Moisture Separator Reheater Source Book

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Technical Report

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REPORT SUMMARY

Moisture Separator Reheater Source Book

Historically, utility engineers have had difficulty in achieving high reliability and performance from Moisture Separator Reheaters installed at nuclear power plants. Typical performance losses due to ineffective MSRs can be as high as 10 to 15 MWe per plant. Although many successful modifications and repairs have been made, very few have been documented for industry use. This source book documents the results of an EPRI Plant Support Engineering (PSE) task to compile the efforts undertaken by the nuclear industry to improve the reliability and performance of the MSRs.

INTEREST CATEGORIES

Plant Support Engineering
Thermal Performance

KEYWORDS

Heat Rate
Moisture
Nuclear Power Plants
Separation Equipment
Thermal Performance

BACKGROUND Plant operating experience has shown many plants have experienced damage to MS/Rs that increased low pressure turbine moisture content and degraded plant heat rate. Some plants have made design modifications to MS/Rs that correct deficiencies and improve plant heat rate. In addition, good operating procedures play an important role in minimizing damage to MS/Rs. Problems and remedies for MS/Rs have been the subject of numerous reports and the topic of discussion at industry conferences.

OBJECTIVE To provide the plant performance or system engineer who is responsible for MSRs with information that is important to understanding the operation of MS/Rs and to operating them reliably and efficiently.

APPROACH A PSE task group was formed and met four times between December 1995 and October 1996. The task group developed a comprehensive survey, studied the acquired data, and developed conclusions from the moisture separator reheater modifications and repairs that had been performed to date.

RESULTS Based on the review of the moisture separator reheater survey results, the following focus areas are addressed in detail in the report:

- MSR function and design
- MSR design evolution, including tables illustrating plants with similar MSR design
- Correct operating procedures to avoid damage to the MSRs
- Field proven concepts and example procedures for all phases of MSR operation: startup, power operations, and shutdown
- Effective techniques to monitor and troubleshoot MSR performance
- The most significant problems and the various modification packages that have been developed to address the problems

EPRI Project Manager: Timothy Eckert

Plant Support Engineering Program
Operations & Maintenance Cost Control Technology Target
Nuclear Power Group

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Moisture Separator Reheater Source Book

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Prepared by
MSR Source Book Task Group

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ABSTRACT

Historically, utility engineers have had difficulty in achieving high reliability from Moisture Separator Reheaters installed at nuclear power plants. Typical performance losses due to ineffective MSRs can be as high as 10 to 15 MWe per plant. Although many successful modifications and repairs have been made to individual MSRs, few have been documented for industry use. The purpose of this report is to collect the MSR operating experiences of the industry and present them in an informative manner.

The Plant Performance Engineering Program (P^2EP) Main, Reheat, and Extraction Steam (MRES) subgroup requested the development of a source book for MSRs. The target end-user is the plant performance or system engineer who is responsible for monitoring the performance of MSRs and recommending modifications and repairs to them. The book should also be useful to the site maintenance engineer who is responsible for completing specific MSR repair activities.

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1.0

INTRODUCTION

Moisture separator reheaters are used in the turbine cycle of nuclear power plants. The function of a moisture separator reheater is to remove moisture from the wet steam that exhausts from the high-pressure turbine and to reheat the dried steam into the superheat region before it flows to the plant's low-pressure turbines. Some plants have only moisture separators without reheat capability*. In either case, the purpose of the equipment is to reduce moisture content in the cycle steam as it flows through the low-pressure turbines. Moisture reduction increases turbine mechanical efficiency, improves plant heat rate, and reduces the potential for erosion or corrosion damage in the low-pressure turbines.

Plant operating experience has shown that many plants have experienced MS/R degradation that increased low-pressure turbine moisture content and degraded plant heat rate. Some plants have made design modifications to MS/Rs that corrected deficiencies and improved plant heat rate. In addition, good operating practices can minimize damage to MS/Rs. Problems of and remedies for MS/Rs have been the subject of numerous reports and the topic of discussion at industry conferences.

The purpose of this source book is to provide plant engineering and management with:

- A summary of known MS/R problems
- Approaches that can be used to assess the extent of the MS/R problems
- Methods for correcting identified deficiencies

This source book includes information that is important to understanding the operation of MS/Rs and to operating them reliably and efficiently.

Section 2.0 contains a primer describing the basic design and operation of MS/Rs.

Section 3.0 describes the design evolution of MS/Rs.

* When this report is referring to moisture separators with reheat capability, the abbreviation MSR is used. When referring to moisture separators without reheat capability or the moisture separator section of an MSR, the abbreviation MS is used. When referring to both types, MS/R is used. MS/Rs are used only in light water reactor nuclear power plants; they are not used in fossil power plants.

Section 4.0 provides information concerning the operation of MS/Rs. A plant survey was conducted to obtain utility input for this source book. The survey results indicate that there is general agreement on how to best operate MS/Rs. The following are considered important precautions and limitations and are representative of practices being followed at many plants:

- Limit heatup and cooldown rates to the manufacturer's specified rates. Most plants that responded to the survey have a rate limit of 125F°/hr or less.

- Reduce thermal cycling of reheaters by delaying heating steam admission to the tube bundles until the plant has achieved substantial power level and the risk of startup transient is reduced. Some plants delay using the reheaters until 35% power or greater.

- When at reduced load, throttle high-pressure heating steam to prevent unnecessarily large temperature differences in MSR reheaters.

Section 5.0 provides information concerning monitoring and troubleshooting. Most MS/Rs do not have sufficient instrumentation to monitor performance and troubleshoot problems. Most plants, however, can do the following with a limited amount of instrumentation:

- Monitor and trend MS/R outlet temperature. Low or decreasing temperature can be an indication of one or more tube leaks, inadequate moisture separation, or low heat transfer capability of the reheat tube bundles.

- Periodically open and visually inspect MS/Rs during refueling outages. Some of the types of damage and anomalies that can be observed during visual inspections include erosion or corrosion of carbon steel components in the path of steam having a high moisture content, distortion of tubes and tube support plates, external tube wear, and deposits of water-soluble material on the tubes due to moisture carryover. The survey indicates that some plants are conducting visual inspection every refueling outage, others every other outage. Plants with only moisture separators should also conduct periodic inspections of MS internals because there is a potential for damage to the moisture separator chevrons and erosion or corrosion of carbon steel components.

Other troubleshooting methods such as tube leak testing, nondestructive evaluation, and moisture removal effectiveness testing should be considered if there is a history of problems or a suspicion that a problem exists because of other monitoring and inspection information.

Section 6.0 provides information concerning improvements and modifications. Many plants have implemented modifications to resolve MS/R problems and to improve their performance. Modifications have included the following:

- Replacement of wire mesh separators with stainless steel chevron-type separators. Wire mesh is susceptible to damage by the moisture in the cycle steam and is not an efficient moisture separator. If wire mesh or chevron separators are replaced, they should be replaced with double-pocket chevron separators. These have improved moisture removal effectiveness under high and adverse cycle steam inlet flow conditions.

- Incorporation of excess steam flow capability to mitigate the phenomenon of condensate oscillation that can cause thermal stress cracking of reheater tubes. Some plants are installing a more efficient four-pass vent chamber arrangement, especially if the tube bundle is being concurrently replaced.

- Replacement of tube bundles with improved tube material and features that prevent known damage mechanisms such as condensate oscillation and tube vibration. In many cases, the tube bundle can be redesigned to incorporate more heat transfer surface and to have lower cycle steam pressure drop within the allowable space envelope of the MS/R.

Decisions to incorporate major modifications should be based on an economic analysis that considers the gain in plant output versus the cost of installation, including critical path outage time. Other benefits that can be considered qualitatively include improved life of the low-pressure turbines and piping due to a reduction in moisture and the potential for reduced erosion or corrosion in these components. Modifications are not just limited to MS/Rs. Replacement of underperforming moisture separators can substantially improve heat rate and reduce moisture and erosion or corrosion in the LP turbines and piping of plants that only have moisture separators.

This report also contains several appendices. A list of the acronyms and a glossary of terms used in this report are contained in Appendix A. Appendix B describes the plant survey conducted for this source book. Appendix C contains edited operating procedures that were made available to EPRI from participating utilities. Literature relevant to MS/Rs is listed and annotated in Appendix D. Appendix E contains photographs of MSR components.

2.0

MSR PRIMER

Most nuclear power plants utilize moisture separator reheaters to improve plant heat rate and reduce moisture in the low-pressure (LP) turbines. This section describes the function and benefits of MS/Rs, their design, and some of the major problems that have been associated with their operation. EPRI NP-3692, *Procurement and Operation Considerations for Moisture Separator Reheaters,* provides additional descriptive MS/R information.

2.1 Function of an MSR

All nuclear power plants have a single or double flow high-pressure (HP) turbine section and one, two or three double flow LP turbine sections. During expansion through the HP section, the moisture content in the steam increases to approximately 12% at the HP turbine exhaust. The function of MS/Rs* located between the HP and LP sections is to remove moisture from the steam in the HP turbine exhaust and, in the case of MSRs, to reheat the dried steam before it flows into the LP turbine sections. Figure 2-1 illustrates this arrangement. A moisture separator (MS) is in a location similar to an MSR.

Figure 2-1 shows the single-stage reheat cycle and Figure 2-2 shows the two-stage reheat cycle. The single-stage reheat cycle uses main steam to reheat the cycle steam after it has been dried in the moisture separator. The reheater is sized to heat the cycle steam to within a specified temperature below main steam temperature. The difference is called the terminal temperature difference (TTD).

The two-stage reheat cycle has a first-stage reheater that uses HP turbine extraction steam to partially heat the cycle steam after it has been dried. The second-stage reheater then uses main steam to heat the cycle steam to its final temperature.

* Not all nuclear power plants have the reheat function. Most plants that do not have reheat have moisture separators (MSs) that remove moisture in the HP turbine exhaust.

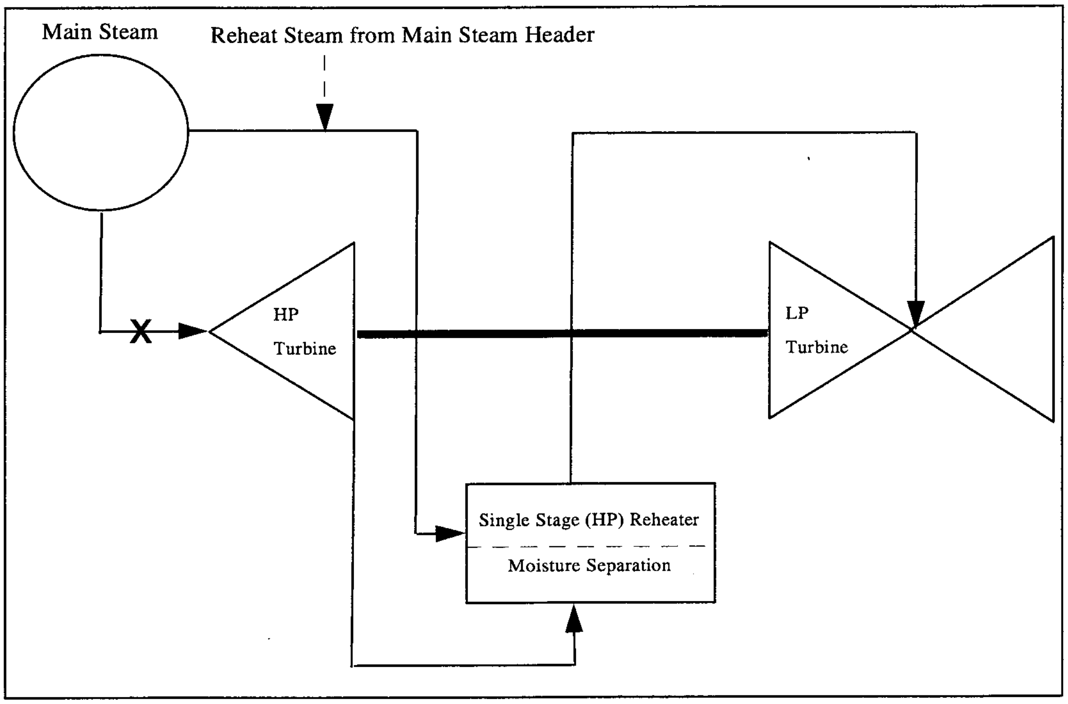

Figure 2-1
Single-Stage Reheater

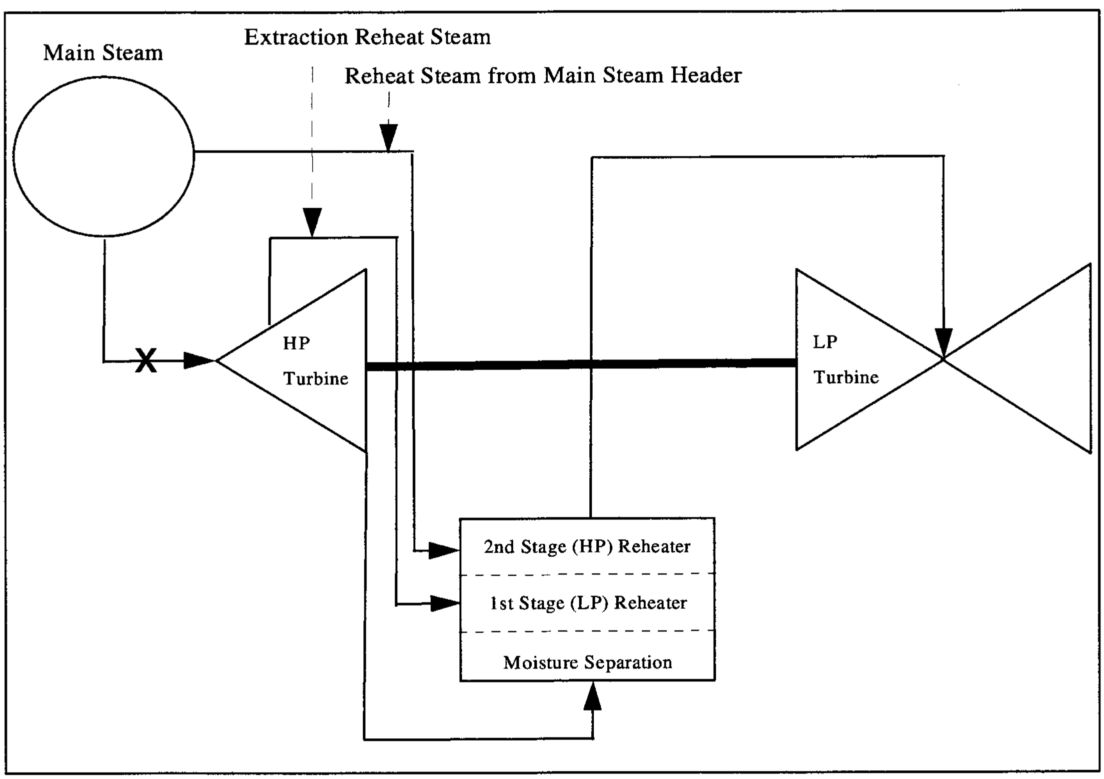

Figure 2-2
Two-Stage Reheater

2.2 Need for MS/R

The function of an MS/R is to remove moisture and to reheat the cycle steam. The MS/R reduces the amount of moisture in the cycle steam as it expands in the LP turbines. The changes in moisture are shown in Figure 2-3. Moisture in the cycle steam reduces the mechanical efficiency in the LP turbines. Moisture separation and reheat do not, however, improve the thermodynamic efficiency of the LP turbines since moisture removal and reheat using main and extraction steam do not increase the overall availability of energy in the steam cycle. In fact, they cause small reductions in thermodynamic efficiency. If it were not for the fact that reduced moisture improves mechanical efficiency, moisture separation and reheat would not improve turbine heat rate.

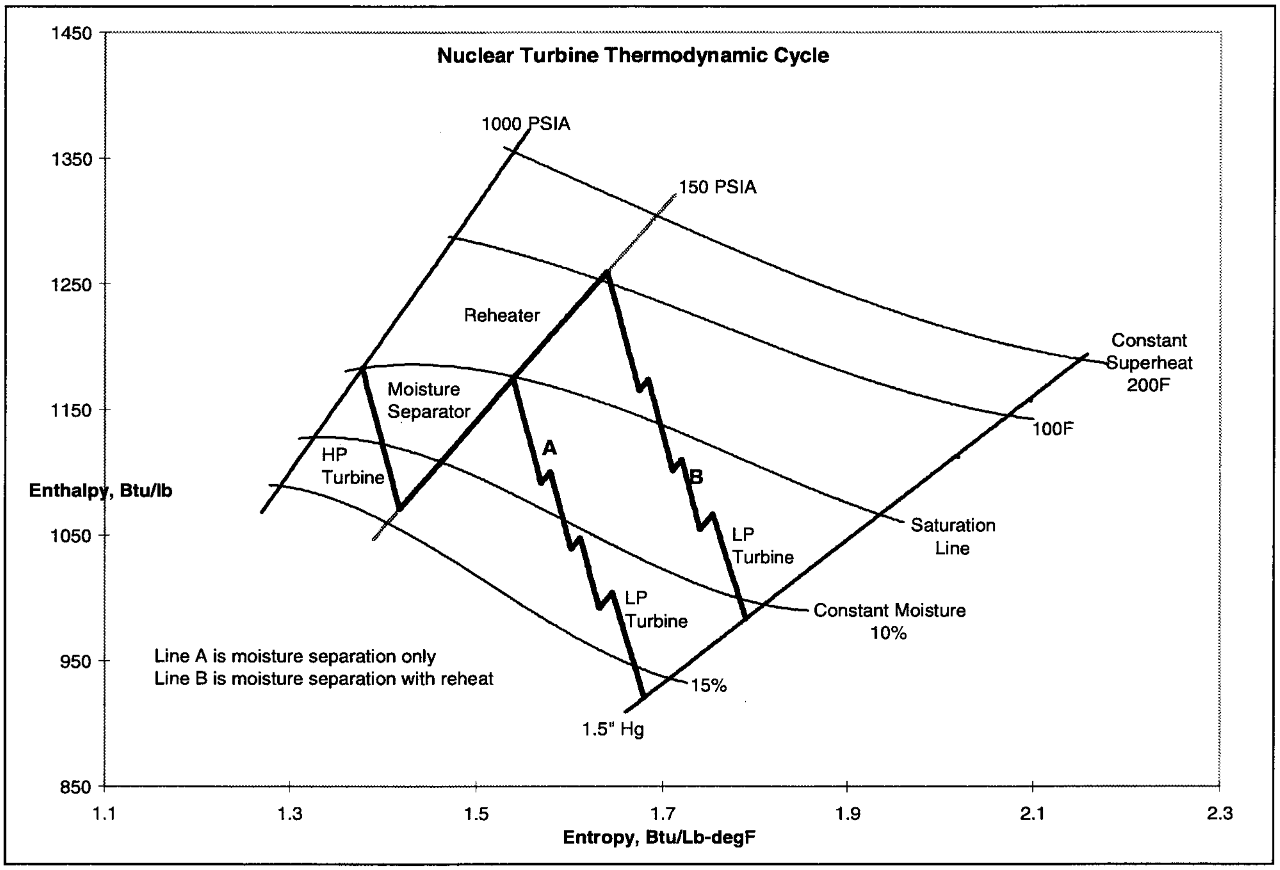

Figure 2-3
Typical Nuclear Turbine Cycle

Moisture entrained in high velocity steam can cause flow erosion of components in the LP turbines. Moisture removal and reheat by MS/Rs reduces moisture in the LP turbine and reduces erosion of LP turbine components in the steam flow path. These benefits were not well recognized during the period when many of the operating plants were designed. Several plants have replaced LP rotors and stationary internals due to erosion and corrosion damage.

In summary, MS/Rs are provided in nuclear steam cycles to reduce the amount of moisture in the steam flowing through the LP turbines. Reduced moisture improves LP turbine mechanical efficiency and reduces moisture related erosion of LP turbine internals. Table 2-1 illustrates the moisture and efficiency gains. A review of Table 2-1 shows that the most gain in cycle efficiency is made by moisture separation. Incremental, but important, gains are made with single- and two-stage reheat. Results will vary with individual plant design.

Table 2-1
Typical Moisture and Efficiency Gains

Condition	LP Turbine Inlet Condition Moisture, % or Superheat, °F	LP Turbine Outlet Condition Moisture, %	Gain in Cycle Efficiency %
No MS or reheat	12 to 15%	24 to 30%	-
MS without reheat	0 to 3%	12 to 18%	4 to 5%
MS and single- stage reheat	140 to 160°F	10 to 12%	5 to 6%
MS and two-stage reheat	140 to 160°F	10 to 12%	6 to 7%

2.3 MS/R Design

The number of MS/R units utilized depends on the size and configuration of the turbine-generator. Usually there are two, four or six units (shells) per turbine generator. Most are arranged to achieve near equal cycle steam flow and reheat in each unit. Although all MSR designs are based on the concepts of moisture separation and reheat, the designs may vary in the details. The descriptions of various designs provided in this section are also applicable to MSs to the extent they use the same principles of moisture separation and use large vessels. Designs, changes in design, and problem descriptions are more fully outlined in Section 3.0, Design Evolution, and Section 6.0, Improvements and Modifications.

2.3.1 Vessel Design

Figure 2-4 shows a schematic of a two-stage MSR. The shell is approximately six feet in diameter and 50 feet long and is typically located in a horizontal position. The vessel is designed to contain moisture separation equipment and tube bundles used to reheat the cycle steam. The vessel is larger than the tube bundles in order to produce low cycle steam velocities needed for efficient moisture separation by surface contact. Figure 2-4 shows two tube bundles. In the case of single reheat, there is one tube bundle per shell. There are no tube bundles in the case of MS only. However, even if the vessel is MS only, it is large in order to the need to have low cycle steam velocity which, in turn, is needed to achieve high moisture separation effectiveness.

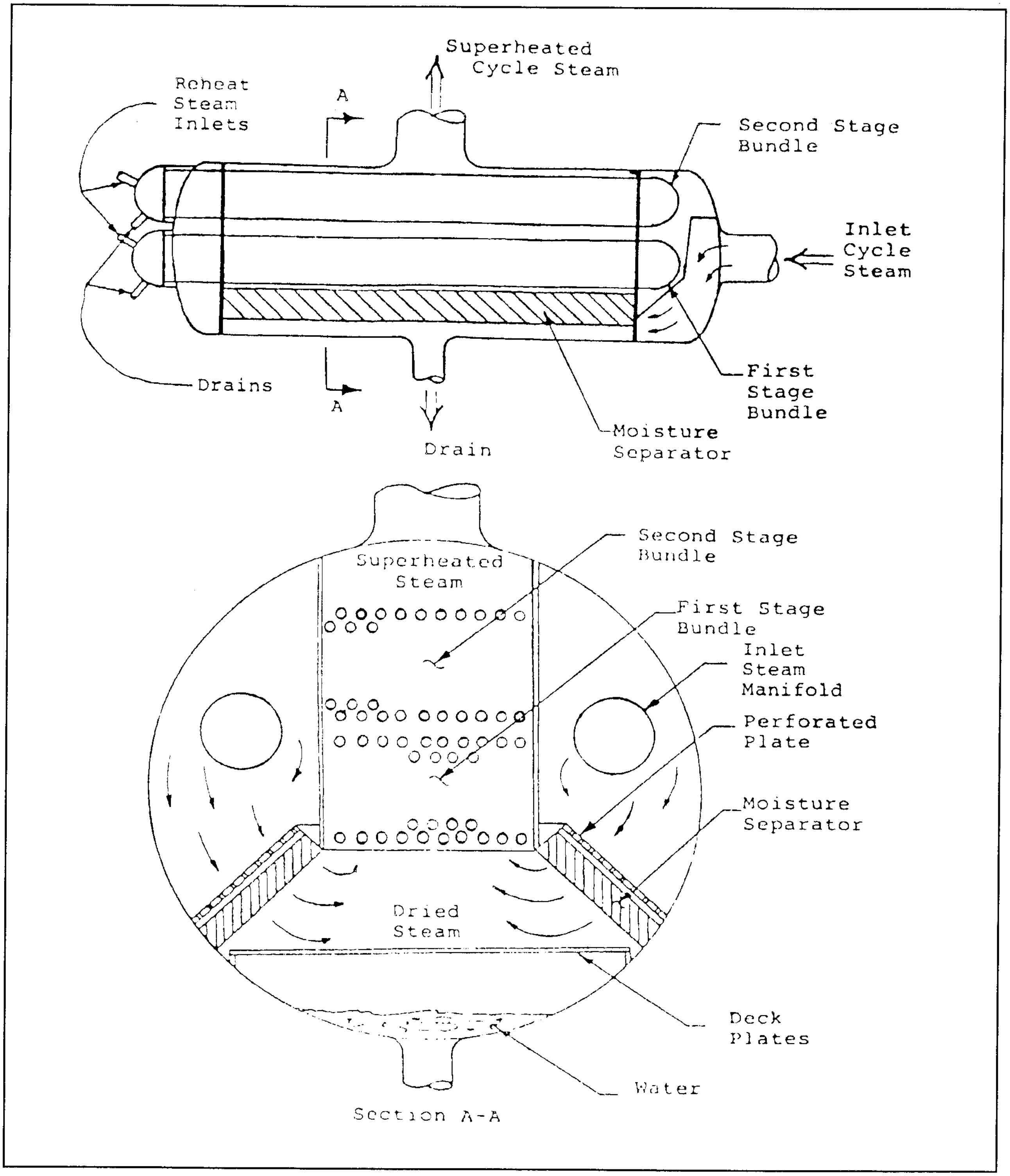

Figure 2-4
Typical Two-Stage MSR

The MSR vessel has several large piping connections, including one for inlet cycle steam at one end and several outlet steam connections on the top of the cylindrical part of the vessel. Some MSRs have one or more inlet connections at the bottom of the vessel. The multiple outlet nozzles aid in distributing cycle steam flow uniformly across the moisture separators and reheat tube bundles and provide multiple feeds to the LP turbines.

The vessel usually has one or more connections at the bottom of the shell to drain water removed from the inlet cycle steam. The water, at saturation temperature corresponding to inlet cycle steam pressure, is directed to a drain tank and then to a feedwater heater stage operating at less than cycle steam pressure in the MS/R.

MSR vessels also have nozzles and channels that supply reheat steam to the tube side of the reheat tube bundles. They have channels and nozzles that drain condensed reheat steam from the outlet of the tube bundles. The condensate, usually at saturation temperature, normally drains to a feedwater heater.

2.3.2 Inlet Cycle Steam Distribution

The cycle steam inlet of nearly all MS/Rs is at one end or the bottom of the vessel. The steam flows through the moisture separators that are distributed along the length of the vessel. The design task is to distribute the steam flow uniformly to the moisture separators. Some MS/Rs use inlet steam manifolds or perforated plates in front of the moisture separator to improve flow distribution.

2.3.3 Moisture Removal Features

The most important function of an MS/R is to remove moisture from the cycle steam. Table 2-1 indicates over half the gain in turbine cycle efficiency is the result of moisture removal. In the case of MSRs, a high moisture removal efficiency is needed to fully utilize the reheater surface to reheat steam rather than evaporate residual moisture in the cycle steam.[**]

The cross-sectional view of Figure 2-4 shows a typical arrangement of MSR components. The most common form of moisture separator is the chevron vane type shown in Figure 2-5. The chevrons are arranged to provide large steam passageways to achieve low steam velocity and to make changes in flow direction. This helps separate the moisture from the steam by change in momentum. The chevrons also provide a large amount of contact surface to collect moisture in the low velocity steam. Moisture collectors in the chevrons are usually oriented vertically or are inclined to provide a

** Turbine vendors do not necessarily base design heat rate and turbine output on 100% moisture removal effectiveness. Some use 85 to 95%. Moisture removal effectiveness is usually not included with other nameplate data but must be calculated from the design turbine heat balance.

drain path to the bottom of the MSR vessel that minimizes re-entrainment of water into the dry steam path. Some MSRs use wire mesh rather than chevrons to separate and collect cycle steam moisture.

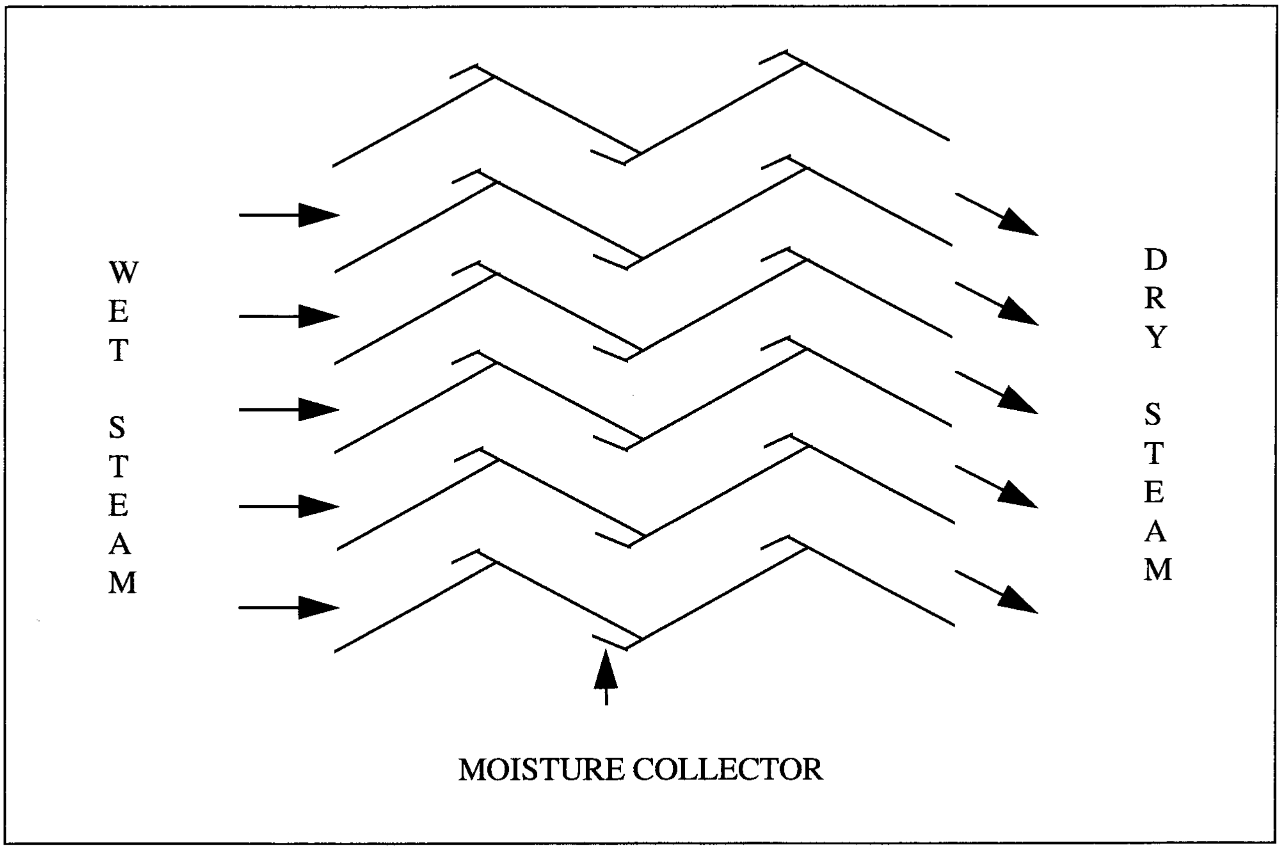

Figure 2-5
Chevron Moisture Separator

2.3.4 Reheater Features

Cycle steam is reheated using heating steam and tube bundles located in the MSR vessel. There are two sources of heating steam depending on the number of reheat stages.

- Single-Stage Reheat: This form of reheat usually uses one tube bundle per MSR vessel with the main steam header as the source of higher temperature heating steam. Some large MSRs have two tube bundles.
- Two-Stage Reheat: This form of reheat usually uses two tube bundles per MSR vessel with an HP turbine extraction point as the source of heating steam for the first or "LP" stage. The main steam header is the source of the second or "HP" stage heating steam. Some large MSRs use two sets of tube bundles for each stage.

Both single-stage and two-stage MSRs use U-tubes, with most having the plane of the U-tube oriented vertically. The heating steam is on the inside of the tubes and cycle steam is on the outside. Heating steam flows into the top leg of the U-tube and condenses along the length of the tube. The condensate and some steam flows out of the bottom leg of the U-tube. Cycle steam is heated by flowing across the outside of the tubes. The outside heat transfer coefficient for heating steam is not high. For this reason, the outside of the tubes are usually finned with integral, low profile fins. The U-tube bundles are enclosed in shrouds that provide a structure for tube support and direct cycle steam flow up between the tubes. The tube sheets are generally located at the end of the vessel, opposite the end that might contain the cycle steam inlet nozzle. The tube bundles extend the length of the MSR vessel. Usually several cycle steam outlet nozzles are provided along the length of the vessel to enhance uniform distribution of steam flow up through the reheater.

A key characteristic of reheaters is the large temperature difference that can exist between cold inlet cycle steam and heating steam temperatures. Figure 2-6 shows typical temperatures for single- and two-stage reheaters. There can be large temperature differences for HP stage tube bundles and the difference increases at part load. The differences are not as large for an LP reheater. The larger temperature differences for HP reheaters results from the use of main steam as heating steam. It remains at constant pressure and temperature or, in the case of some PWRs, increases in pressure and temperature at partial power while inlet cycle steam temperature and pressure decrease at partial power. Larger temperature differences have been the cause of some of the thermal stress-related problems described in Section 6.0.

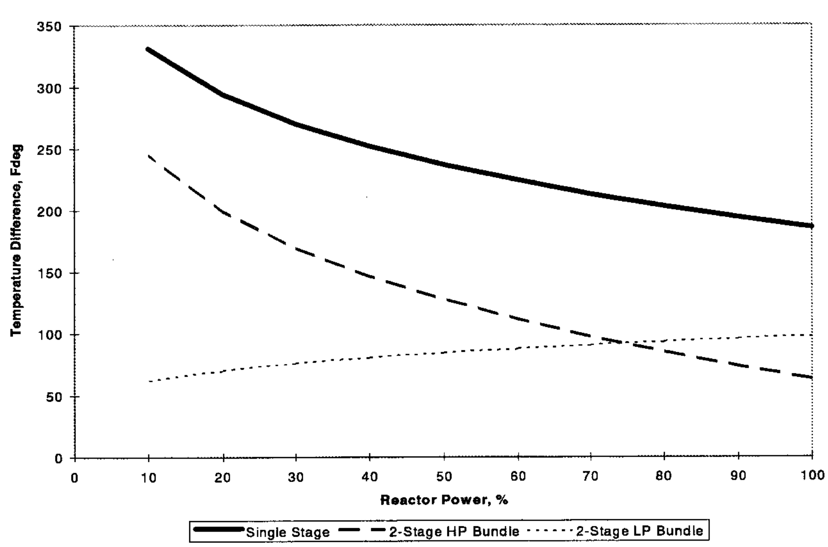

Figure 2-6
MSR Heating Steam vs. Cycle Steam Temperature Differences

2.3.5 Instrumentation

Original equipment manufacturers (OEMs) typically provide little instrumentation to monitor the performance of MSRs. This makes diagnostics and isolation of problem areas difficult. Most MSRs have thermocouples or resistance temperature detectors that measure reheater exit cycle steam temperature. If temperature is low, the reheater tube bundle heat transfer capability might be low. Alternately, the moisture separations efficiency might be low, with part of the reheater surface being used to evaporate carryover moisture.

Table 2-2 lists instrumentation that can be provided on a MSR and the reasons to provide the instrumentation. The instrumentation is discussed in more detail in Power Test Code (PTC) 12.4 and Section 5.6 of this source book. Moisture is not routinely measured. It is possible to set up special tests using tracer techniques, but there is no technology available that can be used to routinely measure moisture content in wet steam.

Table 2-2
Instrumentation for MSRs

Parameter	Purpose
HP heater cycle steam outlet temperature	HP heater TTD and heat balance
HP heater heating steam flow	HP heater heat balance
HP heater steam inlet pressure and temperature (temperature required only if steam is superheated)	Inlet enthalpy and HP heater TTD and heat balance
HP heater outlet flow pressure and temperature	Subcooling, enthalpy and HP heater TTD and heat balance
HP heater excess steam flow	Adequacy, HP heat balance
LP heater cycle steam outlet temperature	LP heater TTD and heat balance
LP heater heating steam flow	LP heater heat balance
LP heater steam inlet pressure and temperature (temperature required only if steam is superheated)	Inlet enthalpy, and LP heater TTD and heat balance
LP heater outlet flow pressure and temperature	Subcooling, enthalpy and LP heater TTD and heat balance
LP heater excess steam flow	Adequacy of flow, LP heat balance
Moisture separator drain flow	Moisture carryover, MSR heat balance
LP turbine inlet pressure	Cycle steam flow
Feedpump turbine steam flow	Cycle steam flow

2.4 References

1. *Procurement and Operation Considerations for Moisture Separator Reheaters*. Electric Power Research Institute, Palo Alto, CA: January 1982. Report NP-3692.

2. ASME Performance Test Codes, "PTC 12.4-1992, Moisture Separator Reheaters". New York, New York: May 24, 1993.

3.0

DESIGN EVOLUTION

Since their first use in the 1960s, MS/Rs have undergone design changes and modifications to improve performance and resolve operating problems. Some of the operating problems are common to all early designs, others are specific to individual vendor designs. The discussion below is organized by vendor: Westinghouse, General Electric and Senior Engineering. Most of the original MS/Rs were supplied by Westinghouse and General Electric. Presently, neither company is actively engaged in designing and installing MS/R modifications and improvements. Most of the recent work has been done by Senior Engineering.

This report addresses common design features of original MSRs and standard modifications. It does not address features that can be considered isolated or trial designs without significant field implementation. For example:

- Nearly all reheater tube bundles are U-tubes with the plane of the U-bend oriented vertically. There are a few MSRs having U-tubes with the plane oriented horizontally. These are not discussed at length except to note that horizontal orientation aggravates the condensate oscillation problem discussed in Section 6.1.

- A few designs use tube bundles with more than one tube diameter or with variations in the number and size of fins. This was done to reduce the variation in heat transfer rate along the length of the tube.

3.1 Westinghouse MS/R Design Evolution

Table 3-1 lists the types of MS/Rs supplied by Westinghouse. Figure 3-1 shows the evolution of Westinghouse MS/Rs since they were first used in the 1960s.

Table 3-1
Westinghouse Installed MS/Rs

FIRST GENERATION		
Plant	**Number of MS/Rs**	**Stages of Reheat**
Haddam Neck 1	4	1
Zorita	2	1
Ginna 1	4	1
Indian Pt. 2	6	1
Indian Pt. 3	6	1
Beznav 1	4	1
Turkey Pt. 3	4	1
Turkey Pt. 4	4	1
Robinson 2	4	1
Cooper 1	4	none
Prairie Island 1	4	1
Prairie Island 2	4	1
Kewaunee 1	4	1
Palisades 1	4	1
Pt. Beach 2	4	1
Surry 1	4	1
Surry 2	4	1
Doel 1	2	1
Doel 2	2	1
SECOND GENERATION		
Plant	**Number of MSRs**	**Stages of Reheat**
Asco 1	4	2
Asco 2	4	2
Almaraz 1	4	2
Almaraz 2	4	2
Farley 2	4	2
ANO 1	4	2
Beaver Valley 1	4	1
Beaver Valley 2	4	1
Diablo Canyon 1	6	2
Diablo Canyon 2	6	2
St. Lucie 1	4	1
St. Lucie 2	4	1
TMI 2	4	2
Calvert Cliffs 2	4	2
Sequoyah 1	6	2
Sequoyah 2	6	2
Watts Bar 1	6	2
Salem 1	6	2
Salem 2	6	2
North Anna 1	4	1
North Anna 2	4	1
Farley 1	4	2
McGuire 1	6	2
McGuire 2	6	2
Crystal River 3	4	2
Zion 1	6	1
Maine Yankee	4	1
Zion 2	6	1

Table 3-1 (Continued)
Westinghouse Installed MS/Rs

THIRD GENERATION "A" TANK		
Plant	**Number of MSRs**	**Stages of Reheat**
Kori 1	2	2
Kori 2	2	2
Chin Shan 1	2	2
Chin Shan 2	2	2
Angra 1	2	2
THIRD GENERATION "B" TANK		
Plant	**Number of MSRs**	**Stages of Reheat**
S. Harris 1	2	1
Kuosheng 1	2	2
Kuosheng 2	2	2
Krsko	2	2
THIRD GENERATION "C" TANK		
Plant	**Number of MSRs**	**Stages of Reheat**
Waterford 3	2	1
S. Texas 1	2	1
S. Texas 2	2	1
Vandellos 2	2	2
WNP 2	2	2
Byron 1	2	2
Byron 2	2	2
Braidwood 1	2	2
Braidwood 2	2	2
Kori 7 Yonggwang 1	2	2
Kori 8 Yonggwang 2	2	2

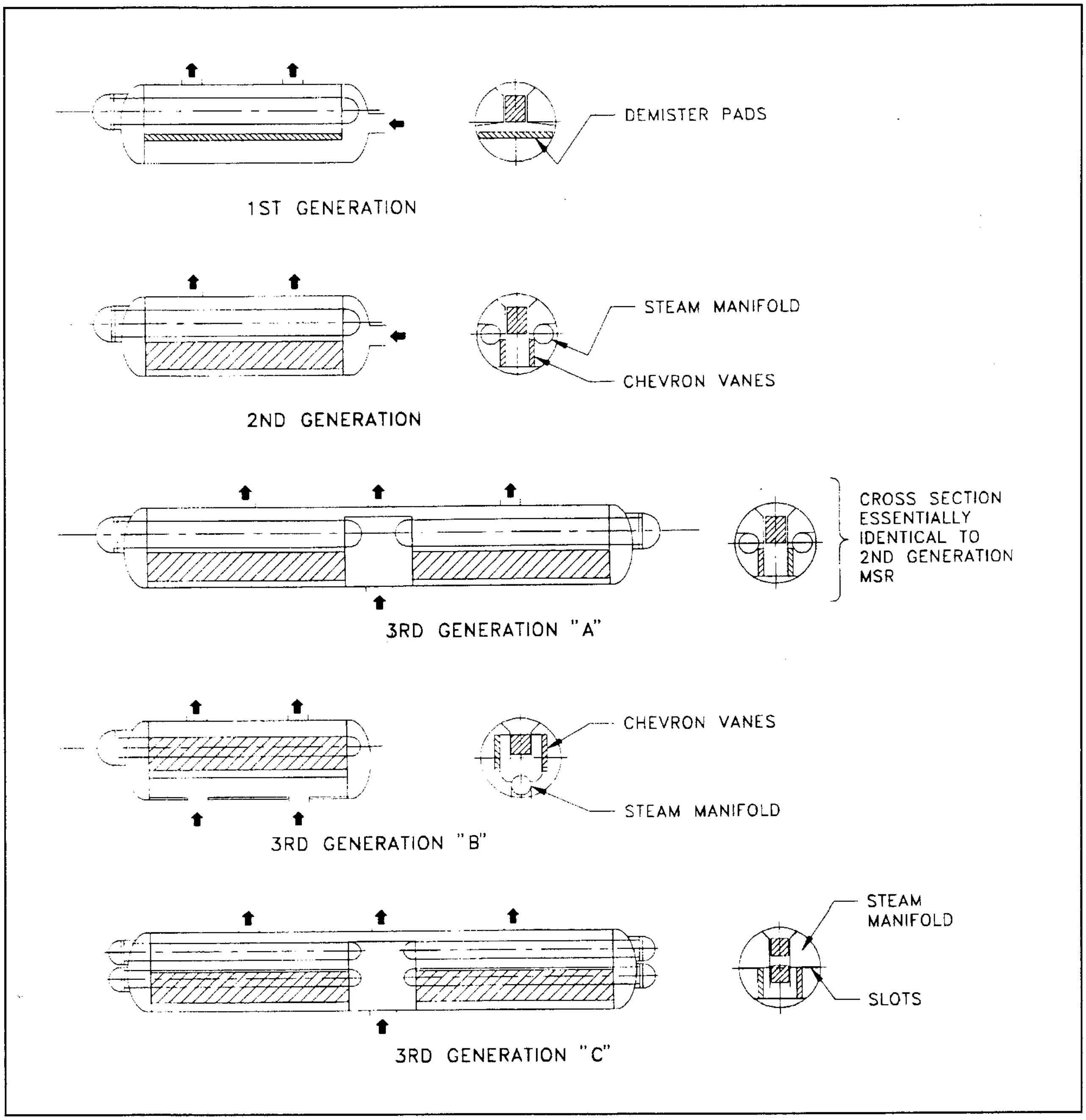

Figure 3-1
Evolution of MS/Rs Designed by Westinghouse
(courtesy of Senior Engineering)

3.1.1 First Generation. Westinghouse MSRs were first installed as original equipment along with Westinghouse supplied turbine-generators. The principal features of the first MSRs included wire mesh demister pads to separate moisture from the inlet cycle steam, CuNi tubed reheaters at PWR plants, and carbon steel tubed reheaters at BWR plants. The MSRs used U-tubes in a two-pass configuration. Some were backfitted or supplied with excess steam or other features to prevent or mitigate condensation oscillation as described in Section 6.1.

3.1.2 Second Generation. The second generation of Westinghouse MSRs and backfits incorporated several significant changes, such as vertically oriented chevron moisture separators and inlet steam distribution manifolds. The chevrons were carbon steel and the tube bundles remained two-pass.

3.1.3 Third Generation. The third generation of Westinghouse MSRs consisted of three different designs. All three use bottom-of-vessel cycle steam inlets instead of an inlet at one end of the vessel. Other features consisted of:

- Third Generation, "A": This design is essentially identical to the second generation design except that it has two sets of moisture separators and reheater tube bundles in one shell. This design has nearly twice the capacity as the second generation and is designed to reduce the number of MSR shells for the large plants from four or six to two.

- Third Generation, "B": This design is smaller than "A," similar in capacity to the first and second generation MSRs. It uses circular steam inlet manifolds located in the bottom of the vessel rather than at mid-level like the second generation and third generation "A" MSRs. This causes the chevron moisture separators to be raised to approximately mid-level of the vessel and the moisture drain path to be different than previous designs.

- Third Generation, "C": This design eliminated the use of circular steam inlet manifolds, relying instead on an axial path between the vessel wall and the reheater shroud, to form a manifold for steam distribution from the center-of-vessel inlet cycle steam nozzle and plenum, to distribute steam to the separators. The manifold and inlet to the vertical chevrons is separated by a plate extending the length of the vessel that has slots to help achieve uniform flow distribution to the chevrons. The design incorporates two sets of moisture separators and reheater tube bundles. This arrangement allows sufficient room for tube bundles needed for a two-stage reheater.

During and since the Westinghouse MSR evolution described above, several other features including the following, might have been added, depending on MSR type and vintage:

1. Stainless steel chevrons to minimize erosion
2. Perforated plates in front of the chevrons to improve inlet cycle steam distribution
3. A deck plate to prevent moisture re-entrainment
4. Modified 439 stainless steel tubes to minimize corrosion and thermal stress
5. A four-pass, excess* steam vent chamber
6. Seal strips to minimize flow bypass in the tube bundles
7. An optimized tube bundle incorporating more heat transfer surface
8. Controls for heating and excess steam

3.2 General Electric MS/R Design Evolution

General Electric supplied MS/Rs to many nuclear power plants as part of the OEM turbine generator package. Table 3-2 lists the types of MS/Rs by plant. The bottom of the table contains a description of the MS/R. GE supplied MS/Rs to 52 domestic nuclear units, of which 19 were MS only.

Some of the MSs supplied by GE are of the vertical design: short, vertically oriented vessels as shown in Figure 3-2. In two cases, separate vessels were used for moisture separation and reheat. Later MSs are of the horizontal design as shown in Figure 3-3. All MSs supplied by GE use stainless steel, single-pocket chevron moisture separators.

Figure 3-4 shows three basic designs of MSRs supplied by GE. These consist of:

- Two-Stage External Header Type: The cycle steam inlet for this design is at one end of the vessel; the other end has the heating steam headers. The banks of chevron vanes are nearly vertical, but tilt slightly toward the center of the vessel.

- Single-Stage External Header Type: The cycle steam inlet for this design is through two nozzles in the bottom of the vessel arranged to help even out the distribution of flow along the length of the vessel. The banks of chevron vanes are oriented at 45°, tilting away from the center of the vessel. This orientation minimizes re-entrainment of moisture after the dry cycle steam leaves the chevrons.

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* Excess steam is also referred to as scavenging steam. The term "excess steam" is used in this report.

Table 3-2
General Electric Installed MS/Rs

Plant Name	Country	Reactor Type	MS/R Type*
Tsuruga 1	JAPAN	BWR2	AO2
Dresden 2	US	BWR3	AO4
Dresden 3	US	BWR3	AO4
Fort Calhoun	US	PWR	AO4
Fukushiima 1-1	JAPAN	BWR3	AO4
Fukushiima 1-2	JAPAN	BWR4	AO4
Millstone 1	US	BWR3	AO4
Monticello	US	BWR3	AO4
Pilgrim	US	BWR3	AO4
Quad Cities 1	US	BWR3	AO4
Quad Cities 2	US	BWR3	AO4
Santa Maria de Garon	SPAIN	BWR3	AO4
Vermont Yankee	US	BWR4	AO4
Limerick 1	US	BWR4	AO6
Limerick 2	US	BWR4	AO6
Peach Bottom 2	US	BWR4	AO6
Peach Bottom 3	US	BWR4	AO6
Browns Ferry 1	US	BWR4	BO6
Browns Ferry 2	US	BWR4	BO6
Browns Ferry 3	US	BWR4	BO6
Fukushiima 1-6	JAPAN	BWR5	CO2
Hope Creek	US	BWR4	CO2
Susquehanna 1	US	BWR4	CO2
Susquehanna 2	US	BWR4	CO2
Tokai 2	JAPAN	BWR5	CO2
Donald C. Cook 1	US	PWR	GB2
Hatch 1	US	BWR4	HC4
Oconee 1	US	PWR	HC4
Oconee 2	US	PWR	HC4
Oconee 3	US	PWR	HC4
Hatch 2	US	BWR4	HE4
ANO2	US	PWR	JD2
Calvert Cliffs 1	US	PWR	JD2
Brunswick 1	US	BWR4	JE2
Brunswick 2	US	BWR4	JE2
Cofrentes	SPAIN	BWR6	JE2
Davis Besse	US	PWR	JE2
Duane Arnold	US	BWR4	JE2
Fitzpatrick	US	BWR4	JE2
LaSalle County 1	US	BWR5	JE2
LaSalle County 2	US	BWR5	JE2
Millstone 2	US	PWR	JE2
Millstone 3	US	PWR	KA2
Seabrook	US	PWR	KD4
Clinton	US	BWR6	KE2
Gentilly 2	CANADA	PHWR	KE2

Table 3-2 (continued)
General Electric Installed MS/Rs

Plant Name	Country	Reactor Type	MS/R Type*
Nine Mile Pt 2	US	BWR5	KE2
River Bend	US	BWR6	KE2
Vogtle 1	US	PWR	KE4
Vogtle 2	US	PWR	KE4
Catawba 1	US	PWR	LD4
Catawba 2	US	PWR	LD4
Callaway	US	PWR	LE4
Maanshan 1	TAIWAN	PWR	LE4
Maanshan 2	TAIWAN	PWR	LE4
Palo Verde 1	US	PWR	LE4
Palo Verde 2	US	PWR	LE4
Palo Verde 3	US	PWR	LE4
Perry 1	US	BWR6	LE4
Wolf Creek	US	PWR	LE4
Nine Mile Pt 1	US	BWR2	XA8
Oyster Creek	US	BWR2	XA8

* **Legend for MS/R Type Letters:**

1st Character: Shell Description			
Moisture Separators		Moisture Separator Reheaters	
A	Vertical with horizontal steam flow	G	Single-stage reheater, internal header, vertical U-tubes
B	Vertical with vertical steam flow	H	Two-stage reheater, external header, vertical U-tubes
C	Horizontal with vertical steam flow	J	Two-stage reheater, internal header, horizontal U-tubes
		K	Single-stage reheater, external header, vertical U-tubes
		L	Two-stage reheater, internal header, vertical U-tubes
		X	Two-stage, separator vessels for moisture separation and reheat stages

2nd Character: Tubing Description			
Moisture Separators		Moisture Separator Reheaters	
O	No tubes (moisture separators)	A	High fin tube, steel
		B	5/8″ diameter 90/10 copper nickel
		C	5/8″ diameter steel
		D	1″ diameter 90/10 copper nickel
		E	1″ diameter steel

3rd Character: Pressure Vessel Unit: 2,4,6, or 8

Example	
JE2	J = Two-stage reheater, internal header, horizontal U-tubes E = 1″ diameter steel tubes 2 = 2 pressure vessels per unit

- Two-Stage Internal Header Type This type has cycle steam nozzle and chevron vane orientations similar to the Single-Stage External Header type MSR. The major difference is that internal headers are used for supplying heating steam. The internal location allows the use of drum type headers rather than conventional thick, round tube sheets. As a result, the tube bundles are wider and flatter, and the cycle steam ΔP is reduced for the same amount of heat transfer surface. This type of MSR was furnished in both vertical and horizontal U-tube orientations.

Since the early MS/Rs were installed, GE has performed extensive testing and modifications that include:

- Severing reheat tube bundle supports in the end region to prevent binding and damage to tubes due to distortion of the tube bundle.

- Orificing of reheater tube inlets to redistribute steam flow through the tube bundle and addition of excess steam lines to pass excess steam through the bundles. The tube bundles remained two-pass.

- Modification of inlet baffles, addition of new preseparator drains, and modifications to drain piping to increase separator efficiency.

- Modification of control schemes and operational revision to provide better venting and heatup rates.

The MS/Rs had other design variations:

- Copper nickel or steel tubes
- 5/8 or 1-inch tubes

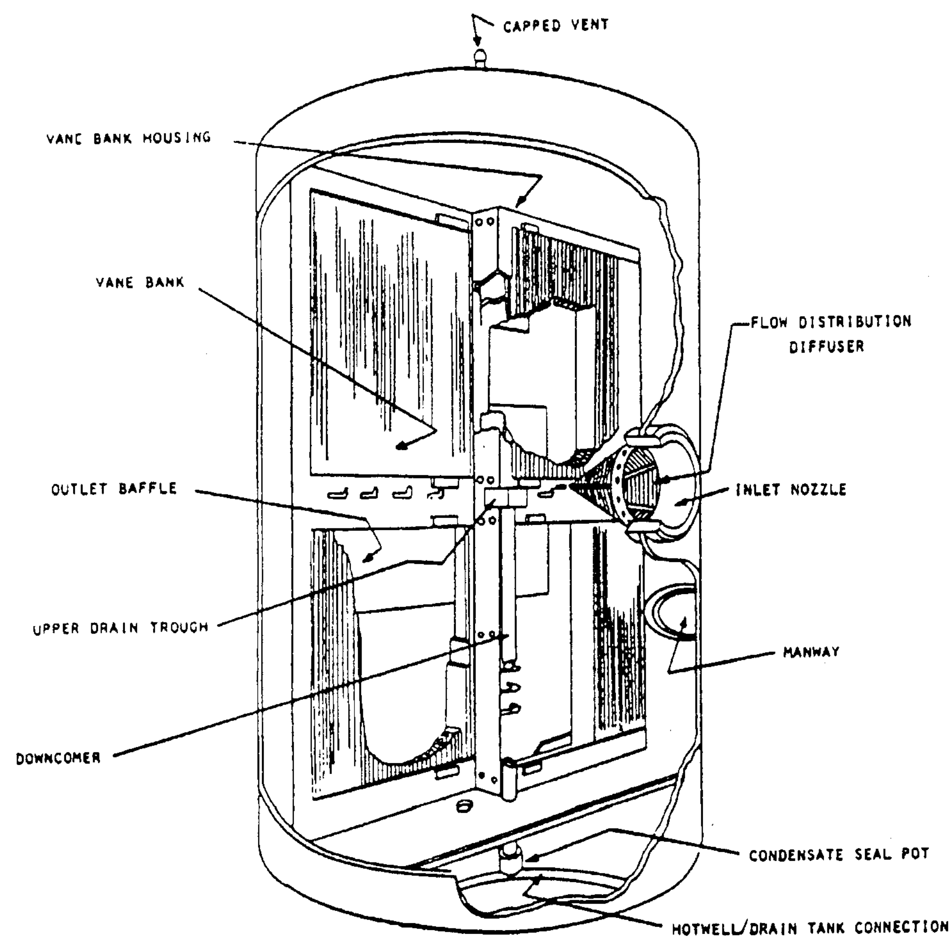


Figure 3-2
Cutaway View of a General Electric Vertical Moisture Separator

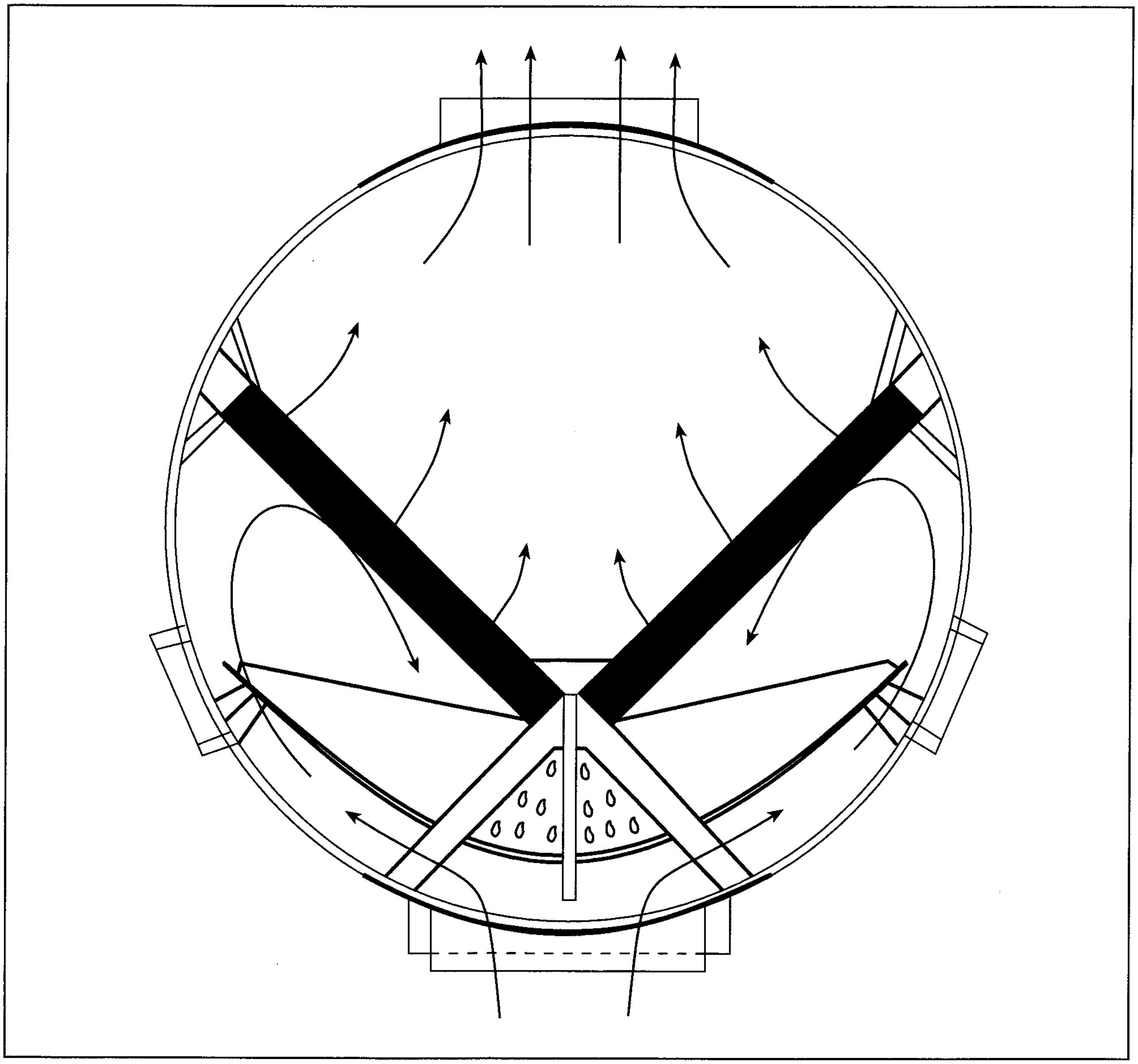


Figure 3-3
Sectional View of a General Electric Horizontal Moisture Separator

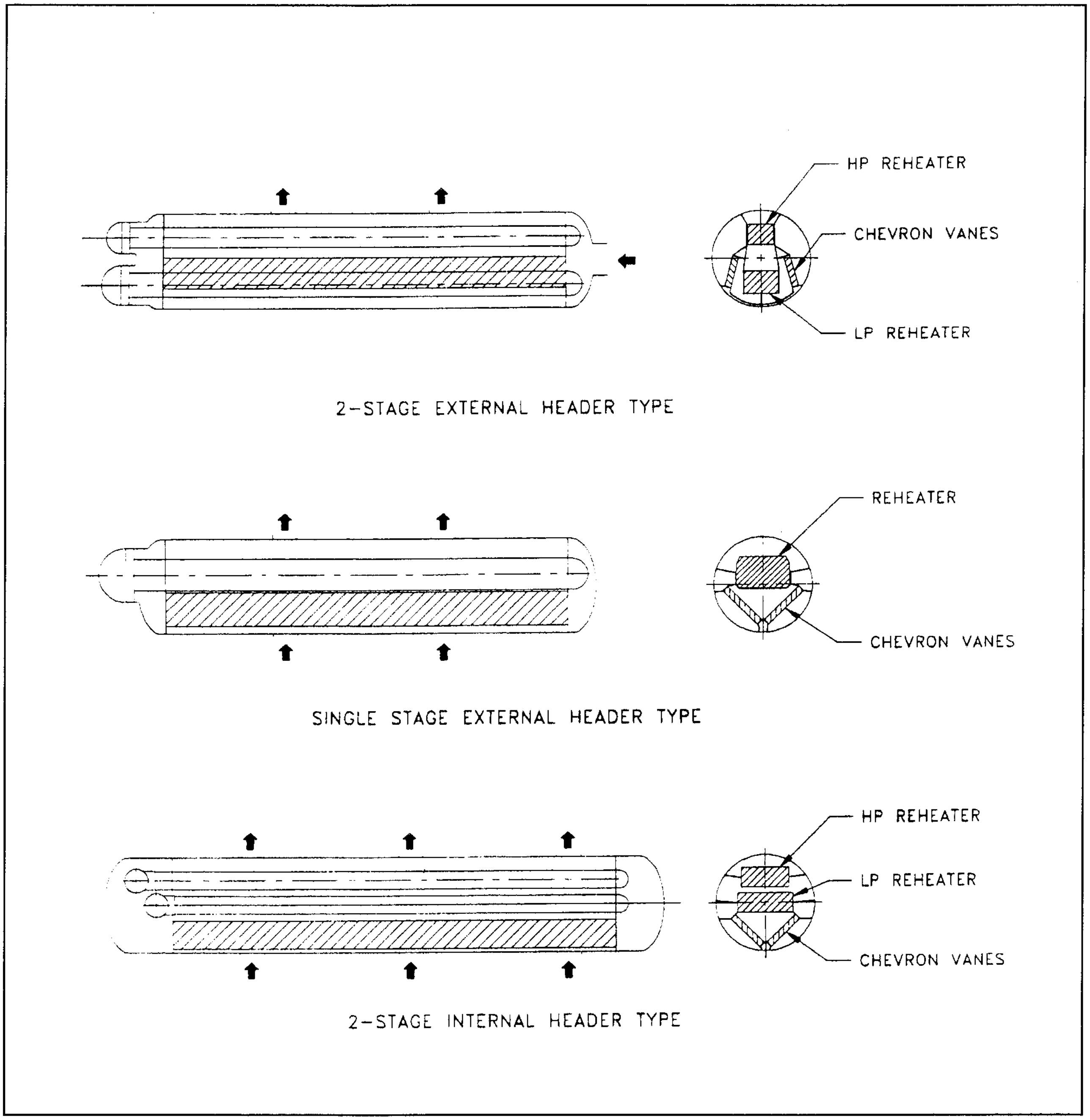


Figure 3-4
Types of MSRs Designed by General Electric
(courtesy of Senior Engineering)

3.3 Senior Engineering MS/R Design Evolution

Senior Engineering was not a supplier of most OEM MS/Rs. Rather, they entered the market as a supplier of modification packages to correct problems discussed elsewhere in this report. There has been some evolution towards their present modification packages. They consist of:

3.3.1 Moisture Separator Improvements.

Improvements in the area of moisture separation include:

- High performance double pocket, stainless steel chevron moisture separators
- Inlet distribution manifolds and perforated plates upstream of the chevrons to reduce high localized inlet steam loading
- Pre-separation and drainage of moisture at the shell entrance

3.3.2 Tube Bundle Improvements.

Improvements in the area of reheat include:

- Type 409 ferritic stainless steel finned tubes with 27 fins per inch
- Four-pass, vertical U-tube bundles
- Individual reusable inlet orifices in tubes with low heat transfer duty (for two-pass design)
- "Hexagonal" tube arrays with more tubes and less ΔP
- Chamfered and hour-glass tube holes in the last tube bundle support plates
- Tube bundle support welded or wedged to shell support channel
- Flexible tube - support - system to minimize distortion and buckling
- Features to minimize steam bypassing around the bundle periphery
- Integral temperature sensing grid in selected tube outlets to optimize excess steam consumption

3.4 References

1. Report on Operational Problems and Modifications of Trojan Moisture Separator Reheaters, Portland General Electric Company (abstract).

2. R. L. Coit, P. D. Ritland, T. J. Rabas, P. W. Viscovich. "Moisture Separator-Reheaters - Entering the Second Decade".

3. J. L. Kratz, P. G. Minard, P. W. Bird, "Moisture Separator Reheaters - Entering the Third Decade." ASME Joint Power Conference, Toronto, Canada, October 1984.

4. A. L. Yarden and C. W. Tam, "The MSR Evolution." *Nuclear Engineering,* December 1994.

5. A. L. Yarden and C. W. Tam, "Excess Steam Flow Optimization in Operating MSRs.", presented at the EPRI Nuclear Plant Performance Improvement Seminar, August 1994.

6. A. L. Yarden, and M. W. Thomas, "MSR Performance Improvement at Prairie Island Nuclear Station.", presented at the EPRI Nuclear Plant Performance Improvement Seminar, May 1993.

4.0

OPERATIONS

Many MSR problems are due to thermal stresses and distortion, the presence of moisture in the cycle steam, or condensate formed in the reheater tubes. Correct MSR operating strategies can lessen these problems; such strategies are provided in this section. Table 4-1 summarizes the salient points of these strategies; details may vary depending on vendor and MSR design. Most of the operating information provided is based on plant operating procedures made available to the MSR Task Group. Examples of procedures are contained in Appendix C.

Table 4-1
Summary of MSR Operating Procedures

MSR STARTUP
• Establish and maintain venting and excess steam flow. • Establish and maintain moisture separator and reheater drain tank levels. Use manual and automatic control as appropriate. • For two-stage reheat MSRs, place the LP stage reheater in service before starting up the HP stage reheater. • Limit HP reheater tube bundle heatup to manufacturer's specified rates (for example, 125 F°/hr). • If more than one reheater tube bundle, limit the difference between tube bundle temperatures to 50 F° or less (an LP turbine concern).
MSR SHUTDOWN
• Maintain excess steam flow until heating steam flow to the reheater tube bundle is shut off. • Maintain moisture separator and reheater drain tank levels. • For two-stage reheater MSRs, maintain the LP stage reheater in service until the HP stage is completely removed from service. • Limit HP reheater tube bundle cooldown to manufacturer's specified rates (for example, 125 F°/hr). • If more than one reheater tube bundle, limit the difference between tube bundle temperatures to 50 F° or less.

Two key objectives need to be met during the three phases of MSR operation: startup, at power, and shutdown, with startup being most critical. These objectives are listed below and each phase of MSR operation is covered in the following text.

- Large temperature differentials between heating and cycle steam in the reheaters need to be minimized to prevent damaging thermal effects.
- Condensate collected in the moisture separators needs to be continually collected and drained in a manner that minimizes moisture carryover to the reheaters.

4.1 MS/R Startup

In reality, the MS/R "starts up" when main steam is first admitted to the high pressure (HP) turbine since the steam path is through the HP turbine, through the MS/R, and then to the low pressure (LP) turbine. Since the steam path is through the moisture separators, the MS/R is performing its moisture removal function throughout startup. For this reason, the moisture removal drain tank level controller and drain valves are placed into service early in turbine startup. Since steam flow is initially low, moisture separator level control can be controlled manually or automatically, depending on the type of controls provided. The consequences of high level will be initiation of level alarms and additional moisture carryover, neither of which is of significant concern during low steam flow. It should be noted that some plants have a trip point on a very high level at a setpoint above the high alarm. At low flow rates, there is usually time after the alarm for the operator to take corrective action before trip level is reached.

The above discussion is based on the reheater bundles* not yet being in reheat service. They are, however, in the cycle steam flow path and cycle steam is flowing across the tube bundles. Since turbine steam flow is low, HP turbine exhaust pressure and cycle steam temperature in the MSR will be low, but main steam pressure will be high. The basic issues are (1) when to start up the HP reheaters, and (2) how to control heating steam using main steam in a manner that minimizes large thermal differences in the tube bundles. The discussion below assumes that there is a heating steam throttling system that can control main steam to a desired pressure (and temperature) before being admitted to the tube side of the HP reheater bundles.

4.1.1 MSR Startup Load. Turbine load at which to admit heating steam to the reheater tube bundles was a subject of the plant survey discussed in Appendix B. In general, the plants rely on the MSR vendors for guidance on this subject. The majority

* This discussion applies to single-stage reheater bundles and the second-stage tube bundles of two-stage reheaters that use high pressure main steam as the source of reheat steam. The first stage of two-stage MSRs uses HP turbine extraction as the heating source. HP turbine extraction steam pressure and temperature might increase at low load. Therefore, the potential for large thermal gradients does not exist in LP reheater bundles; thermally induced failures in LP tube bundles have not occurred nearly as frequently as in HP tube bundles.

surveyed start admitting heating steam to the reheaters at about 35% turbine power, although some start as low as 10% power, and a few as high as 65%. At low turbine load, there is a large temperature difference between main steam and the cycle steam flowing through the reheater bundles. It is important that the heating steam be throttled in order to lower temperature or that initiation of heating steam be delayed until there is a substantially higher load and cycle steam will be at higher temperature. Delaying initiation of reheat until higher turbine load results in more beneficial preheating of the reheater tube bundles by cycle steam prior to admission of heating steam to the reheater tubes.

During the period immediately following plant startup, many planned and unplanned shutdowns and restarts could be experienced before achieving equilibrium power. If reheaters are put into service during this period, they might undergo unnecessary and avoidable thermal cycling. Also, there is little advantage in terms of thermodynamic cycle improvement or minimizing moisture effects in the low pressure turbine if reheaters are not started until there is a higher turbine load and operation is more stabilized. There is little vendor guidance either recommending reheater startup at higher turbine loads or prohibiting the practice. Thus, delaying MSR startup to higher power levels is a method to reduce MSR thermal cycling.

4.1.2 Heating Steam Pressure Control. Heating steam pressure control during reheat startup usually has two objectives: to maintain ΔT between heating steam and cycle steam at acceptable values and to limit reheater tube bundle temperature rate of change. Usually an acceptable ΔT limit is the ΔT that exists when the MSR is operating at full load. These temperature control objectives are usually met by using a pressure control station and pressure control valves between the main steam header and the MSR reheat steam inlet. By reducing steam pressure, steam temperature is also reduced. In some cases, pressure reduction is automatically controlled to a programmed setpoint based on turbine load. The heating steam pressure controller can be programmed to increase heating steam pressure as a function of time after the turbine generator is started. The program assumes that reactor power and turbine output is increased at a specified rate. This could result in high heating steam-cycle steam ΔT if the turbine startup rate is less than that used to program the heating steam pressure controller. In other cases, the operator should consider placing the controller in manual and increasing heating steam pressure at a rate consistent with power increase.

Rate of temperature change is also controlled using the pressure control valves for control of heating steam temperature. Rate of temperature change, especially in the first few hours of startup, might require lower heating steam pressure than that needed to achieve low ΔT.

4.1.3 Excess Steam Control. Condensate subcooling and oscillation, described in Section 6.1, can be aggravated by colder cycle steam that exists during startup. For this reason, most procedures recommend that the excess steam flow path be established before admitting heating steam to the reheater tubes. This is usually done by opening block valves in the vent line, which opens the excess steam flow path to the condenser, heater, or the HP extraction steam path.

4.2 Power Operation

For purposes of this report, power operation is defined as that period of time after MSR heatup is complete and before reactor shutdown commences. During this period, the objectives are to maintain moisture separator and reheat drain tank levels using automatic control, to maintain heating steam pressure near the main steam pressure source in order to maximize reheat, and to maintain excess steam if an excess steam vent is provided. During this period, the MSRs are performing as "demand" type heat exchangers that separate moisture, heat cycle steam, and condense heating steam at rates required by cycle conditions. As a result, there is little operator action to be taken; level control is automatic and heating steam pressure and excess steam flow can be controlled automatically or set at maximum by fully opening the respective control valves.

At least one plant has increased MWe output by throttling and reducing heating steam pressure. This results in lower superheat temperature, less use of heating steam, and increased main steam to the turbine. An excerpt from Reference 1 states:

> In March of 1993 Prairie Island's Performance Engineer manipulated the steam inlet valves to the MSRs and the valves in the fourth pass drain line which delivers the scavenging excess steam/condensate from the MSRs to the steam inlet of the 5th stage heaters. He found that partial closing of these valves forced more steam to the HP turbine. As he gradually closed the valves, the superheat temperature to the LP turbine went down but the MWe output went up until the loss of superheat to the LP turbine and feedwater temperature to the steam generators overcame the additional flow of steam to the HP turbine. This testing optimized the steam flow to the MSRs and HP turbine and gained approximately 1.3 MWe. The new optimized tube bundles have added approximately 5.3 MWe to the output of Prairie Island 2. The same test was tried on Unit 1, but without the optimized tube bundles, no MWe gain was noted. With the favorable results of Unit 2, NSP planned to replace the tube bundles on Unit 1 in 1994.

Increased turbine output occurs if there is not a commensurate decrease in turbine mechanical efficiency due to reduced superheat and increased moisture in the last stages of the LP turbine. The benefit, if any, is plant unique. If this approach is used to increase turbine output and is successful, there are still tradeoffs to consider. For example, there will be increased output, but more moisture and erosion potential in the LP turbines and increased wear using the heating steam pressure control valves to throttle and reduce heating steam flow and pressure. There might also be a potential for increased condensate oscillation if excess steam flow is reduced when heating steam pressure is reduced by throttling.

4.3 MS/R Shutdown

The sequence of operation and limitations during MS/R shutdown is similar to startup except that some are reversed. For example, some procedures contain the caution to limit cooldown rates to 125F°/hour and to maintain differences in temperature of MSRs to less than 50F°, values similar to startup. The procedure also cautions to maintain excess steam flow and control of drain tank levels until shutdown is complete and heating steam is shut off.

The MS/R shutdown procedures reviewed for this report are based on a controlled reactor shutdown transient and do not explicitly address differences that should be considered if a reactor scram occurs. The most significant difference between controlled shutdown and scram is that cycle steam flow and temperature into the MSR will decrease rapidly following scram. Main steam pressure will, however, remain high unless the scram is accompanied by a rapid main steam pressure reduction, an infrequently occurring event for both BWRs and PWRs.

Most procedures do not explicitly address reactor scram. If short term scram recovery is planned, heating steam pressure should be reduced to the value recommended by the vendor for MSR startup at a pressure reduction rate that maintains prescribed cooldown rates. If scram recovery is not planned, controlled shutdown using normal shutdown procedures should be continued.

4.4 MSR Tube Leaks

Tube leaks can occur during operation of MSRs and can be due to one of several causes: tube vibration, condensation oscillation, unequal thermal expansion of the two legs of the U-tubes, or a latent defect in the tube. The size of the leak can vary from that of a crack-like hole in the tube to a guillotine break of the tube. If the leak is directed towards adjacent tubes or the leak is of significant size, the leak can cause damage to adjacent tubes. Reference 2 states:

> In particular, records should be kept and both short- and long-term trends sought in the leak detection readings. An upward trend otherwise unaccountable indicates an incipient leak within the tube bundle. Any such trend must be investigated immediately. If a leak is indicated, remove the bundle from service and check for individual tube leaks at the very earliest opportunity. Early tube leak detection is vital. Leaks are self-propagating and can disable adjacent tubes, ultimately jeopardizing the reliability of the bundle.

Leakage of heating steam into the cycle steam will reduce the amount of cycle steam superheat. Leak detection, however, is not a simple task. For example, a pin-hole leak is virtually undetectable by observing change in cycle steam superheat or change in heating steam flow rate. Pin-hole leaks might grow during operation and become detectable during shutdown testing. On the other hand, a guillotine break of a tube might be detectable during operation as it can cause a noticeable change in heating steam flow and a drop in cycle steam superheat. Reference 3 states:

> 6.1 Heating Steam Flow Rate: Any increase, above normal, in steam flow rate of 5% or greater is sufficient to warrant removal of the reheater from service and require repair. Continuous or daily monitoring is recommended.
>
> 6.2 Reheater Outlet Temperature: A drop in outlet temperature of 15°F or greater from any individual reheater indicates either broken tubes or failure of the drain system to operate properly. Investigate the drain system operation and correct. If the problem cannot be identified, remove the reheater from service. Monitor continuously or daily.

Because of limitations in the ability to detect small leaks, the practical approach to leak detection is to periodically observe superheat temperature and heating steam flow, if measured. Any significant decrease in superheat temperature or increase in heating steam flow is a strong indication of a significant tube leak. If this occurs, the heating steam can be shut down or heating steam pressure reduced significantly to reduce the velocity of the leaking steam and prevent damage of adjacent tubes. The effects on the LP turbines should be assessed before removing the reheater or significantly reducing the amount of reheat during plant operation.

4.5 References

1. A. L. Yarden, and M. W. Thomas, "MSR Performance Improvement at Prairie Island Nuclear Station.", presented at the EPRI Nuclear Plant Performance Improvement Seminar, May 1993.

2. *Two Stage Moisture Separator Reheater,* General Electric General Description, (Internal Header, Vertical U-Bend Design)., January 1982, Revision A. Report GEK-72221A.

3. South Texas Project Electric Generating Station Vendor Manual Cover Sheet, Volume 20, Moisture Separator Reheaters., DO70907.

5.0

MONITORING AND TROUBLESHOOTING

The ability to monitor and troubleshoot MSRs is limited by the fact that most MSRs were originally supplied with a minimum amount of instrumentation. One of the reasons is there was no anticipation that failures and degradation of the type and magnitude described in Section 6 would occur. Most MSRs were supplied with instrumentation to measure MSR outlet superheat temperature, the primary indication of overall MSR performance. They were, however, supplied with little additional instrumentation to determine flows, pressure, temperatures, moisture content and carryover, and other variables useful for troubleshooting and for flow and heat balances. In addition, monitoring and troubleshooting is complicated by the difficulty of measuring moisture content in the cycle steam without special test apparatus, especially during routine operation.

This section will address several issues associated with monitoring and troubleshooting:

- Monitoring and troubleshooting with only reheat temperature instrumentation available
- Tube leak testing
- The role of visual inspection
- The role of the ASME Performance Test Code, PTC 12.4, at operating plants

5.1 Reheat Temperature Instrumentation

Many MSRs were supplied only with thermocouples (TCs) to measure the temperature of the exiting cycle steam. This approach was taken on the basis that exit temperature is the best indicator of overall performance of the MSR and that likely causes of deterioration of MSR performance would be minor tube plugging and fouling, rather than the thermal and moisture related problems that have been the actual source of poor performance.

Reheater outlet temperature is an important, if not the most important, single instrumentation point on an MSR. Reduction in MSR outlet temperature can result in a reduction in heat rate and plant electrical output. Outlet temperature, however, is not a direct indication of the cause or causes, which could be one or more of the following:

- Reduced heat transfer surface due to plugged reheater tubes
- Fouling of reheater heat transfer surface
- Moisture carryover from the moisture separators into the reheater
- Bypass of cycle steam between the tube bundle and shroud
- One or more tube leaks

Since the root cause of a change in outlet temperature cannot be determined using only reheater outlet temperature, other methods are necessary. One method, if instrumentation is available, is to trend heating steam flow rate or heater drain valve position. An increase in either parameter is an indication of a significant tube leak. If neither is provided, additional instrumentation is needed for on-line detection of a significant tube leak. If instrumentation is not available, or the tube leakage is minor, off-line visual inspections and tube leak testing will be needed. Plants with only outlet temperature measurement have to make do with this level of information unless they are willing to implement plant modifications for additional instrumentation.

Assuming that reheater outlet temperature is the only on-line instrumentation, there are several possible responses to a change in this variable, depending on how fast the temperature changes and whether the temperature increases or decreases.

- <u>Temperature gradually decreases:</u> The cause could be a slowly developing tube leak, slowly increasing heat transfer surface fouling, or downward drift of heating steam pressure/temperature due to a malfunction of the heating steam control system.

- <u>Temperature rapidly decreases:</u> The cause could be a rapidly developing large tube leak or a rapid decrease in heating steam pressure/temperature due to a malfunction of the heating steam control system.

- <u>Gradual or rapid increase in temperature:</u> In this case, the cause could be a malfunction of the heating steam pressure controller if the heating steam control valves are initially not wide open.

Except for large tube leaks, there is no phenomenon associated with decreases or increases in reheat temperature that has short-term detrimental effects. If a large tube leak is suspected, the heating steam pressure should be reduced to minimize the potential for further tube damage and plans made to conduct inspections and tube leak testing during the next planned outage (see Section 4.4 concerning tube leaks during operation).

5.2 Visual Inspections

Most MSRs are provided with manways which provide access to visually inspect the shell-side moisture separators and reheater tube bundles when the plant is shut down. Shell-side visual inspection can be used to determine if one or more of the following types of damage has occurred:

- Erosion and moisture damage to demister pads and chevron separators
- Erosion and moisture damage to inlet cycle steam passageways and manifolding
- Deposits between tube fins due to moisture carryover
- Corrosion/erosion of carbon steel reheater finned tube surface
- Distortion of tubes and tube support plates and external tube wear due to unequal thermal expansion of U-tube legs
- Cracked welds in partitions and other plate components
- Erosion damage to carbon steel components downstream of stainless steel weld deposits applied to prevent erosion
- Openings between cold and hot cycle steam sections of the MSR
- Gaps allowing bypass of cycle steam around moisture separator panels
- General area of erosion as evidenced by wall thinning and changes in texture and color of carbon steel surfaces in the cold cycle steam path

Damage phenomenon is described in Section 6.1. There is little guidance available concerning shell-side inspection frequency (extensive shell-side damage was not anticipated during the design and initial operation of most MSRs). The survey discussed in Appendix B shows most MSRs are being visually inspected each refueling outage or every other outage.

5.3 Tube Leak Testing

Removable hemispherical heads and manways on the heating steam inlet and outlet headers provide access to the tube side of the reheater bundles for leak testing and inspection during shutdown.

There is little guidance available on leak rate testing specific to MSRs. There are several approaches that can be taken:

- Hydro testing
- Helium leak testing
- Vacuum testing. This can be done by attaching a thick, leaktight plastic cover on the water head and filling the tube side of the reheater bundle with water so that

the tubes, and the space between tubes and the plastic cover, are submerged. A vacuum is then drawn on the top of the tube sheet/plastic cover space. A tube leak will cause air to leak into the tube from the cycle steam side of the MSR and bubbles to discharge into the tube sheet/plastic cover space.

- Use an air gun to pressurize individual tubes and observe if air pressure drops off when the air supply is turned off. This type of test will miss tube-to-tube sheet weld leaks.

Routine periodic leak testing is usually not done unless there is a significant history of tube failures or other evidence that tube leaks are occurring.

Access through the header manways provides the ability to inspect the inside of the tubes and tube-to-tube support structure joints for evidence of internal corrosion and fatigue cracks due to condensate oscillation. This access also provides a means to use nondestructive evaluation (NDE) methods such as liquid penetrant, ultrasonic, and electromagnetic techniques, for example, eddy current testing.

In general, visual examination provides the most direct method of assessing a problem and, when supplemented with liquid penetrant techniques, can be used to detect cracks starting at or migrating to the inside surface. Visual examination, however, is extremely slow and does not detect outside-diameter originating flaws such as erosion. Electromagnetic and ultrasonic techniques can be used for such flaws. Ultrasonic techniques are slow compared to electromagnetic techniques, making electromagnetics the preferred technique.

NDE methods for MSR tubes is an emerging technology. The EPRI NDE Center has developed the Electromagnetic NDE Guide for Balance-of-Plant Heat Exchangers. The guide contains overviews, details of each electromagnetic technique, and detailed information for several types of heat exchangers and tubes including a 90-10 copper-nickel tube with integral fins. The guidelines will be periodically revised. EPRI members with need for detailed information on particular tubes should contact EPRI to perform necessary testing and include the information in future revisions of the report. The EPRI NDE Center is developing a computer algorithm to assess the need and frequency of NDE testing of heat exchanger tubes that can be used for MSRs.

5.4 Moisture Separation Effectiveness

Moisture carryover in the cycle steam leaving an MS can reduce mechanical efficiency in the LP turbine. In an MSR it can reduce reheat temperature and increase heating steam consumption since the moisture is evaporated using some of the heat transfer surface of the reheater tube bundle provided to superheat dry steam. Measurement of moisture separation effectiveness* can be used to determine if the moisture separator is not meeting design expectations or if the major cause of off-performance is associated with the reheater. At this time, there is no simple, inexpensive method to measure steam quality as cycle steam exits the moisture separators. Several methods discussed by PTC 12.4 are outlined below along with their limitations.

- Reheater Energy Balance Method: This method uses an energy balance conducted around each reheater stage to determine the specific enthalpy (moisture content) of the cycle steam entering each reheater stage. This method requires that all flows entering or exiting each reheater stage, as well as interstage temperature (enthalpy) in a two-stage MSR, be accounted for and used in the determination of specific enthalpy (moisture) leaving the moisture separator and entering the reheaters. This method is not applicable to units that have only MSs. Furthermore, most MSRs are not provided with the extensive amount of instrumentation required by this method. Most of the instrumentation required for the energy balance method is needed for a PTC 12.4 test.
- Throttling Calorimeter Method: This method uses throttling calorimeters and steam sample probes installed at the outlet of the moisture separators to obtain representative samples. The probes need to be designed so they do not preferentially sample either steam or moisture, but sample in proportion to the steam and water content of the cycle steam exiting the moisture separator. Also, there needs to be sufficient sample points to account for variations in exit quality over the large exit area of the moisture separator. In addition to PTC 12.4, see PTC 19.1 for guidance on this method.
- Differential Tracer Method: This method uses a two-step process. The first step uses the tracer method to measure the moisture separator shell drain flow by injecting a tracer into the shell drain flow downstream of the drain tank and sampling the drain flow further downstream after thorough mixing takes place. The second step moves the tracer injection point to a point in the cycle steam upstream of the moisture separator. The moisture carryover is then calculated by accounting for differences between drain flow tracer concentrations and tracer injection rates observed during the two steps.
- Shell Drain Flow Method: This method is applicable if there is flow measurement of moisture separator shell drain flow. This method does not rely on measured cycle steam flow and moisture content. Rather, it uses the turbine vendors thermal kit data for information describing moisture in the cycle steam leaving the HP turbine and entering the moisture separator. As a result, the calculated moisture carryover is only as accurate as measured drain flow and how well the thermal kit represents actual cycle steam conditions when the method is being used.

* Moisture separation effectiveness is defined in PTC 12.4 as the ratio of the mass flow rate of moisture removed from the entering cycle steam to the mass flow rate of moisture entering the separator. A moisture separation effectiveness of 100% means total removal of moisture from the incoming steam.

All four methods are discussed in Sections 4.5 and 5.4 of PTC 12.4. The differential tracer method is the most accurate. This method and the calorimeter method, however, should be considered special tests not practical for continuous use. On the other hand, energy balance and drain flow methods can be used for continuous monitoring but are inherently inaccurate due to the amount of data required and assumptions concerning the applicability of the thermal kit data. They can be used for trending where accuracy is less important.

5.5 Excess Steam Flow

A minimum amount of excess steam flow is needed to protect reheater tubes against condensate oscillation (see Section 6.1.2 for a discussion of condensate oscillation). On the other hand, too much excess steam flow can result in an unnecessary loss of turbine output since the excess steam flows to a feedwater heater or the condenser without further expansion in the turbine. Some plants control excess steam flow by use of fixed orifices or flow nozzles, others use control valves. If fixed orifices or flow nozzles are used to control excess flow, there is little need to monitor the flow since the flow is set by operating pressure and orifice/nozzle design provided the flow device is not susceptible to erosion/corrosion by virtue of its design or materials of construction. On the other hand, if valves are used to regulate excess flow or the orifice/venturi is susceptible to erosion/corrosion, separate flow instrumentation might be needed to accurately measure and optimize excess steam flow.

Many plants have established the required amount of excess steam flow by analysis or on recommendation of the vendor. It is possible to observe if condensate oscillation is occurring and to optimize excess steam flow in a particular MSR by installing temperature detectors in the outlets of several reheat tubes. This is especially useful when modifications are made to install or improve excess steam flow. The instrumentation need not be considered permanent, but is used until the relationship between the amount of excess steam, its control, and suppression of condensate oscillation is understood and accounted for in the control of excess steam flow.

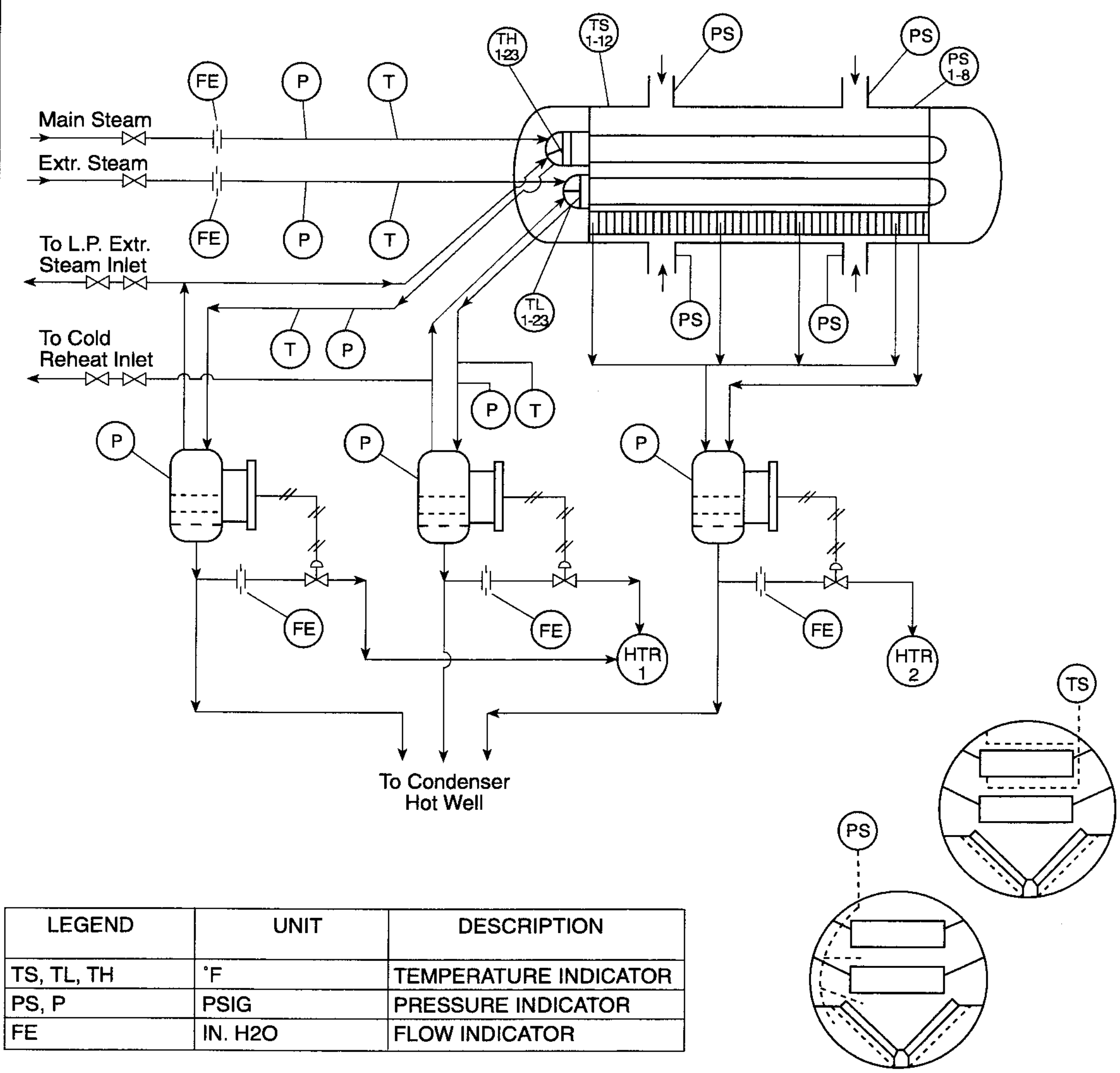
5.6 PTC 12.4 Instrumentation

PTC 12.4 was issued in 1992, after most MSRs were installed and put into operation. The test code states that:

> The purpose of the Code is to determine the performance of the MSR and to provide guidance in the evaluation of its performance effect on the turbine cycle heat rate with regard to:
>
> (a) Moisture Separator Outlet Quality;
> (b) Reheater Terminal Temperature Difference (TTD) per stage;
> (c) Cycle Steam pressure drop across applicable component(s); and
> (d) Excess heating steam flow.

The intent of the code is to determine performance when the MSR is first installed or after it undergoes major modification. The requirements and guidance are also useful for troubleshooting and are summarized below.

Figure 3.1 of PTC 12.4 shows the instrumentation needed to do a PTC 12.4 test of a two-stage MSR. Figure 5-1 of this report shows Senior Engineering's implementation of an instrumentation package designed to meet PTC 12.4 for a typical two-stage MSR. The instrumentation list and their purpose are shown in Table 5-1.



LEGEND	UNIT	DESCRIPTION
TS, TL, TH	°F	TEMPERATURE INDICATOR
PS, P	PSIG	PRESSURE INDICATOR
FE	IN. H2O	FLOW INDICATOR

Figure 5-1
PTC 12.4 Instrumentation Package
(Courtesy of Senior Engineering)

Table 5-1
Instrumentation for MSRs

Parameter	Legend	Purpose	Notes
HP heater cycle steam outlet temperature	TS	HP heater TTD and heat balance	
HP heater heating steam flow	FE	HP heater heat balance	
HP heater steam inlet pressure and temperature (temperature required only if steam is superheated)	P,T	Inlet enthalpy and HP heater TTD and heat balance	1
HP heater outlet flow pressure and temperature	P,T	Subcooling, enthalpy and HP heater TTD and heat balance	
HP heater excess steam flow	FE	Adequacy, HP heat balance	
LP heater cycle steam outlet temperature	TS	LP heater TTD and heat balance	
LP heater heating steam flow	FE	LP heater heat balance	
LP heater steam inlet pressure and temperature (temperature required only if steam is superheated	P,T	Inlet enthalpy and LP heater TTD and heat balance	
LP heater outlet flow pressure and temperature	P,T	Subcooling, enthalpy and LP heater TTD and heat balance	
LP heater excess steam flow	FE	Adequacy of flow, LP heat balance	
Moisture separator drain flow	FE	Moisture carryover, MSR heat balance	2, 3
LP turbine inlet pressure	P	Cycle steam flow	4
Feedpump turbine steam flow	FE	Cycle steam flow	4

Notes

1. Temperature needed only if main steam is superheated
2. The tracer method can be used in lieu of flow elements
3. Required if shell drain flow method of determining moisture separator outlet quality is used
4. Required if turbine flow factors are used to determine cycle steam flow

The scope of instrumentation required to fully implement a PTC 12.4 test is extensive. Note, however, that the instrumentation scope does not include the direct measurement of moisture entering the MSR or the carryover moisture leaving the moisture separator. Instead, these are calculated using the methods described in Sections 4.5 and 5.4 of PTC 12.4. Also, the PTC 12.4 instrumentation described in Table 5-1 does not apply to MSs.

The instrumentation listed in Table 5-1 can be used to calculate several properties of an MSR, including:

1. Heater Terminal Temperature Difference (TTD): The TTD is a measure of the ability of the reheater to achieve a high heat transfer rate indicative of high heat transfer coefficients, low fouling, and good heat transfer surface properties. It can be compared with design and previous operating TTDs.

$$TTD = t_{hs} - t_{cso}$$

Where:

t_{hs}	=	Temperature of the heating steam, °F
t_{cso}	=	Reheater outlet cycle steam temperature, °F

Note that it might not be practical to determine TTDs for the first or LP stage of a two-stage reheater since MSRs are normally not instrumented to measure t_{cso} for the LP heater.

2. Reheater Log Mean Temperature Difference (LMTD): The LMTD is the effective temperature difference that is heating the cycle steam in the reheater.

$$LMTD = \frac{(t_{hs} - t_{csi}) - (t_{hs} - t_{cso})}{\ln \dfrac{t_{hs} - t_{csi}}{t_{hs} - t_{cso}}}$$

Where:

t_{csi}	=	Temperature of the cycle steam flowing into the reheater

In the case of single-stage HP reheaters and LP reheaters, t_{hs} and t_{csi} are saturation temperature. In the case of a two-stage HP reheater, t_{csi} needs to be directly measured. In all cases, t_{cso} is directly measured.

3. Reheater Heat Load: Heat load is needed if moisture carryover from the moisture separator is calculated using the heat balance method described in Section 5.3 and PTC 12.4. Reheater heat load, Q, is calculated by:

$$Q = W_{hs}(h_{hsg} - h_{hsf})$$

where:

W_{hs}	=	Heating steam flow, lb/hr
h_{hsg}	=	Heating steam inlet enthalpy
h_{hsf}	=	Heating steam condensate enthalpy

Both LMTD and Q are needed to calculate the heat transfer effectiveness of the reheat, UA, where:

$$UA = \frac{Q}{LMTD}$$

The term UA is a product of effective overall heat transfer coefficient times the effective heat transfer area. A decreasing value indicates degradation in heat transfer coefficient, area, or both.

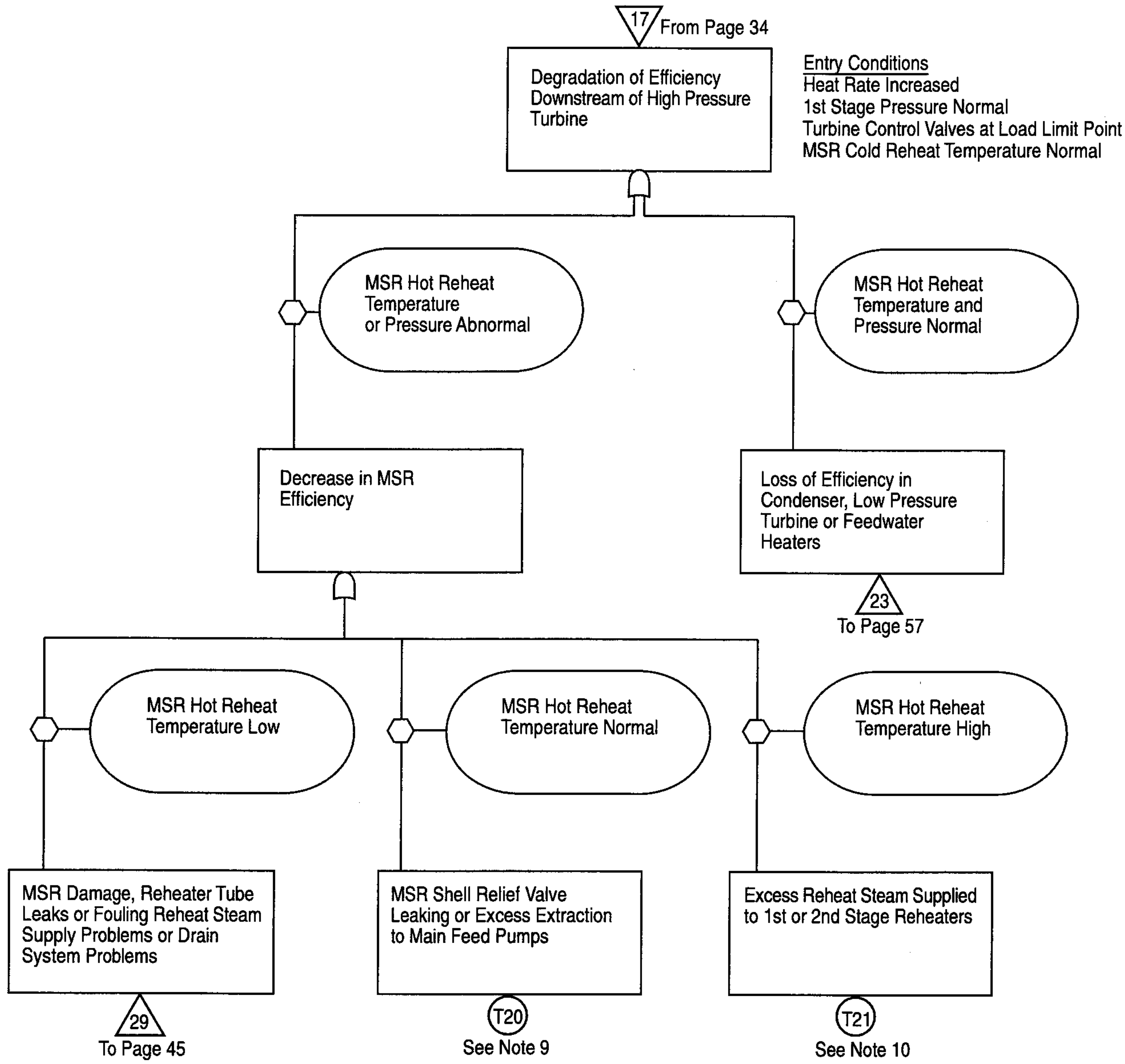
5.7 EPRI Thermal Performance Diagnostic Manual

The Thermal Performance Diagnostic Manual, NP-4990, provides utility engineers with a logical, step-by-step procedure for locating the sources of heat rate degradation in individual nuclear plants. Included in Volume 3 of the manual are sets of diagnostic trees and rules covering both BWR and PWR MSRs.

The entry point for the MSR diagnostic trees starts with the observed condition that the MSR hot reheat temperature and/or pressure is not normal. Figures 5-2 and 5-3 are excerpts from the diagnostic manual, for PWR and BWR plants respectively. The reference to specific pages and note numbers contained in the figures refer to page, and notes in the diagnostic manual and should not be confused with pages in this document. The specific notes are included within the figure.

The diagnostic trees shown in Figures 5-2 and 5-3 are provided in this source book as a summary and introduction, and focus only on the MSR. Considerably more diagnostic detail is contained in the Thermal Performance Diagnostic Manual.

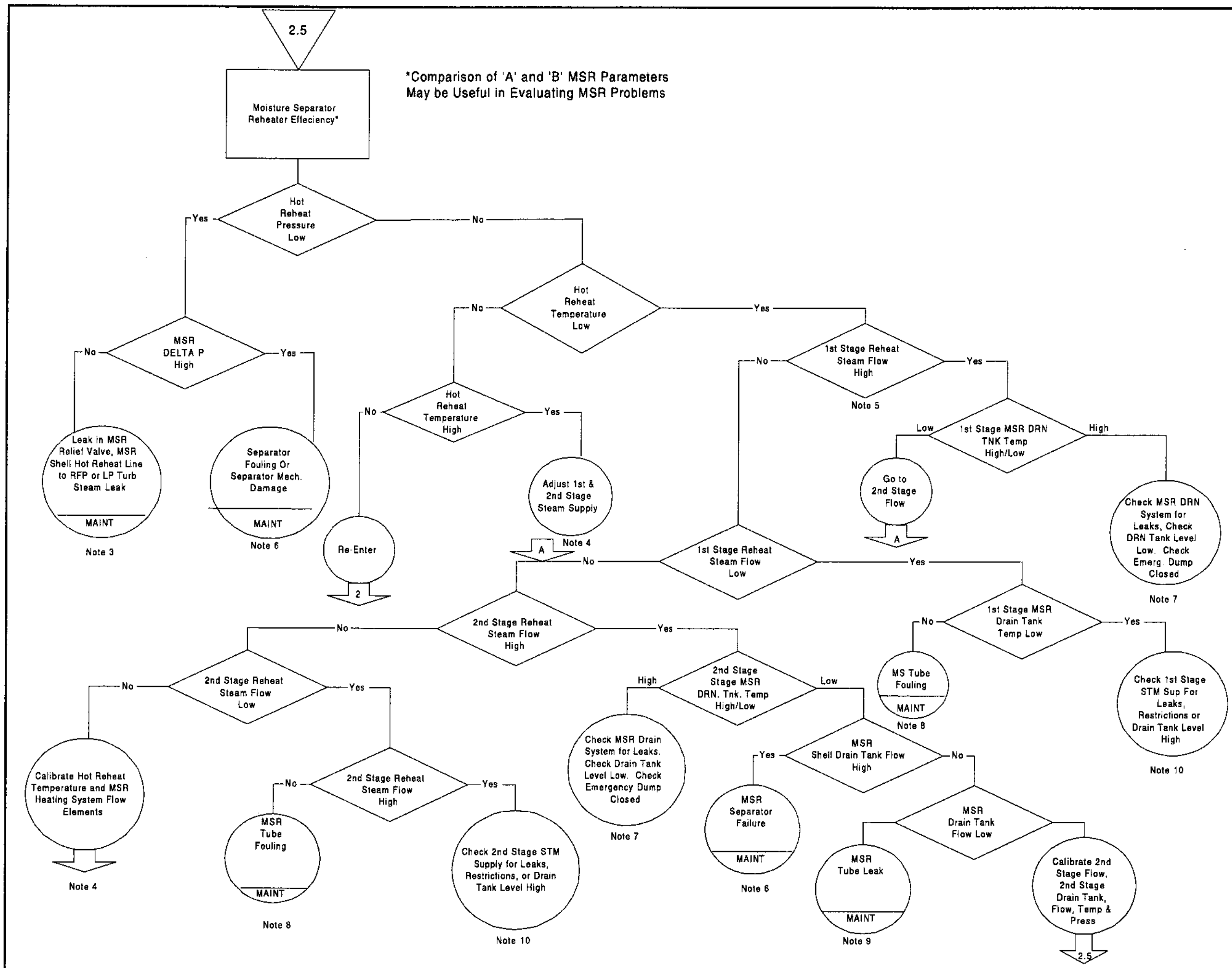
Figure 5-3 contains important advice, namely, to: compare parameters in the several MSR shells at a plant when evaluating MSR problems.



Note 9: A leaking MSR relief valve or excessive extraction steam flow to the main feedwater pumps would also result in low hot reheat pressure for the affected MSR(s). Relief valve leakage can be visually verified. Note 6 on Page 27 provides additional information on main feed pump problems.

Note 10: Those failures can be verified by checking the position of the first and second stage reheat steam supply valves. These failures may also be accompanied by high coil drain flow and temperature from the affected reheat stage. These failures are not applicable if reheat steam supply valves are normally full open.

Figure 5-2
MSR Diagnostic Tree, PWR



Note 3: A leaking MSR relief valve or excessive extraction steam flow to the main feedwater pumps would also result in low hot reheat pressure for the affected MSR(s). Relief valve leakage can be visually verified.

Note 4: These failures can be verified by checking the position of the 1st and 2nd stage reheat steam supply valves. These failures may also be accompanied by high coil drain flow and temperature from the affected reheat stage. These failures are not applicable if reheat steam supply valves are normally full open.

Note 5: High 1st stage reheat steam flow can be caused by a tube leak in the 1st stage reheat tube bundle. A leak in the lower regions of the 2nd stage reheat tube bundle can cause high 1st stage reheat steam flow by injecting additional moist steam in the region of the 1st stage reheat tube bundle. Additional reheat steam flow is required to reheat this additional moist steam. Damaged separators would also product high reheat steam flow due to inadequate moisture removal.

Note 6: Flooding of the separator can result from excess moisture in the incoming steam or from a restriction in the MSR shell drain system. Low drain flows indicate drain restrictions. High drain flows indicate excess moisture.

Note 7: Leaks in the 1st stage reheat drain system or opening of the 1st stage reheat drain tank emergency dump valve will result in loss of the inventory in the drain tank. This will result in increased reheat steam flow into the drain tank and an increased temperature.

Note 8: Carbon steel reheat tubes are susceptible to rust during downtimes due to exposure to moist air. This rust tends to fill in between the tube fins, reducing the heat transfer between the reheat steam and the main steam, thus reducing the hot reheat temperature.

Note 9: Tube leaks result in saturated steam being injected into the separator. The increased moisture in the main steam results in additional reheat steam draw to vaporize this moisture. However, hot reheat temperature will still decrease. Tube leaks near the boundary of either tube bundle may also cause tube wetting which reduces the heat transfer from the reheat steam to the main steam.

Note 10: Reheat steam supply line restrictions include supply valves not fully stroking open, dropped valve seat, foreign object lodged in valve, or operation on bypass steam supplies.

Figure 5-3
MSR Diagnostic Tree, BWR

5.8 References

1. ASME Performance Test Codes, "PTC 12.4, Moisture Separator Reheaters". New York, New York: May 23, 1993.

2. *Electromagnetic NDE Guide for Balance of Plant Heat Exchangers, Revision 1*. Electric Power Research Institute, Palo Alto, CA: December 1995. Report TR-101772R1.

3. ASME Performance Test Codes, "PTC 19.1, Instruments and Apparatus: Part 1 Measurement Uncertainty.", New York, New York: 1991.

4. *Thermal Performance Diagnostic Manual for Nuclear Power Plants, Volumes 1, 2 and 3*. Electric Power Research Institute, Palo Alto, CA: April 1987. Report NP-4990.

5. *Procurement and Operation Considerations for Moisture Separator Reheaters*. Electric Power Research Institute, Palo Alto, CA:, September 1984. Report NP-3692.

6.0

IMPROVEMENTS AND MODIFICATIONS

Plant operating experience has shown that MS/Rs are susceptible to problems that have required significant modifications. This section first discusses the problems that have been most significant. It then discusses topics that should be considered while assessing the need and scope of modifications. The section concludes with a discussion of three basic modification packages:

- Moisture separator modifications
- Excess steam modifications
- Reheater tube bundle modifications

There are many sizes and varieties of MS/Rs. The discussion of these modifications is limited to general features which should be considered when evaluating and implementing modifications. Details need to be developed by the organizations responsible for plant-specific implementation of modifications.

6.1 MSR Problems Discussion

Many MSs and MSRs have had a history of problems starting from the time they were first used; this is the main reason that many plants have made extensive modifications to the equipment. The cause of most of the problems involves the following issues:

- Moisture entrained in the cycle steam and the potential for it to cause erosion, especially erosion of carbon steel components
- Re-entrainment of moisture during the moisture separation process
- Any moisture remaining in the cycle steam after moisture separation has potential to foul reheater heat transfer surface
- Large temperature differences and rates of temperature change in MSRs that can cause significant thermal distortion and high thermal stresses

6.1.1 Moisture Separation. The original design intent was to achieve a high percentage removal of cycle steam moisture in the moisture separators. Moisture carryover in MSs results in higher moisture in the LP turbines. Failure to achieve a high moisture removal efficiency in MSRs results in moisture carryover into the reheater tube bundles. This, in turn, results in evaporation of the moisture in the reheaters, the consequences of which are less reheat or superheating of the cycle steam and higher consumption of heating steam. The net effect is reduction of turbine mechanical efficiency, reduced turbine output, and higher moisture levels in the LP turbines. There have been several problems related to moisture separation:

- Use of wire mesh for moisture separation: Early vintages of some MSRs used wire mesh rather than chevrons. Wire mesh is structurally weak and can be easily damaged in steam flow containing moisture. Furthermore, moisture removal capacity is limited. The solution has been to replace wire mesh with moisture removal chevron plates which are more rigid and have higher moisture removal capacity per unit volume.

- Use of Carbon Steel Chevrons: Chevrons in some plants are fabricated from carbon steel plates. Severe erosion by moisture impingement has been a problem where carbon steel chevrons have been used. The solution has been to replace carbon steel with stainless steel chevrons.

- Low Moisture Removal Efficiency: The moisture removal efficiency of both chevrons and wire mesh has not met expectations. Figure 6-1 shows typical separation efficiency versus the velocity of the steam flowing to the separator. This figure indicates that 100 % efficiency can be achieved provided the steam velocity is low.

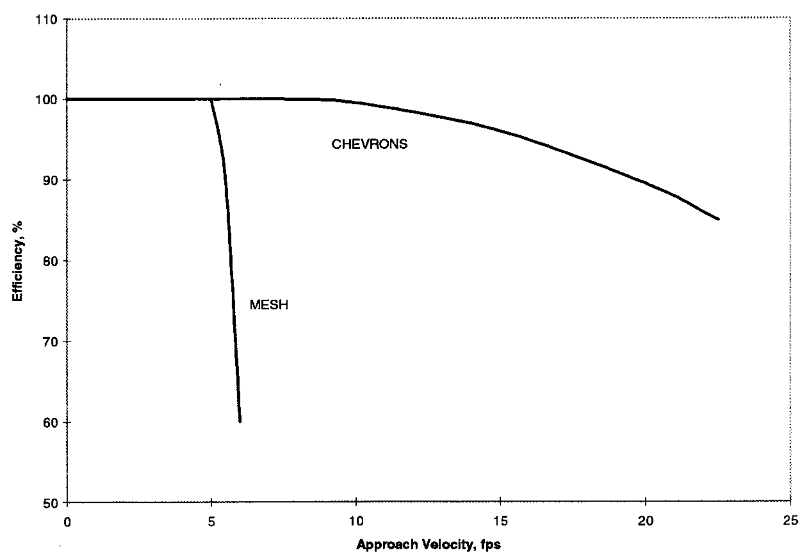


Figure 6-1

Moisture Separation Efficiency

- Poor Inlet Steam Flow Distribution: Moisture separator chevrons extend along the length of the MS/R shell and need low steam velocity to achieve high efficiency. Poor inlet cycle steam distribution, set by inlet nozzle size and location, can result in high local velocity at the moisture separators. This can cause poor moisture removal efficiency and damage to wire mesh and carbon steel chevrons. Solutions include using inlet manifolding and perforated plates in front of the moisture separators.

Early MS/R designs relied on a large axial flow path between the vessel ID and the reheater region to achieve low steam velocity and uniform distribution of cycle steam into the moisture separators. This has not always been satisfactory; flow distribution has been uneven resulting in high local velocities that can cause moisture carryover and erosion damage to the chevrons and wire mesh. Some MS/Rs have been provided with inlet steam manifolds or perforated plates in front of the moisture separators to improve steam flow distribution into the moisture separators (Figure 2-3 shows both manifolds and perforated plates).

Some MS/Rs have used carbon steel for the perforated plates. Carbon steel is very susceptible to erosion by the moisture entrained in the inlet cycle steam. Stainless steel is much less susceptible to moisture erosion and is the preferred material for perforated plates.

Moisture Re-entrainment. Another source of low moisture removal efficiency is re-entrainment of moisture before the steam flows into the reheater. The sources of moisture can be the moisture collectors in the separators and the moisture drain region at the bottom of the vessel. These need to be shielded from high velocity steam flow which can pick up and re-entrain moisture. Figure 2-3 shows a deck plate above the moisture drain region. The plate allows moisture to drain but prevents steam from flowing directly over the water in the drain.

Since the cycle steam is at saturation conditions before reheat, the performance of the moisture separator function is not directly observable by parameters such as steam temperature. Rather, tests such as using a tracer element to estimate moisture entering the reheater are necessary. These types of tests, however, are not practical for routine thermal performance monitoring. One has to rely, instead, on special testing and indirect indications of whether or not the moisture separators are operating effectively. (see Section 5.4 for discussion of moisture measurement.)

It should be noted that steam manifolds and perforated plates increase the cycle steam pressure drop across the MSR. This reduces LP turbine inlet pressure which, in turn, reduces LP turbine thermodynamic efficiency. This effect needs to be considered when modifying inlet cycle steam distribution features. The example calculation of Appendix A, PTC 12.4, illustrates that heat rate can increase 0.32% if MSR ΔP increases from 7.82 to 10.19% of MSR inlet pressure. This is approximately a 0.15% increase in heat rate for each percent increase in MSR ΔP expressed as a percent of MSR inlet pressure. PTC 12.4 cautions that this data is for illustrative purposes only.

In the case of an MSR, low cycle steam temperature leaving the reheater could be an indication of excess moisture carryover from the moisture separator, and that the reheater is evaporating the moisture and not being fully utilized to superheat cycle steam. In the case of an MS only, high heat rate and low turbine output can be an indication of excess moisture carryover, although there might be other reasons for high heat rate.

Moisture Carryover into Reheaters. Moisture carryover from the separators to the reheaters can have adverse effects:

- The moisture will evaporate on the first few rows of reheater tubes, resulting in less heat transfer surface to reheat steam.
- The evaporation process requires additional heating steam, resulting in less steam flow through the turbine and less electrical generation.
- If there is any solid material such as iron from piping, it can deposit in the spaces between fins and reduce heat transfer effectiveness.
- The moisture can cause erosion of the reheater tube fins especially if the tubes are made of material, such as carbon steel, that is susceptible to erosion by moisture impingement. Figure 6-2 illustrates the effects of these deposit and erosion phenomena.

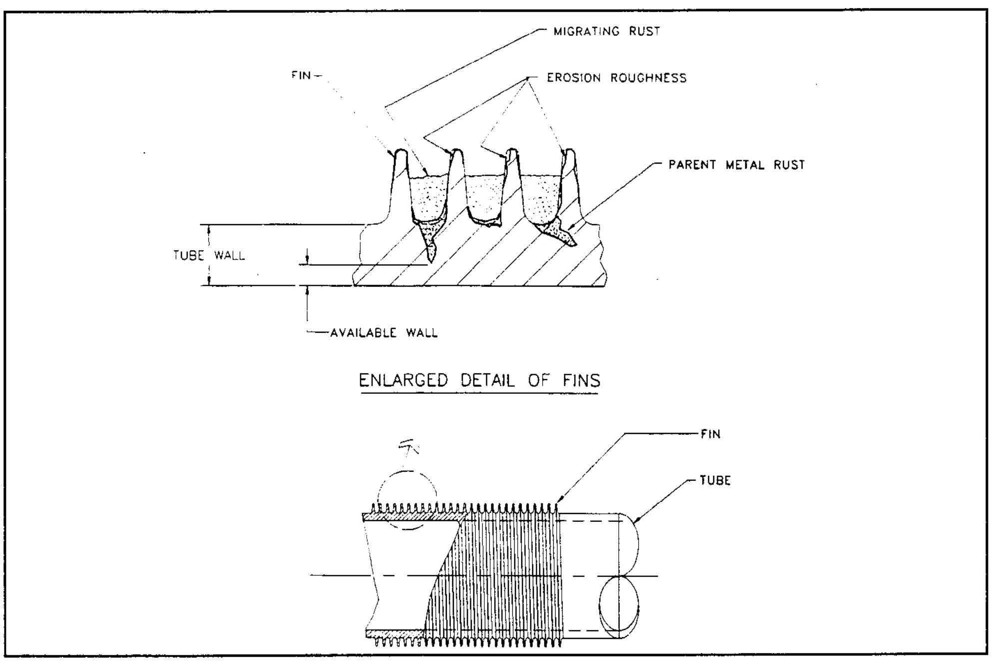


Figure 6-2
Erosion Corrosion on Finned Tube for MSR Application
(Courtesy of Senior Engineering)

6.1.2 Reheater Problems. Many of the MSR problems that have been encountered are associated with the reheater as follows:

Condensate Subcooling and Oscillation. Condensate subcooling and oscillation occurs due to inadequate drainage of condensate from the outlet end of the reheater U-tubes. The condensate can cyclically flood the tube outlets causing temperature oscillations and cyclic thermal stresses that can produce cracks in the tubes. The problem is depicted in Figure 6-3. Ideally, the condensate should readily drain leaving some steam at the top of the tube in the outlet region. With only a small amount or no steam present in the outlet region of the tube, the condensate accumulates and is subcooled to temperatures approaching the colder cycle steam flowing across the tube. The condition is not stable; the subcooled condensate slug is soon expelled from the tube and replaced with a hot steam/condensate mixture that again accumulates, is subcooled, and is again expelled.

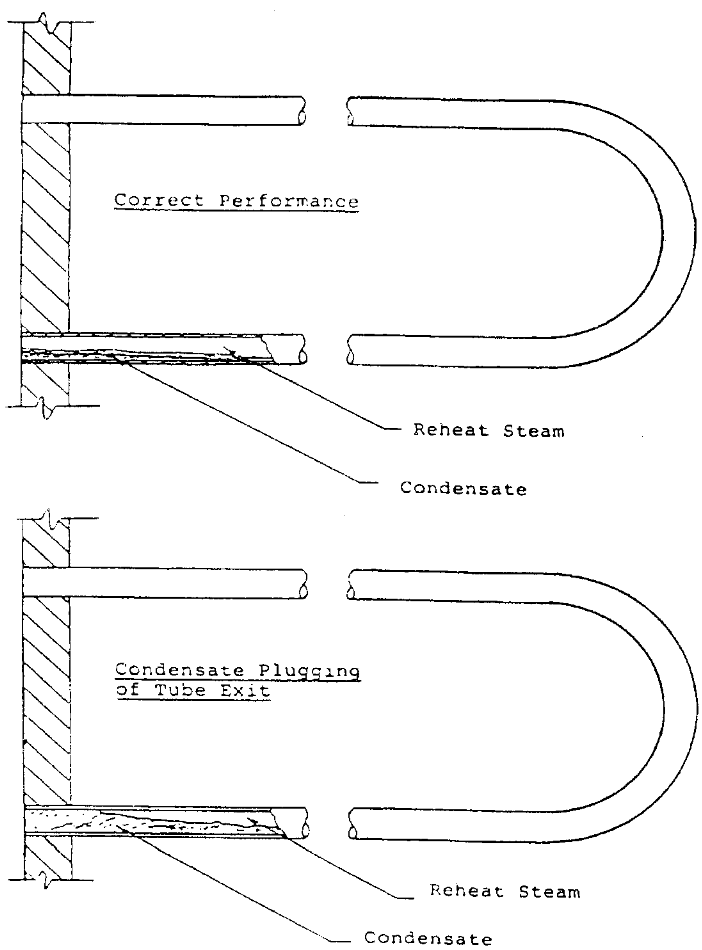


Figure 6-3
Condensate Oscillation

Early vintage MSRs have two-pass tube bundles. An early modification to eliminate condensate subcooling and oscillation was to provide capability to vent excess steam from the outlet channel to one or more feedwater heaters. Excess steam flow on the order of 10% of total heating steam flow is required in a two-pass configuration to effectively eliminate condensate subcooling and oscillation. This steam flow is essentially a thermal loss and results in increased heat rate.

A more recent modification is the conversion of MSR tube bundles from two- to four-pass as illustrated in Figure 6-4. This involves modification of the channel head and tubesheet to incorporate new vents and drains and additional pass partition plates. The four-pass modification reduces the required quantity of excess steam, typically down to 2-3%. The intent of the modification is also to reduce the heat load unbalance between tubes and eliminate condensate subcooling during operation at part load. The part load at which condensate oscillation can become a problem is a function of the MSR design and details of the modification.

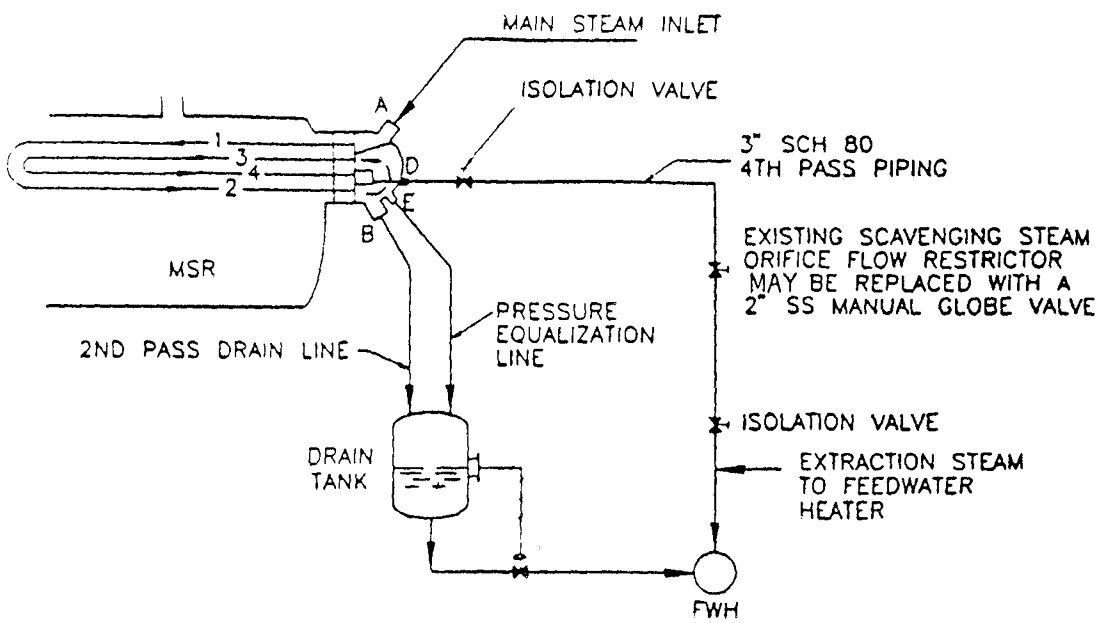


Figure 6-4
Typical Four-Pass Drain System Piping Arrangement

Unequal Thermal Expansion of U-Tube Legs. Differences exist between the metal temperature of the top inlet legs and the bottom outlet legs of the U-tubes due to cycle steam and heating steam temperature differences. Temperature gradients along the U tubes are increased by operation at part load, by condensate subcooling, and by high rates of temperature change during heatup. Temperature gradients cause unequal thermal expansion of the inlet and outlet legs of the U-tubes, which can cause distortion of tubes and support plates in the U-bend region of the tube bundle.

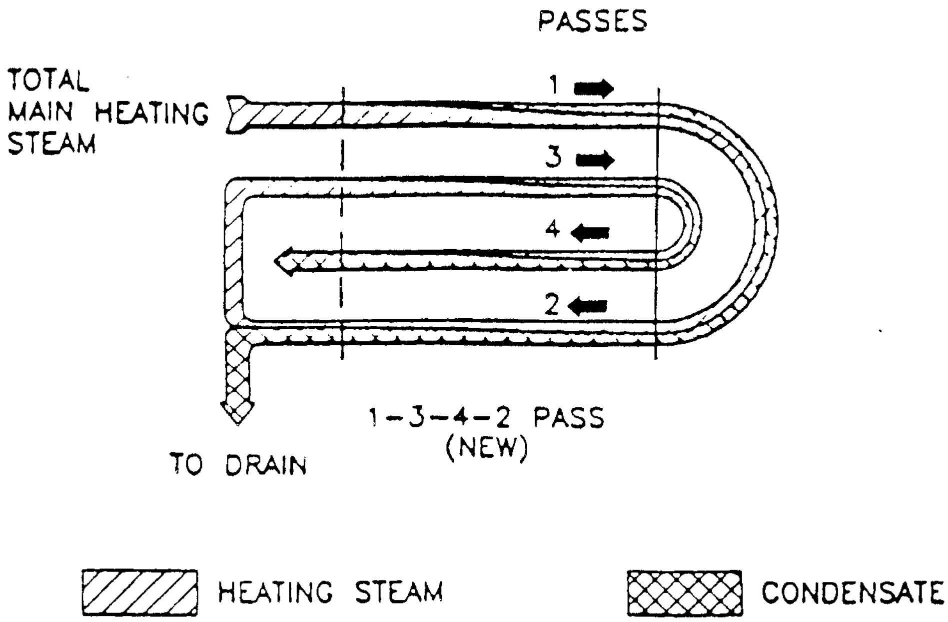


Figure 6-5
Tube Pass Arrangement
(Courtesy of Senior Engineering)

Figure 6-6 illustrates the problem of unequal thermal expansion. The large thermal expansion of the hot leg is accommodated by distortion of the U-bend radius. Instead of the tube entering straight into the last tube support, it enters at the angle, ***a***, shown in Figure 6-6. When ***a*** exceeds some value (which is dependent on tube clearance and tube support hole configuration), the tube can bind in the last tube support. If the MSR is then cooled down, the tube will pull on the tube support resulting in tube support plate distortion (Figure 6-6) and/or tube damage. This causes a ratcheting effect as the MSR goes through thermal cycles. The binding of tubes in the support is most severe for the small radius tubes, since ***a*** will be larger for the small radius tube in order to accommodate a given hot-cold leg differential expansion. As the tube support is bowed by the ratcheting effect, outside tubes might be damaged by tube/tube support binding.

Plants with once through steam generators (OTSGs) use superheated steam for HP heating steam. Since this steam enters the U-tubes at temperatures above the saturation temperature, the average temperature of the inlet U-tube leg will be substantially higher than in an MSR that uses saturated steam for reheat. This can increase unequal thermal expansion of the U-tube legs.

Some solutions to reduce the effects of unequal U-tube leg thermal expansion include:

- Eliminate tube finning at support locations
- Allow the last tube support to "float"
- Modify the configuration of the tube support holes, for example, hour glass contour
- Increase the bend radius of the inside U-tubes
- Increase the tube straight length beyond the last tube support
- Increase the thickness of the last two support plates

Most of these involve major modifications to the MSR tube bundle.

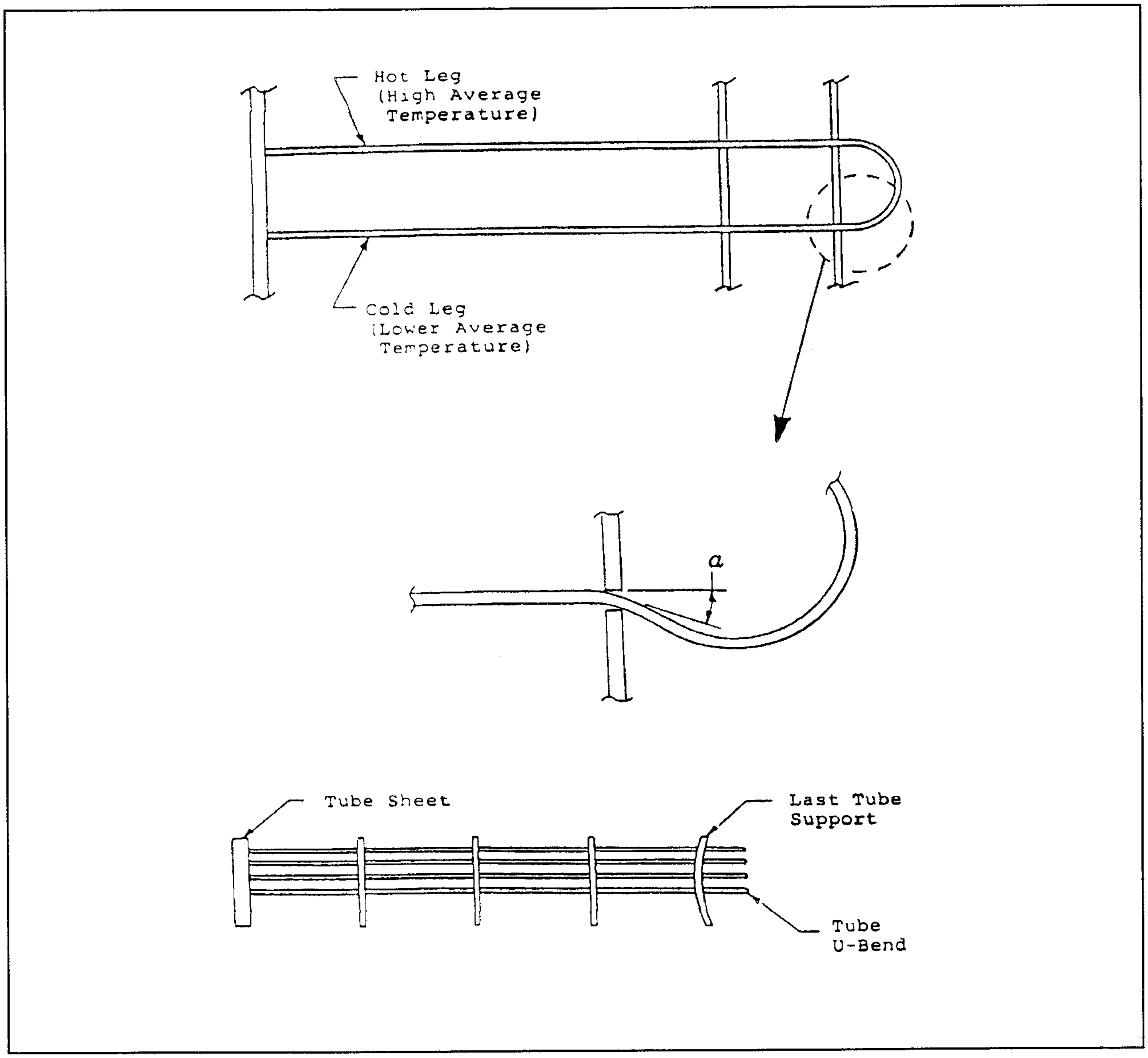


Figure 6-6
Unequal Thermal Expansion of U-Tubes

6.1.3 Shroud Buckling and Reheater Bypass. The shroud on the sides of the reheater tube bundle is exposed to cold cycle steam at the bottom and to the reheated cycle steam at the top (Figure 6-7). At full power operation, this can result in a temperature difference of about 135F° between the bottom and top of the shroud of an HP tube bundle.

Some shroud plates have been thin (about 0.25 inch) plates without adequate reinforcement. This combination of thin material (low buckling resistance) and large temperature differential (high compressive stresses) has resulted in buckling of the shroud plates away from the tube bundles. This then allows bypass of some cycle steam around the tube bundle and a resultant drop in cycle steam superheat. Modifications to avoid this problem have consisted primarily of adding reinforcement to the shroud to improve the lateral bending resistance needed to prevent buckling.

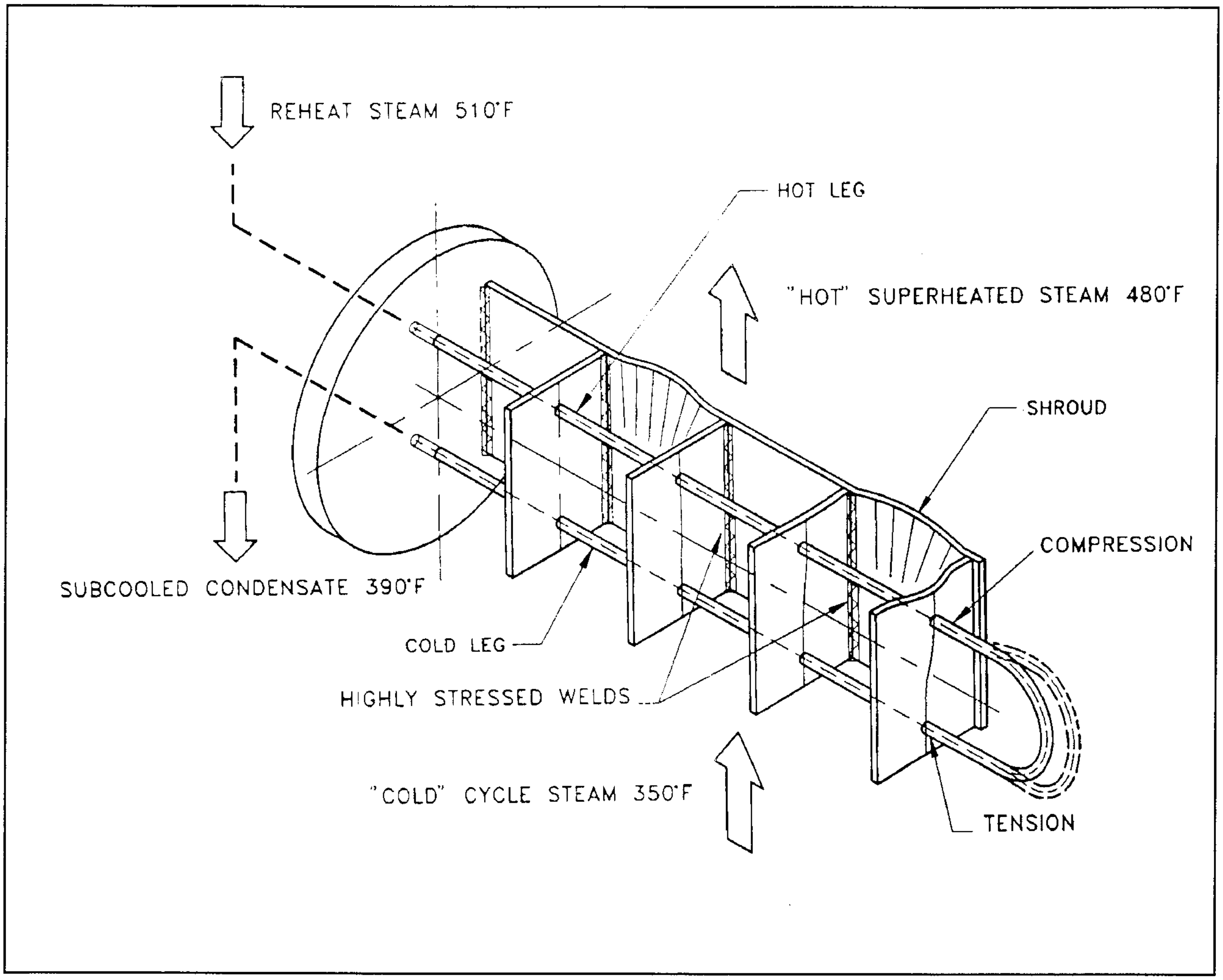


Figure 6-7
Thermal Effects on Shroud and Tubes

6.1.4 Tube Material Problems. Initially many MSRs used copper-based or carbon steel tubes. These materials have serious drawbacks:

- CuNi Tubes Copper-based material has been found to result in unacceptable water quality conditions at both BWR and PWR plants. Furthermore, CuNi has a high coefficient of thermal expansion, low allowable stress and low fatigue limits, making such material more susceptible to damage by high thermal gradients and condensate oscillation.

- Carbon Steel Tubes Carbon steel oxidizes easily especially in the presence of residual water droplets during shutdown when the MSR shell is open for inspection and maintenance. As a result, oxidation of carbon steel MSR tubes has occurred especially if the MSR tube bundles have not been thoroughly dried. This can cause filling of the spaces between tube fins with rust (bridging).

The solution has been to replace CuNi and carbon steel tubes with stainless steel tubes. In the case of carbon steel, an alternate solution is to improve drying procedures during unit shutdown.

6.1.5 Tube Vibration. MSRs are susceptible to tube damage caused by cycle steam flowing across the outside of the reheat tubes. Under some conditions flow can cause excessive vibration of the tubes. The vibrating tubes can collide and be damaged in the spans between tube supports or the vibrating tubes can wear in the tube support plate holes. The problem is accentuated by periodic high flow conditions during turbine stop and intercept valve testing. The problem occurs mostly in MSRs with long spans between tube supports. Tubular Exchanger Manufacturers Association (TEMA) Standards allow unsupported spans in excess of four feet. TEMA also cautions for the need to address vibration and provides guidance to preventing vibration damage. This guidance usually results in tube spans less than two feet depending on tube material and size. TEMA also provides information on MSR reheater tube vibration.

6.1.6 Flow Accelerated Corrosion. The MS/R inlet nozzles and vessel internals upstream of the moisture separators contain cycle steam flowing with large amounts of moisture. These components are subject to the phenomenon of flow accelerated corrosion (FAC), which can cause severe corrosion and wall thinning of carbon steel, if exposed to a flowing mixture of steam and moisture. FAC is also referred to as erosion/corrosion. FAC may not manifest itself by degradation of MS/R performance. It could, however, result in wall thinning ultimately leading to pressure boundary failure.

Stainless steel is much less susceptible to FAC than carbon steel. The solutions to FAC are visual inspection and wall thickness measurements, replacement of carbon steel with stainless steel, or protection of carbon steel surfaces in the flow stream with stainless steel impingement shields and covers. EPRI has conducted extensive investigations of FAC; a product of this is the EPRI integrated software for corrosion control, CHECWORKS. Additional information on FAC can be found in References 3 through 6 at the end of this section.

6.2 The Decision to Make Major Modifications

Decisions to make modifications should be based on economics. Payback from modifications depends, to a large extent, on the utility's ground rules for assessing modification costs, the value of increased output, the actual increase in output that is expected after the modification is implemented, and the intrinsic value of other benefits that cannot be related to increased output. There are no hard and fast rules that can be considered applicable to all plants and MS/R circumstances, however, some general considerations are appropriate.

6.2.1 Assessing the Improvement Potential. Most modifications are made to correct deficiencies that have resulted in plant output that is less than the output that can, at least in theory, be achieved with MS/Rs operating at design or better than design conditions. The first and key step in the assessment process is to estimate the improvement based on hard data and analysis. Only reheater outlet temperature is available for assessment at most plants with MSRs. In the case of two stage MSRs, only the outlet temperature of the HP heater is measured. This information is not a direct indication of conditions in the moisture separator or the LP reheater.

In the case of plants with moisture separators only, moisture carryover is the important data and it is usually not available. The plant might have to conduct moisture carryover tests, as described in Section 5.3, in order to obtain the data needed to assess the need to modify the moisture separators.

Even with only a minimum amount of information, an assessment of the improvement potential can be made.

Moisture Separator-only Plants. As a general rule, each 1% moisture contained in the outlet steam from an MS will result in about a 0.3% increase in heat rate.

> Example: A plant operating at 1000 MWe conducts moisture carryover tests and finds that the exit quality of the cycle steam is 98% (2% carryover). If the MS could be modified to increase the exit quality to 100% (no carryover), there will be a 0.6% or 6 MWe increase in plant output to 1006 MWe. This output will have a significant value to the plant. If the nominal O&M costs are $30.00/MW-hr, an improvement that results in no moisture carryover will reduce O&M cost 0.6% to $29.82/MW-hr. The moisture carryover effects from the moisture separator of an MSR are similar; about a 0.25% increase in heat rate for each 1% moisture contained in the separator outlet steam. The incentives for high effectiveness moisture separation MSRs are similar to MSs.

MSR Plants. As a general rule, each reduction of 1F° in reheater TTD will result in about a 0.015% decrease in heat rate for a single-stage reheater or HP reheater of a two-stage MSR, and 0.004% decrease for the LP stage of a two-stage reheater, depending on plant design and operating conditions.

Example: The single-stage reheater TTD of a 1000 MWe plant is 10F° greater than design. If the reheater could be modified to decrease the TTD to design, there would be a 0.15% or 1.5 MWe increase in plant output. This will have some economic benefit depending on the plant's economic ground rules. If the nominal O&M costs are $30.00/MWe-hr, the improvement will reduce O&M cost 0.15% to about $29.96/MWe-hr.

The above examples are illustrative of the potential incentive to modify and improve MS/R performance. Actual incentives depend on specific plant conditions, the economic model used, and the amount of data available for the assessment.

The assessment should consider other factors:

Is the MS/R performance continuing to degrade? If so, should the MS/R be modified now to prevent further degradation and to recover these additional MWe-hours of production that otherwise would be lost in the future?

Reduced MS moisture carryover and reduced TTD result in reduced moisture in the LP turbines which might avoid or postpone the need to replace or refurbish LP turbines before the end of planned plant life? Should this benefit be considered in the decision to modify the MS/R?

Answers to these questions can influence the modification decision. Most modification decisions will be based on implementing at least one major modification. Concurrently, the decision process should consider whether or not to include other modifications that should be implemented at the same time in order to avoid the need for another MSR outage. On the one hand, it might be more advantageous to break the modification package into several steps in order to avoid plant shutdown critical path situations. On the other hand, it might be advantageous to replace the complete MSR, including vessel, with up-to-date features during one outage. This approach could reduce field work and avoid outage critical path time if structural modifications are not required for replacing the vessel. Such an approach might be necessary if the existing carbon steel vessel walls have extensive erosion/corrosion. The issues involved are unique to the modification and plant conditions anticipated when the modifications are implemented.

6.2.2 Root Cause Analysis. Modifications should not be undertaken without knowing the root cause of the observed deficiencies as they are not always apparent from the operating symptoms. For example, the cause of observed low reheater outlet temperature could actually be one or a combination of several of the following:

- Deficiencies in the moisture separator causing moisture carryover into the reheater.
- If a two-stage reheater, deficiencies in the LP reheater, causing decreased inlet temperature and increased heat load on the HP stage.
- Deficiencies in the HP reheater.

A visual inspection, looking for problem areas discussed in Section 6.1, is a necessity to determine root cause and develop a good action plan.

A precaution: The reheat tubes should not be replaced without first having assurance that the moisture separator is not allowing significant moisture carryover into the reheater. Moisture carryover will accelerate degradation of those reheater tubes that are exposed to the impinging moisture and those that evaporate the moisture carryover before the remainder of the tubes superheat the dry steam. If moisture carryover is a problem, the moisture separator should be modified to reduce carryover and extend the life of the new reheater tubes.

6.3 Moisture Separator Modifications

Moisture separator modifications have included replacing wire mesh with chevrons, replacing carbon steel chevrons with stainless steel, improving inlet cycle steam distribution and, minimizing re-entrainment of separated moisture into the cycle steam. The most recent modification packages have included improvements that address most problems experienced in the past. The moisture separator package usually includes the following:

- Double-pocket, stainless steel chevrons as shown in Figure 6-8. Many MSRs were originally provided with single-pocket chevrons. Double-pocket chevrons can have approximately 97% moisture effectiveness compared to 92% for single-pocket chevrons. The effectiveness depends on the moisture and dynamic head, ρV, of the inlet cycle steam. Figure 6-9 illustrates the effect of these parameters on moisture removal effectiveness.

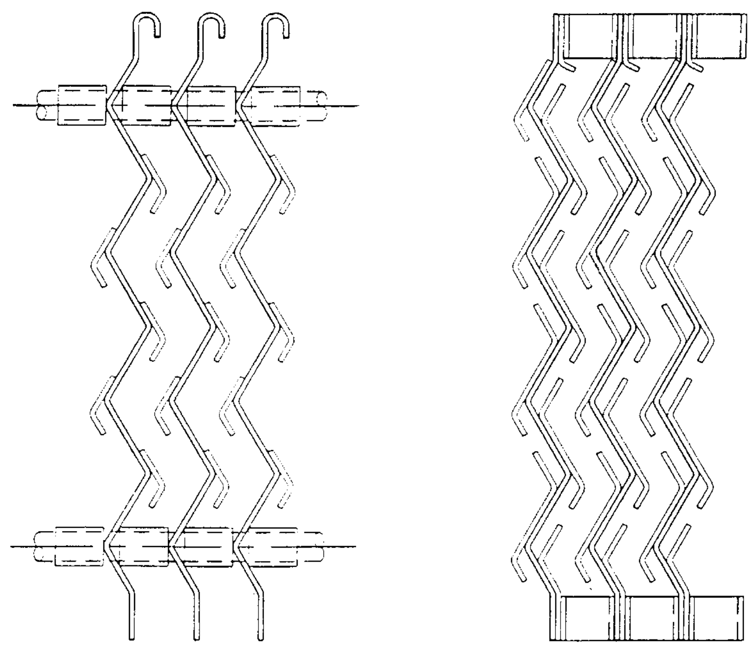


Figure 6-8
MSR Chevrons
(Courtesy of Senior Engineering)

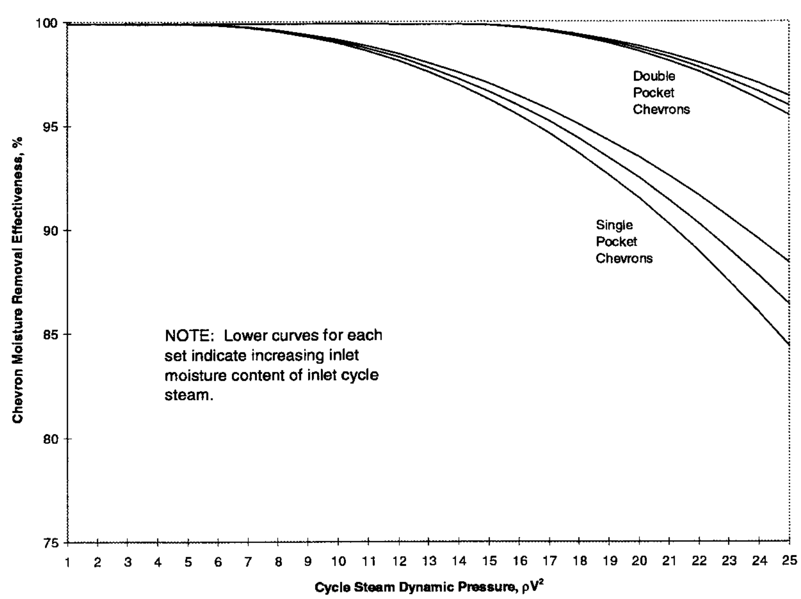


Figure 6-9
Typical Moisture Removal Effectiveness of Chevron Separators

- Chevrons slanted outwards as shown in Figure 6-10. This arrangement allows stray separated moisture to drain back towards the incoming cycle steam rather than into the path of the dry steam leaving the separator where it can re-entrain. Some MSR internal designs might not provide sufficient room for a slanted chevron configuration. Although not ideal, a vertical configuration will give satisfactory results, but chevrons with reverse slope from that shown in Figure 6-10 might not.

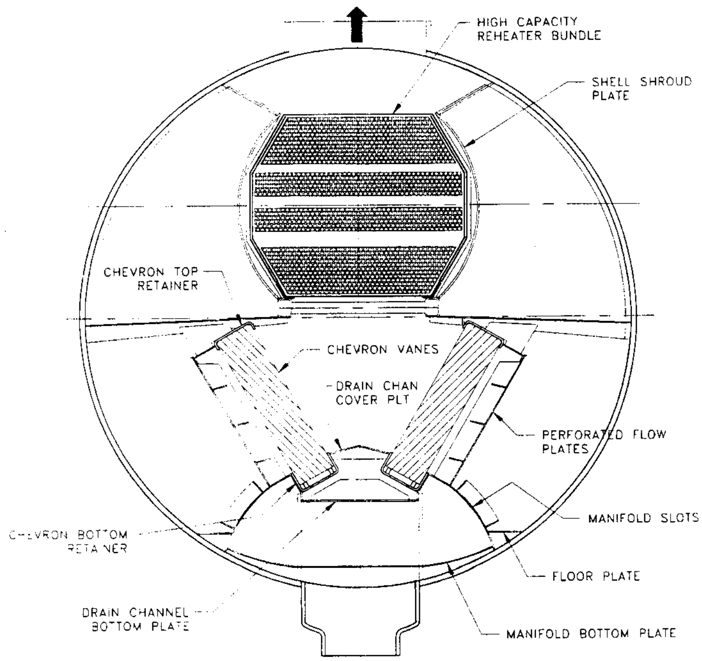


Figure 6-10
General Arrangement of G Type MSR Reconstruction by Senior Engineering
(Courtesy of Senior Engineering)

- Perforated flow plates at the inlet to the chevrons is shown in Figure 6-10. To prevent erosion, the plates should be stainless steel. Although the perforated plates do produce some adverse pressure drop, the added pressure drop is offset by providing uniform, reduced peak cycle steam velocity into the chevrons.

The above features are considered necessary modifications to achieve high moisture removal efficiency. If not incorporated in the original design, the following modifications are considered to be further enhancements that can provide additional assurance of high moisture removal efficiency.

- Steam manifolds that extend the length of the MSR. The purpose of the manifolds is to distribute cycle steam flow entering the end of the MSR to locations along the length of the MSR. This improves flow distribution into the moisture separator. Figure 6-11 shows an MSR with a typical steam manifold arrangement.
- Moisture skimmers are located on the bottom of the MSR to remove moisture in the cycle steam that is skimmed off as the steam turns and is redirected into the moisture separator banks. Skimmers remove a small fraction of the moisture that would otherwise enter into the moisture separators.

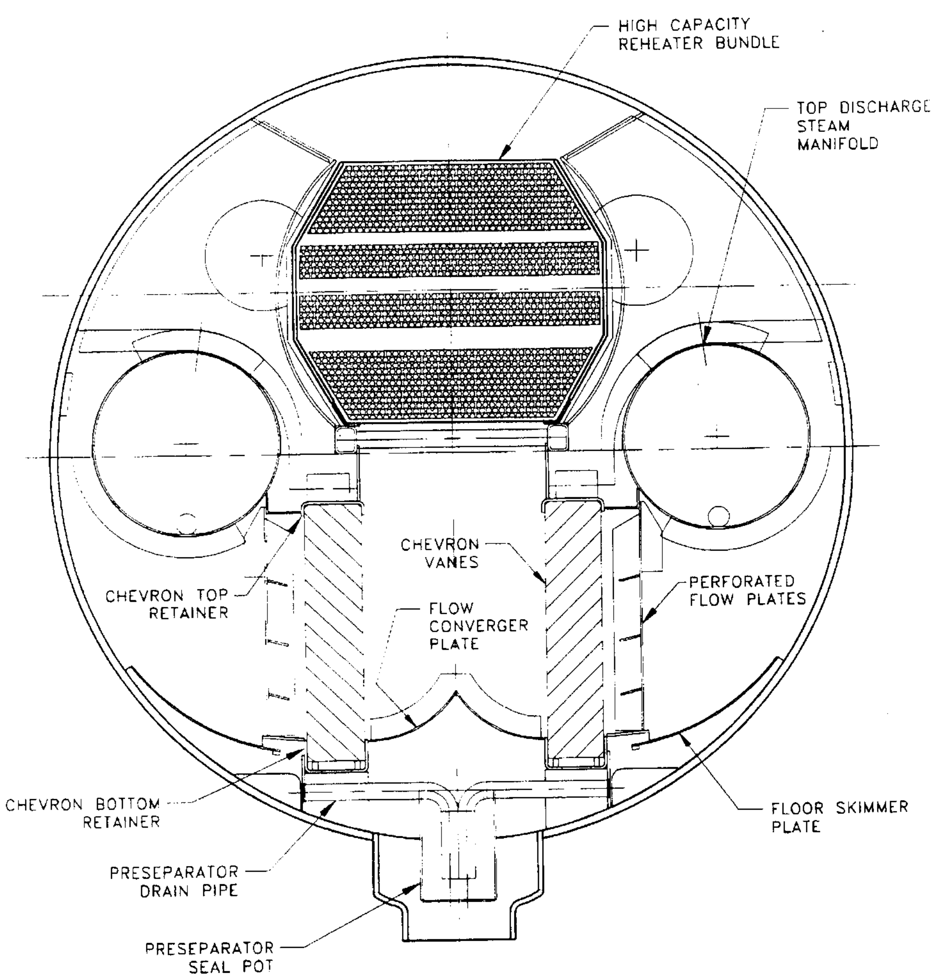


Figure 6-11
General Arrangement of MS Reconstruction by Senior Engineering
(Courtesy of Senior Engineering)

Another method of moisture removal is the high velocity separator, a device designed to be located in the outlet of the high pressure turbine exhaust and the MS/Rs. These types of devices have been evaluated by EPRI. The evaluation assumes that the devices replace the moisture separators in single-stage MSRs. Heat rate changes are evaluated assuming a range of MSR moisture separator effectiveness and a high velocity separator effectiveness greater than 90%. One plant participating in the survey conducted for this source book has installed high velocity separators.

6.4 Excess Steam Modifications

Section 6.1.2 discusses the problem of condensate subcooling and oscillation. It notes that the phenomenon is mitigated by venting excess steam through the reheater tubes to a feedwater heater. Many MSRs were originally supplied with two-pass U-tubes with inlet and outlet headers or channels. The inlet supplied heating steam to the inlet legs of the U-tubes and the outlet had a connection to drain condensate from the outlet legs or second pass to a feedwater heater. The reheater tube bundles were not provided with the capability to vent steam from the second pass to a feedwater heater as a means to establish excess steam in the reheater tubes.

The need for excess steam was recognized during operation of early vintages of MSRs. As a result, newer MSRs were installed and many operating MSRs were modified to a two-pass venting configuration. Figure 6-12 shows a typical arrangement of a two-pass venting system. This modification requires a new nozzle on the outlet tube bundle header, new external piping, and a valve and a flow restrictor to control the amount of excess steam flow. The modification usually includes orifices inserted in some tube inlets or a perforated plate covering part of the tubesheet with varying hole sizes to restrict heating steam flow into those tubes with low heat loads. Although the design is a relatively simple modification, it suffered from several problems:

- A large amount of excess steam is required (10% of heating steam flow). This results in reduced turbine output since the excess steam flows into a feedwater heater rather than the LP turbine. Figure A.10 of PTC 12.4 shows that the heat rate increases 0.07% for each 10% excess steam flow over 2%. It contains the caution that the information shown is illustrative only.

- Inlet perforated plates and orifices, if not properly designed and installed, can reduce accessibility for tube inspection and repair.

- The orifices and perforated plates become less effective at part load.

Despite the benefits of excess steam in a two-pass bundle, there can be inadequate excess steam flow to the tubes with high heat load, such as those tubes exposed to the coldest cycle steam. Increasing the amount of orificing to lightly loaded tubes and the total amount of excess steam flow can be inefficient and wasteful.

As a result of these drawbacks, a more recent modification to resolve the condensate oscillation problem has been the four-pass vent chamber design.

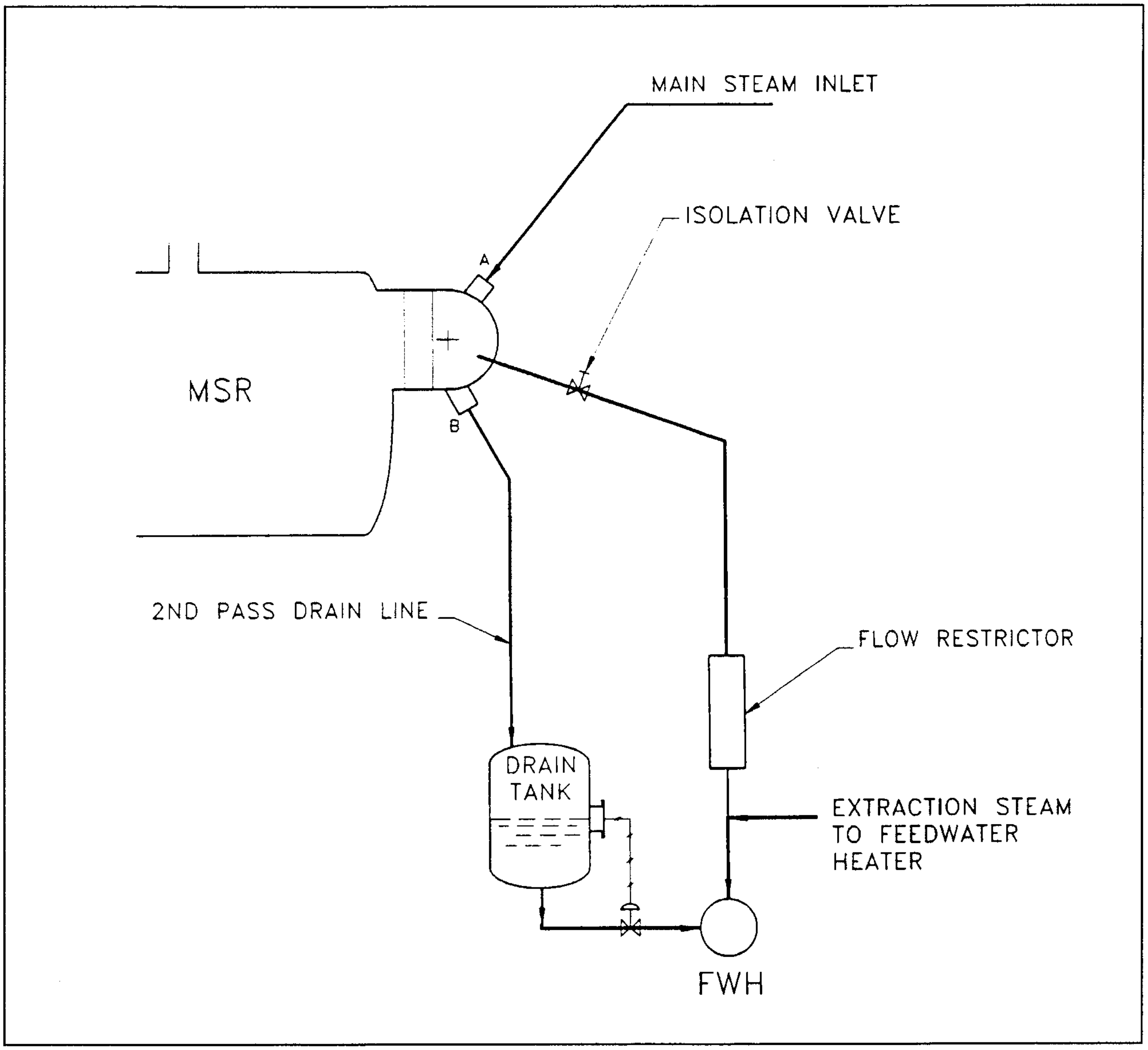


Figure 6-12
Original Drain Venting System
(Courtesy of Senior Engineering)

Figure 6-13 compares the flow paths for the two- and four-pass configurations. There are two possible configurations for the four-pass modification, the 1-3-4-2 pass and the 1-4-3-2 pass. The numbering sequence is based on the relative elevations of the tubes in a vertical U-tube bundle. The 1-3-4-2 arrangement is preferred since the condensate formed in the tubes can drain downward into the lower legs of the U-tubes.

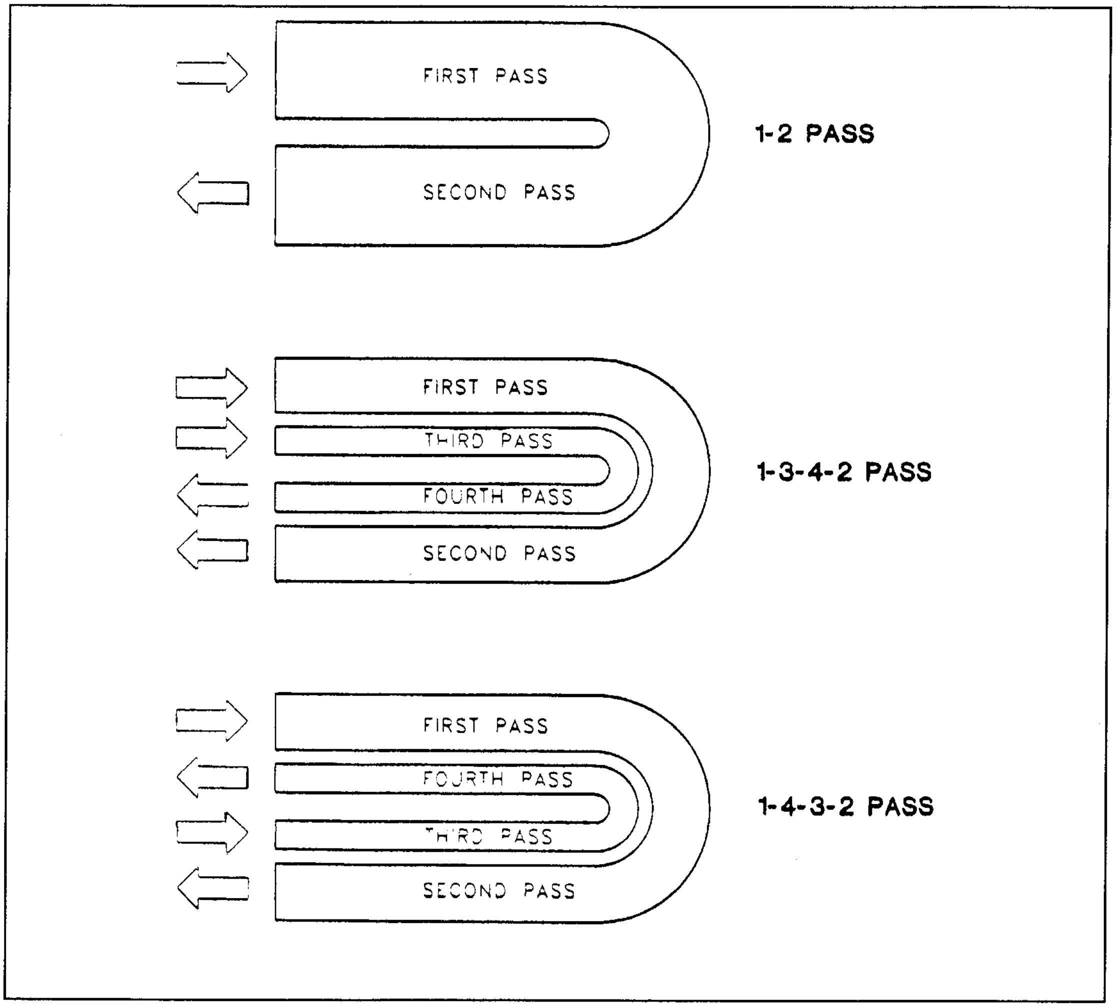


Figure 6-13
Typical Tube Pass Arrangements
(Courtesy of Senior Engineering)

The advantage of the four-pass design is shown in Figure 6-14. The steam flow in the second pass, which is subject to the lowest cycle steam temperature and highest heat load, can be on the order of 33% of the heating steam flow. At this high steam flow, significant condensate subcooling does not occur. Instead, the potential for subcooling moves to the fourth pass. In addition, the maximum possible subcooling is reduced since the temperature of the cycle steam in the fourth pass is significantly higher than in that entering the second tube pass region. Furthermore, this is achieved with approximately 3% excess steam leaving the fourth pass and venting to a feedwater heater. Typical temperatures for two- and four-pass arrangements are shown in Figure 6-15.

The four-pass modification requires changes to the inlet and outlet headers of the reheater to achieve the 1-3-4-2 flow path shown in Figure 6-13. The four pass configuration is illustrated in Figure 6-4. The long radius tubes remain the first and second passes while the short radius tubes are converted to the third and fourth passes.

The existing second pass drain and pressure equalization line and nozzles are retained. An internal pass partition is added to separate the first and third passes and an internal header is added to create a fourth pass out of the outlet legs of the short radius tubes. The fourth pass internal header and the large heater closure channel are provided with nozzles for the fourth pass vent and drain line. This line is sized for approximately 3% excess steam flow plus the condensate formed in the third and fourth passes. Figure 6-4 shows a manual globe valve in the line to control excess flow. This could also be an orifice or a venturi, however, a valve gives more operational flexibility.

This modification, using the existing tubes and tubesheet, lacks the smooth tubesheet surface needed for the first-third pass partition and the fourth-pass vent and drain header gaskets and bolting. Correcting this requires that some tube locations be converted to threaded studs and careful, intricate design of the internal gasketing. If not, leakage between passes can readily occur. As a result, the four-pass modification is usually made in conjunction with replacement of the entire tube bundle so that the tubesheet can be redesigned for pass partitions, bolting, and gasketing.

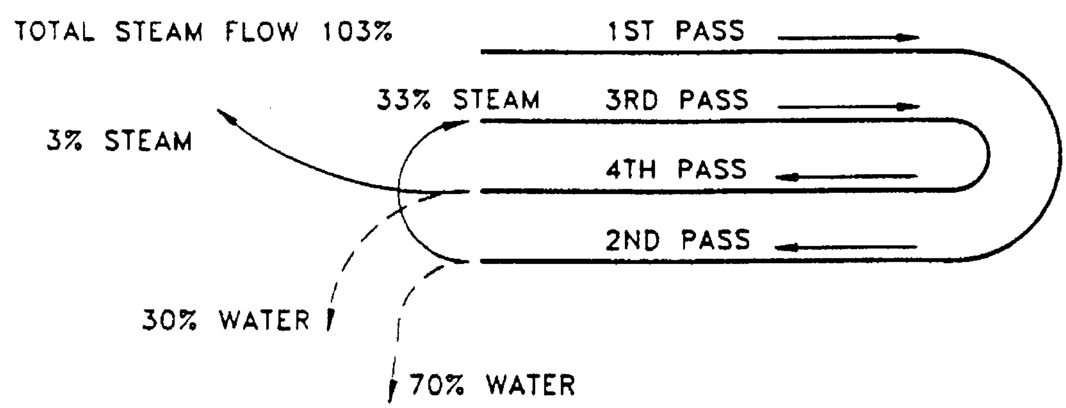


Figure 6-14
Heating Steam Flow Distribution
(Courtesy of Senior Engineering)

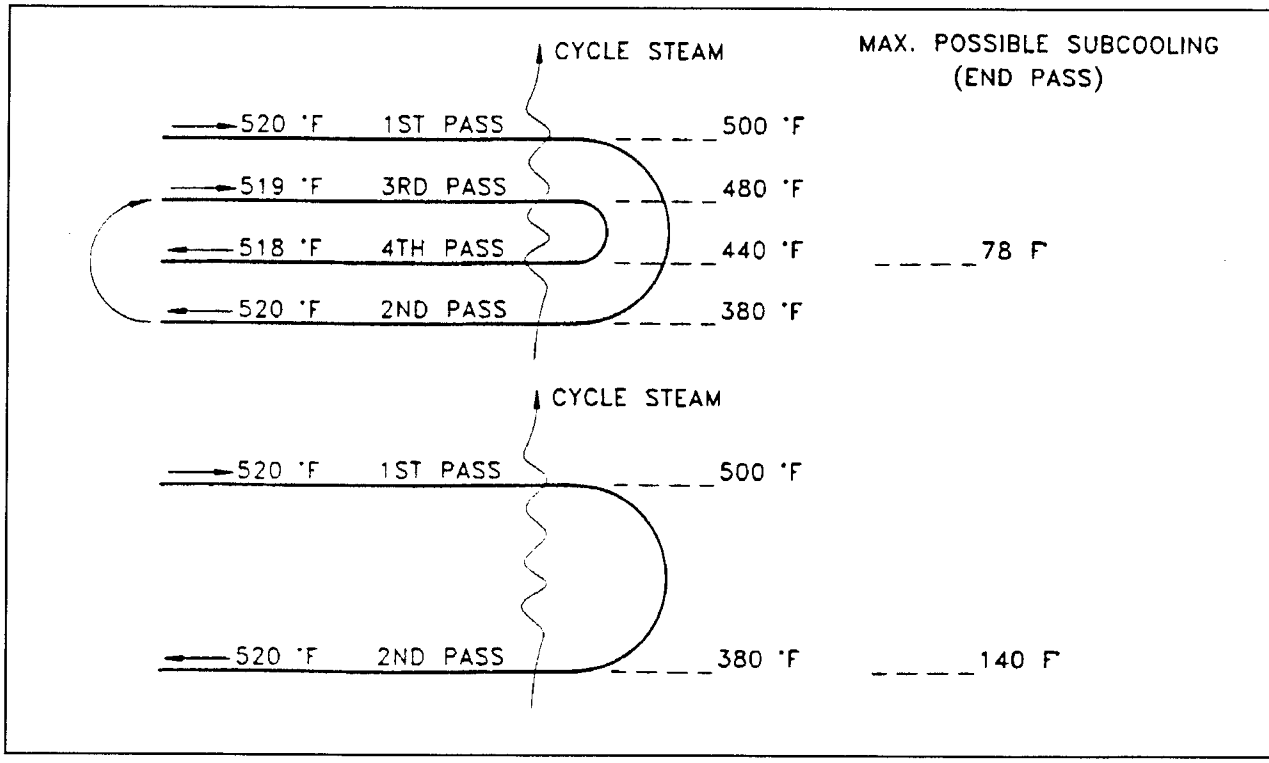


Figure 6-15
Two- and Four-Pass Temperatures
(Courtesy of Senior Engineering)

6.5 Tube Bundle Replacement

Reasons to replace an MSR tube bundle include:

- The need to remove sources of copper from the turbine cycle.
- The tube bundle heat transfer capacity has or is predicted to deteriorate to the point where it is economically justified to replace the tube bundle.
- The improved replacement adds MWe and is cost effective.

The problems discussed in Section 6.1 suggest that it is seldom prudent to replace the tube bundle in kind. There are modification features considered necessary for good performance and long tube life that were not in the design being modified.

- The correct tube material. Operating experience has shown that Type 439 stainless steel has provided the best performance and durability. Stainless steel is susceptible to stress corrosion cracking. Precautions need to be taken to specify material with low residual carbon content and to specify adequate process for rolling fins and for bending, welding, and heat treating the tubes.

- Adequate tube support to prevent tube vibration. Section 12 of the TEMA Standards provides guidance on prevention of tube damage by vibration. As a rule of thumb, a tube span of 24 inches or less will prevent harmful vibration.
- Even if the tube bundle shroud is not replaced, it should be modified to prevent buckling and to minimize bypass of cycle steam around the tube bundle. Figure 6-16 shows a method to restrict bypass flow. The restrictor bars will also strengthen the shroud against buckling. A unique buckling analysis, based on the conditions of the MSR under modification, should be made to assure there is adequate shroud structural rigidity.
- The U-tubes and tubesheet should be designed to provide smooth surfaces and bolt locations for pass partition and fourth pass header bolting and gaskets. The tube arrangement shown in Figure 6-10 provides these features.

The above features should be incorporated in both HP and LP reheater tube bundles if either or both are candidates for replacement. In no case should the tube bundle exposed to cycle steam flow from the moisture separators be replaced unless there is assurance that there is not significant moisture carryover. If this assurance does not exist, first conduct moisture carryover tests and/or modify the moisture separators to reduce carryover.

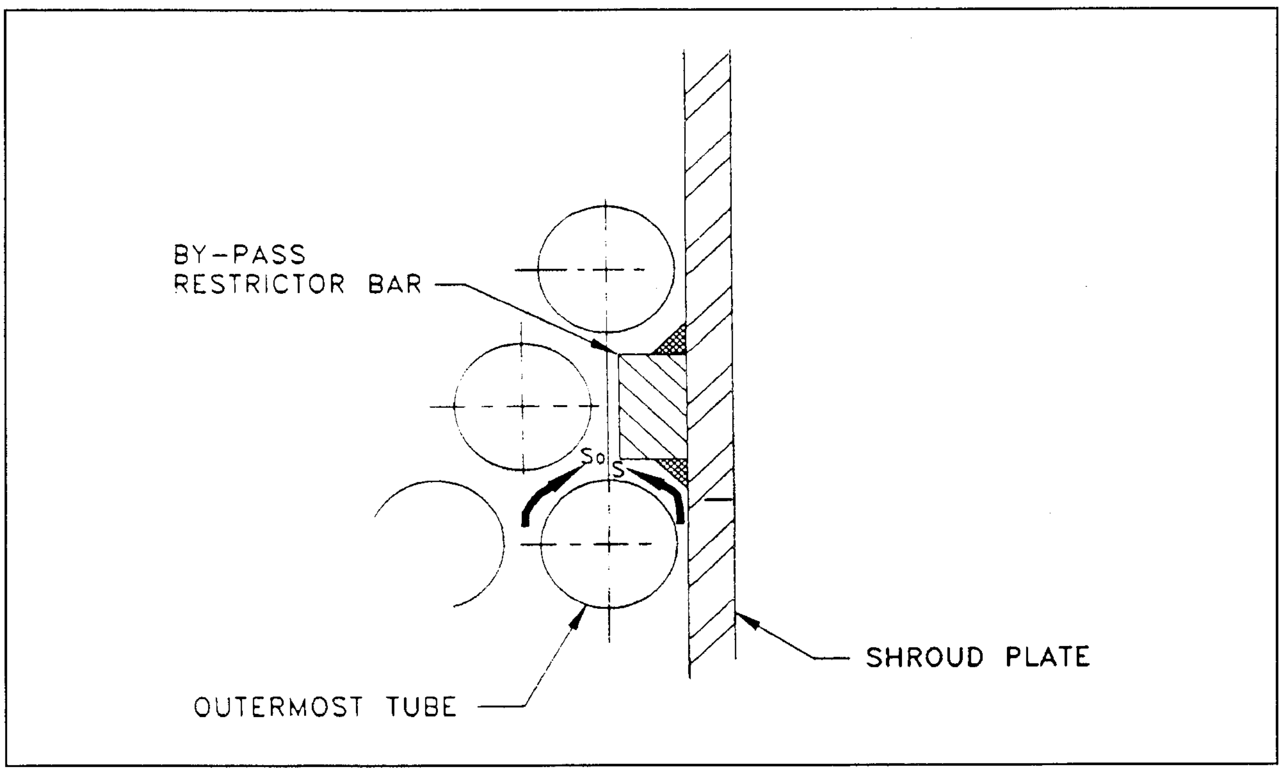


Figure 6-16
Function of By-Pass Restrictor
(Courtesy of Senior Engineering)

If a decision is made to replace a tube bundle, there are other modification features that should be considered as enhancements; their relative cost might be low compared to that of the basic modification.

- Add more tubes by taking advantage of the original tubesheet diameter. Figure 6-10 shows a pattern that does this. Most OEM tube bundles had a rectangular pattern that did not use the 3 and 9 o'clock space in the tubesheet circle. The wider, pancake tube pattern will also reduce cycle steam ΔP and the tendency for high ΔP to lift the tube bundle.

- Add thermocouples in the outlet of select second and fourth pass tubes to determine if condensate oscillation is occurring and to adjust excess steam to prevent condensate oscillation over the MSR operating range.

- Add features to reduce the problem of unequal thermal expansion of U-tube legs. These are discussed in Section 6.1.2.

- Reduce tube diameter to increase the tube-side heat transfer coefficient. Reduced tube diameter also increases cycle steam pressure drop. The tradeoff should be evaluated if this method of tube bundle enhancement is considered.

6.6 References

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APPENDIX A

A.1 Acronyms

BWR	boiling water reactor
ECT	eddy current testing
FAC	flow accelerated corrosion
HP	high pressure
LMTD	log mean temperature difference
LP	low pressure
MS	moisture separator
MS/R	moisture separator/reheater
MSR	moisture separator reheater
O&M	Operating & Maintenance
OEM	original equipment manufacturer
OTSG	once through steam generator
PHWR	pressurized heavy water reactor
PTC	Performance Test code
PWR	pressurized water reactor
TEMA	Tubular Exchanger Manufacturers Association
TTD	terminal temperature difference

A.2 Definitions

1. **Cycle Steam:** The HP Turbine exhaust steam passing through the MS/R shell, delivered to the LP Turbine

2. **Excess Steam:** Non-condensing heating steam that clears the reheater of condensate to minimize subcooling, thermal distortion, and condensate oscillation

3. **Heat Rate, Btu/kW-hr:** Heat required to generate a unit of electrical energy

4. **Heating Steam:** Steam supplied to reheater tubeside for the purpose of transferring its latent heat to the cycle steam

5. **Moisture Carryover:** Moisture remaining in the cycle steam after the moisture separation system

6. **Moisture Separation Effectiveness:** The ratio of the mass flow rate of moisture removed from the entering cycle steam to the mass flow rate of moisture entering the separator

7. **Moisture Separator Outlet Quality, %:** The thermodynamic quality of the steam at the outlet of the moisture separation section (expressed as percent)

8. **MSR Shell:** The vessel containing the reheater(s) and the moisture separator section(s)

9. **Moisture Separator System:** The portion of the MS/R that removes the moisture from the cycle steam

10. **Pass (1-4):** The portion of the reheater section with respect to the number of times that heating steam flow is routed across the cycle steam flow path

11. **Pressure Drop (psi):** The difference in static pressure across the MS/R or its component

12. **Reheater:** The tube bundle portion(s) of the MSR used to transfer energy from the heating steam to the cycle steam

13. **Terminal Temperature Difference (F°):** The difference between heating steam saturation temperature at the reheater inlet and the cycle steam outlet temperature

APPENDIX B

Survey of Operating Plants

As part of the effort to prepare this MSR source book, a survey of the status of MSRs at nuclear plants was conducted via Plant Support Engineering's P^2EP network and follow-up phone calls. A copy of the survey form is contained in Table B-5, located at the back of this appendix. Data from the survey was entered into an EXCEL spreadsheet and used to develop the tabulation discussed below.

The survey forms sent out reached 73 plants covering 96 operating units, while the responses covered 30 plants with 43 operating units. The remainder of the survey data is reported on a per-plant basis.

Twelve of the plants providing data to the survey have single-stage MSRs, nine have two-stage MSRs, and seven have MSs. Fifteen plants report good overall performance of their MS/Rs, with the remainder split about evenly between indifferent and poor performance. The responses to the questions related to MWe loss due to MS/Rs was fairly consistent with the performance question, although a few indifferent and poor responders did not actually report missing MWe. Only 11 plants reported the amount of MWe losses due to MS/Rs. The range varies from 0.5 to 20 MWe with an average of 5.9 MWe for those plants quantifying a loss. This works out to be a total of 67 MWe for the 42 units accounted for in the survey.

Table B-1 describes the survey data related to operation of MS/Rs. Most of the plants are placing the HP heater into service during plant startup at reactor power levels in the range of 10 to 65% with an average of about 35%. During reactor shutdown, they are being removed at approximately the same power levels, for example, 35% if placed into service at 35%. Heatup rates average approximately 100F°/hr, with the maximum reported being 250F°/hr and the minimum reported being 50F°/hr. Table B-1 also describes data related to excess steam usage. Almost all the plants report using excess steam to minimize condensate oscillation. Most report the quantity of excess steam to be about 2% of heating steam flow. Only one plant reports reducing heating steam pressure as a way to increase plant output.

Table B-2 describes the variables being monitored by the plants for routine and special monitoring. Routine monitoring uses permanent instrumentation that is routinely monitored by plant personnel responsible for MS/R performance. Special monitoring might be once or infrequent and uses instrumentation that might be removed after the observations have been made. Many plants report routinely monitoring reheater outlet temperature with this variable being the only one monitored in many cases. Under special monitoring, several plants report having thermocouples in select tubes to determine if condensate oscillation is occurring. Table B-2 reports that PTC 12.4 is not being used by the plants to any extent in the operation and monitoring of the MSRs.

Table B-3 describes the extent and frequency of MS/R maintenance reported in the survey. Most plants are conducting visual inspections and doing routine maintenance on the process instrumentation and control systems every refueling outage (RFO) or every other RFO. Minor repairs and gasket and closures are being maintained at the same frequency or as required.

Table B-4 describes the improvements and modifications reported in the survey. Several have reported replacing tube bundles and/or installing a four-pass vent condenser. One reported replacing the heating steam pressure control valves with drag valves, which are more conducive to throttling duty. Several have installed thermocouples to monitor temperature on the outlet legs of the U-tubes.

Table B-1
MSR Survey Data

Plant	MSR Type SS=Single Stage TS=2 Stage MSO=MS only	What load is heater *Placed Into* service?	What load is heater *Removed From* service?	Heatup Rates Limits?	Describe How Heatup and Cooldown is Controlled	Does MSR Use Excess Steam?	If Yes, How Much? (PPH = Lbm/hr)	Excess Steam Flow Regulator	Throttle heating steam to increase output?
BRAIDWOOD	TS	35%		<100F/HR OR <50F STEPS	Control heating steam pressure	YES		ORIFICE	NO
BYRON	TS	35%	12%	100F/HR	Control heating steam pressure	YES	2%	ORIFICE	NO
CALLAWAY	TS	15%		125F/HR		YES		CTRL Vlv	NO
FITZPATRICK	TS	15%		<250F/HR	AOV	YES	10%		NO
GRAND GULF	TS	11% 1st Stage 15% 2nd Stage		100F/HR	Change controller setpoint	YES	1st-64K PPH 2nd-35K PPH	CTRL VLV	NOT USED
OCONEE	TS	20%		<50F/30 Min	Manual operation	YES	9% DESIGN 2.5%		NO
OYSTER CREEK	TS	70%	70%		Pressure regulator vlvs	NO			N/A
PALISADES	TS	30%	10%	100F/HR	Timed control vlv over 2 hrs	YES	50%	ORIFICE	
PERRY	TS	20% 1st Stage 65% 2nd Stage	20% 1st Stage 65% 2nd Stage	100F/HR	Control heating steam pressure	YES	1.3 PPH		N/A
SALEM	TS	48%	48%	100F/HR	Regulating main steam supply press.	NO			

Table B-1 (Continued)
MSR Survey Data

Plant	MSR Type SS=Single Stage TS=2 Stage MSO=MS only	What load is heater *Placed Into* service?	What load is heater *Removed From* service?	Heatup Rates Limits?	Describe How Heatup and Cooldown is Controlled	Does MSR Use Excess Steam?	If Yes, How Much? (PPH = Lbm/hr)	Excess Steam Flow Regulator	Throttle heating steam to increase output?
SEQUOYAH	TS	35%		100F/HR	Control heating steam pressure	YES	3%	Wide Open Ctrl Vlv	NO
COMANCHE PEAK	SS	N/A			3 air operated valves	YES	10,000 LB/HR		NO
CONN YANKEE	SS	10%	At turbine trip	100F/HR	Control heating steam pressure	YES	3000 LBM/HR	Ctrl Vlv	NO
GINNA	SS	30-35%		100F/HR	4 hour ramp	YES	10,000 LB/HR	ORIFICE	No benefit due to degraded steam pressure
KEWAUNEE	SS	35%	10%	100F/HR	Timed control valve	YES	2%		NO
MILLSTONE 3	SS	30%	30%	50F/HR	Controlling reheat steam supply	YES			NO
RIVERBEND	SS	15%	90%		Manual operation	YES	83,000 LB/HR	ORIFICE	Yes, 620 PSID instead of 920
ROBINSON	SS	10%	35%	100F/HR		YES	2%		NO
SOUTH TEXAS	SS	35%	Reduce htg steam to 425F at 10% - secure when tripped	100F/HR	Automatic control system	YES			N/A
SUMMER	SS	30%		50F/HR	Throttle heating steam flow	NO			Yes, 4th stage extraction steam
VOGTLE	SS	15%-65%	65-15%	125 F/HR	Regulating main steam supply press	YES		ORIFICE	NO
WATERFORD	SS	35%		100 F/HR	Automatic TCV	YES	7%	CTRL VLV	NO
ZION	SS	35%	35%	100F/HR	Valves open over 2 hours	YES	Design 2%	ORIFICE	
BROWNS FERRY	MSO	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
DRESDEN	MSO	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
INDIAN PT	MSO	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
LIMERICK	MSO	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
MONTICELLO	MSO	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
PEACH BOTTOM	MSO	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
TMI-1	MSO	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Table B-2
MSR Variables

Plant	MSR Variables Used for Routine Testing (See Codes below)							MSR Variables Used for Special Monitoring			ASME PTC 12.4 Used?
	1	2	3	4	5	6	OTHER	7	8	OTHER	
BRAIDWOOD	X	X	X	X		X	Drain tank normal control valve position				NO
BYRON	X		X	X		X					NO
CALLAWAY	X		X	X		X					NO
FITZPATRICK	X	X								One time test to detect condensate oscillation	
GRAND GULF	X	X	X	X			Drain flow rate, calculated excess steam flow rate				N/A
OCONEE	X		X	X		X	Several, see Note 1				NO
OYSTER CREEK	X	X	X		X	X					NO
PALISADES	X		X				Several, see Note 1				NO
PERRY	X	X		X							NO
SALEM	X						Cold reheat temp	Note 2			NO
SEQUOYAH	X	X							X	Drain temp	NO
COMANCHE PEAK	X	X		X		X	MS and reheater drain tank temperature		X		NO
CONN YANKEE	X			X	X				X		NO
GINNA	X			X	X	X					NO
KEWAUNEE		X	X								NO
MILLSTONE 3	X	X			X	X		X			YES
RIVERBEND	X			X			TTD				NO
ROBINSON	X	X									NO
SOUTH TEXAS	X	X	X	X		X		?		MS drain tank flow	NO
SUMMER	X	X	X				Inlet heating steam temp		X		NO
VOGTLE	X	X	X		X						
WATERFORD	X	X	X			X				Available data is trended	NO
ZION	X	X	X	X			Degree of superheat			Reheat flow and drain tank temp	YES
BROWNS FERRY											
DRESDEN											NO
INDIAN PT											NO
LIMERICK										MS DP and drain tank level	NO
MONTICELLO											NO
PEACH BOTTOM											NO
TMI-1										DP only	NO

Variable Codes:

1	Reheater outlet temperature	**5**	Excess steam flow
2	Heating steam flow	**6**	delta P
3	Reheat bundle drain temperature	**7**	Moisture separator carryover
4	Heating steam pressure	**8**	Reheater tube outlet temperatures

Notes:

Note 1 Variables measured include tube inlet/outlet temperatures, tube heating steam supply pressure, 1^{st}-stage inlet temperature, 2nd-stage reheat outlet temperature.

Note 2 Temporary lithium tracer test used to measure moisture carryover.

Table B-3
Extent, Frequency, and Key Features of MSR Maintenance

Plant	Visual Inspection	Minor Internal Repairs	Gaskets and Closures	Process Instrumentation	Heating Steam Pressure Control	Drain Tank Level Control Systems
BRAIDWOOD	Shell 18 Mos., Tube 36 Mos.	18 Mos.	36 Mos.	On failure		
BYRON	18 Mos.	18 Mos.	18 Mos.	36 Mos.	18 Mos.	18 Mos.
CALLAWAY	18 Mos.	18 Mos.	18 Mos.	18 Mos.	On demand	On demand
FITZPATRICK	Majors every other outage			When indication is suspect	Leakage repair	PMS
GRAND GULF	Every RFO 18 Mos.	18 Mos.	18 Mos.	Every refueling outage if not accessible during operation		Every RFO
OCONEE	Every RFO	Leak check bundles 2 bundles per RFO		As Needed		Every RFO
OYSTER CREEK	Every 2 RFOs	As Needed	Every 2 RFOs	Every RFO	Every RFO	Every RFO
PALISADES	4 Yr.	4 Yr.	Every 2 RFOs	Every 2 RFOs	N/A	Every 2 RFOs
PERRY	Every RFO	Every 2 RFOs	Every 2 RFOs	Every RFO	Every RFO	Every RFO
SALEM	Every RFO	Every RFO	Every RFO	Every RFO	Every RFO	Every RFO
SEQUOYAH	3 of 6 per outage	As Required	As Required	As Required	As Required	Refueling
COMANCHE PEAK	Every outage 18 Mos.	18 Mos.	18 Mos.	When necessary	N/A	When needed
GINNA	External 2 shift at a minimum	During refueling outages	18 Mos.	Minimal	Outage calibration	During unit startup maintenance increases
KEWAUNEE	Shell side crawl through, tube vac test	Weld connections, shroud wall cracks	Inspect gasket surfaces, replace	Yearly calibration		Yearly calibration
MILLSTONE 3	Every RFO	Every RFO	RFO or MSR closeout	Calibrate during RFO	Calibrate during RFO	Calibrate during RFO
RIVERBEND	Every 2 RFOs	As Required	Every RFO	18 Mos.	Operated in Manual	As Needed
ROBINSON	Every RFO	Every RFO	Every RFO	Every RFO	Every RFO	Every RFO
SOUTH TEXAS	Every RFO					
SUMMER		As Required	As Required	RFO	RFO	RFO
VOGTLE	36 Mos.	None, minor	36 Mos.	As Needed	As Needed	As Needed
WATERFORD	Every RFO	Every RFO	Every RFO	RFO and as needed	RFO and as needed	RFO and as needed
ZION	Refuel	Refuel	Refuel	3 Yr.	3 Yr.	3 Yr. As Needed
BROWNS FERRY	ASME Pressure Boundary Inspection			Periodic checks of hi-level turbine trips	N/A	LCV position failures recurring
DRESDEN		As Required	During maint	As Required	N/A	As Required
INDIAN PT	Every RFO	Every RFO	Every RFO	Every RFO	Every RFO	Every RFO
LIMERICK	6 Yr.	Minimal	6 Yr.	2 Yr.	N/A	2 Yr.
MONTICELLO	Every RFO			RFO	N/A	
PEACH BOTTOM	Once every 12 years	As Required	12 Yr.	2 Yr.	N/A	2 Yr.
TMI-1	Scheduled outages	As Needed	No problems	In and out press only every 5 years	N/A	2 year calib interval

Table B-4
MSR Improvements and Modifications

Plant	Replacement Tube Bundles	Four-Pass Heater Modification	MS Modifications	Control Systems	Process Inst.	Diagnostic Inst.	Pre-separators	Other
BRAIDWOOD			Perforated plates in front of chevrons			1st & 2nd stg heat stm flow		
BYRON	NONE NECESSARY	YES	YES	NO	NO	NO	NO	
CALLAWAY						0		
FITZPATRICK			Some baffle plates	Relocated HP heating stm for manual operation			N/A	
GRAND GULF	N/A	N/A		Replaced with infi-90 system in rf07 (drain tank level controls only)				
OCONEE	Replaced with Senior tube bundles	NO	NO	Currently evaluating	Needs work in PM/calib	NO	NO	
OYSTER CREEK	N/A							
PALISADES								
PERRY	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SALEM	Yes, to remove copper	Y	Increased drain piping diameter					
SEQUOYAH	Y		Added a plate before chevrons	Y		Internal temp & press		
COMANCHE PEAK	N/A	Before plant startup 3 MWe increase	N/A	N/A	NONE	NONE	NONE	N/A
CONN YANKEE	All 4 MSRs for reliability concerns	All 4 MSRs for reliability concerns	Replaced mesh separators with chevron separators			TTD, temp rise, tube pressure inst. added during mods	NONE	
GINNA	Yes - was warped and fouled tubes	Yes - when tubes replaced	Yes - pre-separators	Yes - two steam admission valves for finer control	N/A	N/A	Yes - reduce moisture content	
KEWAUNEE	Upgraded to 439 SS	Vent chambers installed	High capacity chevrons				NONE	
MILLSTONE 3	Yes 1-2 MWe gain	N/A	N/A	Modified for reliability	N/A	Installed T/Cs in tubes	N/A	N/A
RIVERBEND				Replaced ctrl vlvs with drag vlvs				
ROBINSON	From NiCu to SS tubes	Improved vent chamber	Mesh pads replaced w/chevrons	NONE	NONE	NONE	MOPS/ SCRUPS	N/A
SOUTH TEXAS	Replaced prior to 1st startup		Added orifice plates					
SUMMER	Original two-pass replaced by four- pass					Thermo-couple panel installed		
VOGTLE								
WATERFORD	20 MWe gain	Y	Added SS chevrons			Added HTG steam Venturi		

Table B-4 (Continued) MSR Improvements and Modifications

Plant	Replacement Tube Bundles	Four-Pass Heater Modification	MS Modifications	Control Systems	Process Inst.	Diagnostic Inst.	Pre-separators	Other
ZION	12 for 2 units		Peerless chevrons	NONE	Annular	NONE	NONE	NONE
BROWNS FERRY	N/A	N/A			Modified turbine trip logic from 1/1 to 2/3			
DRESDEN	N/A	N/A						
INDIAN PT	N/A	N/A						
LIMERICK	N/A	N/A	NONE	Converted dump valve control system to fail open	NONE	NONE	NO	N/A
MONTICELLO	N/A	N/A	Replaced vanes, gained 1-1.5 MWe	Would like to upgrade pneumatic level control w/ digital				
PEACH BOTTOM	N/A	N/A						
TMI-1	N/A	N/A	NONE	NONE	NONE	NONE	NONE	NONE

Table B-5
MSR Survey Form

PLANT SUPPORT ENGINEERING

EPRI
1300 Harris Blvd. ■
Charlotte ■ NC ■ 28262
(704) 547-6036 ■
Fax: (704) 547-6035

P²EP Survey #96-003 **2/23/96** **MSR Performance Survey**

Moisture separator reheaters(MSRs) are used in most nuclear power plants to improve turbine cycle efficiency and reduce moisture in the low pressure turbine cycle steam. Problems with MSRs have continued to plague the industry, resulting in lost MWe's and increased moisture in the LP turbine sections. The P²EP office is in the process of preparing an MSR Source Book for use by nuclear utilities. The objective of the Source Book is to provide nuclear utility personnel with a source of utility and vendor information related to MSR design, operations, maintenance, monitoring, troubleshooting, improvements and modifications that can be used to help optimize MSR performance and life cycle management.

==

General Information

1. Who was your MSR original equipment manufacturer:
   [ ] Westinghouse [ ] GE [ ] Other (specify) ______________
2. What was the TYPE of your original MSR?
   [ ] Single stage
   [ ] Two stage
   [ ] MS only (no reheater)
3. Overall, the performance of the plant MSRs has been:
   [ ] Good [ ] Indifferent [ ] Poor
4. Have MSR deficiencies contributed to a loss in MWe output?
   [ ] No [ ] Yes If Yes, estimate how much ______________
5. Does your plant have reports, procedures that could be included or referenced in the MSR Source Book? [ ] Yes [ ] No

==

Operations [ ] not applicable, MS only (no reheater)

6. At what load is the single or second stage heater
   placed into service: ______________
   removed from service? ______________
7. What are the heatup rates limits for the single or second stage heater?
   ____
8. Describe how heatup and cooldown is controlled: ______________
   ____
9. Does the MSR use venting or scavenging steam?
   [ ] No
   [ ] Yes If Yes:
   Describe how much flow ______________
   Where does excess flow go? ____ stage heater ___ condenser
   What is used to regulate flow? ____ orifice _____ control valve

10. Some plants have throttled single or second stage heating steam pressure and have concurrently increased MWe output. Is this technique to increase output being used at your plant? If so, describe the reduction in heating steam pressure _______________. ____ Has there been any adverse effect such as increased LP turbine moisture? ___________________________________.

==

Monitoring

11. Describe MSR variables and equipment that are for ***routine*** monitoring [ ] N/A to MS

[ ] Reheater outlet temperature
[ ] Heating steam flow
[ ] Reheat bundle drain temperature
[ ] Heating steam pressure
[ ] Excess steam flow
[ ] delta P
Other ____
____

12. Describe MSR variables and equipment used for **special** monitoring and **on-line trouble shooting**
Moisture separator carryover ____________________________
Reheater tube outlet temperature __________________________ [ ] N/A to MS
Other ____

13. Is the ASME test code for MSRs, PTC 12.4, used?
[ ] No
[ ] Yes If Yes, to what extent? ______________________

14. Are plant monitoring procedures available to include in the P^2EP reference library and in the Source Book in whole, in part or by reference?
[ ] No
[ ] Yes If Yes, please note their numbers below and send a copy to the P^2EP
____

==

Maintenance

15. Describe the extent, frequency and key features of MSR maintenance.

Visual inspections _________________________________
Minor internal repairs ______________________________
Gaskets and closures _______________________________
Process instrumentation _____________________________
Heating steam pressure control system __________________ [ ] N/A to MS
Drain tank level control systems ______________________

16. Are plant maintenance procedures available to include in the P^2EP Technical Library and the Source Book in whole, in part, or by reference? Y or N _____. If YES, note their numbers below and send a copy to the P^2EP office.
____

==

Improvements and Modifications

Approximately half of the nuclear plants with MSRs have incorporated improvements and modifications, some extensive and costly. The Source Book will be of most benefit if it can describe the industry experience with improvements and modifications.

17. For the plant's improvements and modifications provide descriptions, basis, justifications and economics, and benefits such as increased MWe actually occurring.
    Replacement tube bundles ________________________________ [ ] N/A to MS
    ____
    4-pass heater modifications ________________________________ [ ] N/A to MS
    ____
    Moisture separation modifications ________________________________
    ____
    Control systems ____
    ____
    Process instrumentation ____
    ____
    Diagnostic instrumentation ______________________________________
    ____
    Pre-separators ____
    ____
    Other ____
    ____

18. Is literature describing MSR modifications available to include in the P^2EP Technical Library and the Source Book in whole, in part or by reference?
    [ ] No
    [ ] Yes If Yes , note their numbers below and send a copy to the P^2EP office.
    ____

==

Miscellaneous

Attach or use the space below to describe any other information that may be important to the MSR Source Book project.

____
____
____

APPENDIX C

Sample Procedures

This appendix contains excerpts of general interest from the following operating and inspection procedures for MS/Rs:

- Ginna Station MSR Startup and Shutdown Procedures
  (Ginna is a ~470 MWe Westinghouse PWR with a Westinghouse supplied Turbine and MSRs)

- Limerick Generating Station Procedure for MS Internal Examination
  (Both Limerick units are ~1055 MWe GE BWRs with a GE supplied Turbine and MSs)

- Millstone Unit 3 MSR Operating Procedure
  (Millstone-3 is a ~1137 MWe Westinghouse PWR with a GE supplied Turbine and MSRs)

- Senior Engineering Company General MSR Operating Instructions

ABRIDGED VERSION OF GINNA STATION MSR STARTUP AND SHUTDOWN PROCEDURES

(Ginna is a ~470 MWe Westinghouse PWR with a Westinghouse supplied Turbine)

MSR STARTUP

5.7.6 At 100 MWe perform the following:

5.7.6.3 Close vents from the main steam to reheater piping to condenser.

Close MSR Main Steam vent isolation valve to Main Condenser A.

5.7.6.4 Open the following reheater warm-up valves:

Open Main Steam root warm-up valve to MSR 1A/1B and 2A/2B.

Open Main Steam warm-up isolation valves to MSRs.

5.8 Increasing Power from 30% to 100%

5.8.2 At 175 MWe (30%-35% reactor power) perform the following:

5.8.2.1 Check MSR Main Steam Control valves by ensuring blocking device run up AND opening MSR mini warm up steam isolation valves.

5.8.2.5 Open Reheater Steam Supply Line isolation valves.

5.8.2.6 Close the Reheater purge line isolation valves.

5.8.2.7 Switch Reheater high level dump valves from HAND (open) to AUTO.

NOTE: Max heat up of LP Turbine A and B inlet steam is 100°F/hr.

NOTE: Reheater high pressure steam pressure is read locally at the inlet to the reheater.

NOTE: Operation of Reheater Cam will increase reactor power, power increase limits should be observed, IF applicable.

Abridged Version of Ginna Station MSR Startup and Shutdown Procedures

5.8.3 Start timed opening of Reheater Steam Supply Auto valves. Reheater pressures should not exceed the following values:

85 psig for the first hour
170 psig for the second hour
310 psig for the third hour
525 psig for the fourth hour

AFTER FOUR HOURS: Full main steam pressure is permitted at the tubesheets. IF the above stated pressures are reached before the time limit specified, THEN stop the cam shaft UNTIL the hour has been completed.

5.8.4 WHEN reheater steam pressure is greater than crossunder steam pressure, THEN open excess steam line throttle valves.

5.8.5 WHEN Reheater Steam Supply Auto valves are full open, THEN shut off the timer on the Reheater Steam Supply controller.

5.8.6 Close MSR 2A and 2B reheater relief expansion drain valves.

MSR SHUTDOWN

5.5 Decrease from ~20% to ~35% MWe Generator Gross Output:

5.5.1 At ~50 MWe Gross Generator Load, perform the following:

5.5.1.1 Close reheater steam control valves by turning the cam on back of the MCB clockwise until level arm drops down. Verify reheater steam control valves indicate shut.

5.5.1.2 Switch reheater cond. dump valves from AUTO to HAND.

5.5.1.3 Perform the following steps to isolate the live steam from the reheaters:

Close reheater chain isolation.
Open reheater main steam vents to condenser.
Open main vent to condenser isolation valve.
Close reheater 4th pass temp control valves.

ABRIDGED VERSION OF LIMERICK GENERATING STATION PROCEDURE FOR MOISTURE SEPARATOR (MS) INTERNAL EXAMINATION

(Both Limerick units are ~1055 MWe GE BWRs with a GE supplied Turbine and MSs)

1.0 PURPOSE

This procedure provides instruction for the internal examination of the moisture separators, 10T-104 and 20T-104.

4.0 PREREQUISITES

4.2 This procedure requires welding in an ASME, Section VIII, Division I, system. All welding procedures, welder qualifications, non-destructive testing and examination, examination personnel qualifications and weld materials shall conform to the requirements of the ASME Boiler and Pressure Vessel code, Reference 3.3.3.

4.6 Prior to personnel entering the moisture separator, a confined space entry permit shall be obtained from Shift Supervision.

5.0 PRECAUTIONS

5.2 Solvent is used throughout this procedure to clean components. Ensure adequate ventilation is available. Smoking, open flame or hot work is prohibited in the work area while the solvent is in use. Do not dispose of this solvent through the drain system. Solvent and solvent soaked cloths must be disposed of in accordance with approved methods.

5.3 Welding shall be protected from all harmful effects and shall not be performed on wet surfaces.

5.4 Respiratory protection may be required. Contact Health Physics for the proper respirator.

5.5 Contact Health Physics prior to using solvent on contaminated surfaces.

5.6 Have Health Physics survey all contaminated or potentially contaminated tools prior to removal from the work area.

5.7 Sign and date Section 5.0 of the MDRF, Appendix D, to indicate awareness of these precautions.

7.0 PROCEDURE

NOTE

AT THE DISCRETION OF THE JOB LEADER, ONLY THOSE SECTIONS/STEPS OF THIS PROCEDURE NECESSARY TO ACCOMPLISH THE INTENDED

Abridged Version of Limerick Generating Station Procedure for Moisture Separator (MS) Internal Examination

MAINTENANCE NEED TO BE COMPLETED. ALL OTHER SECTIONS/STEPS SHALL BE MARKED N/A.

7.1 BREAK SEAL ON MANWAY DOORS AND OPEN DOORS

7.1.1 Erect scaffolding up to manway door

CAUTION

THE POTENTIAL FOR GENERATION OF AIRBORNE CONTAMINATION EXISTS IN THE SUCCEEDING STEPS.

CAUTION

THE FIREWATCH SHALL NOT BE TERMINATED UNTIL 30 MINUTES AFTER THE USE OF THE IGNITION SOURCE TO DETECT POSSIBLE SMOLDERING FIRES.

CAUTION

REMOVE ALL SOLVENTS FROM WORK AREA PRIOR TO BURNING/ WELDING/GRINDING

7.2 EXAMINATION OF MOISTURE SEPARATOR INTERNALS

NOTE

THE DEGREE AND METHOD OF CLEANING THE MOISTURE SEPARATOR INTERIOR SHALL BE SPECIFIED BY MAINTENANCE SUPERVISION AND HEALTH PHYSICS.

NOTE

MAINTENANCE SUPERVISION SHALL EXAMINE THE INTERIOR OF THE MOISTURE SEPARATOR AND DETERMINE WHAT REPAIRS ARE REQUIRED.

7.2.4 Examine the vessel walls for erosion, "tiger striping," cracked welds or other wear and damage.

7.2.5 Examine the moisture separator panels (Chevron plates) for wear or damage.

7.2.6 Examine the steam distributor for wear or damage.

7.2.7 Examine the manway door hinge arm assemblies for cracks or any other type of failure, and also for alignment.

7.2.8 Lubricate the hinge arm assemblies with anti-seize.

7.2.9 Remove the scaffolding from inside the moisture separators.

7.2.10 Perform a final examination of the interior of the moisture separator to ensure that all foreign material has been removed.

7.3 CLOSE AND SEAL MANWAY DOORS

ABRIDGED VERSION OF MILLSTONE 3 MSR OPERATING PROCEDURE

NOTE: **Figures referred to in the text below are not included in this abridged version.**

1. OBJECTIVE

1.1 To provide a procedure for startup, shutdown, normal and casualty operation of the Moisture Separator/Reheater System.

4. PLANT OPERATING REQUIREMENTS

4.1 The moisture separator drain tank must be available for operation whenever the turbine is expected to accept steam.

4.2 The moisture separator startup drain valves are provided to drain moisture from the MSR shell during turbine shutdown. They are closed on turbine startup at approximately 15% turbine load.

4.3 The moisture separator reheaters should not be placed in service when frequent startups and shutdowns are anticipated. Until such time as sustained loads >65% are anticipated, the MSRs should be left out of service. The MSRs should be started at approximately 30% turbine load.

4.4 All MSR drains should be directed to the main condenser hotwell until the plant has been operating at 50% load or greater for two hours and reheat has been in service for greater than 2 hours to allow potential contamination or crud buildup accumulation to be cleaned through the Condensate Demineralizer System prior to being fed into the steam generators.

5. PREREQUISITES

5.1 125 VDC control power available

5.3 Instrument air available for pneumatic valves and controls

5.4 Moisture separator vents and drains aligned

5.5 Moisture separator reheater vents and drains aligned

5.6 4,160 volt busses energized to supply power to the moisture separator drain pumps

5.7 Main Steam System in operation to provide reheater steam supply

5.8 Turbine plant component cooling water in operation and supplying the moisture separator drain pump(s)

6. PRECAUTIONS

6.1 It is important that steam temperature entering both sides of the low pressure (L.P.) turbine be the same. If these temperatures vary by

Abridged Version of Millstone 3 MSR Operating Procedure

more than 50°F, rotor rubbing may occur. Therefore, the steam supply valves to the reheater tube sections must be operated simultaneously.

6.2 Excessive thermal stressing of reheater tube sections will result if a heatup rate of 100°F/hr is exceeded, when started in "AUTOMATIC," or 50°F/hr is exceeded when started in "MANUAL."

6.3 Full reheat temperature at low turbine loads would result in overheating of the L.P. turbine (reheat temperature and windage losses). Reheat steam high load valves and reheat steam low load valves should be checked for proper automatic operation to preclude this possibility.

6.4 Symmetry of operation should be monitored as load is changed by observing steam pressures, flows and temperatures in the reheater tube bundles.

6.5 The startup drain valves associated with the MSR and crossaround piping should be left open whenever the unit is out of service and during startup and initial loading (but are closed during the HP turbine pressurization).

6.6 Scavenging steam flow must be maintained at all times when the associated tube bundle is in service.

6.7 The importance of early detection of reheater tube leaks is emphasized in order to avoid steam cutting within the tube bundle. Deviations of more than 5% above the operating curve for a particular reheater requires the reheaters be taken out of service until repairs are made. It is absolutely necessary leak detection readings be monitored frequently.

6.8 Until such time as sustained loads above 65 percent of full load are anticipated, the turbine should be operated non-reheat by leaving the reheaters out of service to minimize thermal cycling during frequent startups and shutdowns.

6.9 Expansion joints on the suction side of the moisture separator drain tank pumps are not designed to withstand pump discharge pressure. When isolating a drain tank pump for maintenance, the discharge valve should always be closed prior to closing the suction valve in order to avoid overpressurizing the expansion joint. When closing the suction valves, any increase on drain tank pump local discharge pressure indication should be considered evidence of discharge valve backleakage and the suction valve reopened until the backleakage is corrected.

Abridged Version of Millstone 3 MSR Operating Procedure

7. PROCEDURE

7.1 Place the Moisture Separator Drain Tank Pumps in Operation

7.1.1.1 Before placing the drain tank pump in operation:

a. Check that the plant has been operated at ≥50% load for at least 2 hours.

b. Check turbine power is >10% to satisfy the drain valve interlock.

c. Reset local drain valve to allow valves to go closed.

d. Check moisture separator drain tank level is ≥50%.

7.1.1.2 Close MSR drain tank pump discharge isolation valve.

7.1.1.3 Close MSR pump discharge isolation bypass valve.

7.1.1.4 Open MSR tank pump suction isolation valve.

7.1.1.5 Verify continuous suction and discharge vents aligned as follows:

Suction Vent - OpenDischarge Vent - Throttled

7.1.1.6 Locally check motor oil levels in the upper and lower reservoirs are filled to the "GAUGE MARK."

7.1.1.7 Locally place MSR drain tank normal level control valve in "MANUAL - CLOSED."

7.1.1.8 Start moisture separator drain pump

7.1.1.9 With pump operating properly on recirculation flow, slowly open MSR pump discharge isolation bypass to equalize and warm up the downstream piping.

7.1.1.10 After pressure has equalized across the pump discharge valve, open MSR drain tank pump discharge isolation valves.

7.1.1.11 Close MSR pump discharge isolation bypass valve.

7.1.1.12 Close MSR drain tank pump discharge vent.

7.1.1.13 Shift normal level control to "AUTO" as follows:

a. Verify level controller in "MANUAL" with the setpoint at 50% (local)

b. Slowly open control valve to lower level to 50%.

Abridged Version of Millstone 3 MSR Operating Procedure

c. Place in "AUTO."

7.1.1.14 Verify controller is maintaining ~50%

7.1.1.15 Verify normal system operation by confirming the following alarms do not exist:

- "MOIST SEP DRN TK A LEVEL HI"
- "MST SEP DRN TNK BKUP DRN OPEN"
- "MOIST SEP DRN TK A LEVEL LO"
- "MOIST SEP DRN PP AUTO TRIP/OVERCURRENT"

7.2 Remove the Moisture Separator Drain Tank Pumps from Operation

CAUTION

1. The moisture separator drain pumps should be stopped prior to turbine load dropping to 10%. The moisture separator drain tank high level drain control valve opens at 10% to drain the tank and maintain condenser vacuum in the shell of the MSR. The pump will AUTO TRIP on LOW tank level.

7.2.1.1 Close MSR drain tank pump discharge isolation valve.

7.2.1.2 Stop moisture separator drain pump.

7.2.1.3 Close level control valve as follows (local):

a. Place controller in "MANUAL."

b. Close controller.

7.3 Placing the MSR Reheaters In Service for Automatic Operation

NOTE

1. The reheaters are normally placed in service at approximately 30% of full turbine load.
2. During plant startup, the reference legs for the reheater drain tank level transmitters may flash and indicated level may go to 100%. This condition will clear as steam is admitted to the tank and the reference leg is filled by the condensing pot.

7.3.1 Establish the following initial conditions:

7.3.1.1 Verify the reheater steam supply drains are open.

7.3.1.2 Verify reheater drain tank vent to the condenser is open.

7.3.1.3 Locally verify reheater drain tank high level control valve controllers in "AUTO" and set for 80%.

7.3.1.4 Verify reheater drain tank level control valve controls in "MANUAL."

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> CAUTION
>
> MSR A and B reheater steam load valves must be OPENED simultaneously and reheater operation must be symmetric.

7.3.2 Warm-up reheaters as follows:

7.3.2.1 At approximately 15 psig crossaround pressure, verify MSR load control valves are set to 0% output.

> **NOTE**
>
> The system engineer may recommend adjusting controller outputs to achieve desired steam flow to MSR.

7.3.2.2 Open reheater steam low load valves to a controller output of 1%.

7.3.2.3 Simultaneously open A and B reheater steam supply bypass valves (local) to begin warm-up of the reheater tube bundle.

7.3.2.4 When pressure across valves has equalized to the extent possible, open the reheater steam supply isolation valves.

7.3.2.5 Close reheater steam supply bypass valves.

7.3.2.6 Adjust reheater steam low load valves to establish reheater steam flow of approximately 10,000 lb/hr.

7.3.2.7 Maintain power level steady for a minimum of 15 minutes while tube bundle is being warmed.

> **NOTE**
>
> Do not exceed a heatup rate of 10°F per 15 minutes while admitting steam to the reheater.
>
> Figures 9.1 and 9.2 are to be used to determine the point at which the reheaters are to soak.

7.3.3 Supply steam to reheater as follows:

7.3.3.1 At approximately 30% turbine load, slowly open reheater steam low load valves.

7.3.3.2 If necessary, slowly open reheater steam high load valves.

7.3.3.3 Maintain plant power and reheat steam supply steady for at least 30 minutes.

7.3.3.4 Refer to Figure 9.1 and adjust reheater steam supply pressure to the corresponding crossaround pressure.

7.3.3.5 Place flow controllers in "AUTOMATIC."

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7.3.3.6 If flow oscillations occur in tube bundle due to low turbine load conditions, perform the following:

a. Using manual control, reduce MSR reheat steam controller output until oscillations stop.

b. When turbine load conditions permit, restore controllers to "AUTO."

7.3.4 Check normal level control is established:

7.3.4.1 Check the following alarms not lit:

- "MOIST SEP RHT DRN TK A LEVEL HI/LO"
- "MOIST SEP RHE DRN TK B LEVEL HI/LO"
- "REHEATER DRAIN VALVE LEAKAGE"

7.3.5 Monitor the following parameters for symmetric operation of the MSR reheaters and for tube leak detection:

7.3.5.1 Turbine intermediate pressure against reheat steam supply pressure, follow Figure 9.1, MSR Reheat Steam Supply Pressure vs. Crossaround Pressure

7.3.5.2 Turbine intermediate pressure from computer points against reheat steam temperature and follow Figure 9.2, MSR Startup Temperature Curve, as turbine load is increased.

7.3.5.3 Reheater leak detection curves show normal values for MSR reheat tube detection monitoring between 30% and 100% power.

7.3.6 Open the first point feedwater heater scavenging steam valves.

7.3.7 Close reheater steam valves to the condenser.

7.3.8 Close the reheater steam supply drains.

7.4 Taking the MSR Reheaters Out of Service During Normal Turbine Shutdown

NOTE

Reheat flow control valves will not be fully closed until turbine load is approximately 20% to 25% corresponding to crossaround pressure of approximately 25 psig to 35 psig.

7.4.1 Verify reheat steam high load and low load valves closed.

7.4.2 Place MSR load controllers in "MANUAL" and set to 0% output.

7.4.3 Close reheater steam supply isolation valves.

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7.4.4 Open reheater steam supply line drains.

7.4.5 Open reheater scavenging steam valves to the condenser.

7.4.6 Close the first point feedwater heater scavenging steam valves.

7.5 Manually Placing the MSR Reheaters in Service During Power Ascension (30% - 65%)

CAUTION

- The preferred method of MSR STARTUP is to place reheat in service at as close to 30% as possible and permit MSR heatup during turbine loading.
- Great care must be taken to ensure heatup rates and temperature and pressure curves are followed to prevent damage to the MSRs. If these limits are not followed, adverse temperature gradients will be induced in the shell side structural components and the reheat tube bundle resulting in structural damage and leaking tubes.
- Excessive thermal stressing of reheater tube sections will result if a heatup rate of 50°F/hr is exceeded or if the MSR startup pressure and temperature curves are not adhered to.
- If steam supply pressure or reheat steam temperature vs. cross around pressure are off of the "curve," return to the "curve" slowly rather than with a step change.

7.5.1 Establish the following initial conditions:

7.5.1.1 Reheater steam supply valve, closed.

7.5.1.3 MSR load controller set to 0% output.

7.5.1.4 Reheater scavenging steam valve to the condenser, open.

7.5.1.6 Reheater steam supply drain valves, open.

7.5.1.10 Reheater drain tank high level drain valve controllers, in "AUTO" and adjusted for 80%.

7.5.1.11 Reheater drain tank normal level drain valve controllers in "MANUAL-CLOSED" with all normal level valves closed.

7.5.2 Warm-up reheater as follows:

7.5.2.1 Open reheater steam low load valves to a controller output of 1%.

7.5.2.2 Simultaneously open A and B reheater steam supply bypass valves (local) to begin warm-up of the reheater tube bundle.

7.5.2.3 When pressure across valves has equalized to the extent possible, open reheater steam supply isolation valves.

7.5.2.4 Close reheater steam supply bypass valves.

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7.5.2.5 Adjust reheater steam low load valves to establish reheater steam flow of approximately 10,000 lb/hr.

7.5.2.6 Maintain power level steady for a minimum of 15 minutes while tube bundle is being warmed.

7.5.3 Supply steam to reheater as follows:

NOTE

Do not exceed a heatup rate of 10°F per 15 minutes while admitting steam to the reheater.

Figures 9.1 and 9.2 are to be used to determine the point at which the reheaters are to soak.

7.5.3.1 At approximately 30% turbine load, slowly open reheater steam low load valves.

7.5.3.2 If necessary, slowly open reheater steam high load valves.

7.5.3.3 Maintain plant power and reheat steam supply steady for at least 30 minutes.

7.5.4 The reheater steam supply valves will be opened as follows:

CAUTION

- The reheater steam load valves must be operated simultaneously to prevent differential temperature between the two sides of the low pressure turbine reaching 50°F differential temperature.
- Full reheat temperature (approximately 500°F) at low turbine steam flows will result in overheating of the low pressure turbine.
- Do not exceed a 50°F/hr heatup rate in the reheater tube bundles.
- Do not exceed 250°F/hr temperature change on the LP turbine inlet.

7.5.4.5 Slowly raise MSR steam supply pressure and temperature to value based on crossaround pressures found in Figures 9.1 and 9.2.

7.5.5 When reheater steam supply pressure indicates approximately 300 psig or greater for at least two hours and the unit has operated at 50% or greater for two hours, perform the following valve operations:

7.5.5.1 Open the first point feedwater heater scavenging valves.

7.5.5.2 Close reheater steam valves to the condenser.

7.5.5.3 Close reheater steam supply drains.

7.5.6 Verify reheater steam load flow controllers output at 100%.

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7.5.7 If desired, place reheater steam load flow controllers to "AUTO."

7.6 Manually Placing the MSR Reheater in Service at Power >65%.

CAUTION

- The preferred method of MSR startup is to place reheat in service at lower power levels and permit MSR heatup during turbine loading.
- Excessive thermal stressing of the reheater tube sections will result if a heatup rate of 50°F/hr is exceeded.

7.6.1 Verify the following initial conditions:

7.6.1.1 Reheater steam supply valve, closed.

7.6.1.3 Verify MSR heating steam controller in "MANUAL," and set to 0% output.

7.6.1.4 Reheater scavenging steam valves to the condenser, open.

7.6.1.6 Reheater steam supply drain, open.

7.6.1.10 Reheater drain tank high level drain valve controllers, in "AUTO" and adjusted for 80%.

7.6.1.11 Reheater drain tank normal level drain valve controllers in "MANUAL-CLOSED" with all normal level valves closed.

7.6.2 Warm-up reheater as follows:

7.6.2.1 Open reheater steam low load valves to a controller output of 1%.

7.6.2.2 Simultaneously open A and B reheater steam supply bypass valves (local) to begin warm-up of the reheater tube bundle.

7.6.2.3 When pressure across valves has equalized to the extent possible, open reheater steam supply isolation valves.

7.6.2.4 Close A and B reheater steam supply bypass valves.

7.6.2.5 Adjust reheater steam low load valves to establish reheater steam flow of approximately 10,000 lb/hr.

7.6.2.6 Maintain power level steady for a minimum of 15 minutes while tube bundle is being warmed.

7.6.3 Supply steam to reheater as follows:

7.6.3.1 Slowly open reheater steam low load valves.

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7.6.3.2 If necessary, slowly open reheater steam high load valves.

7.6.3.3 After at least 30 minutes, slowly open reheater low load and high load valves, to increase reheater bundle heating steam temperature at a rate not greater than 10°F every 15 minutes.

CAUTION

IF the reheat was removed from service due to a tube leak, do not perform Section 7.9.

7.9 Operation of the MSRs Without Reheat Steam

7.9.1 Check for one of the following initial conditions:

- Reheaters removed from service.
- Turbine is off the line with reheat not in service.

7.9.2 Close reheater scavenging steam valves to the condenser.

7.9.3 Close first point feedwater heater scavenging steam valves.

7.9.4 Verify heating steam flow controllers set to 0% output.

7.9.5 Verify reheater steam load valves, closed.

7.9.6 Close reheater steam supply isolations.

7.9.7 Open reheater steam supply drain valves.

7.9.8 Close reheater drain tank normal level valve manual isolation valves.

7.9.9 If desired, fail open the reheater drain tanks high level dumps.

7.9.9.4 Place "CAUTION TAGS" on high level dump valve controller and reheater steam isolation valve to indicate that valve is failed open.

7.9.10 Verify the following annunciators lit to ensure tanks are drained:

- "MOIST SEP RHT DRN TK A LEVEL HI/LO"
- "MOIST SEP RHT DRN TK B LEVEL HI/LO"

7.9.11 If reheaters are to remain isolated during power operation, Open and TAGOUT breakers for the following:

7.9.11.1 Steam supply valves

7.9.11.2 Reheat steam valves to the condenser

7.9.11.3 Drains to the condenser.

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7.11 Identifying MSR Tube Leaks

NOTE

- Reheat steam flow during startup of the reheaters is a function of many factors other than tube leaks. these factors, such as a reheat steam control valve position, reheat drain flow to the main condenser, and the transitory nature at a startup should be analyzed before a tube leak is conclusively identified.
- Refer to Figures 9.3 through 9.8, MSR Tube Leak Detection Graphs, for an indication of MSR tube leaks.
- Figures 9.3 through 9.8, MSR Tube Leak Detection Graphs, are for use during steady state operation. the limits on the graphs are expected to be exceeded during transients.

7.11.1 Compare heating steam flow with crossaround pressure per Figures 9.3 - 9.8.

7.11.2 If the plot lies above the curve as indicated on Figure 9.3 - 9.8, the MSR with the potential leak has been identified.

7.11.3 Monitor the level in the associated MSR drain tank to ensure the Level Control System has not failed causing excessive steam flow through the high level dump to the condenser.

7.11.5 If the steam flow vs. crossaround pressure plot is greater than 5% above the baseline curve, immediately remove the MSR reheaters from service.

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3.0 OPERATING PROCEDURE

3.1 Start Up

The replacement bundles are compatible with the original MSR; however, certain improvements have been incorporated into their design. The original MSR supplier's turbine operating procedure for start up should be followed together with the additional requirements as indicated below:

3.1.1 The rate of load increase shall be in accordance with the turbine manufacturer's recommendation.

3.1.2 No specific heating steam flow control is required when putting the low pressure reheater bundle into service.

3.1.3 When putting the high pressure reheater bundle into service, the initial saturation temperature of the **heating steam** should not be lower, but nearly the same as the **cycle steam outlet** temperature (within 50F°) measured at the time before putting the high pressure reheater bundle into service.

3.1.4 The heating rate for the heating steam supply should not exceed 100°F per hour.

3.1.5 Such increase can be performed by either continuous gradual ramping or by step changes of not more than 25F° every 15 minutes.

3.1.6 The excess steam line should be open and remain open at all times when the heating steam flow control valves and shut-off valve are fully opened. The amount of excess steam to be vented should be approximately equal to the amount specified on the reheater bundle specification sheet.

3.2 Operating Problems

The replacement reheater bundle is a state-of-the-art equipment incorporating all the operating experience including the materials selection, thermo-hydraulic and mechanical design. With these, coupled with the improved design of the moisture separation section utilizing the High Capacity chevron vanes, the performance of the MSR is greatly improved. A useful and trouble-free operation is expected for the remaining life of the plant.

However, should the reheater fail to perform properly at the specified performance conditions, one or more of the following problems may exist:

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3.2.1 Insufficient venting or excessive condensate subcooling. Check for proper operation of the excess steam flow control valve.

3.2.2 Blocked or retarded drainage. Check for proper operation of the condensate drain control valves.

3.2.3 Mechanical damage of tubes and/or other components. Check for tube leaks, blown gaskets, etc.

3.3 Load Reduction and Shut Down

3.3.1 Anticipated Gradual Shut Down at Low Load Condition

The MSR bundle is not as susceptible to thermal stress at shutdown situation as it is at startup.

However, in order to avoid overheating the L.P. turbine casing metal, and to prevent excessive thermal gradient between the U-tube legs, it is recommended to remove the high pressure reheater bundle from service below 35% load.

3.3.2 Low Load Operating Condition

If the unit is to be held below 35% load for a long period, or a hot startup is anticipated, instead of removing the high pressure reheater bundle from service, the main steam flow control valve can be throttled down to decrease the cycle steam outlet temperature at the maximum rate of 100°F per hour or 25F° every 15 minutes until the cycle steam outlet temperature is lowered to 400°F where it may be maintained for the duration of the low load condition.

3.3.3 Total Shut Down

No additional procedures are required for shutting down the reheater. Follow procedures recommended by the original MSR manufacturer. If shutdown is going to last for an extended period, see Section 5.2 for extended outage protection.

3.4 Recommended Startup and Shutdown Procedure

Operating procedures for Moisture Separator Reheaters (MSRs) are outlined in this Appendix as Tables C-1 through C-9. A listing of the procedure titles is shown below.

These are generalized procedures based on the MSR Steam Supply Vents and Drains Valve System Diagram shown on Figure C-1. These procedures are intended as a supplement to the Original Equipment Manufacturer's Operating Procedures.

In the event of a conflict between these procedures and the Original Equipment Manufacturer's Operating Procedures or Turbine Operating

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Manual, the most stringent requirement should govern. If the Owner/Operator cannot determine the most stringent procedure, a clarification must be obtained, in writing from SENIOR Engineering Company prior to operating the MSRs. Should the power plant piping be different than the attached diagram, these procedures must be revised accordingly.

Table	Procedure for:
C-1	Activation of a Two Stage Four Pass Reheater Bundle for a Cold Turbine Start
C-2	Shutdown of a Two Stage Four Pass Reheater Bundle on a Turbine Shutdown
C-3	Startup of a Two Stage Four Pass Reheater Bundle for a Hot Turbine Start
C-4	Removal of a High Pressure (2nd Stage) Reheater Bundle from Service while Carrying Load on the Turbine
C-5	Return to Service of a High Pressure (2nd Stage) Reheater Bundle while Carrying Load on the Turbine
C-6	Removal of a Low Pressure (1st Stage) Reheater Bundle from Service while Carrying Load on the Turbine
C-7	Return to Service of a Low Pressure (1st Stage) Reheater Bundle while Carrying Load on the Turbine
C-8	Reheat Stop and Intercept Valve Testing for Two Stage Reheater Bundles
C-9	4th Pass Drain Control Valve Opening Adjustment for Single Line Discharge -(To be used in Conjunction with the Cold Turbine Start Procedure)

The tube bundles must be protected against rapid temperature changes from the heating steam. With manually operated valves (2CV-1S and 2CV-2S), the H.P. bundle heating steam temperature should not be varied more than 25°F every 30 minutes, as indicated in the attached tables. If the valves (2CV-1S and 2CV-2S) are gradually ramped with automatic controllers, temperature variations of up to 25°F every 15 minutes are permissible.

Purging of the tube bundles is required before the admission of heating steam. Each tube bundle must be supplied with adequate excess steam at all operating conditions. The excess steam is vented together with the 4th pass condensate through the 4th pass discharge line.

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The H.P. reheater bundle excess steam flow rate is controlled by valves 2V-4D and 2V-3D. The L.P. reheater bundle excess steam flow rate is controlled by valves 1V-4D and 1V-3D.

The valve 2V-4D should be set to the same opening with valve 2V-3D, and valve 1V-4D should be set to the same opening with valve 1V-3D. The L.P. reheater bundle excess steam control valve should be set first, followed by the setting of the H.P. reheater bundle excess steam control valve. For the first time installation, the valves opening should be set for the design full load condition. The final valves opening position should be set according to the operating procedure section: "Fourth Pass Drain Control Valve Opening Adjustment for Two Stage Four Pass Reheater Bundle."

Operation of the excess steam vent system must be periodically monitored. Inadequate steam venting should be immediately corrected.

It is mandatory that the drain and vents of the MSR be of adequate size. These peripheral systems should, in no way, restrict or impose on the performance of the MSR. Inadequate drainage and venting can cause premature tube failures and a deficient reheater bundle performance.

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Table C-1
Activation of a Two Stage Four Pass Reheater Bundle for a Cold Turbine Start

STEP NO.	CONDITION	VALVE SEQ. SHUT	VALVE SEQ. OPEN	REMARKS
Initial Condition	Zero load unit on turning gear.	2V-1S 2V-2S 2V-3S 2CV-1S 2CV-2S 2V-1D 2V-5D 1V-1D	1V-1S 2V-4S 2V-5S 2V-2D 2V-3D* 2V-4D 1V-2D 1V-3D* 1V-4D	Level Control Valves 1CV-1D, 1CV-2D, 2CV-1D and 2CV-2D in controlling mode (closed).
1	Turbine generator at 10% load		2V-3S	Maintain Valve 2V-3S open not less than 15 minutes prior to Step 2.
2	Turbine generator at 35% load	2V-5S 2V-4S	2V-2S 2CV-2S 2V-1S	Slowly, on a smooth ramp, start opening Valve 2CV-2S until the H.P. reheater bundle heating steam temperature reaches 50F° above the cycle steam **inlet** temp. (Open Valve 2CV-1S to achieve the required temperature, if necessary, after Valve 2CV-2S is fully opened.)
3	Thirty minutes after completion of Step 2		2CV-1S	Increase the H.P. reheater bundle heating steam temperature 25F° every 30 minutes, on a smooth ramp function, until Valves 2CV-2S and 2CV-1S are fully opened. (Do not violate Turbine Manufacturer's Requirements.)
4	When the cycle reheat steam outlet temp is greater than, or equal to, 400°F.	2V-2D 1V-2D	2V-1D 2V-5D 1V-1D	
Final Valve Lineup		2V-4S 2V-5S 2V-2D 1V-2D	1V-1S 2V-1S 2V-2S 2V-3S 2CV-1S 2CV-2S 2V-1D 2V-3D* 2V-4D 2V-5D 1V-1D 1V-3D* 1V-4D	Level Control Valves 1CV-1D and 2CV-1D in controlling mode (open). Level Control Valves 1CV-2D and 2CV-2D in controlling mode (closed).

** The opening of the Fourth Pass Drain Control Valves (1V-3D and 2V-3D) should be set in accordance with the attached procedure, "IX. Fourth Pass Control Valve Opening Adjustment for Single Line Discharge".*

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Table C-2
Shutdown of a Two Stage Four Pass Reheater Bundle on a Turbine Shutdown

STEP NO.	CONDITION	VALVE SEQ.		REMARKS
		SHUT	OPEN	
Initial Condition	Any load above 10% and the reheaters in full service	2V-4S 2V-5S 2V-2D 1V-2D	1V-1S 2V-1S 2V-2S 2V-3S 2CV-1S 2CV-2S 2V-1D 2V-3D 2V-4D 2V-5D 1V-1D 1V-3D 1V-4D	Level Control Valves 1CV-1D and 2CV-1D in controlling mode (open). Level Control Valves 1CV-2D and 2CV-2D in controlling mode (closed).
1A	Scheduled shutdown to total shedding of load and if unit will not be held below 35% load for longer than 15 minutes.			Remove the H.P. reheater bundle from service when load is reduced to 35% power. Go to Step 2. If hot startup is anticipated, follow Step 1B.
1B	Rapid unscheduled total shedding of load and if unit is to be held below 35% load for longer than 15 minutes.			Slowly and carefully throttle Valve 2CV-1S and Valve 2CV-2S, if necessary, to reduce the cycle steam **outlet** temperature to 400°F. Do not reduce the H.P. reheater bundle heating steam temperature more than 25°F/30 minutes. (Do not violate temperature change provisions of the Turbine Manufacturer.)
2	Trip and place unit on turning gear, maintaining condenser vacuum.	2V-1D 2V-5D 2CV-1S 2CV-2S		Valves 2V-1D and 2V-5D are closed to isolate the feedwater heaters from the steam pressure in the tube bundle. These valves must be closed promptly to avoid over-pressurization of the feedwater heaters. Close Valves 2CV-1S and 2CV-2S two minutes following the trip.

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Table C-2 (continued)
Shutdown of a Two Stage Four Pass Reheater Bundle on a Turbine Shutdown

STEP NO.	CONDITION	VALVE SEQ.		REMARKS
		SHUT	OPEN	
Final Valve Lineup (Hot start anticipated)		2V-4S 2V-5S 2V-1D 2V-2D 2V-5D 1V-2D 2CV-1S 2CV-2S	1V-1S 2V-1S 2V-2S 2V-3S 2V-3D 2V-4D 1V-1D 1V-3D 1V-4D	
Final Valve Lineup (Cold start anticipated)		2V-1S 2V-2S 2V-3S 2CV-1S 2CV-2S 2V-1D 2V-5D 1V-1D	1V-1S 2V-4S 2V-5S 2V-2D 2V-3D 2V-4D 1V-2D 1V-3D 1V-4D	Valves may be repositioned from the "Hot start anticipated (final Valve Lineup)" in any convenient sequence. Be sure to relieve pressure from tube bundle prior to removing manway cover.

If a reheater is to be opened to atmosphere, during an outage which would normally allow a Turbine Hot Start, the above procedure should not be followed. Instead, the L.P. turbine must be cooled prior to the shutdown and the Cold Start Procedure must be followed.

Remove the reheater from service, per Procedure IV, while dropping the turbine generator load to below 20%. Allow a minimum cooling period of one (1) hour at 20% load before complete shutdown of the turbine generator system. The unit must not be restarted until the L.P. turbine inlet metal temperature drops below 300°F. Startup must be in accordance with the Turbine Cold Start Procedure I.

In order that the hot start procedure can be applied when the reheater has been opened to atmosphere which may cause the tubesheet to be cooled down to below 400°F, the reheater must be rapidly and smoothly repressurized to a saturated steam temperature equal to the reheater tubesheet temperature, and then smoothly ramped up at the rate of 25 F° per 15 minutes until the saturated heating steam temperature is still 50 F° above the L.P. turbine inlet metal temperature, while the L.P. turbine is still at 500 RPM. After the reheater is at 50 F° above the L.P. turbine inlet metal temperature, and the requirements of the Turbine Manufacturer's operating procedures have been met, continue to follow the hot start procedure as outlined on "III. Startup of a Two Stage Four Pass Reheater Bundle for a Turbine Generator Hot Start."

The thermocouples number 22 and 23 installed on the 1st pass in the hemihead can be used to measure the reheater tubesheet temperature.

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Table C-3
Startup of a Two Stage Four Pass Reheater Bundle for a Hot Turbine Start

STEP NO.	CONDITION	VALVE SEQ.		REMARKS
		SHUT	OPEN	
Initial Condition	Unit on turning gear	2V-4S 2V-5S 2V-1D 2V-2D 2V-5D 1V-2D 2CV-1S 2CV-2S	1V-1S 2V-1S 2V-2S 2V-3S 2V-3D 2V-4D 1V-1D 1V-3D 1V-4D	Level Control Valves 1CV-1D, 1CV-2D, 2CV-1D and 2CV-2D in controlling mode.
1	At 600 RPM		2CV-2S 2CV-1S	Slowly, on a smooth ramp, start opening Valve 2CV-2S (and Valve 2CV-1S, if necessary, after Valve 2CV-2S is fully opened), to achieve hot reheat steam outlet temperature of 400°F.
2	Two hours following completion of Step 1 (see remarks)		2V-2D	Skip this step and go to Step 3 if 35% load has been achieved in less than two hours following completion of Step 1.
3	At 35% load	2V-2D	2V-1D 2V-5D	Open Valve 2CV-2S (and Valve 2CV-1S, if necessary, after Valve 2CV-2S is fully opened) slowly and carefully at a rate so that the H.P. reheater bundle heating steam temperature does not rise more than 25°F/30 minutes on a smooth ramp function until Valve 2CV-1S is fully opened. (Do not violate Turbine Manufacturer's Requirements.)
Final Valve Lineup		2V-4S 2V-5S 2V-2D 1V-2D	1V-1S 2V-1S 2V-2S 2V-3S 2CV-1S 2CV-2S 2V-1D 2V-3D 2V-4D 2V-5D 1V-1D 1V-3D 1V-4D	Level Control Valves 1CV-1D and 2CV-1D in controlling mode (open). Level Control Valves 1CV-2D and 2CV-1D in controlling mode (closed).

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Table C-4
Removal of a High Pressure (2nd Stage) Reheater Bundle from Service while Carrying Load on the Turbine

STEP NO.	CONDITION	VALVE SEQ. SHUT	VALVE SEQ. OPEN	REMARKS
Initial Condition	Both reheaters in full service at any load.	2V-4S 2V-5S 2V-2D 1V-2D	1V-1S 2V-1S 2V-2S 2V-3S 2CV-1S 2CV-2S 2V-1D 2V-3D 2V-4D 2V-5D 1V-1D 1V-3D 1V-4D	Level Control Valves 1CV-1D and 2CV-1D in controlling mode (open). Level Control Valves 1CV-2D and 2CV-2D in controlling mode (closed).
1		2CV-1S 2CV-2S 2V-3S		Slowly and carefully close Valves 2CV-1S and 2CV-2S at a rate so that the H.P. reheater bundle heating steam temperature is not reduced more that 25°F/30 minutes, on a smooth ramp function. (Do not violate Turbine Manufacturer's Requirements.)
2		2V-1S 2V-2S 2V-1D 2V-5D		Isolate the second stage reheater bundle from the feedwater heater.
3			2V-4S 2V-5S	Second stage reheater bundle is now isolated from heating steam.
Final Valve Lineup		2V-1S 2V-2S 2V-3S 2CV-1S 2CV-2S 2V-1D 2V-2D 2V-5D 1V-2D	1V-1S 2V-4S 2V-5S 2V-3D 2V-4D 1V-1D 1V-3D 1V-4D	Level Control Valves 1CV-1D and 2CV-1D in controlling mode (open). Level Control Valves 1CV-2D and 2CV-2D in controlling mode (closed).

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Table C-5
Return to Service of a High Pressure (2nd Stage) Reheater Bundle while Carrying Load on the Turbine

STEP NO.	CONDITION	VALVE SEQ.		REMARKS
		SHUT	OPEN	
Initial Condition	H.P. reheater (second stage) bundle out of service at any load above 10%.	2V-1S 2V-2S 2V-3S 2CV-1S 2CV-2S 2V-1D 2V-2D 2V-5D 1V-2D	1V-1S 2V-4S 2V-5S 2V-3D 2V-4D 1V-1D 1V-3D 1V-4D	Level Control Valves 1CV-1D and 2CV-1D in controlling mode (open). Level Control Valves 1CV-2D and 2CV-2D in controlling mode (closed).
1			2V-2D 2V-3S	Maintain Valve 2V-3S open not less than 15 minutes prior to Step 2.
2		2V-5S	2V-2S 2CV-2S	Slowly and carefully open Valve 2CV-2S until the H.P. reheater bundle heating steam temperature reaches 50°F above the cycle steam **inlet** temperature. (Open Valve 2CV-1S to achieve the required temperature, if necessary, after Valve 2CV-2S is fully opened.)
3	Thirty minutes following completion of Step 2	2CV-4S	2V-1S 2CV-1S	Increase the H.P. reheater bundle heating steam temperature 25°F every 30 minutes, on a smooth ramp function, until Valves 2CV-2S and 2CV-1S are fully opened. (Do not violate Turbine Manufacturer's Requirements.)
4	When the cycle reheat steam **outlet** temperature from the affected reheater is greater than, or equal to, 450°F.	2V-2D	2V-1D 2V-5D	Switch venting from condenser to feedwater heater.
Final Valve Lineup		2V-4S 2V-5S 2V-2D 1V-2D	1V-1S 2V-1S 2V-2S 2V-3S 2CV-1S 2CV-2S 2V-1D 2V-3D 2V-4D 2V-5D 1V-1D 1V-3D 1V-4D	Level Control Valves 1CV-1D and 2CV-1D in controlling mode (open). Level Control Valves 1CV-2D and 2CV-2D in controlling mode (closed).

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Table C-6
Removal of a Low Pressure (1st Stage) Reheater Bundle from Service while Carrying Load on the Turbine

STEP NO.	CONDITION	VALVE SEQ.		REMARKS
		SHUT	OPEN	
Initial Condition	Both reheaters are in service at any load above 10%.	2V-4S 2V-5S 2V-2D 1V-2D	1V-1S 1V-1S 2V-2S 2V-3S 2CV-1S 2CV-2S 2V-1D 2V-3D 2V-4D 2V-5D 1V-1D 1V-3D 1V-4D	Level Control Valves 1CV-1D and 2CV-1D in controlling mode (open). Level Control Valves 1CV-2D and 2CV-2D in controlling mode (closed).
1		2V-1D 2V-5D	2V-2D	Switch the H.P. reheater bundle venting to condenser in preparation for lower operating pressure.
2		2CV-1S 2CV-2S		Throttle down Valve 2CV-1S first and, if necessary, Valve 2CV-2S, until the H.P. reheater bundle heating steam temperature is equal to the L.P. reheater bundle heating steam temperature. In effect, the H.P. (second stage) reheater bundle will now perform as a L.P. (first stage) reheater tube bundle and will not be overloaded. Do not reduce the H.P. reheater bundle heating steam temperature more than 25°F/30 minutes.
3		1V-1S 1V-1D		Isolate the low pressure bundle.

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Table C-6 (continued)
Removal of a Low Pressure (1st Stage) Reheater Bundle from Service while Carrying Load on the Turbine

STEP NO.	CONDITION	VALVE SEQ. SHUT	VALVE SEQ. OPEN	REMARKS
4**	Thirty minutes following completion of Step 3.			Increase the H.P. reheater bundle heating steam temperature 25°F on a smooth ramp function. Continue to increase the H.P. reheater bundle heating steam temperature 25°F every 30 minutes, on a smooth ramp function, until Valves 2CV-1S and 2CV-2S are fully opened. (Do not violate Turbine Manufacturer's Requirements.)
5	When the cycle reheat steam **outlet** temperature of the affected MSR is greater than, or equal to, 450°F.	2V-2D	2V-1D 2V-5D	Switch the H.P. reheater bundle drain and vent from the condenser back to the feedwater heater.
Final Valve Lineup		1V-1S 2V-4S 2V-5S 2V-2D 1V-1D 1V-2D	2V-1S 2V-2S 2V-3S 2CV-1S 2CV-2S 2V-1D 2V-3D 2V-4D 1V-3D 1V-4D	Level Control Valve 2CV-1D in control mode (open). Level Control Valves 1CV-1D, 1CV-2D, and 2CV-2D in control mode (closed).

*** When Valves 2CV-1S and 2CV-2S are fully opened, the heat duty of the H.P. reheater bundle will be increased. Do not perform Step 4 before verifying the adequacy of the 2nd Pass Flow Control Valve (2CV-1D) size.*

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Table C-7
Return to Service of a Low Pressure (1st Stage) Reheater Bundle while Carrying Load on the Turbine

STEP NO.	CONDITION	VALVE SEQ.		REMARKS
		SHUT	OPEN	
Initial Condition	The L.P. (first stage) reheater bundle out of service at any load above 10%.	2V-1S 2V-4S 2V-5S 2V-2D 1V-1D 1V-2D	2V-1S 2V-2S 2V-3S 2CV-1S 2CV-2S 2V-1D 1V-3D 2V-4D 2V-5D 1V-3D 1V-4D	Level Control Valves 1CV-1D, 1CV-2D and 2CV-2D in controlling mode (closed). Level Control Valve 2CV-1D in controlling mode (open).
1			1V-2D	
2			1V-1S	Slowly open Valve 1V-1S.
3		1V-2D	1V-1D	
Final Valve Lineup		2V-4S 2V-5S 2V-2D 1V-2D	1V-1S 2V-1S 2V-2S 2V-3S 2CV-1S 2CV-2S 2V-1D 2V-3D 2V-4D 2V-5D 1V-1D 1V-3D 1V-4D	Level Control Valves 1CV-1D and 2CV-1D in controlling mode (open). Level Control Valves 1CV-2D and 2CV-2D in controlling mode (closed).

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Table C-8
Reheat Stop and Intercept Valve Testing for Two Stage Reheater Bundles

STEP NO.	CONDITION	VALVE SEQ.		REMARKS
		SHUT	OPEN	
Initial Condition	All reheater bundles are in service at any load above 10%.	2V-4S 2V-5S 2V-2D 1V-2D	1V-1S 2V-1S 2V-2S 2V-3S 2CV-1S 2CV-2S 2V-1D 2V-3D 2V-4D 2V-5D 1V-1D 1V-3D 1V-4D	Level Control Valves 1CV-1D and 2CV-1D are in controlling mode (open). Level Control Valves 1CV-2D and 2CV-2D are in controlling mode (closed).
1	Turbine generator at any load above 10%.			Exercise individual reheat stop and intercept valve combinations, in accordance with the approved Valve Test Procedure. Observe all high level indications of reheater drains and take immediate corrective action as required to assure bundles do not become flooded.
Final Valve Lineup		2V-4S 2V-5S 2V-2D 1V-2D	1V-1S 2V-1S 2V-2S 2V-3S 2CV-1S 2CV-2S 2V-1D 2V-3D 2V-4D 2V-5D 1V-1D 1V-3D 1V-4D	Level Control Valves 1CV-1D and 2CV-1D in controlling mode (open). Level Control Valves 1CV-2D and 2CV-2D in controlling mode (closed).

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Table C-9
4th Pass Drain Control Valve Opening Adjustment for Single Line Discharge - (To be used in Conjunction with the Cold Turbine Start Procedure)

STEP NO.	CONDITION	VALVE SEQ.		REMARKS
		SHUT	OPEN	
Initial Condition	Zero load, unit on turning gear.	2V-1S 2V-2S 2V-3S 2CV-1S 2CV-2S 2V-1D 2V-5D 1V-1D	1V-1S 2V-4S 2V-5S 2V-2D 2V-3D 2V-4D 1V-2D 1V-3D 1V-4D	Level Control Valves 1CV-1D, 1CV-2D, 2CV-1D and 2CV-2D in controlling mode (closed). Valves 2V-3D and 1V-3D should be at design full load opening position.
1	Turbine generator at 10% load.		2V-3S	Maintain Valve 2V-3S open not less than 15 minutes prior to Step 2.
2	Turbine generator at 35% load.	2V-5S 2V-4S	2V-2S 2CV-2S 1V-1S	Slowly, on a smooth ramp, start opening Valve 2CV-2S until the H.P. reheater bundle heating steam temperature reaches 50°F above the cycle steam **inlet** temperature. (Open Valve 2CV-1S to achieve the required temperature, if necessary, after Valve 2CV-2S is fully opened.)
3	Thirty minutes following completion of Step 2.		2CV-1S	Increase the H.P. reheater bundle heating steam temperature 25°F every 30 minutes, on a smooth ramp, until the Valves 2CV-2S and 2CV-1S are fully opened. (Do not violate Turbine Manufacturer's Requirements.)
4	When the cycle reheat steam **outlet** temperature is greater than, or equal to, 400°F.	2V-2D 1V-2D	2V-1D 2V-5D 1V-1D	

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Table C-9 (continued)
4th Pass Drain Control Valve Opening Adjustment for Single Line Discharge - (To be used in Conjunction with the Cold Turbine Start Procedure)

STEP NO.	CONDITION	VALVE SEQ.		REMARKS
		SHUT	OPEN	
5	When the turbine is operating at full load.			Adjust Valve 1V-3D opening position so that the temperature readings of the thermocouples in the L.P. reheater bundle hemihead are within the 50F° subcooling range. Then adjust Valve 2V-3D opening position so that the temperature readings of the thermocouples in the H.P. reheater bundle hemihead are within the 50F° subcooling range. Set the Valves 2V-4D and 1V-4D to the same opening of the Valves 2V-3D and 1V-3D, respectively. The valve positions shall then be fixed permanently by locking the handwheel of the valves.
Final Valve Lineup		2V-4S 2V-5S 2V-2D 1V-2D	1V-1S 2V-1S 2V-2S 2V-3S 2CV-1S 2CV-2S 2V-1D 2V-3D* 2V-4D 2V-5D 1V-1D 1V-3D* 1V-4D	Level Control Valves 1CV-1D and 2CV-1D in controlling mode (open). Level Control Valves 1CV-2D and 2CV-2D in controlling mode (closed).

* *The opening of the Fourth Pass Drain Control Valves 1V-3D and 2V-3D should be set in accordance with this procedure, "Fourth Pass Drain Control Valve Opening Adjustment for Two Stage Four Pass Reheater Bundle Procedure."*

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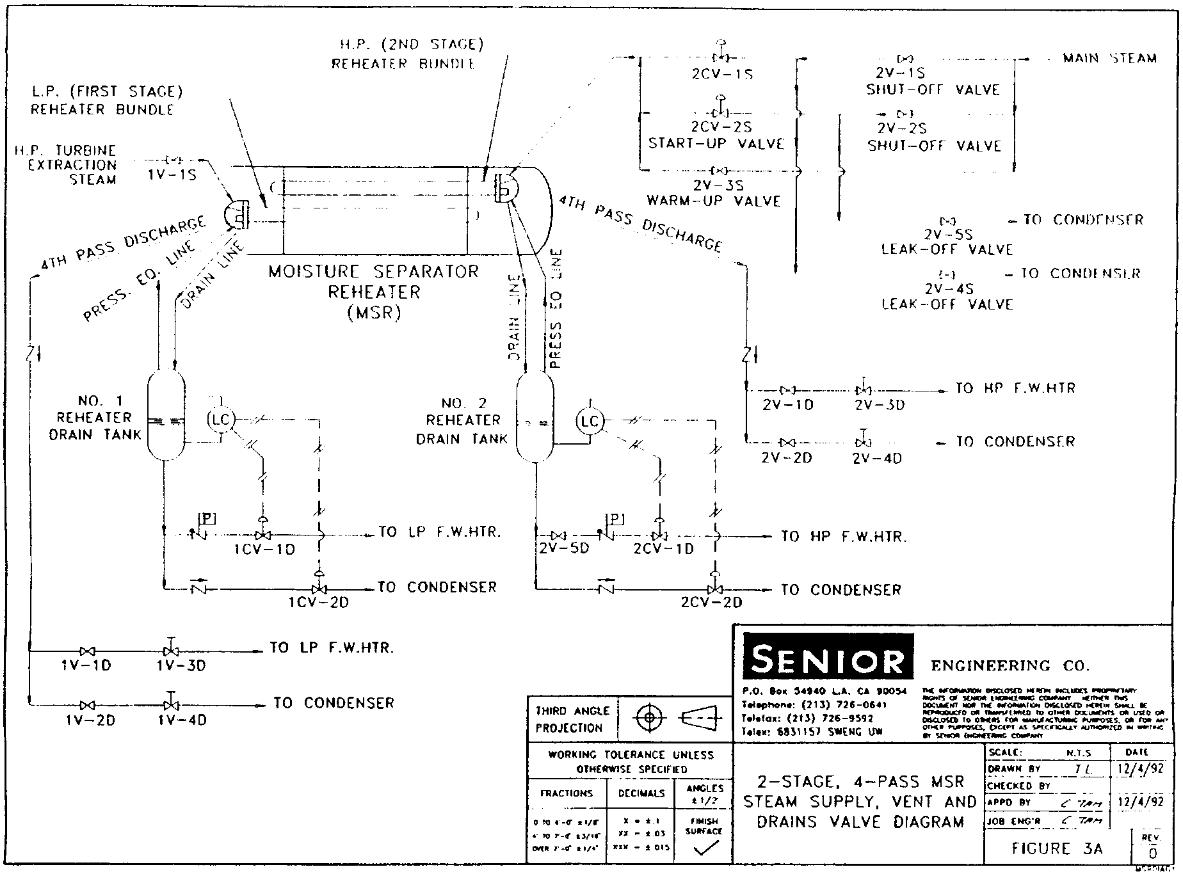


Figure C-1
MSR Steam Supply Vents and Drains Valve System Diagram

APPENDIX D

Bibliography and Abstracts of Selected Technical Papers

Numerous technical papers have been published on the subject of Moisture Separator Reheaters, many of which deal with subject matter covered in this report. This appendix contains abstracts of some of these MSR technical papers.

Procurement and Operation Considerations for Moisture Separator Reheaters. Electric Power Research Institute, Palo Alto, CA: September 1984. Report NP-3692.

This document is intended to assist utility personnel in the procurement and operation of MSRs and in the evaluation of MSR problems. The document should be used as a supplement to operation procedures and maintenance guides provided by the MSR vendor. A brief description of MSR design features is included along with recommendations for procurement of new or replacement MSRs and for operation of MSRs.

Evaluation of a Moisture Removal Device for Turbine Steam Piping. Electric Power Research Institute, Palo Alto, CA: April 1985. Report NP-3927.

This document evaluates retrofitting the high pressure turbine (HPT) exhaust crossaround piping in typical domestic nuclear power plants with a high velocity separator (HVS). It is primarily intended to determine whether such devices can be physically installed in existing plants, at what cost, and with what effect on performance.

It was concluded that it is feasible to install the HVS in typical domestic nuclear turbine cycles, and that for all studied conditions, its application is beneficial to the heat rate. In addition, the improvement in moisture separation effectiveness mitigates erosion/corrosion in crossaround systems which has become a significant industry problem. The approximate capital cost of the installation is $2.0 million. An additional expense for decontamination and storage of radioactive material must be considered in the case of the BWR cycle.

R. L. Colt, P. D. Ritland, T. J. Rabas, P. W. Viscovich, "Moisture Separator-Reheaters Entering the Second Decade", Westinghouse Publication.

This paper describes how MSRs work, why they are used and the design evolution of MSRs from 1965 to 1975. The paper describes operating experience during this time period, as well as the problems identified and their remedies. These include:

- Reheater startup: uneven heatup and differential thermal expansion of the tubes causing cocking and binding of the lower U-tube legs at the supports near the U-bend.
- Tube vibration: Tube damage has occurred due to high cycle steam velocity especially when velocity increases during intercept valve testing.
- Reheater drainage; intermittent flooding of tubes due to a "manometer effect" caused by draining two MSRs to a common tank.
- Individual tube flooding: the condensate oscillation phenomenon.

"Reconstruction of the MSRs in-situ at Beaver Valley." *Nuclear Engineering International,* October 1992, p.49.

This paper describes extensive modification made to MSRs in 1984 and 1991. Modifications included:

- Improvements to the chevron vane separator: more drain holes in the chevron vane bottom support plate to improve draining and perforated plates at the entrance to the chevrons to improve distribution.
- Tube bundle supports to prevent tube bundle lifting.
- Installation of a four pass scavenging steam vent system in 1984 and further improvements in 1991.

The paper also describes development testing and analysis conducted by Senior Engineering prior to the modifications and post-installation testing at the plant.

J. L. Kratz, P. G. Minard, and P. W. Bird, "Moisture Separator Reheaters - Entering the Third Decade," Presented at the ASME Joint Power Conference, Toronto, Canada, (October 1984).

This paper describes operating experience up to 1984, as well as the problems identified and their remedies. These include:

- Tube material: replacement of CuNi and carbon steel with modified 439 stainless steel.
- Condensate subcooling or oscillation: change to a scavenging steam vent condenser design.
- Tube expansion: minimize tube binding during thermal expansion by using "hourglass" shape holes in the tube supports near the U-bends.
- Moisture separator improvements: use chevrons, perforated plates to improve inlet steam distribution, and deck plates to prevent re-entrainment.
- Minimization of flow bypass: prevent bypass of cycle steam around the tube bundle by using seal strips.
- Optimized tube bundles: utilize space to the sides of the existing bundles.

S. Lemezis, J. R. Bushy, and T. J. Rabas, "Progress in Moisture Separator Reheaters for Nuclear Power Plants," Presented at the American Power Conference, Chicago, IL, (April 22-24, 1969).

This report describes some of the problems that were recognized and evaluated when designing the first generation of Westinghouse MSRs.

V. F. Rubano, A. J. Ugelow, and A. G. Menocal, "MSR Performance Enhancements and Modifications at St. Lucie Power Plant," Presented at the American Power Conference, (location and date unknown).

This paper describes the evolution of the changes made to the St. Lucie Nuclear Power Plant MSR. The original design consisted of carbon steel moisture separator chevrons and two-pass CuNi reheater tube bundles without scavenging steam. The final redesign consisted of stainless steel chevrons with perforated plates and four-pass enlarged stainless steel tube bundles.

A. L. Yarden, C. W. Tam, J. D. Benes, and W. E. Arnold., "MSR Redesign and Reconstruction at Indiana Michigan Power Company's Donald C. Cook Nuclear Power Plant, Unit 1," Presented at the American Power Conference, (location and date unknown).

This paper highlights the problems and solutions associated respectively with the original reheaters in the Donald C. Cook Nuclear Plant Unit 1 MSRs and their recent redesign, reconstruction, and performance. The principal design changes were:

- Replacement of CuNi tubes with Type 439 stainless steel tubes
- Change to a four-pass tube bundle
- Seal bars to prevent cold steam bypass
- Perforated plates upstream of the chevrons

"The MSR Evolution." *Nuclear Engineering International*, December 1994, p.44.

This paper describes the key modifications made to MSRs at several plants. Options described include:

- Using Type 439 stainless steel finned tubes with 27 fins/inch
- High performance four-pass or improved two-pass tube arrangements, the latter using individual tube flow restrictors to balance heating steam flow to each tube consistent with heat load and tube location
- Larger tube bundles with more tubes
- Tube support designs that reduce the effect of tube leg differential thermal expansion
- Replacing gaskets with channels welded to the tube sheets
- High-performance Type 430 stainless steel chevron moisture separators

A. L. Yarden, and M. W. Thomas, "MSR Performance Improvement at Prairie Island Nuclear Station," Presented at the EPRI Nuclear Plant Performance Seminar, Scottsdale, AZ, (May 10-11, 1993).

This paper provides a detailed discussion of an extensive redesign and reconstruction of the Prairie Island Nuclear Power Station MSRs. Prior to the changes, the MSR had wire mesh demisters and carbon steel tubes that had been converted to the four-pass design by the OEM. The modifications were done in two phases. Phase I replaced the wire mesh with high performance stainless steel chevron type separators. Modifications were also made to reduce inlet cycle steam velocity and localized high velocity streams, and to enhance the collection of separated moisture and prevent re-entrainment in the dried steam. Phase II consisted of replacing the tube bundle with stainless steel Type 439 tubes and increasing the number of tubes by using space available in the MSR shell. The paper notes a 5.3 MWe, or approximately 1% gain in generator output as a result of the redesign.

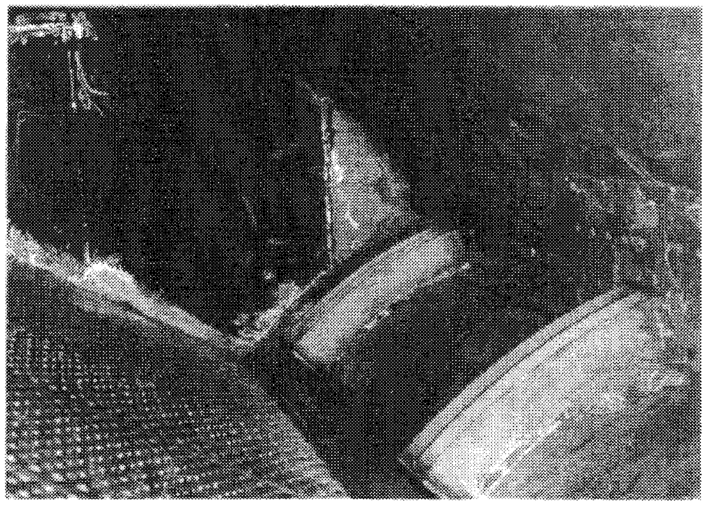
A. L. Yarden, and R. R. Noe, "Improvement in Performance and Availability of Currently Operating MSRs," Paper 80-JPGC/PWR-12, presented at the ASME Joint Power Generation Conference, Phoenix, AZ, (September 28 - October 2, 1980).

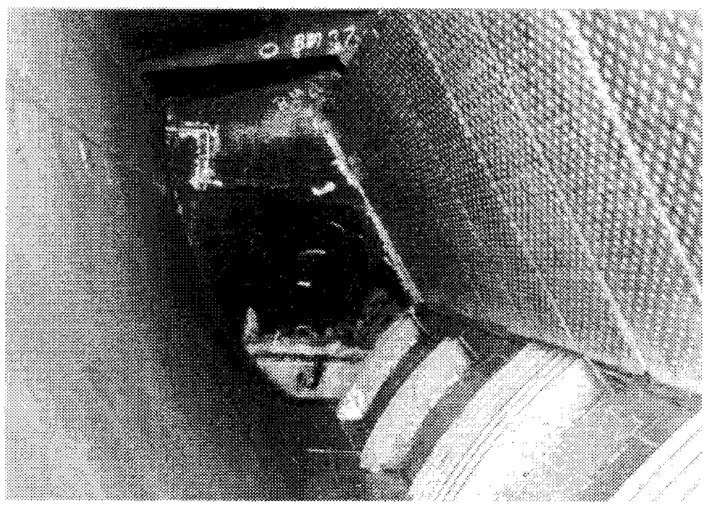
This paper describes modifications made to eliminate condensate subcooling and flow oscillations in MSR tube bundles at Salem 1. The paper outlines the design philosophy associated with the modification, describes the physical modification, and presents actual thermohydraulic data obtained at the plant.

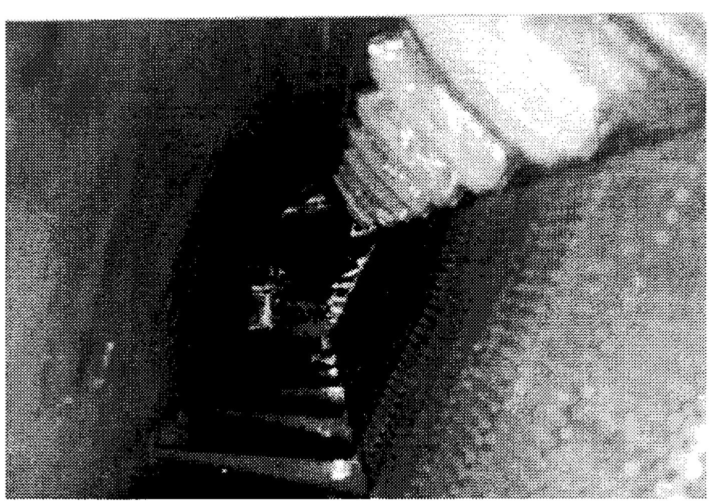
APPENDIX E

Photographs of RGE's Ginna MSR

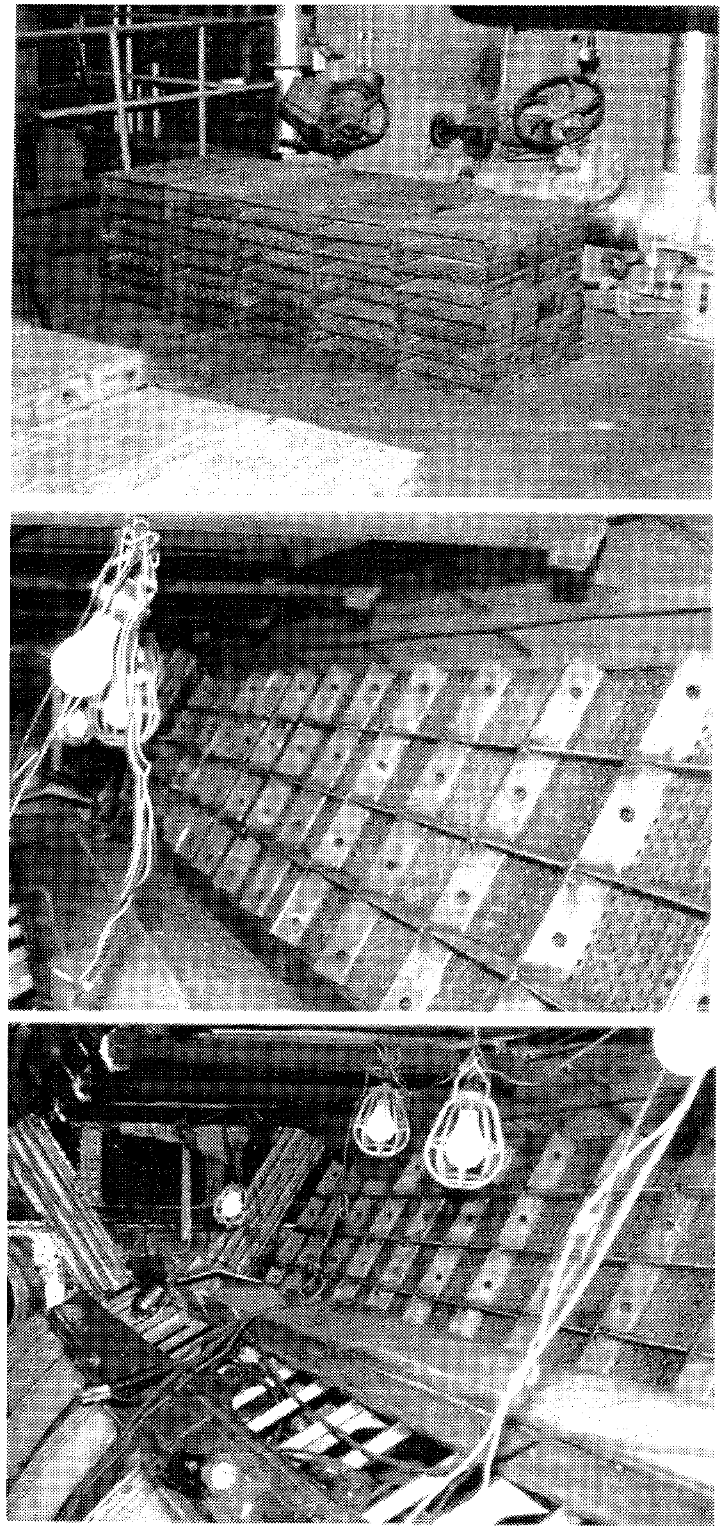
Chevron Separators and Perforated Flow Plates



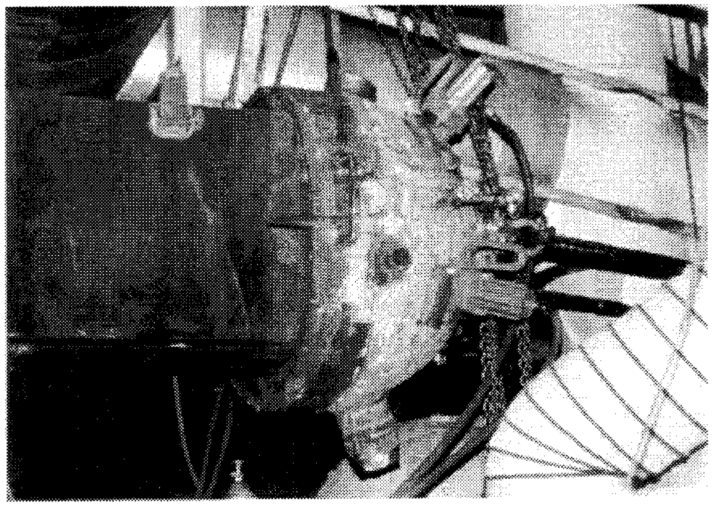


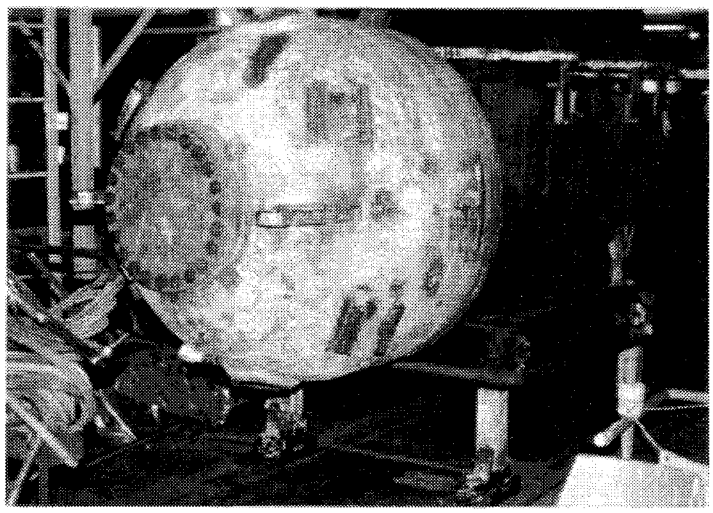


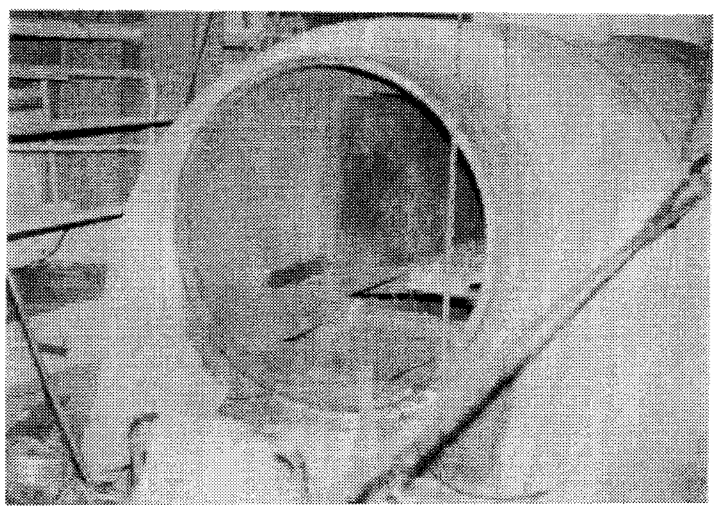
Separator Panels as Delivered and Installed



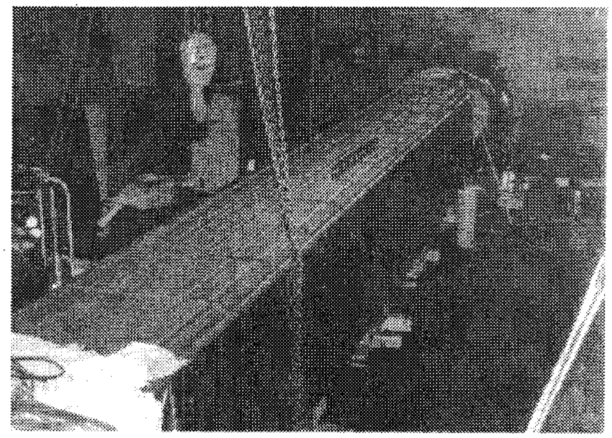
Old Tube Bundle Before and After Extraction

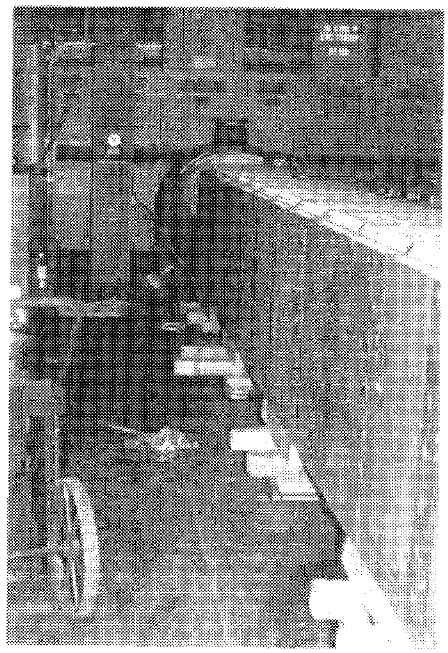


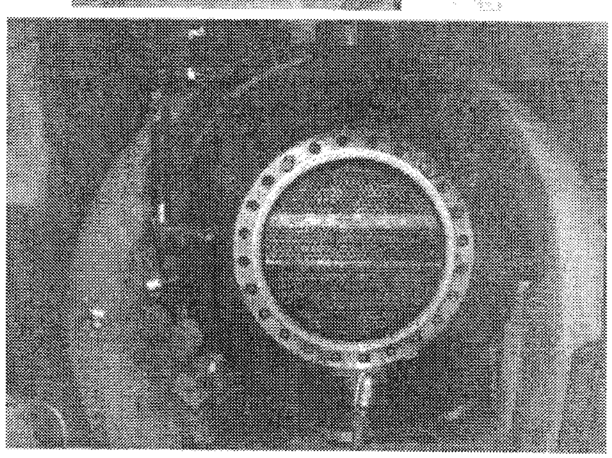




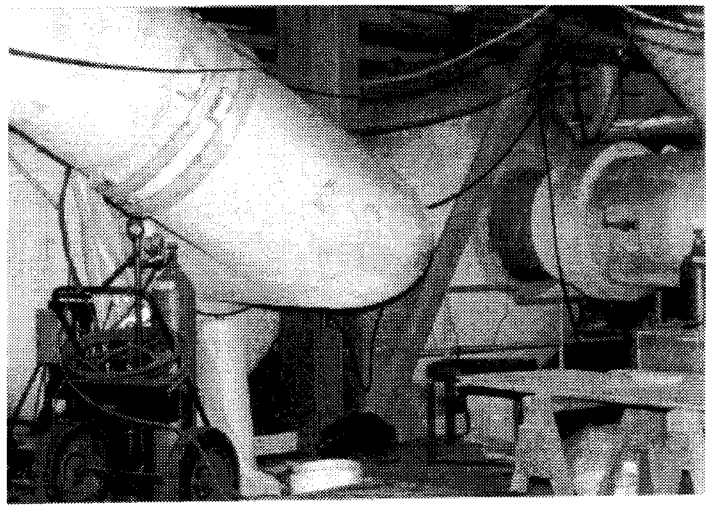
New Tube Bundle: Pre- and Post- Installation

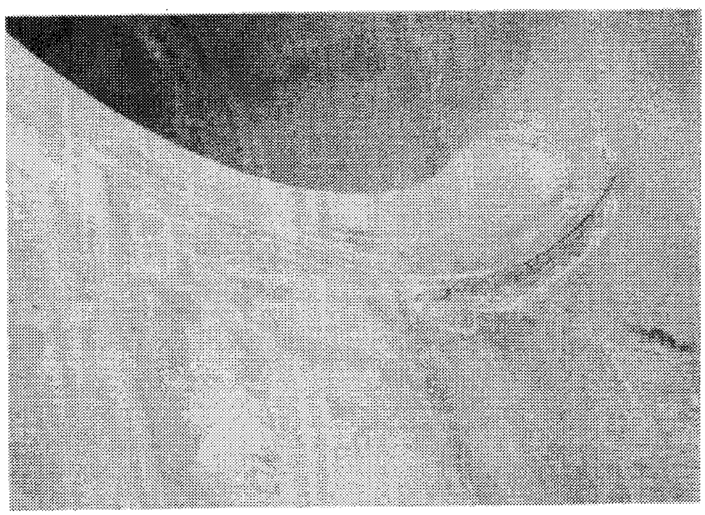


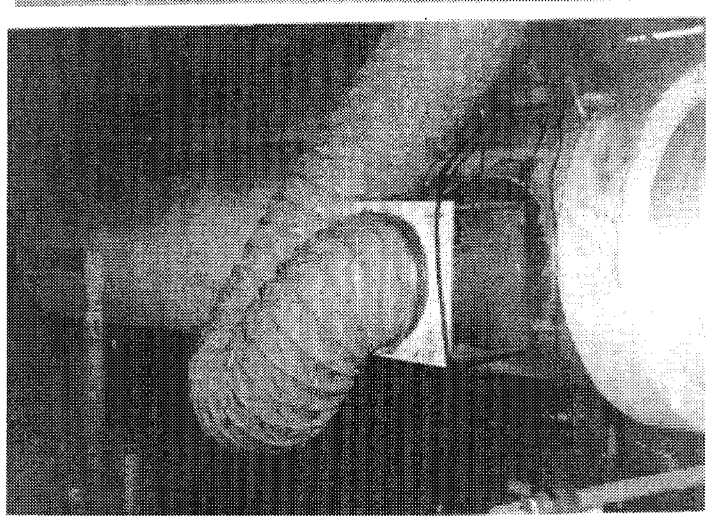




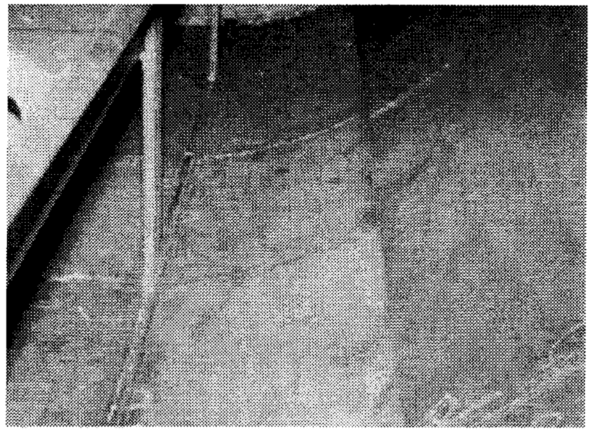
Extraction Lines, Shell Throat and Manway on Extraction Line

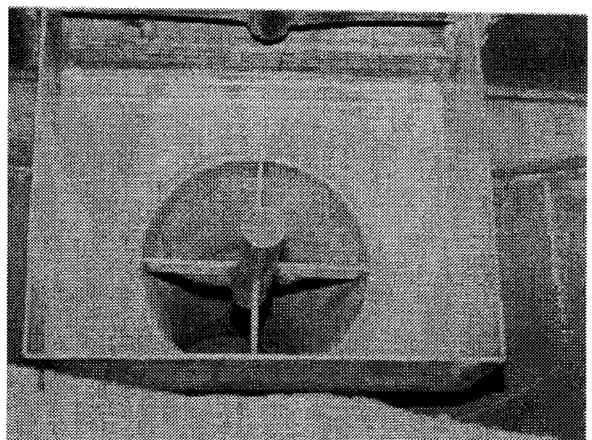


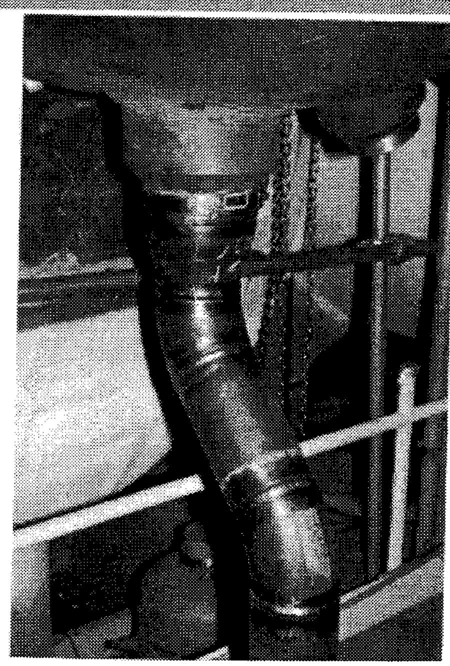




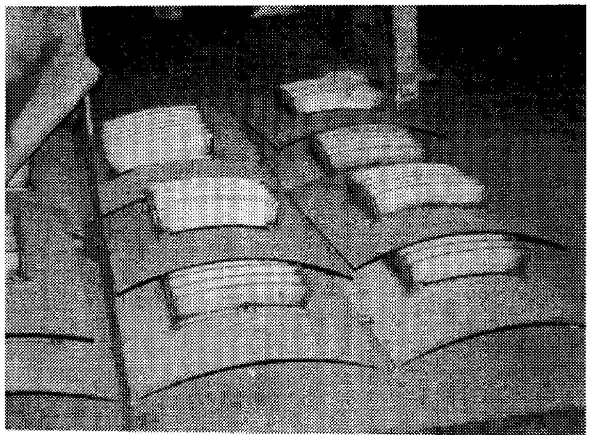
MSR Shell Drain Path, Drain Inlet and Drain Line

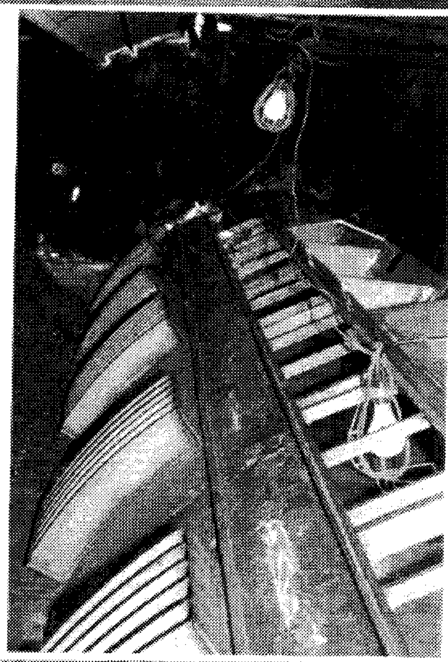


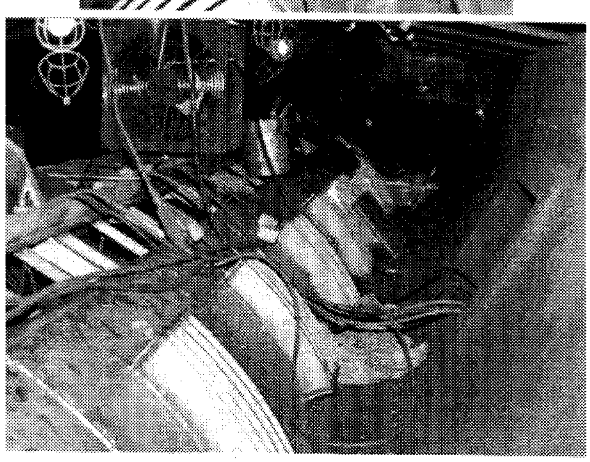




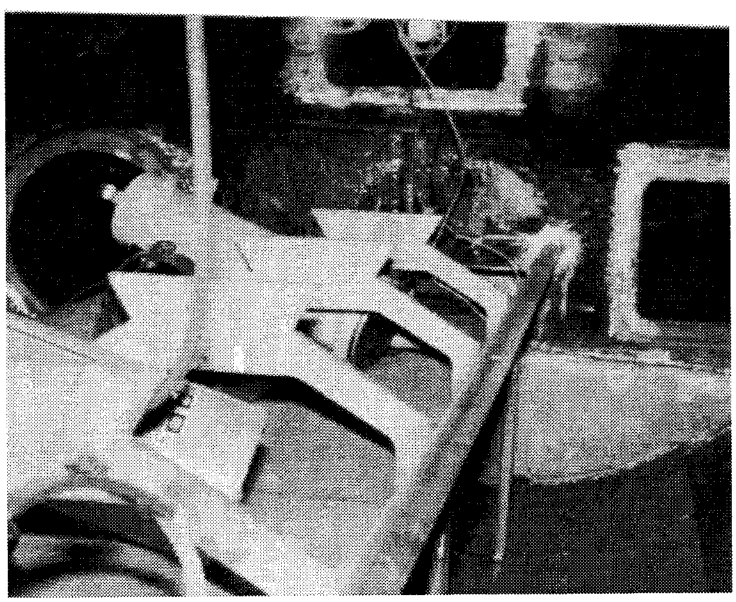
Chevrons: Pre- and Post- Installation







Low Side of Heater Tubes and Separator Plate. Channel Supports.



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