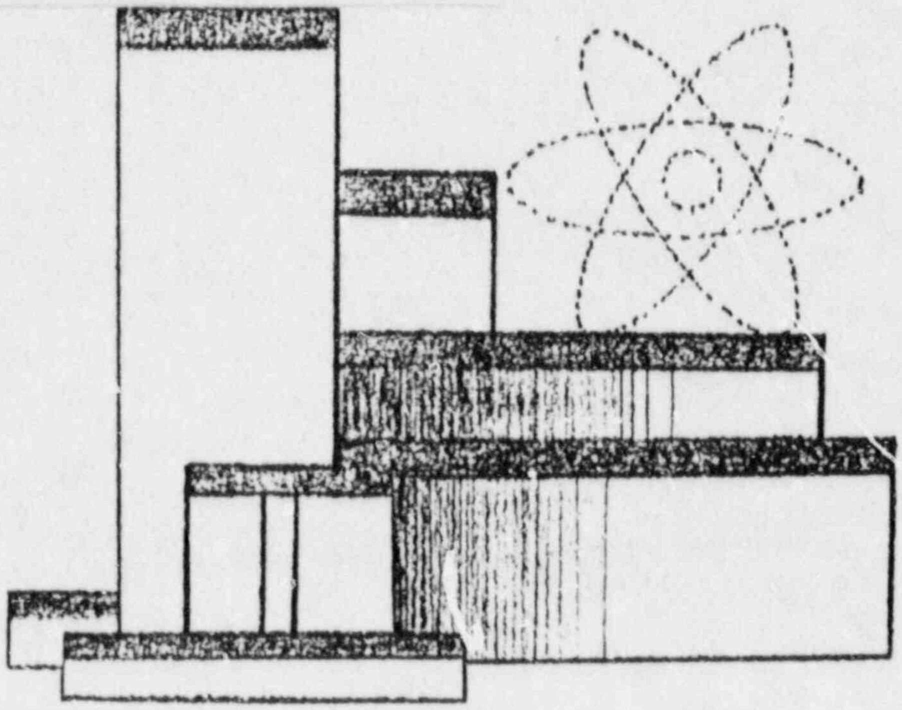
ATTACHMENT 1 (1 of 3)
P-88019

# Fort St Vrain



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# REPORT OF HELIUM CIRCULATOR
# S/N C-2101 AND INLET PIPING S/N 2001
# REPAIR AND MODIFICATION ACTIVITIES

January 22, 1988

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## 1.0 PURPOSE

The purpose of this report is to provide information relative to design changes and controls to be implemented on helium circulators at Fort St. Vrain as a result of damage to circulator C-2101. This report also addresses the damage and repairs associated with circulator C-2101 and inlet piping (penetration assembly) S/N 2001.

## 2.0 SUMMARY AND CONCLUSIONS

Helium circulator S/N C-2101 was removed from service in July, 1987 as a result of excessive shaft wobble indications and a purified helium interspace leak. The circulator was subsequently shipped to GA Technologies (GA) for inspection, evaluation and repair.

From the results of a metallurgical analysis performed on components from circulator C-2101, it has been determined that caustic stress corrosion cracking (SCC) was the initiating cause of component failure. A common environment to all the failed and damaged components is steam utilized for the turbine drive, suggesting this was the source of caustic contamination. The presence of caustics has been verified by a review of the water chemistry system records. There was also a period when significant levels of caustics were utilized in the chemical treatment program for the auxiliary boiler.

Fort St. Vrain's revised water chemistry procedures have made beneficial differences in the quality of condensate and steam. This, coupled with the more stringent water chemistry requirements described by this report, will reduce the potential for caustic SCC in plant components.

As a further precautionary measure, a study was undertaken to find alternative bolting material which is more resistant to caustic SCC than the originally installed material. The study resulted in the decision that Inconel X-750 in a solution annealed and overaged condition be used where possible. One application where Inconel X-750 could not be used is for the steam ducting to bearing cartridge connection. Due to the high material strength requirements for this application, high strength Alloy A-286 will continue to be used.

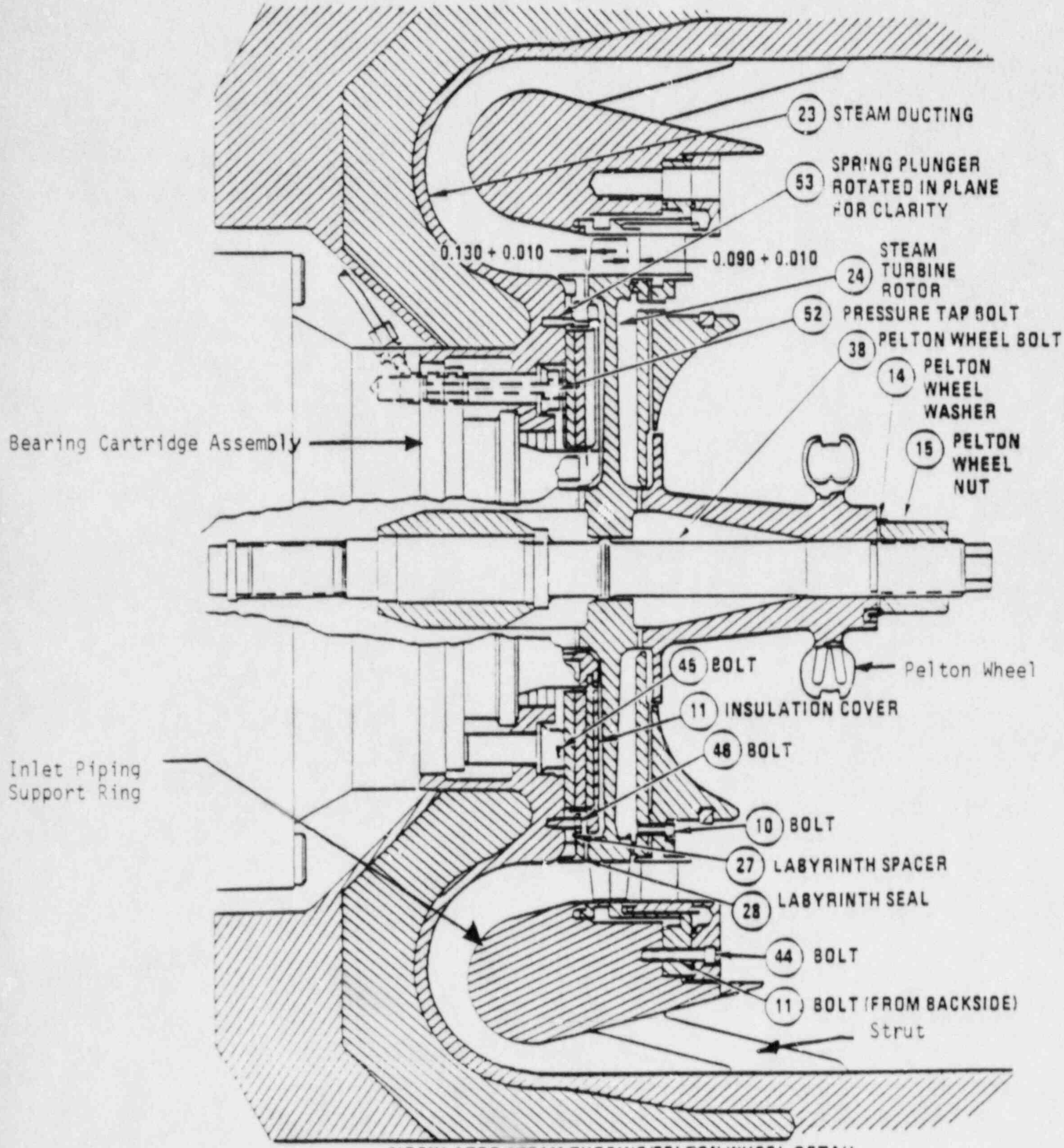
Fasteners in the steam area of each circulator will be replaced in an outage scheduled for Spring, 1988. Subsequent to this, a replacement interval for fasteners exposed to feedwater/condensate and reheat/auxiliary boiler steam has been developed which will mandate replacement (subsequent to initial installation) prior to completing an additional 40,000 operating hours. In addition, during any future circulator refurbishment, all fasteners (with a few exceptions) will be replaced. This includes fastener replacement in the steam, primary coolant, bearing cartridge and service line areas of the helium circulators.

## 3.0 INSPECTION AND REPAIR

Helium circulator S/N C-2101 was removed from service in July 1987 as a result of excessive shaft wobble indications and a purified helium interspace leak. Following its removal it was shipped to GA Technologies in San Diego. On August 14, disassembly of the machine commenced, directed by a team of PSC and GA engineering and metallurgical staff. Specific details of failures and nonconformances were documented in accordance with GA's Quality Assurance Manual.

Initially, the circulator disassembly was confined to removal of the circulator Pelton wheel (90-C2101-407), the turbine stator assembly (90-C2101-460) and turbine wheel assembly (90-C2101-440) (reference Figure 1 for configuration details). At that point the damage to the downstream upper oriented face of the turbine wheel was exposed. The labyrinth spacer (90-C2101-416), the labyrinth seal (90-C2101-421), the insulation cover (90-C2101-402), the spring plunger (90-C2101-300-53) and the labyrinth seal securing screws (90-C2101-300-46) were also observed as being extensively damaged or destroyed. The sintered metal fiber insulation rings (90-C2101-415 and -417) and backing plate (90-C2101-419) could not be found.

Two of the fifteen 3/4 inch diameter bolts (14 solid core, 1 center drilled), which secure the bearing cartridge to the steam ducting, were broken off with their head sections missing and their threaded sections still present in their locating holes. One of the fourteen solid core bolts (90-C2101-300-45) had failed in the shank. After removal, one more -45 bolt was found cracked near total failure in the shank approximately 1" below the bottom of the head. The pressure tap bolt (90-C2101-300-52) had failed in the shank above the first thread. This center drilled bolt provides the means of sensing the static pressure on the downstream side of the turbine wheel.




CIRCULATOR STEAM TURBINE/PELTON WHEEL DETAIL

FIGURE 1

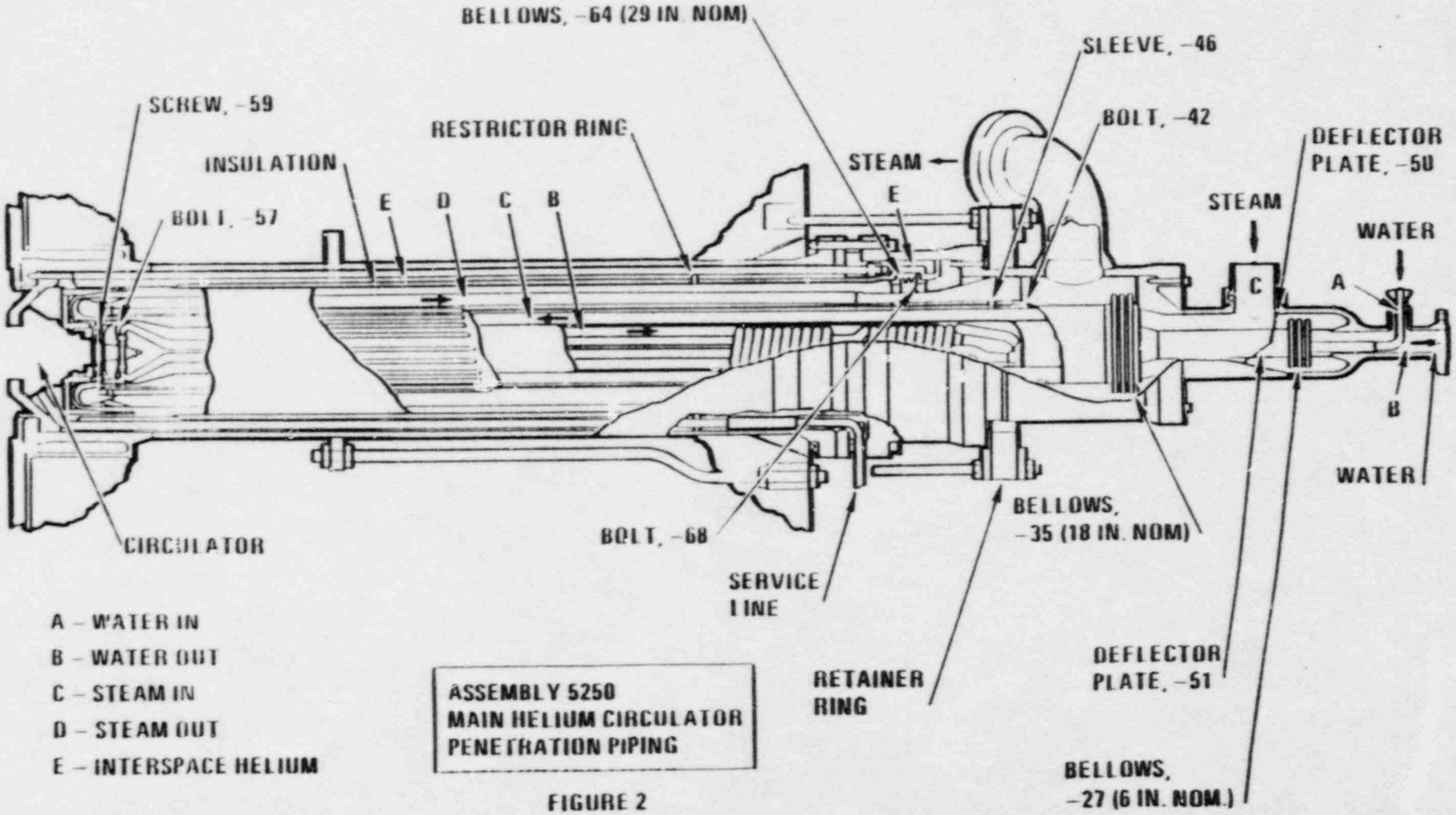
Part of the metallic debris trapped in the upper dished face of the turbine wheel was identified as the remnant of the head of either the missing -45 or -52 bolt previously referenced. During inspection of the vacant steam ducting counterbore hole for the missing -52 bolt head, a fine hair-like crack was observed, running the length of the bore. The crack did not extend to the apex of the collar where the interspace seal is made nor did it penetrate through the steam ducting weldment to have caused an interspace leak.

Cracks were also observed in all of the 90-C2101-431-4 struts in the vicinity of the weld connection between them and the 90-C2101-431-5 forging. Each of the sixteen struts were cracked around 40% of the strut periphery, resulting in a reduction in the strut cross sectional area of approximately 15%. Subsequent inspection has shown that steam ducting dimensions are within tolerance. The struts will be weld repaired to return the support area back to the original configuration.

The helium compressor and the bearing cartridge assembly were disassembled and inspected. The condition of these components was good other than normal expected wear. When compared to past circulator refurbishments (C-2102 and C-2104, which also experienced fewer operating hours than did C-2101), these components are generally considered to be in as good or better condition. There was no damage on the bearing water/primary coolant side of the circulator attributable to the steam side failures. All fasteners examined in these assemblies show no signs of degradation or SCC.

A complete report addressing the disassembly and refurbishment of circulator C-2101 including the elements of technical specification surveillance SR 5.2.18 will be prepared and issued by GA Technologies following refurbishment activities.

Inner piping assembly S/N 2001 was also sent to GA Technologies for inspection, repair and certain previously identified modifications. No failures were observed in bolts and fasteners associated with the inner piping. Each of the convolutions in the 6" bellows was found cracked. This failure is common to all inner piping assemblies repaired to date. Modification of the expansion joint is being implemented to eliminate this type of failure. A crack in the steam deflector weld was also found. This weld cracked due to insufficient weld depth and has been repaired. Figure 2 shows details of the penetration and inner piping.




A – WATER IN
B – WATER OUT
C – STEAM IN
D – STEAM OUT
E – INTERSPACE HELIUM

ASSEMBLY 5250
MAIN HELIUM CIRCULATOR
PENETRATION PIPING

FIGURE 2

## 4.0 COMPONENT FAILURE ASSESSMENT

A detailed metallurgical evaluation was performed under PSC Lab Report No. 138 (Attachment 1) on twenty-four different components including fasteners, expansion joint, steam ducting, and turbine wheel. This included visual examination, scanning electron microscopy, energy-dispersive spectrometry, metallographic examination, x-ray diffraction and chemical analysis.

Failure or damage has occurred in several different materials including 410 martensitic stainless steel, A-286 austenitic stainless steel, carbon steel, 4140 steel, 5% chrome steel, Monel 400 and Inconel 600. SCC was identified in several components including 410 SS bolts, A-286 SS bolts, carbon steel spring plunger, and Monel 400 lockwire. Table 1 summarizes the results of the metallurgical evaluation. In addition, caustic SCC was identified in the NG5250-A-27 Inconel 600 6" diameter bellows and high concentrations of sodium were identified on crack surfaces. Sodium, which is considered the initiator of caustic SCC, was also found in the corrosion products from the C-2101-460-10, 11 and NG5250-A-59 cap screws. Given the appropriate conditions, caustic will cause corrosion and SCC in 410 SS, A-286 SS, carbon steel, 5% chrome, 4140, Inconel 600 and Monel 400 materials.

A common environment to all the failed and damaged components is steam utilized for the turbine drive suggesting this was the source of caustic contamination. From a review of water chemistry records (Reference Section 9.0), significant levels of sodium hydroxide and sodium phosphate could have been carried over into the circulators from auxiliary boiler steam. High levels of caustics in this steam is considered to be the major cause of the corrosion and SCC observed. Other causes of corrosion and SCC were considered such as hydrogen sulfide which could result from the degradation of molydisulfide lubricant. However, since SCC was found in nonlubricated components, such as the 6" expansion bellows, Monel lockwire and fractured surface of the pressure tap bolt, molydisulfide degradation is not considered to be the primary cause of SCC.

## SUMMARY OF METALLURGICAL EXAMINATION

TABLE 1

| PART NO. | NAME | MATERIAL | TOTAL NUMBER | NO. EXAMINED | OBSERVATIONS |
|---|---|---|---|---|---|
| C2101-300-46 | Labyrinth Seal Mounting Bolts | 410SS | 12 | 8 | Pitting and SCC in threads in all 8 bolts examined |
| C2101-300-53 | Spring Plunger | Carbon Steel | 1 | 1 | Pitting and SCC in threads |
| C2101-300-52 | Steam Ducting Pressure Tap Bolt | A-286SS | 1 | 1 | SCC in shank and threads |
| C2101-300-45 | Steam Ducting Bolting | A-286SS | 14 | 14 | SCC in shanks and threads of 8 of 14 bolts |
| C2101-300-23 | Steam Ducting | Inconel 718 | 1 | 1 | Cracking bolt hole 9 & 10 likely from mechanical rubbing damage |
| C2101-460-11 | Steam Turbine Stator Cap Screws | 410SS | 4 | 3 | Pitting and SCC in threads of 3 cap screws |
| C2101-460-10 | Steam Turbine Stator Cap Screws | 410SS | 16 | 16 | SCC along face of threads initiating at manufacturing defects in 10 cap screws |
| --- | Lockwire for 460-10 Bolts | MONEL-400 | 1 | 1 | SCC |
| C2101-300-44 | Socket Head Cap Screws | 410SS | 4 | 4 | SCC at the apex of a thread initiating at a manufacturing defect in one cap screw |
| C2101-300-27 | Labyrinth Spacer | 430SS | 1 | 1 | Damage due to mechanical rubbing |
| C2101-300-28 | Labyrinth Seal | 430SS | 1 | 1 | Damage due to mechanical rubbing |
| C2101-300-11 | Insulation Cover | 430SS | 1 | 1 | Damage due to mechanical rubbing |
| C2101-442-2 | Steam Turbine Rotor Disk | 422SS | 1 | 1 | Slight pitting of disk along dovetail notch |
| C2101-300-38 | Pelton Wheel Bolt | INCONEL 718 | 1 | 1 | No apparent damage |
| C2101-300-14 | Pelton Wheel Lock Washer | INCONEL 600 | 1 | 1 | No apparent damage |
| C2101-300-15 | Pelton Wheel Nut | INCONEL 718 | 1 | 1 | No apparent damage |

SUMMARY OF METALLURGICAL EXAMINATION

TABLE 1 (continued)

| PART NO. | NAME | MATERIAL | TOTAL NUMBER | NO. EXAMINED | OBSERVATIONS |
|---|---|---|---|---|---|
| NG5250-A-59 | Nozzel Support Socket Cap Screw | 4140 | 24 | 3 | Crack like indications (possible SCC) at threads & head of shank junction of 2 out of 3 screws |
| NG5250-A-57 | Nozzle Bolt Assembly | 5% Chrome | 6 | 3 | SCC at head to shank junction in 2 of 3 bolts. General and pitting corr. in all 3 bolts |
| --- | Lockwire For NG5250-A-57 Bolts | 304SS | 1 | 1 | No apparent damage |
| NG5250-A-42 | Special Stud | 5% Chrome | 16 | 1 (1 3/4" Section) | Pitting and general corrosion. |
| NG5250-A-68 | Bellows Support Ring Cap Screw | 4140 | 40 | 4 | Pitting in all four and SCC through entire cross section in one cap screw |
| --- | Lockwire For NG5250-A-68 Cap Screws | INCONEL 600 | 1 | 1 | No apparent damage |
| NG5250-A-27 | Expansion Joint (Bellows) | INCONEL 600 | 1 | 1 | SCC |
| NG5250-A-50 | Deflector Plate | Carbon Steel | 1 | 1 | Cracking due to inadequate weld, also shallow corrosion fatigue cracking |

## 5.0 COMPONENT DESIGN CONSIDERATIONS

Subsequent to the disassembly, inspection and analysis of components from circulator C-2101 and inner piping S/N 2001, design changes were determined necessary to decrease the probability of failure similar to that which occurred in C-2101.

### 5.1 Bolt Material Selection

Stress corrosion cracking was found in certain bolts exposed to reheat and auxiliary boiler steam in Circulator C-2101 (as discussed in 4.0 Component Failure Assessment). As a result of the discovery of SCC, a study was undertaken to find alternative bolting material which is more resistant to the caustic SCC identified in C-2101.

Acceptance Criteria for alternative bolt materials is as follows:

1. Minimum yield strength of 95 ksi at room temperature, 85 ksi at 600°F (based on fastener strength requirements).

2. Superior resistance to SCC from exposure to steam or water containing caustic, chloride, or sulfide at temperatures up to 600°F.

3. Broad data base on mechanical properties and SCC behavior.

4. Availability of materials.

5. Thermal expansion characteristics compatible with surrounding steel and nickel base alloy structures.

#### 5.1.1 Literature Review and Survey

A survey of the literature was conducted to determine materials most resistant to SCC in steam or water with caustic, chlorides, and molydisulfide degradation products such as hydrogen sulfide. Contacts were made by telephone with individuals known to be knowledgeable about and who have had experience with SCC, or who had investigated bolting materials resistant to SCC, primarily in the nuclear industry. Information and opinions were also sought from material suppliers/manufacturers with regard to the materials most resistant to SCC in the above environments.

As a result of this literature review and telephone survey, the list of candidate bolting materials shown in Table 2 emerged. Also included in Table 2, for comparison purposes, are the properties of some bolting alloys currently used in the FSV circulator regions that contact reheat/auxiliary boiler steam.

The review of the literature showed the following:

1. There are no commercially available alloys with required mechanical properties that have demonstrated immunity to caustic-induced SCC. Almost all commercial and nickel base alloys are subject to SCC in the presence of caustic at elevated temperatures. However, some available data indicates that, in certain heat treatment conditions, Inconel Alloy X-750 offers more resistance to caustic-induced stress corrosion crack propagation than many other alloys.

2. For a number of the alloys shown in Table 2, data on elevated-temperature caustic stress corrosion were not available.

3. The high-nickel-content alloys such as Inconel Alloys 718 and X-750 exhibit superior resistance to chloride-induced SCC.

4. The resistance of the alloys to molydisulfide degradation products is not fully defined. However, in general, high-strength, low-alloy steels offer lowest resistance, and nickel base alloys offer greatest resistance.

5. Under PWR core bolting conditions, Inconel Alloy X-750, in certain treatment conditions, offers the greatest resistance to SCC initiation and propagation. Inconel Alloy 718 offers good resistance to crack initiation under these conditions, but poor resistance to crack propagation.

6. The susceptibility of most alloys to SCC is a relatively sensitive function of heat treatment condition. For example, under PWR core bolting conditions: Inconel Alloy X-750, in one heat treatment condition is the most SCC-resistant; whereas, the same alloy, in a different heat treatment condition, is one of the least SCC-resistant. It is important, therefore, in material selection, to consider both the alloy and its metallurgical/heat treatment conditions.

TABLE 2
CANDIDATE BOLTING ALLOYS

| Alloy | UNS No. or AISI No. | Specification | Heat Treat | Minimum Specification Yield Strength ksi | Minimum Specification Tensile Strength ksi | Notes |
|---|---|---|---|---|---|---|
| A286 | UNS-S66286 | ASME-SA453C-660 | 1650° + 1325°F 16 hr<br>1800° + 1325°F 16 hr | 85 | 130 | Bolting |
| | | AMS-5737 | 1650° + 1300°F 16 hr | 95 | 140 | |
| | | SPS | Cold worked, solution, and precipitation-hardened | (180)(a) | 200 | Bolting |
| 718 | UNS-N-7718 | ASME-SB637 | Solution and precipitation-hardened | 150 | 185 | Bar and forging |
| | | SPS | Cold worked and precipitation-hardened | (180)(a) | 220 | Bolting |
| X-750 | UNS-N07750 | ASME-SB637 | 2100°F, stabilize and precipitate | 90 | 140 | Bar and forging |
| | | | 1800°F and precipitate | 115 | 170 | Bar and forging |
| | | | EPRI heat treatment | 100 | 160 | Bar and forging |
| V-57 | None | None | Solution 1800° and 1350°F 16 hr | 160(b)<br>125(c) | 200(b)<br>175(c) | Bolting<br>Forging |
| MP159 | None | None | Solution 1800° and 1350°F 16 hr | 265 | 280 | Bolting |
| W545 | UNS-S66545 | | Solution 2000 and 1350° 20 hr and 1200°F 20 hr | 120 | 155 | Bolting |
| B7 | AISI-4140 | ASTM-A193<br>ASTM-GRB7 | Quenched and tempered at 1100°F | 105 | 125 | Bolting |
| B5 | AISI-501 | ASTM-A193<br>ASTM-GRB5 | Quenched and tempered at 1100°F | 80 | 100 | Bolting |
| B6 | AISI-410 | ASTM-A193<br>ASTM-GRB6 | Quench and tempered at 1100°F | 85 | 110 | Bolting |

(a) Estimated values
(b) Cold worked and aged
(c) Aged only

Overall, the literature data indicated that Inconel Alloy X-750, when used in the solution annealed and overaged condition, offered a range of stress corrosion resistance that suggested it was the better choice for the circulator operating conditions.

The discussions with knowledgeable people from industry produced information similar to that summarized above, with additional comme..s as follows:

1. Elevated temperature caustics produce conditions that can initiate stress corrosion in nickel base alloys as well as iron base alloys. The consensus was that no alloy could be relied upon to fully resist caustic SCC under the kind of conditions believed to have occurred in the circulator reheat/auxiliary boiler steam exposed system.

2. Inconel Alloy X-750, in the solution annealed and overaged condition, was generally favored as the most stress corrosion-resistant, higher-strength bolting material available today for many high-temperature water/steam applications.

3. Nickel base alloys like Inconel Alloys 718 and X-750 are considered more resistant to chloride-induced SCC than iron base alloys like Alloy A286. However, in caustic environments, Inconel Alloy 718 is only slightly better than Alloy A286, whereas, correctly heat treated Inconel Alloy X-750 appears considerably better than either Inconel Alloy 718 or Alloy A286 in caustic.

4. Little relevant data is available on other potentially interesting alloys like V57, MP159, and MP35N.

Overall, the bolting material identified as having superior resistance to SCC was Inconel Alloy X-750, in the solution annealed (2025±25°F, 1 to 2 hours) and overaged (1300°F±25°F, 20 to 22 hours) condition. This heat treatment has been recommended by EPRI draft specification 2322-16322-HC2.

## 5.2 Fastener Review

A review of fasteners and locking mechanisms which are exposed to reheat/auxiliary boiler steam within the circulators was performed. This review resulted in the list of fasteners and lockwashers listed in Table 3.

### 5.2.1 Fastener Material To Be Changed

The review of the effects of SCC on the original materials in Table 3 resulted in the recommendation that certain bolts/fasteners be changed to Inconel X-750 with heat treatment as follows: Solution anneal at 2025°F±25°F, hold for 1 to 2 hours and cool within five minutes to 800°F or less; the material should thereafter be cooled to room temperature as quickly as possible and precipitation hardened at 1300°F±25°F for 20 hours (+2, -0 hours) and air cooled. No hardness requirements have been specified since the minimum required strength and ductility of the material is obtained through heat treatment.

The mechanical properties of the bolts/fasteners shall have:

1. an ultimate tensile strength of 160,000 PSI minimum,
2. a yield strength (0.2% offset) of 100,000 PSI minimum, and
3. a minimum of 20% elongation, in 2 inches.

The above requirements correspond to those in EPRI proposed specification 2322-16322-HC2 "Alloy X-750 for Use in Light Water Reactor Internals" prepared by Stone and Webster Engineering Corporation. The heat treatment conditions recommended for the X-750 FSV helium circulator bolts are those defined as the "core internal basic condition" in the EPRI draft specification.

TABLE 3

| ITEM NO. | DESCRIPTION | MAXIMUM TEMP. °F (2) | ORIGINAL | | | | NEW | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | MATERIAL | MIN. YIELD @ TEMP. KSI | PRELOAD STRESS KSI (3) | PRELOAD KLB (4) | MATERIAL | MIN. YIELD @ TEMP. KSI | PRELOAD STRESS KSI (3) | PRELOAD KLB (4) | TORQUE OR (STRETCH) |
| C-2101-300-38 | Turbine/P.W. tie bolt | 640 | Inconel 718 | 136.86 | (5) 77.68 | 60.0 | Inconel 718 | 136.86 | 77.68 (5) | 60.0 | (.021" - .024") |
| C-2101-300-14 | Pelton nut lockwasher | 640 | Inconel 600 | 35.0 | 30.16 | 60.0 | Inconel 600 | 35.0 | 30.16 | 60.0 | ---- |
| C-2101-300-15 | Pelton wheel nut | 640 | Inconel 718 | (1) 78.97 | (6) 20.59 | 60.0 | Inconel 718 | (1) 78.97 | 20.59 (6) | 60.0 | ---- |
| C-2101-300-29 | Laby seal bolt lockwasher | 600 | AISI 430 SST | 40.5 | 18.37 | 1.8 | Inconel 600 | 35.0 | 11.97 | 1.173 | ---- |
| C-2101-300-44 | Bolt-steam stator | 750 | AISI 410 SST | 69.0 | (7) 56.6 | 1.8 | Inconel X-750 | 93.3 | 36.9 | 1.173 | 40 in.-lb. |
| C-2101-300-45 | Bolt-steam duct brg. assy. | 500 | A286 | 167.0 | 114.5 | 42.7 | A286 | 167.0 | 98.5 (5) | 36.7 | (.008") |
| C-2101-300-46 | Bolt-laby seal | 600 | ASTM A193 GRB6 | 71.7 | (7) 56.6 | 1.8 | Inconel X-750 | 95.0 | 36.9 | 1.173 | 40 in.-lb. |
| C-2101-300-52 | Bolt-press. tap | 500 | A286 | 167.0 | 132.0 | 42.7 | A286 | 167.0 | 102.9 (5) | 36.7 | (.008") |
| C-2101-300-53 | Spring plunger | 600 | Carbon steel | (1) 22.1 | -0- | -0- | Inconel X-750 | 95.0 | -0- | -0- | 5 in.-lb. |
| C-2101-460-10 | Bolt-turbine lwr. seal | 750 | AISI 410 SST | 69.0 | (7) 49.45 | 1.8 | Inconel X-750 | 93.4 | 36.9 | 1.173 | 40 in.-lb. |

(1) Shear

(2) Refs: GADR13, PI22, GADR85

(3) Based on $\frac{\text{Torque (in/lb)}}{.15 \times \text{NOM Dia.} \times \text{stressed area}}$ except at noted otherwise

(4) Ref. NFG-87-0560 for preload evaluations

(5) Based on measured bolt stretch

(6) Ref. SAE HDBK App. E

(7) Based on 0.2 friction coefficient (original design) instead of 0.15

TABLE 3 (Continued)

| ITEM NO. | DESCRIPTION | MAXIMUM TEMP. °F (2) | ORIGINAL MATERIAL | ORIGINAL MIN. YIELD @ TEMP. KSI | ORIGINAL PRELOAD STRESS KSI (3) | ORIGINAL PRELOAD KLB (4) | NEW MATERIAL | NEW MIN. YIELD @ TEMP. KSI | NEW PRELOAD STRESS KSI (3) | NEW PRELOAD KLB (4) | TORQUE OR (STRETCH) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| C-2101-460-11 | Bolt-align. sleeve | 750 | AISI 410 SST | 69.0 | (7) 49.45 | 1.8 | Inconel X-750 | 93.4 | 36.9 | 1.173 | 40 in.-lb. |
| FP-91-M-19-4-42 | Stud-steam inlet | 650 | SA-193-B5 | 60.0 | (7) 25.49 | 5.76 | SA-193-B7 | 81.0 | 33.98 | 7.68 | 60 ft.-lb. |
| FP-91-M-19-4-47 | Nut-guide tube | 650 | Cold rolled steel | (1) 22.5 | (6) 9.52 | 5.76 | Cold rolled steel | (1) 22.5 | 12.69 (6) | 7.68 | |
| FP-91-M-19-1-57 | Bolt-pelton water nozzle | 500 | SA-193-B5 | 60.0 | (7) 61.94 | 4.8 | Inconel X-750 | 96.0 | 68.82 | 5.33 | 22.5 ft.-lb. |
| FP-91-M-19-5-59 | Bolt-nozzle support | 650 | SA-193-B7 | 81.0 | (7) 78.9 | 1.58 | Inconel X-750 | 94.5 | 67.54 | 1.35 | 35 in.-lb. |
| FP-91-M--19-9-68 | Bolt-bellows support ring | 650 | SA-193-B7 | 81.0 | (7) 21.14 | 3.0 | Inconel X-750 | 94.5 | 28.2 | 4.0 | 22.5 ft.-lb. |
| FP-91-M-19-14-122 | Bolt-thermal sleeve to steam piping | 650 | SA-193-B7 | 81.0 | (7) 38.05 | 5.4 | Inconel X-750 | 94.5 | 28.2 | 4.0 | 22.5 ft.-lb. |

(1) Shear

(2) Refs: GADR13, PF22, GADR85

(3) Based on $\frac{\text{Torque (in/lb)}}{.15 \times \text{NOM Dia.} \times \text{stressed area}}$
except at noted otherwise

(4) Ref. NFG-87-0560 for preload evaluations

(5) Based on measured bolt stretch

(6) Ref. SAE HDBK App. E

(7) Based on 0.2 friction coefficient (original design) instead of 0.15

All lockwashers and lockwire exposed to steam are being changed to or will remain Inconel 600. The lockwasher material of Inconel 600 (C-2101-300-14) examined from C-2101 showed no signs of SCC. Inconel 600, although not as resistant to SCC, was chosen over Inconel X-750 for its ductility properties and its acceptable level of resistance to relaxation. This material has adequate strength for the application. Inconel 600 also has superior resistance to SCC compared to the other existing materials, which are primarily carbon and low alloy steel, and 300 or 400 series stainless steel.

5.2.2 Fastener Material Not Changing

The 3/4" steam ducting to bearing assembly bolts (90-C2101-300-45, -52) are installed with significant preload to provide proper seating of an O-ring seal and provide adequate pressure difference capability. These preload requirements are shown in Section 5.3.

Due to the high stresses incurred in this application, Inconel Alloy X-750 is not suitable as a replacement. Since these bolts need to be of higher yield strength, high strength (200 KSI minimum tensile strength) A-286 has been chosen for continued use based on the following:

1. The original A-286 performed satisfactorily for more than 60,000 operating hours.

2. The bolts are captive with respect to the circulator rotating element (i.e. individual bolt failures will not result in impingement of loose parts on the rotating element). The failure of the bolts in this area would result in a loss of secondary interspace pressurization. This interspace pressurization is controlled by technical specification and readily recognizable by the surveillance testing program.

3. Consistent with PSC's commitment to change Technical Specification SR 5.2.18 (details discussed in Section 7.0), an enhanced circulator inspection program and fastener replacement interval is being implemented. This program has been developed based on a review of operating history and disassembly/inspection records.

4. More stringent water chemistry controls have been and are being implemented (discussed in Section 9.0) which will reduce the allowable concentration level of caustics in the steam system.

The steam inlet piping mounting stud material is being changed from SA-193-B5 to SA-193-B7 due only to material availability. The mounting studs will only be changed during a complete inner piping refurbishment, which is currently being done on inner piping S/N 2001. The studs will not be changed out to a caustic resistant material for the following reasons:

1. The stud inspected showed no signs of SCC (see PSC Metallurgical Report #138, Attachment 1).

2. There are 16 studs holding the inner piping to the steam scroll. The probability of all 16 studs completely failing is highly unlikely.

3. The preload stresses on the connection are less than 60% of yield, a condition which makes it less likely to initiate SCC in the studs.

The turbine/pelton wheel tie bolt and nut (Inconel 718 material) are not undergoing a material change for the following reasons:

1. The tie bolt and nut from circulator C-2101 were inspected (Ref. Metallurgical Report #138) showing no indications of SCC.

2. The preload stress is approximately 56% of yield which makes the connection less susceptible to SCC.

5.3 Preload Requirements

The preload for each fastener listed in Table 3 has been analyzed for each application. The preload stress has been minimized to avoid SCC while exceeding a preload value below which fastener loosening might occur.

The method for preloading each fastener has also been evaluated. The most critical preload stress applications have been determined to be in the steam ducting to bearing assembly bolts (C-2101-300-45 and -52). Since these bolts are fabricated from A-286 material, they are not as resistant to caustic SCC as Inconel X-750. They also require a high preload stress to maintain the pressure boundary connection.

For these reasons, the determination of preload stress for the C-2101-300-45 bolts using ultrasonics to measure bolt elongation is being investigated. The system being considered is a Stressmic V82B manufactured by Stresstel Corporation. In anticipation that this system will meet our needs, special manufacturing requirements have been imposed for the A-286 bolts to ensure flat parallel ends of adequate finish to accommodate the measuring device requirements. These methods will determine the bolt length prior to and subsequent to installation.

Since the original torquing application for the -45 bolts provided sufficient preload to maintain the pressure boundary (i.e. interspace to secondary coolant), testing will be performed to ensure the calculated 8 Mils of elongation needed to provide desired preload is not above the elongation developed by torquing at 400 to 410 ft-lbs. If the elongation resulting from the applied torque of the 400 ft.-lb. range is consistently below the calculated 8 Mils, then the preload application method for this connection will be re-evaluated. Applications will be controlled by GA under Shop Traveller and by PSC Maintenance procedures.

The turbine/pelton wheel tie bolt (C2101-300-38) will be preloaded using a micrometer caliper to measure the bolt length before and after tightening. This installation will be accomplished under GA Shop Traveller and PSC Maintenance procedures.

The remainder of the fasteners listed in Table 3 will be preloaded using a precision torque wrench. This will limit torque to the calculated values. Allowing for a ±30% accuracy, the preload stress will generally be maintained below yield. These installations will be controlled under GA Shop Traveller and PSC Maintenance procedures.

5.4 Spring Plunger Addition/Insulation Cover Engagement

The spring plunger, which locks the insulation cover in place could allow the insulation cover to disengage if failed. To eliminate this single failure mechanism, a second spring plunger will be installed to redundantly prevent insulation cover rotation. Since this modification is not considered to be feasible insitu, it will be implemented during complete circulator refurbishments. The direction of installation will be changed during the initial circulator bolt replacement, proposed for the Spring of 1988, so that turbine rotation will force the insulation cover towards 100% engagement. These modifications will not affect the function of the components and will increase their reliability.

5.5 Chamfer C-2101-431 Counter Bore

The counter bores in which the 3/4" bolt heads seat, (C2101-300-45, -52) currently have a square edge on them. This edge contacts the fillet radius at the bolt shank to head interface, which could result in a line of stress concentration upon contact. To eliminate this stress concentration point, the counter bore edge will be chamfered. This modification will be implemented during the initial bolt replacement program.

5.6 Thread Lubricant Change

Industry practice in recent years has been to eliminate the use of molydisulfide lubricant at elevated temperatures, and in the presence of moisture. While the molydisulfide is not considered to be the primary cause of SCC in C-2101 (SCC was also found in non-lubricated components), a review of other lubricants has been completed with the preferred lubricant being Dow Corning Molykote 505. Molykote 505 does not contain any molybdenum disulfide nor is it similar to silicon molykote. Molykote 505 is a paste containing an inorganic solid lubricant stable up to 2000°F in a mineral oil base. Besides reducing break-away torque, the lubricant is designed to provide protection against corrosion. An analysis of the Molykote 505 will be performed to identify its constituents. The results of this analysis will be utilized to ensure material and environmental compatibility. If constituents are found which could enhance SCC, this compound will not be used. Nickel Never-Seez Pure Nickel Special and Felpro Grade N 1000 are also being pursued and will undergo the same evaluation as the Molykote 505.

Mechanical means will be used to remove the molydisulfide lubricant from the bolt and screw holes in the FSV helium circulators. Thread taps and stiff stainless steel wire brushes rotated by a drill motor will be used to loosen the lubricant. The loosened material is then to be removed by blowing it out of the holes with pressurized air and/or by vacuuming to pull out the loose lubricant particles.

Evaluation of chemical means suggested by suppliers of molydisulfide lubricants to remove the lubricant shows them to be dangerous and impractical. Suggested chemical means are very hazardous, do not completely remove the lubricant, and may result in contamination of the circulator with residues which may cause SCC.

## 6.0 QUALITY ASSURANCE REQUIREMENTS FOR HELIUM CIRCULATOR FASTENER PROCUREMENT

To ensure a high quality fastener, avoid manufacturing defects, and ensure fastener cleanliness from manufacturing contaminants, the following Quality Assurance (QA) requirements are being implemented on all current helium circulator fastener procurements:

1. All procurement activities are per GA's QA Manual, PSC Engineering Procedure ENG-16 and PSC Quality Assurance Procedure Q-4.
2. Approved suppliers per the PSC approved vendors list and/or GA QA Manual are being used. (10CFR50 Appendix B and/or ASME Quality Systems Certificate and/or source inspection).
3. Vendors are required to establish in their subtier procurement documents those requirements necessary to assure that each item delivered has been controlled, manufactured and inspected in compliance with the requirements of the GA or PSC purchase order.
4. Vendor(s) are required to obtain written approval of all nonconforming items prior to shipment.
5. Traceability of all materials is required.
6. All fasteners of each type/size are required to be from the same heat of material (within a given purchase order).
7. Chemical and mechanical certified mill test reports are required.
8. Furnace charts for all heat treating, are required.
9. All completed fasteners are required to be fluorescent penetrant inspected per ASME Sec. V Article 6. No linear indications in shank or threads is permitted.
10. Substitutions and/or weld repair are prohibited.
11. All rolled threads are to be rolled per applicable sections of MIL-S-8879 or MIL-S-7742.
12. Vendor special processes must be performed by qualified personnel, procedures, and equipment.
13. Vendor shall provide a certification of compliance for each heat treating, non-destructive examination or similar process performed on this hardware.

14. Detrimental materials (possibly those contained in cutting fluids) will not be used if they cannot be effectively removed.

15. Vendor visual and dimensional inspection is required.

16. Receiving inspection (as a minimum) will include:

    a) 100% visual inspection

    b) Dimensional inspection with sampling per MIL-STD 105 D.

    c) Verification of chemical analysis and tensile strength of two (2) fasteners from each lot.

    d) Random verification of hardness per MIL-STD 105 D.

    e) Cleaning of all fasteners in alcohol or equivalent.

17. Vendor shall certify compliance with all purchase order requirements.

18. 10CFR21 shall be imposed on vendor(s).

Due to the high stress requirements of the C2101-300-45, -52 bolts, the following additional requirements will be applied:

1. Prior to fabrication all material shall be ultrasonically examined per ASME Sec. V, Article 5, Para. T-535. Any imperfection which causes a response in excess of 20% of the reference amplitude shall be cause for rejection.

2. GA to witness ultrasonic testing of material.

3. GA to witness dye penetrant testing of finished hardware.

4. Source inspection of final hardware.

5. Vendor to submit NDE procedures for GA review prior to their use.

## 7.0 CIRCULATOR INSPECTION/REPLACEMENT CRITERIA

A review of the operating history and disassembly/inspection records has been performed. From that review and the hours of operation of C-2101 prior to failure, a conservative inspection/parts replacement interval was developed to include the following:

1. Insure initial replacement of all C2101-300-45, -46, -52, and C2101-460-10 fasteners. Also replace the C2101-300-53 spring plunger. Perform a visual inspection of all components removed for fastener replacement. These activities are scheduled to be completed during a Spring, 1988 outage.

2. Repeat the fastener replacement and component inspection within a time frame not to exceed 40,000 circulator operating hours.

3. Complete disassembly and inspection per Attachment 2 of a second circulator within a 10 year time frame from the first circulator so inspected per Surveillance SR 5.2.18 (reference Section 7.3).

4. Inspection results from any circulator examined or inspected for any reason will be evaluated and factored back into the established programs to reflect any required adjustments.

### 7.1 Determination Of Intervals

Operating history and disassembly/inspection records of three circulators C-2101, C-2102, and C-2104 were examined in an effort to establish a reasonable inspection/replacement interval for various circulator components. The review of operating history indicates that 64% to 72% of operating time of the circulator has been on steam.

Complete disassembly and inspection of circulator C-2102 at 17,142 hours (12,249 on steam; 43 thermal cycles) revealed no failed components. This disassembly and inspection was a Technical Specification surveillance requirement (SR 5.2.18). Circulator C-2104 was disassem[illegible] and inspected at 49,037 hours (34,921 on steam; [illegible] thermal cycles) for repair of the turbine end damaged [illegible]ted foreign material. One 90-C2101-300-46 fastener [illegible] one [illegible]0-C2101-500-51 fastener were found failed. [illegible]ator S/N C-2101 disassembly and inspection at 63,893 hours (41,091 on steam; 136 thermal cycles) revealed extensive failure of turbine end assembly fasteners and hardware with resulting significant turbine end damage. All twelve 90-C2101-300-46 fasteners and 20% of 90-C2101-500-45, -52 fasteners had failed.

Since no failures were found at 17,142 hours and two unrelated fastener failures were found at 49,037 hours, an inspection interval somewhere above 17,142 hours but below 49,037 hours would seem reasonable. The extensive failures at 63,893 hours may indicate an accelerated failure rate as operating hours are extended above 49,037 hours. The two unrelated fasteners found failed on C-2104 at 49,037 hours would not of themselves result in further failures or cause any damage since both are captive. Based on the above, a conservative inspection interval of 40,000 circulator operating hours (combination of steam turbine and pelton wheel drive) has been established.

7.2 Inspection Intervals

The inspection intervals and the inspection methods to be applied are included in the inspection schedule shown in Attachment 2. The inspection schedule basically duplicates that used by GA for the first SR5.2.18 inspection but with the following changes: 1) The inspection interval has been shortened for the turbine end components found failed in C-2101, 2) Scheduled replacement of critical turbine end fasteners that may be susceptible to caustic stress corrosion has been included, and 3) A schedule for inspection of the steam inlet and water piping assembly has been added.

Subsequent to initial fastener replacement, an inspection/replacement interval of 40,000 circulator operating hours will be applied to the circulator steam turbine end components outlined in Section 5.0. During any future circulator refurbishments, all fasteners, with the exception of the speed probe attachment fasteners (90-C2101-500-40, -51), the Pelton wheel tie bolt and nut (90-C2101-300-38, -15) and the inlet piping mounting stud assembly (FP-91-M-19-42, -44), will be replaced. This includes fastener replacement in the primary coolant, steam, bearing cartridge and service line areas. The Pelton wheel tie bolt and nut and inlet piping stud assembly are not being replaced for reasons discussed in Section 5.0. The speed probe attachment fasteners are non-critical to continuing circulator operation.

## 7.3 Technical Specification Upgrade

As a result of the failures observed on circulator C-2101, an enhanced ISI Technical Specification surveillance test, SR5.2.18 will be developed. Based on historical information, a required inspection/replacement program at 40,000 circulator operating hours is being added to the current 10 year disassembly and inspection requirements. This will include the inspection of the turbine end and inlet piping components and the replacement of specified fasteners. The inspection/replacement requirements will receive further evaluation based on the results of fastener replacement scheduled for the Spring of 1988.

Given the positive results of the primary/bearing cartridge side inspection of circulator C-2101, as well as previous inspections of C-2102 and C-2104, there is not sufficient technical information to assess the present ten year interval of inspection specified by SR 5.2.18. It is therefore PSC's intent to remove a circulator either during the Spring of 1988 or, at the latest, during the fourth refueling. This circulator will be disassembled and refurbished under the provisions of SR 5.2.18. The results of this future circulator inspection coupled with our past experience will be utilized as a basis for evaluating the SR 5.2.18 inspection interval. It should also be noted that the provisions of SR 5.2.18 (with a few exceptions) have been applied in the refurbishment efforts on C-2101 to provide a greater data base for evaluating the SR 5.2.18 inspection intervals.

Operation history; refurbishment/repair results, both historical and future; and the continuing operational monitoring program will all be evaluated as elements of the circulator ISI Program. These elements will be utilized to adjust the program as necessary. In the interim the following requirements have been established:

1. Insure initial replacement of all C2101-300-45, -46, -52, and C2101-460-10 fasteners. Also replace the C2101-300-53 spring plunger. Perform a visual inspection of all components removed for fastener replacement. These activities are scheduled to be completed during a Spring, 1988 outage.

2. Repeat the fastener replacement and component inspection within a time frame not to exceed 40,000 circulator operating hours.

3. Complete disassembly and inspection per Attachment 2 of a second circulator within a 10 year time frame from the first circulator so inspected per Surveillance SR 5.2.18 (reference Section 7.3).

4. Inspection results from any circulator examined or inspected for any reason will be evaluated and factored back into the established programs to reflect any required adjustments.

### 7.4 Circulator Operability

The inspection intervals coupled with the material upgrade described in Section 5.0, the enhanced monitoring system described in Section 8.0 and the improved water chemistry controls described in Section 9.0 will provide assurance of operable circulators. Results from continuing circulator inspections will be trended, evaluated and utilized to make necessary adjustments to the program.

## 8.0 MONITORING

As a result of the failures associated with circulator C-2101, a comprehensive monitoring and trending program will be implemented to enhance circulator performance and assist in early detection of any future circulator failures. Circulator shaft wobble is currently being monitored on an interim basis with the use of dedicated oscilliscopes until a continuous monitoring system can be implemented.

### 8.1 Present Monitoring System

Circulator shaft wobble is presently monitored by four dedicated oscilliscopes and data is recorded daily per test T-369. Wobble is also being checked after any unplanned circulator speed changes. The data accumulated to date has not shown any significant wobble increase with speed. The wobble data to date indicates that there is some scatter, but the data remains close enough to the baseline so that the scatter has not been significant.

Surveillance SR-RE-17-W is run on a daily basis to balance the cables to the speed modifiers. This imbalance is caused by the bridge circuitry drifting between their two locations, one at the circulator and the other in the control room. The imbalance is being evaluated as a part of the long term enhanced monitoring program. Instrumentation utilized to support wobble monitoring and surveillance tests is controlled and calibrated as a part of the safety related instrumentation program.

PSC has developed an enhanced circulator performance trend analysis. The data shown in Table 4 is being trended to evaluate circulator operating characteristics. Included in this data are the circulator bearing cartridge differential pressures, which are being logged manually.

The current method of monitoring, displaying and documenting the wobble signal on a daily basis provides assurance of proper circulator shaft operation. The information obtained is being stored, analyzed and trended to show any degradation or changes in circulator rotational dynamics, in support of continued circulator operation and ongoing circulator assessments.

The following data is recorded continuously on the plant data logger:

TABLE 4

GROUP I

| | "A" CIRC. | "B" CIRC. | "C" CIRC. | "D" CIRC. |
|---|---|---|---|---|
| SPEED | ST-2105 | ST-2111 | ST-2106 | ST-2112 |
| STEAM TURBINE CONTROLLER OUTPUT | SC-2105 | SC-2111 | SC-2106 | SC-2112 |
| BEARING WATER FLOW | FM-2183 | FM-2185 | FM-2184 | FM-2186 |
| *BEARING WATER CARTRIDGE δP | PDI-21285-1 | PDI-21285-2 | PDI-21286-1 | PDI-21286-2 |
| BUFFER-MIDBUFFER | PDT-21389 | PDT-21391 | PDT-21390 | PDT-21392 |

GROUP II

| | |
|---|---|
| COLD REHEAT PRESSURE | PT-2243-1 (L I) |
| COLD REHEAT PRESSURE | PT-2244-1 (L II) |
| STEAM TURBINE EXHAUST PRESSURE | PT-2243-2 (L I) |
| STEAM TURBINE EXHAUST PRESSURE | PT-2244-2 (L II) |

GROUP III

| | |
|---|---|
| STEAM TURBINE PRESSURE RATIO | PM-2243 (L I) |
| STEAM TURBINE PRESSURE RATIO | PM-2244 (L II) |
| STEAM TURBINE EXHAUST TEMPERATURE | TE-2255-7 (L I) |
| STEAM TURBINE EXHAUST TEMPERATURE | TE-2256-7 (L II) |

GROUP IV

| | |
|---|---|
| PRIMARY COOLANT PRESSURE | PT-1110 |
| AVERAGE CIRCULATOR INLET TEMPERATURE | (L I) |
| AVERAGE CIRCULATOR INLET TEMPERATURE | (L II) |

* Not currently recorded by the plant data logger (recorded manually).

8.2 Speed and Wobble Computer

The speed and wobble computer system (PDP 11/10), which was functional during initial plant start-up, has not been functional in the past due to parts unavailability and system complexity. The system utilizes a minicomputer and a display panel to compute the actual bearing clearance based upon the phase relationship between upper and lower displacements.

At this time the system has been refurbished and appears to be functional. The interface cable has also been replaced, making the interface functional. Efforts are under way to load the speed and wobble program to check for system operability as part of the enhanced monitoring project.

A Nicolet Oscilliscope representative has demonstrated a model 4094 digital oscilliscope that has alarm capabilities. The scope contains a micropressor and it appears that it could replace the function of the existing computer. The scope is currently being evaluated for use in the system.

8.3 Enhanced Wobble Monitoring

In an effort to increase monitoring capabilities, an enhanced monitoring program is being developed which will provide continuous wobble monitoring, alarm, data acquisition and storage, trending and diagnostic capabilities. The major problem with the development of the system is that the slots in the shaft at the speed probes cause an incompatibility with standard monitoring systems on the market. An interface with the existing probes must first be developed. This will allow a monitor to hook up with the existing speed cables external to the circulator. If this interface cannot be established, then the other two options are to install wobble pick ups into the bearing cartridge or fill in one of the two upper and lower slots in the circulator shaft. Both options would have to be done with the cartridge disassembled and would be extremely long term. Another problem with using the existing wobble system is drifting of the bridge balance circuitry which requires frequent recalibration. If the interface circuit does not remedy this situation a long term system redesign would be required.

If the problems can be resolved, Bently Nevada, who is working with PSC to develop the system, would require one month to gather information and one month to develop a prototype on paper with another month required to physically build the customized prototype. After that time a month of operational data collection would be desired with another month to construct the finalized system. Final installation could then take place within approximately one week, which at best would be mid 1988.

### 8.4 Loose Parts Monitoring

A loose parts monitoring system is being considered which would consist of transducers (noise pick ups) placed near the turbine stage and in a natural collection region with a monitor located in the control room. A meeting with Babcock and Wilcox (B&W) took place on 11/10/87. Questions were raised concerning the ability to gain access to the monitoring regions and the degree of sensitivity required to detect loose parts. It was agreed that a preliminary investigative task would be proposed by B&W to try and determine the feasibility of applying a loose parts monitoring system. The objective of the task is to prove whether the technique is practical and to determine the optimum sensor location.

### 8.5 Continuing Circulator Operability

Although the enhanced wobble monitoring system and a loose parts monitoring system (described in Sections 8.3 and 8.4 above) are long term, the present monitoring system (described in Section 8.1) provides a more than adequate means of monitoring and trending circulator operation. We are continuing in our efforts to enhance this monitoring system with additional information from the existing speed and wobble computer (described in Section 8.2).

## 9.0 WATER CHEMISTRY/TREATMENT REVIEW

### 9.1 Past Water/Steam Chemistry

The three main modes of operation at Fort St. Vrain for the secondary coolant system are shutdown, powering up or down, and power operation. During shutdown, the plant uses condensate/feedwater to drive the helium circulators. During shutdowns or when powering up or down, the condensate/feedwater is converted to steam in the auxiliary boilers. This source of steam in turn drives the circulators via the reheat steam piping system. During power operation, the condensate/feedwater is converted to steam in the steam generators which then drives the circulator steam turbine via the reheat steam piping system.

The chemistry of the condensate/feedwater during plant shutdown has generally been of good quality and therefore is not considered as the caustic contamination source for the recent hardware failures in C-2101. The sodium contained in the condensate is not harmful to the equipment and components because the condensate is in the water phase and the sodium levels are not high enough to deposit onto metal surfaces.

The chemistry of the auxiliary boiler's steam during powering up or down modes and shutdowns has not always been of good quality. For a period of 18-20 months, from December 1983 through July 1985, the boilers were being treated with a phosphate treatment program which consisted of the injection of sodium compounds directly into the boilers. During some routine maintenance on the auxiliary boilers' steam header, deposits of sodium compounds were found near a valve and subsequent analysis samples of the auxiliary boiler steam indicated 79-820 ppb sodium. The boiler systems were not systematically cleaned out after finding the deposits and consequently the sodium continued to contaminate the auxiliary boiler steam whenever that steam was required.

The chemistry of the condensate/feedwater converted to steam during power operation has generally been of good quality. Sodium levels have seldom exceeded the allowable limit of 20 ppb specified in FSV procedures. However, based on a review of EPRI guidelines and literature on SCC, these allowables are considered to be too permissive.

9.2 Present Water Chemistry Procedure Requirements

The controlling procedure for the chemistry of the condensate/feedwater during plant shutdown (PSC Procedure WCP-302) specifies a limit of 1000 ppb for sodium when the demineralizers are bypassed and 20 ppb when they are in service. These limits are in keeping with EPRI guidelines and the additional limit of 20 ppb is more restrictive than EPRI. Sodium levels of 1000 ppb in the condensate itself are not harmful to circulator components when utilized as a pelton wheel drive source.

The controlling procedure for the chemistry of the auxiliary boilers' steam during plant shutdowns and powering up or down modes (PSC Procedure WCP-311) does not specify a limit for the sodium. This is because the condensate/feedwater procedure mentioned previously specifies the allowable sodium levels as the plant rises or comes down from power operation, and this is the originating source for the auxiliary boiler.

The controlling procedure for the chemistry of the condensate/feedwater during power operation is the same procedure as during plant shutdown. It specifies a limit of 20 ppb for sodium and this limit is less restrictive than EPRI guidelines.

9.3 Proposed Water Chemistry Procedure Changes

The allowable sodium limits do not need to be changed for the condensate/feedwater during plant shutdowns. These limits are considered reasonable since sodium levels of 1000 ppb in the condensate cannot cause SCC of helium circulator components at the temperatures present during plant shutdown. However, since there is the potential for sodium buildup on components due to the wetting and drying effects of the pelton wheel's operation during shutdown periods, the 20 ppb limit will be maintained as specified in WCP-302.

Since the procedure for the auxiliary boiler steam did not require the sampling and analyzing of that steam, this procedure will be changed. Even though the quality of the boiler feedwater is controlled by the condensate/feedwater procedure, it is important to keep a tighter control on the boiler steam since it has been the major source of caustic contamination. A modification design package is currently being developed which will install an auxiliary circulator boiler steam sampling system during the Spring, 1988 circulator bolt replacement outage. The procedure will be changed to require sampling of auxiliary boiler steam when it is being used for plant start-up or shutdown, or when the circulators are being driven by it. If the sodium exceeds 3 ppb, Procedure WCP-311 will require cleaning up the auxiliary boiler systems. This procedure change will take place immediately and in the interim will utilize a temporary station for sampling.

The allowable sodium limits for the condensate/feedwater during power operation (above 30% reactor power) will be changed in Procedure WCP-302 to require a maximum of 3 ppb at the outlet of the demineralizers.

### 9.4 Water Chemistry/Treatment Overview

Fort St. Vrain instituted some new water chemistry procedures in 1985 and 1986 which have made some beneficial differences in the quality of the condensate and steam. It is considered that these new procedures plus the changes mentioned above will ensure the integrity of plant components and reduce the potential for SCC. One of the contributing factors to the recent bolting failures of circulator C-2101 was caustic initiated SCC attributed to the poor water chemistry prior to 1985. Specifically, the sodium compound treatment of the auxiliary boilers produced high levels of caustics in the auxiliary boiler steam. The plant will not use this treatment program again so this will decrease the chances for SCC.

## 10.0 SECONDARY COOLANT SYSTEM MATERIAL EFFECTS REVIEW

Due to the presence of the caustics identified in the water chemistry review, it is necessary to review the secondary coolant system for the effects of the caustics throughout the system. This review will be a long term project which will determine components that could have been affected by caustics and an inspection/evaluation program during routine maintenance for replacement of suspect parts as may be required.

## 11.0 REFURBISHMENT PLAN AND SCHEDULE

The failure of circulator C-2101 mandated that several parts undergo a design change. The most significant of these changes is the material change of bolting and fasteners. The failure also required that several repairs be initiated and replacement parts be ordered. A circulator and inlet piping repair schedule is shown in Figure 3.

### 11.1 Inlet Pipe S/N 2001 Repair

The repair of the inlet piping assembly is progressing on schedule. There have been only minor setbacks with little impact to the schedule. It is to arrive at Fort St. Vrain on February 3, 1988.

### 11.2 C-2101 Repair

In the repair of C-2101 two significant setbacks have been encountered. The steam ducting weldment was identified as being cracked. This repair, if successful, will be completed by the end of February, 1988. If the weld repair is not successful, a new steam scroll will be required. This would delay the completion of the total C-2101 repair until the end of 1988.

The compressor rotor was contaminated with little chance of success in decontaminating it to the background level required for vendor high speed spinning. Due to the contamination difficulties the spinning was not completed until late December, which impacted the end date of the schedule. This pushed the C-2101 repair completion to approximately mid-April, 1988.

### 11.3 Parts Schedule

All parts required for the Spring, 1988 circulator outage have been ordered. Although all the delivery dates have not been established, it is expected that the parts will be received to support the above schedule.

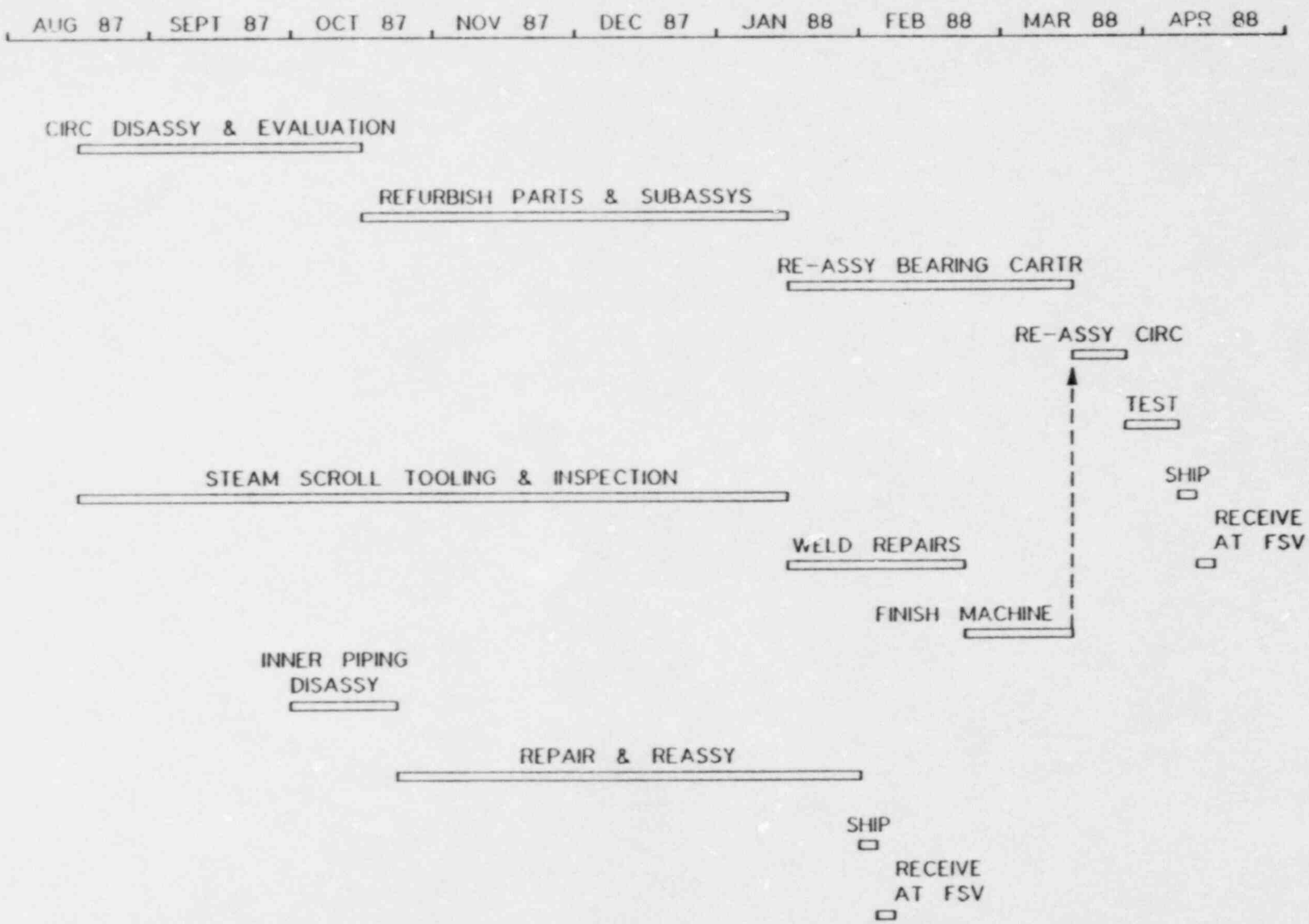



FIGURE 3

FORT ST. VRAIN CIRCULATOR C2101 & INNER PIPING 2001
REPAIR SCHEDULE

## ATTACHMENTS

| Number | Description |
|---|---|
| 1 | Metallurgical Analysis of Components From Helium Circulator C-2101 |
| 2 | Helium Circulator Inspection Schedule |