TECHNICAL ASPECTS OF COUPLING A 6300 m^3/DAY MSF-RO DESALINATION PLANT TO A PHWR NUCLEAR POWER PLANT

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Abstract

Presently, eight pressurised Heavy Water Reactors (PHWRs) each of 235 MWe capacity are operational in India. Four more units of similar capacity are expected to be commissioned soon. Work on two units each of 500 MWe capacity is also initiated. Extensive engineering development work has also been carried out in India, both on the MSF process and the membrane process. Based on the experience obtained from the presently operating 425 m^3/d MSF plant and from the R & D work on the RO process, a 6300 m^3/d MSF-RO plant (4500 m^3/d MSF & 1800 m^3/d RO) has been designed and the work for setting up this plant is undertaken. The steam for the heating duty in the brine heater as well as the steam for the evacuation purpose for the MSF plant is proposed to be obtained from the nuclear plant steam cycle. Sea water feed for the MSF plant as well as for the RO plant will be derived from the sea water discharge system of the nuclear power plant. Provision is made for supply of electrical power also from the power plant. The details of the heating steam supply circuit starting from the steam tapping point on the nuclear plant side to the MSF plant brine heater inlet and the arrangement for the return of condensate to the nuclear plant has been described with component requirement and various technical considerations. All the liquid streams and the steam supplied from the nuclear plant to the desalination plant as well as the product water will be monitored to ensure that there is no radioactive contamination.

1. Introduction

India's nuclear power programme is based mainly on the Pressurised Heavy Water Reactors (PHWRs). At present, the installed capacity is about 1800 MWe. Another 940 MWe is expected to be added in near future with the commissioning of four units each of 235 MWe capacity. The detailed design of 500 MWe unit has been prepared and the work on these units is initiated.

Bhabha Atomic Research Centre (BARC) at Mumbai has been engaged for more than 15 years in the research and development work in the fields of distillation desalination and RO processes. A MSF plant of 425 m^3/d capacity was indigenously designed manufactured and installed at BARC. This plant has been operating for nearly eight years and generated valuable experience for the design and manufacture of commercial MSF plants based on acid pretreatment and long tube evaporator design. Extensive R & D work on the indigenous manufacture of RO membranes has been carried out and a number of small scale RO plants have been installed in India based on work carried out in BARC.

Based on the operational experience and design data from 425 m^3/d MSF plant and the engineering development work on RO, a 6300 m^3/d MSF-RO plant is being set up at Kalpakkam (Tamil Nadu).

MSF plant needs about 21 Te/hr saturated steam at 130°C and 300 kg/hr at 20 kg/cm^2 for the steam jet ejectors of the evacuation system of MSF plant. Both these steam supplies are proposed to be met from the power plant steam cycle of Madras Atomic Power Station (MAPS). Sea water supply for both MSF & RO plants will also come from various sea water outlet streams of the nuclear power plant. Electricity supply for the desalination will also be made from nuclear power plant electrical system.

Use of an oil fired boiler or use of a water ring vacuum pump is an expensive proposal for creating vacuum in the MSF plant. The supply of steam for this purpose also from the nuclear power plant has economic advantage. In a PHWR, large amount of sea water is used for cooling of the

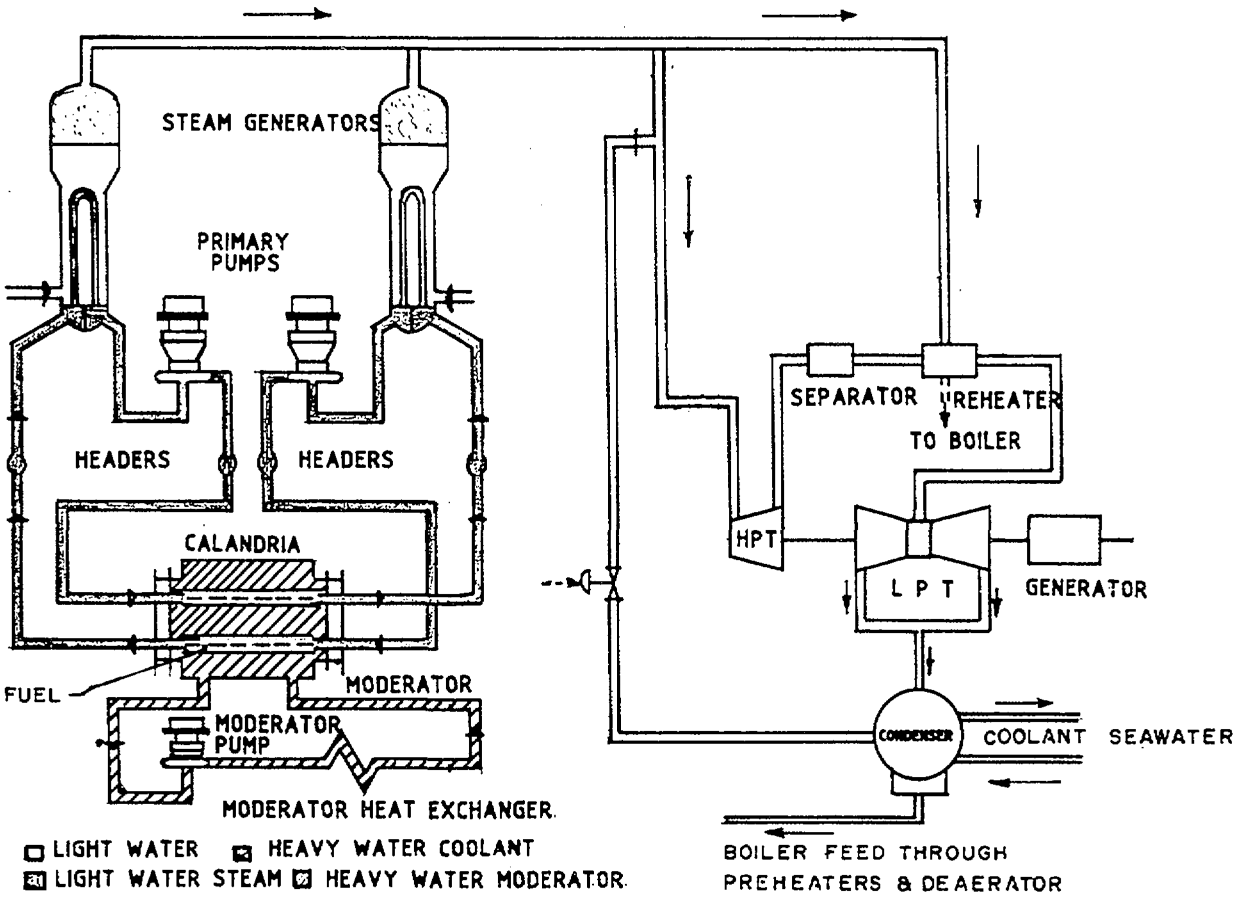
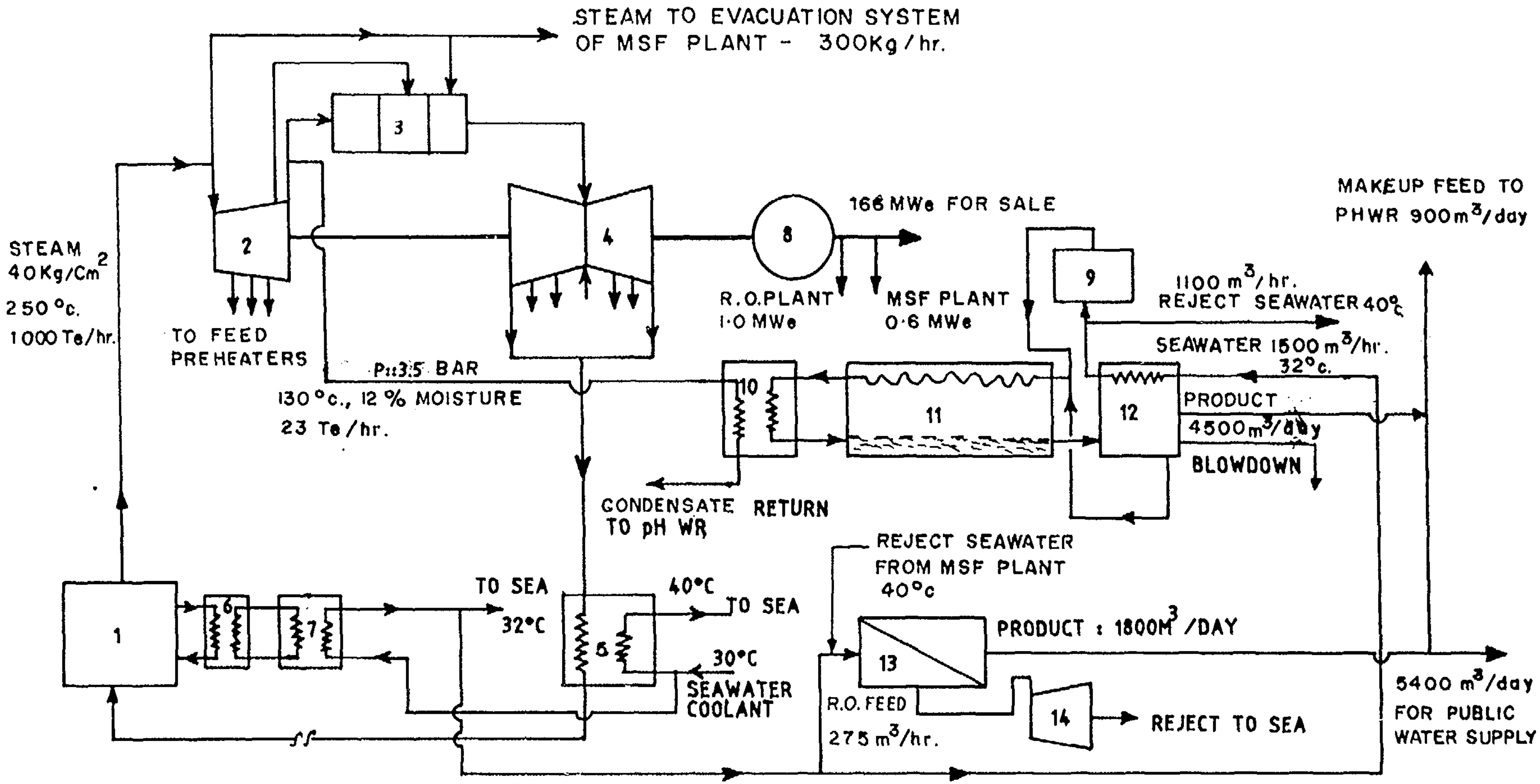


FIG. 1. PHWR SIMPLIFIED FLOW DIAGRAM

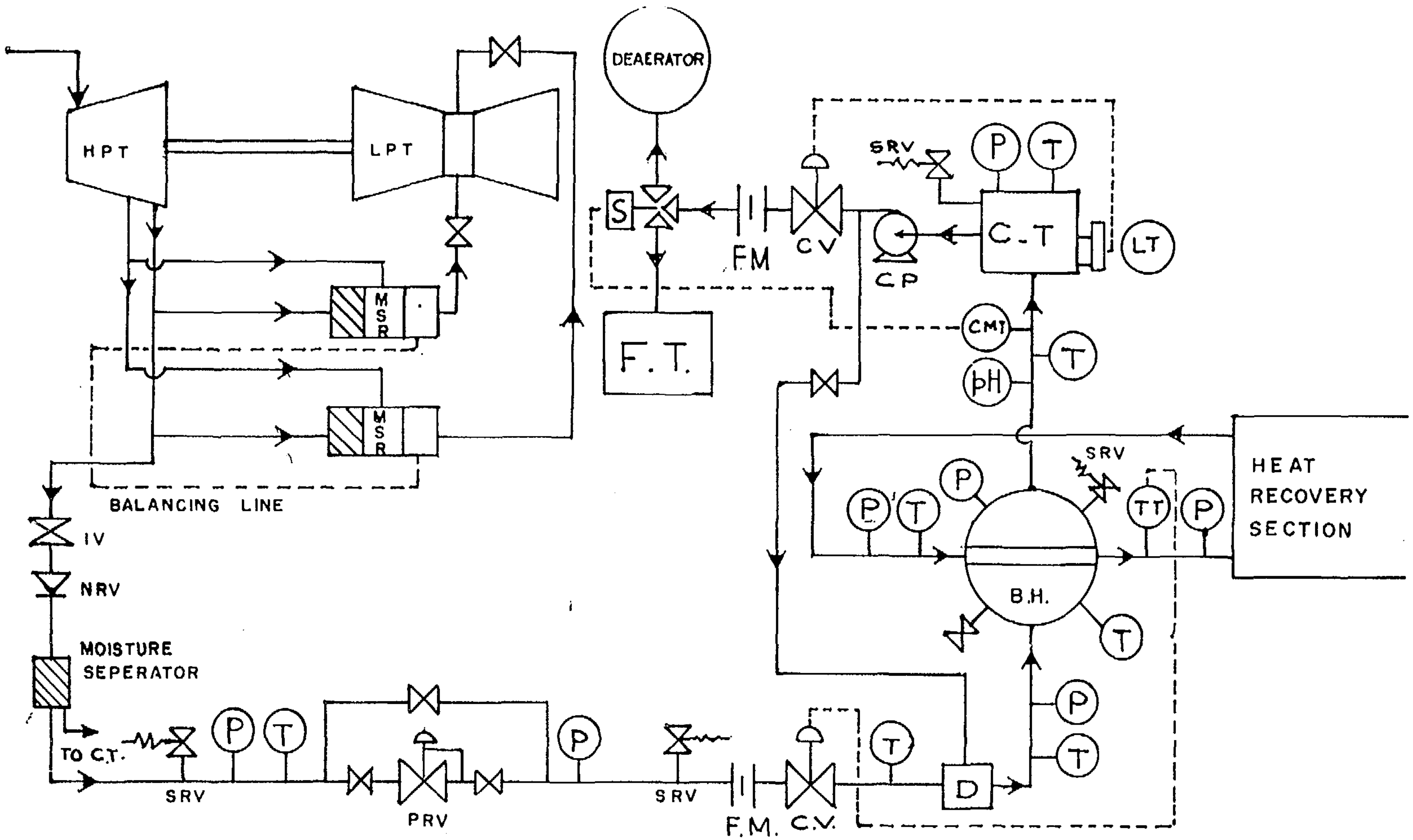
Table I Main Design Parameters of PHWR

1.	Reactor Thermal Rating	: 790 MWth
	Gross Electrical Output	: 235 MWe
	Net Electrical Output	: 220 MWe
2.	Moderator	: Heavy Water, p: 7.5 kg/cm^2 T (in) 44°C, T (out) : 65°C
3.	Primary Heat Transfer coolant	: D_2O, p: 87 kg/cm^2 T (in) 249°C, T (out) : 293°C
4.	Secondary Heat Transfer loop	: Light water/steam Steam p: 40 kg/cm^2, T: 250°C
5.	Exhaust steam from H.P. turbine	: p: 6.0 kg/cm^2, moisture : 11.2%
6.	Steam at Inlet to L.P. turbine	: p: 5.7 kg/cm^2 T: 233.3°C (superheated)
7.	Steam at inlet to condenser	: p: 0.087 kg/cm^2
8.	Sea water coolant temperature	: In : 30°C, Out : 40°C



1. PHWR : 170 MWe
2. H.P. TURBINE
3. MOISTURE SEPERATOR / REHEATER
4. L.P. TURBINE
5. POWER PLANT CONDENSER
6. MODERATOR - DM WATER COOLING LOOP
7. DM WATER - SEAWATER COOLING LOOP
8. GENERATOR
9. MSF PLANT CHEMICAL PRE TREATMENT SECTION.
10. MSF PLANT BRINE HEATER
11. MSF PLANT HEAT RECOVERY SECTION
12. MSF PLANT HEAT REJECT SECTION
13. R.O. PLANT
14. R.O. PLANT ENERGY RECOVERY TURBINE

FIG. 2. 6300 m^3/Day MSF - RO DESALINATION PLANT COUPLED TO 170 MWe PHWR



HPT : HIGH PRESSURE TURBINE.
LPT : LOW PRESSURE TURBINE.
IV. : ISOLATION VALVE
FM : FLOW METER
CV : CONTROL VALVE
MSR : MOISTURE SEPERATOR/ REHEATER.
NRV : NON RETURN VALVE
SRV : SAFETY RELIEF VALVE
PRV : PRESSURE REGULATING VALVE
D : DE SUPER HEATER
BH : BRINE HEATER
TT : TEMPERATURE TRANSMITTER
CP : CONDENSATE PUMP
pH : pH METER
CMT : CONDUCTIVITY METER TRANSMITTER
CT : CONDENSATE TANK
LT : LEVEL TRANSMITTER
S : 3 WAY SOLENOID VALVE
FT : FLASH TANK

FIG. 3. ARRANGEMENT OF SUPPLY OF HEATING STEAM TO DESALINATION PLANT

moderator through an intermediate DM water heat exchange loop. The outlet sea water at the exit of the moderator cooling circuit is available at 32°C (2-3°C higher than the ambient sea water temperature). This 32°C sea water will form the coolant fed to the heat reject section of the MSF plant. This coolant comes out from the MSF plant at 40°C. A part of this sea water at 40°C is mixed in varying ratio with 32°C sea water from the moderator cooling circuit and form the feed to the RO plant at varying temperature in order to study effect of temperature on the performance of RO membrane modules.

2. PHWR Nuclear Power Plant

Fig. 1 shows a general flow diagram of a power plant based on pressurised heavy water reactors. PHWRs use natural uranium dioxide (UO_2) as fuel and heavy water (D_2O) as moderator as well as the primary coolant. The various process parameters mentioned in PHWRs are given in Table I. The Madras Atomic Power Station is presently working at 2 x 170 MWe capacity due to restriction on flow in the coolant channels. Replacement of the coolant channels is planned and full capacity of one of the power units is expected to be restored to 235 MWe by the time desalination plant becomes operational by the middle of year 2001.

Fig. 2 shows the arrangement of coupling between 6300 m^3/d MSF-RO desalination plant and the Nuclear power plant (2 x 170 MWe Madras Power Station). The heating steam supply to the MSF plant is made from the cross over steam pipeline from HP turbine to the moisture separator/reheaters of the power plant. Since steam is wet (12% moisture)steam requirement is 23 Te/hr for a performance ratio of 9 for MSF plant.

Sea water coolant supply to the heat reject section of MSF plant is proposed to be made from outlet sea water (at 32°C) from moderator - DM water - sea water coolant (process sea water) loop. A part of sea water supply to RO plant is made after mixing outlet sea water (32°C) from process sea water cooling loop with 40°C sea water reject from heat reject section of the MSF plant. By this mixing arrangement, temperature of feed to RO plant can be varied and plant performance with respect to product output and product quality can be studied in the range 32°C to 40°C.

300 kg/hr of motive steam is supplied to the steam jet ejectors (of the evacuation system of MSF plant) from live steam line (40 kg/cm^2, 250°C) after reducing the pressure of steam to 20 kg/cm^2 using a PRV. "An NRV is placed in the vent line from last heat reject stage to the evacuation system so that there is no flow of steam to the flash evaporators. Power requirement for the MSF plant is 0.6 MWe. In addition about 2.4 MWe loss of power occurs in the generator due to extraction of 23 Te/hr of heating steam for the MSF plant. RO plant needs 1.0 MW of electrical power.

Fig. 3 gives the details of the heating supply circuit for the MSF plant starting from the tapping point on the power plant side to the brine heater entry point and the condensate return to the power station. The steam from the nuclear boilers is first expanded in HP turbine. At the exist from the HP turbine, the steam is at a pressure of 3.5 kg/cm^2 g and 12% wet. The outlet steam from the HP turbine is divided into two streams and sent to 2 Nos. of combined moisture separators/reheaters in which it is superheated using steam bled at the intermediate pressure from the HP turbine and then by live steam (40 kg/cm^2, 250°C). Superheated steam then flows to LP turbine.

As shown in Fig. 3, steam is tapped from one of the moisture separator - reheater input steam line. An isolation valve and a non return valve are provided just after the tapping point. NRV is necessary since during start up of power plant, the turbine moisture separator/reheater and condenser come under vacuum. The NRV takes care of any leakages of air which may occur on the desalination plant side. The steam is then taken to a small moisture separator where most of its moisture content is removed and sent to the power plant deaerator. A Wiremesh type moisture separator with SS 304 wiremesh is proposed to be used. Expansion loops are provided between long straight pieces of steam pipe after assessing thermal expansion of the piping. Steam velocity is kept 40 - 50 M/Sec.

After moisture separator a vent valve is provided which will vent the steam to atmosphere for short duration if steam consumption stop abruptly in the desalination plant due to brine recycle pump failure or any abrupt rise (above 121°C) in the temperature of hot brine coming out of the brine heater. This vent line will have an orifice fitted for the venting only fixed quantity of steam roughly equal to the steam consumption in the brine heater in normal operation. The steam further flows to a PRV station. After PRV station a safety relief valve is provided which will open if the steam pressure at the input of the brine heater exceeds the set limit. An arrangement is provided to desuperheat the steam if necessary. The steam then enters the brine heater.

The condensate from the brine heater is collected in a condensate tank and pumped to the deaerator of the power plant. A three way solenoid valve is used in the condensate return line to divert the condensate to an intermediate flash tank if found contaminated with sea water. The contaminated condensate is sent to a mixed bed ion-exchanger for polishing and then return to the nuclear power plant.

Pressure of brine in the brine heater will always be kept 0.25 kg/cm^2 more than the heating steam pressure entering the brine heater to prevent any inleakage of tritium activity in the recycle brine. The recycle will be continuously monitored for α, β and tritium activities.

3. Technical Consideration for the Design of Brine Heater

As the brine heat forms the interface between the heat recovery stages of the MSF plant and the nuclear power plant turbine, design of brine heater should be carefully done to give a useful life of at least 30 years. Selection of materials of construction, design temperatures and pressures, recycle brine concentration factor and pH need special care. As the maximum temperature of brine (at outlet from the brine heater) is 121°C, concentration of the recycle brine should be fixed on the basis that solubility product of Ca^{++} and SO_4^{--} ions is appreciably below to the limiting solubility product. The brine velocity in the tubes should not be kept less than 2 m/sec.

The entire steam supply circuit including brine heater shell (steam side) shall be designed for full vacuum to 5.5 kg/cm^2. g (Maximum possible pressure of steam at the tapping point) and 150°C. The pressure of steam entering the brine heater should not exceed 2.8 kg/cm^2. a and as already mentioned flow of steam will be controlled so that outlet brine temperature does not exceeds 121°C.

An impingement baffle should be provided near the top tube rows in order to prevent direct impingement and erosion by entering steam. Proper arrangement in the tube bundle is necessary to remove non-condensable. A safety relief valve on shell side is to be provided which will open if the steam pressure on the shell side exceeds 3.0 kg/cm^2. Differential expansion between tubes and shell should be carefully assessed.

Materials:

Tubes	:	Cu - N: 90 : 10 (Max. 1.5% Fe)
		19 m.m. O.D, 18 BWG
Tubesheets	:	Cu - No. 90 : 10
		Thickness to withstand pressure of 7.0 kg/cm^2
Water Boxes	:	Cu - Ni. 90 : 10
Impingement baffle at steam entry	:	SS 316, 5 mm thick

At BARC, a 425 m^3/D MSF plant is being operated for about 8 years. The brine heater is a four pass shell and tube heat exchanger using 346 No. 19 mm OD. 1 mm thick Cu-Ni 90: 10 tubes. So far, no failure of tubes or leakage of brine to the steam condensate has occurred.

Periodically (once in 2 years) tubes are cleaned using high pressure water jet at a pressure of 200 kg/cm^2 and water flow rate of 15 lpm. A small nozzle with 0.5 mm multiple holes and connected to a high pressure water hose is inserted in the tubes. The nozzle moves forward and the scale gets scrapped off by the high pressure water jet. After once cleaning, boroscopic examination of tubes is carried out and if necessary, second cleaning operation is carried out.

The evaluation of corrosion of tubes by sea water was carried out using eddy current technique and practically no damage to the Cu-Ni tubes was observed.

4. Safeguard Against Radioactive Contamination

All the sea water stream of the desalination plant will be continuously monitored to ensure that no objectionable α, β and tritium activities are there in any of the sea water or any other liquid stream coming into the desalination plant

A six hour interim product water storage (2 tanks) is provided. The product water will be continuously monitored both at the inlet and the outlet of the interim storage tanks and the product water will be released for the public consumption only after having certified by the Health Physicist that the radioactivity levels are not exceeding permissible drinking water limits.