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Kewaunee / Point Beach Nuclear
Operated by Nuclear Management Company, LLC

(KNPP) NRC-02-070
(PBNP) NRC 2002-0063

10 CFR 50.54(f)

July 30, 2002

U.S. Nuclear Regulatory Commission
ATTN: Document Control Desk
Washington, DC 20555

Ladies/Gentlemen:

Dockets 50-266, 50-301, and 50-305
Point Beach Nuclear Plant, Units 1 and 2
Kewaunee Nuclear Power Plant
Electric Power Research Institute Report TR-113594, "Resolution of Generic Letter 96-06 Waterhammer Issues," Volumes 1 and 2 (TAC NOS. M96824, M96852 and M95853)

References:
1. NRC Generic Letter (GL) 96-06, "Assurance of Equipment Operability and Containment Integrity During Design-Basis Accident Conditions," dated September 30, 1996.
2. EPRI Report TR-113594 dated December 2000, "Resolution of Generic Letter 96-06 Waterhammer Issues," Volumes 1 and 2.
3. NRC Acceptance of EPRI Report TR-113594, "Resolution of Generic Letter 96-06 Waterhammer Issues," dated April 3, 2002.
4. Letter from JG Lamb (NRC) to M. Warner (NMC) dated April 25, 2002, Resolution of Generic Letter 96-06 Waterhammer Issues.
5. Letter from D. Spaulding (NRC) to M. Reddemann (NMC) dated May 3, 2002, Resolution of Generic Letter 96-06 Waterhammer Issues.

In Reference 1 the U. S. Nuclear Regulatory Commission (NRC) requested licensees to evaluate the susceptibility of (1) containment air cooler cooling water systems waterhammer and two-phase flow conditions during postulated accident conditions and (2) piping systems that penetrate containment to overpressurization from the thermal expansion of fluid.

Actions to fully address the waterhammer issue were deferred pending NRC review and approval of EPRI Report TR-113594 (Reference 2). NRC accepted the EPRI Report on April 3, 2002 (Reference 3). This submittal provides updated information regarding NMC's response to address the Resolution of GL 96-06 Waterhammer Issues (References 4 and 5).

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Attachments 1 and 2 to this correspondence provide the site-specific information for Point Beach Nuclear Plant and Kewaunee Nuclear Power Plant, respectively. Please contact us if you have any questions.

Sincerely,

A. J. Cayia

A. J. Cayia
Kewaunee/Point Beach Site Director

LAS/kmd

Attachment:
1 PBNP Response to Resolution of GL 96-06 Waterhammer Issues
2 KNPP Response to Resolution of GL 96-06 Waterhammer Issues
3 Fauske & Associates Calculation FAI/97-60 Rev 5, "Point Beach Containment Fan Cooler Analysis in Response to NRC GL 96-06," pages 11-17 and 32-34, dated October 29, 2001.
4 Fauske & Associates Calculation FAI/97-60 Rev 5, "Point Beach Containment Fan Cooler Analysis in Response to NRC GL 96-06," pages 36-40, dated October 29, 2001.

cc:
NRC Regional Administrator
NRC Project Manager – KNPP
NRC Project Manager – PBNP
NRC Senior Resident Inspector - KNPP
NRC Senior Resident Inspector - PBNP

Attachment 1
To the Letter

From:

A. J. Cayia (NMC)

To:

US NRC Document Control Desk

Dated:

July 30, 2002

Response to Resolution of GL 96-06 Waterhammer Issues Point Beach Nuclear Plant Units 1 and 2

References:

1. Letter from DF Johnson (WE) to Document Control Desk dated January 28, 1997, GL 96-06 120-Day Response.
2. Letter from AJ Cayia (WE) to Document Control Desk dated June 25, 1997, Revision to GL 96-06, 120-Day Response.
3. Letter from AJ Cayia (WE) to Document Control Desk dated December 18, 1997, Information pertaining to Implementation of Modifications Associated with GL 96-06.
4. Letter from B Link (WE) to Document Control Desk dated September 9, 1996, Detailed Operability Evaluation of the Service Water System With Respect to Post-Accident Boiling in Containment Fan Coolers.
5. Letter from B Link (WE) to Document Control Desk dated September 30, 1996, Evaluation of Steady-State Service Water System Hydraulic Characteristics During A Design Basis Accident.
6. Letter from B Link (WE) to Document Control Desk dated October 30, 1996, Assurance of Equipment Operability and Containment Integrity During Design Basis Accident Conditions.
7. Letter from LL Gundrum (NRC) to M. Sellman (WE) dated June 25, 1998, Request for Additional Information Regarding Responses to GL 96-06.
8. Letter from VA Kaminskas (WE) to Document Control Desk dated September 4, 1998, Reply to Request for Additional Information to GL 96-06.
9. Letter from D Cole (NMC) to Document Control Desk dated October 12, 2000, Reply to Request for Additional Information to GL 96-06.
10. FAI/97-60 Revision 5, "Point Beach Containment Fan Cooler Analysis in Response to Generic Letter 96-06," dated August 8, 2001.

The NRC staff issued Generic Letter (GL) 96-06 on September 30, 1996. Wisconsin Electric Power Company (WE), then Licensee for the Point Beach Nuclear Plant (PBNP), provided its assessment of the waterhammer and two-phase flow issues for PBNP in References 1, 2, and 3 and related submittals References 4, 5, and 6.

In Reference 7, the NRC requested additional information to complete their review of WE's GL 96-06 submittals. WE replied to the staff's request for additional information (RAI) in References 8 and 9. At that time, WE deferred responding to some of the items pending NRC review and approval of EPRI Report TR-113594.

This submittal is being generated to address those questions concerning waterhammer that had not been fully addressed in Reference 8 and the NRC Resolution of the GL 96-06 letter dated May 3, 2002. Reference 9 fully addresses the GL 96-06 two-phase flow issues. This submittal fully addresses the GL 96-06 waterhammer issues and will be the final response from PBNP on all GL 96-06 issues.

NRC RAI Item 1

If a methodology other than that discussed in NUREG/CR-5220, "Diagnosis of Condensation-Induced Waterhammer," was used in evaluating the effects of waterhammer, describe this methodology in detail. Also, explain why this methodology is applicable and gives conservative results (typically accomplished through rigorous plant-specific modeling, testing, and analysis).

PBNP Response:

The methodology used to evaluate the effects of waterhammer at PBNP was fully described in Reference 8. No changes to the methodology have occurred since the issuance of the Reference 8 response.

Although the full RAI response had been deferred until the issuance of the EPRI Report, due to modifications completed to replace Containment Fan Cooler (CFC) units, it was determined to continue with the original methodology described in the Reference 8 response. The original analysis was reassessed when the EPRI Report was published, and its methodology was found to adequately address the issues outlined in the EPRI Report.

NRC RAI Item 2a:

Identify any computer codes that were used in the waterhammer and two-phase flow analyses and describe the methods used to bench mark the codes for the specific loading conditions involved (see Standard Review Plan Section 3.9.1).

PBNP Response:

All relevant information was provided in Reference 8.

NRC RAI Item 2b:

Describe and justify all assumptions and input parameters (including those used in any computer codes) such as amplifications due to fluid-structure interaction, cushioning, speed of sound, force reductions, and mesh sizes, and explain why the values selected give conservative results. Also provide justification for omitting any effects that may be relevant to the analysis (e.g., fluid-structure interaction, flow induced vibration, erosion).

PBNP Response:

The applicable sections from the Fauske & Associates calculation (FAI/97-60) are included in Attachment 3. Please note that Assumption 4.8, which is unverified as of the date of this response, concerns a CFC unit that has not yet been replaced. This assumption will be verified during the installation of the modification.

NRC RAI Item 2c:

Provide a detailed description of the "worst case" scenarios for waterhammer and two-phase flow, taking into consideration the complete range of event possibilities, system configurations, and parameters. For example, all waterhammer types and water slug scenarios should be considered, as well as temperatures, pressures, flow rates, load combinations, and potential component failures. Additional considerations for two-phase flow include:

- **Effects of void fraction on flow balance and heat transfer;**
- **Consequences of steam formation, transport, and accumulation;**
- **Cavitation, resonance, and fatigue effects; and**
- **Erosion considerations**

PBNP Response:

Waterhammers experienced during Loss of Offsite Power (LOOP) and during LOCA coincident with LOOP were considered. A detailed description was provided in Reference 8. Additionally, the applicable sections from the Fauske & Associates calculation (FAI/97-60) are included in Attachment 4.

NRC RAI Item 2d:

Confirm that the analyses included a complete failure modes and effects analysis (FMEA) for all components (including electrical and pneumatic failures) that could impact performance of the cooling water system and confirm that the FMEA is documented and available for review, or explain why a complete and fully documented FMEA was not performed.

PBNP Response:

A complete FMEA was not performed. The exception to performing an FMEA was fully described in Reference 8. There is no additional information available following the issuance of the EPRI Report.

NRC RAI Item 2e:

Explain and justify all uses of "engineering judgment".

PBNP Response:

No engineering judgment was used to quantify the waterhammer or two-phase flow effects. Analyses based on first principles and using approved computer codes were performed to quantify these effects. Plant specific input data and justified assumptions were used.

NRC RAI Item 3:

Determine the uncertainty in the waterhammer and two-phase flow analyses, explain how the uncertainty was determined, and how it was accounted for in the analyses to assure conservative results.

PBNP Response:

The calculated waterhammer loads are sensitive to the upstream and downstream service water header pressures. The input values for the service water header pressures were selected to bound their extreme values. The upstream header pressure (maximum value is bounding) was taken to be the service water pump's shut-off head. The downstream header pressure (minimum value is bounding) was taken as the lowest achievable service water outlet pressures. The analysis was based on the lowest Lake Michigan level and the elevation difference between the lowest lake level and the points at which each CFC return header intersects the common service water return header. Since the extreme values for the upstream and downstream header pressures were both used in the load calculations, the maximum sensitivity to header pressure was included in the calculated forcing functions.

Overall, given the Point Beach pipe geometry for the CFC supply and return piping, the service water temperature has a small influence on calculated waterhammer pressure rises. In practice, the waterhammer magnitude is influenced by competing effects. For instance, higher waterhammer pressures are observed when two completely separated water columns rejoin. This situation occurs in the LOCA with LOOP scenario. In this scenario the stagnant service water and high containment heat load lead to significant boiling regardless of the inlet water temperature. Hence, the sensitivity to inlet temperature is minor. In the LOOP only scenario, partial voiding is calculated and there was no complete column separation event. This results in smaller waterhammer loads than those for the LOCA with LOOP scenario. As the service water temperature decreases, the void fraction would become smaller. Thus, with colder water, even smaller waterhammer loads could be expected for the LOOP only scenarios. The bounding loads in this calculation were selected from calculations for both types of scenarios, which assured that the potential range of sensitivity to service water temperature was also addressed.

NRC RAI Item 4:

Confirm that the waterhammer and two-phase flow loading conditions do not exceed any design specifications or recommended service conditions for the piping system and components, including those stated by equipment vendors; and confirm that the system will continue to perform its design-basis functions as assumed in the safety analysis report for the facility and that the containment isolation valves will remain operable.

PBNP Response:

Calculation FAI/97-60 (Reference 10) was updated to include the modified piping configurations. The forcing functions developed were incorporated into the design of piping and pipe supports for the modification packages that govern replacement of the CFC units and associated piping (MR-98-024*J, K, X, & Y). Point Beach has reviewed Calculation FAI/97-60 and the subsequent packages described above and has confirmed that the loading conditions do not exceed any design basis specifications or recommended service conditions for the piping system or components.

NRC RAI Item 5:

Provide a simplified diagram of the system, showing major components, active components, relative elevations, lengths of piping runs, and the location of any orifices and flow restrictions.

PBNP Response:

The diagrams provided in Reference 8 were complete. However, there is a minor change to the diagram shown on page 13 of that submittal. The modified piping for the CFCs contain some 6" pipe that acts as a manifold for all the 2½" inlet and outlet pipe shown and feeds into the 8" inlet and outlet pipes shown.

NRC RAI Item 6:

Describe in detail any plant modifications or procedure changes that have been made or are planned to be made to resolve the waterhammer and two-phase flow issue.

PBNP Response:

All procedure changes are relevant to the two-phase flow issue and were fully addressed in Reference 8. The piping support modifications are associated with the waterhammer issue and are also described in Reference 8.

Subsequently, the CFC units and some of their associated piping were replaced under modification packages MR-98-024*J, K, X, & Y. Unit 1 "C" and "D" CFCs are not completed yet but they are scheduled to be completed in the fall of 2002.

All current piping supports and modifications have been reviewed to verify that they were completed in accordance with GL 96-06 issues.

Attachment 2
To the Letter

From:

A. J. Cayia (NMC)

To:

US NRC Document Control Desk

Dated:

July 30, 2002

Response to Resolution of
GL 96-06 Waterhammer Issues
Kewaunee Nuclear Power Plant Unit 1

References:
1. Letter from CR Steinhardt (WPSC) to Document Control Desk dated October 30, 1996, Thirty-Day Response to GL 96-06.
2. Letter from CR Steinhardt (WPSC) to Document Control Desk dated January 28, 1997, 120-Day Response to GL 96-06.
3. Letter from RJ Laufer (NRC) to ML Marchi (WPSC) dated September 16, 1997, Request for Additional Information Regarding Response to GL 96-06.
4. Letter from CR Steinhardt (WPSC) to Document Control Desk dated November 20, 1997, Response to Request for Additional Information.
5. Letter from CR Steinhardt (WPSC) to Document Control Desk dated March 6, 1998, Status of GL 96-06.
6. Letter from WO Long (NRC) to ML Marchi (WPSC) dated May 5, 1998, Request for Addition Information Regarding Response to GL 96-06.
7. Letter from ML Marchi (WPSC) to Document Control Desk dated July 30, 1998, Response to Request for Additional Information.

The NRC staff issued Generic Letter (GL) 96-06 on September 30, 1996. Wisconsin Public Service Corporation (WPSC), then Licensee for the Kewaunee Nuclear Power Plant (KNPP), provided its assessment of the waterhammer and two-phase flow issues for KNPP in References 1 and 2. In Reference 4, WPSC replied to the staff's Request for Additional Information (RAI) (Reference 3).

Subsequently, per Reference 5 dated March 6, 1998, WPSC provided the NRC with an update on WPSC's efforts to resolve the waterhammer issue. In this letter, WPSC stated that an operability evaluation had been completed prior to startup from the 1996-1997 outage and concluded that there were no significant safety concerns. Since the March 1998 letter, EPRI has developed its methodology to evaluate all Containment Fan Cooler (CFC) units. WPSC agreed to support EPRI and to apply the EPRI findings to KNPP after the EPRI project was completed.

In Reference 6, the NRC requested additional information to complete their review of WPSC's GL 96-06 submittals. In Reference 7, WPSC replied to the staff's request for additional information (RAI) regarding the two-phase flow issue. With regards to the waterhammer issue, Reference 7 stated that WPSC has not developed a final resolution to the waterhammer concerns. The response stated that when the EPRI project was complete, WPSC would apply the EPRI findings to the Kewaunee plant and would inform the NRC and provide details of the resolution.

With the approval of the EPRI report, NMC will evaluate the CFC units in accordance with the EPRI methodology. KNPP anticipates that this analysis will be completed in 2003. When the analysis is completed, NMC will inform the NRC and provide details of the resolution. If additional modifications are required, NMC will provide a schedule for completion of the modifications.

Attachment 3
To the Letter

From:

A. J. Cayia (NMC)

To:

US NRC Document Control Desk

Dated:

July 30, 2002

Fauske & Associates Calculation FAI/97-60 Revision 5
Point Beach Containment Fan Cooler Analysis
In Response To NRC Generic Letter 96-06
Dated October 29, 2001

Pages 11-17 and 32-24

3.0 DESIGN INPUT AND REFERENCES

1. NRC Generic Letter 96-06: Assurance of Equipment Operability and Containment Integrity During Design-Basis Accident Conditions (September 30, 1996).
2. WEPCO Calculation 96-0117, Rev. 1, "Containment Fan Cooler Service Water Throttle Valve Setpoint for Three Service Water Pump Operation," Approved 9/19/96. (No longer used.)
3. Sargent & Lundy Report M-09334-186.SW, Rev. 0, Operability Assessment for Transient Conditions in Point Beach Nuclear Plant Service Water System During a Coincidental Loss of Coolant Accident and a Loss of Offsite Power.
4. CRANE Technical Paper No. 410, "Flow of Fluids through Valves, Fittings, and Pipe" 1988 Edition.
5. FAI/97-55 Rev. 1, "TREMOLO (Rev. 1.02) Parameter Files for Point Beach," August, 1997.
6. FAI/97-2 Rev. 0, "FAI Experience on Waterhammer Phenomena in Containment Air Cooler Service Water Systems," (May, 1997).
7. Bennett and Myers, Momentum, Heat, and Mass Transfer, Third Ed. p. 411, McGraw-Hill Book Company, New York (1982).
8. Abdollahian, D., Healzer, J. Janssen, E., and Amos, C., 1982, "Critical Flow Data Review and Analysis," EPRI NP-2192.
9. Ardon, K. H., 1978, "A Two-Fluid Model for Critical Vapor-Liquid Flow," Int. J. Multiphase Flow 4, p. 323.
10. Richter, H. J., 1981, "Separated Two-Phase Flow Model: Application to Critical Two-Phase Flow," EPRI NP-1800 (April).
11. Rivard, W. C. and Travis, J. R., 1980, "A Nonequilibrium Vapor Production Model for Critical Flow," Nuclear Science and Engineering 74, pp. 40-48.
12. WCAP-7336-L, "Topical Report on Reactor Containment Fan Cooler Cooling Coil Test," July 1989, W. B. Boettinger.
13. FAI QA File 5.17 (includes TREMOLO Revision 1 Test Plan, Test Documentation, and User Documentation, March, 1997 and TREMOLO Revision 1.02 Software Change Specification and Test Documentation, August, 1997).

14. Cerne, G., Tiselj, I., and Petelin, S., "Modeling of Water Hammer with Column Separation," ANS 1996 Annular Meeting, Transactions, pp. 387, 388.

15. R. Byron Bird, Warner E. Stewart, Edwin N. Lightfoot - University of Wisconsin at Madison, Transport Phenomenon, pp. 78-79, John Wiley & Sons, Inc., NY (1960)

16. Sargent & Lundy Design Information Transmittal, DIT-PB-EXT-0594-00 (June, 2000).; included here as Appendix H.

17. Chuck Richardson, Wisconsin Electric Power Company, Facsimile to Bob Hammersley, Fauske & Associates, Inc., Water model pressure profile with revised pipe routing (June 14, 2000); included here as Appendix H.

18. HOLTEC International Point Beach Containment Fan Cooler Drawings, Dwg.'s 3086 Rev. 0, 3087 Rev. 0, and 3088 Rev. 0 ; included here as Appendix H.

19. Chuck Richardson, Wisconsin Electric Power Company, Letter to Tom Elicson, Fauske & Associates, Inc., Wisconsin Electric (WE) Supplied Inputs to FAI/97-60, Revision 2 (August 8, 2000); included here as Appendix H.

20. Chuck Richardson, Wisconsin Electric Power Company, Letter to Tom Elicson, Fauske & Associates, Inc., Wisconsin Electric (WE) Supplied Inputs to FAI/97-60, Revision 2 (August 22, 2000) ; included here as Appendix H.

21. Sargent & Lundy Design Information Transmittal, DIT-PB-EXT-0597-00 (August 9, 2000).; included here as Appendix H.

22. Sargent & Lundy Design Information Transmittal, DIT-PB-EXT-0611-00 (10/13/2000).

23. Chuck Richardson, Wisconsin Electric Power Company, Letter to Robert Hammersley, Fauske & Associates, Inc., Wisconsin Electric (WE) Supplement Inputs to FAI/97-60, Revision 3, dated 10/23/2000.

24. Sargent & Lundy Design Information Transmittal, DIT-PB-EXT-0637-00, 10/1/2001.

As part of the iterative design process for the revised pipe routing associated with CFC's 2HX15A, B, and D, the TREMOLO forcing functions were developed in parallel with the pipeline design. Thus, the final set of forcing functions used in the structural design calculations do not rely on information provided in the final Design Information Transmittal (DIT) [19,20,21]. (Note: Reference 20 has not been signed and, therefore, will be treated as an unverified input assumption.) Rather, the final forcing functions reflect a conservative set of accident conditions and geometry based on preliminary DIT values [16,17,18] that produce forcing functions that bound or are similar to those obtained from the final DIT conditions. The resultant loads in the Unit 2 analysis were based on the preliminary DITs, while the Unit 1 analysis were based on the final DIT values. Table 3-1, below, compares the preliminary DIT values to those contained in the final DIT.

Table 3-1 Summary of Key Design Inputs

DESCRIPTION	Preliminary DIT VALUE Ref. 2, 3, 18	Final DIT VALUE Ref. 19, 20, 21, 23
Assumed pump restart time for all sequences	25.8 sec	25.0 sec
CFC tube fouling factor, all CFCs all sequences*	0.0	0.001
Pipe schedule	Schedule 40	Schedule 40
Initial service water pump discharge pressure: 1HX15A, 1HX15C	N/A	67.65 psia
Initial service water pump discharge pressure: 1HX15B, 1HX15D	N/A	68.06 psia
Minimum pump discharge pressure following pump trip: 1HX15A, 1HX15B, 1HX15C, 1HX15D	N/A	6.29 psia
CFC common return header initial pressure: 1HX15A, 1HX15B, 1HX15C, 1HX15D	N/A	6.29 psia
Initial service water pump discharge pressure: 2HX15A	61.48 psia	61.48 psia
Initial service water pump discharge pressure: 2HX15B	61.1 psia	61.1 psia
Initial service water pump discharge pressure: 2HX15C	72.12 psia	72.12 psia
Initial service water pump discharge pressure: 2HX15D	63.27 psia	63.27 psia
Minimum pump discharge pressure following pump trip: 2HX15C	7.85 psia	7.85 psia
Minimum pump discharge pressure following pump trip: 2HX15A, 2HX15B, 2HX15D	5.76 psia	5.76 psia
CFC common return header initial pressure: 2HX15C	7.85 psia	7.85 psia

DESCRIPTION	**Preliminary DIT VALUE Ref. 2, 3, 18**	**Final DIT VALUE Ref. 19, 20, 21, 23**
CFC common return header initial pressure: 2HX15A, 2HX15B, 2HX15D	5.76 psia	5.76 psia
Pump coastdown time (approx.): all CFCs	3 sec	3 sec
Pump ramp up time following restart (approx.) all CFCs	10 sec	20 sec
Pump recovery pressure following restart for all CFCs	Same as initial pressure	126.3 psia
Peak containment temperature for LOCA sequence: all CFCs	280 F @ 5.0 sec	278.7 F @ 7.5 sec
Service water inlet temperature	75 F	80 F

*See discussion on page 15 (Section 4.2).

Note: The final DITs (Ref. 19 & 20) reflect corrected information with regard to node 520, and the correction was implemented in all Unit 2 calculations.

4.0 ASSUMPTIONS

4.1 Friction Losses

Frictional pressure drop is accounted for by combining pipe wall friction for straight pipe sections and friction losses through miscellaneous flow elements. Pipe wall friction is characterized by the term fL/D, where f is the Moody friction factor, L is the actual pipe length, and D is the pipe hydraulic diameter. Friction losses through flow elements are characterized by loss coefficients, K. The pipe diameters (nominal) in the Point Beach CFC circuits range from 22 inches down to 2 ½ inches (not including the CFC tubes). Assuming fully developed turbulent flow in clean commercial steel, this results in Moody friction factors in the range of 0.017 to 0.013 [4].

For the accident scenarios considered here, flow rates may deviate substantially from those characteristic of fully developed turbulent flow. Thus, friction factors are evaluated within TREMOLO for every fluid node at every time step based on smooth pipe correlations [4] as a function of the current flow rate in the fluid node.

4.2 Heat Transfer in the CFC

TREMOLO Revision 1.02 provides a mechanistic heat exchanger calculation which is used to model the CFC heat transfer rate under low flow and two-phase flow conditions. The calculated heat transfer rate is a function of heat exchanger geometry, cooling water flow rate, gas temperature, and tube fouling factor. To maximize heat transfer, a lower bound on CFC fouling factor of 0.0 is used in the TREMOLO model [5]. The mechanistic heat exchanger model has been validated against test data as documented in the TREMOLO 1.02 test documentation [13].

Two TREMOLO steady state sample runs were also performed to verify that the Point Beach-specific fan coil heat removal rate is obtained with the TREMOLO mechanistic heat exchanger model. Sequence PB2A286 uses 280 F saturated steam in the containment, 80 F service water inlet temperature, and 560 gpm service water flow to the fan cooler, and zero fouling. These conditions yield a steady state heat removal rate of 50.2 MBtu/hr. The fan coil test data indicate a heat removal rate of 39.1 MBtu/hr with a tube total fouling of 0.001 [19]. When the TREMOLO case was re-run with 0.001 fouling (case PB2A286_001), the TREMOLO predicted heat removal rate was precisely 39.1 MBtu/hr.

4.3 Containment Gas Temperature

The containment gas temperature is assumed to vary with respect to time according to Westinghouse letter WEP-97-522 (NSD-SAE-ES1-97-302) [Ref. 19]. For the LOOP + LOCA sequences, the containment gas temperature is assumed to rise linearly from 85 F to 278.7 F over a period of 7.5 seconds [19,20,21,23].

4.4 Supply and Return Header Pressures

TREMOLO uses pressure boundary conditions at the upstream and downstream boundaries of the pipe circuit. The current analysis accounts for service water pump trip and restart by varying the upstream and downstream boundary pressures as a function of time. TREMOLO boundary pressures were varied according to the data provided in references [3 and 17]. Linear pressure changes with respect to time were used to simulate the header pressure profiles. The ramp up duration, as well as the maximum and minimum pressures used for the upstream boundary in TREMOLO, are based on the information provided in the references. The coast down time is conservatively assumed to be 3 seconds. The downstream header pressure is set at the minimum of the upstream header pressure and the initial downstream header pressure. More precise modeling of the test data was limited by the TREMOLO Revision 1.02 capabilities.

4.5 Parallel Flow Paths and Pipe Circuit Boundaries

The CFC pipe circuits are actually complex pipe networks consisting of numerous parallel flow paths and several thousand feet of pipe. The portion of the network selected for the current model simplifies the complex pipe network into a single pipe circuit consisting of individual pipe sections of varying diameter, length, and elevations connected in series. Furthermore, the CFC pipe circuit models start at upstream and downstream "header" points rather than the actual service water pump discharge and return canal discharge points. Parallel flow paths are accounted for by selecting an equivalent pipe diameter which conserves the total mass flow rate and actual fluid velocity through each branch. Equivalent pipe diameters are used to model parallel flow paths in the 2 ½ -inch, 8-inch, 10-inch, 12-inch, 14-inch, and CFC cooling tube regions. Details of the selected circuit boundaries and treatment of parallel flow paths can be found in reference [5] and in Appendices E through G for the revised pipe routing models. Selection of the header points and the simplified treatment of parallel flow paths are not expected to significantly alter the results and conclusions derived from the TREMOLO analysis.

4.6 Nominal Flow Through the CFC Circuit

References [17 and 23] reports the steady-state cold water flow rate for each of the eight fan coolers analyzed. Loss coefficients for the flow elements of each CFC were defined such that both the pressure data and the nominal flow rates given in the above references are well matched by TREMOLO steady state results.

4.7 Fluid Compressibility Due to Presence of Steam and Non-Condensible Gas

Experimental evidence [6] indicates that non-condensible gas and steam voids appear rather rapidly following sudden depressurization transients in water-filled fluid systems, and that these gas bubbles go back into solution over several tens of seconds. The lingering presence of the gas bubbles accounts for observed waterhammer pressure loads which are significantly less than the calculated loads based on solid liquid conditions. In essence, the gas bubbles provide a compressibility to the otherwise incompressible liquid system. This is accounted for in TREMOLO Revision 1.02 by maintaining a minimum void fraction once steam and non-condensible gases are released into the pipe system.

There is some uncertainty in the degree to which retained gas increases the compressibility of the fluid. The experimental evidence [6] suggests that a value of 5.E-3 for the minimum void fraction following gas evolution, TREMOLO model parameter VFMIN, is appropriate. Benchmarks of TREMOLO with experimental data [13], show good agreement between the calculated and experimental results for values of VFMIN from 1.E-4 to 5.E-3.

4.8 Unverified Input Assumptions

As part of the analysis on the 1HX15D CFC, there was a slight difference in the TREMOLO model (Appendix L) and that presented in the DIT [24]. The 8" x 8" x 6" reducing tee on the return side was modeled at 26' –6" elevation, not the 25' –9" elevation as shown in the DIT. Thus, the return side piping up to the tee is modeled 9" shorter than it really is. Since the maximum forces (i.e., where the void collapses) are not located in these pipe sections and the location of the maximum force is not > 9" away from another pipe section or flow element, the effects of this modeling assumption will not have any bearing on the maximum forces or its location. No additional volume has been added and the location of the maximum forces would not change due to the inclusion of this modeling flaw.

As part of the analysis of the 1HX15C CFC, there was a slight difference in the TREMOLO model (Appendix K) and that presented in the DIT [24]. The 6' –6 ¾" dimension on the return side piping following the 90° elbow below the CFC on the 27' –6" elevation was modeled as 5' –6¼ ". This dimension was changed per S&L recommendation, however, the information was not formally transmitted to FAI at the time of the issuance of Revision 5.

Table 5-9 Model Parameters Used for Point Beach Analysis

Parameter Name	Point Beach Value	Parameter Description	Technical Basis
NWALL	2.	Number of nodes for pipe wall heat transfer calculations	Maximize wall heat transfer to reduce void influence
NSECT	3.	Number of nodes per pipe section for fluid flow calculations	Model discretion to balance precision and computation requirements
FFRIC	0.016	Nominal friction factor for straight pipe sections	Consistent with clean commercial steel pipe value [4]
HTCO	1.	Heat transfer coefficient at pipe wall outside surface	Outer surface assumed approximately adiabatic
FHTCI	1.0	Wall inside surface heat transfer coefficient multiplier; = 1.0 for normal calculation; = 0.0 for adiabatic BC	Allow fluid-pipe wall heat transfer
FCDUP	1.0	Discharge coefficient for flow at boundary of upstream pipe section	Maximize inlet flow rate
FCVTIM	0.001	MOV CV fraction which defines valve closure; valve is assumed fully closed when CV(t)/CV0 < FCVTIM	Not applicable to current analysis
FFLOW	3	Fluid model type; select void and critical flow models for steady state initialization FFLOW — VOID MODEL/ CRITICAL FLOW MODEL 1 — HOMOGENEOUS / FAUSKE EQUILIBRIUM 2 — FAUSKE / FAUSKE EQUILIBRIUM 3 — HENRY / NONEQUILIBRIUM 4 — LOCKHART-MARTINELLI/ HENRY NONEQUILIBRIUM	Fluid conditions of interest will result in non-equilibrium two-phase flow
FISFIX	0	Steady state initialization convergence control Force DELPUP and DPDZ1 to converge at node ISFIX+1 for steady state initialization If FISFIX = 0, then convergence occurs at node with largest loss coefficient + 1	Converge at the throttle valve

Parameter Name	Point Beach Value	Parameter Description	Technical Basis
FMOM	1	Momentum pressure drop model selection for steady state initialization = 0: bounding model for low quality, high void fraction = 1: detailed model, valid for all qualities and void fractions	Use detailed model
FFMODL	2	Friction pressure drop model selection =2-homogeneous flow =3-homogeneous flow with PROPS based on void =4-Lockhart Martinelli (upper bound) =5-Lockhart Martinelli (lower bound) =6-Lottes and Flinn	Homogeneous model sufficient since frictional pressure drop is not dominant phenomena in analysis
FHXFC	0	Fan cooler heat exchanger model selection =0: mechanistic heat exchanger model =1: LOOK-UP TABLE	Mechanistic model must be used because of low flow and two-phase flow conditions
FQMULT	1.0	Fan cooler heat exchanger heat transfer multiplier. Calculated heat transfer will be multiplied by FQMULT	Only 1 active CFC modeled
FTDBUB	0.001	Characteristic time for bubble growth	Based on photographic studies reported in [7]
FVOIDB	0.01	Upper limit on void fraction for bubble growth model	Not applicable
NBM3	1.E9	Initial bubble density (bubbles/m^3)	Based on best estimate [8-11]
RB0	1.E-6	Initial bubble radius (M)	Based on best estimate [8-11]
PPN2MN	0.33E5	Initial minimum nitrogen partial pressure (PA)	Conservatively selected less than 1 atmosphere
CCOND	0.6	Conduction coefficient	Based on comparison to fan cooler data [12]
PAIR	0.0	Nitrogen partial pressure used in DELPUP for steady state initialization	Not applicable for all liquid steady state conditions
VFMIN	5.E-3	Minimum void fraction following gas release	Based on experimental evidence reported in [6]

Parameter Name	**Point Beach Value**	**Parameter Description**	**Technical Basis**
FROUGH	1.0	Friction factor multiplier to account for pipe wall roughness	Default value, has no impact
PVFMIN	0.2E5	Pressure at which air comes out of solution (Pa)	Based on two-phase waterhammer benchmark [13]

Attachment 4
To the Letter

From:

A. J. Cayia (NMC)

To:

US NRC Document Control Desk

Dated:

July 30, 2002

Fauske & Associates Calculation FAI/97-60 Revision 5 Point Beach Containment Fan Cooler Analysis In Response To NRC Generic Letter 96-06 Dated October 29, 2001

Pages 36-40

3. Standalone benchmark of subroutine XFORCE against a steady state text book sample problem of resultant force at a 90-degree elbow.

4. Steady state containment fan cooler heat removal rate as a function of containment gas temperature and cooling water flow rate.

The purpose of these benchmark runs is to verify the proper implementation of model upgrades 1, 2, 3, 4, and 6 listed above. The upgrades listed under item 5 are verified through repeated use of the TREMOLO code and require no separate benchmarking.

Results from benchmark 1 show good agreement with the experimental test data, thus supporting the validity of the equation of state, the fluid transport equations, and the phase interface and non-condensible gas models.

Results of benchmark 2 indicate a transient force prediction which slightly exceeds the bounding hand calculation. Overall good agreement was obtained indicating proper implementation of the force model.

Results of benchmark 3 are essentially in perfect agreement with the text book sample problem (if the pressure force term is subtracted), indicating steady state forces at 90-degree elbows are properly calculated.

Results of benchmark 4 indicate that the TREMOLO heat exchanger model shows good agreement with measured heat exchanger data.

In summary, the specified benchmarks indicate that the key model upgrades were implemented correctly and that the models, in combination with the integral TREMOLO code, yield physically correct predictions of pipeline transient thermal hydraulic behavior. This V&V effort addresses the dominant phenomena expected in the Point Beach CFC analysis and therefore establishes the applicability TREMOLO Version 1.02 for the current analysis.

5.5 Calculational Results

5.5.1 Loss of Power

A loss of power event (LOOP) is postulated to occur which results in a trip of the service water pump supplying the CFC piping. It is assumed that 25 seconds are required prior to service water pump restart (see Table 3-1). This time delay accounts for the time required to start the emergency diesel generators plus the sequencing delay for service water pump actuation.

The cooling water conditions are temperature of 80 F (see Table 3-1). The initial, cold water flow rate is calculated by TREMOLO. Since no other accident initiators are present, the containment is assumed to be at a nominal temperature and therefore no heat is transferred between the service water piping and the containment atmosphere.

The initial upstream and downstream boundary pressures are based on steady state pipe circuit calculations from Point Beach [18,23] as described in Table 3-1. The pump coastdown is approximated by using linear change in pressure between the upstream and downstream boundary pressures. Pump coastdown is assumed to occur over 3 seconds, while pump restart is assumed to occur over 10 seconds (see Table 3-1).

Appendix A contains input decks and results for the TREMOLO loss of power calculation for the Unit 2 CFCs analyzed (2A, 2B, and 2D). Appendix M contains similar information for the Unit 1 CFCs analyzed (1A and 1B). Appendix P contains similar information for the 3 CFCs (1C, 1D and 2C) analyzed as part of this revision. The results provided document the calculated pressure (PNOD) and void (VFNOD) in each node and the resultant force (PARX) on each flow element modeled. Characteristics of the pump coastdown and restart are evident from the plot of upstream boundary pressure history (PUP). As shown in these figures, following pump trip, void formation occurs in the high points of the service water piping. The voids subsequently collapse after pump restart, leading to dynamic pressure loads and reaction forces along the length of the pipe system. It should be noted that the figures of Appendix A show trends in the data. Due to the large number of data points produced in the TREMOLO output, not every point could be plotted. The plotting program selects a sample of data points from throughout the transient run.

Appendix B provides a summary of the maximum calculated forces at each flow element for each of the eight fan coolers for the loss of power event. The forces reported by TREMOLO are for each flow element as if it were a 90° elbow. This conservatism can result in forces which are higher than the actual force for bends which are less than 90°.

5.5.2 LOCA Coincident with Loss of Power

A LOCA coincident with a loss of power event is postulated to occur which results in a trip of the service water pump supplying the CFC piping. It is assumed that 25 seconds (see Table 3-1) are required prior to service water pump restart. This time delay accounts for the time required to start the emergency diesel generators plus the sequencing delay for service water pump actuation.

The cooling water is initially at a temperature of 80 F (see Table 3-1). The initial, cold water flow rate is calculated by TREMOLO. The LOCA condition results in an increase in the containment gas temperature to a maximum of 278.7 F at 7.5 seconds, as discussed in Section 4.3. As the containment temperature rises, heat transfer across the CFC cooling tubes increases. Then, as the service water flow decreases due to the pump trip, boiling is expected to occur in the CFC tube region.

The initial upstream and downstream boundary pressures are based on steady-state calculations from Point Beach [17, 23] as described in Table 3-1. The pump coastdown is approximated by using a linear change in pressure between the upstream and downstream boundary pressures. Pump coastdown is assumed to occur over 3 seconds, while pump restart is assumed to occur over 10 seconds (see Table 3-1).

Appendix C contains input decks and results for the TREMOLO LOCA with loss of power calculation for the Unit 2 CFCs analyzed (2A, 2B, and 2D). Appendix N contains the similar information for the Unit 1 CFCs analyzed (1A and 1B). Appendix Q contains similar information for the 3 CFCs (1C, 1D and 2C) analyzed as part of this revision. The results provided document the calculated pressure (PNOD) and void (VFNOD) in each node and the resultant force (PARX) on each flow element modeled. Characteristics of the pump coastdown and restart are evident from the plot of upstream boundary pressure history (PUP). It should be noted that the figures of Appendix C show trends in the data. Due to the large number of data points produced in the TREMOLO output, not every point could be plotted. The plotting program selects a sample of data points from throughout the transient run.

As shown in the figures of Appendix C, following pump trip, there is an initial drain down and boiling phase of the accident during which void formation occurs in the high points of the service water piping. Boiling begins in the CFC resulting in a significant void fraction in the CFC and in several nodes downstream of the CFC. As the hot steam void expands and pushes water out of the pipe, the relatively cold pipe walls are exposed. Steam then condenses on these cold pipe walls causing a series of condensation-induced water hammer events during the initial drain down and boiling phase of the accident. The voids subsequently collapse after pump restart, leading to additional dynamic pressure loads and reaction forces along the length of the pipe system.

Appendix D provides a summary of the maximum calculated forces at each flow element for each of the eight fan coolers for the LOCA with loss of power event. The forces are calculated by TREMOLO for each flow element as if it were a 90 elbow. This conservatism can result in forces which are higher than the actual force for bends which are less than 90 .

5.5.3 CFC 2HX15A Bounding Reaction Forces

Several sets of accident conditions are analyzed to develop a conservative set of reaction forces for the supply and return piping associated with CFC 2HX15A. The time histories for the reaction forces, also referred to as the forcing functions, are used subsequently in pipeline structural design calculations.

As part of the iterative design process for the revised pipe routing associated with CFC 2HX15A, the TREMOLO forcing functions were developed in parallel with the pipeline design. Thus, the final set of forcing functions used in the structural design calculations do not rely on information provided in the final Design Information Transmittal (DIT) [19,20,21]. Rather, the final forcing functions reflect a conservative set of accident conditions and geometry [16,17,18] that produce forcing functions that bound or are similar to those obtained from the final DIT conditions.

Typically, a "generic" CFC pipe circuit consists of 500 to 1000 ft of pipe with upwards of 60 elbows, bends, valves, tees, and area changes. Thus, it is not practical to develop a single set of accident conditions that will produce bounding forces at all flow element locations. Therefore, to ensure that the forcing functions provided for the structural design calculations are conservative and bound or are similar to those obtained from the final DIT conditions, sensitivity analyses are performed based on the DIT conditions. The four cases considered for CFC 2HX15A are described below.

Forcing functions for the base case identified as PB2A_LOCA are a conservative set of forcing functions and were transmitted for use in the final structural calculations. PB2A_LOCA is a LOOP + LOCA scenario as described in Section 5.5.2, above. Sensitivity case PB2A_LOCA_H is the same LOOP + LOCA scenario but with all initial and boundary conditions matching the final DIT conditions. Table 3-1 compares the DIT conditions used in PB2A_LOCA_H against the conditions used to generate bounding forcing functions in case PB2A_LOCA. The most significant differences between the bounding analysis and the DIT conditions are the 0.001 fouling factor on the fan coil tubes, the pump restart profile, and the pump recovery pressure.

Figures 5-2 and 5-3, below, compare four sets of TREMOLO calculations considered for CFC 2HX15A. As shown in Figure 5-2, the LOOP + LOCA cases produce more void than the LOOP only cases. Also, in all cases, the void collapse begins shortly after pump restart, which occurs at 25 seconds for the sensitivity cases and 25.8 seconds for the bounding base case. Figure 5-3 indicates the maximum dynamic force for each of the flow elements considered in the analysis. The dependent variable is the flow element number which corresponds to the flow elements identified in the maximum force tables of Appendices B and D.

Although case PB2A_LOCA forcing functions are used in the final structural design calculations, Figure 5-3 indicates that the PB2A_LOCA case does not always provide the largest forces. The forces for which PB2A_LOCA are not bounding, however, are similar in magnitude to the bounding loads. The notable exceptions are force element 2 which is actually a static loading because of the upstream boundary interface, and force element 12 which is a static loading due to the area change across a 10x8" reducer.

The voided region of the piping circuit is identified in Figure 5-4, which provides the axial void profile for the conservative base case, PB2A_LOCA. Figure 5-4 shows the maximum void size and the void location immediately prior to void collapse. The void profile indicates that the fan coil tubes and the return piping out to the top of the 8" return downcomer are completely voided at the time of pump restart. Following pump restart, the voided region is filled with relatively cold water until the last voided region, near the top of the 8" return downcomer, is refilled. Since the 2 ½", 6", and 8" return piping experiences significant voiding, these sections of the return pipe are subject to condensation-induced waterhammer events during the refill phase of the sequence. Thus, as shown in Figure 5-3, it is not surprising that the largest dynamic loads occur in the 2 ½", 6", and 8" return piping (forces 35 through 45).

Typical results for the PB2A_LOCA base case are presented Figure 5-5. This figure provides an indication of the thermal hydraulic performance in the CFC return piping at the junction of the 2 ½" and 6" tee junction for case PB2A_LOCA. As indicated, the loading consists of dynamic loads due to the void collapse and static loading due to the area change as the pipeline repressurizes and the water velocity approaches its equilibrium value. The dynamic loads are the ones of interest for the current analysis. Thus, the loads from 30 to 40 seconds, which are a result of condensation-induced waterhammer events, are reflected in Figure 5-3.

Figure 5-6 provides an indication of the thermal hydraulic performance in the CFC return piping in the vicinity of the final void collapse. The waterhammer load due to final void collapse (i.e., column rejoining) is tempered because of the presence of small gas bubbles in the pipeline.

Typically, conditions for a loss of power (LOOP) which result in a cold water column separation and rejoining will produce waterhammer pressure rises that bound those obtained from LOCA-type accident scenarios for which significant boiling and void formation occur in the pipeline. This is primarily a results of the smaller quantity of gas released during the cold water column separation as opposed to the boiling and void formation during LOCA-type scenarios. However, given the Point

Beach-specific geometry and accident conditions, the LOOP events result in limited voiding of the return piping. For instance, as shown in Figure 5-7, the maximum void fraction in the 8" horizontal return pipe is less than 50%, therefore a complete column separation and rejoining event never occurs. Rather, the partially voided pipe refills and produces moderate waterhammer pressure rises as indicated in Figure 5-7. Thus, for Point Beach CFC 2HX15A, the LOOP + LOCA generally produces the limiting waterhammer loads.

Figure 5-8 provides an indication of the thermal hydraulic performance in the CFC return piping at the junction of the 2 ½" and 6" tee junction for case PB2A_LOCA_H. As indicated, the loading consists of dynamic loads due to the void collapse and static loading due to the area change as the pipeline repressurizes and the water velocity approaches its equilibrium value. The dynamic loads are the ones of interest for the current analysis. Thus, the loads from 30 to 40 seconds, which are a result of condensation-induced waterhammer events, are reflected in Figure 5-3.

5.5.4 CFC 2HX15B Bounding Reaction Forces

Several sets of accident conditions are analyzed to develop a conservative set of reaction forces for the supply and return piping associated with CFC 2HX15B. The time histories for the reaction forces, also referred to as the forcing functions, are used subsequently in pipeline structural design calculations.

As part of the iterative design process for the revised pipe routing associated with CFC 2HX15B, the TREMOLO forcing functions were developed in parallel with the pipeline design. Thus, the final set of forcing functions used in the structural design calculations do not rely on information provided in the final Design Information Transmittal (DIT) [19,20,21]. Rather, the final forcing functions reflect a conservative set of accident conditions and geometry [16,17,18] that produce forcing functions that bound or are similar to those obtained from the final DIT conditions.

Typically, a "generic" CFC pipe circuit consists of 500 to 1000 ft of pipe with upwards of 60 elbows, bends, valves, tees, and area changes. Thus, it is not practical to develop a single set of accident conditions that will produce bounding forces at all flow element locations. Therefore, to ensure that the forcing functions provided for the structural design calculations are conservative and bound or are similar to those obtained from the final DIT conditions, sensitivity analyses are performed based on the DIT conditions. The four cases considered for CFC 2HX15B are described below.

Forcing functions for the base case identified as PB2B_LOCA are a conservative set of forcing functions and were transmitted for use in the final structural calculations. PB2B_LOCA is a LOOP + LOCA scenario as described in Section 5.5.2, above. Sensitivity case PB2B_LOCA_H is the same LOOP + LOCA scenario but with all initial and boundary conditions matching the final DIT conditions. Table 3-1 compares the DIT conditions used in PB2B_LOCA_H against the conditions used to generate bounding forcing functions in case PB2B_LOCA. The most significant differences between the bounding analysis and the DIT conditions are the 0.001 fouling factor on the fan coil tubes, the pump restart profile, and the pump recovery pressure.

Figures 5-9 and 5-10 compare four sets of TREMOLO calculations considered for CFC 2HX15B. As shown in Figure 5-9, the LOOP + LOCA cases produce more void than the LOOP only cases. Also, in all cases, the void collapse begins shortly after pump restart, which occurs at 25 seconds for