ATTACHMENT 39

Heat Exchanger K Values Utilized in EPU Containment Analyses

1.0 Introduction

This attachment provides EPU event-specific RHR heat exchanger K-values and heat removal rates for postulated events. The heat exchanger K-value determinations in this attachment confirm that the specific K-value used in each containment analysis is appropriate and suitable for the expected EPU conditions.

The Browns Ferry Nuclear Plant original design value for the RHR heat exchanger effectiveness K-value is 223 BTU/sec-°F.

In Reference 4.3, TVA previously submitted a License Amendment Request (LAR) to transition the licensing basis for the Browns Ferry Nuclear Plant to National Fire Protection Association standard 805 (NFPA 805) which, in (Ref. 4.3) Attachment X and subsequent responses to NRC requests for additional information (RAIs) *(*Ref. 4.4*)*, included a change to the RHR heat exchanger K-value from 223 BTU/sec-°F to 265 BTU/sec-°F and provided the basis for the change to the K-value. The extended power uprate (EPU) design value used for the containment analyses under the design basis accident (DBA) loss of coolant accident (LOCA), for containment heat removal is 265 BTU/sec-°F, which is consistent with the NFPA 805 LAR (CLTP) K-value of 265 BTU/sec-°F. However, this EPU LAR attachment also identifies changes to specific values reported in the NFPA 805 LAR. These changes are addressed in the following paragraph.

In the NFPA 805 transition LAR (Ref. 4.3) and associated RAI responses (Ref. 4.4) the RHR heat exchanger overall fouling resistance corresponding to a K-value of 265 BTU/sec-°F and a peak suppression pool temperature of 187.4°F (DBA-LOCA temperature) was reported to be 0.001517 hr-ft^2-°F/BTU. This fouling resistance corresponds to a K-value of 284.5 BTU/sec-°F at the CLTP NFPA 805 fire event conditions. However, for conservatism, a K-value of 270 BTU/sec-°F is used in the CLTP NFPA 805 fire event analyses. This attachment provides a re-calculated DBA-LOCA EPU design fouling resistance associated with a K-value of 265 BTU/sec-°F for a peak suppression pool temperature of 179.0°F. This change in the peak suppression pool temperature from 187.4°F to 179.0°F results in a slightly different EPU design fouling resistance, 0.001521 hr-ft^2-°F/BTU. The values of DBA-LOCA peak suppression pool temperature and design fouling resistance that were provided in the NFPA 805 LAR (Ref. 4.3) are superseded by the EPU values provided herein, 179.0°F and 0.001521 hr-ft^2-°F/BTU, respectively, and reflect updated EPU analyses.

EPU licensing basis RHR heat exchanger K-values are as follows:

EPU event	K-value (BTU/sec-°F)
DBA-LOCA	265
Small Break LOCA	265
Loss of Shutdown Cooling	265
Stuck Open Relief Valve	265
Station Blackout (SBO)	265
ATWS	277
Shutdown of Non-Accident Unit	302
Fire	307*

* In addition, the fire event was analyzed using the Emergency High Pressure Make-Up (EHPMU) pump and an RHR heat exchanger K-value of 287 BTU/sec-°F. This represents a defense-in-depth demonstration and is not a licensing basis analysis.

The Browns Ferry Nuclear Plant Updated Final Safety Analysis Report (UFSAR) (Ref. 4.5) provides additional descriptive information concerning the Residual Heat Removal (RHR) heat exchangers in UFSAR sections 1.6.2.12 (Residual Heat Removal System (Containment Cooling)), 4.8.6.2 (Containment Cooling), 4.8.6.3 (Low Pressure Coolant Injection), Table 4.8-1 (Residual Heat Removal System Equipment Design Data) and Table 5.2-1 (Principal Design Parameters and Characteristics of Primary Containment).

2.0 Computations and Analysis

2.1 Methodology

The methodology utilizes an Excel spreadsheet platform, and standard engineering formulas, to solve for the RHR heat exchanger K-value based on the input parameter values.

The formula for heat exchanger effectiveness is a function of the overall heat transfer coefficient, the effective heat transfer area, and other parameters identified below. The Browns Ferry Nuclear Plant RHR heat exchangers are identical single shell pass, two tube pass Tubular Exchanger Manufacturers Association, Inc. (TEMA) type CES heat exchangers. The effectiveness for this type heat exchanger is:

$$\varepsilon = 2 * \left[1 + C_R + \left[\left(1 + C_R^2\right)^{0.5} \right] * \left[\frac{1 + e^{-NTU\left[\left(1+C_R^2\right)^{0.5}\right]}}{1 - e^{-NTU\left[\left(1+C_R^2\right)^{0.5}\right]}} \right] \right]^{-1} \qquad \text{(Equation 1 – Ref. 4.1)}$$

Where:

ε = heat exchanger effectiveness

C_R = heat capacity ratio

= Cmin/Cmax

Cmin	=	minimum mass flow rate times fluid heat capacity product, BTU/hr-°F
Cmax	=	maximum mass flow rate times fluid heat capacity product, BTU/hr-°F
NTU	=	number of transfer units
	=	UA/Cmin
U	=	overall heat transfer coefficient, BTU/hr-ft^2-°F
A	=	effective heat transfer area, ft^2

Equation 1 was used to determine fouling resistance and/or K-values for various state points for the analyzed event sequences.

Tables 1, 2, and 3, below, provide the results from specific evaluations using the overall fouling resistance and the corresponding heat exchanger K-value for each of the fouling resistances in Table 4. The specified fouling resistances cover a wide range from the original supplied RHR heat exchanger design fouling resistance (0.002800 hr-ft^2-°F/BTU) to a clean RHR heat exchanger fouling resistance (0.000000 hr-ft^2-°F/BTU). Specifically, the EPU design fouling resistance, 0.001521 hr-ft^2-°F/BTU; the EPU nominal fouling resistance, 0.001097 hr-ft^2-°F/BTU and the fouling resistances determined from six different Browns Ferry Nuclear Plant RHR heat exchanger tests performed to date are some of the more significant fouling resistances.

Table 4 provides a comparison summary of heat exchanger heat transfer rates and corresponding K-values for the different EPU K-values used in the event analyses:

- 265 BTU/sec-°F (DBA-LOCA, Small Break LOCA, Loss of Shutdown Cooling, Stuck Open Relief Valve and SBO), 302 BTU/sec-°F (Shutdown of Non-Accident Unit), and 287 BTU/sec-°F (fire event defense-in-depth demonstration case) are based on the EPU design fouling resistance, 0.001521 hr-ft^2-°F/BTU.

- 307 BTU/sec-°F (fire event licensing basis) is based on the EPU nominal fouling resistance, 0.001097 hr-ft^2-°F/BTU.

- 277 BTU/sec-°F for the ATWS-MSIVC-EOC event corresponds to a nominal fouling resistance of 0.001220 hr-ft^2-°F/BTU.

2.2 Analysis

RHR heat exchanger K-values used in the containment analyses are identified for each event within the applicable Browns Ferry Nuclear Plant Power Uprate Safety Analysis Report (PUSAR) section. Unless otherwise noted and discussed below for ATWS and fire events, all events were evaluated at the EPU design fouling resistance (same heat exchanger material condition). For the same EPU design fouling resistance, differences in RHR and Residual Heat Removal Service Water (RHRSW) flow rates from one event to another may result in different RHR heat exchanger K-values (see Table 4).

The DBA LOCA discussion provides the basis for the change in the pre-EPU and the EPU design fouling resistance and the corresponding EPU K-value of 265 BTU/sec-°F. The Shutdown of the Non-Accident Unit analysis K-value is also based on the EPU design fouling resistance, 0.001521 hr-ft^2-°F/BTU. The EPU fire event analysis K-value was based on the EPU nominal fouling resistance, 0.001097 hr-ft^2-°F/BTU and the ATWS event analyses were based on a nominal fouling resistance or K-value that lies between the EPU design and EPU nominal fouling resistances. Details are provided in the following discussion of the events.

DBA-LOCA – PUSAR Section 2.6.5.1

The EPU design basis fouling resistance is based on the conditions from the EPU DBA-LOCA. Specifically, the RHR flow rate of 6500 gpm at a peak suppression pool temperature (heat exchanger inlet temperature) of 179.0°F, RHRSW flow rate of 4000 gpm at 95°F RHRSW temperature, with up to 4.57 percent tube plugging, and an RHR heat exchanger K-value of 265 BTU/sec-°F are used to determine the EPU design basis fouling resistance. Equation 1 is used to solve for fouling resistance, based on a given K-value or, to calculate a K-value based on a specified fouling resistance, provided the other state points are known.

The EPU containment response analyses were performed for the long-term DBA-LOCA using a RHR heat exchanger K-value of 265 BTU/sec-°F compared to 223 BTU/sec-°F used in previous analyses. The previous value of 223 BTU/sec-°F was based on the RHR heat exchanger specification sheets, which specified the design fouling resistances. Browns Ferry Nuclear Plant plant-specific RHR heat exchanger testing (Ref. 4.4, including SCVB RAI-5) has shown there is substantial margin between the design and actual (tested) heat exchanger fouling resistances.

Some of this large margin was used to increase RHR heat exchanger heat transfer capability from that specified in the original design to a K-value of 265 BTU/sec-°F. The corresponding “EPU design” fouling resistance at the DBA-LOCA conditions identified above is 0.001521 hr-ft^2-°F/BTU.

Under certain scenarios, higher RHR and/or RHRSW flows may be achieved than those used to establish the EPU design basis fouling resistance. Using minimum flow rates in determining the RHR heat exchanger heat removal capability embeds conservatism into the containment analysis results. A lower containment heat removal rate results in higher suppression pool temperatures; thus, the analysis is conservative with respect to suppression pool temperature.

Other events, including the small break LOCA, loss of RHR shutdown cooling, stuck open relief valve (SORV), and station blackout, were evaluated using an RHR heat exchanger K-value of 265 BTU/sec-°F and are described in PUSAR Section 2.6.5.2.

Shutdown of the Non-Accident Unit – PUSAR Section 2.6.5.1

An RHR heat exchanger K-value of 302 BTU/sec-°F was used in the analysis of the shutdown of the non-accident unit. This value represents the K-value resulting from a design basis fouling resistance, RHR flow of 9700 gpm at the peak suppression pool temperature of 185.1°F, RHRSW flow of 4500 gpm at 95°F, and 4.57 percent tube plugging. These parameters are consistent with the analysis inputs/results described in PUSAR Section 2.6.5.1.

Fire Event – PUSAR Section 2.5.1.4.2

The fire event analysis assumes one RHR heat exchanger available for event mitigation. All other RHR heat exchangers are assumed to be not available which restricts containment heat removal capability. Of all the events analyzed, because of restrictive/conservative assumptions, such as the availability of only one RHR pump and heat exchanger, the fire event results in the highest peak suppression pool temperature. In-situ RHR heat exchanger performance testing (results previously submitted under Browns Ferry Nuclear Plant

NFPA 805 LAR (Ref. 4.3) Attachment X and associated RAI responses (Ref. 4.4)) demonstrate that the actual heat removal capability of RHR heat exchangers exceeds that assumed in the fire event containment analysis.

An RHRSW flow of 4500 gpm is achievable for the fire event. The combination of increased RHRSW flow and the use of a realistic or “nominal” heat exchanger fouling resistance, 0.001097 hr-ft^2-°F/BTU, corresponds to an increase in the EPU fire event heat exchanger K-value to 307 BTU/sec-°F. As discussed in PUSAR Section 2.5.1.4.2, a fire event containment analysis was performed using the K-value of 307 BTU/sec-°F which resulted in a peak suppression pool temperature of 208.0°F.

SECY-11-0014 (Ref. 4.8) provides guidance on the use of realistic or “nominal” inputs for special events such as a fire event. For the Browns Ferry Nuclear Plant EPU, when a nominal K-value was selected or established, the heat exchanger test data available for comparison to the selected realistic or “nominal” value was limited to that reported in the NFPA 805 LAR (Ref. 4.3) Attachment X and associated RAI responses (Ref. 4.4). These reported “as tested” fouling resistances of 0.0005164 and 0.000674 hr-ft^2-°F/BTU, are shown on Figure 1, and resulted in a large difference between the test results and the EPU design (0.001521 hr-ft^2-°F/BTU) fouling resistance. To provide confidence in establishing a reasonable realistic or “nominal” heat exchanger fouling resistance, industry literature was consulted for establishing the realistic or nominal fouling resistance.

EPRI Test Report 107397, “Service Water Heat Exchanger Testing Guidelines,” (Ref. 4.2) section 3.4.2 provides guidance in establishing an acceptance criterion for test uncertainty to determine whether a given test result is acceptable. The guidance suggests that an initial acceptance criterion can be established in terms of the heat transfer rate, at +/- 25 percent of the difference between the design and clean (zero fouling resistance) heat transfer rates. This provided a reasonable bound for establishing the expected deviation from a design heat transfer rate to an actual or tested heat transfer rate. The realistic or “nominal” fouling resistance was determined by taking 25 percent of the difference between the EPU fire event design heat transfer rate and the clean heat transfer rate and adding that to the EPU design heat transfer rate to obtain the heat transfer rate corresponding to the realistic or “nominal” fouling resistance. The results of this computation are provided in Table 4 where this process was followed to determine the fire event K-value, 308 BTU/sec-°F. The value chosen for the RHR heat exchanger fire event nominal K-value was 307 BTU/sec-°F, which is within the range from 287 BTU/sec-°F (EPU design) to 308 BTU/sec-°F.

The nominal fire event K-value of 307 BTU/sec-°F represents an approximate 7 percent increase from the EPU fire event design K-value of 287 BTU/sec-°F (computed using the EPU design fouling resistance, 0.001521 hr-ft^2-°F/BTU, 7500 gpm RHR flow at 208.0°F, 4500 gpm RHRSW flow at 92.0°F and 4.57 percent of the tubes plugged). This approximate 7 percent increase in the EPU fire event design K-value to the EPU fire event nominal K-value compared well with an NRC staff assessment (Ref. 4.6) where conservative and realistic RHR heat exchanger K-values were determined and compared at 147 and 158 BTU/sec-°F, respectively. The increase from 147 BTU/sec-°F to 158 BTU/sec-°F constitutes an approximate 7.5 percent increase in the conservative or design basis K-value, which compares well to the Browns Ferry Nuclear Plant 7 percent increase described above.

Using the nominal fire event K-value of 307 BTU/sec-°F, Equation 1 was used to solve for the resulting EPU nominal fire event fouling resistance, 0.001097 hr-ft^2-°F/BTU (see Table 3). This fouling resistance is used for comparison to Browns Ferry Nuclear Plant RHR heat exchanger test results graphically presented in Figure 1. Figure 1 provides the results from the tests performed to date.

Comparison of the Browns Ferry Nuclear Plant RHR heat exchanger test results to the EPU design and nominal fouling resistances shown in Figure 1 leads to two clear observations: (1) the results from the 2A RHR heat exchanger “as-found” test (two years since last cleaning) closely match the EPU fire event nominal fouling resistance and, (2) the 2A RHR heat exchanger “as-left” test results (0 years since last cleaning) when compared with the 2A RHR heat exchanger “as-found” test results and the other three heat exchanger test results show that the 2A RHR heat exchanger performance, when expressed in terms of fouling resistance, is not as good as the other heat exchangers. These (identical in design) heat exchangers when subjected to identical operating conditions would be expected to demonstrate essentially identical performance; however, the as-tested performance of the 2A RHR heat exchanger differs from that of the other heat exchangers. This apparent anomalous performance of the 2A RHR heat exchanger has been entered into the Browns Ferry Nuclear Plant corrective action program to identify the condition and evaluate the issue to resolution.

The difference between the RHR heat exchanger test results (including the 2A RHR heat exchanger) and the EPU design fouling resistance serves to demonstrate the conservatism embedded in the event analyses where the RHR heat exchanger K-value is determined from the EPU design fouling resistance.

The difference between the RHR heat exchanger test results (excluding the 2A RHR heat exchanger) and the EPU fire event nominal fouling resistance serves to demonstrate that the EPU fire event nominal fouling resistance is appropriate for use in fire event analyses.

The fire event sensitivity case with the EHPMU pump reported in PUSAR Section 2.6.5.2, PUSAR Tables 2.6-4 and 2.6-4a did not use a realistic or “nominal” heat exchanger fouling resistance but instead used a K-value, 287 BTU/sec-°F, corresponding to the EPU design fouling resistance, 0.001521 hr-ft^2-°F/BTU. The sensitivity case demonstrates defense-in-depth for a fire event.

The current licensed thermal power (CLTP) analysis in Table 4 summarizes the fire event analysis parameters and the K-value used in the analysis submitted in the NFPA 805 LAR. As indicated in Table 4, the CLTP NFPA 805 analysis was performed assuming 4400 gpm RHRSW flow and an RHR heat exchanger K-value of 270 BTU/sec-°F. For EPU the RHRSW flow rate is 4500 gpm and the RHR heat exchanger K-value is 307 BTU/sec-°F, as discussed above. No modifications are required to effect the change in the RHRSW flow rate from 4400 gpm to 4500 gpm as the CLTP analysis was performed using a conservatively low flow rate compared to the actual RHRSW flow capability during a fire.

<u>Anticipated Transient Without Scram (ATWS) – PUSAR Sections 2.6.5.2 and 2.8.5.7</u>

The limiting ATWS event with respect to peak suppression pool temperature is the ATWS loss-of-offsite power (LOOP) event (two RHR pumps and two RHR heat exchangers credited) which resulted in a peak suppression pool temperature of 173.3°F. The most limiting non-LOOP (four RHR pumps and four RHR heat exchangers credited) ATWS event is the Main Steam Isolation Valve Closure-End of Cycle (MSIVC-EOC) event which experiences a peak suppression pool temperature of approximately 171.7°F. When the combined transient effects of pool temperature, pool level and pump suction losses are considered, the limiting ATWS event from a net positive suction head (NPSH) perspective is a non-LOOP event (MSIVC-EOC). For Browns Ferry Nuclear Plant EPU ECCS pump NPSH, MSIVC-EOC remains the most limiting ATWS event.

An RHR heat exchanger K-value of 277 BTU/sec-°F was used in each ATWS analysis. The K-value corresponds to an RHRSW temperature of 95°F, 4500 gpm RHRSW flow, RHR (heat exchanger shell inlet) temperature of 173.3°F (peak suppression pool temperature for ATWS-LOOP event as discussed in PUSAR Sections 2.6.5.2 and 2.8.5.7.2), 6500 gpm RHR flow and 4.57 percent tube plugging, at the EPU design fouling resistance, 0.001521 hr-ft^2-°F/BTU, is 277.8 BTU/sec-°F. These conditions are applicable for the ATWS-LOOP event where only two heat exchangers in the ATWS unit are credited with mitigating the event.

Where four RHR heat exchangers in the same unit are credited with mitigating the ATWS event, system hydraulic resistances in common RHRSW piping on the discharge side of the RHR heat exchangers and in the discharge piping where the two loops combine into common piping, results in the RHRSW flow being restricted such that only 4000 gpm is passed through each of the four heat exchangers. This explains the reduction in the RHRSW flow rate per heat exchanger from 4500 gpm per heat exchanger in the two heat exchanger alignment described above, to 4000 gpm per heat exchanger in the four heat exchanger alignment. The effect of this condition on the EPU ATWS analyses is described below.

The analyses K-value of 277 BTU/sec-°F used in the non-LOOP ATWS events, corresponds to a fouling resistance of 0.001220 hr-ft^2-°F/BTU. This was determined using Equation 1 with RHRSW temperature at 95°F, 4000 gpm RHRSW flow, RHR (heat exchanger shell inlet) temperature of 171.7°F, 6500 gpm RHR flow, and 4.57 percent tube plugging. This reduced fouling resistance of 0.001220 hr-ft^2-°F/BTU is justified because it is conservative relative to the EPU nominal fouling resistance of 0.001097 hr-ft^2-°F/BTU (see Figure 1). In addition, the difference between the RHR heat exchanger test results (including the 2A RHR heat exchanger) and this reduced fouling resistance value serves to demonstrate that this fouling resistance value is appropriate for use in ATWS event analyses.

2.3 RHR Heat Exchanger Performance Monitoring

In Attachment X, Section X.4 of Reference 4.3, TVA stated that the Browns Ferry Nuclear Plant RHR heat exchangers would be subject to a performance monitoring program to provide assurance that heat exchanger fouling that could affect the required heat transfer rate is detected and corrected in a timely manner. Reference 4.7 also included a commitment (i.e., Commitment 2) to implement a heat exchanger monitoring program to provide assurance that the RHR heat exchanger performance is maintained for consistency with analytical assumptions associated with the adoption of the NFPA 805 standard. Because the revised performance monitoring program has not been developed at this time, the commitment specifies implementation within six months following NRC issuance of the license amendment approving adoption of the NFPA 805 standard for the Browns Ferry Nuclear Plant. In addition, TVA will revise the program that monitors Browns Ferry Nuclear Plant RHR heat exchanger performance for consistency with the assumptions used in analyses supporting EPU prior to EPU license amendment implementation. TVA intends to include, as requirements in the program, periodic heat exchanger inspections and heat exchanger performance testing requirements to ensure fouling factor assumptions and tube plugging assumptions in the EPU containment analyses remain valid.

3.0 Summary and Conclusion

Based on the analyses described above, the RHR heat exchanger fouling resistances and K-values used in the EPU event analyses are appropriate:

- The EPU design fouling resistance is 0.001521 hr-ft^2-°F/BTU. This was determined using a heat exchanger K-value of 265 BTU/sec-°F with an RHR flow rate of 6500 gpm at RHR (heat exchanger shell side inlet) temperature of 179.0°F, RHRSW flow rate of 4000 gpm at RHRSW inlet temperature of 95°F with 4.57 percent tubes plugged;

- The EPU nominal fouling resistance is 0.001097 hr-ft^2-°F/BTU; and

- RHR heat exchanger as-found test results demonstrate the EPU design and nominal fouling resistance values are appropriate for use in the associated event analyses.

In addition, periodic RHR heat exchanger performance testing will be used to demonstrate that actual heat exchanger performance exceeds the performance credited in the analyses.

4.0 References

4.1 Fundamentals of Heat and Mass Transfer by Frank P. Incropera and David P. Dewitt, John Wiley & Sons, 3rd Edition, 1990

4.2 EPRI Test Report 107397, “Service Water Heat Exchanger Testing Guidelines,” Electric Power Research Institute, March 1998

4.3 TVA Letter to NRC, License Amendment Request to Adopt NFPA 805 Performance-Based Standard for Fire Protection for Light Water Reactor Electric Generating Plants (2001 Edition) (Technical Specification Change TS-480), March 27, 2013 (ADAMS Accession Number ML13092A392)

4.4 TVA Letter to NRC, Response to NRC Request for Additional Information Regarding the License Amendment Request to Adopt NFPA 805 Performance-Based Standard for Fire Protection for Light Water Reactor Electric Generating Plants for the Browns Ferry Nuclear Plant, Units 1, 2, and 3 (TAC Nos. MF1185, MF1186, and MF1187) – Attachment X and Fire Modeling, June 13, 2014 (ADAMS Accession Number ML14167A175)

4.5 Browns Ferry Nuclear Plant Updated Safety Analysis Report, Sections 1.6.2.12, 4.8.6.2, 4.8.6.3, Table 4.8-1, and Table 5.2-1

4.6 NRC Memorandum to ACRS Members, Certification of the Meeting Minutes from the Advisory Committee on Reactor Safeguards 572nd Full Committee Meeting Held on May 6-8 2010 in Rockville, Maryland, August 16, 2010 (ADAMS Accession Number ML101830190)

4.7 TVA Letter to NRC, Response to NRC Request to Supplement License Amendment Request to Adopt NFPA 805 Performance-Based Standard for Fire Protection for Light Water Reactor Electric Generating Plants for the Browns Ferry Nuclear Plant, Units 1, 2, and 3 (TAC Nos. MF1185, MFI186, and MF1187), May 16, 2013 (ADAMS Accession Number ML13141A291)

4.8 SECY-11-0014 – Use of Containment Accident Pressure in Analyzing Emergency Core Cooling System and Containment Heat Removal System Pump Performance in Postulated Accidents," U.S. Nuclear Regulatory Commission, January 31, 2011, (ADAMS Accession No. ML102590196)

Table 1 Overall Fouling Resistances and K-values for Events with RHR Flow Rate 6500 gpm

Event	Trhr[2]	Tsw[3]	RHRSW Flow	Overall Fouling Resistance	K	Tube Plugging[5]
	F	F	gpm	hr-ft^2-°F/Btu	Btu/sec-°F	percent
DBA-LOCA (RSLB[1])	179.0	95	4000	0.000000	333.7	4.57
DBA-LOCA (RSLB)	179.0	95	4000	0.000461	310.7	4.57
DBA-LOCA (RSLB)	179.0	95	4000	0.0005164	308.1	4.57
DBA-LOCA (RSLB)	179.0	95	4000	0.000674	300.7	4.57
DBA-LOCA (RSLB)	179.0	95	4000	0.000820	294.0	4.57
DBA-LOCA (RSLB)	179.0	95	4000	0.000930	289.1	4.57
DBA-LOCA (RSLB)	179.0	95	4000	0.001107	281.6	4.57
DBA-LOCA (RSLB)	179.0	95	4000	0.001097	282.0	4.57
DBA-LOCA (RSLB)	179.0	95	4000	0.001521	265.0	4.57
DBA-LOCA (RSLB)	179.0	95	4000	0.002800[4]	223.1	4.57
ATWS- LOOP	173.3	95	4500	0.000000	355.6	4.57
ATWS- LOOP	173.3	95	4500	0.000461	329.2	4.57
ATWS- LOOP	173.3	95	4500	0.0005164	326.2	4.57
ATWS- LOOP	173.3	95	4500	0.000674	317.8	4.57
ATWS- LOOP	173.3	95	4500	0.000820	310.3	4.57
ATWS- LOOP	173.3	95	4500	0.000930	304.8	4.57
ATWS- LOOP	173.3	95	4500	0.001107	296.3	4.57
ATWS- LOOP	173.3	95	4500	0.001097	296.8	4.57
ATWS- LOOP	173.3	95	4500	0.001521	277.8	4.57
ATWS- LOOP	173.3	95	4500	0.002800[4]	231.9	4.57
ATWS-MSIVC EOC	171.7	95	4000	0.000000	333.9	4.57
ATWS-MSIVC EOC	171.7	95	4000	0.000461	310.9	4.57
ATWS-MSIVC EOC	171.7	95	4000	0.0005164	308.2	4.57
ATWS-MSIVC EOC	171.7	95	4000	0.000674	300.8	4.57
ATWS-MSIVC EOC	171.7	95	4000	0.000820	294.2	4.57
ATWS-MSIVC EOC	171.7	95	4000	0.000930	289.3	4.57
ATWS-MSIVC EOC	171.7	95	4000	0.001107	281.7	4.57
ATWS-MSIVC EOC	171.7	95	4000	0.001097	282.1	4.57
ATWS-MSIVC EOC	171.7	95	4000	0.001220	277.0	4.57
ATWS-MSIVC EOC	171.7	95	4000	0.001521	265.1	4.57
ATWS-MSIVC EOC	171.7	95	4000	0.002800[4]	223.2	4.57

Notes

1. RSLB = recirculation suction line break
2. Trhr = temperature – residual heat removal
3. Tsw = temperature – service water
4. Heat exchanger original design fouling resistance
5. The current condition (number of tubes plugged) of each RHR heat exchanger is bounded by the design value of 4.57 percent tubes plugged. Work processes prohibit returning an RHR heat exchanger (HX) to service following maintenance with more than 4.57 percent tubes plugged without proper design and licensing basis review/evaluation being performed.

Table 2 Overall Fouling Resistances and K-values for Events with RHR Flow Rate 9700 gpm

Event	Trhr[1]	Tsw[2]	RHRSW Flow	Overall Fouling Resistance	K	Tube Plugging[4]
	F	F	gpm	hr-ft^2-°F/Btu	Btu/sec-°F	percent
Shutdown of Non-Accident Unit	185.1	95	4500	0.000000	398.3	4.57
Shutdown of Non-Accident Unit	185.1	95	4500	0.000461	365.0	4.57
Shutdown of Non-Accident Unit	185.1	95	4500	0.0005164	361.3	4.57
Shutdown of Non-Accident Unit	185.1	95	4500	0.000674	350.9	4.57
Shutdown of Non-Accident Unit	185.1	95	4500	0.000820	341.7	4.57
Shutdown of Non-Accident Unit	185.1	95	4500	0.000930	335.0	4.57
Shutdown of Non-Accident Unit	185.1	95	4500	0.001107	324.6	4.57
Shutdown of Non-Accident Unit	185.1	95	4500	0.001097	325.2	4.57
Shutdown of Non-Accident Unit	185.1	95	4500	0.001521	302.4	4.57
Shutdown of Non-Accident Unit	185.1	95	4500	0.002800[3]	248.4	4.57

Notes
1. Trhr = temperature – residual heat removal
2. Tsw = temperature – service water
3. Heat exchanger original design fouling resistance
4. The current condition (number of tubes plugged) of each RHR heat exchanger is bounded by the design value of 4.57 percent tubes plugged. Work processes prohibit returning an RHR HX to service following maintenance with more than 4.57 percent tubes plugged without proper design and licensing basis review/evaluation being performed.

Table 3 Overall Fouling Resistance and K-values for Events with RHR Flow Rate 7500 gpm

Event	Trhr[1]	Tsw[2]	RHRSW Flow	Overall Fouling Resistance	K	Tube Plugging[4]
	F	F	gpm	hr-ft^2-°F/Btu	Btu/sec-°F	percent
FIRE - CLTP	205.7	92	4400	0.000000	366.4	4.57
FIRE - CLTP	205.7	92	4400	0.000461	338.3	4.57
FIRE - CLTP	205.7	92	4400	0.0005164	335.1	4.57
FIRE - CLTP	205.7	92	4400	0.000674	326.3	4.57
FIRE - CLTP	205.7	92	4400	0.000820	318.3	4.57
FIRE - CLTP	205.7	92	4400	0.000930	312.5	4.57
FIRE - CLTP	205.7	92	4400	0.001107	303.6	4.57
FIRE - CLTP	205.7	92	4400	0.001097	304.1	4.57
FIRE - CLTP	205.7	92	4400	0.001521	284.2	4.57
FIRE - CLTP	205.7	92	4400	0.001856	270.0	4.57
FIRE - CLTP	205.7	92	4400	0.002800[3]	236.2	4.57
FIRE - EPU with EHPMU pump	206.2	95	4500	0.000000	370.8	4.57
FIRE - EPU with EHPMU pump	206.2	95	4500	0.000461	342.0	4.57
FIRE - EPU with EHPMU pump	206.2	95	4500	0.0005164	338.8	4.57
FIRE - EPU with EHPMU pump	206.2	95	4500	0.000674	329.7	4.57
FIRE - EPU with EHPMU pump	206.2	95	4500	0.000820	321.5	4.57
FIRE - EPU with EHPMU pump	206.2	95	4500	0.000930	315.6	4.57
FIRE - EPU with EHPMU pump	206.2	95	4500	0.001107	306.5	4.57
FIRE - EPU with EHPMU pump	206.2	95	4500	0.001097	307.0	4.57
FIRE - EPU with EHPMU pump	206.2	95	4500	0.001521	286.7	4.57
FIRE - EPU with EHPMU pump	206.2	95	4500	0.002800[3]	237.9	4.57
FIRE - EPU - No EHPMU pump	208.0	92	4500	0.000000	370.8	4.57
FIRE - EPU - No EHPMU pump	208.0	92	4500	0.000461	342.1	4.57
FIRE - EPU - No EHPMU pump	208.0	92	4500	0.0005164	338.8	4.57
FIRE - EPU - No EHPMU pump	208.0	92	4500	0.000674	329.7	4.57
FIRE - EPU - No EHPMU pump	208.0	92	4500	0.000820	321.6	4.57
FIRE - EPU - No EHPMU pump	208.0	92	4500	0.000930	315.7	4.57
FIRE - EPU - No EHPMU pump	208.0	92	4500	0.001107	306.5	4.57
FIRE - EPU - No EHPMU pump	208.0	92	4500	0.001097	307.0	4.57
FIRE - EPU - No EHPMU pump	208.0	92	4500	0.001521	286.7	4.57
FIRE - EPU - No EHPMU pump	208.0	92	4500	0.002800[3]	237.9	4.57

Notes
1. Trhr = temperature – residual heat removal
2. Tsw = temperature – service water
3. Heat exchanger original design fouling resistance
4. The current condition (number of tubes plugged) of each RHR heat exchanger is bounded by the design value of 4.57 percent tubes plugged. Work processes prohibit returning an RHR HX to service following maintenance with more than 4.57 percent tubes plugged without proper design and licensing basis review/evaluation being performed.

Table 4 Overall Fouling Resistance, K-value and Heat Transfer Rate Summary for Comparison to Heat Exchanger Test Results

SUMMARY		DBA-LOCA (RSLB)		Shutdown of Non-Acc Unit		ATWS-MSIVC-EOC		Fire Event					
		EPU		EPU		EPU		CLTP		EPU - with EHPMU Pump		EPU - No EHPMU Pump	
RHR (HX shell side) flow rate	(gpm)	6500		**9700**		6500		7500		7500		7500	
RHRSW (HX tube side) flow rate	(gpm)	4000		**4500**		4000		**4400**		**4500**		**4500**	
RHR (HX shell side) inlet temperature	(°F)	179.0		**185.1**		**171.7**		**205.7**		**206.2**		**208.0**	
RHRSW (HX tube side) inlet temperature	(°F)	95.0		95.0		95.0		**92.0**		95.0		**92.0**	
Assumed Percentage of Tubes Plugged	(%)	4.57		4.57		4.57		4.57		4.57		4.57	
Number of RHR HXs in Service	(each)	2		1		4		1		1		1	
	Fouling Resistance (hr-ft²-°F/Btu)	Q per HX (Btu/hr)	K per HX (Btu/sec-°F)	Q per HX (Btu/hr)	K per HX (Btu/sec-°F)	Q per HX (Btu/hr)	K per HX (Btu/sec-°F)	Q per HX (Btu/hr)	K per HX (Btu/sec-°F)	Q per HX (Btu/hr)	K per HX (Btu/sec-°F)	Q per HX (Btu/hr)	K per HX (Btu/sec-°F)
Clean (zero fouling resistance) Heat Transfer Capability													
	0.000000	100,910,880	334	129,192,588	398	92,196,468	334	149,974,848	366	148,438,656	371	154,846,080	371
RHR HX Demonstrated (Tested) Heat Transfer Capability[1]													
2C (0 years since last cleaning)	***0.0004610***	93,955,680	311	118,391,400	365	85,845,708	311	138,472,956	338	136,909,440	342	142,860,960	342
3A (2 years since last cleaning)	***0.0005164***	93,169,440	308	117,191,268	361	85,100,184	308	137,163,132	335	135,628,416	339	141,482,880	339
3C (4 years since last cleaning)	***0.000674***	90,931,680	301	113,817,924	351	83,056,896	301	133,561,116	326	131,985,504	330	137,682,720	330
2C (4 years since last cleaning)	***0.000820***	88,905,600	294	110,833,812	342	81,234,504	294	130,286,556	318	128,702,880	322	134,300,160	322
2A (0 years since last cleaning)	***0.000930***	87,423,840	289	108,660,600	335	79,881,516	289	127,912,500	313	126,340,992	316	131,836,320	316
2A (2 years since last cleaning)	***0.001107***	85,155,840	282	105,287,256	325	77,783,004	282	124,269,552	304	122,698,080	307	127,994,400	307
EPU Nominal							[$Q_{nominal} = Q_{EPUdesign} + (Q_{clean} - Q_{EPUdesign})$*0.25] then solving for K					128,505,960	308
	0.001097	85,276,800	282	105,481,872	325	77,893,452	282	124,474,212	304	122,898,240	307	128,203,200	307
	0.001220					76,485,240	277						
EPU Design (assuming DBA-LOCA long-term peak suppression pool temperature = 179.0) Heat Transfer Capability													
	0.001521	80,136,000	265	98,086,464	302	73,199,412	265	116,328,744	284	114,771,744	287	119,725,920	287
	0.001856							110,516,400	270				
Original Design Heat Transfer Capability													
	0.002800	67,465,440	223	80,571,024	248	61,629,984	223	96,681,384	236	95,236,128	238	99,347,040	238

[1] After accounting for test and measurement uncertainties

Figure 1 RHR Heat Exchanger Fouling Resistances