January 11, 2000

Mr. Vaughn Wagoner, Chairman
Utility Advisory Group, GL96-06 Waterhammer Resolution
Carolina Power and Light Company
411 S. Wilmington Street CPB 6A1
Raleigh, NC 27601

SUBJECT: EPRI INTERIM REPORT TR-113594, "RESOLUTION OF GENERIC LETTER 96-06 WATERHAMMER ISSUES"

Dear Mr. Wagoner:

I am responding to your letter of September 23, 1999, requesting NRC review and comment on Electric Power Research Institute (EPRI) Interim Report TR-113594, "Resolution of Generic Letter 96-06 Waterhammer Issues." The NRC staff has worked closely with industry participants on this initiative, and we are pleased with the work that has been done and with the progress that you have made. We are also very pleased with your use of an expert panel to help facilitate this effort.

While completing our review of the EPRI interim report, we were informed that the Advisory Committee on Reactor Safeguards (ACRS) Thermal-Hydraulic Phenomena Subcommittee was interested in the interim report and requested a briefing. Following the industry briefing that was completed on November 17, 1999, the Subcommittee presented its assessment to the ACRS full committee on December 3, 1999, and written comments were provided to the NRC staff in a memo from the ACRS dated December 22, 1999. We appreciate your cooperation and participation, and the cooperation and participation of others from the Utility Advisory Group and expert panel who were present, in briefing the ACRS Subcommittee and in responding to the questions that were raised.

Based on our review of EPRI Interim Report TR-113594, and based on the comments that we received from the ACRS Thermal-Hydraulic Phenomena Subcommittee, we believe that some additional work and refinement are necessary. While the interim report is a good first draft, we believe the formatting could be better structured for presenting the proposed approach for evaluating the Generic Letter 96-06 waterhammer concerns. We also believe that the specific limitations and criteria for applying the proposed methodology for evaluating the GL 96-06 waterhammer concerns are not described and/or defined well enough to assure conservative results, and a number of technical issues remain that have not been adequately addressed. In

Contact: James Tatum, SPLB/DSSA/NRR
301-415-2805

order to assist you in pursuing this initiative, I have enclosed the comments that we received from the ACRS, as well as comments that we received from our Scientech consultant, and NRC staff comments. We are available to discuss these comments with you, and we remain optimistic that with some additional work and restructuring, an acceptable approach can be achieved.

Sincerely,

Original signed by:

John N. Hannon, Chief
Plant Systems Branch
Division of Systems Safety and Analysis
Office of Nuclear Reactor Regulation

Enclosures:

1. Memorandum to John N. Hannon from Howard J. Larson dated December 22, 1999, re: ACRS review of EPRI Interim Report TR-113594.

2. Letter Report No. 243-1, "Review of EPRI/Industry Technical Basis Report for Resolution of GL 96-06 Waterhammer Issues," Dr. Hossein P. Nourbakhsh, dated December 1999

3. NRC staff comments re: EPRI Interim Report TR-113594.

cc: Dr. Avtar Singh
EPRI
3412 Hillview Avenue
Palo Alto, CA 94304-1395

Dr. Thomas C. Esselman, President
Altran Corporation
451 D Street
Boston, MA 02210

Dr. Hossein Nourbakhsh
25 East Loop Road
Stony Brook, NY 11790

Kurt Cozens
Nuclear Energy Institute
1776 I Street, NW Suite 400
Washington, DC 20006-3708

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NRC STAFF COMMENTS RELATED TO
EPRI INTERIM REPORT TR-113594,
"RESOLUTION OF GENERIC LETTER 96-06 WATERHAMMER ISSUES"
DATED JULY 1999

Technical Comments:

- Page 8-4, Section 8.1.4; it should be emphasized that the velocities of both the impacting and the impacted columns of water should be calculated and that the relative velocity between the two columns is the impact velocity of interest.

- Page 8-10, last paragraph, draws the conclusion that CIWH is independent of pipe size. However, the scatter in the data in Figure 8-5B makes this conclusion very suspect.

- Page 8-17, transducer limited to 1000 psig; what is effect on data?

- Figure 8-8, is there a bounding curve (other than Joukowski)?

- Figure 8-9, K_{imp}=3 is not bounding; a more conservative value should be used.

- Figures 8-11, 8-13, and 8-14, need to explain why 1000 psig limit is not a problem. Also, is there a bounding curve for this data?

- Figure 8-12, not bounding for much of the data; assumption for K seems non-conservative.

- Figure 8-17, need to explain why 1000 psig limit is not a problem. Also, what to make of the deaerated loop seal data, and what about aerated loop seal test data?

- Page 8-24, the discussion neglects the condensing effect of the pipe wall. I would think that this could change the conclusions for the range of pipe sizes being considered (i.e., 2" to 16").

- Page 8-26, the conclusion stated in the last paragraph needs to be reexamined based on test data in Figures 8-14 and 8-17, and lack of data for aerated loop seal configuration.

- Page 8-27, 7th bullet; there is no data for the aerated loop seal case for making this conclusion.

- Page 8-27, last bullet; this is not entirely correct. The occurrence of a CCWH does not necessarily represent the worst case condition since it may not include the worst case single active failure.

- Page 9-3, Section 9.1.2; it is not clear how the value "R" is determined. Also, the pulse duration is increased by a 1/R factor for the impulse to equal the momentum change in stopping the columns. However, the actual duration can be no more than 2L/C, which is fixed. Therefore, the method of letting a single impulse equal the total momentum, does not appear to apply.

Enclosure 3

- Page 9-7; the discussion about the condensation of steam on the piping surface (next to last paragraph) is not consistent with the condensing surface area that is described on Page 8-24.

- Page 9-11, Number 2 (at the bottom of the page); what other exceptions are there that are non-conservative that need to be identified and recognized as exceptions to the rigid body model? How is this addressed in the road map?

- Page 9-13, the test configuration is not representative of actual plant configuration, with horizontal tubes of the fan cooler connecting with vertical risers of various diameters, and various elevations relative to the rest of the piping system. Application of the test data is suspect and must be justified.

- Figure 9-9A; curve fit should be based on 0-to-40 second period to be more reflective of the actual scenario.

- Page 9-16; items 1, 2, and 3 are a stretch and probably non-conservative; also, not supported by test data.

- Page 9-17, Section 9.2.3.1; should include some discussion or comparison of the situation that could arise where all of the noncondensible gas is not concentrated in one place.

- Page 9-17, last paragraph; discussion about condensation on pipe surface is not consistent with the discussion on page 8-24. Also, Equation 9.5 fails to consider the effect of the containment temperature on the pipe wall.

- Page 9-18, Section 9.2.4; the inverse relationship between rise time and velocity appears to be based on observation only. Waterhammer theory does not appear to predict forcing functions other than simple rectangular shapes. Is there a theoretical basis for the assumed relationship?

- Page 9-18, eq. 9.5; what about contribution of pipe heat that is due to containment temperature?

- Page 9-19, 1st sentence; use of Appendix E in this fashion would be outside the scope of the NRC endorsement. This would be true for anything that falls outside the road map methodology.

- Page 9-34 (Figure 9-18), the data is not bounded by Joukowski on the low end, and the rigid body model also does not bound all of the data. Some explanation is needed to apparent reflect on this lack of conservatism.

- Page 9-35, Table 9-5; the rigid body model without the steam cushion appears to be conservative, while the other methods do not. Justification for use of the other two methods is needed.

- Page 9-36, 2nd paragraph; the conclusions are not at all obvious from the test data (Figure 9-19). Also, 3rd paragraph conclusion -- where is the data and figure that demonstrates this?

- Page 9-36, last paragraph; thermal layer discussion (especially with regard to upstream piping) is too speculative and does not take into consideration the various piping arrangements that can exist (e.g., check valves to prevent back flow). Also, the discussion in Number 2 is not consistent with the piping arrangement that is offered for the air release argument (Page 9-16), and the discussion that follows on Page 9-37 is mostly speculation (and intuitive), and not much can be made of it as far as the actual methodology is concerned.

- Page 9-38, Fig. 9-19; the question that was raised during a previous meeting (what to make of it?) remains to be addressed.

- Page 9-39, last paragraph; the value of K_R bounds most of the data (Figure 9-21), but why isn't a value selected that bounds all of the data? The specific exceptions must be identified and justified in establishing a conservative approach.

- Pages 9-43 & 9-44; (Figures 9-23 & 9-24); some additional explanation and consideration is needed. The effect of air is evident in Figure 9-23, but the exact amount of air is unknown due to the 2a test arrangement. The effect of air is not evident in Figure 9-24 where the amount of air is known (2b test arrangement). Also, the rigid body model is not bounding for all data.

- Page 9-44; the effects of air cushioning do not seem very obvious.

- Page 9-47, Figure 9-26; does this include the effects of pipe heating from containment atmosphere?

- Page 9-49; how to determine the flow coefficient K?

- Page 9-50, is the 200 °F temperature low enough to include the anticipated low pressure situations that can result from column separation?

- Page 9-51; the approach described in Number 3 would not be included in the NRC endorsement without a better understanding of how this would be applied to assure conservative results. Also, the exact approach for crediting attenuation due to rarefaction waves must be clear for NRC endorsement, and amplification effects must be included in the approach.

- Page 10-11, Section 10.2; it is recommended that for consideration of the effects of fluid-structure interaction (FSI), the peak pressure should be increased by 15% while the pressure pulse would be attenuated by system specific geometry, structural stiffness, and pulse characteristics. However, the waterhammer test data does not appear to indicate a significant correlation between the peak pressure and piping structural characteristics. Additionally, there is significant uncertainty in the modeling parameters involved in evaluating a coupled fluid and structure, such as the fluid and structural wave speeds (especially when there is air or phase separation), the duration and timing of structural and fluid pulses, and the structural stiffness. For these reasons, the staff agrees with the final statement made in Section 10.2 wherein it is not recommended that FSI be specifically analyzed.

- Page 10-16, Section 10.2.3; explain why attenuation of 10% at each change in direction only gives a 50% reduction in pressure after 8 changes in direction.

- Page 11-1, Section 11; a general discussion should be provided relative to how loads are applied to the piping structure, including the application of dynamic load factors to static loads and the application of force-time histories by direct integration techniques. A discussion of necessary bench marking of structural codes for the fluid dynamic loads and the necessary analysis parameters (such as frequency cutoff and time step size) should be provided.

- Page 11-3, Section 11.2.1; a discussion is provided wherein it is stated that there is little response from adjacent supports. However, the test piping has significant bending stiffness and would be expected to transfer some portion of the fluid dynamic loads to surrounding supports. To the extent that some load is actually transferred to points other than the immediate support, the resulting computation of dynamic load factors (DLFs) in Section 11.2.2 may be non-conservative.

- Page 11-5, Section 11.2.2; the DLFs for the proposed trapezoidal load shape are a family of curves lying between the triangular and square shape DLFs, and can approach a value of 2 for certain durations and/or rise times of a single pulse. It should be emphasized that DLF values may need to be increased in some cases to address uncertainties either in the load definition or in the structural model. In addition, waterhammer forces typically consist of several cyclic reversing pulses which repeat for several full cycles. For certain frequencies, structural response is amplified with each pulse such that the DLF will greatly exceed a value of 2.

- Page 11-8, Section 11.2.3; it is concluded that a trapezoidal characterization of the actual fluid pressure history is an accurate approximation. However, this conclusion is reached with knowledge of the actual pressure history for the test. In applying trapezoidal pressure loads in an analysis where the pressure loads are the result of a hydraulic analysis and only peak loads are determined, it is important to emphasize the need to address uncertainties regarding the pressure load duration and rise times.

- Page 11-8, Section 11.2.3; the comparison of analyzed trapezoidal loads to actual measured loads is made with good knowledge of the structural frequencies. It should be emphasized that uncertainties in the structural frequencies need to be addressed in the structural model, because the response of the piping structure is sensitive to both the duration and rise time of the pressure pulse loads.

- Page 11-8, Section 11.2.3; a discussion should be provided of the structural damping values assumed in the ADLPIPE and ANSYS analyses. If none were assumed, then it should be emphasized that the recommended method is to similarly assume no damping in order to be consistent with the verification of the proposed analysis method.

- Page E-9; the second bullet refers to FAI data to justify the 5 L/Ds. Where, specifically in the report, is this information and conclusion presented?

- Page E-9; the last bullet discusses steam condensation on the metal pipe surface. This discussion is not consistent with what is presented on Page 8-24.

- Page E-13, second paragraph; the discussion indicates that the exact amount of air in the void was not measured in either testing program. It is important to keep this “unknown” in mind when trying to draw conclusions from the data.

- Page E-33, under Pipe Size; indicates that it is unnecessary to simulate heat transfer to or from the pipe wall during the closure process. This seems inconsistent with some of the discussion in other areas of the report (Pages 9-7, 9-17).

- Page E-41; a void temperature greater than 200 °F may not include some of the low pressure applications that could result during column separation.

- Page E-42; if plant conditions fall outside the limits, pant-specific submittal will be required to address this.

- Page E-53, Section 2.3.1.1; how does licensee confirm that limitation is satisfied?

- Page E-58, Table 2.3; the MOC peak pressure is non-conservative in a couple of cases, indicating that some adjustment may be needed.

- Page E-87, Nos. 3 and 4 would be beyond scope of NRC endorsement.

- Page G-19, 8th line; the statement is not consistent with discussion in Appendix E and in other locations (e.g., Page 8-24).   Also, relative to this discussion, the air concentration is an unknown quantity in the testing that was performed which limits the discussion to one that is qualitative in nature.

- Page G-22, Section 2.2, 2nd sentence; where’s the data and graphical display that supports this conclusion?

- Page G-23, Table 2-3, Number 3; how was the initial air concentration determined if air measurements were not taken?

- Page G-24, 1st paragraph; “experimental scatter” may also be due to varying amounts of air (if this was an unknown). The reason for the “experimental scatter” should be looked at more closely and taken into consideration when evaluating the test results.

- Page G-24, Section 2.4; the discussion about heating of the surrounding pipe wall seems to be inconsistent with information discussed elsewhere (Page 8-24, and Appendix E).

- Page G-25, Section 3.1; the significant scatter (which could be due to variations in air content) is an important part of the data that must be considered when establishing a conservative analytical methodology. The TBR doesn’t appear to appreciate this particular aspect of the data that has been collected.

- Page G-26, last sentence; not consistent with discussion in Appendix E, and probably incorrect as well.

- Page G-32, why is “Estimated Rise Time” called out?

- Page G-27, neglects heating of pipe wall from containment atmosphere -- could be substantial.

- Page G-44, discussion in 2nd paragraph about Figures 3-3a and 3-3b; the correlation of waterhammer strength with Jakob number is not really all that obvious for much of the data.

- Page G-51, 5th line from the bottom; discussion about “substantial increased noncondensible gas, due to the effect of heating the pipe wall...” is not consistent with discussion in Appendix E, and not necessarily true; speculative.

- Page G-57; discussion about the influence of thermal layer in comparison to noncondensible gases is not necessarily true, and has not been demonstrated. Also, it is speculative as to how much air will be released by heating of the pipe wall. In some plant-specific applications, much of the pipe wall heating will be from containment heating of the outside surface of the pipe and not so much from the inside out.

- Page G-61, 3rd sentence; this seems to be inconsistent with discussion about impulse on Page 8-16.

- Page H-10, Figure 3.1; the road map should reflect the complete methodology, not just CCWH. Criteria and exceptions need to be clearly indicated.

<u>Editorial Comments</u>:

- Symbol No. 43 has a typo in the description.

- Reference to NUREG-5220 should be NUREG/CR-5220 throughout.

- Page 1-1, 1st paragraph, last sentence -- use of “most” would be more accurate.

- Page 1-3, last sentence under Thermal Layer should be “waterhammers.”

- Section 1.5, what are the limitations? Should they be listed?

- Page 1-5, use of “CCWH waterhammer” is redundant

- Page 3-2, power is restored “to the SW pumps”

- Page 4-2, Section 4.1.1, last paragraph, the last sentence should state “The Froude number is calculated as follows:” in order to avoid any confusion about 1.0 being the minimum acceptable value for this application.

- Page 5-1, last sentence should provide some explanation as to why this is so.

- Page 6-5, Table 6-2 is being crowded by the documentation below.

- Page 6-8, Section 6.4, last sentence of the first paragraph -- NRC expectation is that a best estimate approach is used to ultimately arrive at a “credible methodology” that is conservative. Some clarification is needed here.

- Tables 6-3, 6-4, 6-5, and 6-6; info should be better reflected in the Appendix H Road Map (e.g., vertical risers, closed end branches)

- Table 6-7, no reference to Appendix H in first bullet, typo in 2^{nd} bullet (should end with period), and alternate wording is suggested for the 2^{nd} bullet -- “which indicates that CCWH is more limiting than CIWH in most low-pressure service water system applications.”

- Table 6-7, page 6-13, omit the 2^{nd} sentence of the last bullet.

- Section 7 seems to be very short on data upon which decisions can be made. What can we make of this?

- Page 8-1, should state “NUREG/CR-5220.”

- Page 8-2, “E=28E psi” typo?

- Page 8-5, move eq. 8.9 down below the paragraph.

- Page 8-10, a blanket statement that CIWH magnitude is independent of pipe size seems a bit too strong given the limited amount of data that’s presented and the variation in data scatter between the two pipe sizes.
- Page 8-10, why was α of 0.5 selected for the comparison?

- Page 8-11, no Analytical Model in Fig. 8-5.B, remove from legend.

- Page 8-24, 3^{rd} paragraph; should say “area.”

- Page 8-26, 6^{th} line from the bottom; is “The longer duration, lower duration events” what was intended here? I was expecting it to say “The longer duration, lower pressure events.”

- Page 8-27, 2^{nd} bullet; should it be “normal aerated water tests?”

- Page 8-27, last three bullets; need to reflect these in the road map; need to be clear on how much non-condensables is necessary to qualify; and last bullet should refer to “the worst-case CCWH.”

- Page 9-2, 1^{st} sentence; should state “The magnitude of the...”

- Page 9-16; how to determine air concentration of water for a given system configuration (i.e., open loop, closed loop)?

- Page 9-20, eq. 9.10; shouldn’t there be parentheses after the 2?

- Page 9-37, 1st paragraph; this conclusion is not at all obvious and probably incorrect. The upstream boundary layer probably is formed for the most part after flow is reinitiated through the fan cooler. Also, "fil" should be "fill."

- Page 9-38, Figure 9-19; spelling of Jakob.

- Pages 9-43 & 9-44 (Figures 9-23 and 9-24); the title is incomplete, the units are missing from the oxygen content, and the key is incomplete.

- Page 9-36, No. 2 is rather speculative and dependent on system configuration (e.g., what if there is a check valve to prevent flow?).

- Page 9-50, 3rd paragraph and last paragraph, typos.

- Page 9-50, Info needs to be reflected in the road map. Also, is restriction on T(void) low enough for typical plant?

- Page 9-51, Reductions in second order velocity (nos. 3 and 4) and attenuation w/out amplification considerations?

- Pages 9-52 through 9-57; how to determine mg air for void, also distinction between open loop and closed loop systems.

- Page 10-8; 3rd bullet from bottom, should be "less than the distance."

- Page 10-15; Figures 10-10 and 10-11 appear to be labeled wrong.

- Page 10-16, Section 10.2.3, 1st paragraph; if attenuated 10% at each change in direction, why does it take 8 changes in direction to attenuate 50% (i.e., why not 5 changes in direction)?

- Page 11-6; page not numbered, and should include the results of ANSYS and ADLPIPE correlation.

- Page 11-8; page not numbered, sentence in the 2nd paragraph would be clearer if a hyphen was used "A set of 44 test-measured pressure traces from the tests was used," and where it refers to Figure 11-6 (end of 2nd paragraph) shouldn't this be Figure 11-7?

- Page 12-1; need to include guidance (in appropriate section of TBR) for evaluating LOOP only waterhammer, and include the 15% assumed amplification when crediting attenuation.

- Page 13-1; Reference 4 should be NUREG/CR.

- Page A-2; should give the table a name so it can be referred to.

- Page C-2; 1st paragraph talks about an analytical model presented above. There is no "above."

- Page D-2, 2nd paragraph; should state that "Voiding occurred in a horizontal pipe..."

- Page D-3; the sentence “The pressure measurements were made with...” is redundant to the previous sentence.

- Page E-9 and Figure 1.1-B; says piping surface area was ignored; not consistent with discussion in Appendix G.
- Page E-34, bottom of page; the equation that is referred to is missing.

- Pages E-35 & E-41; is this reflected in road map/screening criteria?

- Page E-45, 1st sentence; should it state “steam condensation rate”?

- Page E-60, No. 1 is incomplete.

- Page E-86, 1st line; should say “plant with a means for taking credit...”

- Page E-96; what happened to general recommendation that FSI not be included?

- Appendix G; this appendix is very confusing and not easy to follow. Except for the qualitative value (which is intuitive for the most part), it is not clear how the test data can be used in a more rigorous, quantitative fashion. Also, it is not clear why it was important to collect the test data in some arbitrary, random order (mentioned on the bottom of Page G-31). Some additional thought and effort is needed to determine how the data can be used (i.e., what can be made of it, especially since the air content was not measured), and how to best present the information so it can be easily understood.

- Page G-6 & G-7; the sentence that starts at the bottom of Page G-6 does not make sense.

- Page G-24, last line; should be NUREG/CR.
- Page G-25, 8th line; should state “on the abscissa were manipulated...”

- Pages G-26, Section 3.2; since the air content was not measured, the test results are limited in their application.

- Page G-35, in looking at the numbers, it appears that some of the data is not listed (Test Nos. 207 through 220, and 228 through 299). Also, there is no explanation about what the abbreviations are (WH, U, S).

- Page G-44, 1st sentence; not well written.

- Page G-46, Figure 3-3b; abscissa is not labeled.

- Appendix G, Figures 3-4b & 3-5b; check spelling of “Jakob.”

- Page G-51, last sentence of 1st paragraph; should state “information shown in...”

- Page G-56, bottom half of page; the discussion is confusing and whatever the point is, it needs to be better explained.

- Page G-58; should move the figure to Page G-56.
- Page G-62, 2^{nd} line of 2^{nd} paragraph; should state "derivative of the acceleration or..." Also, should 3^{rd} sentence say 100 msec instead of 10 msec?
- Page G-63, Figure 3-11; the figure appears to be out of place relative to the text.
- Page G-64 and beyond; many figures are illegible (especially axis information), some enhancement is needed.
- Page G-66, Figure 3-14; at top, should say "only the Condensate."
- Page G-69, what are units of ordinate axis?
- Page G-71, Ref 4; should be NUREG/CR.
- Page H-8, Section 3.7; should either say equation 9.9 or Figure 9.10.
- Page H-7, Section 3; should be in body of report, not in an appendix.
- Page H-10, Figure 3.1; there is no action referred to coming out of the LOOP waterhammer box, and the diamond should refer to Table 9-6, not Table 9-5.
- Page H-22, should refer to equation 9.9.