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Aging of Non-Power-Cycle Heat Exchangers Used in Nuclear Power Plants

Operating Experience and Failure Identification

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Prepared for
U.S. Nuclear Regulatory Commission

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Abstract

This report presents the results of an assessment of the time-related degradation of non-power-cycle heat exchangers used in nuclear power plants. The assessment was sponsored by the U.S. Nuclear Regulatory Commission's Nuclear Plant Aging Research Program.

Heat exchanger design characteristics and applications in the plants are described and stressors leading to degradation are identified. Operating experience, as identified from nuclear industry data bases, is reviewed and failure types and causes are summarized. Regulatory requirements for inspection and testing, with a brief discussion of industry practices in this area, are presented.

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Summary

This report presents the results of a Phase I assessment of the time-related degradation (aging) of non-power-cycle heat exchangers used in safety-related systems or to provide normal operating capability in nuclear power plants. The assessment was sponsored by the Office of Nuclear Regulatory Research, U.S. Nuclear Regulatory Commission, as an element of the ongoing Nuclear Plant Aging Research (NPAR) Program. The objective of an NPAR Phase I assessment is to review operating experience and other information, to identify failure modes and causes resulting from aging, and to identify measurable parameters that might provide a better indication of equipment condition.

The report briefly reviews the design and application of the heat exchangers in both PWR and BWR plants. Typical design characteristics and materials of construction are given for the various applications. Operational stressors are categorized and discussed.

Operating experience events reported in data bases for nuclear power plants and in nuclear industry reports were examined. These data bases included the Licensee Event Report file as cataloged in the Sequence Coding and Search System maintained by ORNL's Nuclear Operations Analysis Center, the Nuclear Plant Reliability Data System compiled by the Institute for Nuclear Power Operations, Nuclear Power Experience published by Stoller Power, Inc., and maintenance records for a two-unit PWR plant as furnished by a cooperating utility. A total of 710 reported events were examined. Of these, 279 events involved interfluid leakage, 217 involved external leakage, 156 involved tube-side flow blockage, and 25 involved impaired heat transfer.

There are only minimal regulatory or Technical Specification requirements for inservice inspection and testing, limited primarily to those inspections and tests required to maintain the integrity of the pressure-containing boundary. The general philosophy of plant operators regarding flow blockage and leakage is that repairs and maintenance will be done as required. Improvements to this philosophy that potentially would lead to enhanced reliability are not apparent and none is suggested in the report.

Inservice testing to determine the heat transfer capability of the heat exchangers has normally been done only when possible degradation was indicated from observation of process parameters; scheduled performance testing was not normally done. However, largely as a result of NRC concerns for the capability of safety-related, service-water-cooled, heat exchangers to perform as required under accident conditions and the resulting issuance of Generic Letter 89-13, plant-specific inservice performance testing programs are being developed by plant owners. In addition, the Operation and Maintenance Committee of the American Society of Mechanical Engineers is developing standards to address both vibration monitoring and inservice performance testing of heat exchangers. As a follow-on to this assessment, an evaluation of utility experience and findings resulting from response to Generic Letter 89-13 is recommended. This evaluation should provide valuable insights of as-found conditions in plant heat exchangers, the effectiveness of maintenance practices, and improved inservice testing methodology.

Acknowledgments

The author gratefully acknowledges the continuing support and counsel of the NRC Nuclear Plant Aging Research Program manager, J. P. Vora, and project manager, W. S. Farmer, in the planning and implementation of this study.

The assessment was carried out under the general guidance of D. M. Eissenberg, ORNL NPAR Program manager; the author appreciates his encouragement and advice. D. A. Casada of ORNL's NPAR staff was very helpful in sharing his experience in the nuclear plant operating environment and in searches of the NPRDS data base.

Insights on the operating plant experience and the procedures under development and in place at the plants were gained from discussions with other members of the American Society of Mechanical Engineers' Working Group OM-21, of which the author is a member. Additional information was obtained from Tom Golston, Isidoro DiBiase, Bob Ives, and Ed Craig of the Tennessee Valley Authority and from Mike Pugh of Carolina Power and Light. Their willingness to share this information is deeply appreciated.

1 Introduction

1.1 Background

The Office of Nuclear Regulatory Research of the U.S. Nuclear Regulatory Commission (NRC) has an ongoing program, the Nuclear Plant Aging Research (NPAR) Program,[1] aimed at understanding the time-related degradation (aging) of nuclear power plant systems and equipment. It includes assessing the effectiveness of methods of inspection and surveillance that monitor such degradation and establishing guidelines for maintenance. The program is intended to provide technical bases for examining the ongoing operational safety of operating plants.

This report addresses the time-related degradation of heat exchangers used in safety-related systems or that provide normal operating capability in nuclear power plants. These heat exchangers usually serve as interfaces between systems in the plant, transferring heat to or toward the plant's normal or ultimate heat sink to maintain desired process temperatures. Heat exchangers that are associated with the power conversion systems, such as steam generators, main condensers, feedwater heaters, and turbine plant equipment coolers are not included in this assessment. These power conversion system exchangers are, of course, necessary for stable power operation but are not required to function to bring the plant to a safe shutdown condition.

A major concern for the operational readiness of safety related heat exchangers that reject heat to the plant service water has resulted from numerous reported events in which the service water sides of these exchangers have experienced fouling or clogging from corrosion products or from sediment, debris, or organisms originating in the service water source. The NRC, in 1981, issued IE Bulletin 81-03[2] that pointed out an incident of blockage of flow to containment cooling units by Asiatic clams and calling for licensees to check for the presence of clams or mussels in the plant vicinity and, if present, to check fire protection and safety related systems for blockage by these organisms or their shells and to describe methods for detection and control of future blockage. A summarization of the licensee responses[3] to IEB 81-03 showed that approximately half the active U.S. nuclear plants have high potential for biofouling, and many of these had poor programs for detection and control.

In 1982, the NRC established Generic Issue 51, *Improving the Reliability of Open-Cycle Service Water Systems*, and initiated a research program to compare alternative surveillance and control programs to minimize the effects of fouling on plant safety. Although the program was initially aimed at biofouling, it was later expanded to address fouling by silt and corrosion products. The resulting document[4] presents the results of a review of surveillance and control programs in use by utilities and provides guidance for developing such programs.

In 1988, NRC's Office for Analysis and Evaluation of Operational Data issued a report[5] documenting and evaluating the safety implications of service water system failures and degradations observed in light water reactors from 1980 to 1987. From a total of 980 events, 276 were deemed to have potential generic safety significance. The most frequent (in 58% of those with safety significance) system degradation mechanism was fouling, from corrosion/erosion, biofouling, foreign material or debris, and siltation. Surveillance methods in use in most plants were incapable of detecting the condition; detection was generally only in an on-demand situation. Four operating events reported in Ref. 5 involved serious heat exchanger degradation due to fouling of the exchangers. It was concluded that the safety significance of service water system failures and degradations is high.

As a part of NRC's NPAR Program, Pacific Northwest Laboratory conducted a Phase I aging degradation assessment of service water systems and published their findings[6] in 1989. Conclusions from the assessment were that a.) aging-related degradation of service water systems is prevalent and constitutes a valid safety concern, b.) corrosion, compounded by biological and inorganic accumulation, is the primary degradation mechanism, and c.) the accuracy and completeness of failure data are insufficient to provide the basis for root cause determination and the assessment of time-related degradation. A Phase II assessment to examine methods for managing aging degradation of service water systems is currently underway.

As a result of concern due to continuing problems with service water systems and the heat exchangers served by those systems, the NRC, on July 18, 1989, issued Generic Letter 89-13.[7] The Letter points out the statutory requirements, under 10 CFR 50, for a.) provision of a service water system to transfer heat from systems and components important to safety to the ultimate heat sink, b.) design provisions for periodic inspection and tests to assure integrity and capability of the cooling water system, and c.) establishment of a test program, with written test procedures, to demonstrate that the systems and components will perform satisfactorily in service. The Letter requested that licensees perform the following actions (or explain why the actions are not needed) to ensure that the service water system and any intermediate systems used to transfer heat from safety-related items to the ultimate heat sink are in compliance with 10 CFR Part 50.

a. Implement and maintain an ongoing surveillance and control program to significantly reduce the incidence of biofouling flow blockage.

b. Implement a test program that includes both initial and periodic tests to verify the heat transfer capability of all safety-related heat exchangers cooled by service water.

c. Implement a routine inspection and maintenance program for open cycle service water system components to ensure that any of various fouling agents cannot degrade the performance of safety-related systems supplied by service water to a level below the safety function requirements during the interval between inspections.

d. Confirm that the service water system will perform its intended function in accordance with the licensing basis for the plant.

e. Confirm that maintenance practices, operating and emergency procedures, and training involving the service water system are adequate to ensure system functionality and operator effectiveness.

In addition to problems with flow blockage and fouling in heat exchangers served directly by service water, numerous instances of external and inter-fluid leakage have occurred in various heat exchangers. Although minor leakage in many cases may not compromise the ability of the operators to bring the reactor to a safe shutdown condition, leakage can result in cross-contamination of systems or in releases to the environment.

1.2 Objective

The objective of this NPAR Phase I assessment is to review operating experience, to identify failure modes and causes resulting from aging of non-power system heat exchangers in nuclear plant service, and to identify measurable parameters which, if tracked in improved inspection, surveillance, and monitoring procedures, might result in improved system reliability.

1.3 Project Scope

This assessment covers the following information for non-power-system heat exchangers used in nuclear power plants.

1. Background information on heat exchangers - boundary of equipment to be studied, types, uses, requirements, and materials of construction.
2. Review of regulatory requirements, guides, and standards.
3. Summary of operational and environmental stressors.
4. Summary of operating experience.
5. State-of-the-art aging monitoring and assessment.

1.4 Definitions

For the purposes of this report, the following definitions apply:

Failure type - one element of a systematic categorization of the various ways in which a component does not perform a function for which it was designed.

Failure cause - the mechanism or agent that is responsible for the degradation present in a given component at a given time.

Aging - the combined cumulative effects over time of internal and external stressors acting on a component, leading to time-related degradation of the component.

Measurable parameters - physical or chemical characteristics of a component that can be described or measured directly or indirectly and that can be correlated with aging. Useful measurable parameters are those that can be used to establish trends of the magnitude of aging associated with each failure cause, that have well-defined criteria for quantifying the approach to failure, and that are able to discriminate between the degradation that leads to failure and other degradation.

Inspection, surveillance, and condition monitoring (ISCM) - the spectrum of methods for obtaining qualitative or quantitative values of a measurable parameter of a component. The methods may be periodic or continuous, and may involve dynamic or static measurements.

2 Basic Information

2.1 Principal Uses and Types of Heat Exchangers in LWRs

Numerous heat exchangers are utilized in pressurized water and boiling water nuclear power plants, usually serving as interfaces between plant systems while transferring heat to or toward the normal or ultimate heat sink to establish or maintain desired process or equipment temperatures. With the exception of containment or room coolers, which are finned coil types with air on the outside of the tubes, the predominant heat exchanger type is shell-and-tube. Normally, to permit effective cleaning in a shell-and-tube exchanger, the stream most likely to promote fouling is on the tube side.

2.1.1 Heat Exchangers in Pressurized Water Reactor Plants

Typical thermal management in pressurized water reactor (PWR) plants is represented schematically in Fig. 2.1. Due to variations in plant designs, the immediate heat sink for certain heat exchangers differs as indicated by dashed lines in the figure. The function and typical descriptions of the various principal exchangers follow.

<u>Residual Heat Removal (RHR) Heat Exchangers.</u> These exchangers are used in the second phase of shutdown cooling, to reduce reactor coolant temperature to and maintain it at the refueling temperature. (The first phase of shutdown cooling, to a coolant temperature of approximately 350°F, is accomplished by the main steam and feedwater systems.) They may also provide cooling for recirculating containment sump water for core cooling and for containment spray following a loss-of-coolant accident (LOCA). The usual heat sink for the RHR heat exchangers is the Component Cooling Water System. During normal plant operation, the RHR exchangers are idle.

The RHR heat exchangers are classified as safety-related.

Typical RHR heat exchanger design characteristics, as used in an 1100 MWe plant, are:

HX type		Shell-and-U-tube, with welded tube/tubesheet joints
Shell side (component cooling water)		
	flow	2.5 x 10^6 lb/hr, 95 → 108.8°F
	material	carbon steel
	design	150 psig/250°F
Tube side (reactor coolant)		
	flow	1.5 x 10^6 lb/hr, 137 → 114°F
	material	austenitic stainless steel
	design	600 psig/400°F
Tubesheet		carbon steel w/stainless overlay

<u>Component Cooling Water (CCW) Heat Exchangers.</u> The Component Cooling Water System functions as an intermediate barrier between systems and equipment that are potentially contaminated and the external environment. Corrosion-inhibited demineralized water is recirculated through various source heat exchangers and coolers to the Component Cooling Water heat exchangers. These latter exchangers transfer heat from the Component Cooling Water System to the Service Water System. The CCW heat exchangers are classified as safety related.

CCW heat exchangers are specified by the plant engineering firm and, as a result, often differ in characteristics between plants having the same reactor supplier and nominal rating. Typical CCW heat exchanger design characteristics, for an 1100 MWe plant, are:

HX type		Shell-and-straight-tube, with rolled tube/tubesheet joints (also plate type)
Shell side (component cooling water)		
	flow	3.4 x 10^6 lb/hr, 107.9 → 95°F
	material	carbon steel
	design	150 psig/200°F
Tube side (service water)		
	flow	5.0 x 10^6 lb/hr, 85 → 93.9°F
	material	admiralty, 90-10 Cu-Ni, aluminum-brass, or titanium
	design	150 psig/200°F

<u>Containment Spray Heat Exchangers.</u> These heat exchangers can be used for post-accident containment cooling to avoid excessive containment pressure buildup. Water is pumped from the containment

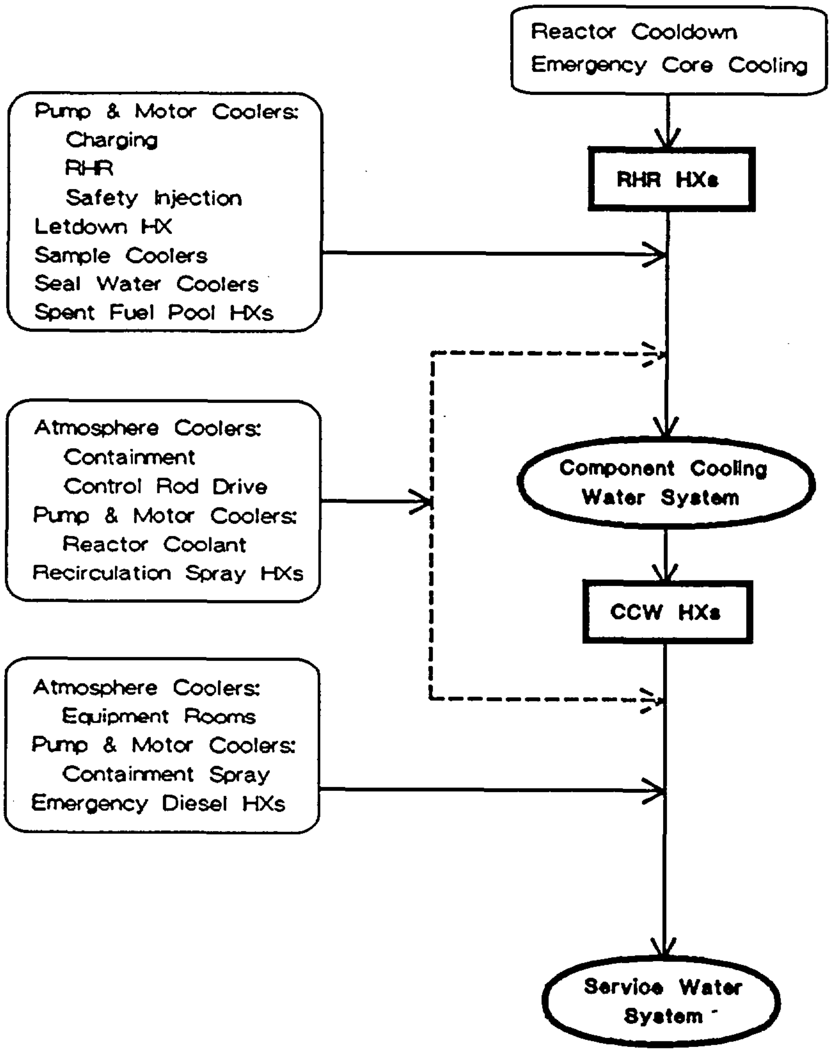

Figure 2.1 Thermal management in PWR plants

sump through the exchangers to spray headers located high in the containment vessel.

Typical containment spray heat exchanger design characteristics for an 1100 MWe plant are:

HX type	Shell-and-U-tube, with welded tube-to-tubesheet joints
Shell side (essential raw cooling water)	
flow	5000 gpm, 83 → 109°F
material	carbon steel
design	150 psig/200°F
Tube side (spray water)	
flow	4750 gpm, 135.8 → 108.5°F
material	austenititc stainless steel
design	300 psig/300°F

Containment Atmosphere Coolers. These fan-coil units are used to maintain containment air temperature at desired levels during normal operation and to assist in limiting containment temperature and pressure during accident conditions. Design and application of these coolers vary considerably from plant to plant. The units usually utilize coils having horizontal tubes with vertical fins on the air side and may be cooled with service water, emergency raw water, component cooling water, or chilled water. Tube materials are selected based on cooling water characteristics; tube materials used in various plants include copper, copper-nickel, austenitic stainless steel, superaustenitic stainless steel, or admiralty metal. Two-speed fan motors are used in some cases, with high-speed operation during normal plant operation and low-speed operation under accident conditions. Containment atmosphere coolers, are classified as safety related.

The following complement of containment atmosphere coolers is included to illustrate a "typical" application for an 810 MWe unit.

> Four fan coil units, cooled by component cooling water.
> (Three are used during normal plant operation; two units plus one of two containment spray systems are adequate for design basis accident conditions.) Values given are for each unit.

Air flow	60,000 acfm (normal, high fan speed) 40,000 acfm (accident, low speed)
Air temp.	120 → 103.2°F (normal) 264 → 257.3°F (accident)
Water flow	1200 gpm (both conditions)
Water temp.	100 → 101.8°F (normal) 100 → 206.4°F (accident)
Heat load	1.0 Mbtu/hr (normal) 61.6 MBtu/hr (accident)

Regenerative Heat Exchanger. The regenerative heat exchanger is a component of the Chemical and Volume Control System (CVCS), serving to partially cool the reactor coolant letdown stream by regeneratively extracting heat from the letdown stream and transferring it to the reactor coolant charging stream. To minimize the potential for external leakage, all-welded construction is typical. Both the shell side and the tube side of the exchanger are fabricated from austenitic stainless steel. Since both shell-side and tube-side streams are reactor coolant at high pressure, there is no strong preference for one or the other stream being on the shell side; either arrangement is used.

Design characteristics of a typical regenerative heat exchanger, for an 1100-MWe unit, are:

HX type	Shell-and-tube, all welded, designed for >2,000 shell-side temperature step changes from 130 to 550°F
Shell side (reactor coolant letdown)	
flow	37,050 lb/hr, 545 → 290°F
design	2485 psig/650°F
Tube side (reactor coolant charging)	
flow	27,170 lb/hr, 130 → 495°F
design	2735 psig/650°F

Letdown Heat Exchanger. The letdown heat exchanger (also referred to as the nonregenerative heat exchanger) is a component of the CVCS and follows the regenerative heat exchanger in the reactor coolant letdown stream, cooling the letdown stream to a temperature suitable for demineralizer operation. Because of a pressure reducing orifice in the letdown circuit between the regenerative heat exchanger and the letdown heat exchanger, the latter exchanger is exposed to a pressure intermediate to those of the reactor coolant system and the demineralizer.

Design characteristics of a typical letdown heat exchanger, as used for an 1100 MWe unit, are as follows:

HX type	Shell-and-tube
Shell side (component cooling water)	
flow	203,000 lb/hr, 95 → 125°F
design	150 psig/250°F
material	carbon steel
Tube side (reactor coolant letdown)	
flow	37,050 lb/hr, 290 → 127°F
design	600 psig/400°F
material	austenitic stainless steel

<u>Excess Letdown Heat Exchanger.</u> During reactor startup, when the reactor coolant volume is increasing because of rising temperature, the letdown stream flow is greater than can be effectively cooled in the regenerative heat exchanger (i.e., there is insufficient charging flow to absorb the heat). The excess letdown heat exchanger, a component of the CVCS, essentially parallels the regenerative and letdown heat exchangers to provide additional cooling capacity for the letdown stream while in this mode of operation.

Design characteristics of an excess letdown heat exchanger for an 1100 MWe unit follow.

HX type	Shell-and-tube
Shell side (component cooling water)	
flow	115,000 lb/hr, 95 → 135°F
design	150 psig/250°F
material	carbon steel
Tube side (reactor coolant letdown)	
flow	12,380 lb/hr, 545 → 195°F
design	2485 psig/650°F
material	austenitic stainless steel

<u>Seal Water Heat Exchanger.</u> The seal water heat exchanger, also a component of the CVCS, cools the portion of reactor coolant pump injection flow that has cooled and lubricated the pump radial bearing and exited the pump above the lower seal. The cooled seal water is then returned to the charging pump suction.

Design characteristics of a typical seal water heat exchanger, as used in an 1100 MWe unit, follow.

HX type	Shell-and-tube
Shell side (component cooling water)	
flow	99,500 lb/hr, 95 → 120°F
design	150 psig/250°F
material	carbon steel
Tube side (reactor coolant)	
flow	160,500 lb/hr, 144 → 127°F
design	150 psig/250°F
material	austenitic stainless steel

<u>Spent Fuel Pool Coolers.</u> The spent fuel pool coolers are designed to remove the decay heat from the spent fuel elements stored in the pool. System design usually considers that a complete core loading may be placed in the pool to permit reactor vessel inspection or maintenance when there is already 1/3 of a core loading from each reactor at the site in the pool. The spent fuel cooling system normally can maintain the pool temperature at less than 120°F when only 1/3 of a core from each reactor is present; when an additional full core is added to the pool, the pool temperature can be maintained at approximately 150°F.

Design characteristics of a typical spent fuel pool cooler, as used in an 1100 MWe unit, are as follows:

HX type	Shell-and-U-tube, with welded tube/tubesheet joints
Shell side (component cooling water)	
flow	1.5×10^6 lb/hr, 95 → 103°F
material	carbon steel
design	150 psig/200°F
Tube side (fuel pool water)	
flow	1.1×10^6 lb/hr, 120 → 109.5°F
material	austenitic stainless steel
design	150 psig/200°F

<u>Pump Coolers.</u> Small heat exchangers are employed to cool the lubricating oil for the reactor coolant, RHR, main and auxiliary feed, charging, containment spray, safety injection, and service water pumps. In addition, coolers to prevent excessive temperatures in the seal regions of the reactor coolant and main feedwater pumps are provided as integral parts of

these pumps. Either the Component Cooling Water System or the Service Water System serves as the heat sink for the pump coolers.

Equipment Room Coolers. Equipment room coolers, used to cool enclosures housing safety related equipment to protect the operability of that equipment, consist of fan-coil units that may be cooled by service water, component cooling water, or chilled water. Air-side filters are provided in some cases to remove particulates from the recirculating air stream. The coils are constructed from finned tubes, with materials selection based on the cooling water characteristics. Because they serve to protect safety related equipment, the coolers themselves are classified as safety related.

Emergency Diesel Generator Heat Exchangers. The emergency diesel generators are served by a shell-and-tube heat exchanger for each engine that extracts heat from the engine coolant and transfers it to the Emergency or Standby Service Water System, or by an air-cooled radiator. Engine coolant serves as the heat sink for the engine lubricating oil cooler.

2.1.2 Heat Exchangers in Boiling Water Reactor Plants

Typical thermal management in boiling water reactor (BWR) plants is represented schematically in Fig. 2.2. The functions served by the complement of heat exchangers in BWR plants are similar to those in PWR plants as discussed in the preceding section, and the designs are similar, also. Those functions that are served by the Component Cooling Water System in PWRs generally are fulfilled by the Reactor Building Closed Cooling Water System in BWRs. Upon loss of offsite power, critical cooling loads are shifted from the Service Water System to the Emergency Equipment Cooling Water System, as indicated by the dashed lines in the figure.

Noteworthy differences in BWR plants are the multiple functions of the RHR heat exchangers and the heat sink for these exchangers. In addition to providing for shutdown cooling and containment spray cooling as in PWRs, the BWR RHR exchangers may be used, depending upon individual plant design, to condense reactor-generated steam during reactor core isolation conditions, to cool the suppression pool water, and for augmented fuel pool cooling. While the RHR exchangers in PWRs are usually cooled by the component cooling water system, service water is often used in BWRs. As in PWRs, the RHR exchangers are idle during normal operation.

2.2 Equipment Boundaries

For purposes of this report, the heat exchangers are defined to include the following:

1. For shell and tube heat exchangers, the shell and its nozzles for piping attachment, the channel head(s) and its (their) nozzles for piping attachment, the heat exchange tubes, the tubesheet(s), and, if used, the floating head.

2. For air-to-water heat exchangers, the tube bundles and their associated headers. Associated blowers, air-flow-directing ducting and unit housings are not included.

2.3 Functional Requirements

The general functional requirements of the heat exchangers are to transfer the design heat load from the source system or component to either an intermediate system or to the normal or ultimate heat sink, while maintaining fluid isolation between the source and the intermediate or final sink. (An exception is the regenerative heat exchanger in PWR Chemical and Volume Control Systems and in BWR Reactor Water Cleanup Systems, where heat is regeneratively transferred from the reactor coolant letdown stream to the reactor coolant charging stream.) In certain applications, the heat exchanger is specified and designed to transfer heat at a given rate when under specified conditions (e.g., RHR exchangers under design basis conditions). Other applications require only that the temperature of a component or subsystem (e.g., pump lubricating oil) be maintained at or below a specified temperature under specified conditions.

2.4 Materials of Construction

Typical materials of construction for certain of the heat exchangers used in PWR plants were given in Sect. 2.1.1. Generally, in PWRs, austenitic stainless steel (type 304 or 316) is used for the side (shell or tube) of a heat exchanger that is in contact with

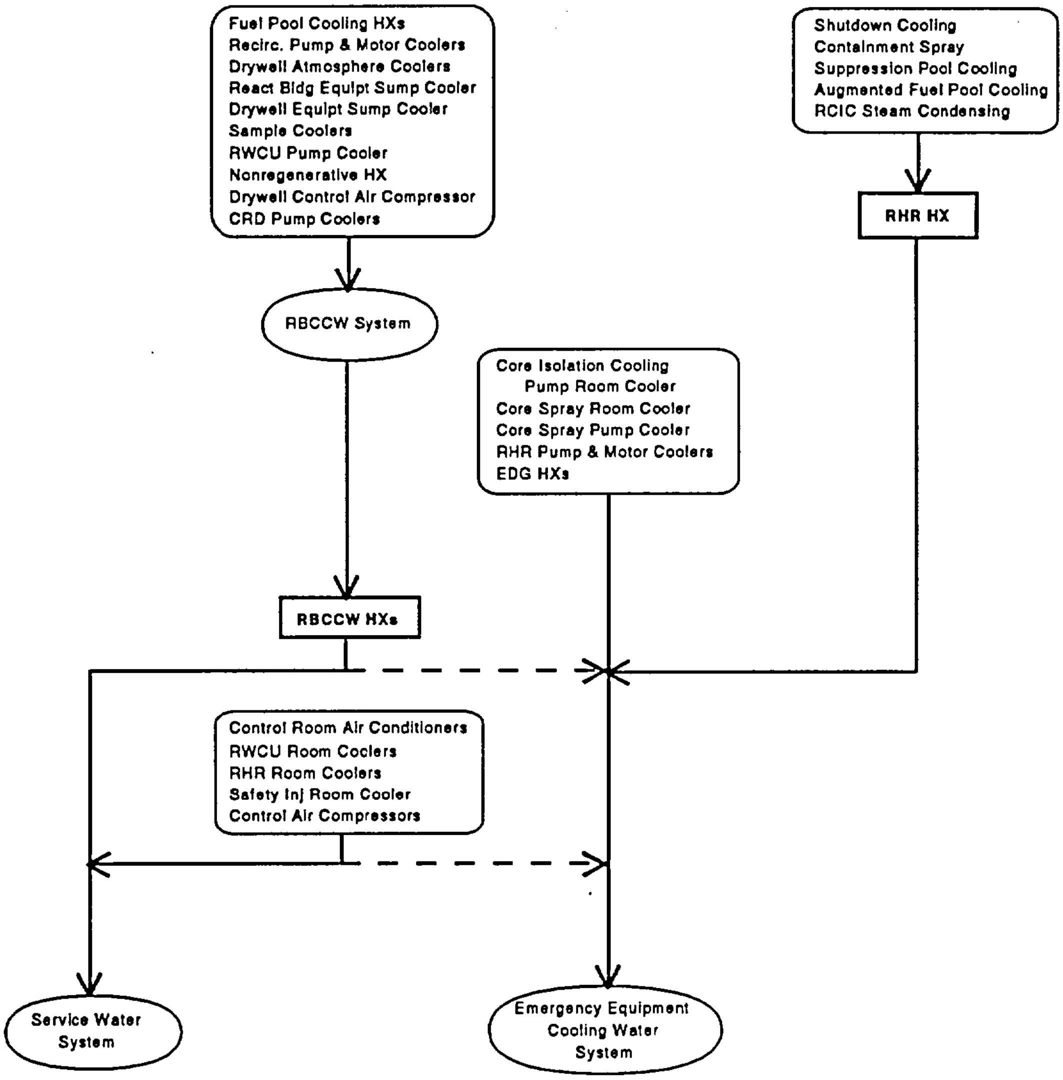

Figure 2.2 Thermal management in BWR plants

reactor coolant. In BWRs, because of rigid specifications for the chemistry of the reactor water, carbon steel or copper-nickel alloy is used in some components in contact with the reactor water. The side of a heat exchanger contacting the water in a closed, corrosion inhibited, cooling water system (e.g., the shell sides of CCW or PWR RHR heat exchangers) is usually constructed of carbon steel. In heat exchangers that reject heat to service water, the material used in the side exposed to service water (usually the tube side, to facilitate cleaning) is selected for compatibility with that water. Materials used for this application include copper-nickel, aluminum-brass, admiralty alloy, austenitic stainless steel (type 304 or 316), copper, and superaustenitic stainless steel.

3 Technical Specification Requirements

The Technical Specifications for each nuclear power plant specify Limiting Conditions of Operation (LCO) that establish requirements for certain system and component operability* during various operational modes for the plant. Surveillance requirements are included in the Technical Specifications that verify that the LCOs are satisfied. When an LCO is not met, action requirements for correcting the situation or for bringing the plant to an operating mode closer to cold shutdown within a specified time period must be followed.

Surveillance requirements for inservice inspection and testing of American Society of Mechanical Engineers (ASME) Code Class 1,2, and 3 components are to be performed in accordance with the ASME Boiler and Pressure Vessel Code, Section XI, unless relief has been granted by the NRC. Section XI includes inservice testing provisions for pumps and valves only; inservice inspection of heat exchangers is limited primarily to that necessary to assure the integrity of the pressure-containing capability of the exchangers. Neither the Technical Specifications nor ASME Section XI includes requirements for inservice testing to determine heat exchanger thermal performance or limiting values for that performance.

As an example of Technical Specification requirements pertaining to heat exchangers for one PWR plant, the following summary is presented.

a. In *hot shutdown*, at least two loops consisting of any combination of reactor coolant loops or the RHR loops shall be operable and at least one of these shall be in operation. If less than the required complement are operable, immediate corrective action is to be taken to return the required loops to operable status, and if the remaining operable loop is an RHR loop, the plant shall be in *cold shutdown* in 24 hours. Surveillance requirements are that at least one coolant or RHR loop be verified in operation and circulating reactor coolant at least once per 12 hours.

b. In *cold shutdown*, two RHR loops shall be operable and at least one shall be in operation, with proper operation verified at least once per 12 hours.

c. To provide for *emergency core cooling*, one (when T_{avg} <350°F) or two (when T_{avg} ≥350°F) independent ECCS subsystems shall be operable. One operable RHR heat exchanger and one RHR pump are included in each operable ECCS subsystem. Verification procedures for the operability of the RHR exchangers are not specified.

d. During *refueling operations*, one (with high water level) or two (with low water level) independent RHR loops shall be operable and at least one shall be in operation. Proper operation shall be verified at least once per 12 hours.

e. Two independent *containment spray* systems shall be operable during operational modes 1, 2, and 3, capable of taking suction from the refueling water storage tank and transferring suction to the containment sump.

f. Two independent *component cooling water* loops shall be operable during operational modes 1, 2, and 3.

Operability is to be demonstrated by a.) verifying that each valve is in its correct position once per 31 days and b.) verifying, every 18 months, that each automatic valve goes to its correct position upon test signal and that each CCW pump starts on safety injection test signal.

g. Four *containment fan coolers* shall be operable, with one of two fans per unit capable of operation at low speed. Operability shall be verified by a.) once every 31 days, operating fans for 15 minutes and verifying cooling water flow to each cooler is adequate and b.) once every 18 months, verifying that fans start automatically upon injection signal.

h. *Area temperatures*, in tabulated equipment areas (including rooms for CCW pumps, auxiliary feedwater pumps, charging pumps, RHR pumps, containment spray pumps, and others) shall not exceed specified values by more than 30°F or for

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*A system or component is defined in the Technical Specifications as being operable or having operability when it is capable of performing its specified function, and when all necessary system auxiliaries are also capable of performing their support functions.

more than 8 hours. If the area temperature exceeds the specified value by more than 30°F, the temperature is to be restored to the specified value within four hours or the affected equipment shall be declared inoperable.

i. *Primary containment average air temperature* shall not exceed 120°F. To verify, average of temperatures at three levels in containment shall be determined once per 24 hours.

Technical Specification requirements for BWR plants generally are similar to those for PWRs, except for additional requirements for suppression pool spray and cooling functions. Example requirements for these functions include:

a. The RHR system shall have two independent loops operable in the *suppression pool spray* mode during plant operating conditions 1, 2, and 3. Each loop consists of one operable RHR pump and an operable flow path capable of recirculating water from the suppression chamber through an RHR heat exchanger and the suppression pool spargers.

   Surveillance requirements include a once-in-31-days verification that each valve is in the correct position and verifying, per ASME Section XI, that each of the required RHR pumps develops the specified flow through the heat exchanger and spray sparger.

b. Two independent loops of the RHR system shall be operable in the *suppression pool cooling* mode during operating conditions 1, 2, and 3. Each loop consists of one operable RHR pump and an operable flow path capable of recirculating suppression pool water through an RHR heat exchanger.

   Surveillance requirements include verification, once per 31 days, that valves are in their correct positions and, per ASME Section XI, that each required RHR pump develops the specified flow through the RHR heat exchanger, the suppression pool, and the full-flow test line.

4 Summary of Operational Stressors

During their service life in a nuclear power plant, heat exchangers are exposed to operational stressors that may result in functional degradation. These stressors are described in the following subsections.

4.1 Electrical Stressors

The only electrical stressor for heat exchangers is galvanic corrosion resulting from coupling of materials remote from one another on the electromotive series. The potential for galvanic corrosion can be reduced by the use of sacrificial anodes, usually magnesium, inserted in the fluid path of the exchanger.

4.2 Mechanical Stressors

a. Fluid pressure. Fluid pressures exert mechanical stress on the heat exchanger shell, tubes, tubesheet, channel heads and partitions, gaskets, and nozzles. The exchangers are designed with comfortable strength margins to withstand those pressures expected to be encountered under both normal and accident conditions. However, exchanger damage may result from excessive pressures from improper isolation of the exchangers from systems undergoing hydrostatic testing, from transient pressure excursions caused by water hammer, or in the case of channel partitions, from tube flow blockage.

b. Piping system reactions. Piping systems attached to the heat exchanger nozzles exert thrusts and moments on the heat exchangers at their nozzles as the piping undergoes expansion and contraction from system temperature changes or moves from fluid forces.

c. Differential expansion. The tubes in a shell-and-tube heat exchanger are often fabricated from a metal having a different coefficient of thermal expansion than the shell material. In addition, the fluid temperatures in the shell and the tubes may be quite different in steady state operation or may undergo large variations in temperature, with time, during cyclic operation. As a result, in fixed tubesheet designs, tensile or compressive stresses are imposed on the shell and tubes during operation. Floating head or U-tube designs are often adopted for applications having large temperature differences to minimize differential expansion stresses. Some exchangers have a specified maximum lifetime number of thermal cycles.

   Differential expansion stresses may lead to relaxation and leakage at rolled tube-to-tubesheet joints. In recognition of this, recommended maximum metal temperatures for various tube materials used with carbon steel tubesheets are given in the Heat Exchange Institute's Standard for Power Plant Heat Exchangers.[8]

d. Tube vibration. Vibration of the tubes in a heat exchanger can lead to failure due to either fatigue of the tubes or to fretting corrosion where the vibrating tubes contact baffles. Tube vibration can result from excessive shell-side flow velocities across the tubes, often in the area where shell-side flow enters the tube bundle, and can be attributed to improper design or to operation at flow rates outside the design specifications.

e. Tube erosion. Tube erosion may result from excessive tube-side velocity, excessive shell-side velocity (especially in areas near the inlet nozzles), or from suspended abrasive material in the cooling water. Recommended maximum tube-side velocities for different tube materials with clean water are included in Ref. 8, and range from 10 ft/sec for stainless steel, nickel alloys, and titanium, to 8.5 ft/sec for copper, admiralty alloy, and aluminum-brass. Lower velocities should be used with water containing erosive solids. Heat exchangers containing erosive solids in the shell side water require an impingement plate to protect the tube bundle from erosion near the shell inlet nozzle.

4.3 Chemical Stressors

Corrosion is a major form of heat exchanger degradation and, except for galvanic corrosion caused by electrical currents generated by the coupling of dissimilar metals in an electrolyte, is caused by chemical agents to which the heat exchanger materials are exposed. These agents may be constituents of the water flowing through the exchanger, or may be generated or concentrated by organisms or mechanisms within the exchanger. An excellent summary description of the various corrosion mechanisms applicable to heat exchangers is provided in a draft document[9] prepared by Pacific Northwest

Laboratories and is included in the following paragraphs.

Pitting is a localized form of corrosion that results in small craters or holes in the metal. Pitting is potentially one of the most insidious forms of corrosion because it can lead to component failure by perforation while producing only a small loss of metal. Because of their small size and because the pits are often covered with corrosion products, they can be difficult to detect. Pitting occurs when one area of a metal surface becomes anodic with respect to the rest of the surface, or when highly localized changes in the environment in contact with the surface cause accelerated attack. Causes of pitting include local inhomogeneities on or beneath the metal surface, local loss of passivity, mechanical or chemical rupture of the protective oxide surface film, galvanic corrosion from a relatively distant cathode, and the formation of a metal ion or oxygen concentration cell under a solid deposit (crevice corrosion). The rate of penetration into the metal by pitting may be 10 to 100 times greater than for general corrosion. The most common causes of pitting in steels are surface deposits that set up local concentration cells, and dissolved halides that produce local anodes by rupture of the protective surface scale. With corrosion resistant alloys, such as stainless steels, the most common cause of pitting is the highly localized destruction of passivity through contact with a halide-containing environment.

Intergranular attack is preferential dissolution of the grain boundary regions of a metal with only slight or negligible attack of the grain matrix. This preferential attack can be enhanced by segregation of specific elements or impurities, by enrichment of one of the alloying elements in the grain boundaries, or by the depletion of an element that imparts corrosion resistance to the grain boundary areas. Susceptibility to intergranular attack usually develops during thermal processing such as welding or heat treatments. The susceptibility to intergranular attack can often be corrected by redistributing alloying elements more uniformlythrough solution heat treatment, by modifying the alloy to increase resistance to segregation, or by use of a completely different alloy.

Stress corrosion cracking (SCC) is an aging mechanism that occurs by the combined and synergistic interaction of tensile stress, an aggressive environment, and a susceptible material. The material fails by slow, environmentally-induced crack growth that occurs with little or no attendant macroscopic plastic deformation. The stresses required to cause SCC are usually below the yield strength, and are tensile in nature. These stresses can be either applied or residual, and may result from the fabrication process or inservice loading of the component or structure. Common sources of stress include thermal processing and stress risers created during surface finishing, fabrication, or assembly. The length of time required to produce SCC decreases for increasing stress level. The minimum stress at which cracking will occur depends on the temperature, the composition and microstructure of the alloy, and the environment. SCC may initiate at pre-existing mechanical cracks or other surface discontinuities, such as pits produced by chemical attack. Although high tensile stresses are not necessary for irradiation-assisted SCC, they can aggravate the phenomenon.

Microbiologically influenced corrosion occurs when biological organisms affect corrosion processes on metals by directly influencing the anodic and cathodic reactions, by affecting the protective surface scales on metals, by producing corrosive substances, or by creating solid deposits. These organisms include microscopic forms, such as bacteria, and macroscopic types, such as algae and barnacles. Microscopic and macroscopic organisms have been observed to live and reproduce under broad ranges of pressure, temperature, humidity, and pH; thus biological organisms may influence corrosion in a variety of environments.

Erosion-corrosion is an accelerated form of corrosion caused by the relative motion of a corrosive fluid with respect to a metal component. The corrosion process is accelerated because of erosive destruction of the protective oxide film.

4.4 Environmental Stressors

Heat exchangers operating with service water on one side are exposed to environmental stressors that depend upon the quality of the service water. Degradation may be in the form of reduced cooling water flow from siltation or accumulation of living organisms or their debris, reduced heat transfer capability from fouling of the heat transfer surfaces by mineral scale, silt, or biological slime, or corrosion either from the chemical nature of the water or from the effects of accumulated silt or organisms.

Macrofouling by bivalves. Flow blockage problems by bivalve organisms are frequently experienced in plants using fresh water, brackish water, and seawater as service water. The principal organisms causing macrofouling, in fresh water systems, the Asiatic clam and the zebra mussel. In brackish water and seawater systems, macrofouling is caused by the blue mussel and the American oyster. A brief discussion of these organisms, their habitat, and their impact on heat exchangers served by service water follow.

Asiatic clams. Asiatic clams are non-native fresh water mollusks that were first found in the Columbia River in 1938 and now are found in most major river systems in the United States. The larvae (less than 200 microns in size) are released by the adults during the spawning season and are swept, suspended in the water, into the plant via the water intake. In regions of low flow velocity (up to about 1 ft/sec), they then attach themselves to solid surfaces and grow to approximately 0.2 inch, at which size they lose the ability to remain attached. (Under suitable conditions, the adult clam may reach an average length of about 1.4 inches.) Once unattached, the clams or their shells may be swept deeper into the plant and clog piping or heat exchanger tubes. Systems that are used infrequently, with periods of near-stagnant conditions under which the larvae flourish, are most susceptible to clam fouling.

Continuous chlorination of the intake water during peak spawning season appears to offer a substantial degree of control, but can lead to accelerated corrosion unless properly managed. Shock chlorination is ineffective; the clams restrict their feeding and respiratory functions or burrow into sediments to resist the treatment. Clams are very susceptible to heat; Ref. 2 cites TVA tests showing 100%-mortality (at a 99% confidence level) of larvae, young, and half-inch clams when exposed to 120°F water for two minutes.

Zebra mussels. The zebra mussel was introduced to North America in 1985 by a European ship discharging ballast water into Lake St. Clair. Since then, it has spread into Lake Erie, Lake Ontario, and Lake Michigan and is expected to eventually spread throughout the U.S. and southern Canada.[10] Like the Asiatic clam, zebra mussel larvae are carried into power plants by the raw cooling water and settle out in low-velocity areas where they attach to hard surfaces. Unlike the clam, they remain firmly attached and accumulate in great numbers to form mats that may reach a thickness of up to 12 inches. Shells that break loose from these mats can be carried downstream and block heat exchangers. Corrosion enhancement due to reduced flow velocities can occur.

Zebra mussel infestation is a relatively new problem in the U.S., and control methodology is still under investigation.[11,12,13,14]

Blue mussels. Blue mussels are found along the entire west coast of the U.S. and along the east coast as far south as the Carolinas, with growth supported by a temperature range of 34 to 79°F (Ref. 4). They settle and attach to firm, rough substrata or to each other in regions where flow velocity is less than about four ft/sec, forming clusters and mussel beds. From these communities, mussels or their shells may break free and be carried into the heat exchangers. A continuous flow of water is conducive to growth.

Continuous chlorination of the service water, at a concentration of approximately 0.2 ppm and especially during the spawning season, appears to be effective in controlling blue mussels. Thermal backflushing with hot water (113°F for 20 minutes) has also been found to be an effective control method (Ref. 3).

American oysters. American oysters are found along the entire Atlantic and Gulf coasts of the

U.S., with growth supported by water temperatures between 34 and 97°F (Ref. 4). The larvae settle and attach themselves to solid surfaces, including the shells of dead oysters, and proceed to grow with, some reaching a maximum size of more than 8 in. As with the blue mussel, a continuous flow of nutrient-containing water, at a velocity up to 4 ft/sec, is conducive to growth. Oysters and shells that break free create flow blockage in heat exchangers.

Control of oysters can be achieved in the same manner as for blue mussels.

Microbiological fouling. Microbiological fouling can seriously degrade the performance of heat exchangers by coating the heat transfer surface with slime and is conducive to pitting corrosion damage. Microbiological fouling increases rapidly at velocities less than 3 ft/sec, but has also has been found to occur in condenser tubes at velocities of 6 to 8 ft/sec (Ref. 4).

Microbiological fouling may be removed from heat exchanger tubes by pumping sponge balls through the heat exchangers or by chemical or other mechanical cleaning methods. However, a preferred approach is to prevent its formation by the use of biocides, such as chlorine.[15]

5 Operating Experience

5.1 Information Sources

Aging information for heat exchangers was obtained from various sources of nuclear power plant operating experience documentation. These include Licensee Event Reports (LER), Nuclear Plant Reliability Data System, and Nuclear Power Experience (NPE). Maintenance records from two individual plants, one a single-unit BWR for which maintenance records are cataloged in the In-Plant Reliability Data System (IPRDS) and the other a two-unit PWR plant for which maintenance records were made available by the owning utility, were examined but are not included in the assessment. Very few heat exchanger related maintenance calls were included and they provided little additional insight to the aging process.

LERs are issued by nuclear-plant-operating utilities to inform the NRC of plant events having significant safety implications. ORNL's Nuclear Operations Analysis Center (NOAC) maintains a depository of these documents and provides a search capability through the Sequence Coding and Search System (SCSS); it was through this system that LERs applicable to heat exchanger problems were identified and retrieved. A total of 194 LERs, representing operations during the 1980-1989 time period, were included in this assessment. These LERs are summarized in the Appendix.

The NPRDS, compiled by the Institute for Nuclear Power Operations, provides a searchable data base of safety-related events that occur in U.S. nuclear power plants. Although the NPRDS collection usually includes LER-reported events, many others that are of lower safety significance are also included. A total of 510 heat exchanger related events, occurring in the 1974-1989 time frame, were identified. Of these, 470 were not covered in the LER compilation.

Nuclear Power Experience, published by Stoller Power, Inc., is a compilation, derived from several sources, of operating experience in light water reactors. A search of this data base for heat exchanger events was carried out by the NOAC, and 109 heat exchanger related events were identified. Only 46 of these were not included in the LER and NPRDS compilation.

The events were categorized by heat exchanger function, failure type, and failure cause. Function categories include emergency diesel generators, containment cooling, residual heat removal, component cooling water, component coolers, and miscellaneous. The component coolers category includes lube oil coolers for pumps, motors, and gear boxes, pump seal coolers, and motor coolers. The miscellaneous category includes gland seal condensers for pump drive turbines, sample coolers, letdown coolers, and sump coolers. Failure types and the causes attributed to each will be delineated in the following section.

5.2 Summary of Failure Types and Causes

The numbers of events identified from the operating experience information sources, broken out by information source, heat exchanger function, failure type, and cause are given in Table 5.1. In examining the number of events from each information source, the order used in considering the sources should be kept in mind: all of the LER-reported events are included; only those NPRDS-reported events not included in the LER information are included; and only NPE-reported events not included in either the LER or NPRDS information are included. It is obvious, even with this ordering, that the NPRDS provides the richest source for failure data.

The distribution of reported events by failure type for all heat exchanger functions is shown in Fig. 5.1. Three failure types account for more than 90% of the total number of reported events. Internal leaks, between the two fluid streams, is the leading failure type at 39% of the total. External leaks is the second-most prevalent failure type, at 30% of the total, and tube blockage is third,-at 22% of the total. Minor internal or external leakage often does not compromise the safety function of a heat exchanger, but may result in low-magnitude environmental releases. Tube blockage is a safety-threatening event, involving not only the affected exchanger but indicating the potential for a common-mode failure of other exchangers receiving flow from the same source. Impaired heat transfer events, in which the heat transfer surface becomes fouled to the extent that the exchanger cannot accomplish its intended function, account for less than 4% of the total. This paucity of reported events may be due to limited application of performance testing programs needed to detect the degradation of heat transfer capabilities.

Table 5.1 Net Types of Failures and Failure Causes from All Databases

Failure Type and Cause	DIES				CONT				RHR				CCW				COMP				MISC				TOTAL			
	A	B	C	T	A	B	C	T	A	B	C	T	A	B	C	T	A	B	C	T	A	B	C	T	A	B	C	T
Shell-side flow blockage, total	0	0	1	1	3	0	0	3	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	3	1	1	5
Scale buildup	0	0	1	1	2	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	1	3
Other debris	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1
Coating failure	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	1	0	1
Tube-side flow blockage, total	2	15	5	22	10	9	0	19	6	4	0	10	9	73	2	84	8	13	0	21	0	0	0	0	35	114	7	156
Unspecified	0	2	0	2	0	0	0	0	0	0	0	0	4	4	0	8	0	1	0	1	0	0	0	0	4	7	0	11
Scale buildup	1	2	1	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2	1	4
Silt buildup	0	3	0	3	6	3	0	9	0	2	0	2	0	13	0	13	3	6	0	9	0	0	0	0	9	27	0	36
Biological growth	0	7	3	10	4	4	0	8	2	1	0	3	2	1	0	3	1	4	0	5	0	0	0	0	9	17	3	29
Biological debris	1	0	1	2	0	1	0	1	3	0	0	3	2	35	2	39	3	0	0	3	0	0	0	0	9	36	3	48
Other debris	0	1	0	1	0	1	0	1	0	1	0	1	1	14	0	15	0	1	0	1	0	0	0	0	1	18	0	19
Shell/head/nozzle corrosion/erosion	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	1	0	0	1
Coating failure	0	0	0	0	0	0	0	0	1	0	0	1	0	6	0	6	0	0	0	0	0	0	0	0	1	6	0	7
Other	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	1	0	1
External leakage, total	6	20	1	27	56	24	0	80	0	30	1	31	3	30	1	34	15	12	2	29	12	4	0	16	92	120	5	217
Unspecified	2	1	0	3	24	3	0	27	0	1	0	1	0	0	0	0	3	0	0	3	0	0	0	0	29	5	0	34
Tube failure, corrosion	0	0	0	0	8	8	0	16	0	0	0	0	0	0	0	0	0	1	1	2	0	0	0	0	8	9	1	18
Tube failure, erosion/wear	0	3	0	3	21	2	0	23	0	0	0	0	0	0	0	0	6	0	1	7	0	0	0	0	27	5	1	33
Tube failure, fatigue/mech. stress	0	0	1	1	0	6	0	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	1	7
Shell/head/nozzle corrosion/erosion	2	3	0	5	0	0	0	0	0	0	1	1	1	11	1	13	2	1	0	3	0	0	0	0	5	15	2	22
Weld failure	0	1	0	1	0	1	0	1	0	2	0	2	2	2	0	4	2	0	0	2	0	0	0	0	4	6	0	10
Coating failure	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	1	0	1
Gasket failure	0	9	0	9	0	1	0	1	0	18	0	18	0	13	0	13	1	8	0	9	11	4	0	15	12	53	0	65
Other	2	3	0	5	3	3	0	6	0	9	0	9	0	3	0	3	1	2	0	3	1	0	0	1	7	20	0	27
Impending external leakage, total	1	0	0	1	0	0	0	0	0	0	0	0	2	16	0	18	0	0	0	0	0	0	0	0	3	16	0	19
Shell/head/nozzle corrosion/erosion	1	0	0	1	0	0	0	0	0	0	0	0	1	10	0	11	0	0	0	0	0	0	0	0	2	10	0	12
Coating failure	0	0	0	0	0	0	0	0	0	0	0	0	0	6	0	6	0	0	0	0	0	0	0	0	0	6	0	6
Weld failure	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	1	0	0	1

Table 5.1 Net Types of Failures and Failure Causes from All Databases (continued)

Failure Type and Cause	DIES				CONT				RHR				CCW				COMP				MISC				TOTAL			
	A	B	C	T	A	B	C	T	A	B	C	T	A	B	C	T	A	B	C	T	A	B	C	T	A	B	C	T
Inter-fluid leakage, total	11	22	2	35	1	0	2	3	20	33	13	66	5	121	6	132	11	22	2	35	6	0	2	8	54	198	27	279
Unspecified	8	6	0	14	0	0	2	2	6	0	3	9	1	4	3	8	6	6	1	13	3	0	2	5	24	16	11	51
Tube failure, corrosion	1	3	1	5	1	0	0	1	3	14	2	19	2	48	0	50	4	4	0	8	0	0	0	0	11	69	3	83
Tube failure, erosion/wear	2	9	1	12	0	0	0	0	0	5	3	8	0	58	0	58	0	6	0	6	1	0	0	1	3	78	4	85
Tube failure, fatigue/mech. stress	0	2	0	2	0	0	0	0	1	1	1	3	2	6	3	11	0	1	0	1	1	0	0	1	4	10	4	18
Tube-to-tubesheet joint failure	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1	0	0	1	1	1	0	2
Shell/head/nozzle corrosion/erosion	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	2	0	0	0	0	0	0	0	0	0	2	0	2
Weld failure	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	1	1	0	0	0	0	0	0	2	2
Gasket failure	0	0	0	0	0	0	0	0	9	10	3	22	0	0	0	0	0	2	0	2	0	0	0	0	9	12	3	24
Other	0	2	0	2	0	0	0	0	1	3	0	4	0	3	0	3	1	2	0	3	0	0	0	0	2	10	0	12
Impending inter-fluid leakage, total	0	1	0	1	0	0	0	0	0	0	3	3	0	1	1	2	0	0	0	0	0	0	0	0	0	2	4	6
Tube failure, erosion/wear	0	1	0	1	0	0	0	0	0	0	1	1	0	1	0	1	0	0	0	0	0	0	0	0	0	2	1	3
Tube failure, fatigue/mech. stress	0	0	0	0	0	0	0	0	0	0	2	2	0	0	1	1	0	0	0	0	0	0	0	0	0	0	3	3
Impaired heat transfer, total	2	3	1	6	4	0	0	4	0	1	0	1	1	7	1	9	0	5	0	5	0	0	0	0	7	16	2	25
Unspecified	2	0	1	3	4	0	0	4	0	0	0	0	0	1	0	1	0	2	0	2	0	0	0	0	6	3	1	10
Scale buildup	0	1	0	1	0	0	0	0	0	1	0	1	0	2	0	2	0	0	0	0	0	0	0	0	0	4	0	4
Silt buildup	0	0	0	0	0	0	0	0	0	0	0	0	0	4	1	5	0	3	0	3	0	0	0	0	0	7	1	8
Biological growth	0	2	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	2
Fluid circuitry damage	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	1	0	0	1
Other, total	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	2	0	1	0	1	0	0	0	0	0	3	0	3
GRAND TOTAL	22	61	10	93	74	33	2	109	26	68	17	111	20	251	11	282	34	53	4	91	18	4	2	24	194	470	46	710

A - From LER database
B - From NPRDS database, exclusive of LER events
C - From NPE database, exclusive of LER and NPRDS events
T - Net total

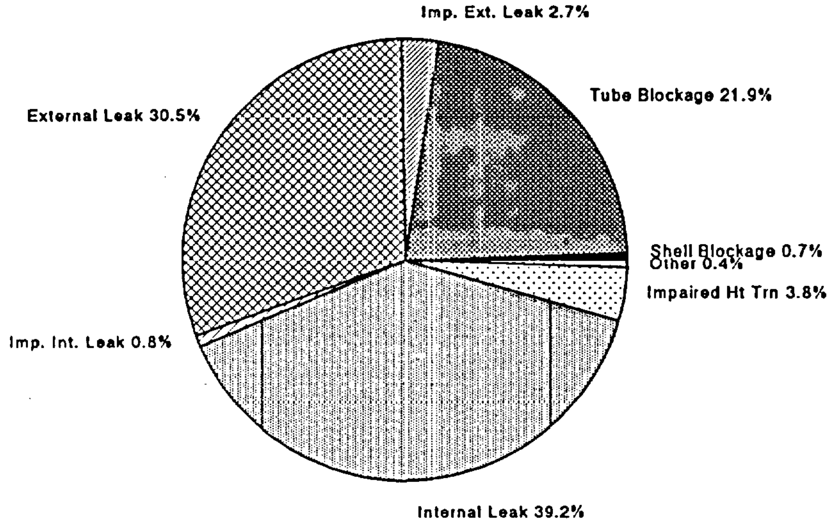

Figure 5.1 Distribution of events by failure type, all functions

5.2.1 Shell-side Flow Blockage

Shell-side flow blockage is a relatively infrequent type of failure because usual practice in design is to place the fluid with fouling or flow-blocking tendencies on the tube side of the exchanger to facilitate cleaning. Only one instance of shell-side blockage in a shell-and-tube exchanger was reported, in a CCW heat exchanger from failure of the coating. The other four shell-side blockages were actually air-side blockages in air-to-water exchangers, three in containment air coolers which were blocked by boric acid accumulations or repair debris and one diesel air-cooled radiator with blockage from fin corrosion.

5.2.2 Tube-side Flow Blockage

Tube-side flow blockage, in which solid material accumulates in the channel heads or in the tubes themselves, is a problem found in the various heat exchangers cooled by service water. The blockage may build up with time, as biofouling, siltation, or debris accumulation progresses, or it may occur quickly due to an upset in the service water system that loosens shells or silt which then are transported into the heat exchanger.

The distribution of the 156 reported tube-side blockage events among the various heat exchanger functions is shown in Fig. 5.2. More than half the events occurred in the Component Cooling Water exchangers, and about an eighth each in component exchangers, containment atmosphere coolers, and emergency diesel exchangers. Tube blockage events in RHR exchangers were limited to BWR plants; in PWR plants, the RHR exchangers are not exposed to service water.

The distribution of blockage events by reported cause is shown in Fig. 5.3. Half the events are attributed to biological causes, either biological growth that occurs in place or debris from bivalves. Blockage by silt (23%) and debris (12%) account for most of the remaining identified event causes.

5.2.3 External Leakage

External leakage, where one of the fluids flowing through the heat exchanger leaks to the surrounding environment, is the second-most prevalent failure type, with 217 reported events. External leakage results from failure of the shell or its joints in shell-and-tube exchangers, or from tube failure in an air cooler. It should be noted that leakage in an air cooler might be classified as interfluid leakage. However, since this leakage is to the surrounding environment, it is included here. It should be further noted that minor external leakage may not interfere with an exchanger's ability to fulfill its safety function.

The distribution of external leakage events by heat exchanger function is shown in Fig. 5.4. More than

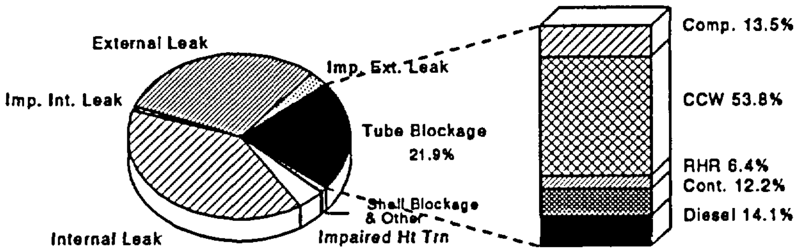

Figure 5.2 Distribution of tube blockage by heat exchanger function

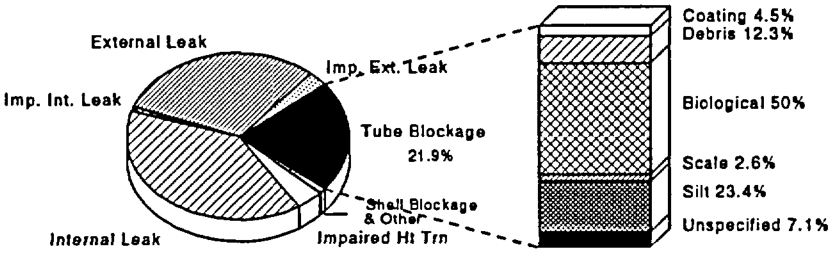

Figure 5.3 Distribution of tube blockage by cause

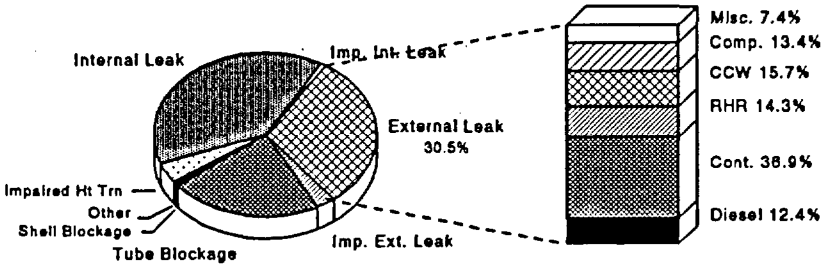

Figure 5.4 Distribution of external leakage by heat exchanger function

one third of the reported events were associated with containment atmosphere coolers. Shell-and-tube exchangers for the component cooling water, RHR, component cooling, and diesel cooling functions each account for 12-16% of the events.

Distribution of the events by cause is shown in Fig. 5.5. Gasket and weld failures and shell corrosion, all in shell-and-tube exchangers, account for about 45% of the total. Almost all of the cause-unspecified failures represent tube failures in containment atmosphere coolers; these and other tube failures attributed to erosion, corrosion, and fatigue occurred in air coolers, either containment atmosphere or motor coolers. Erosion due to excessive water velocity or entrained silt was the most-often cited cause of tube failures. The 'Other' cause category includes a wide variety of miscellaneous occurrences, such as loose flange bolts, faulty fittings and plugs, and manufacturing or design deficiencies.

5.2.4 Impending External Leakage

Impending external leakage events are those in which inspection revealed wall thinning or pitting of the shell or channel heads that would ultimately lead to external leakage if corrective actions in the form of repair or control measures were not taken. In most instances, the cause was attributed to coating failure (sometimes due to erosion) or to lack of proper cathodic protection.

5.2.5 Inter-fluid Leakage

Inter-fluid leakage, where one of the fluids leaks into the fluid flowing on the other side of the heat exchanger, was the most prevalent failure type identified in the data sources, with 279 reported events. This type of failure may cause undesirable contamination of normally low-activity systems (e.g., the Component Cooling Water System or the Service Water System), possibly leading to environmental releases, or may result in contamination of clean, closed systems such as the Component Cooling Water System with service water.* Inter-fluid leaks in some component coolers may result in severe degradation of the component's lubricating oil and lead to component damage.

The distribution of the inter-fluid, or internal, leakage events by heat exchanger function is shown in Fig. 5.6. Almost half the reported events were in component cooling water heat exchangers and almost one-quarter were in RHR exchangers. Review of the data revealed that 94% of the internal leakage events for RHR exchangers occurred in BWR plants, resulting to some extent from the practice of using service water to cool these exchangers in those plants. Heat exchangers for cooling components and for diesel cooling each accounted for one-eighth of the total.

Distribution of the events by attributed cause is shown in Fig. 5.7. Two-thirds of the events were from tube leaks attributed to corrosion, erosion, and fatigue. In addition, many of the cause-unspecified events were tube leaks. Corrosion was the major cause of tube failures in RHR exchangers and 84% of these corrosion-caused failures occurred in BWR plants, probably reflecting the effect of long periods of idleness (during normal reactor operation) with

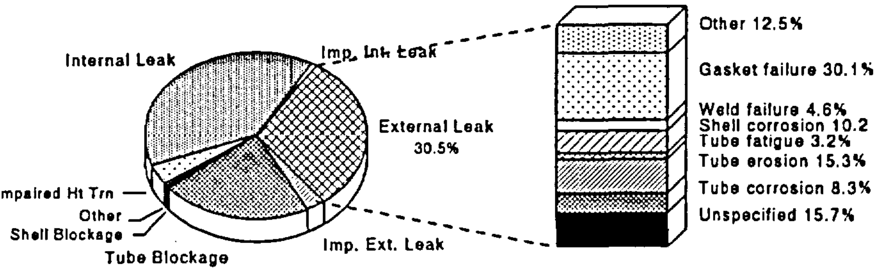

Figure 5.5 Distribution of external leakage by cause

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*In some applications, system design establishes the differential pressure between the two sides of the exchanger such that any interfluid leakage will be in the desired direction (e.g., in fuel pool coolers, any leakage will be service water into the pool water to preclude releases of contaminated water to the environment.

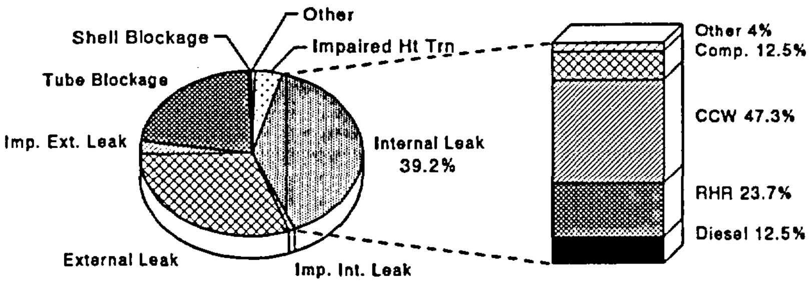

Figure 5.6 Distribution of internal leaks by heat exchanger function

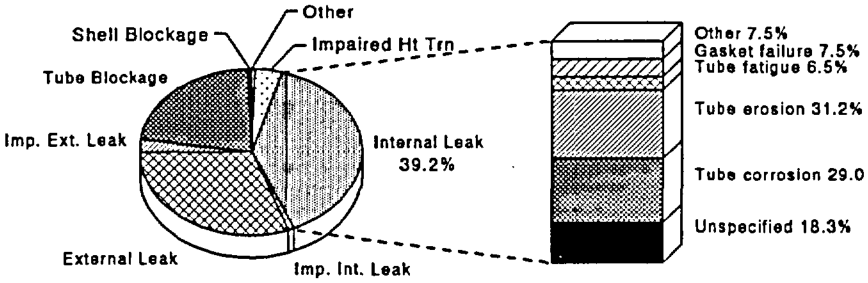

Figure 5.7 Distribution of internal leaks by cause

incomplete replacement of contained service water by demineralized water for the idle periods. In CCW exchangers, erosion was the leading attributed tube failure cause (49% versus 42% due to corrosion), reflecting continuous flow of service water in these exchangers. Most of the inter-fluid leaks attributed to gasket failures were in RHR heat exchangers, occurring in floating head joints.

5.2.6 Impending Inter-fluid Leakage

Impending inter-fluid leakage events consisted of the discovery, during inspection or cleaning, of erosion or vibration damage to tubes before actual leakage had occurred. Only six of these events were reported, one in a diesel glycol cooler, three in RHR exchangers, and two in CCW exchangers.

5.2.7 Impaired Heat Transfer

Impaired heat transfer events consisted of instances where a heat exchanger was unable to transfer the required amount of heat because of fouling of the heat exchange surface or fluid circuitry damage. Although event descriptions were not definitive in all cases, it appears that these events were not caused by flow blockage. Of the 25 events reported, six were related to the emergency diesel coolers, four to containment coolers, one to RHR heat exchangers, nine to component cooling water heat exchangers, and five to component coolers. Eight of the events with identified cause were attributed to silt buildup, four to scale buildup, and two to biological fouling. Only one was attributed to fluid circuitry damage, due to pass partition plate deflection because of inadequate design.

5.3 Failure Types as a Function of Cooling Water

It has been noted previously that certain failure types occur primarily in heat exchangers cooled by service water. This is substantiated by the data in Table 5.2, in which the events reported in the NPRDS data base for RHR heat exchangers are separated by reactor type. In PWR plants, with few exceptions, these exchangers are cooled by component cooling water. In BWR plants, the usual practice is to utilize raw service water for this function. Although the population of BWR reactors is approximately half that of PWR reactors and the population of RHR exchangers in BWRs is approximately 70% of that for PWRs, events reported for BWR exchangers were higher by a factor of 3.4.

Table 5.2 Failure Types and Causes for RHR Heat Exchangers, by Reactor Type

Failure Type and Cause	PWR	BWR
Tube-side flow blockage, total	0	4
Silt buildup	0	2
Biological growth	0	1
Other debris	0	1
External leakage, total	14	16
Unspecified	1	0
Weld failure	0	2
Gasket failure	8	10
Other	5	4
Inter-fluid leakage, total	2	38
Unspecified	0	1
Tube failure, corrosion	1	16
Tube failure, erosion/wear	1	4
Tube failure, fatigue/mech. stress	0	1
Gasket failure	0	13
Other	0	3
Impaired heat transfer, total	1	0
Scale buidup	1	0
GRAND TOTAL	17	58

There were no instances of tube-side flow blockage reported for PWR plants, while four events were reported for BWR plants. These BWR events were due to silt, biological growth, and miscellaneous debris from the raw service water used to cool the exchangers.

External leakage events occurred in the RHR heat exchangers of both PWR and BWR plants, due primarily to gasket failures. Except for the propensity for corrosion of components operating in untreated service water, a failure cause for which there were no reported external leakage events for either reactor type, cooling water quality should have little influence on this failure type.

Inter-fluid leakage events were prevalent in BWR plant RHR heat exchangers but rare in those for PWRs. For the BWRs, approximately 40% of these failures were attributed to corrosion of tubes (water-quality-related) and more than 30% were attributed to gasket failures in the floating heads of the exchangers (probably not water-quality-related). Five events, one in a PWR plant that uses component cooling water for cooling the RHR exchangers and four in BWRs, were attributed to wear (usually not further defined).

Only one impaired heat transfer event, due to fouling of the heat exchange surface by deposit buildup, was reported. This occurred in a PWR plant that uses raw service water (lake water) for RHR heat exchanger cooling.

5.4 Frequency of Failures

Data from which the frequency of heat exchanger failures can be determined are not available from the information sources used in this assessment. From consideration of the operating experience data and from the very nature of heat exchanger failures, it is questionable whether frequency of failures, or mean time between failures, is a meaningful index of reliability for these components.

The failures are of two basic types - impaired flow passing or heat transfer capabilities due to fouling of the flow passages or heat transfer surface, and leakage either between fluid streams or to the external environment. Impaired flow passage events were attributed predominantly to biological growth or debris, the development of which is not normally a long term time-dependent phenomenon but is related to seasonal effects and inadequacy of control methods. Impaired heat transfer events were attributed to a variety of causes, some of which (e.g., scale and silt buildup) are time-related, but this problem type accounted for less than four percent of the total reported events. Inter-fluid leakage was most often attributed to tube-side corrosion and erosion/wear.

Both corrosion and erosion damage are cumulative with time.

When failures have occurred, they usually have been attributable to plant-specific equipment designs, materials of construction, or local water conditions or methods of treatment. Failures from these local situations are not amenable to the derivation of global representations of frequency of failures.

5.5 Method of Detection

The NPRDS data base includes information identifying how each reported failure was recognized or brought to the attention of the plant staff. The detection means are categorized as follows.

Operational abnormality. A failure detected from indications received during normal operation of the system or component by individuals assigned duties involving the system.

Inservice inspection. A failure detected during a scheduled inservice inspection, such as might be required by the ASME Boiler and Pressure Vessel Code, Section XI.

Surveillance testing. A failure detected through routine periodic testing, as for calibration, trip-point checks, or functional checks.

Preventive maintenance. A failure detected while performing preventive maintenance.

Special inspection. A failure detected during the performance of an inspection not routinely scheduled or required.

Audiovisual alarm. A failure detected by an alarm that either can be heard or seen.

Routine observation. A failure detected as a result of normal log taking, log review, or daily/weekly inspections. Usually, this would be within the normal duties or job function performed by plant personnel.

Incidental observation. A failure detected by casual observation or chance witnessing by individuals not assigned duties involving the system.

Other. A failure in which the method of detection cannot be assigned to any of the above categories.

The distribution of all failure types by detection category is shown in Fig. 5.8. Detection by routine observation during normal activities of plant personnel was the leading means for failure recognition, accounting for almost one-third of the total. Detection from operational abnormalities, surveillance testing, and special inspections each account for near-equal fractions of the total and, in combination, accounted for half the total. Detection during preventive maintenance activities accounted for eight per cent of the total, and less than five per cent each were detected by incidental observation, audiovisual alarms, or inservice inspection.

As would be expected, the incidence of failure discoveries by the various detection categories varies significantly between the different failure types. Figs. 5.9 - 5.12 present the distributions, by detection method, for the more significant failure types.

Flow blockage failures were most often recognized by excessive pressure differential (approximately 53% of events). Other blockages were found during inspections and tests (21%), by high system or component temperatures (14%), or by low flow (12%). The distribution, by method of detection, of tube blockage failures as shown in Fig. 5.9 is quite similar to that for total failures. Routine observations account for about one-third of the total, followed by operational abnormalities and surveillance testing at one-fifth each. Special inspections detected about one-eighth of the tube blockage failures, and the remainder were detected by audiovisual alarms, preventive maintenance, inservice inspection, and incidental observation.

Detection of external leakage failures was distributed among detection methods as shown in Fig. 5.10. This type of failure often has visible effects and is more readily observable than other failure types. As with tube blockage failures, the dominant detection method was routine observation, comprising 37 per cent of the total. Special inspections detected more than one-fifth, and incidental observation one-tenth of the total.

Internal leaks, between the two fluid streams, are detectable from changes in closed system surge tank level, from chemical or activity measurement, from

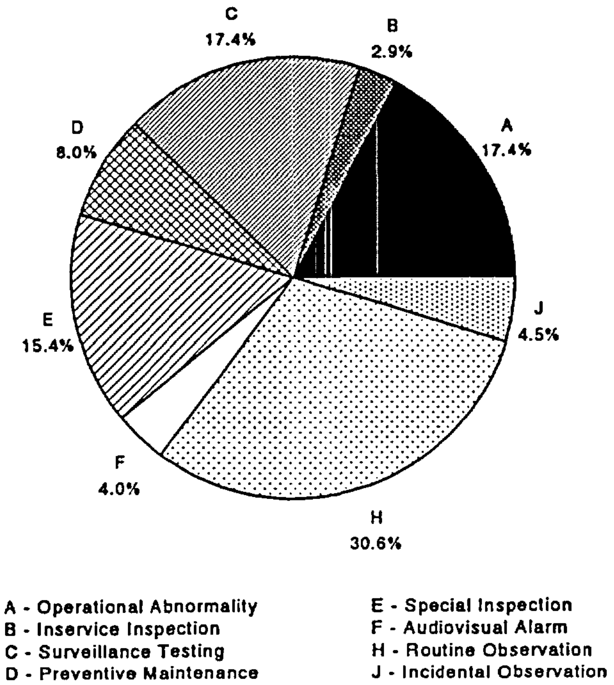

Figure 5.8 Detection methods, all failure types

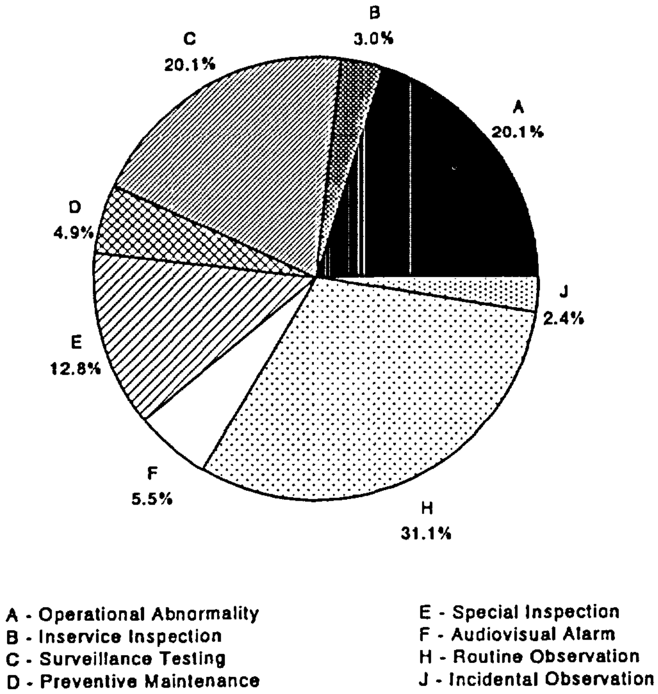

Figure 5.9 Detection methods, tube blockage

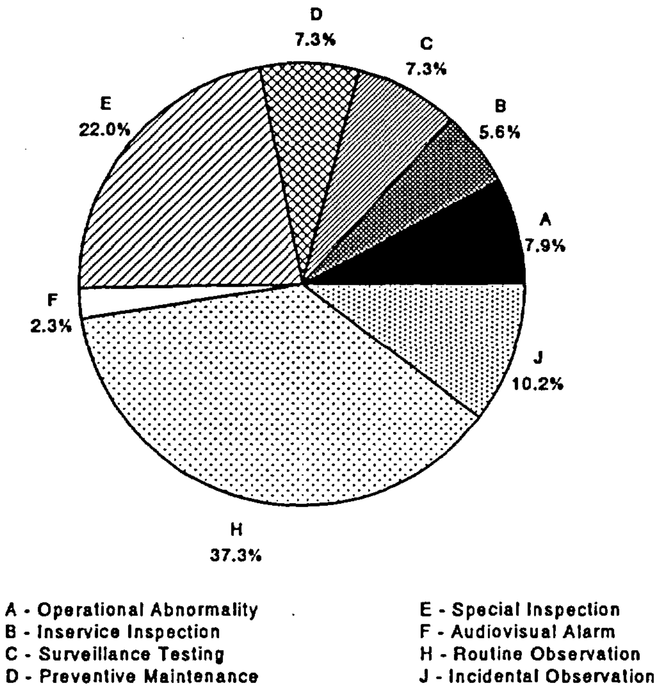

Figure 5.10 Detection methods, external leakage

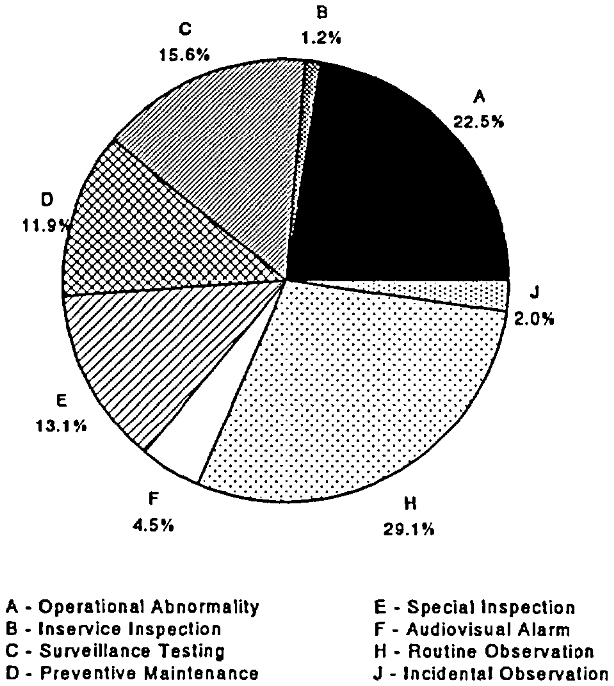

Figure 5.11 Detection methods, internal leakage

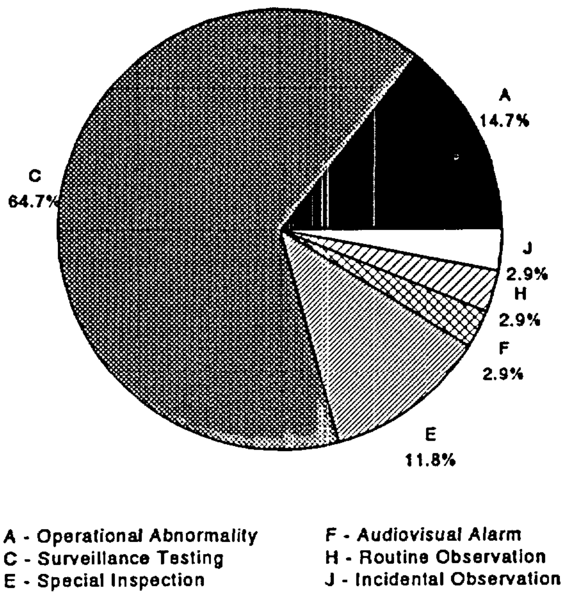

Figure 5.12 Detection methods, impaired heat transfer

inspections and tests, or from visual observation (such as water in lubricating oil). Distribution, by detection method, of the internal leak failures is shown in Fig. 5.11. Slightly more than half the failures were detected by routine observations and operational abnormalities. Surveillance testing, special inspections, and observations during preventative maintenance each accounted for about one-eighth of the total.

Failures due to impaired heat transfer were detected as shown in Fig. 5.12. Almost two-thirds were detected during surveillance testing. Operational abnormalities, often consisting of excessive system or component temperatures, revealed almost 15 per cent of the failures and special inspections, often resulting from observance of operational abnormalities, accounted for almost 12 per cent of the total.

6 Maintenance and Surveillance Practices

6.1 Codes and Standards Requirements

The Code of Federal Regulations (10 CFR Part 50) General Design Criteria 44, 45, and 46 require provision of a service water system to transfer heat from systems and components important to safety to the ultimate heat sink. They further require that the system design permits periodic inspection and testing of important components, such as heat exchangers, to assure the integrity and capability of the system. Generic Letter 89-13 (GL 89-13), issued in July 1989, requires nuclear plant licensees and applicants to provide assurances of compliance with 10 CFR Part 50 and that the safety functions of their service water systems are being met. Initially, GL 89-13 requires testing of safety-related heat exchangers at least once per refueling cycle; after three cycles, the licensee may modify the frequency of testing as appropriate to assure that the equipment will perform the intended safety function during the interval between tests. The minimum final testing frequency should be once every 5 years.

The ASME Boiler and Pressure Vessel Code, Section XI, the provisions of which are incorporated by reference in plant Technical Specifications, is aimed primarily at assuring the integrity of pressure containing boundaries and includes requirements for preservice inspection and subsequent periodic reexamination of welds in pressure-containing parts of heat exchangers. Also included are requirements for periodic system leak and hydrostatic tests. There are no requirements for inservice performance testing of the exchangers.

The ASME Operation and Maintenance Committee is in the process of developing standards and guides that cover inservice testing of various nuclear plant components and systems. Parts of these that are applicable to heat exchangers are:

> Part 2 - *Requirements for Performance Testing of Nuclear Power Plant Closed Cooling Water Systems.* This Part was published as a part of the ASME OM-S/G-1990 Standard. Requirements include tests to demonstrate system operability at intervals of not greater than 18 months, and tests to evaluate heat removal capability of the system and degradation of system components at 5-year intervals. It is suggested that heat removal capability be evaluated in terms of the overall heat transfer coefficient, U, that is derived from measured parameters, the available heat transfer area, A (accounting for plugged tubes), and the available log mean temperature difference. Any heat exchanger degradation would be revealed by monitoring the product of U and A.
>
> Part 11 - *Vibration Monitoring of Heat Exchangers.* This Part, recently accepted by the ASME/ANSI OM approval procedures, has not been published. The Part provides guidance for the development of test procedures and evaluation of data for the measurement and evaluation of heat exchanger vibration.
>
> Part 21 - *Inservice Performance Testing of Heat Exchangers in LWR Plants.* This Part is under development, with presentation for first-level balloting scheduled for late 1992. The Part will provide performance and functional testing criteria for auxiliary safety related heat exchangers to assure that they meet their intended safety functions from a thermal performance standpoint.

The ASME O&M Part 21 will provide methodology for selecting those heat exchangers to be included in the inservice testing program, for selecting the types of tests to be conducted, and for the conduct and results analysis of the tests. In recognition of varying degrees of difficulty associated with establishing suitable test conditions and means for measuring test parameters, a hierarchy of test methods ranging from heat transfer coefficient determination to visual inspection is being developed. Part 21 is limited to evaluation of thermal performance; flow-induced vibration, structural integrity, pressure boundary integrity, and erosion/corrosion are not addressed.

6.2 Electric Power Research Institute (EPRI) Guidelines

In recognition of the utility industry's need for guidance in developing test programs applicable to heat exchangers cooled by service water, EPRI has developed and published the Heat Exchanger Performance Monitoring Guidelines.[16] Original development of the Guidelines was carried out by two utility engineers who later were appointed chairman and secretary of the ASME O&M Part 21 Working Group. As a result, the structure of the Guidelines and early drafts of Part 21 have many similarities. The Guidelines document provides a valuable tool to assist the utilities in developing programs for performance monitoring of heat exchangers subject to fouling.

6.3 Utility Practices

Inservice inspection activities conducted by plant owners varies, depending upon operating experience at each plant. For plants having no serious fouling potential from the service water, inservice inspections are often limited to those required to assure integrity of pressure containing boundaries, as required by the ASME Code.

Other plants that have experienced biofouling, fouling by siltation or scale, or MIC may have regularly scheduled inspections that consist of removing the exchanger heads and inspecting for the presence of fouling or MIC. One plant schedules these inspections at 3-year intervals for shell-and-tube CCW exchangers. This same plant has replaced some of its shell-and-tube exchangers with plate type exchangers. Operating experience with these exchangers is limited; disassembly and cleaning is presently scheduled on an annual basis until further experience is gained. In addition, a performance test is scheduled for once per refueling cycle. In this test, sufficient data is obtained to permit determining the overall heat transfer coefficient and, from this, the fouling factor is derived for comparison with its limiting value.

The Turkey Point Nuclear Plant, owned and operated by Florida Power and Light, utilizes a recirculating open-loop Intake Cooling Water System to provide cooling water for the CCW heat exchangers. Because of the high mineral content of this water, the fouling factor for the CCW exchangers has been observed to increase at a rate of 0.00007 to 0.00009 hr-ft^2-F/Btu/day[17]. Since 1985, a heat exchanger performance testing program has been conducted to track the degradation of heat transfer ability and to aid in determining the schedule for tube cleaning such that the exchangers can meet their accident condition performance requirements with the existing intake cooling water temperature. As needed, tube cleaning is accomplished by forcing cleaning plugs through the tubes by water pressure.

7 Aging Degradation Monitoring

7.1 Aging-Related Degradation

The results of the degradation of heat exchangers generally are limited to flow blockage on either the shell or tube side, leakage to the external environment of one of the fluids flowing through the exchanger, leakage of one of the fluids into the other, or reduced heat transfer capability due to fouling of the heat transfer surface. Each of these degradation types may be time-related (although on quite different time scales) and may, therefore, be considered a result of aging.

7.2 Degradation Monitoring

Degradation monitoring methods were discussed generally in an earlier section describing the methods of detection of failures in heat exchangers, and are summarized as follows.

Flow blockage

- Direct flow measurement
- Abnormal pressure differential across exchanger
- Reduced heat transfer function
- Excessive temperature rise in cooling fluid
- Physical inspection

External leakage

- Physical observation
- Fluid accumulation in sumps
- Hydrostatic and leak testing
- Acoustic emission testing
- Radiographic or ultrasonic inspection (for impending leakage)

Interfluid leakage

- Chemical and radiolytic analysis
- Surge tank level monitoring
- Hydrostatic and leak testing
- Acoustic emission testing
- Eddy current tube testing (for impending leakage)
- Observation of fluid appearance (e.g., water in oil)

Fouling of heat exchange surface

- System or component temperature monitoring
- Performance testing
- Abnormal pressure differential across exchanger

8 Summary and Recommendations

Nuclear power plants utilize many heat exchangers in the non-power-cycle portion of the plants to provide system and component cooling in both safety-related and non-safety systems. These exchangers are exposed to stressors that have, in numerous instances, resulted in degraded performance or in failures of various types.

Many of the leakage failures, either external or internal, do not compromise the ability of the exchangers to fulfill their safety functions but may result in low magnitude environmental releases. Failures of more serious consequence are those that result in inadequate heat transfer ability for normal operations or for meeting more stringent requirements associated with accident conditions. These failure types consist of blockages that prevent adequate cooling water flow or fouled heat transfer surfaces that degrade cooling performance. Both of these types of failures are limited primarily to exchangers that utilize raw cooling water as their heat sink. A major problem is the control of biological organisms in the raw water; biocide injection at the raw water intakes is the most common control method, but this increasingly is in conflict with environmental regulations.

Flow blockage and external or interfluid leakage problems are usually detectable through careful monitoring of process variables and routine observations. Detection and assessment of the severity of fouled heat transfer surfaces are more difficult, often requiring a special performance test and evaluation of the acquired data. It appears that, in the past, this was done on a sporadic basis, possibly because there were no firm Code or Technical Specification requirements that these tests and evaluations be conducted. Recently, probably because of the requirements contained in Generic Letter 89-13, procedures for the performance tests and subsequent analyses have been or are being developed for many plants. Part OM-21 of the ASME Operation and Maintenance Standards, now under development, will formalize the requirements for and present such procedures.

The difficulties in conducting performance tests, assessing the results, and predicting performance at accident conditions for certain heat exchangers are recognized. In many cases, installed instrumentation is not available to accurately measure the needed parameters. Sufficient heat load to permit effective performance testing may not be available for some exchangers except during reactor cooldown (e.g., the RHR exchangers), requiring that the tests be conducted within a relatively narrow time frame. In other cases, a system or storage tank must be abnormally heated to provide the heat load for exchanger testing during the return to normal temperatures, necessitating testing under transient conditions.

It is concluded that presently used methods for the detection of flow blockage and leakage, either external or interfluid, are adequate and means for improvement are not evident. Although it appears that degradation of heat transfer ability due to fouled heat exchange surface has not been monitored, through inservice performance testing, as well as it should have been, extensive activity to establish programs in this area is underway both by plant owners and the ASME Operation and Maintenance Committee and improvements should be forthcoming.

An evaluation of experience and findings resulting from utility response to Generic Letter 89-13 is recommended. This evaluation should provide valuable information and insights on the as-found conditions and capabilities of plant heat exchangers, the effectiveness of extant and enhanced maintenance practices, and improved inservice testing methodology.

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Appendix A. Heat Exchanger Problems Identified From LER Search

RHR HEAT EXCHANGER PROBLEMS FROM LER SEARCH
(BY PROBLEM TYPE AND CAUSE)

PLANT NAME	DATE	LER	PROBLEM
PROBLEM TYPE: Tube-side Blockage			
CAUSE TYPE: Biological Growth			
BEAVER VALLEY 2	04/27/89	89-13	SERVICE WATER FLOW RESTRICTION THROUGH RECIRCULATION SPRAY HX FROM ASIATIC CLAMS.
OYSTER CREEK	12/30/82	82-64	HIGH BAFFLE PLATE DELTA P DUE TO BIOFOULING IN CONTAINMENT SPRAY HX.
CAUSE TYPE: Biological Debris			
BRUNSWICK 1	04/19/81	81-32	BAFFLE PLATE IN CHANNEL HEAD OF 1B RHR HX WAS DISPLACED, DUE TO EXCESSIVE PRESSURE DIFFERENTIAL FROM BLOCKAGE BY SHELLS.
BRUNSWICK 2	04/12/80	80-30	BAFFLE PLATE IN CHANNEL HEAD OF RHR HX WAS DISPLACED DUE TO HIGH DIFFERENTIAL PRESSURE FROM SHELL ACCUMULATION.
BRUNSWICK 2	05/06/81	81-49	PARTIAL DISPLACEMENT OF CHANNEL HEAD DIVIDER PLATE IN RHR HX DUE TO HIGH DIFFERENTIAL PRESSURE FROM BLOCKAGE BY SHELLS.
CAUSE TYPE: Coating Failure			
OYSTER CREEK	07/22/85	85-18	FRAGMENTS OF PIPE-COATING COAL TAR ENAMEL PARTIALLY BLOCKED TUBESHEET OF CONTAINMENT SPRAY HX, CAUSING HIGH BAFFLE PLATE DELTA P.
PROBLEM TYPE: Inter-fluid Leakage			
CAUSE TYPE: Unspecified			
ARKANSAS NUCLEAR 2	01/09/83	83-3	ACTIVITY IN SERVICE WATER SYSTEM DUE TO TUBE LEAKS AND TUBE-TO-TUBESHEET WELD LEAKS IN THE SHUTDOWN COOLING HX.
DRESDEN 3	06/20/80	80-26	THIRTEEN LEAKY TUBES WERE FOUND IN THE LPCI HEAT EXCHANGER.

RHR HEAT EXCHANGER PROBLEMS FROM LER SEARCH (cont'd)
(BY PROBLEM TYPE AND CAUSE)

PLANT NAME	DATE	LER	PROBLEM
MAINE YANKEE	09/29/82	82-32	TRANSIENT LEAKAGE IN RHR HX WAS DETECTED BY XE-133 ACTIVITY IN SECONDARY CCW SYSTEM.
PEACH BOTTOM 2	03/28/84	84-6	CONTAMINATION IN HPSW SYSTEM FROM LEAK IN BELLOWS PORTION OF RHR HX.
PEACH BOTTOM 3	11/04/82	82-22	RADIOACTIVE LEAK TO INTAKE STRUCTURE VIA LEAK IN RHR HX.
SURRY 2	07/20/86	86-11	SERVICE WATER LEAKAGE INTO CONTAINMENT DUE TO EIGHT LEAKING TUBES IN RECIRCULATING SPRAY HX.
CAUSE TYPE: Tube Failure, Corrosion			
DRESDEN 2	09/04/80	80-33	CORROSION-INDUCED LEAKAGE FOUND IN 46 TUBES OF LPCI HX.
DRESDEN 3	12/15/80	80-44	CORROSION-CELL CORROSION RESULTED IN LEAKS THAT SHOWED UP AFTER CLEANING IN 4 TUBES IN THE LPCI HX.
OYSTER CREEK	02/19/80	80-9	THE FOUR CONTAINMENT SPRAY HXS DEVELOPED CORROSION-INDUCED LEAKS
CAUSE TYPE: Tube Failure, Fatigue or Mechanical Stress			
OYSTER CREEK	08/27/81	81-38	FATIGUE-INDUCED FAILURE OF TUBES IN SHUTDOWN COOLING HX.
CAUSE TYPE: Gasket Failure			
BROWNS FERRY 1	04/11/80	80-43	LEAKAGE FROM GASKET IN RHR HX DUE TO LOOSENED LOCK NUTS.
BROWNS FERRY 1	06/20/80	80-49	LEAKAGE AT FLOATING HEAD OF RHR HX DUE TO LOOSE LOCKING AND FULL NUTS RESULTING FROM THERMAL CYCLING AND VIBRATION.
BROWNS FERRY 1	11/28/85	86-4	LEAKAGE AT INNER FLOATING HEAD GASKET OF RHR HX, CAUSED BY RELAXATION OF GASKETED JOINT.
BROWNS FERRY 2	08/15/80	80-33	LEAKING GASKET ON 2B RHR HX DUE TO LOOSE FLANGE NUTS RESULTING FROM THERMAL CYCLING AND VIBRATION.

RHR HEAT EXCHANGER PROBLEMS FROM LER SEARCH (cont'd)
(BY PROBLEM TYPE AND CAUSE)

PLANT NAME	DATE	LER	PROBLEM
BROWNS FERRY 2	08/15/80	80-34	GASKET LEAK ON 2C RHR HX DUE TO LOOSENED LOCK NUTS AND FULL NUTS, RESULTING FROM THERMAL CYCLING AND VIBRATION.
BROWNS FERRY 2	12/05/80	80-53	LEAKY INNER HEAD GASKET ON 2C RHR HX DUE TO LOOSE FLANGE NUTS RESULTING FROM THERMAL CYCLING AND VIBRATION.
BROWNS FERRY 3	08/15/80	80-33	LEAKING GASKET IN RHR HX DUE TO LOOSE FLANGE NUTS, CAUSED BY THERMAL CYCLING AND VIBRATION.
MONTICELLO	05/04/82	82-6	LEAK IN RHR HEAT EXCHANGER AT FLOATING HEAD GASKET.
QUAD CITIES 1	01/09/83	83-4	MINOR LEAKAGE BETWEEN PRIMARY SYSTEM TO RHR SERVICE WATER DUE TO INNER HEAD GASKET FAILURE IN THE 1A RHR HX.
CAUSE TYPE: Other			
BROWNS FERRY 3	01/16/83	83-4	LEAK OF REACTOR COOLANT TO RHR SERVICE WATER VIA CRACKED TUBE IN RHR HX. CAUSE WAS MECHANICAL DAMAGE PRIOR TO TUBE INSTALLATION.

Appendix A

CONTAINMENT HEAT EXCHANGER PROBLEMS FROM LER SEARCH
(BY PROBLEM TYPE AND CAUSE)

PLANT NAME	DATE	LER	PROBLEM
PROBLEM TYPE: Shell-side Blockage			
CAUSE TYPE: Scale Buildup			
MILLSTONE 2	04/08/88	88-8	AIR FLOW BLOCKAGE IN CEDM COOLER RESULTED IN OVERHEATING OF CONTROL ELEMENT GRIPPER COILS AND PREMATURE DROPPING OF CONTROL ELEMENTS. BLOCKAGE WAS FROM BORIC ACID ACCUMULATION.
OCONEE 3	01/12/89	89-1	AIR-SIDE SERVICE-INDUCED FOULING OF REACTOR BUILDING COOLING UNITS REDUCED PERFORMANCE CAPABILITIES OF THE UNITS TO UNACCEPTABLE LEVEL. (PER NPRDS, FOULING WAS BORON (BORIC ACID?))
CAUSE TYPE: Other Debris			
TURKEY POINT 3	01/25/86	86-4	DEBRIS FROM PREVIOUS STEAM GENERATOR REPAIR WAS FOUND ON THE AIR SIDE OF THE CONTAINMENT FAN COIL COOLERS.
PROBLEM TYPE: Tube-side Blockage			
CAUSE TYPE: Silt Buildup			
FITZPATRICK	10/21/88	88-9	EXTENSIVE FOULING OF REACTOR BUILDING UNIT COOLERS BY MUD AND SILT.
KEWAUNEE	09/28/84	84-18	ESF EQUIPMENT AREA FAN COIL UNITS FOUND TO HAVE SUBDESIGN AIR FLOW AND PARTIAL PLUGGING OF WATER FLOW PASSAGES BY SILT, SUCH THAT ACCIDENT CONDITIONS CAPABILITY WAS INADEQUATE.
SALEM 2	08/31/82	82-96	LOW SERVICE WATER FLOW THROUGH CONTAINMENT FAN COIL UNIT #23 DUE TO SILT BUILDUP IN COOLING COILS.
SALEM 2	09/01/82	82-98	LOW SERVICE WATER FLOW THROUGH CONTAINMENT FAN COIL UNIT #21 DUE TO SILT BUILDUP IN COOLING COILS.
SALEM 2	09/02/82	82-99	LOW SERVICE WATER FLOW THROUGH CONTAINMENT FAN COIL UNIT #23, DUE TO SILT BUILDUP IN COOLING COILS.

CONTAINMENT HEAT EXCHANGER PROBLEMS FROM LER SEARCH (cont'd)
(BY PROBLEM TYPE AND CAUSE)

PLANT NAME	DATE	LER	PROBLEM
SALEM 2	09/08/82	82-105	REDUCED SERVICE WATER FLOW THROUGH CONTAINMENT FAN COIL UNIT #22 DUE TO SILT BUILDUP IN COILS.
CAUSE TYPE: Biological Growth			
ARKANSAS NUCLEAR 1	09/16/80	80-35	LOW SERVICE WATER FLOW THROUGH REACTOR BUILDING COOLING COILS DUE TO GROWTH OF ASIAN CLAMS IN COOLERS.
ARKANSAS NUCLEAR 2	09/03/80	80-72	SERVICE WATER FLOW RESTRICTION IN CONTAINMENT BUILDING COOLERS DUE TO BUILDUP OF ASIAN CLAMS GROWING IN THE COOLERS.
BROWNS FERRY 3	11/08/80	80-47	FLOW RESTRICTIONS TO CORE SPRAY ROOM COOLER DUE TO BIOFOULING, SILT ACCUMULATION, AND CORROSION.
ROBINSON 2	09/05/88	88-19	BIOLOGICAL FOULING OF TUBE-SIDE OF CONTAINMENT FAN COOLERS REDUCED FLOW ABILITY TO LESS THAN REQUIRED FOR DESIGN BASIS HEAT REMOVAL.
PROBLEM TYPE: Exterior Leakage			
CAUSE TYPE: Unspecified			
DAVIS-BESSE 1	09/15/81	81-57	MINOR TUBE LEAKS IN ECCS ROOM AIR COOLERS.
INDIAN POINT 2	08/19/82	82-33	SERVICE WATER LEAK FROM MAIN COIL OF FAN COOLER UNIT.
INDIAN POINT 2	09/02/82	82-37	SERVICE WATER LEAK FROM COIL OF FAN COOLER UNIT.
INDIAN POINT 3	12/05/80	80-16	TUBE LEAK IN MAIN COIL OF FAN COOLER UNIT #35.
ROBINSON 2	07/04/83	83-14	SERVICE WATER LEAK FROM DEFECTIVE TUBE BUNDLE IN CONTAINMENT FAN COOLER HVH-2.
ROBINSON 2	08/23/83	83-22	SERVICE WATER LEAK FROM DEFECTIVE TUBE BUNDLE IN CONTAINMENT FAN COOLER HVH-2.

CONTAINMENT HEAT EXCHANGER PROBLEMS FROM LER SEARCH (cont'd)
(BY PROBLEM TYPE AND CAUSE)

PLANT NAME	DATE	LER	PROBLEM
ROBINSON 2	09/26/83	83-25	SERVICE WATER LEAK FROM DEFECTIVE TUBE BUNDLE IN CONTAINMENT FAN COOLER HVH-2.
ROBINSON 2	11/03/83	83-27	COOLING COIL LEAKS FROM DEFECTIVE TUBE BUNDLES IN CONTAINMENT FAN COOLERS HVH-1 AND HVH-3.
SALEM 1	08/13/81	81-72	SERVICE WATER LEAKAGE FROM COILS IN CONTAINMENT FAN COIL UNITS #12 AND #14.
SALEM 1	08/26/81	81-74	SERVICE WATER LEAKAGE FROM FAILED BOTTOM SECONDARY COIL IN CONTAINMENT FAN COIL UNIT #11.
SALEM 1	09/02/81	81-76	SERVICE WATER LEAKAGE FROM A SECONDARY COIL IN CONTAINMENT FAN COIL UNIT #14.
SALEM 1	09/02/81	81-77	SERVICE WATER PINHOLE LEAK FROM A SECONDARY COIL IN CONTAINMENT FAN COIL UNIT #11.
SALEM 1	09/03/81	81-78	SERVICE WATER LEAKAGE FROM FAILED TOP SECONDARY COIL IN CONTAINMENT FAN COIL UNIT #11.
SALEM 1	09/28/81	81-84	SERVICE WATER LEAK FROM BOTTOM PRIMARY COIL IN CONTAINMENT FAN COIL UNIT #11.
SALEM 1	10/28/81	81-94	SERVICE WATER LEAKAGE FROM FIFTH AND SIXTH PRIMARY COILS OF CONTAINMENT FAN COIL UNIT #14.
SALEM 1	11/07/81	81-96	SERVICE WATER LEAKAGE FROM COILS OF CONTAINMENT FAN COIL UNITS #11 AND #15.
SALEM 1	11/17/81	81-105	SERVICE WATER LEAK FROM HOLE IN UPPER PRIMARY COIL OF CONTAINMENT FAN COIL UNIT #12.
SALEM 1	11/25/81	81-108	SERVICE WATER LEAKAGE FROM A PRIMARY COIL IN CONTAINMENT FAN COIL UNIT #14.
SALEM 1	11/29/81	81-109	SERVICE WATER LEAKAGE FROM A PRIMARY COIL OF CONTAINMENT FAN COIL UNIT #12.

CONTAINMENT HEAT EXCHANGER PROBLEMS FROM LER SEARCH (cont'd)
(BY PROBLEM TYPE AND CAUSE)

PLANT NAME	DATE	LER	PROBLEM
SALEM 1	12/08/81	81-114	SERVICE WATER LEAKAGE FROM TOP SECONDARY COIL OF CONTAINMENT FAN COIL UNIT #11.
SALEM 1	12/26/81	81-118	SERVICE WATER LEAKAGE FROM A PRIMARY COIL OF CONTAINMENT FAN COIL UNIT #11.
SALEM 2	09/13/81	81-90	SERVICE WATER LEAK FROM A PRIMARY COIL ON CONTAINMENT FAN COIL UNIT #22.
SALEM 2	09/18/81	81-94	SERVICE WATER LEAK FROM A PRIMARY COIL IN CONTAINMENT FAN COIL UNIT #23.
SALEM 2	11/27/81	81-115	SERVICE WATER LEAK FROM A PRIMARY COIL ON CONTAINMENT FAN COIL UNIT #24.
CAUSE TYPE: Tube Failure, Corrosion			
BIG ROCK POINT	09/30/81	81-24	CORROSION-INDUCED LEAKS AT 'U' BENDS OF PIPEWAY AIR COOLER.
BIG ROCK POINT	01/28/82	82-3	CORROSION-INDUCED FAILURE OF TUBES IN PIPEWAY AIR COOLER.
CT. YANKEE	01/05/83	83-1	SERVICE WATER LEAK FROM ONE COIL OF CONTAINMENT FAN COOLER, DUE TO CORROSION/EROSION.
INDIAN POINT 2	10/17/80	80-16	CORROSION-INDUCED LEAKAGE FROM CONTAINMENT FAN COOLER UNITS.
ROBINSON 2	04/10/83	83-3	SERVICE WATER LEAK IN CONTAINMENT FAN COOLER HVH-3 DUE TO CORROSION/EROSION OF COOLER TUBING.
ZION 2	05/12/83	83-13	SIX LEAKING TUBES IN REACTOR CONTAINMENT FAN COOLER, DUE TO PITTING CORROSION.
ZION 2	12/13/83	83-45	PINHOLE LEAK IN ONE TUBE OF REACTOR CONTAINMENT FAN COOLER, DUE TO PITTING CORROSION.
ZION 2	05/03/84	84-13	LEAKAGE FROM PITTED TUBES IN REACTOR CONTAINMENT FAN COOLER COILS. GENERAL CONDITION DETECTED BY EDDY CURRENT TESTING. UNDER-DEPOSIT CORROSION IS CAUSE.

CONTAINMENT HEAT EXCHANGER PROBLEMS FROM LER SEARCH (cont'd)
(BY PROBLEM TYPE AND CAUSE)

PLANT NAME	DATE	LER	PROBLEM
CAUSE TYPE: Tube Failure, Erosion/Wear			
KEWAUNEE	12/06/83	83-34	SERVICE WATER LEAKS FROM CONTAINMENT FAN COIL UNIT DUE TO SAND AND WATER EROSION OF TUBE RETURN BENDS.
SALEM 2	08/09/82	82-70	SERVICE WATER LEAK FROM SILT-ERODED COIL IN CONTAINMENT FAN COIL UNIT #24. NEW-DESIGN COILS INSTALLED AT NEXT REFUELING.
SALEM 2	08/13/82	82-73	SERVICE WATER LEAK FROM SILT-ERODED COIL IN CONTAINMENT FAN COIL UNIT #23. NEW-DESIGN COILS WILL BE INSTALLED DURING NEXT REFUELING.
SALEM 2	08/13/82	82-74	SERVICE WATER LEAK FROM SILT-ERODED COIL IN CONTAINMENT FAN COIL UNIT #25.
SALEM 2	08/14/82	82-75	SERVICE WATER LEAK FROM CONTAINMENT FAN COIL UNIT #22. NEW-DESIGN COILS WILL BE INSTALLED DURING NEXT REFUELING.
SALEM 2	08/18/82	82-77	LEAKAGE FROM A SECONDARY COIL OF CONTAINMENT FAN COIL UNIT #21. CAUSE WAS EROSION OF THE COPPER-NICKEL PIPING.
SALEM 2	08/21/82	82-80	SERVICE WATER LEAK FROM ERODED COILS IN CONTAINMENT FAN COIL UNIT #24.
SALEM 2	08/29/82	82-84	SERVICE WATER LEAK FROM ERODED COILS IN CONTAINMENT FAN COIL UNIT #23.
SALEM 2	08/30/82	82-89	SERVICE WATER LEAK FROM COIL IN CONTAINMENT FAN COIL UNIT #23.
SALEM 2	09/06/82	82-91	SERVICE WATER LEAK FROM SILT-ERODED COIL IN CONTAINMENT FAN COIL UNIT #23.
SALEM 2	09/10/82	82-93	SERVICE WATER LEAK FROM ERODED COIL IN CONTAINMENT FAN COIL UNIT #21.
SALEM 2	09/15/82	82-100	SERVICE WATER LEAK FROM SILT-ERODED COIL IN CONTAINMENT FAN COIL UNIT # 22.
SALEM 2	09/16/82	82-101	SERVICE WATER LEAK FROM SILT-ERODED COIL IN CONTAINMENT FAN COIL UNIT #21.

CONTAINMENT HEAT EXCHANGER PROBLEMS FROM LER SEARCH (cont'd)
(BY PROBLEM TYPE AND CAUSE)

PLANT NAME	DATE	LER	PROBLEM
SALEM 2	09/23/82	82-109	SERVICE WATER LEAK FROM SILT-ERODED COILS IN CONTAINMENT FAN COIL UNIT #21.
SALEM 2	10/05/82	82-113	SERVICE WATER LEAK FROM SILT-ERODED COILS IN CONTAINMENT FAN COIL UNIT #22.
SALEM 2	10/08/82	82-119	SERVICE WATER LEAK FROM SILT-ERODED COILS IN CONTAINMENT FAN COIL UNIT #21.
SALEM 2	10/11/82	82-120	SERVICE WATER LEAK FROM SILT-ERODED COILS IN CONTAINMENT FAN COIL UNIT #21.
SALEM 2	10/18/82	82-122	SERVICE WATER LEAK FROM SILT-ERODED COILS IN CONTAINMENT FAN COIL UNIT #24.
SALEM 2	10/31/82	82-128	SERVICE WATER LEAK FROM SILT-ERODED COILS IN CONTAINMENT FAN COIL UNIT #23.
SALEM 2	11/21/82	82-135	SERVICE WATER LEAK FROM SILT-ERODED COILS IN CONTAINMENT FAN COIL UNIT #25.
SALEM 2	11/24/82	82-136	SERVICE WATER LEAK FROM SILT-ERODED COILS IN CONTAINMENT FAN COIL UNIT #23.
CAUSE TYPE: Other			
BROWNS FERRY 3	07/01/81	81-32	LEAK FROM CRACK IN VENT NIPPLE OF RHR PUMP ROOM COOLER.
FT. CALHOUN 1	09/24/81	81-9	LEAK OF COMPONENT COOLING WATER TO CONTAINMENT RESULTED FROM BLOW OUT OF LOOSE COIL END PLUG IN CONTAINMENT COOLING FAN COIL UNIT.
INDIAN POINT 2	10/04/85	85-13	SERVICE WATER LEAK FROM FAN COOLER UNIT, FROM A TUBE THAT HAD BEEN CUT OUT IN EARLIER CHECK IN 1983.
PROBLEM TYPE: Inter-fluid Leakage			
CAUSE TYPE: Tube Failure, Corrosion			
BIG ROCK POINT	05/25/82	82-18	CORROSION-RELATED FAILURE OF 20 TUBES IN REACTOR BUILDING HEATING/COOLING SYSTEM HX.

CONTAINMENT HEAT EXCHANGER PROBLEMS FROM LER SEARCH (cont'd)
(BY PROBLEM TYPE AND CAUSE)

PLANT NAME	DATE	LER	PROBLEM
PROBLEM TYPE: Impaired Heat Transfer			
CAUSE TYPE: Unspecified			
MCGUIRE 1	11/12/83	83-109	FOULING OF LOWER CONTAINMENT VENTILATION SYSTEM AIR HANDLING UNIT COOLING COILS RESULTED IN EXCESSIVE LOWER CONTAINMENT TEMPERATURES.
OCONEE 1	03/31/87	87-4	FOULING OF REACTOR BUILDING COOLING UNITS AND THE DECAY HEAT (LPI) COOLERS REDUCED POST-ACCIDENT COOLING CAPACITY TO UNACCEPTABLE LEVELS.
OCONEE 3	08/19/88	88-3	SERVICE-INDUCED FOULING OF REACTOR BUILDING COOLING UNITS MAY HAVE REDUCED PERFORMANCE CAPABILITY OF THE COOLERS TO UNACCEPTABLE LIMITS.
SURRY 1	07/21/85	85-13	FOULING OF SERVICE WATER SIDE OF CONTAINMENT CHILLER RESULTED IN TRIP OF CHILLER ON HIGH CONDENSER PRESSURE.

COMPONENT COOLING WATER HEAT EXCHANGER PROBLEMS
FROM LER SEARCH
(BY PROBLEM TYPE AND CAUSE)

PLANT NAME	DATE	LER	PROBLEM
PROBLEM TYPE: Tube-side Blockage			
CAUSE TYPE: Unspecified			
MCGUIRE 1	11/25/87	87-31	EXCESSIVE DIFFERENTIAL PRESSURE ACROSS CCW HX, DUE TO TUBE-SIDE FOULING.
MCGUIRE 1	09/12/88	88-24	DIFFERENTIAL PRESSURE ACROSS CCW HXS IN ACTION RANGE, DUE TO TUBE-SIDE FOULING.
MCGUIRE 2	09/06/87	87-17	INADEQUATE FLOW THROUGH CCW HX, DUE TO FOULING.
TURKEY POINT 3	12/11/86	87-20	UNEXPECTED INADEQUATE RESULTS FROM TUBE CLEANING REDUCED ABILITY OF CCW HX TO MEET DESIGN BASIS FLOW REQUIREMENTS.
CAUSE TYPE: Biological Growth			
SAN ONOFRE 1	06/09/81	81-9	TUBES PARTIALLY BLOCKED BY GOOSENECK BARNACLES IN CCW HX.
SAN ONOFRE 3	08/04/86	86-11	RESTRICTED SALTWATER FLOW THROUGH CCW HX DUE TO MARINE GROWTH.
CAUSE TYPE: Biological Debris			
CALVERT CLIFFS 2	10/15/85	85-9	PARTIAL BLOCKAGE OF SALTWATER FLOW THROUGH SERVICE WATER HX, DUE TO SHELLS DISLODGED IN SEAWATER SYSTEM.
SAN ONOFRE 2	07/06/83	83-72	FOULING OF SEAWATER SIDE OF CCW HX BY MARINE DEBRIS INTRODUCED DURING TRAVELING SCREEN INCIDENT. (SIMILAR EVENT OCCURRED IN UNIT 3).
CAUSE TYPE: Other Debris			
MCGUIRE 2	09/17/88	88-11	EXCESSIVE DIFFERENTIAL PRESSURE ACROSS CCW HX, DUE TO BUILDUP OF 'ENVIRONMENTAL DEBRIS'.

COMPONENT COOLING WATER HEAT EXCHANGER PROBLEMS (cont'd)
FROM LER SEARCH
(BY PROBLEM TYPE AND CAUSE)

PLANT NAME	DATE	LER	PROBLEM
PROBLEM TYPE: External Leakage			
CAUSE TYPE: Shell Corrosion/Erosion			
TURKEY POINT 4	06/17/80	80-10	LEAKAGE FROM CORROSION-INDUCED CRACK IN CHANNEL COVER OF CCW HX.
CAUSE TYPE: Weld Failure			
NINE MILE POINT 1	11/21/86	86-33	REACTOR BUILDING CLOSED LOOP COOLING HX FAILED HYDRO TEST DUE TO CRACK IN WELD.
SAN ONOFRE 1	08/13/82	82-24	PRESSURE-TRANSIENT FAILURE OF PREVIOUSLY LEAKING WELD IN CCW HX.
PROBLEM TYPE: Impending External Leakage			
CAUSE TYPE: Shell Corrosion/Erosion			
CALVERT CLIFFS 1	05/03/84	84-5	WALL THINNING AND SOME THROUGH-WALL HOLES WERE FOUND IN CAST IRON CHANNEL HEADS OF COMPONENT COOLING HXS AND SERVICE WATER HXS DUE TO CORROSION.
CAUSE TYPE: Weld Failure			
SAN ONOFRE 1	05/23/80	80-23	FLAW EXTENDING BELOW MINIMUM WALL THICKNESS DETECTED IN WELD IN CCW HX.
PROBLEM TYPE: Inter-fluid Leakage			
CAUSE TYPE: Unspecified			
TURKEY POINT 4	06/08/87	87-11	LEAK IN CCW HX TUBE.
CAUSE TYPE: Tube Failure, Corrosion			
CALVERT CLIFFS 1	09/17/80	80-52	TUBE LEAK IN SALTWATER/SERVICE WATER HX.
CALVERT CLIFFS 2	03/16/80	80-17	TUBE LEAK IN SALTWATER/SERVICE WATER HX.

COMPONENT COOLING WATER HEAT EXCHANGER PROBLEMS (cont'd)
FROM LER SEARCH
(BY PROBLEM TYPE AND CAUSE)

PLANT NAME	DATE	LER	PROBLEM
CAUSE TYPE: Tube Failure, Fatigue/Mechanical Stress			
OYSTER CREEK	08/19/81	81-39	TUBE VIBRATION DURING FLOW TRANSIENT CAUSED TUBE FAILURES IN CCW HX.
SAN ONOFRE 2	10/01/82	82-125	TUBE LEAK IN CCW HX DUE TO IMPINGEMENT OF SEASHELLS.
PROBLEM TYPE: Impaired Heat Transfer			
CAUSE TYPE: Fluid Circuitry Damage			
PILGRIM 1	08/28/81	81-49	DESIGN DEFICIENCY IN PASS PARTITION PLATES CAN LEAD TO PLATE DEFORMATION AND EXCESSIVE BYPASS.

COMPONENT HEAT EXCHANGER PROBLEMS FROM LER SEARCH (BY PROBLEM TYPE AND CAUSE)

PLANT NAME	DATE	LER	PROBLEM
PROBLEM TYPE: Tube-side Blockage			
CAUSE TYPE: Silt Buildup			
FARLEY 1	08/01/86	86-14	GEAR OIL COOLER ON CHARGING PUMP PARTIALLY BLOCKED BY MUD, SLUDGE, AND/OR CLAMS.
GRAND GULF 1	11/22/83	83-186	RESTRICTED COOLING WATER FLOW THROUGH STANDBY SERVICE WATER PUMP COOLER, DUE TO SEDIMENT BUILDUP.
TROJAN	01/27/84	84-2	SERVICE WATER FLOW BLOCKAGE IN SAFETY INJECTION PUMP LUBE OIL COOLER DUE TO ACCUMULATION OF SEDIMENT.
CAUSE TYPE: Biological Growth			
BROWNS FERRY 3	07/30/83	83-47	FLOW RESTRICTION IN SEAL COOLER FOR RHR PUMP, DUE TO CLAMS AND SILT.
CAUSE TYPE: Biological Debris			
ARKANSAS NUCLEAR 2	01/20/82	82-3	SERVICE WATER FLOW RESTRICTION TO LPSI PUMP SEAL COOLER, DUE TO ASIATIC CLAM SHELLS.
SALEM 2	04/09/83	83-13	SERVICE WATER FLOW TO CHARGING PUMP LUBE OIL COOLERS WAS RESTRICTED BY OYSTER AND MOLLUSK SHELLS, WHICH HAD BEEN RELEASED DURING SWS MAINTENANCE.
TROJAN	09/16/88	88-29	CLAM DEBRIS WAS FOUND IN SAFETY INJECTION PUMP LUBE OIL COOLER.
CAUSE TYPE: Shell Corrosion/Erosion			
RANCHO SECO	03/12/81	81-16	LUBE OIL COOLER FOR HPI PUMP PARTIALLY PLUGGED BY CORROSION PRODUCTS FROM COOLER HEADS.
PROBLEM TYPE: External Leakage			
CAUSE TYPE: Unspecified			
INDIAN POINT 3	07/16/80	80-11	WATER LEAK FROM MOTOR COOLER ON CONTAINMENT FAN COIL UNIT.

COMPONENT HEAT EXCHANGER PROBLEMS FROM LER SEARCH (cont'd)
(BY PROBLEM TYPE AND CAUSE)

PLANT NAME	DATE	LER	PROBLEM
INDIAN POINT 3	12/08/81	81-10	WATER LEAK FROM TUBE OF MOTOR COOLER IN FAN COIL UNIT.
SALEM 2	11/19/81	81-114	SERVICE WATER PINHOLE LEAK IN MOTOR COOLER OF CONTAINMENT FAN COIL UNIT #22. COOLER WAS REPLACED.
<u>CAUSE TYPE: Tube Failure, Erosion/Wear</u>			
OCONEE 1	02/16/80	80-4	MOTOR COOLER TUBE LEAKS ON HPSW PUMP B, DUE TO EROSION FROM CONSTANT FLOW OF LAKE WATER.
OCONEE 1	06/01/80	80-18	TUBE LEAKS IN MOTOR COOLER FOR HPSW PUMP B DUE TO EROSION/CORROSION FROM CONSTANT FLOW OF LAKE WATER.
OCONEE 1	07/07/80	80-22	LEAKAGE FROM MOTOR COOLER OF HPSW PUMP B DUE TO EROSION/CORROSION FROM CONSTANT FLOW OF LAKE WATER THROUGH TUBES.
OCONEE 1	08/11/80	80-26	MOTOR COOLER TUBE LEAKS IN HPSW PUMP B DUE TO EROSION FROM CONSTANT FLOW OF LAKE WATER. COOLER AND HOUSING REPLACED. SOLENOID VALVES ADDED TO ALLOW FLOW ONLY WHEN PUMP IS OPERATED.
SALEM 2	08/19/82	82-78	LEAKAGE FROM SILT-ERODED MOTOR COOLER ON CONTAINMENT FAN COIL UNIT #25. COOLER WAS REPLACED WITH ONE OF MORE EROSION-RESISTANT MATERIAL.
SALEM 2	09/08/82	82-92	SERVICE WATER LEAK FROM SILT-ERODED MOTOR COOLER FOR CONTAINMENT FAN COIL UNIT #21. COOLER WAS REPLACED.
<u>CAUSE TYPE: Shell Corrosion/Erosion</u>			
BRUNSWICK 2	07/31/83	83-72	DRAIN PLUG IN PUMP SHAFT SEAL COOLER FOR RHR PUMP CAME OUT. CAUSE WAS PLUG CORROSION, COUPLED WITH VIBRATION.
GINNA	03/02/90	81-4	SERVICE WATER LEAK FROM CONTAINMENT FAN COOLER MOTOR COOLER, DUE TO CORROSION OF STEEL PLUG IN COPPER COOLER.

COMPONENT HEAT EXCHANGER PROBLEMS FROM LER SEARCH (cont'd)
(BY PROBLEM TYPE AND CAUSE)

PLANT NAME	DATE	LER	PROBLEM
CAUSE TYPE: Weld Failure			
SALEM 2	08/06/81	81-64	SERVICE WATER LEAK FROM FAILED WELD ON CONTAINMENT FAN COOLER MOTOR COOLER.
SALEM 2	05/26/82	82-39	LARGE SERVICE WATER LEAK FROM FAILED SEAM WELD IN MOTOR COOLER OF CONTAINMENT FAN COIL UNIT #21. COOLER REPLACED.
CAUSE TYPE: Gasket Failure			
SALEM 1	03/20/85	85-6	WATER LEAK FROM FAILED MOTOR COOLER HEAD GASKET ON CONTAINMENT FAN COIL UNIT #13.
CAUSE TYPE: Other			
GINNA	04/26/81	81-11	LEAK FROM FITTING ON RHR PUMP SEAL COOLER, DUE TO WORN THREADS.
PROBLEM TYPE: Inter-fluid Leakage			
CAUSE TYPE: Unspecified			
SALEM 1	06/26/80	80-38	LEAK FROM FAILED TUBE IN LUBE OIL COOLER FOR CHARGING PUMP #12. COOLER WAS REPLACED.
SALEM 1	07/08/80	80-41	LEAKAGE FROM FAILED TUBE IN LUBE OIL COOLER FOR SAFETY INJECTION PUMP #11.
SALEM 1	02/01/81	81-13	LEAK IN OIL COOLER FOR CHARGING PUMP #12. COOLER REPLACED.
SURRY 1	07/06/82	82-69	WATER ENTERED LUBE OIL OF CHARGING PUMP 'A' VIA LEAK IN ONE TUBE OF OIL COOLER. COOLER REPLACED.
SURRY 1	09/05/82	82-91	WATER ENTERED LUBE OIL OF CHARGING PUMP 'A' VIA LEAK IN ONE TUBE OF LUBE OIL COOLER. COOLER REPLACED.
SURRY 2	08/04/81	81-50	WATER ADMITTED TO OIL IN CHARGING PUMP VIA TUBE LEAK IN OIL COOLER.

COMPONENT HEAT EXCHANGER PROBLEMS FROM LER SEARCH (cont'd)
(BY PROBLEM TYPE AND CAUSE)

PLANT NAME	DATE	LER	PROBLEM
CAUSE TYPE: Tube Failure, Corrosion			
SALEM 1	06/26/82	82-41	SERVICE WATER LEAKED INTO GEAR OIL RESERVOIR OF CHARGING PUMP, VIA LEAKING GEAR OIL COOLER. CAUSE WAS EROSION AND CORROSION.
SALEM 1	08/15/83	83-48	LEAKAGE FROM FAILED TUBES IN SPEED INCREASER LUBE OIL COOLER FOR CHARGING PUMP. FAILURE DUE TO EROSION AND CORROSION.
SALEM 2	09/15/82	82-86	WATER ENTERED LUBE OIL OF MOTOR ON SERVICE WATER PUMP VIA MOTOR BEARING OIL COOLER. CAUSE WAS ACCELERATED EROSION/CORROSION.
SALEM 2	10/19/82	82-126	WATER ENTERED LUBE OIL IN CHARGING PUMP DUE TO LEAK IN OIL COOLER. CAUSE WAS DISSIMILAR-METALS CORROSION AND SILT-INDUCED EROSION.
CAUSE TYPE: Other			
CALVERT CLIFFS 1	08/12/80	80-41	FAILURE OF INSTRUMENT AIR COMPRESSOR AFTERCOOLER INJECTED AIR INTO SERVICE WATER SYSTEM. FAILURE DUE TO OVERROLLING ON INSTALLATION.

Appendix A

EDG HEAT EXCHANGER PROBLEMS FROM LER SEARCH
(BY PROBLEM TYPE AND CAUSE)

PLANT NAME	DATE	LER	PROBLEM
PROBLEM TYPE: Tube-side Blockage			
CAUSE TYPE: Unspecified			
YANKEE ROWE	07/06/81	81-16	INADEQUATE DIESEL GENERATOR COOLING DUE TO RADIATOR PARTIALLY BLOCKED BY CORROSION PRODUCTS AND SCALE.
CAUSE TYPE: Biological Debris			
BROWNS FERRY 3	01/03/84	84-1	FLOW BLOCKAGE OF EECW FLOW TO DIESEL ENGINE COOLERS, DUE TO CLAM SHELLS MOVING INTO COOLERS AFTER HEAVY CHLORINATION OF INTAKE.
PROBLEM TYPE: External Leakage			
CAUSE TYPE: Unspecified			
FT. CALHOUN 1	01/22/80	80-3	DIESEL GENERATOR RADIATOR TUBE LEAK.
OYSTER CREEK	01/25/82	82-5	DIESEL GENERATOR RADIATOR TUBE LEAK.
CAUSE TYPE: Shell Corrosion/Erosion			
MILLSTONE 2	01/27/81	81-7	SERVICE WATER LEAK FROM DIESEL GENERATOR OIL COOLER. SACRIFICIAL ANODE HAD CORRODED.
SALEM 2	09/28/82	82-115	SERVICE WATER LEAK FROM ERODED PIPE CAP IN DIESEL GENERATOR OIL COOLER.
CAUSE TYPE: Other			
BROWNS FERRY 3	04/11/83	83-26	CRACKED HEAD ON EDG COOLER, DUE TO MANUFACTURING DEFECT.
TURKEY POINT 3	02/25/80	80-4	A FOREIGN OBJECT, DRIVEN BY THE FAN, CAUSED DAMAGE TO DIESEL ENGINE RADIATOR. SUBSEQUENT DEGRADATION DUE TO EXTERNAL ENVIRONMENT RESULTED IN LEAK.

EDG HEAT EXCHANGER PROBLEMS FROM LER SEARCH (cont'd)
(BY PROBLEM TYPE AND CAUSE)

PLANT NAME	DATE	LER	PROBLEM
PROBLEM TYPE: Impending External Leakage			
CAUSE TYPE: Shell Corrosion/Erosion			
RIVERBEND 1	03/21/89	89-11	CORROSION REDUCED WALL THICKNESS OF DIESEL GENERATOR WATER COOLER TO BELOW ASME CODE REQUIREMENTS.
PROBLEM TYPE: Inter-fluid Leakage			
CAUSE TYPE: Unspecified			
DRESDEN 2	07/25/80	80-27	LEAKS DEVELOPED IN TUBES OF EDG COOLING WATER/SERVICE WATER HX.
INDIAN POINT 2	07/05/81	81-16	LEAK IN DIESEL GENERATOR LUBE OIL COOLER RESULTED IN WATER IN OIL.
INDIAN POINT 2	09/16/81	81-22	LEAK IN DIESEL GENERATOR OIL COOLER RESULTED IN WATER IN OIL. (NOT SAME ENGINE AS REPORTED IN LER 81-16.)
INDIAN POINT 2	09/09/88	88-11	WATER FROM THE LUBE OIL COOLER LEAKED INTO THE DIESEL ENGINE LUBE OIL.
NINE MILE POINT 1	08/18/81	81-40	LEAK IN EDG RAW WATER/CHROMATED WATER HEAT EXCHANGER.
SEQUOYAH 1	05/12/83	83-70	COOLING WATER LEAK TO CRANKCASE OF D/G 1A-A. ENGINE OIL COOLER WAS REPLACED.
SEQUOYAH 1	10/10/83	83-137	WATER IN OIL OF DIESEL GENERATOR 2B-B DUE TO LEAKAGE IN LUBE OIL COOLER. COOLER WAS REPLACED.
ZION 1	06/13/83	83-19	TUBE LEAK IN EDG ENGINE COOLER WAS BEING MONITORED BUT FLOODED AIR MANIFOLD AFTER DRAIN VALVE WAS CLOSED BY CLEANING PERSONNEL.
CAUSE TYPE: Tube Failure, Corrosion			
KEWAUNEE	01/26/83	83-2	CORROSION-INDUCED LEAKS IN DIESEL GENERATOR COOLING SYSTEM HX.

EDG HEAT EXCHANGER PROBLEMS FROM LER SEARCH (cont'd)
(BY PROBLEM TYPE AND CAUSE)

PLANT NAME	DATE	LER	PROBLEM
CAUSE TYPE: Tube Failure, Erosion/Wear			
DRESDEN 2	01/26/80	80-8	DIESEL GENERATOR COOLING WATER HX DEVELOPED LEAKS DUE TO NORMAL ENVIRONMENTAL WEAR.
ZION 2	04/19/81	81-5	ERODED TUBES IN EDG OIL COOLER CAUSED LEAKAGE OF WATER TO LUBE OIL.
PROBLEM TYPE: Impaired Heat Transfer			
CAUSE TYPE: Unspecified			
BEAVER VALLEY 1	09/19/82	82-36	FOULING OF DIESEL GENERATOR COOLING WATER HX CAUSED EXCESSIVE TEMPERATURES OF COOLING WATER.
QUAD CITIES 2	10/06/82	82-18	FOULING OF DIESEL GENERATOR COOLING WATER SYSTEM HX RESULTED IN HIGH TEMPERATURE TRIP OF DIESEL GENERATOR.

MISCELLANEOUS HEAT EXCHANGER PROBLEMS FROM LER SEARCH (BY PROBLEM TYPE AND CAUSE)

PLANT NAME	DATE	LER	PROBLEM
PROBLEM TYPE: External Leakage			
CAUSE TYPE: Gasket Failure			
BROWNS FERRY 2	05/07/81	81-21	LEAKING UPPER HEAD GASKET IN HPCI GLAND SEAL CONDENSER AFTER OVERPRESSURIZATION (150 PSI VS 60 PSI).
BROWNS FERRY 2	07/20/81	81-39	LEAKING UPPER HEAD GASKET IN HPCI GLAND SEAL CONDENSER AFTER TUBE-SIDE OVERPRESSURIZATION (150 VS 60 PSI).
BROWNS FERRY 2	09/16/81	81-45	LEAKING UPPER HEAD GASKET IN HPCI GLAND SEAL CONDENSER AFTER TUBE-SIDE OVERPRESSURIZATION.
BROWNS FERRY 3	04/23/81	81-19	UPPER AND LOWER HPCI GLAND SEAL CONDENSER HEAD GASKETS WERE BLOWN DUE TO OVERPRESSURE DURING AUTOMATIC REACTOR SHUTDOWN.
COOPER	02/27/86	86-5	FAILED HEAD GASKET IN HPCI GLAND STEAM CONDENSER.
FITZPATRICK	03/22/84	84-9	GASKET FAILED ON HPCI GLAND SEAL CONDENSER.
FITZPATRICK	03/25/84	84-10	GASKET FAILURE IN HPCI GLAND SEAL CONDENSER.
PEACH BOTTOM 2	09/23/81	81-41	LEAKAGE FROM FAILED GASKET ON HEAD OF HPCI GLAND SEAL CONDENSER.
PEACH BOTTOM 2	10/21/81	81-42	LEAKAGE FROM FAILED GASKET ON HEAD OF HPCI GLAND SEAL CONDENSER.
PILGRIM 1	08/13/82	82-24	HPCI GLAND SEAL CONDENSER GASKET FAILURE CAUSED WETTING OF HPCI CONTROL CIRCUITRY.
PILGRIM 1	08/30/82	82-35	HPCI GLAND SEAL CONDENSER GASKET FAILED DUE TO OVERPRESSURE DURING STARTUP.
CAUSE TYPE: Other			
PALISADES	11/25/80	80-44	LEAK AT RETURN HEAD FLANGE OF LETDOWN HX DUE TO IMPROPER TORQUING SEQUENCE AND CORRODED FLANGE STUDS.

MISCELLANEOUS HEAT EXCHANGER PROBLEMS FROM LER SEARCH
(BY PROBLEM TYPE AND CAUSE)

PLANT NAME	DATE	LER	PROBLEM
PROBLEM TYPE: Inter-fluid Leakage			
CAUSE TYPE: Unspecified			
CRYSTAL RIVER 3	01/27/82	82-8	REACTOR COOLANT LEAK TO SERVICE WATER VIA TUBE-TO-SHELL LEAK IN LETDOWN COOLER 'A'.
RANCHO SECO	01/12/81	81-2	ACTIVITY IN CCW SYSTEM FROM LEAK IN LETDOWN COOLER.
RANCHO SECO	09/20/83	83-35	ACTIVITY IN CCW SYSTEM FROM APPARENT LEAK IN LETDOWN COOLER.
CAUSE TYPE: Tube Failure, Erosion/Wear			
ROBINSON 2	01/16/81	81-4	LEAK FROM PRIMARY SYSTEM TO CCW SYSTEM THROUGH FAILED SAMPLE COOLER TUBE BUNDLE. FAILURE DUE TO NORMAL OPERATIONAL WEAR.
CAUSE TYPE: Tube Failure, Fatigue/Stress			
CRYSTAL RIVER 3	11/25/82	82-72	LEAK OF REACTOR COOLANT TO NSCCCS VIA LETDOWN COOLER 'B'. LEAK APPARENTLY CAUSED BY THERMAL SHOCK DUE TO LONG ISOLATION AND RAPID RESTORATION TO SERVICE.
CAUSE TYPE: Tube-to-tubesheet Joint Failure			
OCONEE 2	11/03/80	80-19	LEAKAGE FROM FAILED TUBE-TO- TUBESHEET WELDS IN LETDOWN COOLER 2A.

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11. ABSTRACT *(200 words or less)*

This report presents the results of an assessment of the time-related degradation of non-power-cycle heat exchangers used in nuclear power plants. The assessment was sponsored by the U.S. Nuclear Regulatory Commission's Nuclear Plant Aging Research Program.

Heat exchanger design characteristics and applications in the plants are described and stressors leading to degradation are identified. Operating experience, as identified from nuclear industry data bases, is reviewed and failure types and causes are summarized. Regulatory requirements for inspection and testing, with a brief discussion of industry practices in this area, are presented.

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