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EPRI

September 17, 2001

Document Control Desk
U.S. Nuclear Regulatory Commission
11555 Rockville Pike
Rockville, MD 20852

Attention: Mr. Jim Tatum

Reference: Letter from Mr. Vaughn Wagoner to Mr. Jim Tatum, Response to Questions on Generic Letter 96-06, August 9, 2001

SUBJECT: Additional Response to Questions on Generic Letter 96-06

Enclosed are additional responses and clarification to our previous letter that responded to questions raised on the document "Resolution of Generic Letter 96-06 Waterhammer Issues", EPRI Interim Report TR-113594--V1 & V2, December 2000. The attachment to this letter includes responses to specific questions raised by the NRC. This information will be added to the final revision of the Technical Basis Report.

Please note that the enclosed document does not contain any proprietary information.

If you have any questions on the enclosed information or the general subject it addresses, please call me at 919-546-7959 or Avtar Singh at 650-855-2384.

Sincerely,

Avtar Singh for

Vaughn Wagoner
Carolina Power & Light Company
Chairman, EPRI Waterhammer Project Utility Advisory Group

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1. **The relationship of pressure rise time to impact velocity is given only for test configuration No. 1 which did not include air in the steam void. Please provide a comparison of the pressure rise time relationship with the data from test configuration 2 which did include air.**

Response:

The individual rise times for the Configuration 2a and 2b tests have been calculated. This data is provided in Figure 10-8 in the referenced letter. That figure utilized calculated "cushioned" velocity for the abscissa. The ordinate is test data; the abscissa is calculated. The rise time test data has also been plotted against the "uncushioned velocity". A figure showing the rise time versus the "uncushioned" velocity is attached to this letter and is referred to as Figure 10-8a. The uncushioned velocity is a parameter that is much more accurately calculated since it is dependent only on the system hydraulics and not the dynamics of void closure. The uncushioned velocity is readily known for the plant configurations. Note that in Figure 10-8a the rise time equation generally falls on or under the Configuration 2 test results. This is conservative since using a shorter rise time produces higher differential pressures across a pipe segment, and therefore, higher loads. Configuration 2b best represents the plant configuration as it has a longer column that test 2a. Referring to Figure 10-8a, it can be seen that the Configuration 2b test results are all conservative (have longer rise times) relative to the rise time equation recommended for use.

2. **For all the air release tests, the system pressure was decreased to approximately 7.4 psia (15" Hg). We cannot determine how much of the air release was due to the depressurization and how much was due to heat addition. Would the data apply to plants that have closed containment cooling systems and don't depressurize on LOOP?**

Response:

The amount of air released due to depressurization alone, without the agitation and increased nucleation sites developed during boiling, was investigated as part of this project. Research performed by Schweitzer et. al. and Zielke et. al. was reported in the TBR, Section 6.1. Figure 6-1 shows that the amount of dissolved gas released due to depressurization alone reaches a maximum value of approximately 0.031 gm/m^3 during the 30 second transient. The testing performed in the development of the data used to create Figure 6-1 was based on an agitated sample of water that was super-saturated with gas. The agitation was caused either by flow of the water through a pipe or through simple shaking. No boiling occurred in these tests.

Tests performed as part of the TBR development showed that water in the tubes, when exposed to boiling, would release approximately 50% of their dissolved non-condensable gas. Solubility curves were presented (revised TBR sections, Figure 6-7) that show the concentration of dissolved gas in saturated water to be approximately 20 mg/L or 20 gm/m^3. If 50% of the gas is released, the non-condensable gas mass is 10 gm/m^3.

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Therefore, the effect of pressure alone is approximately 0.3% of the mass released by boiling.

Since pressure alone accounts for little gas release, the effect of applying the data to closed cooling water systems where boiling occurs is expected to be insignificant.

3. **The header air content was determined to be reduced by at least 25%. How much of the air reduction was from de-aerating of the original header water and how much of the reduction was from mixing with the water from the test section that was discharged into the header?**

Response:

The water that was selected to be a conservative representative was water that was in the moisture separator region of the test. This water was carried with steam that was being expelled from the tube out of the header region into the moisture separator region. This water had the least amount of air released and had the least amount of mixing in the header. Very little of the air that was released was due to mixing with water from the tube that could have occurred in the header region.

4. **EPRI provided a theoretical argument that pressure in a gas volume between closing water columns is independent of pipe area and the heat transfer coefficient is not a function of pipe diameter. The argument appears correct provided the void shape remains cylindrical so that the heat transfer area does not change shape with piping diameter. Would the heat transfer area change shape for pipe sizes larger than the 2 inch size in the CCWH tests?**

Response:

Several potential physical phenomena could account for a change in surface area, but they can be shown to not occur or they are not credible reasons for making the test data unconservative.

First, the flow area could be postulated to slope away from its assumed planar shape. Calculations show that the "keep-full" velocity for piping is related to the Froude number (TBR Equation 7-1). For pipes up to 18" diameter, the keep-full velocity is between 4 and 7 ft/sec. Since the refill velocity to close a void will be greater than this, the pipe will not fill in a stratified manner, and the shape will remain nearly planar as assumed.

Second, the surface roughness of the exposed water in the closing column could be postulated to increase and thereby increase the surface area. Surface roughness is related by Taylor instability as primarily a function of acceleration (or deceleration), and not of pipe diameter (see TBR section 8.3.3). The tests performed as a part of the TBR preparation were run for closure velocities ranging from 10 to 45 ft/sec. The actual closure velocities in the plant are on the order of 15 to 20 ft/second. The higher tested

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closure velocity would lead to increased deceleration and increased surface roughness compared to the plant. Therefore, the water surface area available for condensation of steam would be larger in the tests than in the plant configuration, relative to the pipe diameter. As described in the TBR, the water surface area change per unit flow area due to surface roughness is pipe diameter independent. Because of the larger relative water surface area in the tests, the steam condensation rate in the plant configuration will be *lower* than those derived from the tests. This would provide more cushioning in the plant than measured in the tests.

5. **CIWH tests were performed at low pressures, less than 15 psig. The TBR states that the report's conclusions should not be utilized above 15 psig. The UM states that the results can be utilized up to 20 psig. What will be the basis for approving analyses for plants where CIWH might occur above 15 psig?**

Response:

The mechanism of the occurrence of condensation induced waterhammer (CIWH) was investigated in detail following the receipt of the test data. No mechanism exists that would result in a change of the behavior of the CIWH in a system that has a pressure that is five psia higher than that tested. The TBR concluded that the CIWH event would not impact the integrity of the system. This conclusion is not different for a modest increase in the system pressure from 15 to 20 psig.

6. **EPRI stated that the comparison of analyzed vs. test data loads was based on a structural damping value of 0.1%. A better comparison would be for typically assumed damping values (2-3%).**

Response:

The calculated responses shown in the predicted to measured support load comparisons provided in TBR Figures 13-7 and 13-8 were made from the results of a structural model with 0.1% damping. The analytical model was loaded by trapezoidal idealizations of the pressure pulses. These calculated loads were compared to actual support load data from the tests.

To determine the effect of increasing the damping to 2%, a single degree of freedom (SDOF) model was made for each pipe segment in the test, using measured geometry and structural frequencies. This is an appropriate model as there was very little participation between the legs of the test model. These SDOF models were loaded with forces of equivalent rise time and duration as developed by the tests and previously used. The resulting dynamic load factors decreased 1.9% to 7.7% with the increased damping. The magnitude of the change depended upon the pulse duration, specific pipe leg being loaded, and stiffness of that pipe leg. Translating these results to Figures 13-7 and 13-8, it can be seen that lowering the predicted forces 1.9% to 7.7% would not significantly impact the comparison between the measured and calculated forces. The conclusion that

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the trapezoidal representation of the pulse is an appropriate modeling method would not change.

7. **The air release experiment was performed at a pressure of approximately ½ atmosphere.**

   a. **What would be the expected amount of air released for other (especially increased) initial pressure conditions?**
   b. **For the actual plant situation, wouldn't pressure be expected to actually increase and not remain at ½ atmosphere? What effect would this have on the amount of air that is released?**

   <u>**Response:**</u>

   The pressure change had very little to do with the amount of air released as this is a secondary effect in comparison to boiling (see response to question 2). If boiling does not occur but a pressure reduction did occur, no credit would be taken for air release. The pressure in the test was selected to assure that there was very little residual air in the test fixture prior to the initiation of the test and so that boiling would occur quickly following the initiation of the test. Typically, open loop plants will have pressures that are initially lower than ½ atmosphere and then the pressures will increase to a pressure that is on the order of 1 atmosphere at the time that the pumps are restarted. Closed loop plants will typically have a higher initial pressure (around atmospheric) and the pressure will increase during the event. The test configuration is approximately in the middle of the ranges of pressure expected. Given the small impact of pressure on air release, the amount of air would be independent of the precise pressures reached in the plants.

9. **If the fan coolers are at a low point and the water in the supply and return headers maintain enough pressure on the water in the fan cooler tubes, boiling will not occur and no credit is allowed for air release. Now suppose that the height of water in the supply and return headers is slightly reduced to the point where nucleate boiling occurs in the fan cooler tubes. How much air would be released? Continuing with this thought, as the height of water is gradually decreased, what amount of air would be released for the various boiling intensities that are experienced?**

   <u>**Response:**</u>

   Credit for air will not be taken unless the water is exposed to temperatures above the boiling point corresponding to the pressure. All the water does not boil, but it has to be exposed to boiling that occurs in the region for the air to be removed. In order to assure that the water is exposed to boiling, a condition will be added to the TBR and the User's Manual that will eliminate credit for air release unless the temperature of the tubes reaches a temperature that is 10°F above the temperature at which boiling would occur. This will assure that the water in the tubes is exposed to boiling and that air release due to "air stripping due to boiling" will occur.

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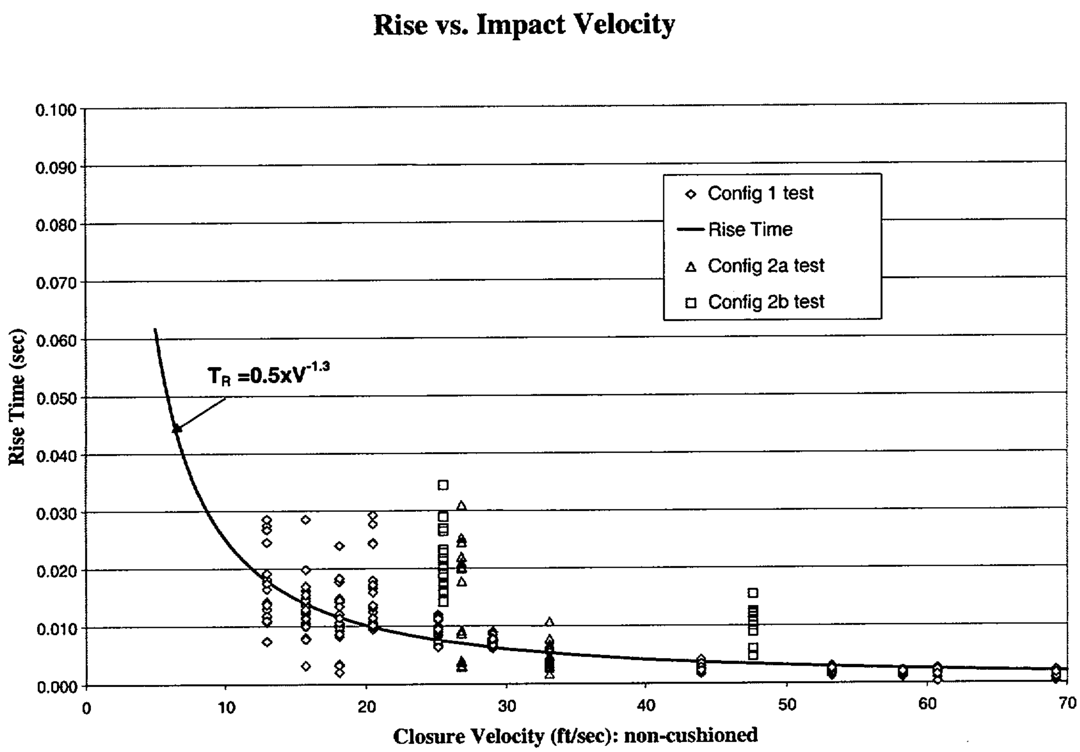

Figure 10-8a: Rise Time vs. Non-cushioned Impact Velocity