1.75 in. Coil ID 0.91 in. Wire OD 0.420 in. Active coils 8 Coiling R. H. Solid length 4.20 in. Spring const 2400 lb/in.		100-2-1130 100-4-460	Argon and Sodium Vapor (Sodium Drippings)	Range (ppm) Avg.	Oper. Temp.	Hr of Exposure
			Flexible Joint	1	304 SS	See drawing		100-1-780		Not available	≈ 175 to 350° F ≈ 325° F Avg. (Ref. 3)	Not available
			Outer Bushing Housing	1	304 SS	Bushing seat ID 1.625 in./1.626 Length 0.625 in./0.630	Clearance Bushing with housing 0.001 in./0.003	100-4-460				Total Moves Not available
			Outer Bushing	1	440 C SS Surfkote M1280	OD 1.624 in./1.623 ID 1.130 in./1.132 Length 0.620 in./0.625	Clearance Housing with bushing 0.001 in./0.003 Bushing with index rod 0.005 in./0.009	100-1-430				
			Seal Bellows	1	321 SS	2 in. OD Mfg. print not available		100-2-1430 Robertshaw Fulton Dwg 13 595-R				
			Link Index Rod	1	304 SS	Rod OD 1.125 in./1.123	Clearance Index rod with bushing 0.005 in./0.009	100-2-1100				
			Latch	4	304 SS	Bushing seat ID 0.625 in./0.628 Thickness 0.627 in./0.623	Clearance OD bushing ID latch -0.001 in./0.003	100-1-520 100-1-530 100-1-500		Range (ppm) Avg.	≈ 175 to 350° F (Ref. 3)	Hr of Exposure
Latching Mechanism Assembly										Not available		Not available
Baldwin Lima Hamilton Assy. Dwg. 100-7-1470												Total Moves
1) Fuel Can	1											to Jan 1965
2) Shield Plug	1											≈ 315 (Ref. 154)

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Mechanism	No. in Plant	Design Information						Operating Environment				
		Primary Material of Construction	Component	No. per Mechanism	Material of Construction	Dimensions and Manufacturing Tolerances	Clearances, Loading, and Speed	Drawing No.	Operating Medium	Operating Medium Impurities	Temperature, Velocity and Pressure	Exposure to Environment (hr)
Cask Car			Gear	4	304 SS	Bushing seat ID 0.625 in./0.628 D Pitch 16 Pitch dia 1-1/8 P. A. 20° Cut 7 full teeth only Height of gear 0.941 in./0.933	Clearance OD Bushing ID Gear -0.001 in./0.003	100-1-520 100-1-530 100-1-570	Argon and Sodium Vapor (Sodium Drummings)	Range ^(ppm) Avg.	Temperature, Velocity and Pressure	Exposure to Environment (hr)
Latching Mechanism Assembly										Not available	≈ 175 to 350° F (Ref. 3)	Not available
Baldwin Lima Hamilton												Total Moves to Jan 65 ≈ 315 (Ref. 154)
Assy. Dwg. 100-7-1470 (Continued)			Bushing	4	440C - SS	ID 0.503 in./0.500 OD 0.626 in./0.625 Flange to base height 1.563 in./1.558 Surf fin 63 Rockwell C 60, 62	Clearance Axial clearance between latch gear and bushing height -0.010 in./0.007 OD bushing ID gear and latch -0.001 in./0.003 Interference fits will be intolerable	100-1-520 100-1-530 100-1-480				
1) Fuel can 2) Shield plug	11 1		Latching Ring Gear	1	304 SS	Follower surface diameter 10.745 in. / 10.742 Follower track height 0.630 in./0.627 D Pitch 16 Pitch dia 10-7/8 in. P. A. 20° Cut 8 full teeth only	Clearance follower to latch ring follower track surface 0.004 in./0.010 Follower track height to follower height 0.002 in./0.012	100-2-1060 100-2-1070				
			Follower Roller	4	304 SS	Follower surface ID 10.752 in. / 10.749 OD 0.690 in. / 0.693 Bearing surface 0.390 in./0.388 Height 0.625 in./0.618 Surf fin 63	Clearance follower to latch ring follower track surface 0.004 in./0.010 Follower track height to follower height 0.002 in./0.012 Roller ID to bearing OD 0.004 in./0.009	100-C-840 100-1-340				

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Mechanism	No. in Plant	Design Information						Operating Environment				
		Primary Material of Construction	Component	No. per Mechanism	Material of Construction	Dimensions and Manufacturing Tolerances	Clearances, Loading, and Speed	Drawing No.	Operating Medium	Operating Medium Impurities	Temperature, Velocity and Pressure	Exposure to Environment (hr)
			Follower Bearing	4	440 C SS Surfcoat M1280	OD 0.686 in./0.684 ID 0.505 in./0.502 Height 0.402 in./0.400 Rockwell C-60-62	Clearance Bearing OD to follower ID 0.004 in./0.009 Bearing ID to stud OD 0.003 in./0.007 Bearing height to bearing surface height 0.003 in./0.006	100-2-840 100-1-350	Argon and Sodium Vapor (Sodium Drippings)	(ppm) Range Avg. Not available	Oper. Temp. ≈ 175 to 350° F (Ref. 3)	Hr of Exposure Not available Total Moves to Jan 65 ≈315 (Ref. 154)
			Follower Stud	4	304 SS	Bearing surface OD 0.499 in./0.498 Height of bearing surface 0.405 in./0.406 Surf fin 32	Clearance Bearing ID to stud OD 0.003 in./0.007 Bearing height to bearing surface height 0.003 in./0.006	100-2-840 100-1-370				
			Drive Lever	1	C-1020 Steel	Pin diameter 1/2 in. Pin length 1-5/16 in.	Clearance not critical	100-2-1050				
			Rotating Finger	1	304 SS	Drive shaft seat ID 0.628 in./0.626 Finger diameter 1/2 in. Finger length 1-7/8 in.	Clearance Finger assy seat with shaft (keyed) 0.002 in./0.006	100-2-1090				
			Actuating Shaft	1	304 SS	OD 1.003 in./1.000 OD at pillow block seat 0.750 in./0.745 OD at rotating finger 0.624 in./0.622 Length 64 in.	Clearance Shaft OD to finger assy (keyed) 0.002 in./0.006 Shaft OD to pillow block 0.003 in./0.011 Shaft OD to seal bushings -0.001 in./0.004	100-3-750				
			Split Pillow Block	1	304 SS	ID Shaft seat 0.756 in./0.753 Brg length 2 in.	Clearance Shaft OD to pillow block 0.003 in./0.011	100-3-980				

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EFAPP CASK CAR ROTOR PLATE AND LATCH ASSEMBLY
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Mechanism	No. in Plant	Design Information							Operating Environment			
		Primary Material of Construction	Component	No. per Mechanism	Material of Construction	Dimensions and Manufacturing Tolerances	Clearances, Loading, and Speed	Drawing No.	Operating Medium	Operating Medium Impurities	Temperature, Velocity and Pressure	Exposure to Environment (hr)
			Seal Bushing	2	304 SS Surf coat M1280	ID Shaft seat 1.002 in./1.004 Length 1 in.	Clearance Shaft OD to seal bushings -0.001 in./0.004	100-1-550	Argon and Sodium Vapor (Sodium Drippings)	Range (ppm) Avg. Not available	Oper. Temp. ≈ 175 to 350°F (Ref. 3)	Not available
Cask Car (Modifications)	1		Finger Shafts	2	Stellite 6B	Length to tru arc end rings 13.616 Shaft OD 0.625 in./0.624	Axial clearance of shaft in bearings 0.010 in./0.015 Shaft to finger and crank (keyed) 0.001 in./0.003 Shaft to bearing 0.005 in./0.008	6XN5604 84XN5603			≈ 175 to 350°F ≈ 325°F Avg.	Total Moves to July 1967 ≈ 240
Latching Assembly March 1965 Shield Plug	3		Bearing Blocks (Common to finger shaft)	8	Ampco No. 18 or 21	ID of bearing surface 0.630 in./0.632 Bearing surface length 0.50 each block	Clearance Bearing to shaft 0.005 in./0.008	6XN5604 6XN5607				
Finned Pot			Fingers (Keyed to shaft)	4	347 SS	Shaft bore ID 0.626 in./0.627 Contact surface with finned pot or plug 0.38 in. deep	Clearance Finger to shaft (keyed) 0.001 in./0.003	6XN5608 6XN5606				
Assy. Dwg. 84XN5603			Shaft Crank (Keyed to shaft)	2	304 SS	ID of shaft bore 0.626 in./0.627 ID of crank pin bore 0.626 in./0.627 Face to face link clearance 0.61 in./0.63	Clearance Link surface to crank surface when centered 0.06 typ Shaft crank to shaft (keyed) 0.001 in./0.003	6XN5604 84XN5603				
(Drawer MR Vellums)			Crank Pin	2	Stellite 6B	1.38 in. length OD 0.625/0.624 Surf fin 16	Clearance Crank pin to link 0.005 in./0.008	6XN5608				
			Link L.H. R.H.	1 1	Ampco No. 18 or 21	Pin G ₁ to G ₂ 7.753 in./7.749 Pin bore ID 0.630 in./0.632 Surf fin 16	Clearance Link surface to crank cam surface 0.004 in./0.008 Link to pins 0.005 in./0.008	6XN5608 84XN5603				

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EFAPP CASK CAR ROTOR PLATE AND LATCH ASSEMBLY
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Mechanism	No. in Plant	Design Information							Operating Environment			
		Primary Material of Construction	Component	No. per Mechanism	Material of Construction	Dimensions and Manufacturing Tolerances	Clearances, Loading, and Speed	Drawing No.	Operating Medium	Operating Medium Impurities	Temperature, Velocity and Pressure	Exposure to Environment (hr)
			Bearing Pin LH RH	1 1	Stellite 6B	LH length 2.00 in. RH length 1.38 in. Pin OD 0.625 in./0.624	Clearance Bearing pin to link 0.005 in./0.008	6XN5608	Argon and Sodium Vapor (Sodium Drippings)	Range ^(ppm) Avg. Not available	Oper. Temp. ≈ 175 to 350° F ≈ 325° F Avg.	Hr of Exposure Not available Total Moves to July 1967 ≈ 240
			Cam-Crank	1	Stellite 6B	LH pin bore 5/8 in. dia snug S. F. with bearing pin RH pin bore 5/8 dia snug S. F. with bearing pin Cam surface width 0.250 in./0.248	Clearance Cam surface to follower way 0.060 in./0.064	6XN5610B				
			Cam Crank - Shaft	1	Stellite 6B	Length face cam crank to face driver crank 2.510 in./2.512 OD shaft 1.244 in./1.242	Clearance Shaft to bushing 0.007 in./0.010 Length face to face shaft to bushing housing 0.008 in./0.016	6XN5610B				
			Crank Bushing	2	Ampco No. 18 or 21	OD 1.503 in./1.502 ID 1.251 in./1.252 Flange width 0.125 in./0.123	Clearance Bushings to shaft 0.007 in./0.010 Bushings to housing -0.001 in./0.001	6XN5608				
			Bushing Housing (Split)	1	304 SS	ID 1.502 in./1.503 Length with bushing flanges 2.373 in./2.377	Bushing housing to bushing OD -0.001 in./0.001 Bushing housing to shaft length 0.008 in./0.016	6XN5611				
			Skid Button	1	416 SS	0.06 in. crown 0.50 diam head	Skid button head to cam crank surface clearance 0.002 in./0.004	6XN5607 4XN5603				
			Drive Crank	1	Stellite 6B	1.75 in. width 0.75 in. thick Shaft to drive pin Q _L 5.000 in.	Clearances not critical	6XN5610B				

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EFAPP CASK CAR ROTOR PLATE AND LATCH ASSEMBLY
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Mechanism	No. in Plant	Design Information							Operating Environment			
		Primary Material of Construction	Component	No. per Mechanism	Material of Construction	Dimensions and Manufacturing Tolerances	Clearances, Loading, and Speed	Drawing No.	Operating Medium	Operating Medium Impurities	Temperature, Velocity and Pressure	Exposure to Environment (hr)
			Drive Pin	1	Stellite 6B	0.75 in. OD 2-5/8 in. length	Clearances not critical	6XN5610B	Argon and Sodium Vapor (Sodium Drippings)	Range ppm Avg. Not available	Oper. Temp. ≈ 175 to 350°F ≈ 325°F Avg.	Hr of Exposure Not available Total Moves to July 1967 ≈ 240
			Drive Pin Seat	1	304 SS	1-1/4 in. OD 0.75 in. ID	Clearances not critical	6XN5610B				
			Cam Follower	1	Ampco 18 or 21	Follower way 0.310 in./0.312 ID pivot (shoulder screw) 0.630 in./0.632 Sliding surface raised 0.06 in. Follower pivot height 0.725 in./0.723	Clearance follower to shoulder screw diameter 0.005 in./0.008 Follower to shoulder screw height 0.007 in./0.022 Follower way to cam surface 0.060 in./0.064	6XN5609B				
			Mechanism Flipper	1	347 SS	Length 5.88 in. Width 0.625 in. Depth 0.88 in. Shaft bore 0.998 in./0.999	Clearance flipper to shaft 0.000 in./0.002	6XN5609B				
			Drive Shaft Flipper	1	Stellite 6B	OD 0.998 in./0.997	Clearance shaft to flipper 0.000 in./0.002 Shaft to bearing 0.008 in./0.013	6XN 5609B				
			Drive Shaft Flipper Bearing	1	Ampco 18 or 21	OD 1.500 in./1.499 ID 1.006 in./1.010 Bearing contact length total 2.00 in.	Clearance flipper shaft to bearing 0.008 in./0.013	6XN5609B				
			Universal Joint	2	Alloy steel	Boston J200B Bored joints	Standard Component commercial tolerances	84XN5603 1XN5638A				
			Drive Shaft Bearing Surface	1	Stellite 6 weld	Bearing OD 1.062 in./1.061 Bearing length 2 in.	Clearance shaft to bearing 0.010 in./0.013	6XN5610B				

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EFAPP CASK CAR ROTOR PLATE AND LATCH ASSEMBLY
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[illegible]

the new rotor previously described. Partial closure was completed as the finned pot was brought to rest on the fingers. This unit functioned for its limited life without incident.⁽¹¹⁷⁾ The support latch drive shaft, however, seized in its outer support bushing (both of Type 440 C-CRES). The shaft was undercut and chromed 0.0015 in., out to the Stellite overlay, and new bushings were fabricated.

f. Argon Circulation Heating and Cooling System (Table 45)

The circulation system consists of two axial-type blowers circulating argon cover gas through a heating or cooling section, regulating flow by means of dampers.

(1) Statement of Operability. Continuous operation of the blowers was very limited. Blower shafts developed critical frequencies at speeds below the operating speeds and the bearings of the blower motors failed as a result of the imbalance. The blower shaft rubbed in the blower housing and in the penetration through the roof of the cask.

(2) Statement of Maintainability. Maintenance of the original blower was impossible without the cask car being disassembled. The original motors were replaced with motors having special provision for changing the bearings external to the cask.

Sodium deposited on the impeller; due to the length-to-diameter ratio of the shaft it would bend on starting, and the resulting vibration shortened bearing life.

The high flow of argon gas through the cask created a sodium aerosol which resulted in sodium deposits in all sections of the cask. This led to problems such as argon heater failure when sodium shorted-out the leads to the heaters.

(3) History of Malfunction and/or Modification. The axial blowers had chronic lower motor bearing problems. Maintaining a balanced shaft was difficult due to sodium-sodium oxide deposition on the impeller (Refs. 44, 48, 105, 118, 120, 122). Clearances remained a problem at shaft penetration points through the blower compartment and impeller housing. Shaft slip was accommodated by opening up clearances. Holes were drilled in the impellers to permit sodium drainage (8 grams of deposit removed from the impeller at one point in its history).

TABLE 45

EFAPP CASK CAR ARGON CIRCULATION HEATING AND COOLING SYSTEM
(Sheet 1 of 2)

Mechanism	No. in Plant	Design Information							Operating Environment			
		Primary Material of Construction	Component	No. per Mechanism	Material of Construction	Dimensions and Manufacturing Tolerances	Clearances, Loading, and Speed	Drawing No.	Operating Medium	Operating Medium Impurities	Temperature, Velocity and Pressure	Exposure to Environment (hr)
Cask Car										(ppm)		
Argon Blowers and Dampers			Blower Upper Shaft	1				100-3-1270 BLH	Argon and Sodium Vapor	Range Not available	Oper. Temp. ≈175 to 350°F 325°F Avg. (Ref. 3)	Hr. of Service Not available
Blower-Joy			Blower Lower Shaft	1				380480 (Joy)				
Mfg. Co. 1R-200-150 D1738 Assy. Dwg. X-722-21			Shaft Sleeve	2				100-1-1700 100-1-1720				
Baldwin Lima Hamilton Modification Assy. Dwg. 100-7-1630Z			Bushing	2	440C SS Surf-kote on ID M-1280	OD 3.250 in. line online fit with retainer ball ID 2.649 in. / 2.651 Rockwell C-60 Height bearing surface 1-1/4 in.		100-1-1710 100-1-1730				
Dampers 100-4-740 100-4-750			Bushing Retainer Ball	2	440C SS	ID Bushing Seat 3.250 in.		100-1-1690 100-1-1770				
			Damper housing with vane shaft bushings	6	Bushing Bronze Oilite A-842-2	Vane shaft bushing ID 1/2 in. press fit into housing sleeve Housing internal width 34 in.		100-3-1320				
			Damper housing with vane shaft bushings	6 bushings	Bushing Bronze Oilite A-842-2	Vane shaft bushing ID 1/2 in. press fit into housing sleeve Housing internal width 24 in.		100-3-1310				

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Mechanism	No. in Plant	Design Information						Operating Environment				
		Primary Material of Construction	Component	No. per Mechanism	Material of Construction	Dimensions and Manufacturing Tolerances	Clearances, Loading, and Speed	Drawing No.	Operating Medium	Operating Medium Impurities	Temperature, Velocity and Pressure	Exposure to Environment (hr)
			Vane	3	HR Sheet Steel AARM-117	Width 33-7/8 in.		100-4-750	Argon and Sodium Vapor ↑ ↓			
			Vane	3	HR Sheet Steel AARM-117	Width 23-7/8 in.		100-4-740				
			Vane Shaft	12	HR Steel AISI C-1020	Length varies with application OD 1/2 in. fit with bushing not defined		100-1-1070				
			Operating Arm	6	HR Steel AISI C-1020	Operator pin ID 25/64 in.		100-1-1080				
			Operator	2	HR Steel AAR-M 117	Pin ID 13/32 in.		100-1-1090 100-1-1091				
			Operator pin	6	Steel no callout	Pin OD 3/8 in.		100-1-1100				

The air-pressure sensing lines for the flowmeter reading air-argon heat exchanger pressure drop accumulated sodium-sodium oxide deposits requiring routine cleaning.^(41,120)

The damper shaft seal had to be replaced,^(6,118) and the heat exchanger continuously built up large sodium-sodium oxide deposits, requiring removal and cleaning.

12. FARB Equipment (No drawings available)

a. Transfer Rotor and Steam Cleaning Facilities

Facilities in the FARB were employed in the fuel handling cycle. Here, core and blanket components are placed in a sodium-filled transfer tank, then into a steam cleaning and water washing mechanism, and finally into a cutup pool. The transfer tank is filled with sodium at 400 to 450°F. The tank is provided with sodium plugging indication and cold trap facilities with surface skimming capabilities.^(126,127) The steam cleaning mechanism provides cleaning capability for the irradiated core components at a position 180 deg from the FARB cleaning mechanism-transfer rotor port. The system incorporates a waste gas storage system and component cooling or heating capability.

The interior of the steam cleaning mechanism is exposed to sodium contamination; however, continuous cleaning procedures minimize adverse sodium effects.

The rotor tank shaft penetration seal and bearing assembly operates in a sodium vapor environment. The system port valves also are exposed to sodium vapor and crud accumulation from drippage.

(1) Statement of Operability. Operation of the transfer rotor in the transfer tank of the FARB has been very satisfactory. The seals have functioned satisfactorily and no difficulty with the transfer rotor has been experienced.

Operating experience with the steam cleaning facilities has demonstrated adequate performance, but high maintenance can be expected. The steam cleaning process has been very efficient in the removal of sodium. No evidence of distortion or damage to components has been observed. Although the steam cleaning process is satisfactory for the present metallic fuel elements, the adaptability of the process to future fuel designs remains to be demonstrated.

The operation is complex due to the electrical interlocks for safety in preventing water-sodium reactions. The operation is also difficult to perform. When circuit malfunctions occur, the trouble-shooting process becomes quite involved and requires extensive knowledge of the system. Additional operating difficulty arises from the use of the same process piping for dry and inert gases as well as water or steam. Therefore, in going from one state to another (fluid or gas) the process lines must be dried.

Extensive difficulties have been experienced with the seals for the steam cleaning chamber. These seals must be replaced frequently.

Problems have also been experienced with the steam cleaning chamber gripper which is alternately exposed to sodium in the transfer tank, water in the cutup pool, or air in the dry loading tunnel. Each exposure must be followed by a cleaning and drying procedure using steam, followed by heated argon.

Additional difficulties experienced with the steam cleaning chamber gripper have been the occurrence of hangups caused by interferences which result from the tight fit between the steam cleaning chamber gripper and the steam chamber. The tight fit is needed to eliminate bypass gas flow. If the seal between the gripper and the steam cleaning chamber is insufficient, a large bypass flow of gas will result. Even though the design allows adequate clearances at room temperature or under isothermal conditions, operation of the steam cleaning chamber produces strong thermal gradients as a result of either steam flow or gas flow in this region, and uneven or unbalanced distortions result which have tended to obstruct the free travel of the gripper.

Further difficulty with the gripper has been experienced following insertion into the sodium transfer tank to pick up or deposit a subassembly. The coating of the gripper with a sodium film and the subsequent exposure to steam and water sometimes results in insufficient cleaning of the gripper and the "packing-up" of moving surfaces and joints, thus inhibiting its operation. Extensive modifications have been required to attain a workable gripper for all conditions of operation.

Operational experience indicates the desirability of the following changes or additions:

- 1) Arrangement of the equipment in "module" form in the steam cleaning room, for better accessibility and for removal in making repairs.
- 2) Enlargement of the cutup pool.
- 3) Regeneration of resins, in the pool water treatment, with a regenerative-type back-flushing system rather than the present non-regenerative-type disposal (demineralization) tanks.

(2) Statement of Maintainability. The steam cleaning chamber has been reasonably accessible because no high radiation level subassemblies have been cleaned; however, in the event of malfunctions during the cleaning of extended operation subassemblies, accessibility will be poor because of extremely high radiation levels.

The original design and construction was inadequate to meet the exacting demands of the operation. Consequently, extensive redesign, modifications and maintenance were required. Items such as valves and relays, for example, are expected to require considerable routine maintenance.

(3) History of Malfunction and/or Modification. Experience in use of the FARB facilities has been limited; however, service has been satisfactory.

Most steam cleaning mechanism gripper malfunctions were not caused by sodium environment effects. Initially, cleaning chamber distortion caused binding of the gripper housing. Machining greater clearances between the housing and chamber, although providing freedom of travel, also permitted bypass of a large percentage of the cooling cover gas flow. A 500°F silicone-rubber seal ring with a Type 304 CRES retainer ring was installed at the upper gripper full-stop position to act as a seal, eliminating bypass flow (Refs. 13, 128-132).

Scoring and galling of the gripper mechanism index cams necessitated removal of the index cam spring; increase of clearances in the "Graphitar" bushing and eventual replacement with parts fabricated of Type 304 CRES; and chrome plating of the stationary cam.⁽¹²⁹⁾ Erratic operation of both grippers necessitated an increase in clearances. The clearance was increased for the shroud spring in its seat. The shroud guide and finger guide inside diameters were made larger, and clearance of the shroud at the top inside diameter was

increased. The push rod spring was replaced with a counter weight. A stepped push rod assembly was installed, relieving binding in the radial bushing resulting from sodium oxide deposits. The spring retainer lip on the shroud was removed to provide spring compression clearance. A 75-deg camming surface was machined on the inside of the lower shroud lip. The interlock ball bearings were replaced with solid rollers of Type 440 C-CRES hardened to Rockwell 50 C.⁽¹²⁹⁾

The argon blower and cooler required disassembly to remove corrosion products from the internal surfaces.⁽¹³³⁾

The cleaning mechanism valve required modification due to operational difficulty. A new double O-ring seal replaced the original inflatable seal. The original seal elastomer was inadequate at system operating temperatures. The new seal utilized a double-wall metal bellows as the actuator, having a 5/16-in. stroke. The transfer tank cleaning mechanism port valve operating clearances were opened up. Operating seals, springs, drain holes and machined surfaces were modified. The cutup pool-cleaning machine port valve only required replacement of the packing and the Buna "S" seats with neoprene seats.^(134,135)

The steam cleaning machine valve failed to open three times due to galling of the valve stem and valve plate carrier. The Type 304 CRES bushing was replaced with Type 440 C-CRES (Rockwell 50 to 55 C) and Stellite 6. The bearing-to-shaft clearance was opened to 0.008 in. The stem bushing, also Type 440C CRES, had 1/16-in. wiper grooves machined on its inside surface. The cast-steel (hard-chrome-plated) bearing support pad of the valve plate carrier galled on the Type 304 CRES mating surface. The pad was machined off and Stellite weld deposited and finish machined. The valve housing has a new Type 304 CRES insert fabricated and pressed into place. The Buna "S" and asbestos gland packing was again modified, this time using Teflon.⁽¹³⁶⁻¹³⁸⁾

The steam cleaning chamber was remade using centrifugally cast CF-8M to eliminate distortion problems which had developed in the original chamber.⁽¹³⁴⁾

Indexing difficulty was experienced with the cleaning machine. The Ni-Resist gaskets in the main service line "Barco" joints became corroded. A lower temperature Buna N-carbon-asbestos material was used to make repairs.⁽¹³⁹⁾

Transfer tank shaft binding occurred as a result of a heavy deposit of sodium oxide and foreign material on the clamp ring bellows and outer housing. The lower face seal bellows was fully compressed with all expansion resilience gone. The lower rotating face seal developed a wear trail indicating poor contact with the stationary seal; and the O-ring seal became flattened. As a consequence, the following repairs and modifications were made. The radial bearing was replaced. The bellows was fully extended and heat treated to reseal the carbon face seals. The clamp ring was remachined and chrome plated, 12.005/12.004-in. ID and 13.862 in. OD, with 0.0005/0.001-in. chrome. The retainer and seal ring viton seals were replaced with a metal O-ring. The copper tube was replaced by one of CRES. A metal O-ring was installed at the upper inside edge of the support ring.⁽¹⁴⁰⁾

The oxide cleanup system was enlarged to 430 gal with a 20-gpm sodium flow cooled by a 5000-cfm nitrogen flow.⁽¹³⁴⁾

13. System Pumps (Table 46)

a. Primary Pumps

The primary sodium system consists of three interrelated loops, each delivering sodium to the reactor lower plenum region by means of separate pumps. The primary pumps (Figs. 57-60) are electric-motor-driven, centrifugal, vertical-shaft, sump-type pumps utilizing a nonhydrogenous oil-lubricated, inert-gas shaft seal with hydrostatic shaft bearings. The pump may be removed from its housing without draining the primary system. Pony motors provide 15% flow, as required, during pump power loss or reactor shutdown. Since maintenance on the inert gas seal was anticipated, a temporary static seal was included below the gas seal.

(1) Statement of Operability. The primary pumps have operated very successfully in sodium for almost 30,000 hr at speeds in the 300- to 860-rpm range. And in sodium temperatures of 450 to 1000°F no difficulties have been experienced with the shaft seals, main drive motor, bearings and liquid rheostat speed control. Pump internals, including sodium hydrostatic bearings, have operated successfully. The sodium bearings have imposed limitations on low-speed operation. Examination of the bearings after approximately 7000 hr of operation in sodium showed only normal wear marks.

Fig. 57. EFAPP Primary Sodium Pump

ITEM NO.	DESCRIPTION
1	Discharge Piping
2	Discharge Containment
3	Bottom Lower Section
4	Seal Face
5	Bottom Upper Section
6	Bellows
7	Seal Face Guide
8	Bellows Ring
9	Cone Section
10	Discharge Pipe Stub
11	Pump Tank
12	Inlet Nozzle
13	Check Valve (Original Design)
14	Bell-shaped Housing
15	Lower Bearing Riser
16	Discharge Manifold
17	Manifold Pipes
18	Impeller Case
19	Impeller
20	Pump Shaft
21	Lower Bearing
	Cylinder Flange

*Pump Case Components

Direction of Sodium Flow →

Fig. 58. EFAPP Primary Sodium Pump Lower Assembly

Fig. 59. EFAPP Primary Sodium Pump Bearing Cylinder

Fig. 60. EFAPP Primary Sodium Pump Shield Plug

TABLE 46
EFAPP SYSTEM PUMPS
(Sheet 1 of 3)

Mechanism	No. in Plant	Design Information							Operating Environment			
		Primary Material of Construction	Component	No. per Mechanism	Material of Construction	Dimensions and Manufacturing Tolerances	Clearances, Loading, and Speed	Drawing No.	Operating Medium	Operating Medium Impurities	Temperature, Velocity and Pressure	Exposure to Environment (hr)
Primary Pump [Byron Jackson] (Ass'y IF-3435)	3	304 SS	Upper Hydro-static Bearing	1	304 SS Plated with Colmonoy 6	12.000 in. ID 12.002 in. ID Length 12-1/2 in.	Clearance: 0.020 in. 0.024 in.	3E-4044 Replaced by: 3E-4666	Liquid Sodium	<u>Range (ppm)</u> <u>Avg.</u> Oxygen (Sodium monoxide) 300 to 1000°F 493 Ave. 6 to 27, 12 Carbon 19 to 231, 62 Hydrogen 0.7 to 11, 2.4 Iron 0.1 to 6.7, 2.5 Nickel 0.05 to 3.4, 0.7 Chromium 0.1 to 2.0, 0.7	Sodium Liquid 300 to 1000°F 493 Ave. Shaft Speeds 300 to 800 RPM <u>Discharge Pressure</u> 110 psig (Ref. 3) <u>Flow Range</u> 0 thru 10.8 x 10 ⁻⁶ lb/hr maximum 8.85 x 10 ⁶ nominal (Ref 155)	<u>Pump Hr oper.</u> 1 23,085 2 20,880 3 20,012 (Ref 157 Feb. 19 Exposure hr 49,200)
			Upper Hydro-static Bearing Journal	1	304 SS Plated with Colmonoy 5	11.980 in. OD 11.978 in. OD		3B-7480				
			Lower Hydro-static Bearing	1	304 SS Plated with Colmonoy 6	12.000 in. ID 12.002 in. ID Length: 12-1/2	Clearance: 0.020 in. 0.024 in.	3E-4665				
			Lower Hydro-static Bearing Journal	1	304 SS Plated with Colmonoy 5	11.980 in. OD 11.978 in. OD		3B-7480				
			Upper Impeller Wear Ring	1	304 SS	18.940 in. OD 18.938 in. OD		RC-3215-1				
			Lower Impeller Wear Ring	1	304 SS	17.685 in. OD 17.683 in. OD		RC-3215-1				
			Lower Wear Ring Surfaces (Pump case)	1	304 SS	17.755 in. ID 17.757 in. ID	Clearance: 0.070 in. 0.074 in.	3F-4989				
			Upper Wear Ring Surface (Pump case)	1	304 SS							
Primary Pump Dis-charge Seal Assem-bly	3	304 SS	Seal Face	1	304 SS Faced with Colmonoy 6	15.875 in. ID 15.885 in. ID 18.700 in. OD 18.690 in. OD Length: 3-3/16 in.		3F-12963	Liquid Sodium			
			Discharge Pipe	1	304 SS	15.750 in. OD 15.740 in. OD	Clearance 0.125 in. 0.145 in.	3B-8408				
			Bellows	1	304 SS	19-3/4 in Mean diameter Length: 9 in.		3A-13364				
			Seal Ring	1	304 SS	16-3/16 in ID		3A-14550				
			Seal Face Guide	1	304 SS	25 in. OD		3A-12964				
			Seal Face Bearing	1		25-1/8 in. OD	Clearance: 1/8 in.	IF-3435	Liquid Sodium			

TABLE 46
EFAPP SYSTEM PUMPS
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Mechanism	No. in Plant	Design Information							Operating Environment			
		Primary Material of Construction	Component	No. per Mechanism	Material of Construction	Dimensions and Manufacturing Tolerances	Clearances, Loading, and Speed	Drawing No.	Operating Medium	Operating Medium Impurities	Temperature, Velocity and Pressure	Exposure to Environment (hr)
Overflow Pumps (Primary System)	2	304 SS	Bearings	5	304 SS Hard Surface with Colmonoy 6	3.625 in. ID 3.626 in.	Clearance: 0.018 in. 0.020 in.	1E-2843	Sodium Liquid	Range Avg. (ppm) Oxygen (sodium monoxide) 6 to 27, 12 Carbon 19 to 231, 62 Hydrogen 0.7 to 11, 2.4 Iron 0.1 to 6.7, 2.5 Nickel 0.05 to 3.4, 0.7 Chromium 0.1 to 2.0, 0.7	Sodium Liquid 300° to 1000°F 493°F Ave. Design Flow Range 0 to 100 gpm Design Outlet Pressure 56 psig max.	≈49,200
			Bearing Journals	5	304 SS Hard Surface with Colmonoy 5	3.607 in. OD 3.606 in. Length: 6-1/8 in.		3A-14730				
			Impeller Wear Rings	5	304 SS	6.101 in. OD 6.100 in.		1E-2843				
			Impeller Wear Ring Surface (pump case)	5	304 SS	6.125 in. ID 6.126 in.	Clearance: 0.024 in. 0.026 in.	1E-2843				
			Pump Case Wear Ring (bottom four)	4	304 SS	3.024 in. ID 3.025 in.	Clearance: 0.024 in. 0.026 in.	1E-2843				
			Pump Shaft	1	304 SS	3.000 in. OD 2.999 in.		1E-2843				
			Pump Case Wear Ring (top case)	1	304 SS	3.631 in. ID 3.632 in.	Clearance: 0.024 in. 0.026 in.	1E-2843				
			Pump Shaft Sleeve	1	304 SS	3.607 in. OD 3.606 in.		1E-2843				
			Labyrinth Seal Ring	1	304 SS	3.030 in. ID 3.032 in. Length: 1-1/2 in.	Clearance: 0.030 in. 0.033 in.	3T-27598				
Secondary Pumps [Byron Jackson] (Assy Dwg IF-4172 & IF-4399 Fermi)	3	304 SS	Hydrostatic Bearing	1	304 SS Faced with Colmonoy 6	12.000 in. ID 12.001 in. Length: 12-1/4 in.	Clearance: 0.017 in. 0.019 in.	3F-4580 3E-4733	Liquid Sodium	(Three samples Jan. 1967) Oxygen 8 to 27 Hydrogen 1.4 to 3.6	Temp. Range 300. to 767°F Flow Range 0 to 10.8 x 10 ⁶ lb/hr max. 8.85 x 10 ⁶ Nominal outlet pressure design Max. 51 psig	Oper. hr/loop 1. 11,633 2. 9,502 3. 15,246 Ref. 157 Hr of Expos. ≈49,200
			Hydrostatic Bearing Journal	1	304 SS Faced with Colmonoy 5	11.983 in. OD 11.982 in. Length: 13-3/4 in.		No Value				
			Upper Impeller Wear Ring	1	304 SS	18.462 in. OD 18.460 in. Length: 2-1/2 in.		RC-3343				

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TABLE 46
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Mechanism	No. in Plant	Design Information							Operating Environment			
		Primary Material of Construction	Component	No. per Mech- anism	Material of Construction	Dimensions and Manufacturing Tolerances	Clearances, Loading, and Speed	Drawing No.	Operating Medium	Operating Medium Impurities	Temperature, Velocity and Pressure	Exposure to Environment (hr)
Secondary Pumps (continued)	3	304 SS	Lower Impeller Wear Ring	1	304 SS	<u>18.442 in.</u> OD <u>18.440 in.</u> Length: 2-1/2 in.		RC-3343	<div style="text-align: center;"> ↑ ↓ Liquid Sodium </div>			
			Upper Impeller Wear Ring Surface (pump case)	1	304 SS	<u>18.500 in.</u> ID <u>18.502 in.</u>	Clearance: 0.038 in./0.042	3F-5012				
			Lower Impeller Wear Ring Surface (pump case)	1	304 SS	<u>18.500 in.</u> ID <u>18.504 in.</u>	Clearance: 0.058 in./0.064	3F-5011				

Operating experience with the shaft seals has indicated excessive wear on the seal faces. Modifications to the seal assembly to increase the service life of the seals were unsuccessful. Design improvements have been recommended to reduce excessive flexibility between stationary and rotating faces, provide positive lubrication at the seal interfaces, and to maintain adequate cooling of the seals. Control of minor cover gas leakage following shaft seal failure was successfully demonstrated by the use of a clean gas purge system operating as a backup.

The original thrust bearing in the drive was replaced with preloaded ball bearings to reduce end play created by reversal of pump thrust. The preloaded bearings have reduced the severity of damage but have not completely eliminated it.

(2) Statement of Maintainability. Rather frequent maintenance work has been required on the oil-lubricated, inert-gas shaft seal, the seal oil supply system pumps, and the liquid rheostat system. This work can be done in a conventional manner because of the accessible location of these components.

Major maintenance operations on the pump internals will be difficult after extended nuclear operation. The removability feature of the pumps was demonstrated when the check valves were replaced before nuclear operation began.

(3) History of Malfunction and/or Modification. The primary pump operated very well for approximately 30,000 hr at speeds from 300 to 860 rpm and at a temperature range of 450 to 1000°F.

Common operating difficulties were found with the shaft thrust bearings. The bearings operated noisily and overheated. A new 200-lb preloaded bearing set was installed as required.⁽¹⁴¹⁻¹⁴³⁾

Argon face seals required continuous maintenance. Replacement of the seal faces was required on the rotary and in some cases the stationary faces; twice for No. 1 and No. 2 pumps, and eight times for No. 3 pump (Refs. 46, 51, 142, 145).

A period of high shaft torque developed (100 to 300 ft-lb startup, 60 to 80 normal) for a period of 2 months in 1964, but did not hinder pump operation.^(141, 146)

Shaft hydrostatic bearings in No. 1 and No. 2 pumps developed shallow scoring which required polishing. The No. 1 pump lower journal and the No. 2 pump upper and lower journals required polishing. The No. 1 pump lower bearing pads (Colmonoy) were found slightly cracked. These cracks were ground through the hard facing to reduce the hazard of spalling.^(147,148)

Feasibility of pump removal and replacement was confirmed when the primary system check valves were replaced with new units that had closure dash pot assemblies (Refs. 36, 79, 148-150).

b. Secondary Pumps

The secondary sodium system consists of three distinct loops, each delivering sodium to the IHX by means of three vertical, centrifugal, single-stage pumps. The secondary pumps (Fig. 61, 62) utilize shorter drive shafts but, otherwise, are similar to the primary pumps.

(1) Statement of Operability. The secondary sodium pumps have operated very successfully for ~18,000 hr. Eddy current speed control coupling performance has been highly satisfactory.

The shaft seal oil system must be in service when the pump is shut down because of a temperature limit on the upper pump housing.

The interlock trips on the primary and secondary pumps affect each other because these motors are fed from the same 4800-v breaker. This has required interlock defeats during some maintenance periods, which is time consuming.

(2) Statement of Maintainability. Very little maintenance has been required on the secondary pumps. Some modifications to seal design could improve reliability and simplify seal replacement.

For major maintenance work on pump internals, the loop can be drained and pump internals removed vertically. This operation should be considerably easier than for the primary pumps. Contact maintenance on the secondary pump internals could be performed if required.

(3) History of Malfunction and/or Modification. The secondary pumps have operated successfully for approximately 18,000 hr. Frequent replacement was required of the argon gas face seals as in the primary pumps.^(3,41)

Fig. 61. EFAPP Secondary Sodium Pump

Item No.	Description
1	Impeller Nut
2	Relief Hole
3	Impeller Key
4	Lock Pin
5	Pressurized Bearing and Orifice
6	Bearing Housing
7	Journal
8	Bearing Sodium Inlet Pipe
9	Journal Key
10	Inner Barrel
11	Overflow Nozzle
12	Shaft
13	Cover Gas Nozzle
14	Baffle Plates
15	Outer Barrel
16	Oil Inlet - Cooling Jacket
17	Cooling Jacket
18	Oil Outlet Cooling Jacket
19	Bearing Cylinder Flange
20	Pump Case Flange
21	Oil Drain Outlet
22	Oil Inlet - Flange
23	Pipe Stub
24	Impeller Nut - Lock Screw
25	Impeller Case
26	Impeller
27	Deflector Plate
28	Vortex Breaker Plate
29	Windows
30	Journal Drain Holes
31	Connecting Plate
32	Cover Plate
33	Weir

Fig. 62. EFAPP Secondary Sodium Pump Section

c. Overflow Pumps

The two overflow pumps (Figs. 63-66) provide makeup sodium in the primary system and flow to the sodium service system. The pumps are multi-stage, centrifugal, sump-type units. The shaft-impeller assembly is supported by five, sodium-lubricated hydrodynamic bearings. A check valve is positioned around the upper bearing support operating vertically.

(1) Statement of Operability. Performance of the overflow pumps has been very satisfactory in intermittent service for more than 5 years. The five hydrodynamic sleeve bearings have operated without difficulty.

The excess capacity provided in the pumps required the addition of speed controls to prevent possible damage to other system components.

(2) Statement of Maintainability. The shaft face seal has required fairly frequent replacement. This has been accomplished with no major difficulty. Major maintenance operations on pump internals would be difficult after extended nuclear operation, requiring vertical removal of this presumably somewhat radioactive component.

(3) History of Malfunction and/or Modification. The shaft seized on the No. 2 pump in the labyrinth seal. The shaft center and upper bearings were found slightly scored with grooves approximately 0.003 in. deep. The shaft sleeves and one set of bearing inserts required resurfacing. Sleeve-to-insert clearances were 0.012 in. in the upper and lower impeller cases, and 0.015 in. in the intermediate column. The labyrinth type seal was abandoned in favor of the face-type seals, which were also present in the pumps. The seal contained a black carbonaceous deposit introduced by the fluorlube used in the pump oil seal. The shaft oil seal assembly was found in good condition with the exception of deformed and hardened O-rings. Four times during its operating history, the pump shaft face seals required repair. Difficulties realized were carbon face seal damage, binding or interference of the spring pressure rings, and general contamination from foreign deposits (Refs. 9, 22, 23, 44-46, 137, 141, 151-157).

Fig. 63. EFAPP Sodium Overflow Pump

<u>Item No.</u>	<u>Description</u>
1	Shaft Sleeve - Bottom Case
2	Bearing Ring
3	Case Bearing Housing
4	Bottom Case
5	Impeller
6	Series Case
7	Drain Holes
8	Impeller Pin
9	Bearing Pin
10	Pump Shaft
11	Lower Discharge Column

Fig. 64. EFAPP Sodium Overflow Pump Bowl

<u>Item No.</u>	<u>Description</u>
1	Pump Shaft - Lower Segment
2	Lower Discharge Column
3	Intermediate Discharge Column
4	Bearing
5	Column Bearing Housing
6	Shaft Sleeve
7	Upper Discharge Column
8	Pump Shaft - Intermediate Segment
9	Lock Screw
10	Key-coupling
11	Coupling Sleeve
12	Split Ring
13	End Collar
14	Upper Pump Shaft

Fig. 65. EFAPP Sodium Overflow Pump Discharge Column

Item No.	Description	Item No.	Description
1	Overflow Tank Support Nozzle	14	Bearing Support
2	Seal Ring	15	Outer Barrel
3	Check Valve	16	Upper Chamber
4	Inner Barrel	17	Deflector Sleeve Pin
5	Plate	18	Deflector Sleeve
6	Sleeve Pin	19	Deflector Ring
7	Orifice Holes	20	Fins
8	Upper Discharge Column Flange	21	Baffles
9	Shield Plug Bottom Flange	22	Flinger Grooves
10	Spacer	23	Labyrinth Ring
11	Discharge Nozzle	24	Labyrinth Ring Pin
12	Bearing	25	Steel Shield Plate
13	Column - Bearing Housing

Fig. 66. EFAPP Sodium Overflow Pump Discharge Section and Check Valve

14. System Check Valves (Table 47)

a. Primary System Check Valves

A check valve (Fig. 67) is attached at the lower end of each primary pump and provides loop isolation during pump shutdown. The valves operate at the discharge port of the pump (Fig. 58) and are removed with the pump on dis-assembly. The valve is a swing-disk type with a downflow configuration.

(1) Statement of Operability. Following the replacement in 1964 of the original check valves with new units, no difficulty of any kind has been experienced with these valves.

(2) Statement of Maintainability. The location of the check valves, integral with the primary pump internals, requires that the pump be removed before access to the check valves is possible. This was accomplished once before nuclear operation to replace the original valves. Repair or replacement of the new valves after extended nuclear operation will be very difficult, requiring semi-remote or remote maintenance operations.

(3) History of Malfunction and/or Modification. The valves originally used (Fig. 67) performed satisfactorily with regard to pressure drop; however, upon closure, considerable fluid hammer occurred in the system. The new valves (Fig. 67) utilized antihammer dash pot assemblies with spring-loaded disks which positioned the disk at approximately 12 deg from closure. Subsequent operation of the new design was satisfactory, with fluid hammer effects eliminated (Refs. 9, 3, 86, 147-149, 158).

a. Overflow Pump Check Valves

The overflow pump check valves (Fig. 66) are located internal to the overflow pump upper housing at the discharge nozzle elevation. Pump flow lifts the valve 1/2 in. vertically, uncovering eight, equally spaced 1-1/2-in.-diameter orifices discharging into the nozzle chamber.

(1) Statement of Operability. Check valve operation has been satisfactory except for a possible hangup as described in Section (3) of the following text.

(2) Statement of Maintainability. No maintenance has been required on the check valves.

a. ORIGINAL

b. REVISED

Fig. 67. EFAPP Primary System Check Valve

TABLE 47
EFAPP SYSTEM CHECK VALVES
(Sheet 1 of 5)

Mechanism	No. in Plant	Design Information							Operating Environment				
		Primary Material of Construction	Component	No. per Mechanism	Material of Construction	Dimensions and Manufacturing Tolerances	Clearances, Loading, and Speed	Drawing No.	Operating Medium	Operating Medium Impurities	Temperature, Velocity and Pressure	Exposure to Environment (hr)	
Throttle Valve (6 inch) Copes Vulcan Ass'y Dwg. X62209	1	304 SS	Plug Guide	1	A-167-54-GR-3 Stellite inner Surface	1-3/8 in radius ID profile 1.375 ID min. 1.370 center 3/4 in. height Surf. Fin - 63	<u>Clearance</u> 0.005 in. 0.012 in. <u>Speed</u> Infrequent Slow	W 63134 S 62258	Sodium Liquid	(ppm) Range Avg. Oxygen (Sodium Monoxide) 6 to 27, 12 Carbon 19 to 231, 62 Hydrogen 0.7 to 11, 2.4 Iron 0.1 to 6.7, 2.5 Nickel 0.05 to 3.4, 0.7 Chromium 0.1 to 2.0, 0.7	Sodium Liquid 300 to 1000°F 493°F average	Hr of Expos. ≈49,200	
			Plug-Lead Probe	1	Stellite outer surface	1.365 OD after stellite 1.363 2-1/2 in. height Surf fin - 63	<u>Clearance</u> 0.005 in. 0.012 in. <u>Speed</u> Infrequent Slow	L-65821 M-62252	Sodium Liquid				
			Plug-Main Portion	1	Stellite outer surface	Maximum diam. 4.826 in. Surf fin - 63		L-65821 M-62252	Sodium Liquid				
			Plug Seat	1	Stellite outer surface			W-63134	Sodium Liquid				
			Bellows	8	321 SS	Free length 2 ± 1/32 in. 1.500 in. 1.497 ID		M-62218	Sodium Liquid Outer Surface Argon Cover Gas Inner Surface				
			Inner Casing Centering Guides	a) bar 3 b) pin 6	A-167-54-GR-3	7.978 in. final 7.975 Effective OD Surf fin - 125	<u>Clearance</u> 0.008 in. 0.014 in. <u>Speed</u> motion only during valve mechanism removal	W-62210 a) S-62238 b) S-62237	Sodium Liquid				
			Outside Casing	1	A-312-SS GR-T 304 SS	7.986 in. 7.989 ID Surf fin - 63	<u>Clearance</u> 0.008 in. 0.014 in. <u>Speed</u> motion only during valve mechanism removal	M-62231	Sodium Liquid				

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EFAPP SYSTEM CHECK VALVES
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Mechanism	No. in Plant	Design Information							Operating Environment				
		Primary Material of Construction	Component	No. per Mechanism	Material of Construction	Dimensions and Manufacturing Tolerances	Clearances, Loading, and Speed	Drawing No.	Operating Medium	Operating Medium Impurities	Temperature, Velocity and Pressure	Exposure to Environment (hr)	
	1		With Primary Bellows Failure Operation Being Maintained With The Following Components In Sodium							Range (ppm)	Avg	Sodium Liquid	Hr of Expos.
			Bottom Valve Stem	1	A-276-55 304 SS Stellite surface in guide region	0.8753 in. OD 0.8750 in. After stellite 2-5/8 in. length	Clearance 0.0017 in. Speed Infrequent Slow	M-62224	Sodium Liquid with primary bellows failure				
			Stem Guide	1	A-167 304 SS Stellite surface	0.879 in. ID 0.877 in. ID	Clearance 0.0017 in. Speed Infrequent Slow	M-62219	Sodium Liquid with primary bellows failure				
Check Valve Original (16 inch) Edward Valves Inc. Ass'y Dwg. AE3960-8	3	304 SS	Disc	1	304 SS Stellite No. 6 contact surface	Minor diam. 14.492 in. 14.487 in. Major diam. 14.952 in. 14.946 in. 30° 5' face 29° 55' angle	Face of seat and disc are lapped after final machining	C-39793 C-39794	Sodium Liquid	Oxygen (Sodium Monoxide) 6 to 27, 12 Carbon 19 to 231, 62 Hydrogen 0.7 to 11, 2.4 Iron 0.1 to 6.7, 2.5 Nickel 0.05 to 3.4, 0.7 Chromium 0.1 to 2.0, 0.7	300 to 1000°F 493°F ave. Angular velocity of disc at closure 500 ft/sec Surge Pressure 500 psi at pump rpm = 850 Minor modification reduced pressure to 248 psi (Ref 160)	Valve Hours 1. ≈27,000 2. ≈28,440 3. ≈27,720 Operation Cycles 1. 255 2. 365 3. 289	
			Disc Bearing	2	CF-8 SS Stellite No. 6 bearing surfaces	1.278 in. ID 1.275 in. ID Seat depth 0.987 in. 0.984 in.	Clearance Pin to seat 0.0165 in. 0.0125 in. on radius	C-39793	Sodium Liquid				
			Bearing Pin	2	C. D. B-8 SS Stellite No. 6 bearing surfaces	1.250 in. OD 1.245 in. OD Final effective OD with stellite segmented. See drawing for details	Clearance Seat to pin 0.0165 in. 0.0125 in. on radius	C-39792	Sodium Liquid				
			Body Disc Seat	1	CF 8 SS Stellite No. 6 contact surface	Minor diam. 14.505 in. 14.500 in. Major diam. 14.902 in. 14.896 in. 30° 30' face 29° 30' angle	Face of seat and disc are lapped after final machining	A-39796.02	Sodium Liquid				

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Mechanism	No. in Plant	Design Information							Operating Environment			
		Primary Material of Construction	Component	No. per Mech-anism	Material of Construction	Dimensions and Manufacturing Tolerances	Clearances, Loading, and Speed	Drawing No.	Operating Medium	Operating Medium Impurities (ppm)	Temperature, Velocity and Pressure	Exposure to Environment (hr)
Check Valve Replacement (16 inch) Edward Valves Inc. Ass'y Dwgs AE5403-1 L-1948	3	304 SS	Disc Face	1	A-182 GR 304 SS	<u>Minor diam</u> 14.492 in. 14.487 in. <u>Major diam</u> 14.892 in. 14.886 in. Surf fin 125 60° 5' 59° 55' Angle with disc plane	Face of seat and disc are lapped after final machining	A-80409-01	Sodium Liquid			Hr of Expos. Valve 1. ≈22,200 2. ≈20,760 3. ≈21,480
			Body Disc Seat	1	A-351 GR CF8 Stellite seat surface	<u>Minor diam</u> 14.505 in. 14.500 in. <u>Major diam</u> 14.892 in. 14.886 in. 60° 2' 59° 58' Angle with seat plane Surf fin 16 after lapping	Face of seat and disc are lapped after final machining	A-44734-02	Sodium Liquid			
			Disc Bearing	2	A-182 GR-304 SS Stellite faced	2.278 in. ID 2.275 in. Final stellite facing Surf fin 125	a) 48° travel of pin in bearing b) load low c) speed of rotation approx. 500 ft/sec d) end pin to seat 0.033 in. 0.013 in.	A-80409-01 File 746 APDA A-44734-02	Sodium Liquid			
			Bearing Pin	2	304 SS Stellite faced	<u>Springbore</u> 1.728 in. 1.718 in. <u>OD</u> 2.250 in. 2.245 in. Surf fin 125 rms <u>Shoulder to end surface</u> 4.906/4.903	<u>Clearance</u> Bearing to pin 0.017 in. on radius 0.013 in. End pin to seat 0.033 in. 0.010 in.	B-45024 A-44734-02				
			Torsion Spring	2	Inconel X Jan W 562 A Class	5-3/8 in. free length 1.630/1.620 OD 0.314/0.310 wire	Travel 48° full torque 180 in-lb	C-44996	Sodium Liquid			

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Mechanism	No. in Plant	Design Information							Operating Environment			
		Primary Material of Construction	Component	No. per Mechanism	Material of Construction	Dimensions and Manufacturing Tolerances	Clearances, Loading, and Speed	Drawing No.	Operating Medium	Operating Medium Impurities (ppm) Range Avg.	Temperature, Velocity and Pressure	Exposure to Environment (hr)
Check Valve (Replacement) 16-inch (Continued)			Disc Damping Arm	1	304 SS Stellite contact face	17° angle with disc plane 3/16 stellite facing	Pressure surge on piston and rod expected at 600 psi maximum	A-80409-01 B-44933 File 746 APDA	Sodium Liquid			
			Piston Rod	1	Haynes Al-loy 25	Contact end with damping arm 3/4 radius 1.000 OD 0.999 Surf fin 32 8-3/4 length	a) Pressure surge on piston expected at 600 psi max. b) Speed sliding approx 500 ft/sec c) Clearance rod in guide 0.004 in/0.008	C-80396-01 D-45008 File 746 APDA	Sodium Liquid			
			Rod Guide	1	A-182 Gr F 304 Stellite faced	1.007 in. ID final 1.094 After stellite faced	a) Low surface load b) Speed sliding approx 500 ft/sec	A-45001-01 File 746 APDA	Sodium Liquid			
			Dashpot Piston	1	A-182 Gr F 304 Stellite faced	4.000 in. OD 3.999 Surf fin 32 5/8 in height	a) Clearance 0.004 in/0.006 b) Pressure surge on piston expected at 600 psi max. c) Speed sliding approx 500 ft/sec	C-80396-01 D-45005-01 File 746 APDA	Sodium Liquid			
			Dashpot Housing	1	A-182	4.005 in. ID 4.004 Surf fin 32	a) Low surface load b) Speed sliding approx 500 ft/sec	A-45001-01 File 746 APDA	Sodium Liquid			
			Closure Spring	1	Inconel X Jan W 562 A Class 2	3-15/16 in. free length 3.760 OD 3.740 0.137 wire diam. 0.133	Compression to solid height 2-15/16 in. compression supporting 16 lb	D-44998	Sodium Liquid			
Check Valve Sodium Overflow Pump Upper Discharge Plenum Assy Dwgs 1F4041-B 1F4192 (Byron Jackson)		304 SS	Orifice Plate	1	304 SS	16 in. overall OD Orifice holes eight equally spaced on 8-1/2 in. diam. 1-1/2 in. drill thru contact surface finish with valve plate 64 RMS		3C5404	Sodium Liquid	Oxygen (Sodium Monoxide) 6 to 27, 12 Carbon 19 to 231, 62 Hydrogen 0.7 to 11, 2.4 Iron 0.1 to 6.7, 2.5 Nickel 0.05 to 3.4, 0.7 Chromium 0.1 to 2.0, 0.7	Sodium Liquid 300 to 1000°F 493°F Ave.	Hours of Expos. ~49,200

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Mechanism	No. in Plant	Design Information							Operating Environment			
		Primary Material of Construction	Component	No. per Mech- anism	Material of Construction	Dimensions and Manufacturing Tolerances	Clearances, Loading, and Speed	Drawing No.	Operating Medium	Operating Medium Impurities (ppm)	Temperature, Velocity and Pressure	Exposure to Environment (hr)
Check Valve (Continued)			Support Sleeve	1	304 SS Sliding sur- faces Stellite 6 Colmonoy or equivalent *See note	5.250/5.248 in. OD 6-5/8 in. height above orifice plate Sliding surface finish 125 RMS	<u>Clearance</u> Sleeve to valve plate 0.040/0.042 in. on the radius	3C5404 *PRDC spec 4 for over- flow pumps page 3	Sodium Liquid			
			Valve Plate	1	304 SS Sliding sur- faces Stellite 6 Colmonoy or equivalent *See note	5.330/5.332 in. OD Overall height 6 in. Sliding surface finish 125 RMS Closure surface finish 4 RMS	<u>Clearance</u> Valve plate to sleeve 0.040/0.042 in. on the radius	3B9400 *PRDC Spec 4 for over- flow pumps page 3	Sodium Liquid			

(3) History of Malfunction and/or Modification. The only incident occurred during a filling of the reactor on June 12, 1968. Sodium back-flowed into the overflow tank, indicating possible improper seating of the check valve or valves.⁽¹⁵⁹⁾

15. Primary Throttle Valves (Table 47)

The bypass throttle valves (Fig. 68) are used as a variable-orifice controlling flow to the radial blanket at between 10 to 30% of the total system flow. The plug design permits partial flow at a fully inserted position. The valve is an angle-type, double-bellows seal valve contained within a pipe riser. The entire valve inner section can be disassembled from the operating floor level.

a. Statement of Operability

Performance of the primary throttle valves has been entirely satisfactory. It should be noted that because of the infrequent need to adjust blanket flow, these valves operate as essentially fixed-position (partially open) units. No operating difficulties have been experienced on the few occasions blanket flow adjustment has been required.

b. Statement of Maintainability

No maintenance of any kind has been required on these valves. Vertical removal of the valves would be required for access to valve internals. Valve replacement, rather than valve maintenance would probably be more practical, depending on the circumstances requiring valve removal.

c. History of Malfunction and/or Modification

The disk on valve No. 2 was found cracked early in its service life. The bellows and guides have performed well in sodium.⁽¹⁶⁰⁻¹⁶²⁾

16. Service System Valves (Table 48)

Valves in the service system (Fig. 69) are bellows seal valves (unless specified) of various sizes and configurations.

a. Statement of Operability

(1) Primary Service System Valves. Performance of the primary service system valves has been good, with the exception of some bellows failures. These failures are believed to have occurred as a result of impurities left on the

Fig. 68. EFAPP Throttle Valve

Fig. 69. EFAPP Sodium Service System

TABLE 48
EFAPP SERVICE SYSTEM VALVES
(Sheet 1 of 2)

Mechanism	No. in Plant	Design Information							Operating Environment			
		Primary Material of Construction	Component	No. per Mechanism	Material of Construction	Dimensions and Manufacturing Tolerances	Clearances, Loading, and Speed	Drawing No.	Operating Medium	Operating Medium Impurities	Temperature, Velocity and Pressure	Exposure to Environment (hr)
Valves, Small Primary Sodium Service 6P-721-1002-1R	27 (1) 1 (2) 2 (3) - (4) 9 (5) 1 (6) 1 (7) 1 (8) 1 (9) 1 (10) 1	304 SS	Bellows (Seamless Single Ply)	(1)(2)(3)(4)	(1)(2)(3)(4)(5)(6)(7)(8) 321 SS	(1)(2) FL 2-1/2 in. OD 1-1/2 in. ID 1 in. 3/8 in. stroke		(1) B41563 (2) B41564 (3) B41565 (4) B41566 (5) B41567 (6) B41863 (7) B41864 (8) B42214 (9) B45210 (10) B46445	Sodium Liquid Outer Surface Air Inner Surface	(ppm) Range Avg. Primary System Sodium Liquid Oxygen (Sodium Monoxide) 6 to 27, 12 Carbon 19 to 231, 62 Hydrogen 0.7 to 11, 2.4 Iron 0.1 to 6.7, 2.5 Nickel 0.05 to 3.4, 0.7 Chromium 0.1 to 2.0, 0.7 Secondary System Sodium Liquid Oxygen (Sodium Monoxide) 8 to 27 Hydrogen 1.4 to 3.6 (Three samples Jan. 1967) Sodium Vapor Cover Gas	Hours of Exposure ±49,200 (Bellows failures do not apply)	
				(5)(7)(9) 2	(9)(10) 347 SS	(3) FL 4-3/16 in. OD 2 in. ID 1-1/2 in. 5/8 in. stroke (4)(5)(6)(7)(8)(10) FL 6-1/4 in. OD 2 in. ID 1-1/2 in. 15/16 in. stroke 0.008 in. wall (9) FL 4.158 in. OD 1-3/4 in. ID 1-1/4 in. 5/8 in. stroke		See list above				
Secondary Sodium Service GP-721-1008-1K	45 (1) 4 (2) 2 (3) - (4) 1 (5) 2 (6) 1 (7) 1 (8) 1	304 SS	Bellows (8) Single Ply Seamless (1)(2)(3)(4)(5)(6)(7) Single Ply Seam Welded	1	(8) 321 SS (1)(2)(3)(4)(5)(6)(7) 347 SS	(1)(6)(7) FL 2.500 OD 1-1/2 in. ID 3/8 in. stroke 0.005 in. wall (8) FL 2-1/8 in. OD 1-1/2 in. ID 1 in. 3/8 in. stroke 0.009/0.010 in. wall (2)(3)(4)(5) FL 6.250 OD 2 in. ID 1-1/2 in. 15/16 in. stroke 0.008 in. wall		(1) B44660A (2) B44661A (3) B44662 (4) B44663 (5) B45146 (6) C47228 (7) C47229A (8) B48551	Sodium Liquid Outer Surface Air Inner Surface	Oxygen <25 to 90, <32 Carbon Monoxide <10 to <50, <11 Carbon Dioxide 4 to 100, <17 Hydrogen 2 to 1230, <69 Helium <4 to 680, <24 Methane <10 to 560, <40 Nitrogen 260 to 4960, 1958		

TABLE 48
EFAPP SERVICE SYSTEM VALVES
 (Sheet 2 of 2)

Mechanism	No. in Plant	Design Information							Operating Environment			
		Primary Material of Construction	Component	No. per Mechanism	Material of Construction	Dimensions and Manufacturing Tolerances	Clearances, Loading, and Speed	Drawing No.	Operating Medium	Operating Medium Impurities	Temperature, Velocity and Pressure	Exposure to Environment (hr)
			Seat and Plug Surfaces	1	304 SS Stellite-6 Faced	Not Available		See list above	Sodium Liquid			
Primary Cover Gas Recirculating System	28	304 SS	Bellows (Single Ply Seamless)	1	321 SS	(1a)(1b)(1c)(2)(3) FL 2-1/2 in. OD 1-3/8 in. ID 7/8 in. 3/8 in. stroke (4)(5)(7) FL 5-13/32 in. OD 1-3/4 in. ID 1-1/4 in. 13/16 in. stroke (6) FL 1-43/64 in. OD 1-1/8 in. ID 3/4 in. 9/16 in. stroke (8) FL 8-5/16 in. OD 2-3/8 in. ID 1-3/4 in. 1-1/4 in. stroke		(1a) C-43559A (1b) C-43560 (1c) C-46579 (2) C-45579A (3) C-45580A (4) B-45581A (5) B-45582 (6) D-45585 (7) C-45593 (8) B-45595A	Sodium Vapor			
	(1) 5								Outer Surface			
	(2) 5								Air Inner Surface			
	(3) 3											
	(4) 3											
	(5) 1											
	(6) 4											
	(7) 3											
	(8) 4											
			Seat and Plug	1	304 SS Stellite-6 Faced	Not Available		See list above	Sodium Liquid			

bellows during manufacture, and unsatisfactory heating design or heater failure. In several instances the cause of bellows failure is unknown. Special instructions to operating personnel are required to avoid the use of excessive force in closing these valves because of the potential for shear pin failure and consequent bellows damage.

(2) Secondary Service System Valves. With the exception of several instances of valve bellows failure, the performance of the secondary service system valves has been very good. The bellows failures are attributed to one or both of the following reasons:

- 1) Valve heating system design which does not permit sequential thawing or provides inadequate heating, thus allowing frozen sodium to damage the bellows on sodium thermal expansion or during valve operation.
- 2) Cold trapping of impurities in the bellows region of the valves with subsequent failure due to bellows fatigue or overstressing.

The valve extension rod design (reach-rod) for remote valve operation is not satisfactory, although this is not critical on the nonnuclear secondary system valves.

b. Statement of Maintainability

(1) Primary Service System Valves. Routine maintenance on these small primary system valves is not required. Because the valves are located in an inerted, shielded cell with the cold trap, plugging meter, etc., prompt access to the cell for valve repair or replacement is not possible after extended nuclear operation.

Repair or replacement of valves can normally be postponed to a scheduled shutdown because the valves are equipped with freeze seals and packing glands to prevent leakage to the inerted cell environment.

(2) Secondary Service System Valves. No routine maintenance is required for these valves. The few bellows failures have required bellows replacement. This effort, while more extensive than water system valves, can be accomplished relatively easily.

c. History of Malfunction and/or Modification

Operation in general has been satisfactory. Operational malfunctions are listed in Table 49.

TABLE 49
EFAPP SERVICE SYSTEM VALVES MALFUNCTIONS

System	Valve	Size (in.)	Location	Malfunction	Reference
Primary	V 502-1	3	Storage Tank	Bellows leak	163
Primary	FCV 504	1	Plugging indicator	Bellows leak	164
Primary	FCV 505	3	Economizer cold trap	Bellows leak	27, 165
Primary	FCV 506	3	(Double bellows) Overflow line pump	1. Bellows leak 2. Bellows leak 3. Bellows leak (manufacturer's defect)	166, 165 50 51
Primary	FCV 508	3	Cold trap economizer shell	Bellows leak	26, 165
Primary	V 514	3	Makeup line	Bellows leak	28
Primary	V 516	3	Overflow recirculating bypass	Bellows leak	167
Primary	V 521	3	IHX drain	1. Bellows leak 2. Disk leak (relapped disk and seat)	168 169
Primary	V 522	3	Overflow line	Bellows leak	168
Secondary	FCV 829	-	Plugging indicator	1. Bellows leak 2. Bellows leak	170 50
Secondary	V 836	-	Inlet cold trap	Bellows leak	47
Secondary	V 840	-	Cold trap line	Bellows leak	171
*	FCV 101	2	Return line, cold trap to transfer tank	Bellows leak	172
*	FCV 401	-	Return line, cold trap to transfer tank	Bellows leak	163

*Location not specified in drawings reviewed.

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APPENDIX

Bearing Material	Shaft Material	Bearing Diameter (in.)	Bearing Length (in.)	Diametral Clearance (in.)	Operating Temperature (°F)	Operating Loads	Operating Speeds	Surface Hardness	Maximum Exposure (hr)	Maximum Operating Cycles or hr	O ₂ Impurities Range/Avg (ppm)	Surface Finish (rms)	Comments or Failure Mode
EBR-II													
304 CRES, Haynes overlay	304 CRES, hard chrome plate	-	-	-	700 liquid	neglig	10 in./min	-	3,600	10 cycles	3.2 to 11.5 5.8	-	Shaft galled, bushing failure; replaced with the next listed bearing
Ampco 18-13	304 CRES, hard chrome plate	3.559/3.564	2-3/4	0.062/0.071	700 liquid	neglig	10 in./min	-	38,700	66 cycles	3.2 to 11.5 5.8	-	-
304 CRES, Haynes overlay	304 CRES	3.058/3.060	2-3/4	0.003/0.010	700 vapor	neglig	10 in./min	-	3,600	10 cycles	3.2 to 11.5 5.8	-	No failure, however replaced with the next listed bearing (Precautionary move)
Ampco 18-13	304 CRES	-	-	-	700 vapor	neglig	10 in./min	-	38,700	66 cycles	3.2 to 11.5 5.8	-	-
Ampco 18-13	304 CRES	6.024/6.032	1	0.024/0.036	700 liquid	neglig	6 in./min	-	39,420	2,255 cycles	3.2 to 11.5 5.8	-	-
Ampco 18-13	304 CRES	2-1/32	1/2	1/32	700 vapor	neglig	-	-	39,420	-	3.2 to 11.5 5.8	125	-
Ampco 18-13	304 CRES	3.720	1-1/8	0.052	700 liquid	neglig	5 in./min	-	39,420	70 cycles	3.2 to 11.5 5.8	-	Split bushing
Ampco 18-23	304 CRES	6.007/6.009	1.510/1.515	0.007/0.011	700 liquid	neglig	20 in./min	-	39,420	2,255 cycles	3.2 to 11.5 5.8	-	-
Ampco 18-23, centrifugal cast	304 CRES	7.007/7.008	-	0.007/0.010	150 vapor	-	-	-	39,420	2,255 cycles	3.2 to 11.5 5.8	-	-
304 CRES, Colmonoy face	304 CRES	11.983/11.982	-	0.018/0.020	700 liquid	mech. & hydr.im-balance	108 to 1075 rpm	-	30,240	10,080 hr	3.2 to 11.5 5.8	-	-
304 CRES, Colmonoy face	304 CRES	12.000/11.982	-	0.018/0.020	700 liquid	mech. & hydr.im-balance	108 to 1075 rpm	-	30,240	10,080 hr	3.2 to 11.5 5.8	-	-
304 CRES, Stellite face	304 CRES	14.000/13.958	-	0.042/0.044	700 liquid	-	108 to 1075 rpm	-	39,420	10,080 hr	3.2 to 11.5 5.8	-	-
304 CRES, Stellite face	304 CRES	18.000/17.958	-	0.042/0.044	700 liquid	-	108 to 1075 rpm	-	39,420	10,080 hr	3.2 to 11.5 5.8	-	-
420 CRES, chromed	18-4-1 or-2 tool steel chromed	0.375/0.376	-	0.010/0.013	700 to 845 liquid	-	-	Rc 50-55	39,420	2,255	3.2 to 11.5 5.8	-	-
Ampco 18-13	304 CRES	4.275/4.280	3	0.025/0.030	700 liquid	radial load 21 lb	very low	-	39,420	2,255	3.2 to 11.5 5.8	32	-
17-4 PH CRES	304 CRES	1.280	1-1/2	0.030	700 liquid	neglig	-	-	39,420	800	3.2 to 11.5 5.8	-	-
Ampco 18-23	304 CRES	1.265/1.270	0.770/0.760	0.015/0.022	700 liquid	neglig	-	-	39,420	800	3.2 to 11.5 5.8	-	-
Ampco 18	304 CRES	3.502/3.503	3/4	0.002/0.003 (or more)	700 liquid	neglig	7 ft/sec	-	39,420	8,055 hr	3.2 to 11.5 5.8	-	-
Ampco 18	304 CRES	3.501/3.502	1	0.001/0.002 (or more)	700 liquid	neglig	7 ft/sec	-	39,420	8,055 hr	3.2 to 11.5 5.8	-	Clearance was increased with no record of amount
Berylko 25 on 416 CRES carrier	347 CRES, hard chrome plate	1.866/1.864	0.0461	0.008/0.012	700 liquid	neglig	7 ft/sec	Berylko Rc 43 347 HCP Brinn 700-800	Guide tube 39,420	Guide tube 8,055 hr	3.2 to 11.5 5.8	32, Guide tube 20	-

Table A-1. Summary of Journal Bearings Used in Facilities Studied (Sheet 1 of 6)

Bearing Material	Shaft Material	Bearing Diameter (in.)	Bearing Length (in.)	Diametral Clearance (in.)	Operating Temperature (°F)	Operating Loads	Operating Speeds	Surface Hardness	Maximum Exposure (hr)	Maximum Operating Cycles or hr	O ₂ Impurities Range/Avg (ppm)	Surface Finish (rms)	Comments or Failure Mode
EBR-II (Continuation)													
Berylko 25 on 416 CRES carrier	347 CRES, hard chrome plate	2.190/2.187	0.0461	0.008/0.013	700 liquid	neglig	8.5 ft/sec	Berylko Rc 43 347 HCP Brinn 700-800	variable	variable	3.2 to 11.5 5.8	32, Guide tube 20	After 1 year of operation, bearings found severely corroded or eroded
Berylko 25 on 416 CRES carrier	347 CRES, hard chrome plate	1.783/1.781	0.0461	0.008/0.012	700 liquid	neglig	8.5 ft/sec	Berylko Rc 43 347 HCP Brinn 700-800	variable	variable	3.2 to 11.5 5.8	32, Guide tube 20	After 1 year of operation, bearings found severely corroded or eroded
Ampco 18-13	304 CRES, Colmonoy-5 hard face	2.250/2.252	5/8	0.0115/0.0150	150	-	-	-	3,360	52 hr	4 to 20 11.2	-	-
Ampco 22	304 CRES, Colmonoy-5 hard face	1.3780/1.3785	0.625	0.0045/0.0055	150 air	-	450 rpm	-	3,360	52 hr	-	8 to 16	-
Ampco 22	304 CRES, Colmonoy-5 hard face	1.6875/1.6880	1/2	0.0045/0.0055	650 vapor	-	450 rpm	-	3,360	52 hr	4 to 20 11.2	8 to 16	-
Stellite 6B	304 CRES, Colmonoy-4 hard face	1.6850/1.6855	1/2	0.0045/0.0055	700 liquid	-	450 rpm	-	3,360	52 hr	4 to 20 11.2	8	-
Stellite 6B	304 CRES, Colmonoy-4 hard face	1.9645/1.9650	1/2	0.0045/0.0055	700 liquid	-	450 rpm	-	3,360	52 hr	4 to 20 11.2	8	-
Stellite 6B	304 CRES, Colmonoy-4 hard face	1.4900/1.5005	-	0.0045/0.0055	700 liquid	-	480 rpm	-	3,360	52 hr	4 to 20 11.2	-	-
SRE													
304 CRES, Colmonoy-6, plated (1/32 in.)	304 CRES, Colmonoy-5 plated (1/32 in.)	10.000/10.002	-	0.016	300 to 700 liquid	-	to 1050 rpm	-	21,447	17,532 hr	1.6 to 30 10	-	-
304 CRES	304 CRES	13.500/13.502	-	0.027	300 to 700 liquid	-	to 1050 rpm	-	21,447	17,582 hr	1.6 to 30 10	-	-
304 CRES	304 CRES	12.000/12.002	-	0.037	300 to 700 liquid	-	to 1050 rpm	-	21,447	17,582 hr	1.6 to 30 10	-	-
304 CRES, Colmonoy-6, plated (1/32 in.)	304 CRES, Colmonoy-5 plated	8.000/8.002	-	0.016	300 to 700 liquid	-	to 1500 rpm	-	21,447	11,442 hr	-	-	-
304 CRES	304 CRES	9.500/9.501	-	0.028	300 to 700 liquid	-	to 1500 rpm	-	21,447	11,442 hr	-	-	-
304 CRES	304 CRES	9.500/0.505	-	0.028	300 to 700 liquid	-	to 1500 rpm	-	21,447	11,442 hr	-	-	-
HNPF													
304 CRES, Colmonoy-6, facing	304 CRES, Colmonoy-5 facing	12.000/12.002	13-1/2	0.020/0.021	300 to 945 liquid	-	to 850 rpm	-	22,000	21,897 hr	5 to 95 14	-	-
304 CRES	304 CRES	16.125/16.127	1-1/2	0.063/0.067	300 to 945 liquid	-	to 850 rpm	-	22,000	21,897 hr	5 to 95 14	-	-
304 CRES	304 CRES	15.310/15.312	1-3/4	0.060/0.074	300 to 945 liquid	-	to 850 rpm	-	22,000	21,897 hr	5 to 95 14	-	-
304 CRES, Colmonoy-6, facing	304 CRES, Colmonoy-5 facing	12.000/12.002	13-1/2	0.020/0.024	300 to 900 liquid	-	to 850 rpm	-	19,000	18,470 hr	5 to 95 14	-	Tramp debris migrated to bearing, caused binding

Table A-1. Summary of Journal Bearings Used in Facilities Studied (Sheet 2 of 6)

Bearing Material	Shaft Material	Bearing Diameter (in.)	Bearing Length (in.)	Diametral Clearance (in.)	Operating Temperature (°F)	Operating Loads	Operating Speeds	Surface Hardness	Maximum Exposure (hr)	Maximum Operating Cycles or hr	O ₂ Impurities Range/Avg (ppm)	Surface Finish (rms)	Comments or Failure Mode
HNPF (Continuation)													
304 CRES	304 CRES	16.125/16.127	1-3/4	0.063/0.067	300 to 900 liquid	-	to 850 rpm	-	19,000	18,470 hr	5 to 95 14	-	-
304 CRES	304 CRES	15.310/15.312	1-3/4	0.060/0.064	300 to 900 liquid	-	to 850 rpm	-	19,000	18,470 hr	5 to 95 14	-	-
EFAPP													
Inconel X	Inconel X	0.505/0.500	1.25	0.009/0.005	300 to 1000 493 avg liquid	-	-	-	49,200	2,039 hr 774 cycles	6 to 27 12	-	8 slots equally spaced around ID
Inconel X	304 CRES	0.645/0.641	1.180	0.098/0.096	300 to 1000 493 avg liquid	-	-	-	49,200	2,039 hr 774 cycles	6 to 27 12	-	-
304 CRES, nitrided	304 CRES, Colmonoy-4 overlay	2.126/2.125	1-3/4 to 2	0.005/0.007	300 to 1000 493 avg liquid	-	-	-	29,160	-	6 to 27 12	-	-
304 CRES, nitrided	304 CRES, Colmonoy-4 overlay	1.501/1.500	2	0.005/0.007	300 to 1000 493 avg liquid	-	-	-	29,160	-	6 to 27 12	-	-
316 CRES	304 CRES	0.777/0.775	0.375	0.003/0.009	300 to 1000 493 avg liquid	-	-	-	29,160	-	6 to 27 12	-	-
316 CRES	304 CRES	0.932/0.930	-	0.005/0.009	300 to 1000 493 avg liquid	-	-	-	29,160	-	6 to 27 12	-	-
Inconel X	304 CRES	2.188	5/8	0.063/0.068	300 to 1000 493 avg liquid	-	-	-	29,160	-	6 to 27 12	-	-
Inconel X	304 CRES	1.875	-	0.063/0.068	300 to 1000 493 avg liquid	-	-	-	29,160	-	6 to 27 12	-	-
Inconel X	304 CRES	0.505/0.500	0.316/0.312	0.007/0.001	300 to 1000 493 avg liquid	-	-	-	33,480	-	6 to 27 12	-	-
310 CRES, nitrided, Inconel X overlay	Inconel X	1.814/1.810	-	0.042/0.028	300 to 1000 493 avg liquid	-	-	-	33,480	-	6 to 27 12	-	-
CRES	304 CRES	3.64/3.62	7.26	0.075/0.100	300 to 1000 493 avg vapor	-	-	-	49,200	-	25 to 90 32	-	-
304 CRES, Colmonoy-4 facing	347 CRES, Colmonoy-4 facing	4.004/4.005	3	0.004/0.008	300 to 1000 493 avg liquid	-	-	-	49,200	657 move-ments	6 to 27 12	-	-
304 CRES	304 CRES, Colmonoy-4 facing	5.800/5.795	3.4	0.010/0.020	300 to 1000 493 avg liquid	-	-	-	49,200	657 move-ments	6 to 27 12	-	-
304 CRES	304 CRES, Colmonoy-4 facing	5.805/5.795	2.3	0.010/0.024	300 to 1000 493 avg vapor	-	-	-	49,200	657 move-ments	25 to 90 32	-	-
Colmonoy-5	304 CRES, Colmonoy-5 facing	0.640/0.641	0.45	0.015/0.016	300 to 1000 493 avg liquid	-	-	-	33,480	539	6 to 27 12	-	-
Colmonoy-5	304 CRES, Colmonoy-5 facing	0.890/0.891	3/8	0.015/0.016	300 to 1000 493 avg liquid	-	-	-	33,480	539	6 to 27 12	-	-
Colmonoy-5	304 CRES, Colmonoy-5 facing	1.270/1.274	1-1/2	0.025/0.020	300 to 1000 493 avg liquid	-	-	-	33,480	539	6 to 27 12	-	-
A-167-54, Gr 3, Stellite facing	Stellite surface	1.375/1.370	3/4	0.005/0.012	300 to 1000 493 avg liquid	-	-	-	49,200	-	6 to 27 12	a) 63 b) 63	-

Table A-1. Summary of Journal Bearings Used in Facilities Studied (Sheet 3 of 6)

Bearing Material	Shaft Material	Bearing Diameter (in.)	Bearing Length (in.)	Diametral Clearance (in.)	Operating Temperature (°F)	Operating Loads	Operating Speeds	Surface Hardness	Maximum Exposure (hr)	Maximum Operating Cycles or hr	O ₂ Impurities Range/Avg (ppm)	Surface Finish (rms)	Comments or Failure Mode
EFAPP (Continuation)													
CF-8 CRES, Stellite-6 facing	304 CRES, Stellite-6 facing	1.278/1.275	0.987/0.984	0.033/0.025	300 to 1000 493 avg liquid	-	500 ft/sec maximum	-	28,440	365 cycles	6 to 27 12	-	-
A-182, Gr-304 CRES, Stellite facing	304 CRES, Stellite facing	2.278/2.275	-	0.034/0.026	300 to 750 493 avg liquid	-	500 ft/sec maximum	-	22,200	519 cycles	6 to 27 12	a) 125 b) 125	-
A-182, Gr-F 304 CRES, Stellite facing	Haynes Alloy-25	1.007/1.004	-	0.008/0.004	300 to 750 493 avg liquid	-	500 ft/sec maximum	-	22,200	519 cycles	6 to 27 12	a) 32 b) 32	-
A-182, Gr-F 304 CRES	A-182, Gr-F 304 CRES, Stellite facing	4.005/4.004	5/8	0.006/0.004	300 to 750 493 avg liquid	-	500 ft/sec maximum linear	-	22,200	519 cycles	6 to 27 12	a) 32 b) 32	-
304 CRES, Stellite-6, or Colmonoy or equiv, facing	304 CRES, Stellite-6, or Colmonoy or equiv, facing	5.330/5.332	6	0.080/0.084	300 to 1000 493 avg liquid	-	-	-	49,200	-	6 to 27 12	a) 125 b) 125	-
304 CRES, Colmonoy-6 facing	304 CRES, Colmonoy-5 facing	12.000/12.002	12-1/2	0.020/0.024	300 to 1000 493 avg liquid	-	300 to 800 rpm	-	49,200	23,085 hr	6 to 27 12	-	-
304 CRES	304 CRES	17.755/17.757	-	0.070/0.074	300 to 1000 493 avg liquid	-	300 to 800 rpm	-	49,200	23,085 hr	6 to 27 12	-	-
304 CRES, Colmonoy-6 facing	304 CRES, Colmonoy-5 facing	3.625/3.626	6-1/8	0.018/0.020	300 to 1000 493 avg liquid	-	-	-	49,200	-	6 to 27 12	-	-
304 CRES	304 CRES	6.101/6.100	-	0.024/0.026	300 to 1000 493 avg liquid	-	-	-	49,200	-	6 to 27 12	-	-
304 CRES	304 CRES	3.024/3.025	-	0.024/0.026	300 to 1000 493 avg liquid	-	-	-	49,200	-	6 to 27 12	-	-
304 CRES	304 CRES	3.631/3.632	-	0.024/0.026	300 to 1000 493 avg liquid	-	-	-	49,200	-	6 to 27 12	-	-
304 CRES, Colmonoy-6 facing	304 CRES, Colmonoy-5 facing	12.000/12.001	12-1/4	0.017/0.019	300 to 770 liquid	-	-	-	49,200	15,246 hr	8 to 27 (3 samples)	-	-
304 CRES	304 CRES	18.500/18.502	2-1/2	0.042/0.038	300 to 770 liquid	-	-	-	49,200	15,246 hr	8 to 27 (3 samples)	-	-
304 CRES	304 CRES	18.500/18.504	2-1/2	0.064/0.058	300 to 770 liquid	-	-	-	49,200	15,246 hr	8 to 27 (3 samples)	-	-
304 CRES, Colmonoy-6 facing	304 CRES (insert material not given)	14.737/14.736	2.62	0.053/0.052	300 to 1000 493 avg liquid	-	-	-	49,200	7,510 cycles	6 to 27 12	-	Spiral grooves cut across length of bearing insert; 90 grooves 4.5 to 3.5 deg apart
304 CRES, Colmonoy-6 facing	304 CRES, Colmonoy-6 facing	11.699/11.698	-	0.080/0.078	300 to 1000 493 avg liquid	-	-	-	49,200	8,225 cycles	6 to 27 12	-	-
304 CRES	304 CRES	1.003/1.001	1.36	0.380/0.377	300 to 1000 493 avg liquid	-	-	-	49,200	766 mini-mum oper.	6 to 27 12	-	-
304 CRES, Colmonoy-5 inserts	347 CRES, Stellite-6 inserts	1.771/1.770	0.63/0.61 (2 areas)	0.022/0.020	300 to 1000 493 avg liquid	-	-	-	49,200	-	6 to 27 12	-	Two inserts, upper and lower

Table A-1. Summary of Journal Bearings Used in Facilities Studied (Sheet 4 of 6)

Bearing Material	Shaft Material	Bearing Diameter (in.)	Bearing Length (in.)	Diametral Clearance (in.)	Operating Temperature (°F)	Operating Loads	Operating Speeds	Surface Hardness	Maximum Exposure (hr)	Maximum Operating Cycles or hr	O ₂ Impurities Range/Avg (ppm)	Surface Finish (rms)	Comments or Failure Mode
EFAPP (Continuation)													
304 CRES	347 CRES, Colmonoy-6 inserts	1.140/1.142	0.031 (2 areas)	0.018/0.015	300 to 1000 493 avg liquid	-	-	-	49,200	-	6 to 27 12	-	Two inserts, upper and lower
304 CRES	Stellite-6B overlay	1.975/1.970	1-1/4	0.216/0.210	300 to 750 490 avg liquid	-	0 to 600 rpm	-	33,480	-	6 to 26 12	Journal 16, Brg. 125	-
304 CRES, Stellite-6 overlay	304 CRES, nitrided, Stellite-6B overlay	1.980/1.985	0.19	0.035/0.025	300 to 750 490 avg liquid	-	0 to 600 rpm	-	33,480	-	6 to 27 12	Journal 16, Brg. 125	-
304 Boron CRES, Ampco-22 inlay	304 Boron CRES, Colmonoy-5 overlay	1.025/1.026	1/4	0.011/0.009	300 to 750 490 avg vapor	-	0 to 600 rpm	-	33,480	-	25 to 90 32	-	-
304 CRES, nitrided	Colmonoy-4	1.584/1.587	3-3/4	0.025/0.020	300 to 750 490 avg liquid	-	0 to 600 rpm	-	33,480	-	6 to 27 12	-	Six each in two rows of journal pads
304 CRES	Colmonoy-4	0.343/0.346	7/32	0.025/0.020	300 to 750 490 avg liquid	-	0 to 600 rpm	-	33,480	-	6 to 27 12	-	Three each on each of two rings
304 CRES	Inconel X	0.717/0.718	1.375	0.004/0.001	300 to 750 490 avg	-	0 to 600 rpm	-	33,480	-	6 to 27 12	-	-
Colmonoy-4	Stellite-6 overlay	2.1005/2.1010	1	0.008/0.006	300 to 750 490 avg	-	0 to 600 rpm	-	33,480	-	6 to 27 12	-	-
304 CRES	304 CRES	2.002/2.003	1/4 (2 locations)	0.002/0.009	175 to 350 vapor	-	-	-	-	System oper. min./555 times	-	63	-
440 C CRES	304 CRES	2.004/2.003	2.31 and 3.00	0.003/0.010	175 to 350 vapor	-	-	Rc 60 to 62	-	System oper. min./555 times	-	63	-
440 C CRES, Surf-kote M-1280	304 CRES	1.756/1.755	1	0.005/0.008	175 to 350 vapor	-	-	Rc 60 to 62	-	System oper. min./555 times	-	Bushing 63, Shaft 125	-
440 C CRES	304 CRES	1.506/1.505	1	0.005/0.007	175 to 350 vapor	-	-	Rc 60 to 62	-	System oper. min./555 times	-	63	-
440 C CRES, Surf-kote M-1280	304 CRES	1.506/1.505	1-1/4	0.005/0.007	175 to 350 vapor	-	-	Rc 60 to 62	-	System oper. min./555 times	-	63	-
440 C CRES, Surf-kote M-1280	304 CRES	1.503/1.504	0.993	0.003/0.005	175 to 350 vapor	-	-	Rc 60 to 62	-	System oper. min./555 times	-	Bushing 63, Shaft 250	-
440 C CRES	440 C CRES, Surf-kote M-1280	1.503/1.504	1-3/4	0.003/0.005	175 to 350 vapor	-	-	Rc 60, 62	-	System oper. min./555 times	-	Shaft 125, Bearing 63	-
440 C CRES	440 C CRES	2.004/2.003	1.063	0.003/0.010	175 to 350 vapor	-	-	Rc 43, 45	-	-	-	63	-
440 C CRES	440 C CRES	0.879/0.877	1	0.003/0.007	175 to 350 vapor	-	-	Bushing Rc 48-50, Shaft Rc 43-45	-	-	-	63	-
440 C CRES	440 C CRES	1.505/1.503	0.750	0.002/0.006	175 to 350 vapor	-	-	-	-	-	-	63	-
304 CRES	440 C CRES	0.502/0.500	3/8	0.002/0.006	175 to 350 vapor	-	-	Shaft Rc 48-50	-	-	-	63	-

Table A-1. Summary of Journal Bearings Used in Facilities Studied (Sheet 5 of 6)

TABLE A-1. SUMMARY OF JOURNAL BEARINGS USED IN FACILITIES STUDIED (Continued)

Bearing Material	Shaft Material	Bearing Diameter (in.)	Bearing Length (in.)	Diametral Clearance (in.)	Operating Temperature (°F)	Operating Loads	Operating Speeds	Surface Hardness	Maximum Exposure (hr)	Maximum Operating Cycles or hr	O ₂ Impurities Range/Avg (ppm)	Surface Finish (rms)	Comments or Failure Mode
EFAPP (Continuation)													
440 C CRES	440 C CRES	0.504/0.502	1-31/32	0.004/0.008	175 to 350 vapor	-	-	Shaft Rc 48-50, Bushing Rc 43-45	-	-	-	63	-
304 CRES	440 C CRES	0.504/0.502	3/4	0.004/0.008	175 to 350 vapor	-	-	Shaft Rc 43-45	-	-	-	63	-
440 C CRES	304 CRES	0.504/0.503	0.375	0.003/0.005	175 to 350 vapor	-	-	Bushing Rc 60-62	-	Oper.315 times	-	63	-
440 C CRES	304 CRES	0.754/0.753	1.062	0.003/0.005	175 to 350 vapor	-	-	Bushing Rc 60-62	-	Oper.315 times	-	63	-
440 C CRES	304 CRES	0.504/0.503	9/32	0.003/0.005	175 to 350 vapor	-	-	Bushing Rc 60-62	-	Oper.315 times	-	63	-
440 C CRES	304 CRES	0.504/0.503	1	0.003/0.005	175 to 350 vapor	-	-	Bushing Rc 60-62	-	Oper.315 times	-	63	-

Table A-1. Summary of Journal Bearings Used in Facilities Studied (Sheet 6 of 6)

Bellows Material	Bellows Type	Wall Thickness (in.)	Bellows OD or ID (in.)	Active Conv.	Bellows Height (in.)			Operating Temperature (°F)	Medium		Operating Pressure or Speed	Exposure (hr)	O2 Impurities Range/Avg (ppm)	Operating Cycles or hr	Comments or Failure Mode	
					Neutral	Extended	Compressed		Inner	Outer						
EBR-II																
304 CRES	welded nested	-	8-3/4 OD	-	-	30	15	700	vapor (Argon)	air	10 in./min	38,920	3.2 to 11.5 5.8	70 cycles	-	
304 CRES	welded nested	-	15-3/4 OD	-	-	30	15	700	air	vapor (Argon)	10 in./min	38,920	3.2 to 11.5 5.8	70 cycles	-	
304 CRES	conv.	-	3 OD	70.5	14-3/4	-	12-3/16	700 maximum	air	vapor (Argon)	-	39,420	3.2 to 11.5 5.8	-	-	
347 CRES	welded flat	-	12 ID	4	4-1/4	-	3-1/4	700	liquid	liquid	60 psi	39,420	3.2 to 11.5 5.8	39,360 hr	-	
347 CRES	conv. 2 ply	0.010 total	1-11/64 OD 13/16 ID	89-1/2	9.991	9.991	8.866	700	air	liquid	5 psi	39,420	3.2 to 11.5 5.8	2,255 cycles	-	
347 CRES	conv. 2 ply	0.010 total	1-9/16 OD 1-7/64 ID	53-1/2	7.772	7.772	7.022	700	liquid	air	5 psi	39,420	3.2 to 11.5 5.8	2,255 cycles	-	
347 CRES	welded nested	0.010	4-1/2 OD 2-9/16 ID	-	-	24-13/16	9-15/16	150	air	vapor (Argon)	-	39,420	3.2 to 11.5 5.8	8,470 hr	Failed after 2,796 hr, March 1966	
321 CRES	conv.	0.006	1-1/2 ID 2.085 OD	-	11	(1.938 stroke)		700	air	liquid	-	39,420	3.2 to 11.5 5.8	2,255 cycles		-
304 CRES	welded opposed	0.010	9 OD 4 ID	-	20	(14-5/8 stroke)		150	air	vapor (Argon)	1 psi	39,420	3.2 to 11.5 5.8	8,055 hr	-	
SRE																
321 CRES	conv.	-	140-1/4 OD max 132 ID min	-	10-5/16/ 10-11/16	-	-	300 to 1030	vapor (helium)	air	-	-	93,600	-	93,600 hr	Small leak during full life
HNPF																
321 CRES ASTM A-240	conv.	0.050	228-7/8 OD maximum 222-3/4 ID minimum	-	20-3/4	-	22-1/4 (oper. length)	150 to 1000	vapor (helium)	air	-	-	≈22,000	-	-	-
EFAPP																
316 CRES	welded	0.006	1.080/1.040 ID 1.740/1.700 OD	20	-	(0.750 stroke)		300 to 1000 493 avg	Argon	liquid	-	-	≈25,850	6 to 27 12	full life 774 cycles 2,039 hr	Leak developed in first bellows Aug 64;
316 CRES	welded	0.010	2.270/2.230 ID 3.770/3.730 OD	700	-	(60 stroke)		300 to 1000 493 avg	vapor (Argon)	Argon	30 psi	49,200	25 to 90 32	774 cycles 2,039 hr	-	
316 CRES	welded	0.004	1.015/1.005 ID 1.605/1.595 OD	77	3.62	3.87	2.87	300 to 1000 493 avg	Argon	liquid	-	33,480	6 to 27 12	-	-	
316 CRES	welded	0.010	2.255/2.245 ID 3.755/3.745 OD	389	38.87	47.37	13.37	300 to 1000 493 avg	Argon	vapor (Argon)	-	33,480	25 to 90 32	-	-	
304 CRES	welded	-	3.625 ID 6.000 OD	-	-	20.88	8.88	300 to 1000 493 avg	Argon	vapor (Argon)	-	49,200	25 to 90 32	539 cycles	-	
304 CRES	conv.	-	19-3/4 mean diameter	-	9	-	-	300 to 1000 493 avg	liquid	liquid	110 psi	49,200	6 to 27 12	23,085 maximum	-	
304 CRES	welded	0.047/ 0.027	8.75 ID 11.00 OD	10 sections 65/section	-	137-1/2	-	300 to 1000 493 avg	Argon	vapor (Argon)	-	49,200	25 to 90 32	8,225 cycles elevation	-	
304 CRES	welded	-	1.050/0.950 ID 2.070/2.050 OD	-	-	5.25	4.12	300 to 1000 493 avg	Argon	liquid	-	49,200	6 to 27 12	8,225 cycles elevation	-	
304 CRES	-	-	16.00 ID 19.00 OD	-	-	Face Seal (No stroke length)		300 to 1000 493 avg	Argon	vapor	300 lb force on face seal	49,200	25 to 90 32	none	-	
321 CRES	welded nested	0.007	3-9/16 ID 4-1/2 OD	732	-	(Compressed 11.0)		300 to 750 490 avg	Argon	vapor	-	33,480	25 to 90 32	-	-	
304 CRES	welded	-	17-5/8 ID	-	-	(3/4 stroke)		175 to 350 325 avg	vapor (Argon)	air	-	-	-	-	-	

Table A-2. Bellows Used in Facilities Studied (Valve Bellows not included)