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Report No.: FAI/13-0392

*Request for Additional Information*
*by the Office of Nuclear Reactor Regulation*
*Joseph M. Farley Nuclear Plants, Units 1 and 2*
*Southern Nuclear Operating Company*
*Docket Nos. 50-348 and 50-364*

*Revision 0*

Project No.: SNC-WRAI-CST-Vortex

Submitted to:

*Southern Nuclear Company*
*(Farley Nuclear Generating Station)*
*Dothan, Alabama*

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*June, 2013*

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## CALCULATION NOTE COVER SHEET

### SECTION TO BE COMPLETED BY AUTHOR(S):

Calc-Note Number: FAI/13-0392 Revision Number: 0

Title: Request for Additional Information by the Office of Nuclear Reactor Regulation Joseph M. Farley Nuclear Plants, Units 1 and 2 Southern Nuclear Operating Company Docket Nos. 50-348 and 50-364

Project: RAIs Support for Farley for Vortex Suppression Project Number Or Shop Order: SNC-WRAI-CST-Vortex

Purpose: The document is issued to provide support to RAIs in regards to vortex suppression work at Farley.

Results Summary: The document provides information to address NRC's RAIs.

References of Resulting Reports, Letters, or Memoranda (Optional)

| Author(s): Name (Print or Type) | Signature: | Completion Date: |
|---|---|---|
| Robert E. Henry | Robert E. Henry | 6/13/13 |

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| Verifier(s): Name (Print or Type) | Signature: | Completion Date: |
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| Damian D. Stefanczyk | [signature] | 06/14/13 |

Method of Verification:

- ☐ Design Review
- ☐ Independent Review or Alternate Calculations
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- ☒ 3-Pass Method
- ☐ Other (specify):

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| Responsible Manager: Name (Print or Type) | Signature: | Approval Date: |
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| Jens Conzen | [signature] | 6/14/13 |

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| 3-Pass Verification Review Topic | Yes | No | N/A |
|---|---|---|---|
| **First Pass** | | | |
| 1. Were the general theme, scope of document and scope of review clear? | ☒ | ☐ | |
| **Second Pass** | | | |
| 2. Do the references appear to be documented correctly? Is there enough information present to ensure the referenced document is retrievable? | ☒ | ☐ | |
| 3. Do the acceptance criteria seem appropriate? | ☐ | ☐ | ☒ |
| 4. Does the technical content of the calculation note make sense from a qualitative standpoint and are appropriate methods used? | ☒ | ☐ | |
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| 5. Do the results and conclusions meet the acceptance criteria? Do the results and conclusions make sense and support the purpose of the calculation note? | ☒ | ☐ | |
| 6. Has the technical content of the document been verified in adequate detail? Examples of technical content include inputs, models, techniques, output, hand calculations, results, tables, plots, units of measure, etc. | ☒ | ☐ | |
| 7. Does the calculation note provide sufficient details in a concise manner? Note that sufficient detail is enough information such that a qualified person could understand the analysis and replicate the results without consultation in the author. | ☒ | ☐ | |
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| 9. Are the references accurate? Do the references to other documents point to the latest revision? If not, are the reasons documented? Are the references retrievable? | ☒ | ☐ | ☐ |
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# EDITORIAL REVIEW CHECKLIST

Reviewer Name: Damian D. Stefanczyk     Date: June, 2013
Document Number: FAI/13-0392

| | Yes | No | N/A |
|---|---|---|---|
| **General Documents** | | | |
| 1. Proofread the document for general format, readability, punctuation, and grammar. Are these acceptable to you? | ☒ | ☐ | ☐ |
| 2. Is the documentation legible, reproducible and in a form suitable for archiving as a Quality Record? | ☒ | ☐ | ☐ |
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| 5. Are the page numbers in the Table of Contents provided and correct? | ☒ | ☐ | ☐ |
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| 12. Are all References listed referred to in the text? | ☒ | ☐ | ☐ |
| 13. Is the content of the Appendices consistent with what the document states it is? | ☐ | ☐ | ☒ |
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| **Body of Calc Notes** | | | |
| **(Note that different Calc Note templates have different Section numbering. See the Section Numbering Key on last page for assistance.)** | | | |
| 14. Is all information in the cover page header block completed appropriately? | ☒ | ☐ | ☐ |
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| 17. Are Tables labeled consistently and do they include units of measure? | ☐ | ☐ | ☒ |
| 18. Is background information and purpose of the calculation clearly stated in the appropriate section? | ☒ | ☐ | ☐ |

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|---|---|---|---|
| 19. Have the limits of applicability been listed in the appropriate section? | ☐ | ☐ | ☒ |
| 20. Are open items identified in the appropriate section and on the cover page header block? | ☐ | ☐ | ☒ |
| 21. Are the Acceptance Criteria listed in the appropriate section (if applicable)? | ☐ | ☐ | ☒ |
| 22. Does the Calc Note include a discussion on the methodology used? | ☒ | ☐ | ☐ |
| 23. If applicable, are references to the utility, plant, unit, and cycle correct with respect to spelling and consistency of use? | ☒ | ☐ | ☐ |
| **Body of Document** | | | |
| 24. Is the Summary of Results and Conclusions section consistent with the purpose stated and consistent with the results section? | ☐ | ☐ | ☒ |
| **Computer Runs** | | | |
| 25. Are the computer codes used clearly identified in the appropriate section and is all required information included? | ☐ | ☐ | ☒ |
| 26. Are all electronic files listed in the electronically attached file listing? | ☐ | ☐ | ☒ |
| 27. Does the electronically attached file listing appropriately reference the codes used? | ☐ | ☐ | ☒ |
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| 31. Are Author's responses provided to Additional Verifier Comments or noted as not required? | ☐ | ☐ | ☒ |
| **Additional Questions for Software Calc Notes** | | | |
| 32. Is the software name, version number, and system state(s) where the software was created or validated provided? | ☐ | ☐ | ☒ |
| 33. Is a source code listing or reference to a controlled location of the source code included? | ☐ | ☐ | ☒ |
| 34. Do the test results include the date of execution and the machine name? | ☐ | ☐ | ☒ |
| 35. Do the test cases include a description of what is being tested? | ☐ | ☐ | ☒ |
| Editorial Reviewer Comments (if needed): | | | |

## RECORD OF REVISIONS

| Rev. | Date | Revision Description |
|---|---|---|
| 0 | June, 2013 | Original issue.<br>This document is being issued as non-proprietary and is available for public release through the NRC. |
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# LIST OF ACRONYMS

| | |
|---|---|
| BWST | Borated Water Storage Tank |
| CST | Condensate Storage Tank |
| FAI | Fauske & Associates, LLC |
| FWST | Fueling Water Storage Tank |
| LAR | License Amendment Request |
| NRC | Nuclear Regulatory Commission |
| RAI | Request for Additional Information |
| RWST | Refueling Water Storage Tank |

# 1.0 BACKGROUND/PURPOSE

Farley uses a vortex correlation developed by Harleman (1959) for a vertically downward configuration that differs from the 45 degree upward flow pipe used at Farley. This correlation is shown to over-predict the submergence by a factor of three when compared to Catawba and McGuire test data at the Froude number that corresponds to the maximum flow rate from the CST. This would be a sufficient margin to justify using the Harleman correlation to support the LAR if the test data were established to be applicable. Achieving this requires an acceptable description of the plant configurations, the test configurations, and the test data. Thus, it is necessary to provide a complete description of the tests and test results for each test used to substantiate determination of critical submergence that includes the following:

1. Drawing of the plant tank and the plant suction pipe within the tank that provides all relevant dimensions,
2. Drawing of the corresponding test configuration that provides all relevant dimensions,
3. Description of how quantitative air entrainment is determined during testing,
4. Description of conduct of the test that includes any observations, and
5. Summary of the test data such as a plot of critical submergence as a function of Froude number.

## 2.0 RESPONSES TO RAIs FOR FARLEY CST TS VOLUME LAR

1. Drawings of the plant tank and the plant suction pipe within the tank that provide all relevant dimensions are the following applicable Farley CST drawings:

   U-161693 Version 2.0; Unit 1 CST General Plan,

   U-213481 Version 3.0; Unit 2 CST General Plan,

   U-161703 Version B; Unit 1 CST 8 inch Auxiliary Feed Pump Suction Nozzle, and

   U-213493 Version A; Unit 2 CST 8 inch Auxiliary Feed Pump Suction Nozzle.

2. Drawings of the corresponding test configuration that provide all relevant dimensions are as follows:

   D.C. Cook simulation, RWST dimensions:

   48 feet diameter,

   32 feet high with a 24 inch diameter suction pipe.

The model was a 12 foot diameter and 6 feet high tank with a 5.73 inch horizontal suction pipe that was approximately 5.5 inches above the tank floor and approximately 1.75 feet of suction piping inside the tank. See Figure 2-1 that is re-drawn from the figure in the referenced paper which is difficult to read in the original reference (Sanders et al., 2001).

The scaled tests for D.C. Cook provide insights into whether important rotational flow conditions are generated as a result of the tank geometry, the drain down transient, etc. These results are compared to the Harleman correlation, on page 12 of the report (FAI, 2009), where the submergence is increased by one-half of the suction pipe diameter. The submergence in the D.C. Cook experiments was defined with respect to the inside bottom surface of the suction pipe, as noted in Figure 5b of (FAI, 2009). The chart in Figure 3 of (FAI, 2009) shows that the Harleman correlation agrees well with the results of the D.C. Cook tests. Based on the D.C. Cook tests, the FAI report states that the Harleman correlation provides good agreement with the D.C. Cook data for critical submergence characterizing the onset of air entrainment for radial inflow process.

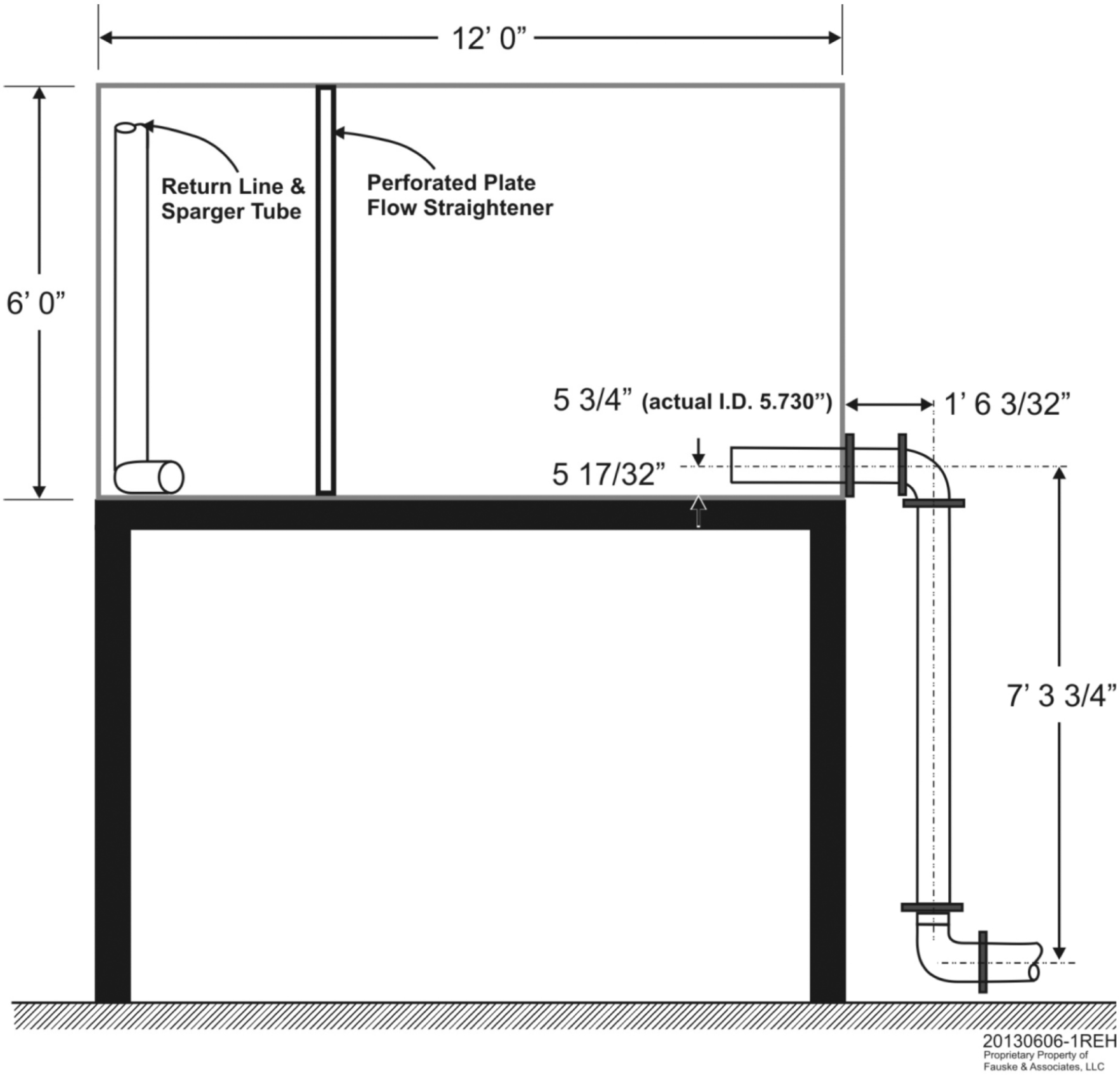


***Figure 2-1 Re-drawn figure showing the dimensions of the scaled test for D.C. Cook (Sanders et al., 2001).***

Figure 9 (Johansson et al., 2006) of the Catawba FWST scaled tank configuration is the type of configuration used for the CST at Farley. It has a suction port with a 45 degrees angled downward configuration that requires the suction flow to enter the pipe from below. Figure 4 (Johansson et al., 2006) provides the test configuration, as well as some of the essential tank and nozzle dimensions. (The tank diameter is not shown, but estimated to be approximately 40 feet in diameter based on the drawing scale of Figure 4). This downward oriented suction configuration acts to considerably suppress the potential for air intrusion as demonstrated in the main body of the FAI report (FAI, 2009) for a downward facing elbow which is part of a FAI investigation for Cooper's CST (FAI, 2007). This information for the downward facing elbow in the Cooper tests demonstrated that the water level had to be very close to the bottom of the elbow before gas intrusion would occur.

3. Description of how quantitative air entrainment is determined during testing is described as follows:

The FAI report (FAI, 2009) does not exactly identify the method in which the quantity of air entrainment is determined in the experiments. The following is related information provided in addition to the FAI report that best describes or discusses air entrainment:

> Upon reviewing the referenced paper documenting the D.C. Cook experiments (Sanders et al., 2001), it was observed that a rectangular Plexiglas box was built on the transparent downcomer piping. This box was filled with water to compensate for the pipes' curvature. The flow through this region was video recorded to capture when a continuous stream of air bubbles was detected in each test. In addition, the point at which the gas flow was estimated to occupy 2% of the downcomer volume was also noted. A similar technique was used to observe the onset of gas intrusion in the McQuire and Catawaba tests.
>
> Figure 3 of the FAI report (FAI, 2009) shows the results of air intrusion as Critical Submergence versus Froude number. Results show that there is not much difference in the two methods: visual detection of a continuous stream of bubbles and visual estimate that the gas volume fraction in the downcomer pipe is equal to 2%.
>
> A similar technique of constructing a rectangular box around the outlet pipe and filling the box with water was used to observe the onset of gas intrusion in the McQuire and Catawaba tests.

In the Cooper experiments performed at FAI (FAI, 2007), the tests were performed in a long rectangular flume with the water added at one end and the suction oriented at the other end as illustrated in Figure 2-2. This transparent configuration enabled the vortex behavior to be observed directly. The tests included formation of very tight Type 6 vortices (Figure 2-3) that were so small that they did not cause any degradation in the pump performance. In these experiments, it is conservative to assume that the air pulled in by the vortex is traveling at the same average velocity as the water. With this no slip assumption, it follows that a vortex transporting a 1% void fraction would have a diameter that is 10% of the suction pipe diameter:

$$\alpha = \frac{\frac{\pi}{4} D^2_{vortex}}{\frac{\pi}{4} D^2_{pipe}} = \frac{D^2_{vortex}}{D^2_{pipe}}$$

$$\alpha \ = \ 1\% \ = \ 0.01$$

$$0.01 = \frac{D^2_{vortex}}{D^2_{pipe}}$$

$$D^2_{vortex} = 0.01\, D^2_{pipe}$$

$$D_{vortex} = \ 0.1 \ D_{pipe}$$

$$D_{vortex} = \ 10\% \text{ of } D_{pipe}$$

$D_{vortex} =$ diameter of vortex, $D_{pipe} =$ inner suction pipe diameter, and $\alpha$ = area void fraction.

For the 4 inch suction pipe used in these tests, the vortex diameter would have to be more than about 3/8”. From the stainless steel scale shown in Figure 2-3, the figure, the vortex diameter is much smaller that this which explains why the pump discharge flow rate was not degraded by the vortex.

When air flow intrusion begins at a submergence consistent with radial inflow, this shows that the air intrusion is not due to a vortex generated through rotational flow. Air intrusion consistent with radial inflow has nothing to do with rotational flows, i.e. vortex behavior. If rotational flow in the tank produced a vortex, then air intrusion would occur at a higher water level than that calculated by radial inflow.

The Harleman et al. correlation (Harleman et al., 1959) and the Lubin-Springer correlation (Lubin/Springer, 1967) can be viewed as defining (bounding) the minimum submergence that would prevent air intrusion in the absence of rotational flows that induce vortex formation. In this regard, the Harleman correlation is conservative for defining the minimum submergence level where air intrusion would be expected to occur.

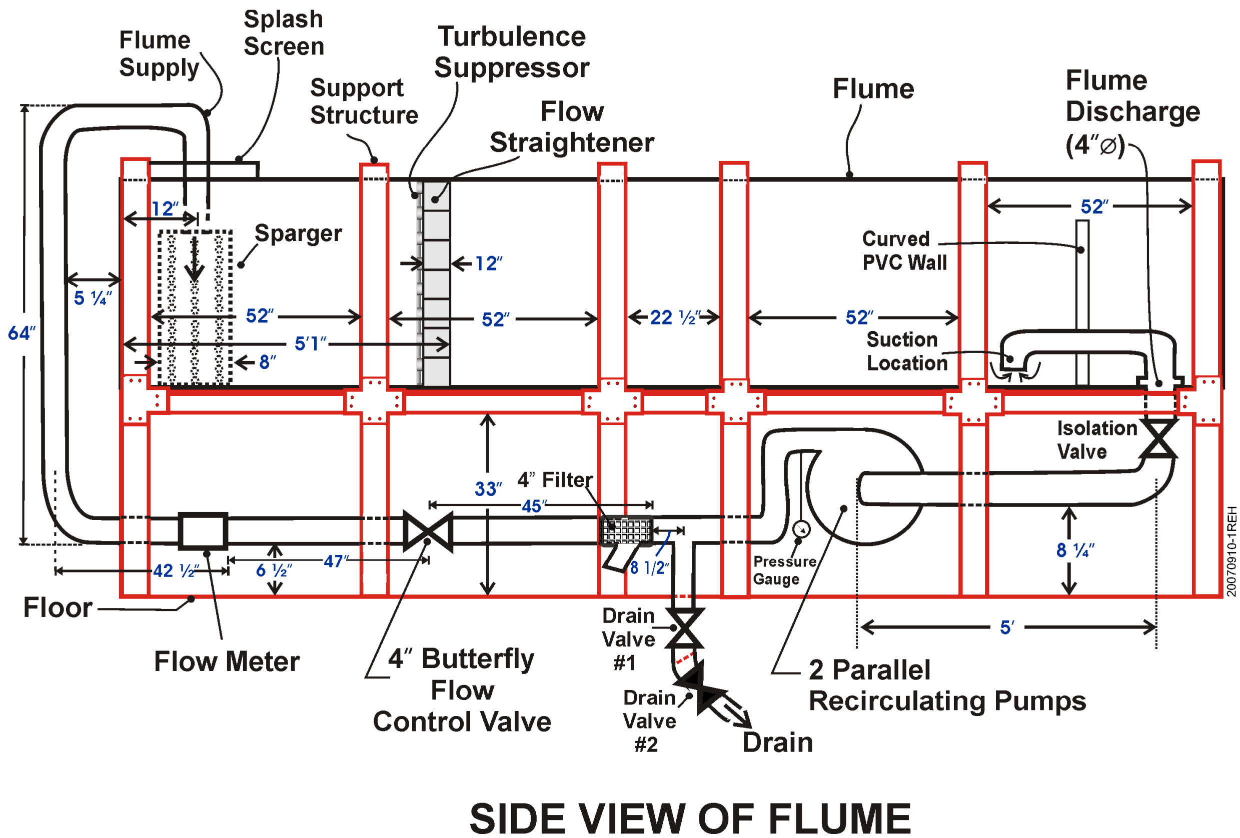


*Figure 2-2 FAI #1 flume test facility (side view) with a downward facing elbow (FAI, 2007).*

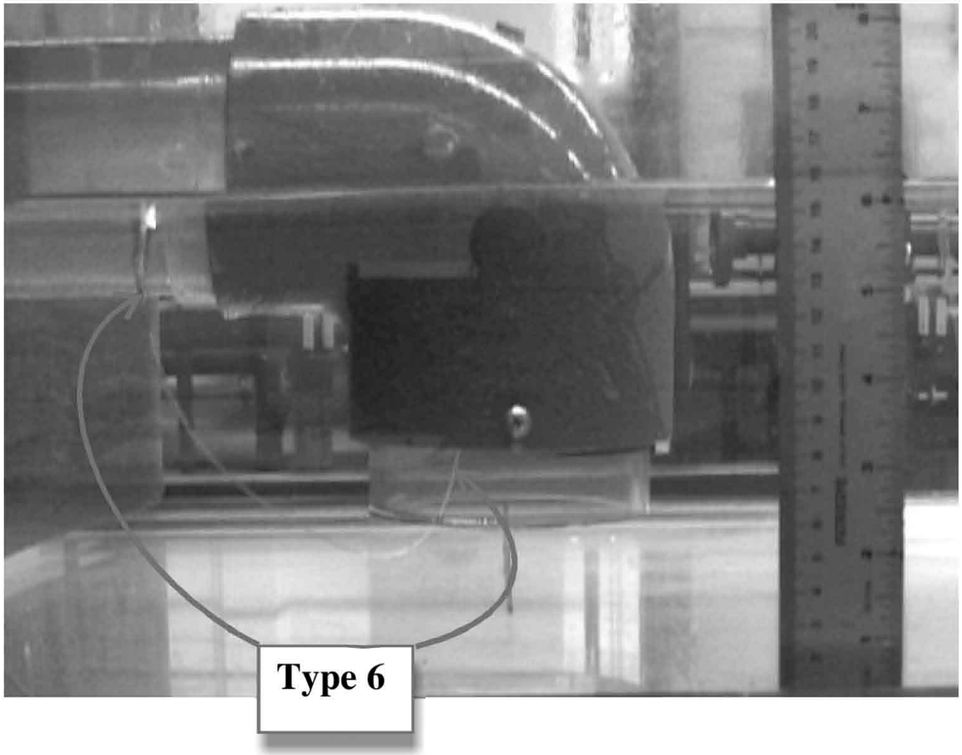


***Figure 2-3 Example of ordinary Type 6 vortex (FAI, 2007).***

As noted in Section 3 of (FAI, 2009), the Oconee tests performed by Alden Labs for Duke Power (Johansson et al., 2006) were performed in two ways: with and without recirculation to the simulated BWST. This is important for the assessment of vortex formation in the transient, because the outflow consumes much of the turbulence/swirl that is trying to organize into a vortex. As noted in Section 2 of (Knauss, 1987): "Once a vortex is reduced in strength or dissipated, such as by wall friction, it takes some time for the flow to 'reorganize' and produce enough circulation for the vortex to reform." Examining the Oconee tests, it is noted that tests with no flow return to the tank have lower submergence levels than those with return flow to the tank. The same behavior is observed in numerous FAI tests that have been performed for various tanks for different reactor sites. Specifically, recirculating all of the suction to the tank is a very conservative representation of the flow field since it provides a steady-state source to eventually organize into a swirl and the level remains constant as this happens. Representing the drain-down behavior results in water levels that are in a region bounded by the Harleman and Lubin-Springer radial inflow correlations.

4. Description of conduct of the test that includes any observations, and

   See the expanded discussion given above in point 3.

5. Summary of the test data such as a plot of critical submergence as a function of Froude number:

   Figure 3 of (FAI, 2009) is a plot of the reported test data for the onset of air intrusion and the conditions that resulted in an estimate void fraction of 2%. These data points are represented in terms of dimensionless water submergence as a function of the Froude Number. As discussed in point 1, the D.C. Cook tests are a representation of air intrusion (open loop) and steady state (closed loop) modes in which the water level, at a given flow rate, was decreased until air intrusion into the horizontal pipe was observed.

   Figure 3 of (FAI, 2009) also plots the Harleman et al. and Lubin-Springer correlations to compare to the experimental data from the D.C. Cook tests. The Lubin-Springer correlation somewhat underestimates the critical submergence observed in the D.C. Cook tests. However, the Harleman et al. correlation is in good agreement with the data for the critical submergence characterizing the onset of air entrainment. The Harleman et al. correlation for horizontal suction pipe is described in the second equation on Page 13 of 25 of (FAI, 2009). As noted earlier, the 0.5 is added because the submergences reported for the scaled D.C. Cook RWST are with respect to the inner bottom surface of the discharge pipe.

Figure 6 of (FAI, 2009) plots data which represents the test results of the scaled Oconee BWST during a drain-down transient. The figure compares the onset of air entrainment test results for the no recirculation configuration with the two radial inflow correlations, Harleman et al. and Lubin-Springer. The Oconee BWST is configured with a horizontal suction pipe that is flush mounted onto the side of the tank. The difference between these tests and the D.C. Cook tests is that submergence defined as the water depth with respect to the centerline of the suction pipe. The pipe had a smaller inner diameter which resulted in Froude numbers from one to four. Here again, the Harleman et al. correlation applied to the horizontal suction pipe for tests in which the drain-down is represented is in good agreement with the data and bounds the test results.

Figure 8 of (FAI, 2009) plots data taken from the McGuire and Catawba scaled experiments (Johansson et al., 2006). This figure compares steady-state and transient (drain-down) data taken with downward facing elbow suction nozzles as illustrated in Figure 7 of (Johansson et al., 2006). This is the suction configuration used for the Farley CSTs. In addition to the test results, this figure shows a bounding correlation developed for air intrusion into the downward facing suction configuration for the CST at Cooper. This correlation is presented on Page 21 of 25 of (FAI, 2009). It is seen that the test data developed in the McGuire and Catawba experiments are in good agreement with that developed in the Cooper CST experiments. Note that, like the test data discussed above for the Oconee BWST, the transient (drain-down) test data result in lower submergence water levels than the steady-state data. Also, once the Froude number becomes less than 0.5, gas can begin to accumulate in the discharge piping as was observed for the D.C. Cook tests. With this background, the FAI report (FAI, 2009) concludes that the McGuire and Catawba scaled experiments provide a significant technical basis for assessing both the Farley and Vogtle RWST behaviors. Since the Farley CSTs have the same downward facing suction configuration, this conclusion can also be applied to the Farley CSTs.

## 3.0 REFERENCES

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Knauss, J. (1987). *"Swirling Flow Problems at Intakes"*. Roterdam: Hydraulic Structures Design Manual, A. A. Balkema.

Lubin/Springer. (1967). *"The Formation of a Dip on the Surface of a Liquid Draining from a Tank"*. Journal of Fluid Mechanics, 29, pp. 385-390.

Sanders et al. (2001). *"Air Entrainment in a Partially Filled Horizontal Pump Suction Line"*. New Orleans, La., Paper JPGC2001/PWR-19010, pp 95-103: Proceedings of the JPGC'-01, 2001 International Joint Power Generation Conference.