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MEMORANDUM FOR: File

FROM: Eugene Imbro and Joan Giannelli
Office for Analysis and Evaluation of Operational Data

50-325
50-324

SUBJECT: LOSS OF RESIDUAL HEAT REMOVAL (RHR) CAPABILITY AT BRUNSWICK UNITS 1 AND 2

The purpose of this memo is to document our findings to date on the loss of RHR at Brunswick Units 1 and 2 that occurred during April and May 1981. The majority of the information presented was obtained during the June 17, 1981 site visit with Carolina Power and Light Company (CP&L). Michael T. Masnik, NRR, a fisheries biologist, accompanied us on the site visit and provided the necessary expertise on the biological aspects of the marine organisms.

Brunswick 1, which was shutdown on April 17, 1981 to begin a scheduled maintenance outage, experienced a total loss of RHR on April 25 when the baffle plate which divides the water box of RHR heat exchanger (HX) 1A failed thus allowing service water to bypass the HX tubes. RHRHX 1B was out of service for maintenance at the time as a result of a prior licensee commitment (LER-2-80-30). The damage was caused by excessive differential pressure across the baffle plate which resulted when a second RHR service water pump was started due to the degradation of cooling capability observed by the operators. The degradation of cooling capability stemmed from the buildup of shells and shell fragments from marine organisms which blocked the HX tubes. During the time that both trains of RHR were out of service an alternate cooling flow path was first established using the spent fuel pool HXs, the condensate storage tank, and the core spray system to provide makeup to the reactor vessel. Later a flow path was established using the main condenser as a heat sink. In this mode of cooling, the main steamlines were flooded and the water level in the condenser was raised above the tubes. Primary water was then circulated through the condenser using the turbine bypass valves. Before initiating this mode of cooling, however, the main steamline pipe hangers had to be pinned so that the weight of water in the flooded lines would not cause excessive deflection of the piping. In order to return to a normal cooling flow path as expeditiously as possible, temporary repairs were performed. These consisted of cleaning the shells from the 1A RHRHX, jacking the baffle plate back into position and welding strong backs to the baffle plate for support.

As a result of the problems found on the Unit 1 RHRHXs a special inspection was performed on the Unit 2 RHRHXs. An ultrasonic examination of RHRHX 2A indicated that the baffle plate was not displaced, however, flow tests indicated a higher than normal differential pressure (DP) at design flow. Similar examinations of RHRHX 2B indicated that the baffle plate was displaced. Both HXs were declared inoperable and Unit 2 was shutdown using RHRHX 2A at reduced capacity due to the flow blockage. After Unit 2 was in cold shutdown, the main condenser was used as the heat sink as was done on Unit 1. This allowed both RHRHXs to be taken out of service in order that they could be simultaneously repaired.

The RHRHXs at Brunswick are vertical "U" tube HXs and are arranged such that the water box is below the copper nickel (Cu Ni) tubesheet. The water box of the HX is carbon steel explosively clad with Cu Ni and has a 70-30 Cu Ni baffle plate that separates the inlet and outlet service water flow. The one-inch thick baffle plate, fabricated from Cu Ni, is welded on top to the tubesheet and on the sides to the water box. The bottom of the baffle plate extends approximately 3/8 inch into a machined groove in the water box cover which along with the baffle plate to tubesheet weld provides lateral stiffness. The baffle plate is 54 1/2 inches wide and 44 3/4 inches high and can generate significant horizontal and bending forces even at relatively low DPs due to its large surface area. It was stated by the licensee that ASME Code allowable stress would be reached in the baffle plate at a DP of 10.4 psi. The licensee, however, was of the opinion that the deflections were caused by DPs between 50 and 100 psi since they had experienced DPs of 30 psi with no apparent damage to the baffle plate.

The inspection of the RHRHXs revealed the following:

Unit 1 RHRHX 1A

The baffle plate was displaced nine inches.

Unit 1 RHRHX 1B

The baffle plate was displaced nine inches and the side welds pulled loose to within eight to ten inches of the tubesheet.

Unit 2 RHRHX 2A

The baffle plate was intact. A layer of shells and shell fragments approximately 1/4 to 1/2 inch in depth was found on the inlet side of the water box cover. When held up against the tubesheet by the flow, these shells provided some flow blockage to approximately 60% of the tubes.

Unit 2 RHRHX 2B

The baffle plate was displaced approximately three inches at the bottom center. The deflection started three inches from one side of the water box and extended to nine inches from the opposite side. The side welds were intact and a layer of shells and shell fragments from two to five inches deep was found on the inlet side of the water box cover. Approximately 50% of the tubes had some shell blockage.

Further examination of the service water system revealed that the 30-inch concrete lined nuclear and conventional service water headers were completely covered; principally, with marine organisms that are enclosed in a calcareous shell or test. Species present included the American oyster, Blue mussel, barnacles, and serpulids (tubeworms). The most frequently encountered non-calcareous organisms were hydrozoans and polycheate worms. The most common species encountered was the American oyster. These organisms formed a layer approximately one-inch thick on the bottom of the pipe tapering off to 1/2 inch on the top. As was expected, more organisms were found in the larger diameter pipes, where flow rates are lower (about 3.36 fps in the 30 inch header with one service water pump running) than in the smaller diameter pipes with higher flow rates. Settlement of marine fouling larvae is dependent on flow velocity and larvae have difficulty attaching if the flow velocity is above four fps. It was also noted that the accumulation of organisms decreased proportionately with the distance from the intake structure. This may be due to the existence of an unfavorable temperature gradient or a depletion of the food supply. Pipes which are normally isolated were, for the most part, found to be clean. Isolated portions of the system including the RHRHXs are generally layed-up with well water. Detailed information on the location and extent of marine growth is shown in Figure 2.

Live organisms were not found in the RHRHXs, only shells and shell fragments. The reason for this is the Cu Ni water box surfaces are toxic to marine organisms and the Cu Ni prevents attachment and growth. Although it was indicated that in some cases 50 to 60% of the RHRHX tubes had some flow blockage, the actual amount of debris removed from the tubes amounted to approximately one cup per HX as compared to the several gallons of shells found in some of the inlet water boxes. The shells are preferentially swept into the RHRHXs since they are at a low elevation (ten foot) in the reactor building and form a trap in the service water system. The service water is supplied to the RHRHXs from the 50-foot elevation where the RHR service water pumps are located. After leaving the RHRHX, the service water piping returns to the 50-foot elevation before exiting to the circulating water discharge canal. Shell growth was not detected in the four diesel generator heat exchangers or in the core spray pump room cooler; however, approximately one handful of shell fragments was found in each of these heat exchangers.

Some shells were found in the turbine building component cooling water (TBCCW) heat exchangers, however, these are not safety-related components. Like the reactor building component cooling water (RBCCW) heat exchangers, the TBCCW heat exchangers can be periodically taken out of service, inspected, and cleaned as needed.

With the exception of the polycheate worms, all organisms listed above securely attach themselves to the inside surface of the pipe. Even after death the calcareous tests (shells) of the oysters, barnacles, and serpulids (tubeworms) remain attached providing an ideal substrate for subsequent larval settlement and the growth of new organisms. The only way the attached tests from either live or dead organisms can be removed from the piping is by mechanical means, flushing is totally ineffective. Some organisms, such as the Blue mussel will eventually release from the substrate after death. American oysters will lose their top shell after death. The shells which are released from the substrate will be swept through the piping.

As a first step in cleaning out the piping, the licensee flushed the Unit 2 nuclear service water header for 40 hours with heavily chlorinated water prior to cleaning. The Unit 2 conventional header was chlorinated for 190 hours and then flushed for 260 hours using the RBCCW HX water boxes as a collection point for shells. Figure 1 shows the chlorination and flush paths for the conventional and nuclear service water headers. Since shells were still found after 260 hours, the licensee concluded that cleaning the system by flushing was ineffective and resorted to mechanical cleaning.

Workers entered the Unit 2 nuclear header in the service water building and mechanically scraped the pipe walls. As previously mentioned, an inch of shells was found at the bottom of the pipe. This tapered off to one-half inch of shells at the top. The header was then back flushed and the shells were washed out onto the service water building floor. The conventional header and the smaller pipes were Hydrolazed (a process utilizing water sprayed through a nozzle at 8,000 to 10,000 psi). Figures 2, 3, 4, and Table 1 give more details as to where and what types of shells were found and how each section of pipe was cleaned.

During the initial startup of Brunswick, shells and shell fragments were found in the service water and circulating water systems. At that time, there were no provisions for chlorinating. A study was begun which concluded that chlorination would provide an effective means of controlling marine growth in the plant. A chlorination program was begun in the Spring/Summer of 1975 (prior to commercial operation of Unit 2) which called for continuous chlorination of the service water, except during times when the screen wash pumps were operating, and chlorination of the circulating water for two hours a day. This amounted to adding 300 pounds of chlorine a day for each service water pump that was operating, yielding a free residual chlorine concentration of about 1 ppm at the RHR heat exchangers and an undetectable concentration at the plant discharge due to the dilution with the circulating water from the main condensers. Figures 5 and 6 show the chlorination system. As can be seen from Table 2, the chlorination was stopped during the Spring/Summer 1980 outage. This was done primarily to protect employees from being overcome by chlorine while working near the intake or on the associated piping. During the 1980 Summer outage, a fine mesh screen (1 mm) was temporarily added to one bay of the circulating water intake on a trial basis in an attempt to reduce fish entrainment. In going from the 3/8 inch mesh to the one millimeter mesh, continuous screen washing was required. Chlorination was reinitiated in November 1980, after overcoming a series of mechanical and electrical problems. This resulted in a high fish kill due to the proximity of the chlorination piping and the screen wash pump suction in the intake bay. The highly chlorinated water being taken up by the screen wash system is discharged into the intake canal after performing its screen wash function. To eliminate this problem a dike was installed, in April 1981, in the 1-A service water bay between the service water pumps and the chlorination piping (see Figure 6). Chlorination was reinitiated on May 10, 1981 by this time the chlorination had been stopped for approximately 14 months. This corresponds with the size of the oyster shells that were found. The largest oysters were approximately 1 to 1 /12 inches in total length or about one year old.

Since the amount of loose shells and shell fragments found in the heat exchangers was relatively small compared to the amount of oyster growth in the service water headers, it is thought that, statistically, some small percentage of the organisms, principally young oysters, (they can live as long as 40 years) died for whatever reason, and as their shells detached they were swept, by the flow in the piping, into the heat exchangers where they gradually accumulated. Eventually, the shells and shell fragments impinged on the tubesheet and were held blocking the tubes by the differential pressure between the inlet and outlet water box. As the number of tubes blocked increased, the differential pressure became greater until ultimately, the baffle plate became displaced.

Following the cleaning operations, the buckled RHR heat exchanger baffle plates were replaced and the heat exchangers were returned to their original design specifications (see Figure 8). Due to the Cu Ni used in these components, neither the welds nor the baffle plates themselves are as strong as in HXs in other plants with carbon steel baffles and water boxes. Figure 7 illustrates the deformation found in the heat exchangers and Table 3 summarizes the work which has been performed.

In addition, a monitoring program has been initiated at Brunswick (see Table 4). The RHR heat exchangers will be tested monthly, at which time the flow rate and DP across the heat exchangers will be measured. The licensee stated that a sharp rise in DP would be expected as shells accumulate in the heat exchanger.

The RBCCW and TBCCW heat exchangers will continue to be periodically inspected. The service water headers will also be inspected on an annual basis.

CP&L has made a commitment to modify the screen wash system by 1983. Fine mesh screens (1 mm) will be permanently installed in the circulating water bays and unchlorinated water will be used for the screen wash. The service water system will retain the 3/8 inch mesh screens. All of these screens are Cu Ni.

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Attendance List

AEOD - BSEP Visit 6-17-81

NAME	Organization
*Walt J. Schrade	BSEP ENGINEERING
[illegible]	BSEP Engineering
C S Bohanan	BSEP Reg. Comp.
Don Johnson	Senior Resident NRC
R.E. Morgan	BSEP Mgr Plt Ops
Gene Imbro	NRC, AEOD
John Giannelli	NRC, AEOD
Chris Benedict	BSEP Biological Lab
Bill Hogarth	Mgr. - Env. Technology Section
Mike Masnik	NRC, Environmental Engineering Br.
W. M. Tucker	CP&L Rgv. Tech Supp.
[illegible]	[illegible] Engineering
[illegible]	BSEP Chemist
George [illegible]	BSEP Manager E&RC

Line No.	From	To	AMOUNT of Growth	TYPE of Growth	Cleaned	Comments
2-SW-103-30-157	Intake	90^0 Elbow 50' El Rx Bldg	Heavy 1" Bottom Tappering to 1/2" on top	Bottom of pipe Oysters 74% Mytilus 17% Barnacles 1% side of pipe Oysters 91.4% Mylitus 1.1%	Yes Scraping	Growth was most abundant near intake tapered off proportionally with the distance from the intake
2-SW-29-18-157	Nuclear Header	Just past (10') V255	Moderate-light 1/2" all the way around ID of the pipe	At inlet Oysters 90.6% Polycheates 8.2%	Yes Hydrolaze	Growth was most abundant near inlet tapered off to 1/ft2 at valve V255 toward Diesels (1/2 shell/ft2)
2-SW-1-20-157 2-SW-2-20-157 2-SW-3-20-157	2A CSW Discharge 2B CSW Discharge 2C CSW Discharge	2-SW-V14 2-SW-V16	Light-moderate 6-8 oysters per foot squared	On valve V14 11 oysters 3 tube worms barnacles hydrozoan	Yes hydrolaze	No growth was found between the pump discharge & the check valves. All growth was found between the check valves & the nuclear & conventional headers
2-SS-4-20-157 2-SW-6-20-157	2ANSW Discharge 2BNSW Discharge	2-SW-V19 2-SW-V20	light to none	small oysters barnacles, tube worms	No	Areas around valves were cleared, all other areas did not need cleaning
2-SW-117-6-157	Nuclear header	Valve 2-SW-V117	Heavy to light	same as 2-SW-103-30-157	Yes Scraping	Area between nuclear header & valve V116 was scrapped, the area between V117 & V116 did not need cleaning

TABLE 1

Line No.	From	To	AMOUNT of Growth	Type of Growth	Cleaned	Comments
2-SW-103-30-157	90^{0} Elbow 50' El Rx bldg	2-SW-V105 & V103	Moderate	Side of pipe Oysters 64% Mylitus 35% bottom of pipe Mylitus 6% Barnacles 12%	Yes Scraping	1 layer of growth on bottom of pipe 50% coverage of sides & top some oyster bottom shell halfs on sides
2-SW-103-24-157	2-SW-V105	2-SW-V102	light to none	Oysters & barnacles	No	Very few oysters or other growth found. This is generally a stagnant line
2-SW-106-20-157	2-SW-V106	2-SW-V193	light to none	Oysters & barnacles	No	Pipe elevation for this section obtained from a comparison to Unit #1
2-SW-107-14-157	2B RBCCW Hx	2-SW-V108	light to none	hydrozoan & barnacles	No	Scattered barnacle growth patches 3 to 4 in.^{2} No oysters found
2-SW-234-6-157	2-SW-V275	DG#4 Hx	None	None	No	No attached marine growth. All shells were older & appeared to have been washed in.
2-SW-100-30-157	Intake	2-SW-V3	Heavy 1" Bottom tapering to 1/2" top	Same as Nuclear Header	Yes Hydrolaze & Scraping	Growth tapered off proportional to the distance from the intake
2-SW-100-24-157	Conventional Header	25 to 30' from header	Moderate	Oysters, barnacles, tubeworms & some mylitus	Yes Hydrolaze & some scraping	Growth was most abundant near the inlet & tapered off rapidly

TABLE 1 (CONTINUED)

TABLE 2

Chronology of Chlorinator Outage

-February 22, 1980 - Train #4 shutdown due to mechanical and electrical problems.

-March 15, 1980, to September 21, 1980 - Unit Nos. 1 and 2 outages. (workers)

-September 1980 - Restart of Chlorinator System failed due to electrical problems with heaters and controls.

-October 1980 - Restart of Chlorinator System revealed holes in the evaporators. Evaporators were replaced.

-October 31, 1980 - The Chlorinator System was run for three days. The system was shut down because of fish kill.

-November, 1980 - Attempts were made to operate the system in a manner that would not kill fish.

-December 1980 - Contacts were made with involved groups to resolve the problem of chlorine in the screen wash.

-January 1981 - Trouble ticket submitted to have dam installed.

-March 1981 - A second trouble ticket was submitted.

-April 1981 - The dam was installed in 1A service water bay.

-May 1981 - System line up was completed. Held up start up due to oysters in heat exchangers.

-May 10, 1981 - Restarted chlorination.

The following is a breakdown of the work performed on both Unit 1 and Unit 2 RHR heat exchangers:

2A RHR Heat Exchanger

Spring 1980	- Heat exchanger inspected and inlet and outlet elbows replaced (PM 79-232T). Baffle plate inspected and no degradation noted.
13 May 81	- Heat exchanger drained. Baffle plate inspected with no signs of deformation. Exchanger cleaned of shells and put back into service 14 May 81.
3 Jun 81	- High ΔP noted across baffle plate. Exchanger cleaned of shells, no signs of deformation. Returned to service 4 Jun 81.

2B RHR Heat Exchanger

Spring 1980	- Heat exchanger inspected and a 9 inch deflection discovered in baffle plate. Vertical plate attachment welds cracked ∿ 33 inches. Baffle plate and elbows replaced per PM 79-232S and returned to service.
6 May 81	- Exchanger drained and inspected. A 3 inch deflection of plate noted. Fillet welds along side walls showed one 2 inch crack. Baffle plate removed and heat exchanger bolted up and put back into service on 9 May 81. Unit used as flow path without plate with heavy chlorination of service water system.
16 May 81	- Exchanger drained and lower channel head once again removed so that baffle plate replacement work could begin. Work completed on 24 May 81 and returned to service.

1A RHR Heat Exchanger

25 Apr 81	- Lack of heat transfer noted by Operations. Heat exchanger drained to flow and channel head removed. A 6 to 9 inch deflection noted and plate jacked into position with porta-powers. Bracing stays welded to back of plate for temporary support. Heat exchanger head reinstalled and put back into service 27 Apr 81.
2 Jun 81	- Exchanger drained and lower channel head removed. Permanent repair replaced baffle plate and inlet and outlet elbows per PM 79-231T. Work completed on 13 Jun 81. Awaiting reinstallation of inlet isolation valve (removed for vessel hydro) before returning to service.

1B RHR Heat Exchanger

12 Apr 81	- Heat exchanger drained and inspected. A deflection of 8 to 9 inches noted on baffle plate. Plate replaced along with inlet and outlet elbows via PM 79-231G. Work compelted on 31 May 81 and returned to service.
3 Jun 81	- High ΔP noted across baffle plate. Plans are to drain and remove channel head in order to clean shells - tentatively scheduled for 18 June 81.

TABLE 3

Heat Exchanger Monitoring Program

I. Short Term

RHR Heat Exchangers

Divider plate ΔP monitoring

Verification of design ΔP

Trend analysis of ΔP

Heat transfer evaluation

Other Safety Related Heat Exchangers

Internal inspections

II. Long Term

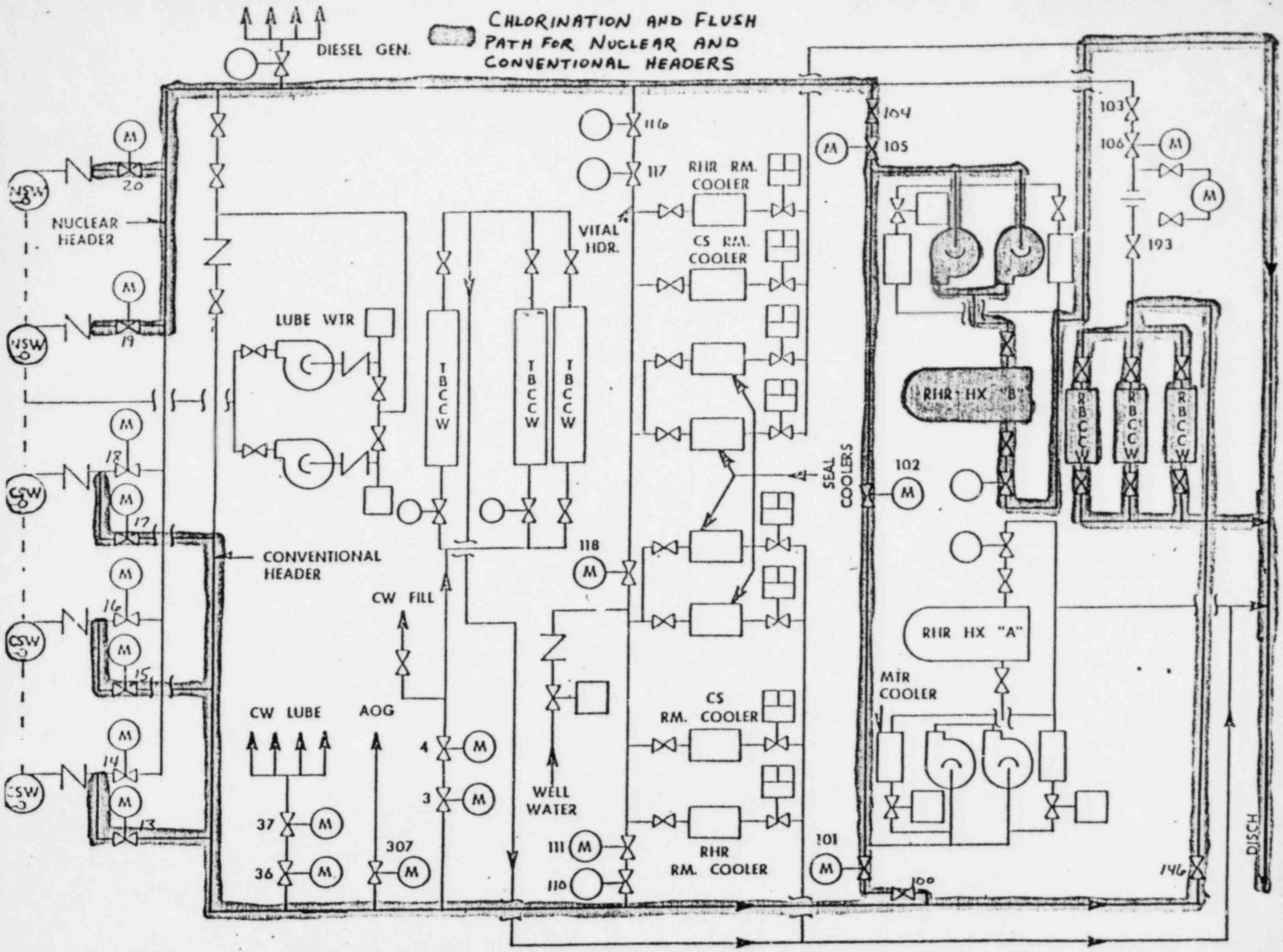
RHR Heat Exchangers

Periodic test for checking ΔP

Other Safety Related Heat Exchangers

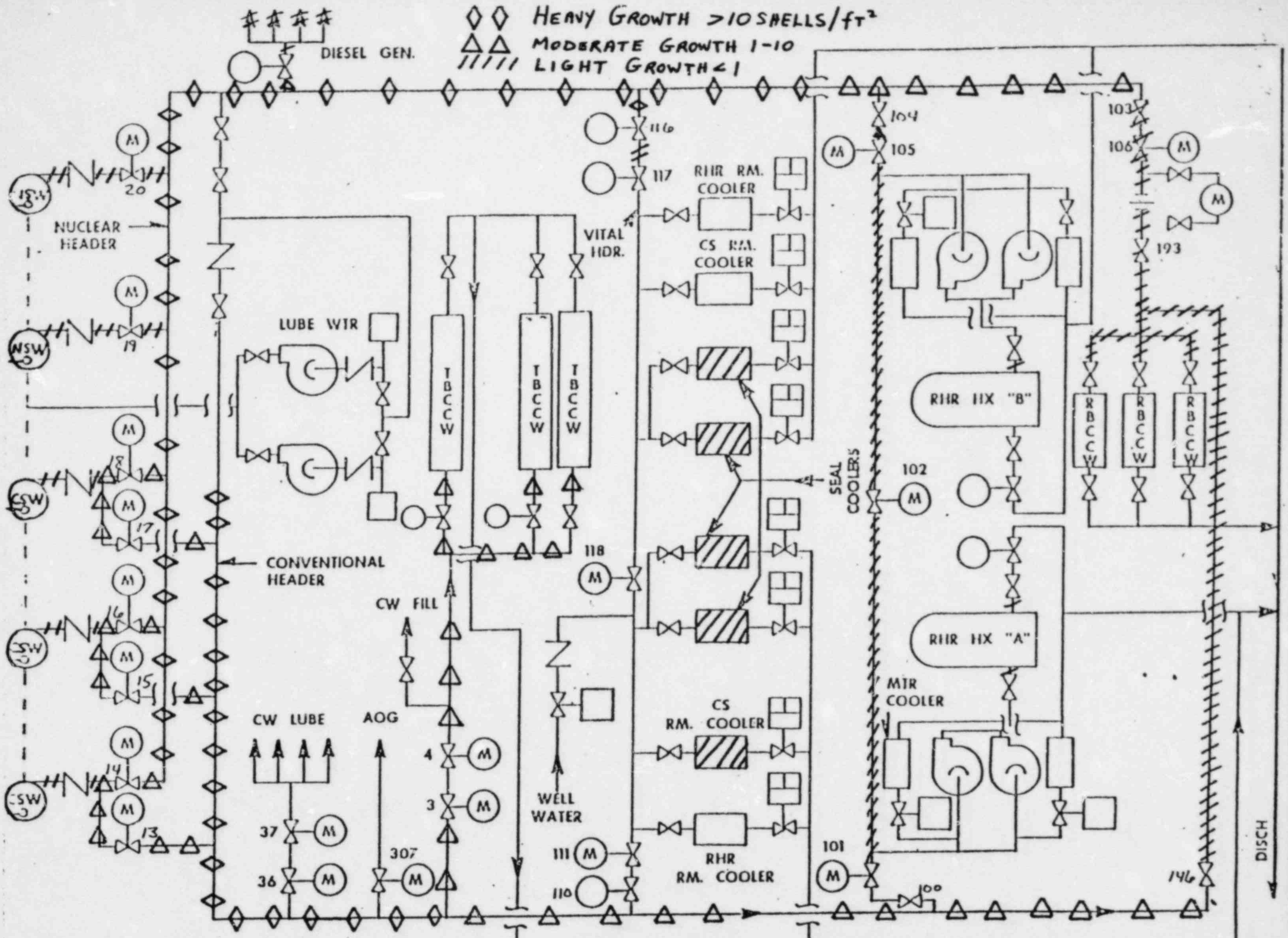
Periodic tests requiring internal inspection

TABLE 4



CHLORINATION AND FLUSH PATH FOR NUCLEAR AND CONVENTIONAL HEADERS
DIESEL GEN.
NSW
CSW
NUCLEAR HEADER
CONVENTIONAL HEADER
LUBE WTR
TBCCW
VITAL HDR.
RHR RM. COOLER
CS RM. COOLER
SEAL COOLERS
RHR HX "B"
RBCCW
RHR HX "A"
MTR COOLER
CW FILL
CW LUBE
AOG
WELL WATER
CS RM. COOLER
RHR RM. COOLER
DISCH

Figure 1



Heavy Growth >10 shells/ft²
Moderate Growth 1-10
Light Growth <1
DIESEL GEN.
NUCLEAR HEADER
CONVENTIONAL HEADER
LUBE WTR
TBCCW
VITAL HDR.
RHR RM. COOLER
CS RM. COOLER
SEAL COOLERS
RHR HX "B"
RHR HX "A"
MTR COOLER
RBCCW
CW FILL
CW LUBE
AOG
WELL WATER
DISCH

Figure 2

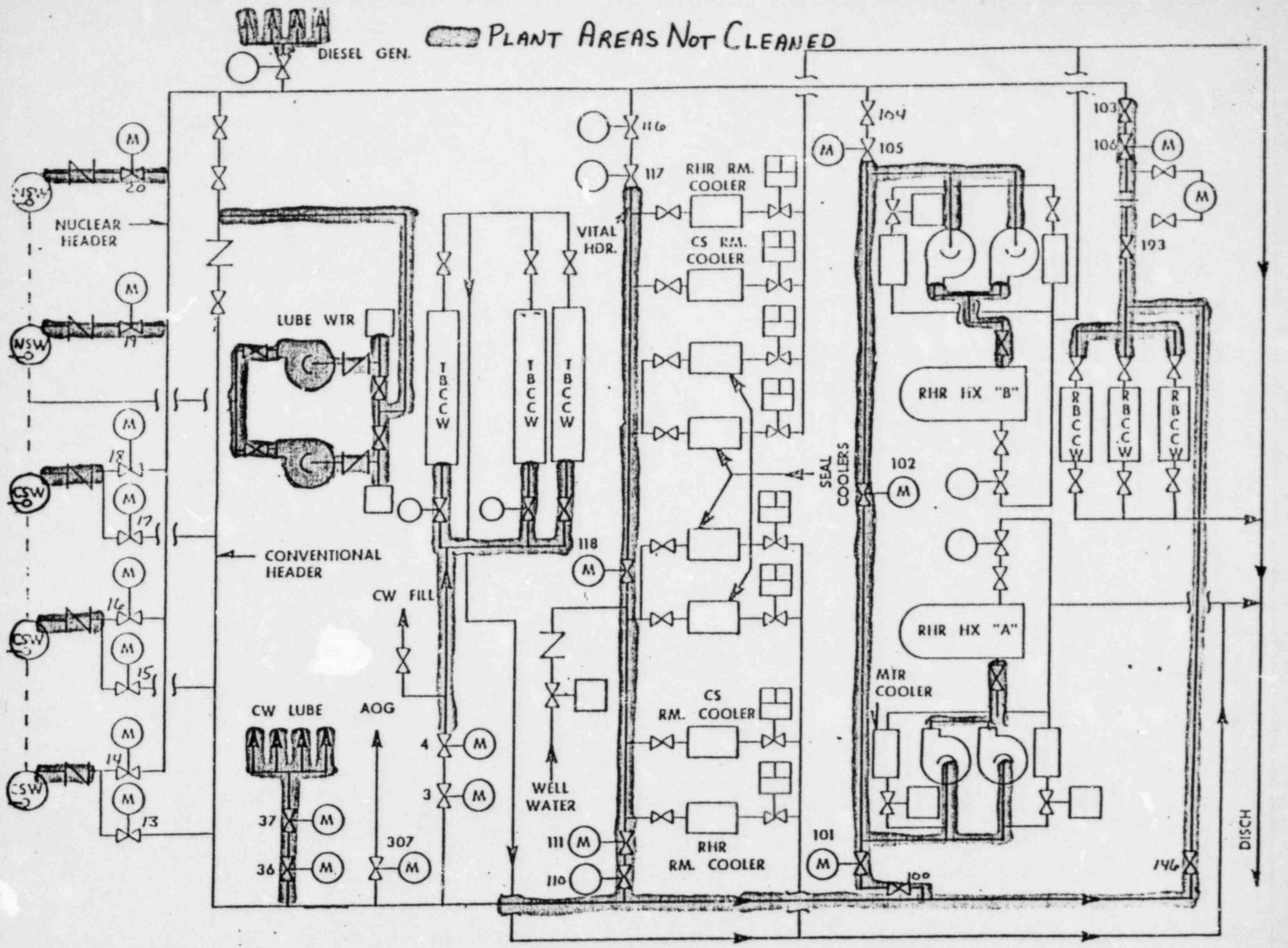
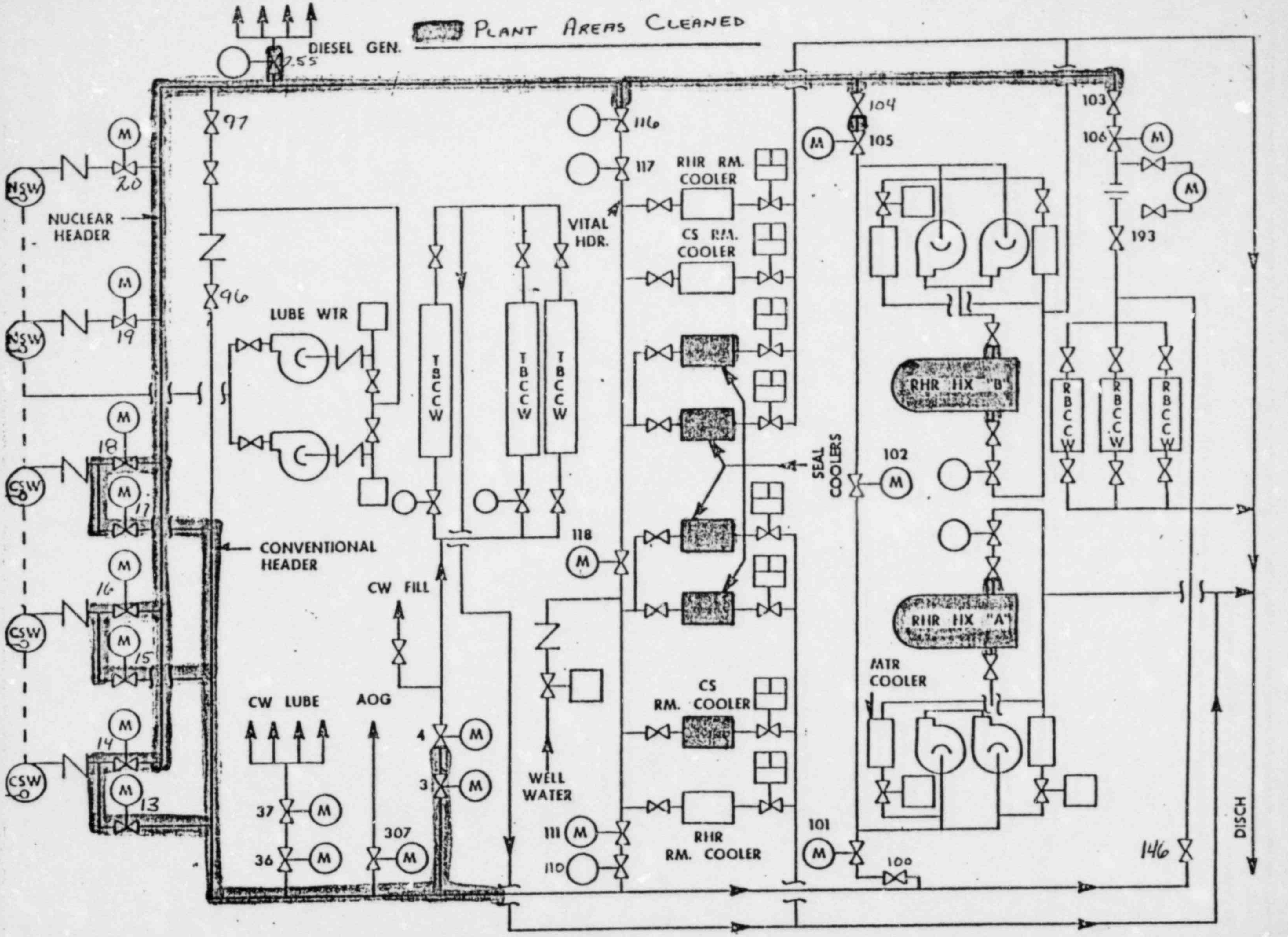

PLANT AREAS NOT CLEANED
DIESEL GEN.
NUCLEAR HEADER
NSW
CSW
20
19
18
17
16
15
14
13
LUBE WTR
CONVENTIONAL HEADER
CW FILL
CW LUBE
AOG
37
36
307
4
3
T B C C W
VITAL HDR.
116
117
118
111
110
WELL WATER
RHR RM. COOLER
CS RM. COOLER
CS RM. COOLER
RHR RM. COOLER
SEAL COOLERS
104
105
102
101
100
103
106
193
146
RHR HX "B"
RHR HX "A"
R B C C W
MTR COOLER
DISCH

Figure 3



PLANT AREAS CLEANED
DIESEL GEN.
255
NSW
NSW
CSW
CSW
CSW
NUCLEAR HEADER
CONVENTIONAL HEADER
20
19
18
17
16
15
14
13
97
96
LUBE WTR
T B C C W
T B C C W
T B C C W
CW FILL
CW LUBE
AOG
4
3
37
36
307
VITAL HDR.
116
117
118
111
110
WELL WATER
RHR RM. COOLER
CS RM. COOLER
CS RM. COOLER
RHR RM. COOLER
SEAL COOLERS
104
105
102
101
100
RHR HX "B"
RHR HX "A"
MTR COOLER
103
106
193
R B C C W
R B C C W
R B C C W
146
DISCH

Figure 11

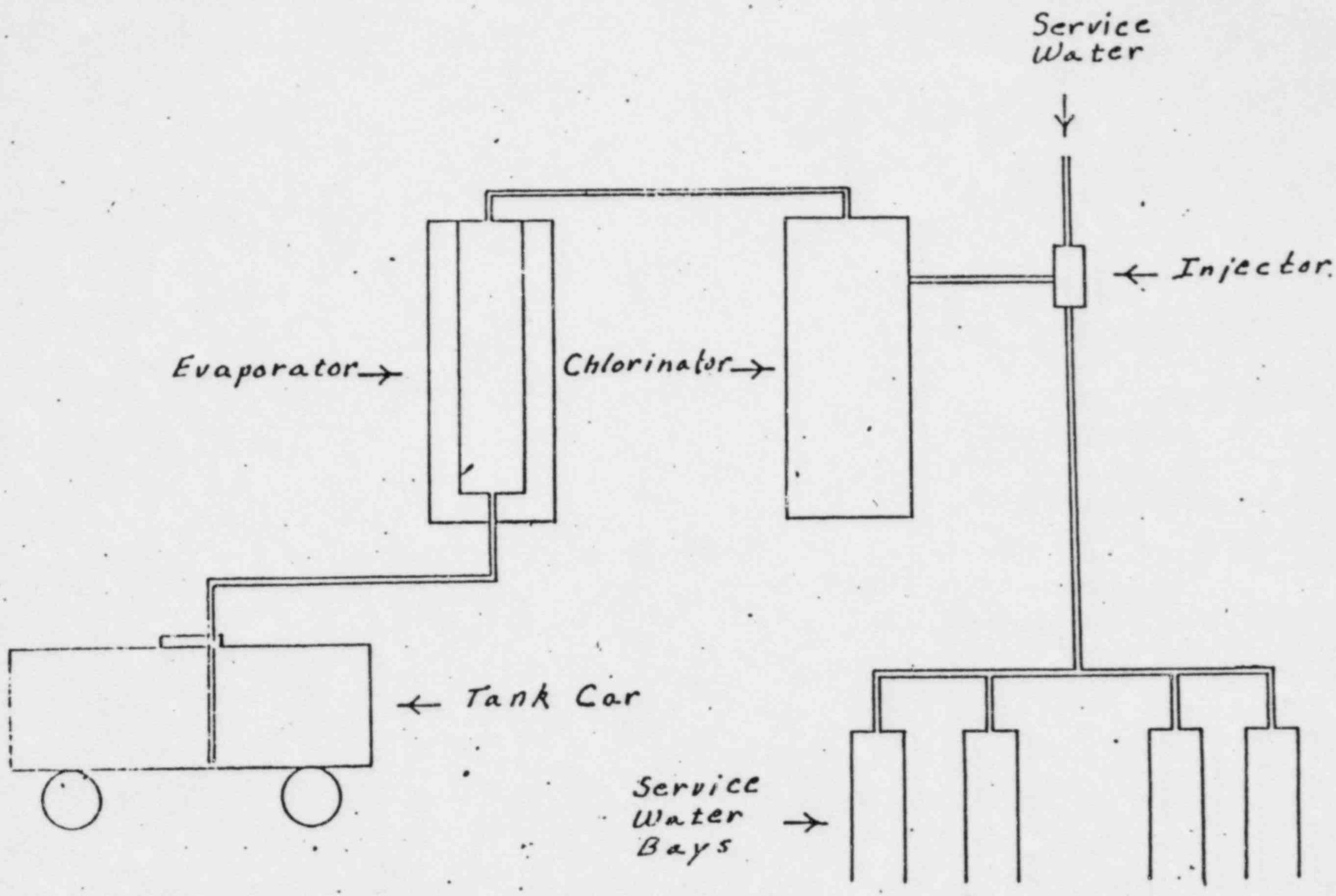
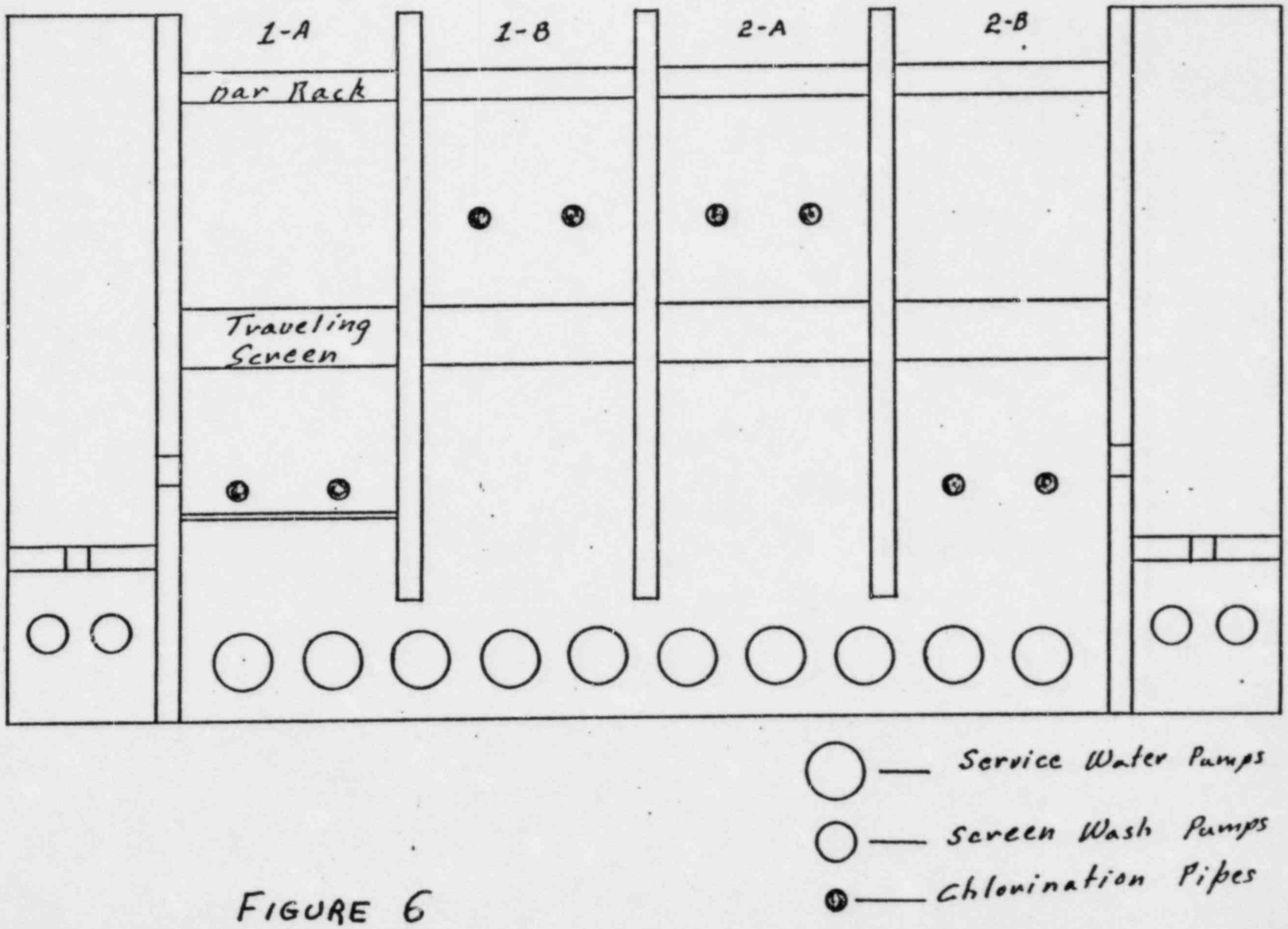
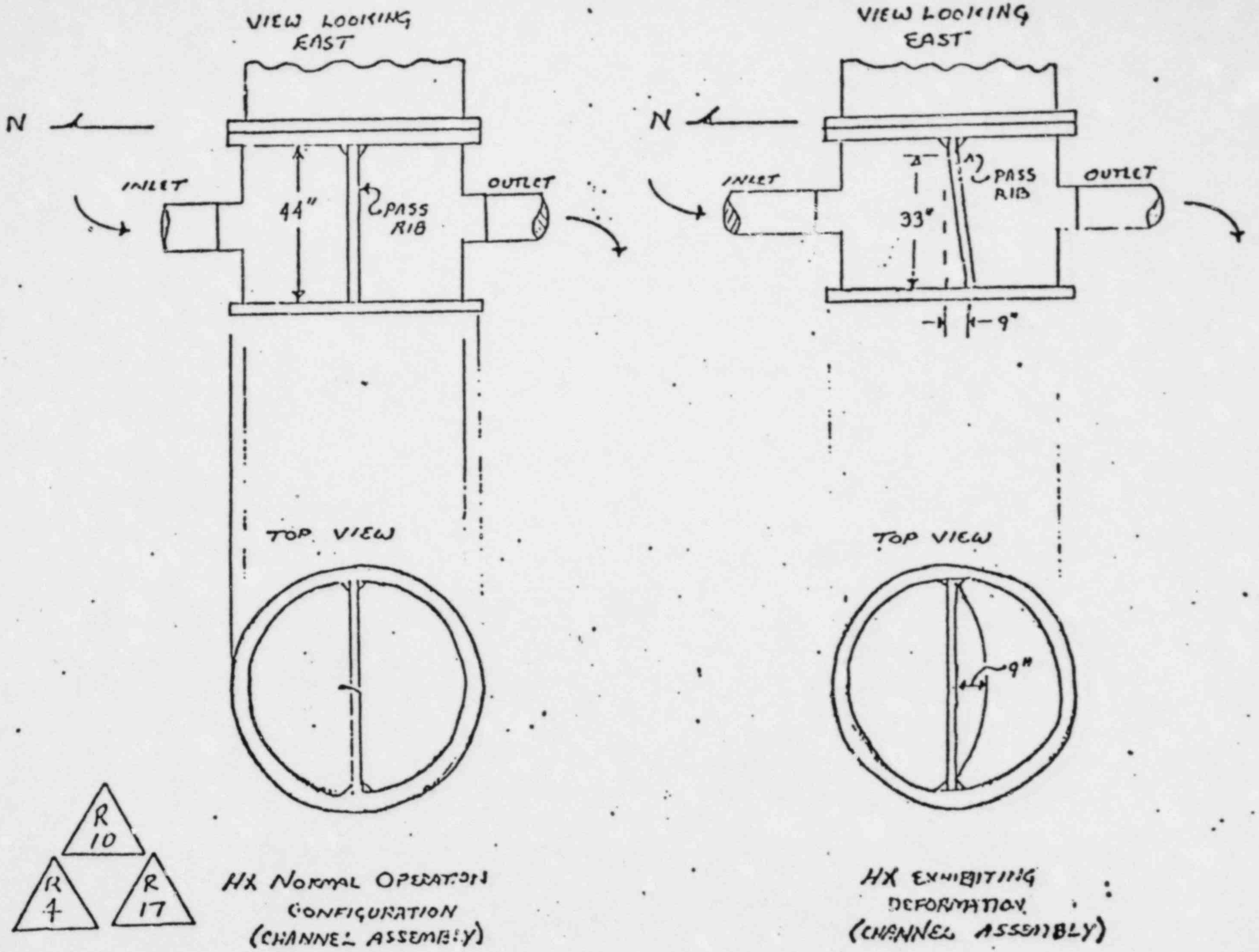

Service
Water
Injector.
Evaporator
Chlorinator
Tank Car
Service
Water
Bays

FIGURE 5



1-A
1-B
2-A
2-B
Bar Rack
Traveling Screen
Service Water Pumps
Screen Wash Pumps
Chlorination Pipes

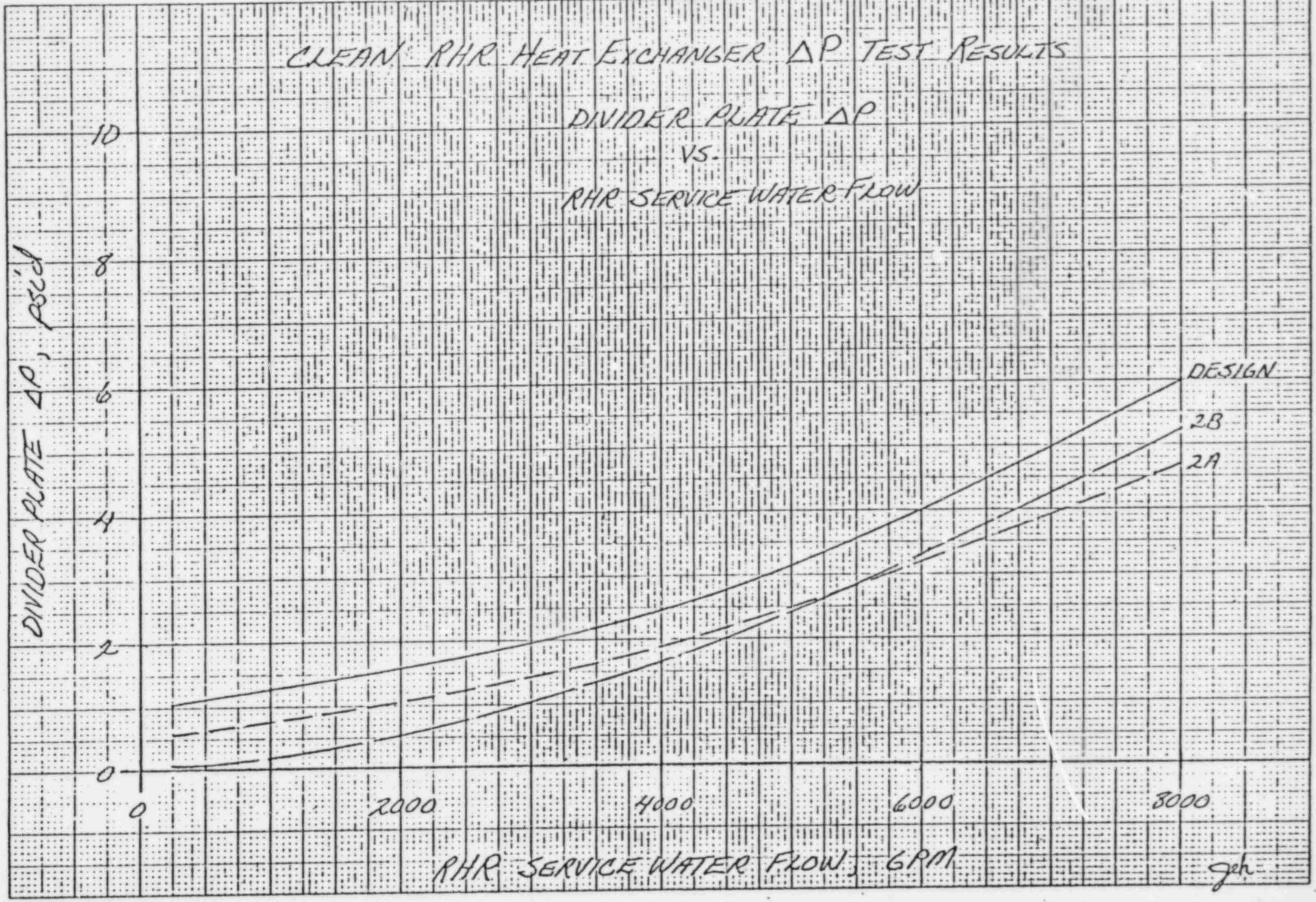
FIGURE 6



PM 79-232 S Rev. 4

FIGURE 7

FIGURE 8


CLEAN RHR HEAT EXCHANGER ΔP TEST RESULTS
DIVIDER PLATE ΔP
VS.
RHR SERVICE WATER FLOW
DIVIDER PLATE ΔP, psid
10
8
6
4
2
0
0
2000
4000
6000
8000
DESIGN
2B
2A
RHR SERVICE WATER FLOW, GPM