GAS FLOW CHART REVISION

Some of the conditions necessary to reasonably ensure operability due to vortex concerns were discussed in Session T8 of the 2013 Regulatory Information Conference (RIC). This was followed by preparation of a draft report and discussions were held between NRC and industry representatives that resulted in the Figure 1 flow chart to address vortexing concerns (Agencywide Documents Access and Management Systems (ADAMS) Accession No. ML13224A120) (Lyon, no date).

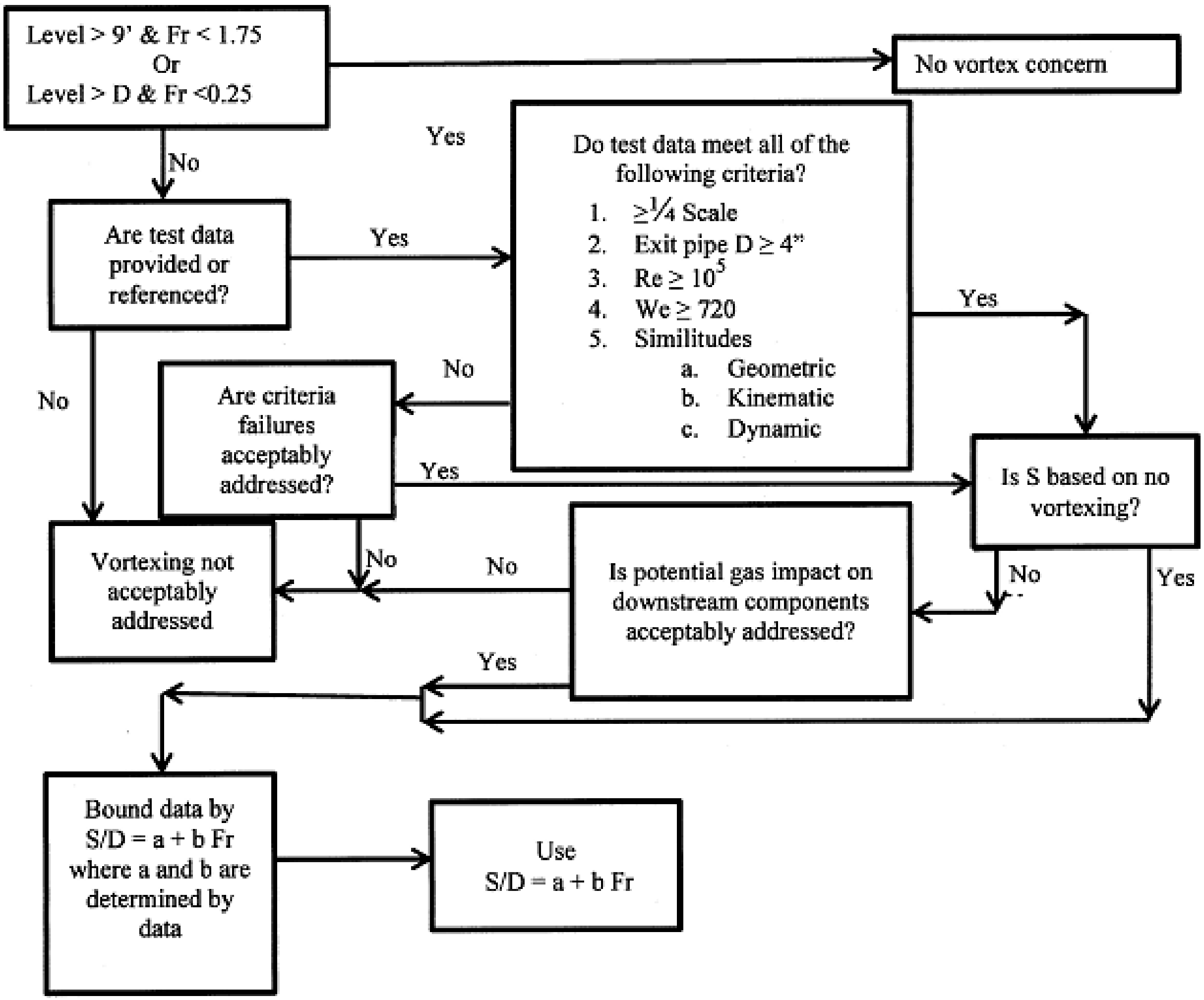

Figure 1 Historic flow chart that addresses vortexing

A preliminary version of this chart was provided in an April 18, 2013 meeting (Lyon W. C., May 9, 2013).

Limiting the phenomena to vortexing misses the important characteristic of localized level depression. Under some circumstances a localized level depression will form in the vicinity of an exit pipe without a surface swirl that would be characteristic of a vortex. Figure 2 illustrates two possibilities.

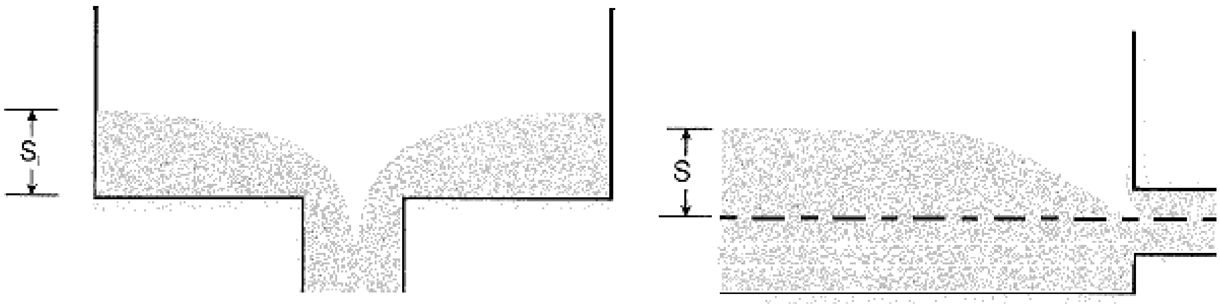

Figure 2. Illustration of Level Depression

The exit pipe configuration may also be important. In the Figure 3 configuration, the horizontal pipe section may be partially voided with gas ingestion determined by flow rate down the vertical pipe section.

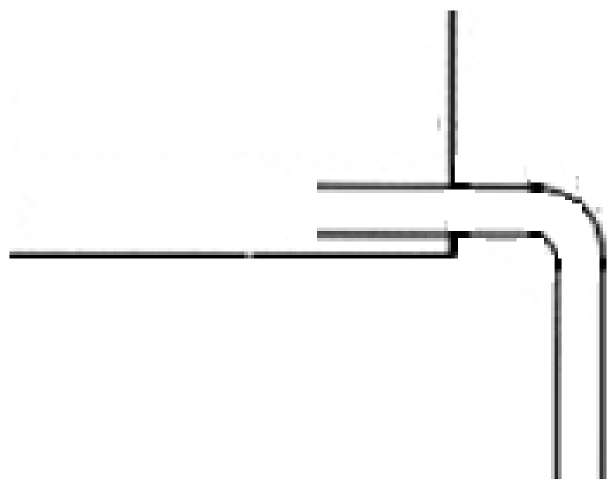

Figure 3 Configuration where gas transport may depend on vertical pipe flow rate

Figure 1 was not limited to draining from tanks but was also applicable to residual heat removal (RHR) midloop operation when taking suction from pressurized water reactor (PWR) hot legs. The Nuclear Regulatory Commission (NRC) Reactor Systems Branch (SRXB) position is considering whether a revised flow chart could be applicable to such conditions and configurations.

On November 7, 2016, Warren Lyon (NRC) received an email from Anderson Lin that provided the Figure 4 suggested draft modification of the flow chart. This flow chart was prepared by three individuals from industry (Lin, November 7, 2016).

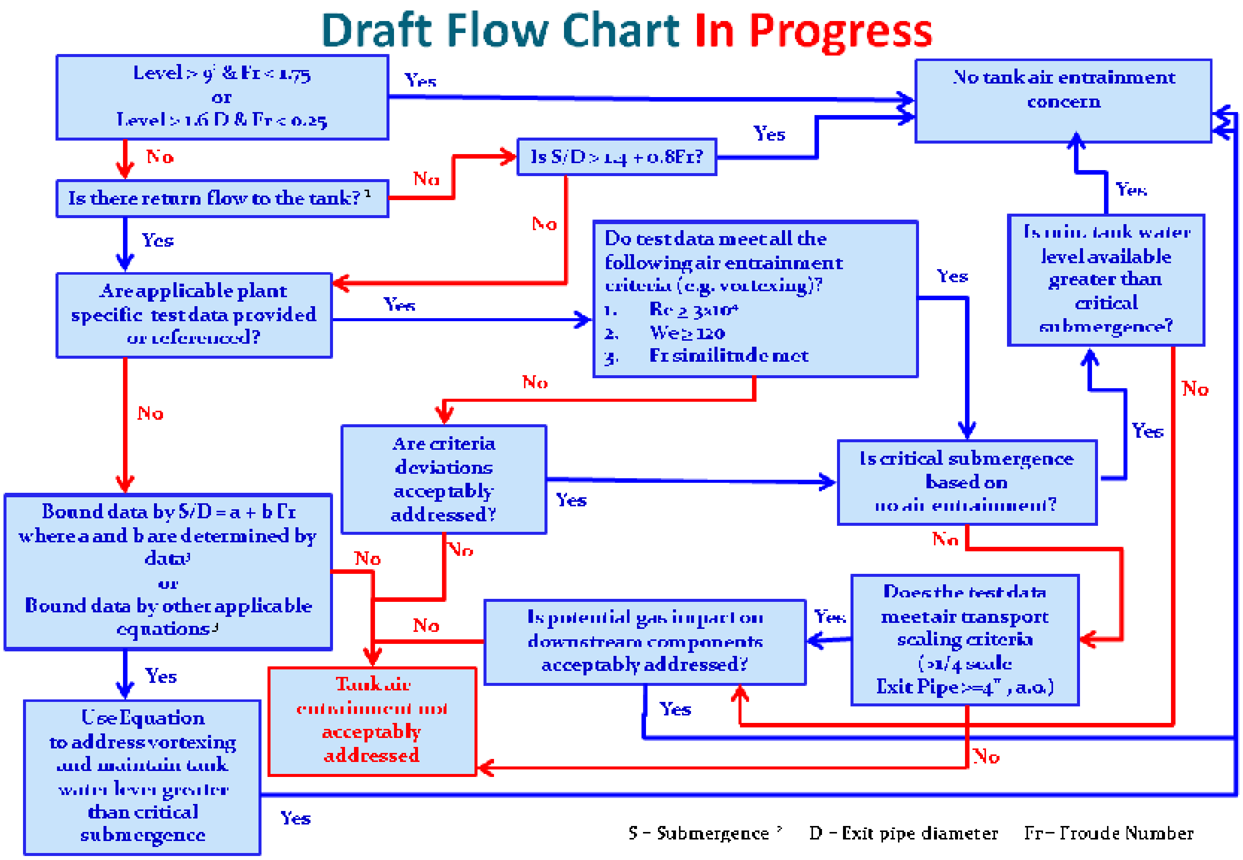

Figure 4 Suggested Modified Flow Chart

A telephone conference call was held on November 17, 2016 to discuss potential plans for holding a public meeting to discuss the technical merits of the draft flow chart. Topics discussed were limited to the process for submitting material to the NRC and did not include any technical discussion of the draft flow chart.

SRXB has reviewed Figure 4. Several items were immediately identified as warranting discussion during a public meeting:

1. The focus is on vortexing and drawing water from a tank. A broader scope is needed that addresses other phenomena and other water sources.
2. The test using S/D = 1.4 + 0.8 Fr is not useful since S is not known. (S = critical water level, the level where gas ingestion becomes a concern; D = exit pipe inside diameter). If "water level" is substituted for "S," this becomes a useful improvement.
3. If applicable plant data are not provided or referenced, then apparently, any data can be used to eliminate a gas concern. Acceptable data should be limited to data that meet specified criteria.

SRXB has drafted the Figure 5 chart for discussion during the public meeting.

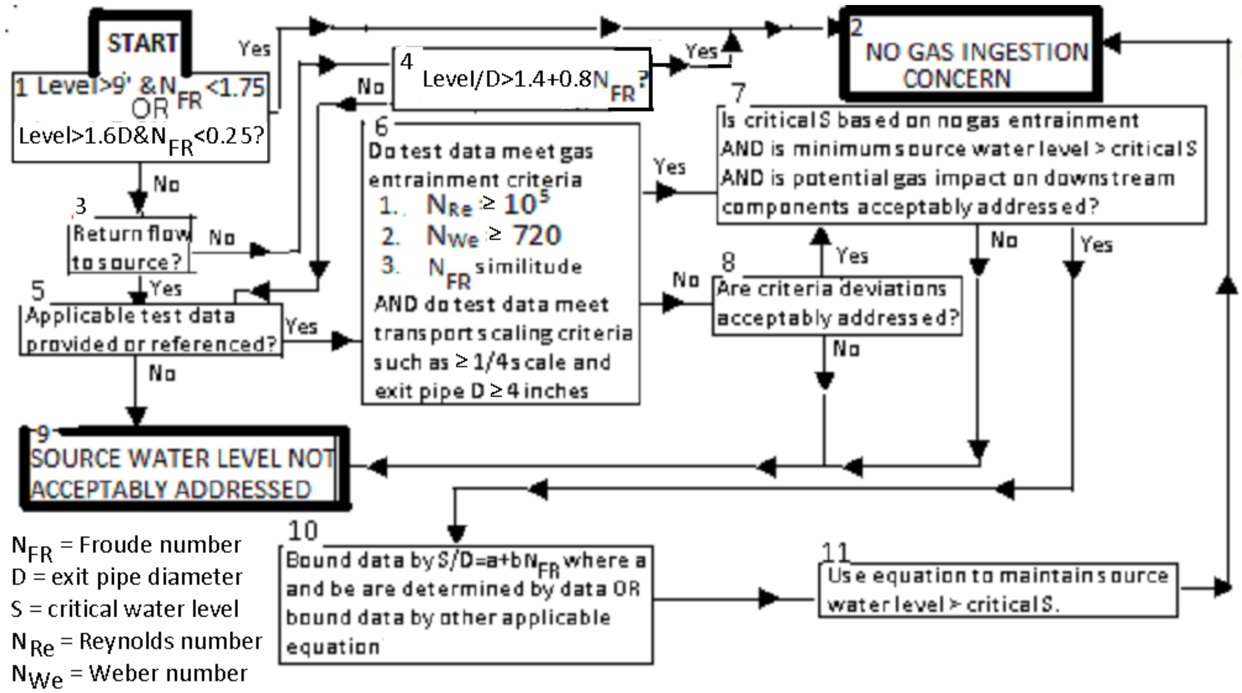

Figure 5 Revised flow chart

The Figure 1 chart focused on vortexing as part of a planned NUREG. The NRC is no longer considering preparation of a NUREG but rather is considering development of a Regulatory Guide that addresses gas ingestion topics. The scope will include both draining from tanks and from other water sources such as RHR operation using PWR hot legs as the water source. Phenomena will not be limited to vortexing but will include such topics as localized reduced water level. The SRXB draft flow chart reflects these considerations.

Each step in the SRXB chart is numbered. Information regarding these steps is as follows:

Item 1. Figure 6 provides a summary of experimental data.

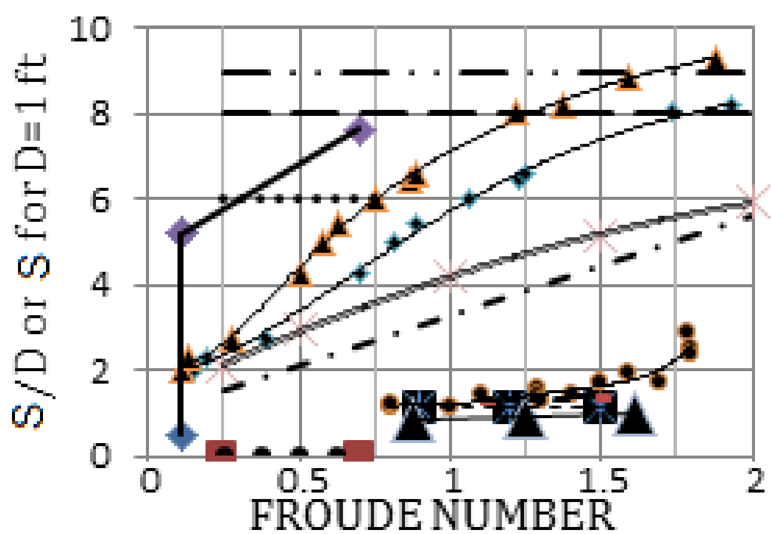

Figure 6 Typical critical submergence levels

The data are widely scattered but establish that a water level (a) greater than nine feet with a Froude number in the exit pipe (N_{FR}) less than 1.75 or (b) greater than 1.6 times the exit pipe diameter (D) with N_{FR} less than 0.25 will not transport gas from a source of water. Consequently, if these conditions exist, there will be no gas ingestion concern and the flow chart indicates a transfer to **Item 2**.

Item 2. **Item 2** is reached if conditions establish that gas ingestion is not a regulatory operability concern.

Item 3. If the Item 1 test conditions are not satisfied, then the question is asked if there is return flow to the water source since return flow can increase conditions where gas ingestion can occur. If there is no return flow, then **Item 4** is entered to check whether the water level is less than an acceptable level as discussed in **Item 4**.

Item 4. The Alden Research Laboratory (ARL) has conducted about 20 separate tests with 15 tanks that represented different customers and applications. Vertical scaled cylindrical tanks tested ranged from 30 ft to 57 ft in diameter. Two 12 ft diameter horizontal tanks were tested. Test model scales ranged from 1:2 to 1:6. Suction nozzle diameters ranged from 6 inches to 24 inches. Tank outlets included horizontal, vertical, outlet flush with the tank wall, and outlet penetrating the tank wall (re-entrant) with the outlet exit a straight pipe and with the exit pipe angled downwards (elbow and miter). Tests were conducted with and without vortex suppressors. Some tests incorporated return flow to the tank from submerged return flow and others included overhead return. Some tanks had multiple outlets. Multiple outlet tests included one, two, and three suction nozzles. In general, each configuration was tested over a range of flow rates. Froude numbers ranged from 0.08 to 4.45. All tests were run with draindown conditions to include the transient effect that would be achieved in a plant application. S was determined on the basis of observing an air bubble or observation of an air core from a vortex entering the suction nozzle. Thus, some gas may be ingested near the end of draindown. This is judged to be of short duration, the gas quantity will typically be small, and it should not normally be an issue that requires an in-depth investigation.

Figure 7 presents a summary of Alden test results (Lin, November 7, 2016). The following observations apply:

- All suction flow only data without return flow are below S/D = 2.
- Caution is necessary when drawing a conclusion for $N_{FR} > 2$ as all data come from one configuration.
- In general, it is not possible to state whether return flow will increase or decrease required submergence. This depends on return angle, return height, and its location relative to the outlet.
- The Froude similitude model does not fully model all of the characteristics of overhead return flow. Bubble behavior and impact may be issues.
- Bubble size and rise velocity are scalable but are prototypic. Therefore, initiation and the extent of air bubble withdrawal into the suction nozzle from jet impingement is not conservative.

- Bubble size and therefore rise velocity does not scale.
- The data are not conservative since the basis was observation of air ingestion or a Type 6 vortex. Users of the ARL data should address the potential for some gas to have been ingested and should address the implications accordingly. An estimate of the time in which gas could have been ingested is acceptable as part of this assessment.

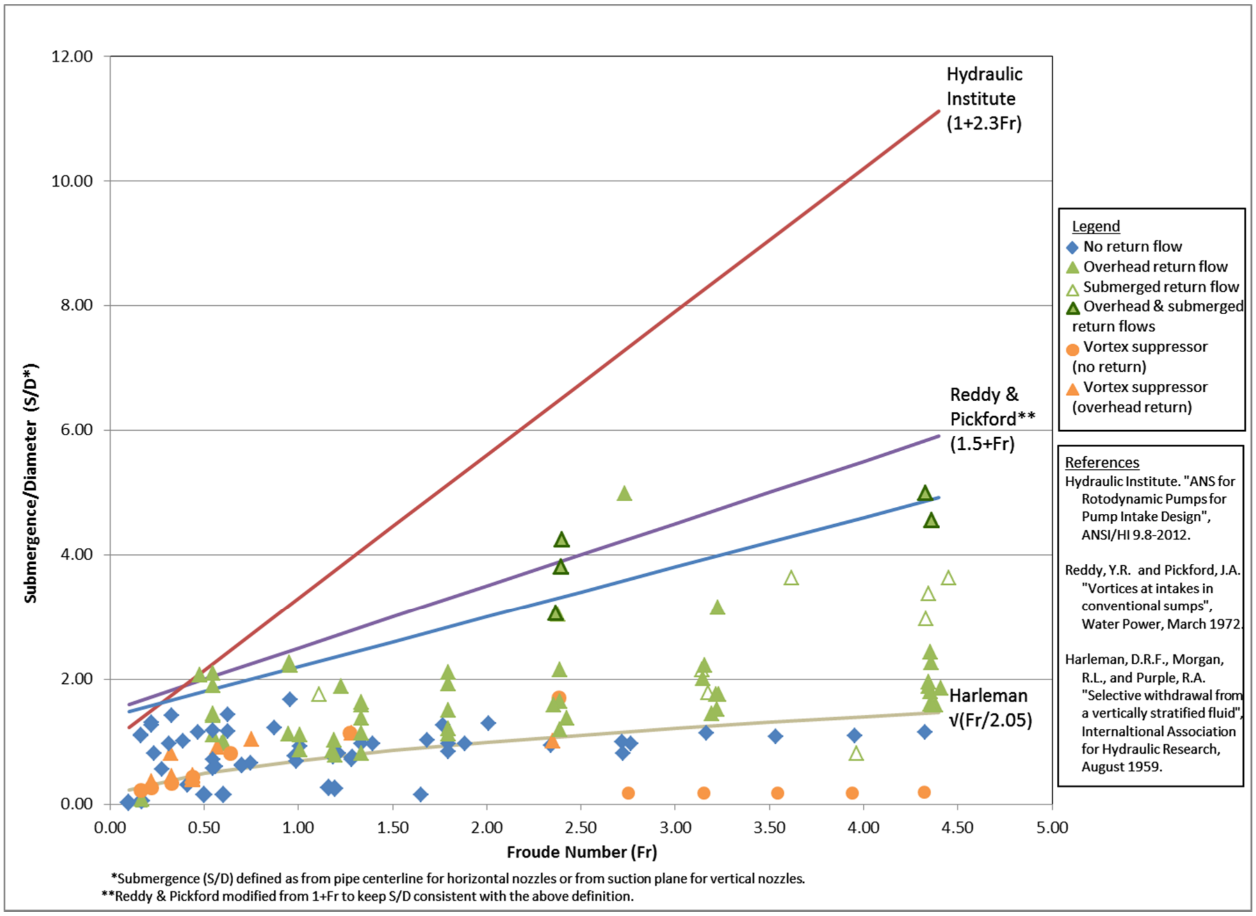

Figure 7. Alden Test Results

The unlabeled blue line is described by $S/D = 1.4 + 0.8\ N_{FR}$ which describes the data obtained when there is return flow to a simulated refueling water storage tank (RWST). This line generally bounds the data by a substantial margin where there is no return flow. Therefore, if level is greater than this line with no return flow, it is acceptable to assume little gas ingestion and **Item 2** is entered.

The Alden tests may have been conducted with a two percent ingestion rate close to the end of a drain-down test. This may lead to challenges to pump acceptance criteria and may cause plant changes that could mislead operators. However, as discussed in the April 18, 2013 meeting (Lyon W. C., May 9, 2013), there are circumstances where prevention of incipient gas ingestion may be unnecessarily conservative and cannot be achieved in existing plants without impractical hardware modifications that are unnecessary to achieve safe operation.[1] Consequently, a small air ingestion rate may be proposed to support an operability determination but, to be acceptable, it must be justified with respect to potential downstream accumulation and subsequent movement of accumulated air with an increased void fraction, potential operator response concerns, vortex instability, and pump acceptance criteria. Therefore, with respect to **Items 6** through **8** and downstream components, operating experience may be used as a justification. This is true for midloop operation.

Item 5 is entered if level is less than allowed by the previously entered items. In this case, applicable data are required to establish that water level is above the critical level. The Figure 7 data may be used if applicable. If acceptable data are not provided or referenced, then **Item 9** is entered that indicates an unacceptable condition.

Item 6 addresses general criteria that test data often should meet. If the criteria are not met, then **Item 8** checks if deviations are acceptably justified. In general, test models can be no smaller than one-fourth (1:4) scale and, when the Reynolds number is greater than 10^5 and the Weber number is greater than 720, surface tension and viscous effects are negligible so that dynamic similarity is obtained. Test models should have no exit pipes associated with air ingestion that are smaller than 4 inches in diameter to avoid perturbation of test results caused by bubble interactions. If these criteria are met, test conditions may be based on an equal Froude number between the model and the plant hardware when the model is acceptably scaled.

With respect to Reynolds and Weber numbers, Johansson stated that viscous and surface tension effects are weak in vortexes that do not have strong air cores (Johansson, December, 2006). Since viscous effects representation is limited to viscosity in Reynolds number and surface tension by surface tension in Weber number, he reported that vortex behavior can be studied in scaled tests by maintaining Reynolds number provided the approach flow pattern in the vicinity of the intake, which governs the circulation contributing to vortexing, is maintained. Johansson referenced reports (1) that an inlet Reynolds number of 3×10^4 is sufficient to model a prototype correlation of vortices and that viscous forces become negligible at this value of a radial Reynolds number and (2) that a Weber number of greater than 120 results in negligible surface tension effects. He also stated that the Hydraulic Institute Standards (HI Standards) uses a safety factor of two for these values to ensure minimum scale effects for test conditions based on Froude similitude. Consequently, his recommendation was that model scaling be consistent with Reynolds number greater than 6×10^4 and Weber number greater than 240. This is consistent with scaling conclusions numerous investigators have provided in describing testing of tanks, containment emergency sumps, and hot leg and RHR pipe connections. However, Odgaard was more conservative (Odgaard, 1986). He used Weber number greater than 720 and Reynolds number greater than 1.1×10^5 for assuming surface tension and viscous effects were negligible. SRXB has selected 720 and 10^5, respectively, as bounding values with the qualification that smaller values are acceptable when justified.[2]

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[1] Industry representatives provided examples such as circumstances where the RCS water level required to support RHR operation would potentially prevent maintenance and the water available in tanks would not be sufficient to support operation with recirculation from containment emergency sumps.

[2]A number of other investigators provided different values. One reason for the differences may be that different geometrical and flow conditions lead to different minimum values to achieve dynamic flow similarity.

Item 7. This checks for additional items that an acceptable gas assessment must meet. If the criteria are met, then **Items 10** and **11** are entered followed by the conclusion that gas ingestion is not a concern in **Item 2**.

Application of Figure 5 to a PWR hot leg during RHR midloop operation can be shown to be acceptable. This is a lengthy process to describe and is not included here.

REFERENCES

Johansson, A. E. (December, 2006). *"Hydraulic Model Study of High Pressure Core Spray Pump Suction to Evaluate the Formation of Air Drawing Vortices and Air Withdrawal for Clinton Nuclear Power Station," ARL, ML063620264.*

Lin, A. (November 7, 2016). *email to Warren Lyon (NRC), "Votrtex NUREG Flow Chart modified Alden.ppt (599 KB)," ML17055A937, ML17055A908.*

Lyon, W. C. (May 9, 2013). *"Meeting Minutes Covering the April 18, 2013 Closed Meeting to Discuss Gas Intrusion due to Vortexing," ML13129A089. See ML13150A153 for complete meeting coverage.*

Lyon, W. (no date). *Draft, no title, ML13224A120.*

Odgaard, A. J. (1986). *"Free-Surface Air Core Vortex," J. Hydraul. Eng. 112, 610.*