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SEP 11 2009

U. S. Nuclear Regulatory Commission
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**SUSQUEHANNA STEAM ELECTRIC STATION
AMENDMENT REQUEST NO. 296 TO UNIT 1 LICENSE NPF-14
AND AMENDMENT REQUEST NO. 266 TO UNIT 2 LICENSE NPF-22:
EMERGENCY CORE COOLING SYSTEM INSTRUMENTATION –
TECHNICAL SPECIFICATION (TS) TABLE 3.3.5.1-1 AND
EDITORIAL CHANGE TO TS 3.10.8.F
RESPONSE TO REQUEST FOR ADDITIONAL
INFORMATION
PLA-6561**

**Docket Nos. 50-387
and 50-388**

Reference:
1) *PLA-6235, Mr. W. H. Spence (PPL) to Document Control Desk (USNRC), "Susquehanna Steam Electric Station Amendment Request No. 296 to Unit 1 License NPF-14 and Amendment Request No. 266 to Unit 2 License NPF-22: Emergency Core Cooling System Instrumentation – Technical Specification (TS) Table 3.3.5.1-1 and Editorial Change to TS 3.10.8.F," dated March 24, 2009.*
2) *E-mail from B. Vaidya (NRC) to D. L. Filchner (PPL), "TAC Nos. ME0933 and ME0934, Draft RAIs RE: Changes Related to ECCS TSs 3.3.5.1-1 and 3.10.8.f," (Instrumentation and Controls Branch), dated May 4, 2009.*
3) *E-mail from B. Vaidya (NRC) to D. L. Filchner (PPL), "Susquehanna Units 1 and 2 TAC Nos. ME0933 and ME0934, RAIs (SRXB) for Amendment Request RE: Changes to TS Table 3.3.5.1-1 and TS 3.10.8.f," dated May 29, 2009*
4) *PLA-6501, Mr. W. H. Spence (PPL) to Document Control Desk (USNRC), "Susquehanna Steam Electric Station Amendment Request No. 296 to Unit 1 License NPF-14 and Amendment Request No. 266 to Unit 2 License NPF-22: Emergency Core Cooling System Instrumentation – Technical Specification (TS) Table 3.3.5.1-1 and Editorial Change to TS 3.10.8.F Supplemental Information," dated April 24, 2009.*

In accordance with the provisions of 10 CFR 50.90, PPL Susquehanna, LLC (PPL) submitted a request for amendment to the Technical Specifications (TS) for Susquehanna Units 1 and 2 in Reference 1.

References 2 and 3 are Requests for Addition Information (RAI) from the Nuclear Regulatory Commission (NRC) Instrumentation and Controls Branch and Reactor Systems Branch. These RAIs were discussed with the NRC staff on June 22, 2009.

A001
NRR

Reference 4 provided supplemental information as requested by the NRC staff during teleconferences on April 6 and April 8, 2009.

The attachments provide the PPL responses to the NRC RAIs in References 2 and 3. Attachment 1 addresses the Instrumentation and Controls Branch RAIs. Attachment 2 responds to the Reactor System Branch RAIs. Attachment 3 provides the revised No Significant Hazards Consideration Determination. Attachment 4 is PPL calculation EC-052-1055 in response to Reactor Systems Branch RAI No. 1.

There are no new or revised regulatory commitments contained herein.

If you have any questions regarding these responses, please contact Mr. D. L. Filchner - Nuclear Regulatory Affairs at (610) 774-7819.

I declare under penalty of perjury that the foregoing is true and correct.

Executed on: 9/11/09

T. S. Rausch

Attachments:
1) Response to the Instrumentation and Controls Branch RAIs
2) Response to the Reactor System Branch RAIs
3) Revised No Significant Hazards Consideration Determination
4) PPL Calculation EC-052-1055

Copy: NRC Region I
Mr. R. Janati, DEP/BRP
Mr. F. W. Jaxheimer, NRC Sr. Resident Inspector
Mr. B. K. Vaidya, NRC Project Manager

Attachment 1 to PLA-6561

Response to the Instrumentation and Controls Branch RAIs

The NRC review of References 1 and 4 by the Instrumentation and Controls Branch (EICB) concluded that additional information is needed, as described in the RAIs below:

NRC EICB RAI No. 1:

The licensee is not adding any footnotes for the proposed condensate storage tank low-level allowable value changes in the technical specifications (TS) because the Magnetrol float switches used are of the mechanical type. The Magnetrol float switch catalog the licensee gave to the U.S. Nuclear Regulatory Commission does not indicate any provision for adjusting the setpoint. However, clause 6.1.8 of licensee plant procedure SI-152-308, page 6, describes adjusting the setpoint if the as-found trip setpoint is greater than or equal to the allowable value. Furthermore, in calculation EC-037-1001, page 14, the licensee specified ±1 inch as the calibration accuracy for these switches.

Please provide the details regarding how the setpoint adjustments are performed in the field.

PPL Response:

PPL surveillance procedures SI-152-308 (Unit 1) and SI-252-308 (Unit 2) provide identical instructions to perform and document the quarterly calibration of the condensate storage tank low level channels LSLL-E41-1N002 and LSLL-E41-1N003 (Unit 1), and LSLL-E41-2N002 and LSLL-E41-2N003 (Unit 2). Unit 1 procedure SI-152-308 was previously submitted in Reference 4.

Setpoint adjustments are not normally required for these level switches to meet the surveillance acceptance criteria. The ±1 inch calibration accuracy on page 13 and 14 of calculation EC-037-1001 was established based on the original GE documentation for these switches. The surveillance results from 2003 to 2006, as documented on pages 9 and 10 of EC-037-1001, show that the limit switches did not require adjustment because the "as found" setting was within the "Final" tolerance band. Discussions with PPL I&C personnel familiar with this surveillance confirmed that the Magnetrol float level switches did not require any adjustment to the float setpoint to maintain the "Final" tolerance band. Although the limit switch manufacturer's information provided in Reference 4 provides an illustration for adjusting the jam nuts that support the float, these jam nuts have not required adjustment because of the consistent results documented in the surveillances. In order to perform the surveillance, the procedure provides direction to isolate the level switch from the tank, raise the water level in the sight glass, and allow the water to drain from the sight glass to obtain the channel trip.

NRC EICB RAI No. 2:

Page 11 of setpoint calculation EC-037-1001 states, "There is no Analytical Value for this setpoint." The applicant also stated on page 4 of this calculation that to avoid vortex formation in the high-pressure coolant injection suction piping, the high pressure coolant injection suction transfer from the condensate storage tank to the suppression pool should take place with the condensate storage tank water level above 36 inches. The staff believes that this setpoint calculation should comply with this analytical limit to avoid vortex formation.

Please provide the justification for the lack of an analytical limit for this setpoint calculation.

PPL Response:

There is no safety analysis that credits this setpoint for protection against any reactor core Safety Limit or a reactor coolant system pressure Safety Limit. Therefore, an analytical limit has not been specified for the High Pressure Coolant Injection (HPCI) suction transfer from the condensate storage tank (CST) to the suppression pool (SP). This position is consistent with the GE documentation for establishing TS limits that do not have analytical limits and PPL Susquehanna's existing TS. The TS limit for the "CST Level- Low" function has a specified design basis limit which assures adequate Net Positive Suction Head to the HPCI pumps while preventing unacceptable vortex formation in the pump suction piping. The proposed TS allowable value of 40.5" assures that the HPCI suction transfer design basis is maintained.

NRC EICB RAI No. 3:

Plant procedure SI-152-308, page 6, clause 6.1.6, refers to the Required Action section in the Data Form if the trip setting is not greater than or equal to the allowable value.

Please provide the details regarding the required actions, specifically when the as-found values are (a) beyond the acceptable as-found tolerance, or (b) beyond allowable value, or (c) cannot be set within the acceptable as-left values.

PPL Response:

As-left trip settings are controlled under the PPL programs for Surveillance Testing and Preventative Maintenance. As-found settings that are outside acceptable tolerances are controlled through the SSES 10 CFR 50, Appendix B, Criterion XVI, corrective action program. Operability and Reportability determinations are integral to the corrective action program.

The as-found and as-left tolerances specified in calculations are incorporated into appropriate surveillance procedures. The Surveillance Testing program establishes the administrative controls for Surveillance Testing which includes the following:

- Specifying requirements for preparation and control of surveillance test procedures.
- Specifying the requirement to generate a Condition Report for any failed calibration activity that references a surveillance procedure.

The maintenance and calibration of installed plant instrumentation procedure defines the responsibilities and controls for I&C activities affecting installed plant instrumentation. This process applies to activities associated with testing, calibration, corrective maintenance, and modification.

Calibration corrective action is controlled under this procedure which includes the following requirements:

- If an instrument is found outside of the as-found tolerance, it shall be calibrated and left within the final tolerance, and
- An Action Request (AR) shall be generated for any equipment exceeding as-found tolerances or any other condition considered adverse to quality.
- The AR is processed as required by the corrective action process, "Action Request and Condition Report Process."

NRC EICB RAI No. 4:

On page 8 of calculation EC-037-1001, TS Allowable Value & TRM Trip Setpoint (New) has been specified as 36 inches for LSL-E51-1N035A, LSL-E51-1N035, LSL-E51-2N035A, and LSL-E51-2N035E instruments.

Please explain how you derived the allowable value of 36 inches and justify why it is not specified in the TS.

PPL Response:

The TS Allowable Value and TRM trip setpoint of 36 inches for the RCIC LSL-E51-1N035A, LSL-E51-1N035E, LSL-E51-2N035A, and LSL-E51-2N035E was calculated from the same flow model in PPL calculation EC-052-1055 utilized to determine the HPCI trip setpoint of 40.5 inches. Calculation EC-052-1055 is provided in Attachment 4 and demonstrates that a RCIC suction transfer setpoint of 36 inches maintains adequate RCIC pump suction to remain above the CST vortex limit. Therefore, it is concluded that the existing Allowable Value of 36 inches for RCIC is acceptable and therefore no change to the TS is required.

NRC EICB RAI No. 5:

The analysis of No Significant Hazards Consideration Determination in your application dated March 24, 2009, as supplemented by letter dated April 24, 2009, does not address the analysis of the proposed changes in TS 3.10.8.f.

Please provide the revised analysis of NSHCD that addresses the analysis of the proposed changes in TS 3.10.8.f.

PPL Response:

The revised NSHCD is provided in Attachment 3 in its entirety. Text that has been added to address the proposed changes to TS 3.10.8.f is shown in bold italics. Text that has been deleted is shown as strikethrough.

Attachment 2 to PLA-6561

Response to the Reactor System Branch RAIs

The NRC Reactor Systems Branch (SRXB) requested the following additional information to complete the review of References 1 and 4:

NRC SRXB RAI No. 1:

Please provide the flow analysis as documented in EC-052-1055 to determine the new TS allowable value of 40.5 inches for the CST low level.

PPL Response:

See PPL Calculation EC-052-1055 (Attachment 4) for the flow analysis used to determine the new TS allowable value of 40.5 inches.

NRC SRXB RAI No. 2:

Please clarify whether the float type level switches are safety-related or not? If they are not safety-related then justify its operability during transient and accident conditions.

PPL Response:

The float type level switches are safety-related as confirmed by review of design documents.

NRC SRXB RAI No. 3:

Provide operating history of these float type level switches.

PPL Response:

The operating history of these float type level switches has been very reliable and their "as found" settings have been consistently within the "as left" final tolerance as demonstrated by the quarterly surveillance results. A review of the work order history for both the Unit 1 and 2 HPCI and RCIC CS Tank low level switches (8 total) indicated the following:

- LSLL-E41-1N002, LSLL-E41-2N002, LSLL-E41-2N003, LSL-E51-2N035A, and LSL-E51-2N035E indicated no surveillance failures going back to 1990.
- LSLL-E41-1N003, LSL-E51-1N035A, and LSL-E51-1N035E experienced a total of six surveillance failures during the same period. These failures were due to micro-switch problems which were resolved by either adjustment or replacement.

There were 32 surveillance opportunities per year (8 switches receiving quarterly surveillances) for a total of 624 surveillances over the last 19.5 years. These six failures constitute a failure rate of less than 1%.

Attachment 3 to PLA-6561

Revised No Significant Hazards Consideration Determination

Added text is shown in ***bold italics***. Text that has been deleted is shown as ~~strikethrough~~.

<u>No Significant Hazards Consideration</u>

The Commission has provided standards in 10 CFR 50.92(c) for determining whether a significant hazards consideration exists. A proposed amendment to an operating license for a facility involves no significant hazards consideration if operation of the facility in accordance with the proposed amendment would not (1) involve a significant increase in the probability or consequences of an accident previously evaluated; (2) create the possibility of a new or different kind of accident from any accident previously evaluated; or (3) involve a significant reduction in a margin of safety.

PPL proposes changes to Appendix A, Technical Specifications (TS), of Facility Operating License Nos. NPF-14 and NPF-22 for the Susquehanna Steam Electric Station Units 1 and 2 respectively.

The ***first*** proposed change revises TS Table 3.3.5.1-1 to increase the technical specification allowable value for the high pressure coolant injection (HPCI) suction low level automatic transfer from the condensate storage tank (CST) to the suppression pool (SP).

Additionally, an editorial /administrative change is proposed which corrects a typographical error in the SSES Units 1 and 2 TS Section 3.10.8.f. ~~No further discussion of this editorial / administrative change is provided hereafter because it does not involve a significant increase in the probability or consequences of an accident previously evaluated; it does not create the possibility of a new or different kind of accident from any accident previously evaluated; and it does not involve a significant reduction in a margin of safety.~~

In accordance with the criteria set forth in 10 CFR 50.92, PPL has evaluated the proposed TS change***s*** and determined ~~it~~ ***they*** do~~es~~ not represent a significant hazards consideration. The following is provided in support of this conclusion.

1. **Does the proposed change involve a significant increase in the probability or consequences of an accident previously evaluated?**

   No. The proposed change ***to TS Table 3.3.5.1-1*** increases the Technical Specification allowable value for the HPCI suction low level automatic transfer function from ≥ 36 inches to ≥ 40.5 inches above the CST bottom. There are no process setpoint changes associated with this TS allowable value change. This TS change does not introduce the possibility of an increase in the probability or consequences of an accident because the HPCI automatic transfer function is not an initiator of any new accidents nor does it introduce any new failure modes. The

CST is not safety related and therefore not credited in any design basis accident analyses. However, the CST reserve volume is credited in anticipated transients without scram (ATWS), Appendix R and station blackout (SBO) evaluations. The reserve volume available in the CST at the proposed allowable value of 40.5 inches above the CST bottom remains adequate to fully support these HPCI system support functions and the change fully supports HPCI system operation. The reserve volume is not reduced as a result of the proposed change in the TS allowable value since the transfer will still occur at the CST low level instrument setpoint of 43.5 inches above tank bottom, which remains unchanged.

The HPCI system automatic transfer function occurs at the point in a design basis accident (DBA) when the CST level reaches the low level transfer setpoint. This proposed change will require the HPCI pump suction to be transferred from the CST to the SP at 40.5 inches versus 36 inches above the CST bottom. Currently, the TS allow this transfer to occur at 36 inches. This proposed change is conservative because it assures the suction transfer will occur while there is more water in the tank, thus eliminating the possibility of vortex formation and air intrusion to the HPCI pump suction. Since this proposed change ensures the HPCI system automatic suction transfer function occurs without adversely impacting HPCI system operation, it does not involve a significant increase in the probability or consequences of an accident previously evaluated.

The proposed editorial /administrative change is necessary to correct a typographical error in the SSES Units 1 and 2 TS Section 3.10.8.f. This editorial change does not involve a significant increase in the probability or consequences of an accident previously evaluated.

2. Does the proposed change create the possibility of a new or different kind of accident from any accident previously evaluated?

No. As discussed above, the proposed change ***to TS Table 3.3.5.1-1*** involves increasing the TS allowable value for the HPCI low level automatic transfer function from the CST to the SP at $\geq$ 36 inches to $\geq$ 40.5 inches above the CST tank bottom. This change ensures the HPCI automatic transfer function occurs without introducing the possibility of vortex formation or air intrusion in the HPCI pump suction path. All HPCI system support functions remain unaffected by this change. This TS change does not introduce the possibility of a new accident because the HPCI automatic transfer function is not an initiator of any accident and no new failure modes are introduced. There are no new types of failures or new or different kinds of accidents or transients that could be created by these changes. Therefore, this change does not create the possibility of a new or different kind of accident from any accident previously evaluated.

The proposed editorial /administrative change only corrects a typographical error in the SSES Units 1 and 2 TS Section 3.10.8.f. This editorial change does not create the possibility of a new or different kind of accident from any accident previously evaluated.

3. **Does the proposed change involve a significant reduction in a margin of safety?**

No. The margin of safety is established through equipment design, operating parameters, and the setpoints at which automatic actions are initiated. The proposed change ***to TS Table 3.3.5.1-1*** involves increasing the allowable level at which the HPCI automatic suction transfer from the CST to the SP must occur to avoid the possibility of vortex formation or air intrusion into the HPCI pump. This change does not result in a change to the level switch setpoint, which initiates the HPCI suction transfer from the CST to the SP. Although the allowable value for the transfer is now closer to the process setpoint for activation of the level switch, this reduction in operating margin was reviewed and determined to be acceptable. The level switch setpoint tolerances were established based on historical instrument data and instrument characteristics. These tolerances provide adequate margin to the proposed TS allowable value of 40.5 inches above the CST bottom. The tolerances further ensure the transfer will occur prior to level reaching the technical specification allowable value. Therefore, the proposed change does not result in a significant reduction in a margin of safety

The proposed editorial /administrative change only corrects a typographical error in the SSES Units 1 and 2 TS Section 3.10.8.f. This editorial change does not result in a significant reduction in a margin of safety.

Attachment 4 to PLA-6561

PPL Calculation EC-052-1055

NUCLEAR ENGINEERING CALCULATION COVER SHEET
NEPM-QA-0221-1

1. Page 1 of 49
Total Pages 51

>2. TYPE: CALC >3. NUMBER: EC-052-1055 >4. REVISION: 1

*>5. UNIT 3 *>6. QUALITY CLASS: Q

>7. DESCRIPTION: CST Water Level for HPCI Suction Transfer

8. SUPERSEDED BY: NA

9. Alternate Number: NA 10. Cycle: NA

11. Computer Code/Model used: 12. Discipline: M

>13. Are any results of this calculation described in the Licensing Documents?

☒ Yes, *Refer to NDAP-QA-0730 and NDAP-QA-0731* ☐ No

>14. Is this calculation changing any method of evaluation described in the FSAR and using the results to support or change the FSAR? (Refer to PPL Resource Manual for Definition of FSAR)

☒ Yes, *50.59 screen or evaluation required.* ☐ No

>15. Is this calculation Prepared by an External Organization?

☐ Yes ☒ No

EG771 Qualifications may not be required for individuals from external organizations (see Section 7.4.3).

	Print Name	Signature	Date
>16. Prepared by[1]:	M. A. Chaiko *Print Name (EG771 Qualification Required)*	Mark A. Chaiko	10/5/07
>17. Reviewed by[1]:	R. M. Centenaro *Print Name (EG771 Qualification Required)*	R.M. Centenaro	10/8/07
>18. Verified by:	R. M. Centenaro *Print Name (EG771& QADR Qualification Required)*	R.M. Centenaro	10/8/07
>19. Approved by:	D. G. Kostelnik *Print Name (Qualified per NEPM-QA-0241 and comply with Section 7.8 of NEPM-QA-0221)*	D. G. Kostelnik	10/17/07
>20. Accepted by:	*Print Name (EG771 Qualification Required) and comply with Section 7.9 of NEPM-QA-0221*		

[1] For Fire Protection related calculations see Section 7.4.3.14 for additional qualification requirements

CALCULATION REVISION DESCRIPTION SHEET
NEPM-QA-0221-2

REVISION NO: 1	CALCULATION NUMBER: EC-052-1055

☒ FULL REVISION ☐ SUPERSEDED

☐ PAGE FOR PAGE ☐ VOIDED

Revised Pages	Add	Rpl	Rmv	Description of Revision on the Listed Pages
All	☐	☒	☐	Replace all Rev. 0 pages with Rev. 1 pages.
	☐	☐	☐	
	☐	☐	☐	
	☐	☐	☐	
	☐	☐	☐	
	☐	☐	☐	
	☐	☐	☐	
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	☐	☐	☐	

TECHNICAL CHANGE SUMMARY PAGE
NEPM-QA-0221-5

Calculation: Number: EC-052-1055 **Revision No.** 1

This form shall be used to (1) record the Technical Scope of the revision and (2) record the scope of verification if the calculation was verified. It should not be more than one page. Its purpose is to provide summary information to the reviewer, verifier, approver, and acceptor about the technical purpose of the change. For non-technical revisions, state the purpose or reason for the revision.

Scope of Revision: Revision 1 includes an evaluation of Net Positive Suction Head (NPSH) during the HPCI suction transfer from the CST to the suppression pool. For the design case (Case 1), there is no reduction in the available margin. NPSH is also evaluated based on minimum acceptable surveillance stroke times for HPCI and RCIC CST suction valves and design maximum values, including degraded voltage conditions, for the suppression pool suction valves (Case 5). This highly conservative combination of valve stroke times maximizes the flow resistance associated with the HPCI and RCIC suction paths. Even for this extreme case there is still significant margin (4.5 ft) in the available NPSH.

The hydraulic model was modified to prevent the occurrence of reverse flow in the RCIC suppression pool suction line. For the valve stroke times used in the NPSH evaluation (Case 5 in Table 6-1), the potential exists for reverse flow in this line; however, flow from the CST to the suppression pool is prevented by check valve 149F030. The effect of 149F030 on system flow was included in the computer model by adding a large resistance (1×10^{12}) to the RCIC suppression pool suction path if the onset of reverse flow is detected during the flow iteration.

A Computer Case Summary, Table 6-1, was added to define the case-specific stroke times used for the HPCI and RCIC CST and suppression pool suction valves.

The assumption that no vortex formation will occur with tank level above the vortex breaker is validated in Attachment 4. Preoperational test data, which shows no vortex formation at 6000 gpm and tank level of 34" is used along with the onset-of-air-ingestion curve provided in §5.3 to demonstrate that no vortex formation will occur with water level above the vortex breaker.

Scope of Verification (If verification applies): Technical changes associated with Revision 1 are to be verified. Revision 1 changes are indicated using rev. bars.

Table of Contents

Rev. 1

Rev. 1

1. Objective

The purpose of this calculation is to determine the initial CST level required to maintain adequate HPCI/RCIC pump suction conditions in the event of an automatic suction transfer from the CST to the suppression pool. This will serve as the basis for the revision of TS (Technical Specification) 3.3.5.1 (Ref. 17) for the allowable value of the HPCI suction transfer trip function (Function 3.d of TS Table 3.3.5.1-1). This calculation also evaluates the impact on HPCI pump NPSH available during an automatic suction transfer with the CST and suppression pool suction valves operating in parallel. Rev. 1

2. Conclusions

This evaluation determined that the new allowable value for CST level required for satisfactory pump operation during a HPCI suction transfer is 40.5 inches. This is above the current TS Table 3.3.5.1-1 value of 36.0 inches. Therefore, a TS change will be necessary.

The design case (Case 1) demonstrates that there is no impact on pump NPSH available during the transfer with suction valves operating in parallel. Even in an extreme case with regard to pump NPSH (Case 5), where HPCI suction flow resistances from the CST and suppression pool are maximized by selectively applying degraded voltage conditions to the suppression pool suction valves, but not to the CST suction valves, significant margin (4.5 ft) exists between NPSHA and NPSHR. Rev. 1

3. Assumptions

1. The CST and suppression pool suction valves for the HPCI system operate in parallel rather than in series as currently designed. A modification to the HPCI suction transfer logic will be required to support this assumption (Ref. CRA 685368, EC 823975, and EC 823991).

2. Both HPCI and RCIC are assumed to be in operation in order to simulate "worst case" conditions during a suction transfer. Total HPCI and RCIC flow is constant during the transfer.

3. The RCIC suction set point will remain at the current TS value of 36.0 inches (Ref. 2).

4. The Unit 1 HPCI and RCIC systems are modeled. Differences between the suction piping on Units 1 and 2 are relatively small (Ref. 4 and 5). Results based on the Unit 1 model should conservatively bound Unit 2 for purposes of evaluating the potential for vortex formation because the distance from the CST to HPCI and RCIC pumps on Unit 1 is less than on Unit 2. Smaller CST suction line losses on Unit 1 would result in slightly higher flow from the CST during the suction transfer which would tend to minimize CST level thus reducing margin to the onset of vortex formation. Rev. 1

5. Pressure in the suppression chamber air space is 1 atm. This minimizes HPCI and RCIC suction flow from the suppression pool during the HPCI suction transfer evolution, which results in a greater flow from the CST and a faster drop in CST level.

6. Owing to the large size of the suppression pool and the short time for the transfer (<3 minutes), pressure and level in the suppression chamber are taken as constant during the suction transfer.

7. Suppression pool water is assumed to be at 140°F, the maximum temperature for HPCI operation with suction from the pool (Ref. 18). Using a maximum temperature minimizes suppression pool water density which in turn minimizes HPCI suction from the pool during the transfer. Pool density is 61.38 Lbm/ft^3 (Ref. 27).

8. Height of the pool is assumed to be at the TS minimum value of 22 feet (Ref. 1). The normal band is 22 ft to 24 ft with a typical operating height of 23 ft. This assumption tends to minimize HPCI suction flow from the pool during the transfer which results in greater suction from the CST.

9. CST is at atmospheric pressure.

10. CST water temperature is 100°F (Ref. 19). Density is 62.00 Lbm/ft^3 (Ref. 27). This water temperature is conservative relative to 140°F (the maximum temperature for HPCI operation) because it provides a greater coolant density which tends to maximize flow from the CST during the suction transfer.

11. CST water level at the time HPCI suction transfer initiates is adjusted in the model until acceptable HPCI/RCIC pump suction conditions with regard to vortex formation are obtained. This determines the TS allowable value for the HPCI suction transfer trip function (Function 3.d of TS Table 3.3.5.1-1).

12. Valve stroke times for the HV1(2)55F042 valve is adjusted for degraded DC voltage under dynamic loading (Ref. 3). The fraction that the valve is open is assumed to be a linear function of the valve stroke time.

13. Acceptance criteria is based on final CST level remaining above the vortex breaker or above the level associated with the onset of air ingestion, as described in Ref. 16. (Refer to Attachment 4 for validation of this acceptance criteria.) Note that no credit is taken for the CST vortex breaker when establishing the onset-of-air-ingestion curve.

14. The most limiting condition for HPCI NPSH available occurs at the instant the HPCI CST suction valve HV1(2)55F004 goes closed and pump suction is aligned exclusively on the suppression pool. Suction line elevation head and friction losses are essentially independent of Unit when HPCI suction is aligned to the suppression pool (see Attachment 1 of Ref. 29); therefore, the minimum NPSHA margin, which is obtained using a Unit 1 hydraulic model (see Assumption 4), applies also to Unit 2. Rev. 1

4. Inputs

4.1 Valve Stroke Times

Reference 3 was used to determine dynamic stroke times for each valve. These are the design stroke times for the valves, which consider maximum design loadings, and also consider degraded voltage conditions (AR 667984). In evaluating vortex formation, the following stroke times were obtained by using the higher of Unit 1 and Unit 2 dynamic stroke times and rounding the "worst case" stroke time up to the nearest second: Rev. 1

HPCI HV1(2)55F042 = 115 seconds (Open) = t_{F042},

HPCI HV1(2)55F004 = 108 seconds (Close) = t_{F004},

RCIC HV1(2)49F031 = 44 seconds (Open) = t_{F031}, and

RCIC HV1(2)49F010 = 44 seconds (Close) = t_{F010}.

For purposes of evaluating NPSHA (Net Positive Suction Head Available), the minimum acceptable surveillance stroke times for HPCI and RCIC CST suction valves HV1(2)55F004 and HV1(2)49F010 are used in order to maximize pump suction path resistance from the CST. These values as specified in HPCI and RCIC quarterly surveillance procedures SO-152/252-004 and SO-150/250-004, respectively, are

HPCI HV1(2)55F004 = 53.6 seconds (Close) = t_{F004}, and

RCIC HV1(2)49F010 = 25.5 seconds (Close) = t_{F010}.

Opening stroke times for HPCI and RCIC suppression pool suction valves HV1(2)55F042 and HV1(2)49F031 are maintained at their design maximum values for degraded voltage conditions (115 seconds and 44 seconds, respectively). This maximizes the flow resistance associated with the suppression pool suction path. Combining stroke times in this manner is extremely conservative since a degraded voltage condition is selectively applied to the suppression pool suction valves, but not to the CST suction valves. Rev. 1

4.2 Flow Rates

According to Calculations EC-052-0002 (Ref. 4) and EC-050-0001 (Ref. 5), the flow rates for HPCI and RCIC are 5000 and 600 gpm respectively. However, the flow rates used for the calculations were 5100 and 625 gpm to account for flow controller tolerances (EWR 686614, SO-150-001, and SO-152-001). Note that both HPCI and RCIC are assumed to be in operation in order to simulate "worst case" conditions during a suction transfer, i.e., maximum rate of CST level decrease.

4.3 Tank Data and Elevations

Condensate Storage tank parameters and piping elevations are summarized in the following table.

Table 4-1 Elevation and CST Data

Parameter	Value	Reference
Elevation at bottom (floor) of CST	672.10 ft	6
CST volume per unit height	9,350 gal/ft	6, 23
Free cross-sectional area of CST	1,250 ft^2	6, 23
Elevation at inside bottom of CST suction pipe relative to tank floor	0.84 ft	20, 21
Elevation at bottom of suppression pool	648 ft	7
Elevation at HPCI Node 3 on Fig. 1	653.25 ft	8
Elevation at RCIC Node 4 on Fig. 1	648.7 ft	9
Elevation at top of vortex breaker relative to tank floor	30.875 inches	10

<u>CST volume per unit height</u>

Tank diameter = 40.0 ft – (2)(0.375)/12 = 39.94 ft (Ref. 6, 23)
Free cross-sectional area = $\pi(39.94\,\text{ft})^2/4 \approx 1{,}250\ \text{ft}^2$.
Volume per height = 9350 gal/ft

<u>Elevation at bottom (inside) of CST suction pipe relative to bottom of tank</u>

Suction pipe is 20" HCD/HCB Schedule 10 Pipe (Ref. 13, 20)
ID = 19.5" = 1.625 ft (Ref. 14)
Centerline elevation of suction pipe = 673'-9" = 673.75 ft (Ref. 21)
Elevation at inside bottom of suction pipe = 673.75' – 1.625'/2 = 672.94 ft
Elevation at bottom of pipe relative to bottom of tank = 672.94' – 672.10' = 0.84 ft

4.4 Valve Flow Coefficients

Values of the valve flow coefficients at full open is supplied by the vendor (see Table 4-2 below). The vendor has also supplied a generic curve for a gate valve C_v (as a fraction of max C_v) vs. percent open (Ref. 15). This curve is represented by the polynomial,

$$C_v(x) = C_v\left(0.9602x^4 - 0.1689x^3 - 0.1857x^2 + 0.3952x\right),$$

where x is the fraction that the valve is open. The fraction x is assumed to be linear through the valve stroke time. The initial system configuration has the HPCI F004 and RCIC F010 valves fully open and the HPCI F042 and RCIC F031 valves fully closed. For calculational purposes, the HPCI F042 valves starts to open at $t = 0^+$. The RCIC F031 valve starts to open after CST level drops to its TS allowable value of 36.0 inches relative to the tank bottom (Assumption 3). HPCI system valves will be run in parallel such that the HPCI F004 valve starts closing when the HPCI F042 begins to open. The original logic was a series configuration and will be modified to a parallel operation. RCIC system valves remain functioning in series, such that the RCIC F010 valve starts closing after the RCIC F031 reaches full open.

Table 4-2 Full-open Valve C_V Data

Valve	Flow Coefficient, C_V	Reference
HPCI Valve HV1(2)55F042	20,700 gpm	11
HPCI Valve HV1(2)55F004	20,700 gpm	11
RCIC valve HV1(2)49F031	2,300 gpm	12
RCIC valve HV1(2)49F010	2,300 gpm	12

4.5 Unit 1 Pipe Data

The common HPCI/RCIC suction from the CST (downstream of node 1 in Fig. 1) is 20" Schedule 10 pipe (Ref. 13, 20).
$A_1 = 2.074$ ft^2, $D_1 = 19.5$ in = 1.625 ft (Ref. 14)

HPCI suction pipe from the CST and SP at node 3 on Fig. 1 consists of 16" Schedule 30 pipe (Ref. 20, 24).
$A_3 = 1.2684$ ft^2, $D_3 = 15.250$ in = 1.271 ft (Ref. 14)

Per Ref. 20 and 26, RCIC suction piping from the CST and SP at node 4 consists of 6" Schedule 40 pipe.
$A_4 = 0.2006$ ft^2, $D_4 = 6.065$ in = 0.5054 ft (Ref. 14)

4.6 Net Positive Suction Head

The following FSAR NPSH requirements and results are taken from EC-059-1036, Rev. 2 (See FSAR Sections 6.3.2.2.1.1, 6.3.2.2.1.2, and 5.4.6.2.2.2.)

Unit	Suction Source	NPSHR HPCI (ft)	NPSHR RCIC (ft)	NPSHA HPCI (ft)	NPSHA RCIC (ft)
1	CST	21.0	21.3	47.32	49.10
2	CST	21.0	21.3	42.26	44.43
1 or 2	SP	21.0	21.3	31.4	39.52

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5. Method

A hydraulic model of the HPCI and RCIC Pump suction piping has been developed based on conservation of mass and mechanical energy. The model is used to determine CST level versus time during a HPCI suction transfer from the CST to the suppression pool. Suction valves at the CST and the suppression pool are assumed to function in parallel for the HPCI system (i.e., at

t=0, the HPCI CST suction valve HV1(2)55F004 begins to close and the suppression pool suction valve HV1(2)55F042 begins to open). Pressure drop relations were developed for the suction piping in order to predict the change in flow in each line with the changing valve positions. The model incrementally calculates the change in flow in each line and the corresponding change in CST level until the suction valves complete their position change (from open to close or close to open). Initial CST level assumed in the model is adjusted until the final level in the CST is at an acceptable value after a suction transfer. The level can not drop below the point where air intrusion would be introduced from vortex formation in the suction piping. Acceptable results are achieved when the final level is determined to be at or above the vortex breaker elevation in the CST or the level is determined to be above the onset of air ingestion curve as described in Ref. 16. This acceptance criterion is incorporated into the hydraulic model.

In order to determine the reduction in CST level during a suction swap, it is necessary to determine separate flow rates from the CST and suppression pool while both valves are open. This is accomplished by balancing the suction heads and flow losses at the point where the two suction flow paths meet (Nodes 3 and 4 on Figure 5-1).

5.1 Governing Equations

Bernoulli's equation is used to calculate the flow rates from the CST and suppression pool as a function of time. Governing equations are solved at specific time steps to simulate the transient response of CST level.

Based on Fig. 5-1, the Bernoulli equations for the CST and suppression pool suction paths consist of (Ref. 28, pp. 16-3 and 17-7)

$$\left(\frac{g}{g_C}Z_1+\frac{P_1}{\rho_C}\right)=\left(\frac{g}{g_C}Z_3+\frac{P_3}{\rho_C}+\frac{Q_{HC}^2}{2g_C A_3^2}\right)+K_{1-2}\frac{(Q_{HC}+Q_{RC})^2}{2g_C A_1^2}+K_{2-3}\frac{Q_{HC}^2}{2g_C A_3^2}, \quad (1)$$

$$\left(\frac{g}{g_C}Z_1+\frac{P_1}{\rho_C}\right)=\left(\frac{g}{g_C}Z_4+\frac{P_4}{\rho_C}+\frac{Q_{RC}^2}{2g_C A_4^2}\right)+K_{1-2}\frac{(Q_{HC}+Q_{RC})^2}{2g_C A_1^2}+K_{2-4}\frac{Q_{RC}^2}{2g_C A_4^2}, \quad (2)$$

$$\left(\frac{g}{g_C}Z_5+\frac{P_5}{\rho_S}\right)=\left(\frac{g}{g_C}Z_3+\frac{P_3}{\rho_S}+\frac{Q_{HS}^2}{2g_C A_3^2}\right)+K_{5-3}\frac{Q_{HS}^2}{2g_C A_3^2}, \quad (3)$$

and

$$\left(\frac{g}{g_C}Z_5+\frac{P_5}{\rho_S}\right)=\left(\frac{g}{g_C}Z_4+\frac{P_4}{\rho_S}+\frac{Q_{RS}^2}{2g_C A_4^2}\right)+K_{5-4}\frac{Q_{RS}^2}{2g_C A_4^2}. \quad (4)$$

By conservation of mass, the following two relations also hold (total HPCI and RCIC flow rates are constant per Assumption 2 and §4.2)

$$Q_{HC} + Q_{HS} = \left(\frac{5{,}100}{449}\right)\frac{\text{ft}^3}{\text{sec}}, \tag{5}$$

and

$$Q_{RC} + Q_{RS} = \left(\frac{625}{449}\right)\frac{\text{ft}^3}{\text{sec}}, \tag{6}$$

The elevation Z_1 of the water surface in the CST is determined from

$$A_C \frac{dZ_1}{dt} = -Q_{HC} - Q_{RC} \tag{7}$$

Equations (1)-(7) are sufficient to determine the unknowns $Z_1, Q_{HC}, Q_{RC}, Q_{HS}, Q_{RS}, P_3,$ and P_4. Variables are defined according to

A_C = free cross-sectional area in CST = 1,250 ft^2 (§4.3),
A_1 = flow area of 20" common CST suction pipe = 2.074 ft^2 (§4.5),
A_3 = flow area of 16" HPCI CST and SP suction pipe at node 3 = 1.268 ft^2 (§4.5),
A_4 = flow area of 6" RCIC CST and SP suction pipe at node 4 = 0.2006 ft^2 (§4.5),
g = acceleration due to gravity = 32.2 ft/sec^2,
g_C = 32.2 ft-Lbm/Lbf-sec^2,
$K_{1\text{-}2}$ = friction loss coefficient for path from CST to node 2,
$K_{2\text{-}3}(t)$ = friction loss coefficient for path from node 2 to node 3,
$K_{2\text{-}4}(t)$ = friction loss coefficient for path from node 2 to node 4,
$K_{5\text{-}3}(t)$ = friction loss coefficient for path from SP to node 3,
$K_{5\text{-}4}(t)$ = friction loss coefficient for path from SP to node 4,
P_1 = pressure in CST above water surface = 2116.8 psfa (Assumption 9),
$P_3(t)$ = pressure at node 3 (psfa),
$P_4(t)$ = pressure at node 4 (psfa),
P_5 = pressure in SP above water surface = 2116.8 psfa (Assumption 5),
$Q_{HC}(t)$ = HPCI suction flow from CST (ft^3/sec),
$Q_{HS}(t)$ = HPCI suction flow from SP (ft^3/sec),
$Q_{RC}(t)$ = RCIC suction flow from CST (ft^3/sec),
$Q_{RS}(t)$ = RCIC suction flow from SP (ft^3/sec),
t = time (sec),
$Z_1(t)$ = elevation of water surface in CST = 672.10 ft + tank level (ft) (§4.3),
Z_3 = elevation at node 3 = 653.25 ft (§4.3),
Z_4 = elevation at node 4 = 648.7 ft (§4.3),
Z_5 = elevation of water surface in SP = 648 ft + 22 = 670 ft (§4.3 and Assumption 8),
ρ_S = density of water in suppression pool = 61.38 Lb_m/ft^3 (Assumption 7), and
ρ_C = density of water in CST = 62.00 Lb_m/ft^3 (Assumption 10).

In both the CST and SP suction lines, the friction coefficient K has two components: the loss due to the suction valve, which is expressed in terms of the valve C_V and the loss due to piping friction K'. These losses can be expressed as (Ref. 14, p. 3-4)

$$K_{2-3} = K'_{2-3} + \frac{891(12D_3)^4}{\left[C_{V,F004}(t)\right]^2},$$

$$K_{2-4} = K'_{2-4} + \frac{891(12D_4)^4}{\left[C_{V,F010}(t)\right]^2},$$

$$K_{5-3} = K'_{5-3} + \frac{891(12D_3)^4}{\left[C_{V,F042}(t)\right]^2},$$

and

$$K_{5-4} = K'_{5-4} + \frac{891(12D_4)^4}{\left[C_{V,F031}(t)\right]^2},$$

where the pipe diameters D_3 and D_4 are expressed in units of ft. The loss coefficient K_{5-4} accounts for flow resistance in the RCIC suppression pool suction line. In some cases, a potential exists for reverse flow in this line; however, this would not occur owing to the presence of check valve 149F030. In order to prevent the development of reverse flow in the RCIC suppression pool suction line, a large flow resistance (1×10^{12}) is added to K_{5-4} if the onset of reverse flow is detected during the flow iteration. This simulates closure of check valve 149F030. Rev. 1

5.2 Friction Coefficients

Friction coefficients $K_{1-2}, K'_{2-3}, K'_{2-4}, K'_{5-3},$ and K'_{5-4} are determined from data provided in Ref. 4 and 5.

From Ref. 4, pp. 24 and 45, loss coefficient K_{1-2} is equivalent to 290.51 ft of 20" pipe (*ID*=19.5",*f*=0.0131) plus 116.63 ft of 16" pipe (*ID*=15.5",*f*=0.0133). Basing the total equivalent length on 19.5" *ID* pipe gives

$$L_{eq} = 290.51\,\text{ft} + (116.63\,\text{ft})\left(\frac{0.0133}{0.0131}\right)\left(\frac{19.5}{15.5}\right)^5 = (290.51 + 373.2)\,\text{ft} = 663.7\,\text{ft},$$

and K_{1-2} is given by

$$\boxed{K_{1-2} = \frac{(0.0131)(663.7\,\text{ft})}{(19.5/12)\,\text{ft}} = 5.35}$$ (Based on pipe *ID*=19.5")

Based on Ref. 4, pp. 24 and 45, loss coefficient K'_{2-3} is equivalent to 43.83 ft of 16" pipe (*ID*=15.5", *f*=0.0133) and 164.9 ft of 16" pipe (*ID*=15.25", *f*=0.0134).

Converting the entire equivalent length to 15.25" *ID* pipe gives

$$L_{eq} = 164.9\,\text{ft} + (43.83\,\text{ft})\left(\frac{0.0133}{0.0134}\right)\left(\frac{15.25}{15.5}\right)^5 = (164.9 + 40.1)\text{ft} = 205.0\,\text{ft}$$

Therefore,

$$\boxed{K'_{2-3} = \frac{(0.0134)(205.0\,\text{ft})}{(15.25/12)\,\text{ft}} = 2.16} \qquad \text{(Based on pipe } ID = 15.25\text{")}$$

The loss coefficient K'_{2-4} is equivalent to 123.87 ft of 6" pipe (*ID*=6.357", *f*=0.0164) and 62.78 ft of 6" pipe (*ID*=6.065", *f*=0.0163); see pp. 24 and 64 of Ref. 5).

Converting the entire equivalent length to 6.065" *ID* pipe leads to

$$L_{eq} = 62.78\,\text{ft} + (123.87\,\text{ft})\left(\frac{0.0164}{0.0163}\right)\left(\frac{6.065}{6.357}\right)^5 = (62.78 + 98.52)\text{ft} = 161.3\,\text{ft}$$

This gives K'_{2-4} as

$$\boxed{K'_{2-4} = \frac{(0.0163)(161.3\,\text{ft})}{(6.065/12)\,\text{ft}} = 5.20} \qquad \text{(Based on pipe } ID = 6.065\text{")}$$

For the HPCI suppression pool suction path, the loss coefficient K'_{5-3} consists of the suction strainer loss coefficient ,$K_{HPCI,Strainer}$, and a loss equivalent to (136.26+270.21-10.90) = 395.6 ft of 16" pipe (*ID*=15.25"=1.271 ft, *A*=1.268 ft^2, *f*=0.0131); see Ref. 4, pp. 24, 25, and 49. The suction strainer has a pressure drop of 2.80 psi (403 Lb$_f$/ft^2) at 5,000 gpm (11.14 ft^3/sec) and suction water temperature equal to 140^{o}F (Ref. 4, p. 49), which yields a loss coefficient of

$$K_{HPCI,Strainer} = \frac{2 g_C A^2 \Delta P}{\rho Q^2} = \frac{(2)(32.2)\,\text{ft Lb}_m}{\text{Lb}_f\,\text{sec}^2}\left(\frac{1.268\,\text{ft}^2}{1}\right)^2\left(\frac{403\,\text{Lb}_f}{\text{ft}^2}\right)\left(\frac{\text{ft}^3}{61.38\,\text{Lb}_m}\right)\left(\frac{\text{sec}}{11.14\,\text{ft}^3}\right)^2$$

$K_{HPCI,Strainer} = 5.48$ (Based on pipe *ID* = 15.25")

$$\boxed{K'_{5-3} = 5.48 + \frac{(0.0131)(395.6\,\text{ft})}{(1.271\,\text{ft})} = 9.56} \qquad \text{(Based on pipe } ID\text{=15.25")}$$

With regard to the RCIC suppression pool suction path, the loss coefficient K'_{5-4} consists of the suction strainer loss coefficient, $K_{RCIC,Strainer}$, and a loss equivalent to (63.04+7.08+10.11+7.08+12.10+5.01+5.85+7.08+5.42+7.08+64.15+10.11) = 204.11 ft of 6" pipe (ID=6.065" = 0.5054 ft, A=0.2006 ft^2, f=0.0160); see Ref. 5, pp. 26, 27, and 70. The suction strainer has a pressure drop of 0.90 psi (130 Lb_f/ft^2) at 600 gpm (1.34 ft^3/sec) and suction water temperature equal to 140°F (Ref. 5, p. 70), which yields a loss coefficient of

$$K_{RCIC,Strainer} = \frac{2 g_C A^2 \Delta P}{\rho Q^2} = \frac{(2)(32.2)\,\text{ft Lb}_m}{\text{Lb}_f\,\text{sec}^2}\left(\frac{0.2006\,\text{ft}^2}{1}\right)^2\left(\frac{130\,\text{Lb}_f}{\text{ft}^2}\right)\left(\frac{\text{ft}^3}{61.38\,\text{Lb}_m}\right)\left(\frac{\text{sec}}{1.34\,\text{ft}^3}\right)^2$$

$K_{RCIC,Strainer} = 3.06$ (Based on pipe ID = 6.065")

$$\boxed{K'_{5-4} = 3.06 + \frac{(0.0160)(204.11\,\text{ft})}{(0.5054\,\text{ft})} = 9.52}$$ (Based on pipe ID = 6.065")

Loss coefficients for the HPCI and RCIC suction lines are summarized in Table 5-1

Table 5-1
Summary of Loss Coefficients for HPCI and RCIC Suction Pipe

Path	Loss Coefficient	Value
HPCI and RCIC CST suction	K_{1-2}	5.35 (Based on pipe *ID*=19.5")
HPCI CST suction	$K_{2-3} = K'_{2-3} + \frac{891(12D_3)^4}{[C_{V,F004}(t)]^2}$	$K'_{2-3} = 2.16$ (Based on pipe *ID* = 15.25") $D_3 = 1.271$ ft $C_{V,F004}(t) = (20{,}700)(0.9602x^4 - 0.1689x^3$ $-0.1857x^2 + 0.3952x)$ $x = 1 - t/t_{F004}$ for $t \le t_{F004}$ $x = 0$ for $t > t_{F004}$
RCIC CST suction	$K_{2-4} = K'_{2-4} + \frac{891(12D_4)^4}{[C_{V,F010}(t)]^2}$	$K'_{2-4} = 5.20$ (Based on pipe *ID* = 6.065") $D_4 = 0.5054$ ft $C_{V,F010}(t) = (2{,}300)(0.9602x^4 - 0.1689x^3$ $-0.1857x^2 + 0.3952x)$ $x = 1$ for $t \le t_2$ $x = 1 - (t - t_2)/t_{F010}$ for $t_2 < t \le t_2 + t_{F010}$ $x = 0$ for $t > t_2 + t_{F010}$ $t_2 = t_1 + t_{F010}$ t_1 = time (sec) when RCIC CST-to-SP suction transfer set point of 36.0" is reached
HPCI SP suction	$K_{5-3} = K'_{5-3} + \frac{891(12D_3)^4}{[C_{V,F042}(t)]^2}$	$K'_{5-3} = 9.56$ (Based on pipe *ID*=15.25") $D_3 = 1.271$ ft $C_{V,F042}(t) = (20{,}700)(0.9602x^4 - 0.1689x^3$ $-0.1857x^2 + 0.3952x)$ $x = 0 + t/t_{F042}$ for $t \le t_{F042}$ $x = 1$ for $t > t_{F042}$
RCIC SP suction	$K_{5-4} = K'_{5-4} + \frac{891(12D_4)^4}{[C_{V,F031}(t)]^2}$	$K'_{5-4} = 9.52$ (Based on pipe *ID* = 6.065") $D_4 = 0.5054$ ft $C_{V,F031}(t) = (2{,}300)(0.9602x^4 - 0.1689x^3$ $-0.1857x^2 + 0.3952x)$ $x = 0$ for $t \le t_1$ $x = 0 + (t - t_1)/t_{F031}$ for $t_1 < t \le t_1 + t_{F031}$ $x = 1$ for $t > t_1 + t_{F031}$.

5.3 Vortex Limit

Acceptable results are determined by meeting one of two criteria:

1. CST level is at or above 32". This level is higher than the vortex breaker to account for field installation tolerances. With the CST level higher than the vortex breaker, there will be no vortex created in the suction pipe (Ref. 10). See Attachment 4 for validation of this assumption using field test data. Rev. 1

2. CST suction pipe submergence is at or above the onset of air ingestion curve provided in Ref. 16. As described in Ref. 16, the onset of air ingestion curve gives the required submergence of the suction pipe as a function of Froude number. Maintaining suction pipe submergence above the ingestion curve will ensure satisfactory pump operation.

The onset of air ingestion curve (Eqs. 9 and 10 in Ref. 16) is given by

$$S = 2.087(\mathrm{Fr})^{0.670} \quad \text{for } 0 \le \mathrm{Fr} < 0.35$$

$$S = 1.363(\mathrm{Fr})^{0.261} \quad \text{for } 0.35 \le \mathrm{Fr} \le 1.40$$

where

Fr	=	Froude number for 20" CST suction pipe = $V/\sqrt{gD}$,
V	=	CST suction pipe velocity based on the full pipe flow area (ft/sec)
	=	$(Q_{HC} + Q_{RC})/(2.074\,\mathrm{ft}^2)$,
D	=	inside diameter of 20" CST suction pipe = 1.625 ft,
S	=	dimensionless submergence of suction pipe = H/D,
H	=	submergence of pipe entrance measured with respect to the inside bottom of the suction pipe (ft)
	=	$Z_1 - (672.10 + 0.84)\,\mathrm{ft} = Z_1 - 672.94\,\mathrm{ft}$

5.4 Net Positive Suction Head

The NPSHA (Net Positive Suction Head Available) for HPCI and RCIC is computed for case of parallel operation of HPCI CST and suppression pool suction valves. The most restrictive situation occurs when the closure times for the HPCI and RCIC CST suction valves HV1(2)55F004 and HV1(2)49F010 are at their minimum values while the opening times for the suppression pool suction valves HV1(2)55F042 and HV1(2)49F031 are at their maximum values as discussed in §4.1. Rev. 1

5.4.1 HPCI

The NPSHA (ft) for HPCI is calculated as described in FSAR Section 6.3.2.2.1.1.

$$NPSHA = h_S - h_f + h_a - h_{vpa}$$

where h_S is the static head, h_f denotes the friction head, h_a is the atmospheric pressure head, and h_{vpa} is the head equivalent of vapor pressure. In terms of the variables defined in this calculation, the HPCI NPSHA can be calculated as (see Fig. 5-1)

$$NPSHA = \frac{P_3}{\bar{\rho}}\frac{g_C}{g} + 1.75\,\text{ft} - \left[\frac{K_{16"}}{A_{16"}^2} + \frac{K_{14"}}{A_{14"}^2}\right]\frac{(Q_{HC} + Q_{HS})^2}{2g} - h_{vpa} \qquad (8)$$

where

P_3 = pressure at node 3 in Fig. 5-1 (psfa),

$\bar{\rho}$ = flow-weighted density at node 3 = $\dfrac{(\rho_C Q_{HC} + \rho_S Q_{HS})}{Q_{HC} + Q_{HS}}$ (Lb_m/ft^3),

$A_{16"}$ = flow area of 16" HBB107 pipe = $\pi(15.25")^2/4 = 182.65$ in^2 = 1.27 ft^2 (EC-052-0002, Rev. 2, p. 24),

$A_{14"}$ = flow area of 14" HBB107 pipe = $\pi(13.25")^2/4 = 137.89$ in^2 = 0.958 ft^2 (EC-052-0002, Rev. 2, p. 24),

$K_{16"}$ = resistance coefficient for 16" HBB piping in flow path from node 3 to HPCI pump suction,

$K_{14"}$ = resistance coefficient for 14" HBB piping in flow path from node 3 to HPCI pump suction, and

h_{vpa} = vapor pressure of water at HPCI pump inlet (ft).

Other variables in Eq. (8) have been defined previously. Node 3 in Fig. 5-1 corresponds to the pipe junction at the 16"x16"x16" tee shown on Isometric HBB107-1 (Elevation 653'-3"). In Eq. (8), an elevation head of 1.75 ft is added to account for the fact that the HPCI suction piping drops this amount in elevation between node 3 and the pump center line elevation (Ref. HBB107-1). The vapor pressure of the water at the HPCI pump suction is determined by flow weighting the suction flows from the CST and suppression pool as follows:

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$$h_{vpa} = \frac{\left(h_{vpa,C}\,Q_{HC} + h_{vpa,S}\,Q_{HS}\right)}{Q_{HC} + Q_{HS}} \qquad (9)$$

where $h_{vpa,C}$ is the vapor pressure of 100°F CST water (0.94924 psia = 2.2 ft), and $h_{vpa,S}$ is the vapor pressure of 140°F suppression pool water (2.8892 psia = 6.8 ft). From Isometric HBB107-1, the flow resistance terms are

$$K_{16"} = [\text{tee branch}] + [\text{area contraction}] + [90\text{ deg elbow}] + [16"\times 14"\text{ reducer}] + [4'\text{ of }16"\text{ HBB Pipe}]$$

and

$$K_{14"} = [4.4\text{ ft of }14"\text{HBB pipe}]$$

For the 16-inch pipe,

[tee branch] $= 60\text{ f} = 60\times 0.013 = 0.78$ (Ref. 14, pp. A-26 and A-29)

[area contraction] = contraction from two 16" pipes into a single 16" pipe.

$$= \frac{0.5\left(1-\beta^2\right)}{\beta^4} = \frac{(0.5)(1-0.5)}{(0.50)^2} = 1.0$$

$$\beta^2 = \frac{A_1}{A_2} = \frac{1}{2} = 0.50$$

[90 deg elbow] $= 14\text{ f} = 14\times 0.013 = 0.18$

[16"×14" reducer] $= \frac{0.5\left(1-\beta^2\right)}{\beta^4} = \frac{(0.5)(1-0.75)}{(0.75)^2} = 0.22$

$$\beta^2 = \frac{0.958\text{ ft}^2}{1.27\text{ ft}^2} = 0.75$$

[4' of 16" HBB Pipe] = (0.013) (4.0 ft)/ (1.27 ft) = 0.041

$$K_{16"} = 0.78 + 1.0 + 0.18 + 0.22 + 0.041 = 2.2$$

For the 14-inch pipe,

$$K_{14"} = (0.013)(4.4')/(1.104') = 0.052$$

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5.4.2 RCIC

The NPSHA (ft) for RCIC is calculated as described in EC-050-0001, Rev. 2, p. 149.

$$NPSHA = h_S - h_f + h_a - h_{vpa}$$

where h_S is the static head, h_f denotes the friction head, h_a is the atmospheric pressure head, and h_{vpa} is the head equivalent of vapor pressure. In terms of the variables defined in this calculation, the RCIC NPSHA can be calculated as (see Fig. 5-1)

$$NPSHA = \frac{P_4}{\bar{\rho}}\frac{g_C}{g} - \frac{K_{6"}}{A_{6"}^2}\frac{(Q_{RC}+Q_{RS})^2}{2g} - h_{vpa} \qquad (10)$$

where

P_4 = pressure at node 4 in Fig. 5-1 (psfa),

$\bar{\rho}$ = flow-weighted density at node 4 = $\frac{(\rho_C Q_{RC} + \rho_S Q_{RS})}{Q_{RC}+Q_{RS}}$ (Lb_m/ft^3),

$A_{6"}$ = flow area of 6" HBB103 pipe = $\pi(6.065")^2/4 = 28.89\ in^2 = 0.201\ ft^2$ (Ref. 14, 20),

$K_{6"}$ = resistance coefficient for 6" HBB piping in flow path from node 4 to RCIC pump suction,

h_{vpa} = vapor pressure of water at RCIC pump inlet (ft).

Other variables in Eq. (10) have been defined previously. Node 4 in Fig. 5-1 corresponds to the pipe junction at the 6"x6"x6" tee shown on HBB103-1. The node corresponds to elevation 648.7 ft. Isometric HBB103-1 shows that the RCIC pump centerline elevation and the elevation of node 4 are essentially equal; therefore, no elevation correction is included in Eq. (10). The vapor pressure of the water at the RCIC pump suction is determined by flow weighting the suction flows from the CST and suppression pool as follows:

$$h_{vpa} = \frac{(h_{vpa,C}\,Q_{RC} + h_{vpa,S}\,Q_{RS})}{Q_{RC}+Q_{RS}} \qquad (11)$$

where $h_{vpa,C}$ is the vapor pressure of 100°F CST water (0.94924 psia = 2.2 ft), and $h_{vpa,S}$ is the vapor pressure of 140°F suppression pool water (2.8892 psia = 6.8 ft). From Isometric HBB103-1, the flow resistance terms are

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$$K_{6"} = [\text{tee branch}] + [\text{area contraction}] + [90\text{ deg elbow}] + [6"\text{gate valve 150F016}] + [6.5'\text{ of }6"\text{ HBB Pipe}]$$

The individual loss coefficients are computed as follows:

[tee branch] $= 60\ f = 60 \times 0.015 = 0.9$ (Ref. 14, pp. A-26 and A-29)

[area contraction] = contraction from two 6" pipes into a single 6" pipe.

$$= \frac{0.5(1-\beta^2)}{\beta^4} = \frac{(0.5)(1-0.5)}{(0.50)^2} = 1.0$$

$$\beta^2 = \frac{A_1}{A_2} = \frac{1}{2} = 0.50$$

[90 deg elbow] $= 14\ f = 14 \times 0.015 = 0.21$

[6" gate valve] $= 8\ f = 8 \times 0.015 = 0.12$

[6.5' of 6" HBB Pipe] = (0.015) (6.5 ft)/ (0.505 ft) = 0.19

$$K_{6"} = 0.9 + 1.0 + 0.21 + 0.19 \approx 2.5$$

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5.5 *Numerical Solution Method*

Bernoulli Equations (1)-(4) were solved by means of functional iteration with under-relaxation on pressures P_3 and P_4 to support convergence. The mass balance on CST inventory, Eq. 7, was solved with first-order explicit integration with a time step size of 0.1 seconds. The FORTRAN program used to carry out the solution is provided in Attachment 1 and on CD. Sensitivity of the solution to time step size and convergence criterion was investigated and the results are summarized in Table 5-2.

Table 5-2
Sensitivity of Calculation Results to Time Step Size and Convergence Criterion

Case	Time Step (sec)	Convergence Criterion	CST Level (inches) at t = 100 seconds
1	0.1	10^{-7}	31.3109
2	0.1	10^{-6}	31.3109
3	0.5	10^{-7}	31.2937
4	1.0	10^{-7}	31.2733

Results in Table 5-2 show that the numerical error in Case 1 results is on the order of 0.02 inches, which is acceptable. Computer output for Cases 1-4 is included on CD.

5.6 Verification of Results

Computer results for Case 1 are verified by substituting numerical results at a particular time step back into Eqs. (1)-(6) to demonstrate that the governing equations are satisfied (see Attachment 2). An additional peer check of the results is provided in Attachment 3 through comparison of the present calculations against an independently developed Excel spreadsheet model of CST water level response.

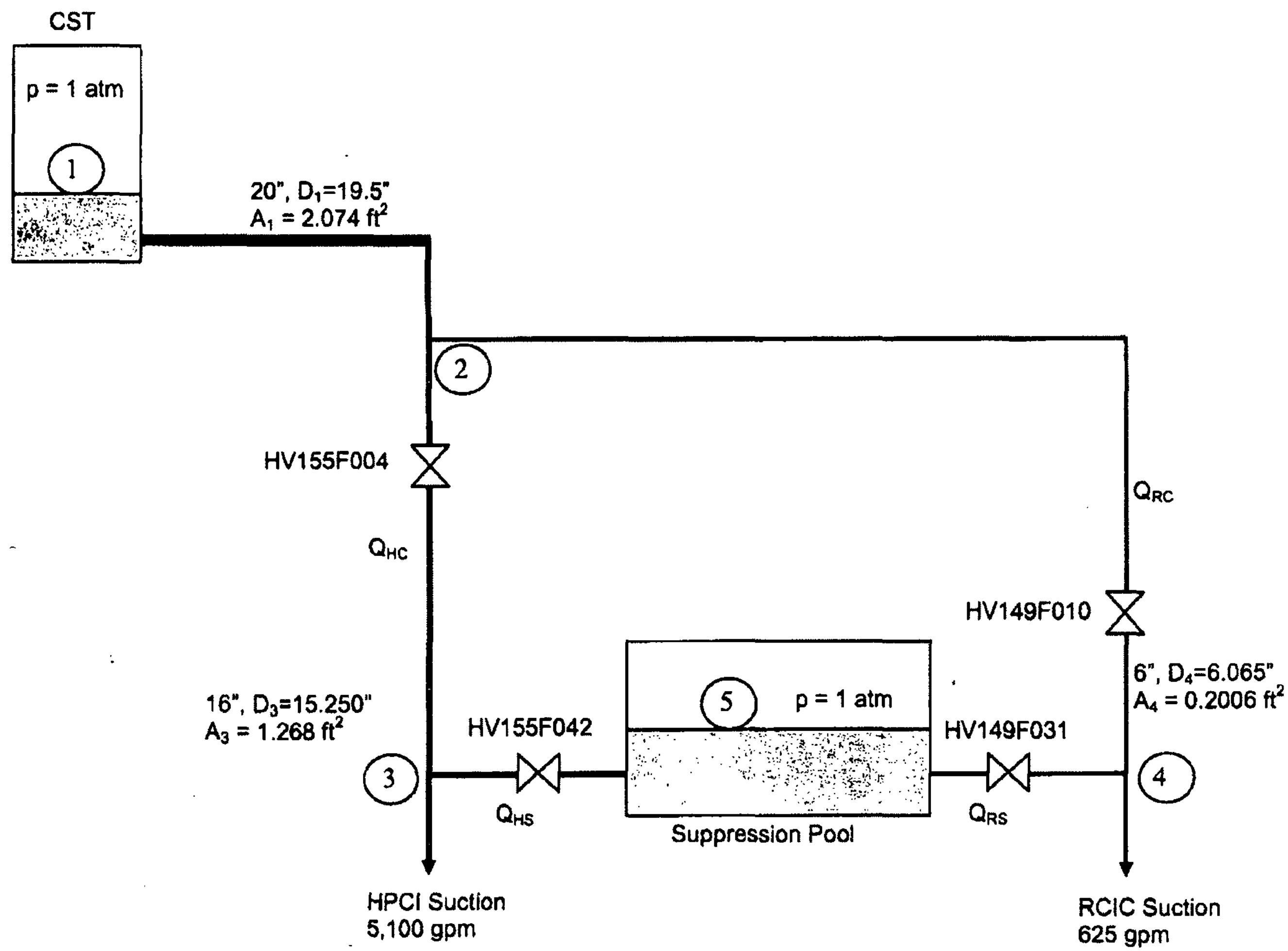

Figure 5-1 Schematic of HPCI and RCIC CST and suppression pool suction flow paths.

6. Results

A computer case summary is provided in Table 6-1. Case 1 is the design case for evaluation of CST vortex formation during transfer of HPCI and RCIC suction from the CST to the suppression pool on low CST water level. Case 5 provides a highly conservative calculation of the NPSHA for HPCI and RCIC pumps during the transfer. As discussed in §5.5, Cases 2 through 4 demonstrate an acceptable level of error in the numerical calculations.

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Calculation results for Case 01 presented in Fig. 6-1 demonstrate that a HPCI suction transfer set point of 40.5 inches maintains adequate HPCI/RCIC pump suction conditions in that CST water level remains above the vortex limit. The vortex limit line is a combination of the two acceptance criteria specified in §5.3. CST level must stay above the vortex limit line at all times in order to satisfy the acceptance criteria of not introducing air into the HPCI/RCIC pump suction line. The specified initial water level in the CST was adjusted to achieve a depletion curve that remained above the vortex limit. The initial CST level that was required is greater than the current technical specification value of 36.0 inches; therefore, a technical specification change will be necessary in order to prevent vortex formation in this application. The computed HPCI and RCIC CST and suppression pool suction flows are shown in Fig. 6-2 and the calculated loss coefficients are plotted in Fig. 6-3 in order to provide indication of valve position. Available NPSH for Case 1 during the transfer is plotted in Fig. 6-4 where it is compared to the NPSH required. As can be seen from Fig. 6-4, there is no reduction in the available margin during the suction transfer for the design case (Case 1).

Case 5 provides a bounding assessment of NPSHA during the HPCI suction transfer. As discussed previously in §4.1, the choice of valve stroke times maximizes pump suction path resistance from the CST and the suppression pool. Results in Fig. 6-6 show that the minimum available margin in NPSHA for HPCI is 25.45 ft – 21.0 ft = 4.5 ft, even in this extreme case. As expected, the minimum in the available margin occurs at the point where the HPCI CST suction valve [HV1(2)55F004] goes closed at 53.6 seconds. At this instant, the HPCI SP suction valve [HV1(2)55F042] is in an intermediate position during its opening stroke of 115 seconds. Suction line elevation head and friction losses are essentially independent of Unit when HPCI suction is aligned to the suppression pool; therefore, the minimum NPSHA margin shown in Fig. 6-6, which was obtained using a Unit 1 hydraulic model (see Assumption 4), applies also to Unit 2 (see Attachment 1 of Ref. 29).

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Table 6-1
Computer Case Summary†

Case	t_{F042} (sec)	t_{F004} (sec)	t_{F031} (sec)	t_{F010} (sec)	Time Step (sec)	Convergence Criterion
	HPCI SP	HPCI CST	RCIC SP	RCIC CST		
1	115	108	44	44	0.1	10^{-7}
2	115	108	44	44	0.1	10^{-6}
3	115	108	44	44	0.5	10^{-7}
4	115	108	44	44	1.0	10^{-7}
5	115	53.6	44	25.5	0.1	10^{-7}

In all Cases, suction transfer set points are 40.5" for HPCI and 36.0" for RCIC. All input and output files are included on CD.

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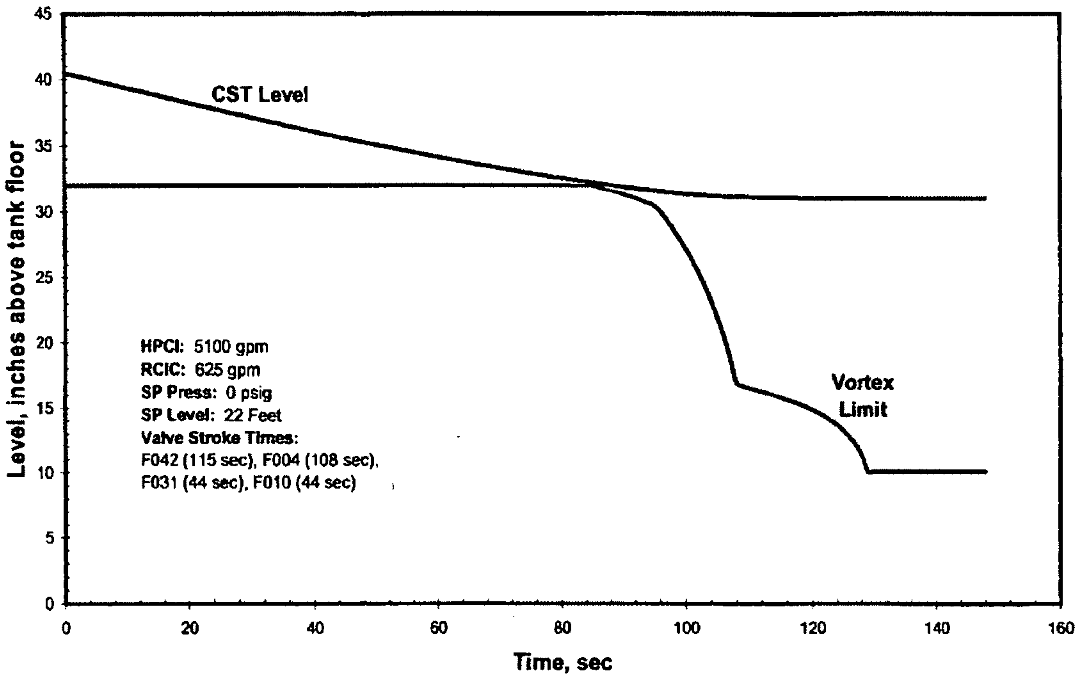

Fig. 6-1 FORTRAN calculation of CST water level vs. vortex limit for **Case 1**. Suction transfer set points are 40.5" for HPCI and 36.0" for RCIC.

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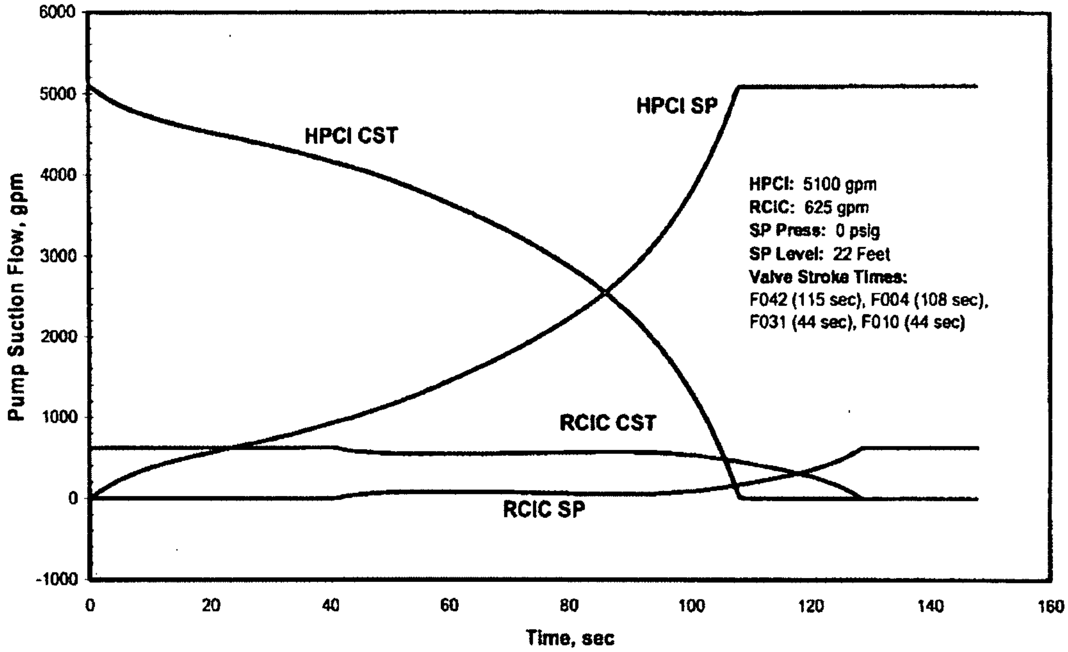

Fig. 6-2 FORTRAN calculation of HPCI and RCIC suction flow for **Case 1**. Suction transfer set points are 40.5" for HPCI and 36.0" for RCIC.

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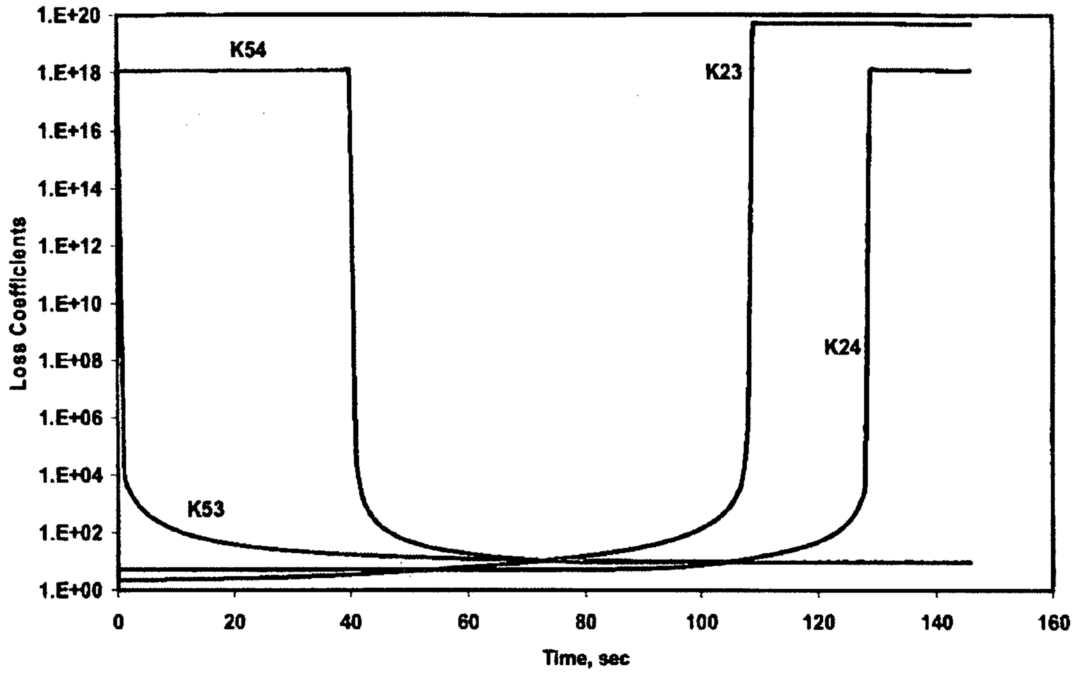

Fig. 6-3 FORTRAN calculation of HPCI and RCIC suction path loss coefficients for **Case 1**. Suction transfer set points are 40.5" for HPCI and 36.0" for RCIC.

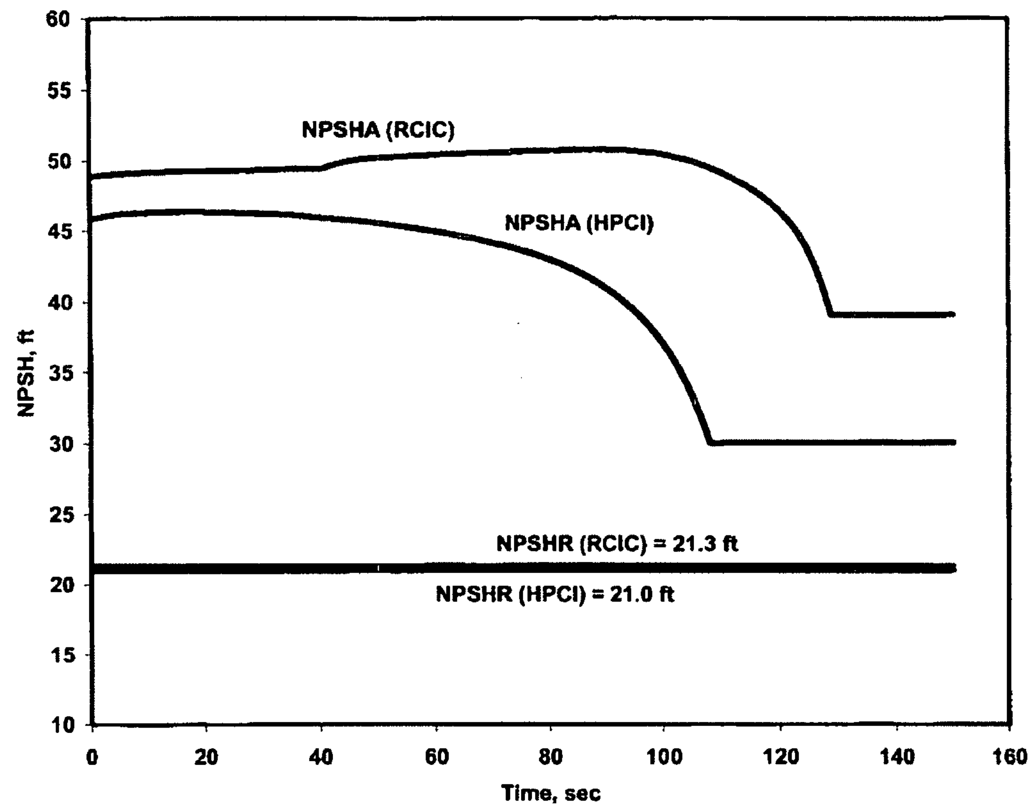

Fig. 6-4 FORTRAN calculation of HPCI and RCIC NPSHA for **Case 1**. Suction transfer set points are 40.5" for HPCI and 36.0" for RCIC.

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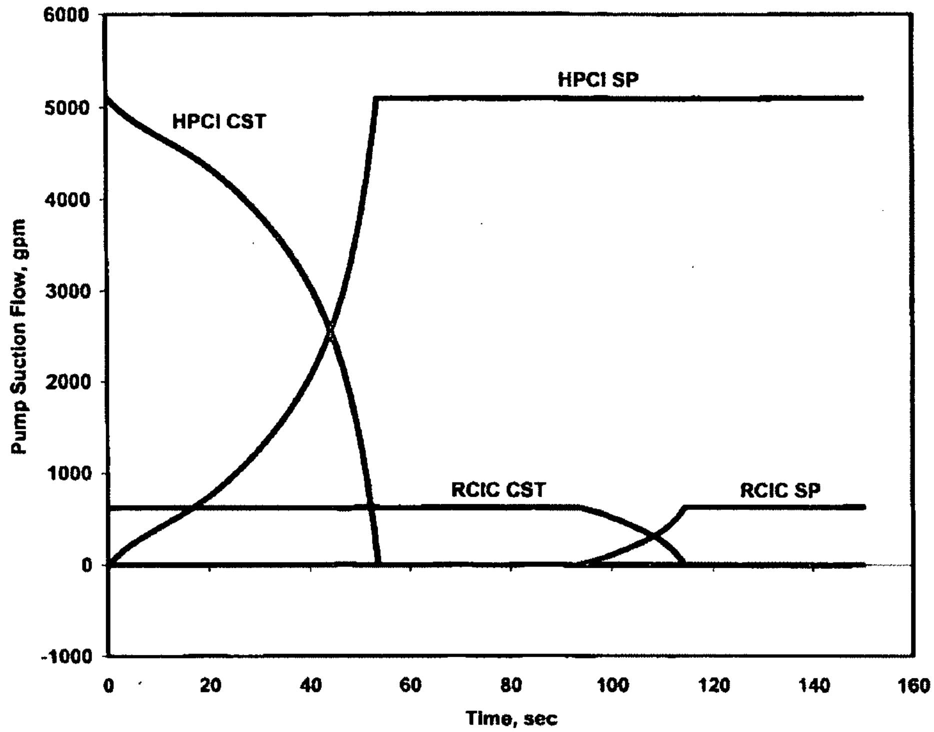

Fig. 6-5 FORTRAN calculation of HPCI and RCIC suction flow for **Case 5**. Suction transfer set points are 40.5" for HPCI and 36.0" for RCIC.

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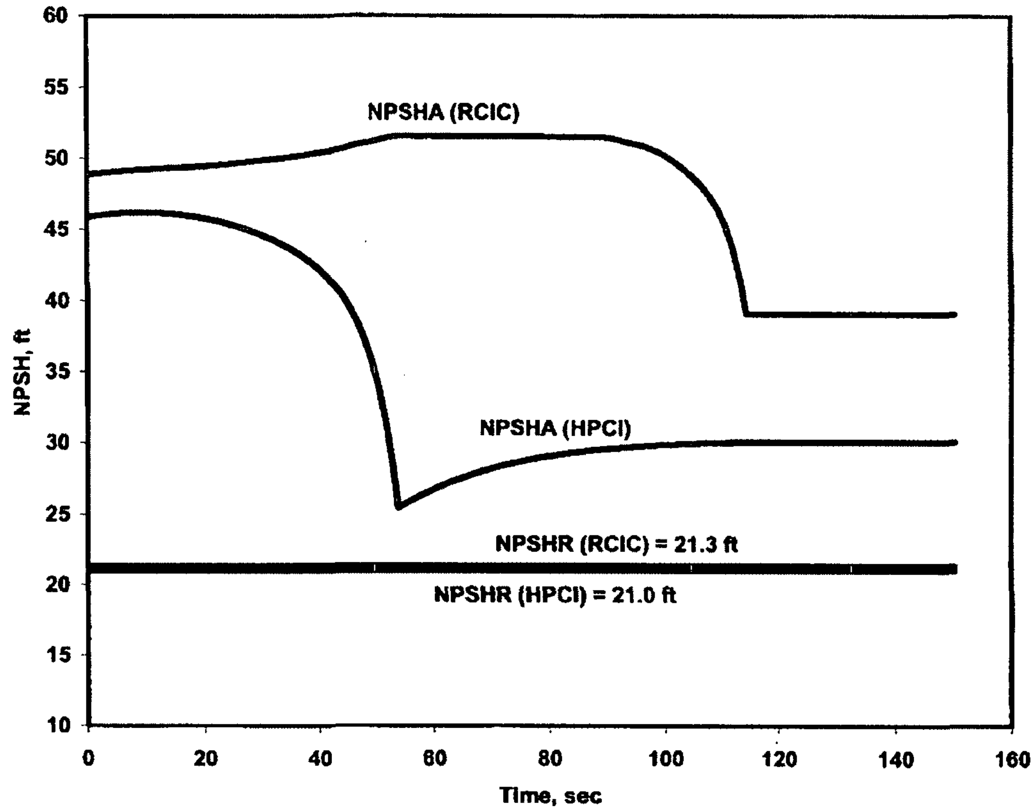

Fig. 6-6 FORTRAN calculation of HPCI and RCIC NPSHA for **Case 5**. Suction transfer set points are 40.5" for HPCI and 36.0" for RCIC.

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7. References

1. Tech Spec 3.6.2.2, "Containment Systems—Suppression Pool Water Level."

2. Technical Specification 3.3.5.2, "Reactor Core Isolation Cooling (RCIC) System Instrumentation," and Table 3.3.5.2-1, "Reactor Core Isolation Cooling System Instrumentation.

3. Calculation EC-VALV-1072, "Actuator Sizing & Diagnostic Test Acceptance Criteria for GL 89-10 DC Rising-Stem MOVs, Rev. 29.

4. Calculation EC-052-0002, "High Pressure Coolant Injection DP Calculations," Rev. 2.

5. Calculation EC-050-0001, "Reactor Core Isolation Cooling Pressure Drop Calculations," Rev. 2.

6. Drawing J-653, Sheet 21, "Level Settings Diagram Condensate Storage Tank 0T522A & 0T522B."

7. Drawing C-1932, Sheet 4, "Reactor Primary Containment Reactor Building Composite Overview," Rev. 0.

8. Drawing HBB107-1, Sheet 1, "Isometric Reactor Building High Pressure Coolant Injection," Rev. 3.

9. Drawing HBB103-1, Sheet 1, "Isometric Reactor Building Reactor Core Isolation Cooling," Rev. 4F6.

10. Calculation EC-037-0013, "Technical Specification Limit For 0T522A," Rev 0.

11. Vendor Drawing FF110120, Sheet 7901, "16-inch, 150-pound Weld Ends Carbon Steel Flex Wedge Gate Valves with SMB-00-7 1/2 Limitorque Operator," Rev. 3.

12. Vendor Drawing FF110120, Sheet 1601, "6-inch 150-pound Weld Ends Pressure Seal Flex Wedge Carbon Steel Gate Valves 1 SMB-000-2 Limitorque Operator Forged," Rev. 6

13. M-108, Sheets 1 & 2, "P&ID Condensate & Refueling Water Storage."

14. Crane Technical paper No. 410, 1982 printing.

15. Calculation EC-052-0500, "Motor Operated Valve Data Detail Calculation for HV255F006," Rev. 14.

16. Sanders, R.R., Smith, L.A., Padmanabhaw, M., Johansson, A., and Hafer, D.R., "Air Entrainment in a Partially Filled Horizontal Pump Suction Line," Proceedings of 2001

International Joint Power Generation Conference, New Orleans, June 4-7, 2001.

17. Technical Specification 3.3.5.1, "Emergency Core Cooling System (ECCS) Instrumentation," and Table 3.3.5.1-1, "Emergency Core Cooling System Instrumentation."

18. FSAR Section 6.3.2.2.1.2, "High Pressure Coolant Injection (HPCI) System—NPSH Available with Suction from the Suppression Pool."

19. FSAR Section 6.3.2.2.1.1, "High Pressure Coolant Injection (HPCI) System—NPSH Available with Suction from the Condensate Storage Tank."

20. M-199, Sheet A, "Piping Class Sheets Summary Sheets & Standards," Rev. 66.

21. Drawing HCB1-2, "Isometric Condensate Storage," Rev. 4F12.

22. Vendor Drawing FF101270, Sheet 3101, "General Plan 30-foot Outside Diameter by 100-foot High Dome Roof Tank," Rev. 8.

23. Vendor Drawing FF101270, Sheet 7901, "General Plan 40 Feet Diameter by 36 Feet High Condensate Storage Tank 0T522A."

24. Drawing M-155, Sheet 1, "P&ID High Pressure Coolant Injection."

25. Drawing M-150, Sheet 1, "P&ID RCIC Turbine Pump."

26. M-149, "P&ID Reactor Core Isolation Cooling."

27. ASME Steam Tables, 5th Edition.

28. Lindeburg, M.R., *Mechanical Engineering Reference Manual*, Professional Publications, Belmont, CA, 2001.

29. EC-059-1036, "Bases for ECCS & RCIC FSAR Net Positive Suction Head Calculations," Rev. 2. Rev. 1

Attachment 1: FORTRAN Program Used to Solve Eqs. in §5.1

```
      IMPLICIT REAL*8(A-H,O-Z)
      REAL*8 k12,k23,k24,k53,k54,k23p,k24p,k53p,k54p
      COMMON /SET1/ a1,a3,a4,acst,cvf042,cvf004,cvf031,cvf010,
     &              d1,d3,d4,efcst,ebcstsp,ebsp,etvb,g,gc,
     &              k12,k23,k24,k53,k54,k23p,k24p,k53p,k54p,
     &              p1,p3,p4,p5,qhc,qhs,qrc,qrs,t1,t2,tf042,
     &              tf004,tf031,tf010,z1,cstL,z3,z4,z5,
     &              rcictr,rhoc,rhos,err0,vxL
C     OPEN (UNIT=5,FILE='c:\documents and settings\hp_owner\my documents
C    &\mark\vortex\cst1.out',STATUS='OLD')
C     OPEN (UNIT=7,FILE='c:\documents and settings\hp_owner\my documents
C    &\mark\vortex\cst2.out',STATUS='OLD')
C     OPEN (UNIT=8,FILE='c:\documents and settings\hp_owner\my documents
C    &\mark\vortex\cst3.out',STATUS='OLD')
C     OPEN (UNIT=9,FILE='c:\documents and settings\hp_owner\my documents
C    &\mark\vortex\cst4.out',STATUS='OLD')
      OPEN (UNIT=5,FILE='cst1.out',STATUS='NEW')
      OPEN (UNIT=7,FILE='cst2.out',STATUS='NEW')
      OPEN (UNIT=8,FILE='cst3.out',STATUS='NEW')
      OPEN (UNIT=9,FILE='cst4.out',STATUS='NEW')

C.... Nomenclature
C     a1      = flow area of 20" common CST suction pipe (ft**2)
C     a3      = flow area of HPCI CST and SP suction pipe at node 3 (ft**2)
C     a4      = flow area of RCIC CST and SP suction pipe at node 4 (ft**2)
C     acst    = free cross-sectional area of cst (ft**2)
C     cstL    = level in CST relative to floor of CST (inches)
C     cvf004  = full-open cv for HV155F004 (gpm)
C     cvf010  = full-open cv for HV149F010 (gpm)
C     cvf042  = full-open cv for HV155F042 (gpm)
C     cvf031  = full-open cv for HV149F031 (gpm)
C     d1      = diameter of 20" CST suction pipe (ft)
C     d3      = diameter of HPCI CST and SP suction piping at node 3 (ft)
C     d4      = diameter of RCIC CST and SP suction piping at node 4 (ft)
C     efcst   = elev at floor of CST (ft)
C     ebcstsp = elevation at inside bottom of CST suction pipe relative
C               to tank floor (ft)
C     ebsp    = elevation at bottom of SP (ft)
C     etvb    = elevation at top of vortex breaker relative to tank floor (ft)
C     g       = acceleration due to gravity (ft/sec**2)
C     gc      = 32.2 ft-Lbm/Lbf-sec**2
C     k12     = friction coeff for path from CST to node 2
C     k23     = friction coeff for path from nodes 2 to 3
C     k24     = friction coeff for path from nodes 2 to 4
C     k53     = friction coeff for path from SP to node 3
C     k54     = friction coeff for path from SP to node 4
C     k23p    = friction coeff for path from nodes 2 to 3 excluding F004 valve
C     k24p    = friction coeff for path from nodes 2 to 4 excluding F010 valve
C     k53p    = friction coeff for path from SP to node 3 excluding F042 valve
C     k54p    = friction coeff for path from SP to node 4 excluding F031 valve
C     p1      = press in CST above water surface (psfa)
C     p3      = press at node 3 (psfa)
C     p4      = press at node 4 (psfa)
C     p5      = press in SP above water surface (psfa)
C     qhc     = HPCI suction flow from CST (ft**3/sec)
C     qhs     = HPCI suction flow from SP (ft**3/sec)
C     qrc     = RCIC suction flow from CST (ft**3/sec)
C     qrs     = RCIC suction flow from SP (ft**3/sec)
C     t       = time (sec)
```

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```
C      t1       = time at which HV149F031 begins to open (sec)
C      t2       = time at which HV149F010 begins to close (sec)
C      tf042    = stroke time (open) for HV155F042 valve (sec)
C      tf004    = stroke time (close) for HV155F004 valve (sec)
C      tf031    = stroke time (open) for HV149F031 valve (sec)
C      tf010    = stroke time (close) for HV149F010 valve (sec)
C      z1       = elevation at water surface in CST (ft)
C      z3       = elevation at node 3 (ft)
C      z4       = elevation at node 4 (ft)
C      z5       = elevation at water surface of SP (ft)
C      rcictr   = RCIC suction transfer setpoint (inches)
C      rhoc     = density of water in CST (Lbm/ft**3)
C      rhos     = density of water in SP (Lbm/ft**3)

C.... I N P U T   D A T A
       a1       =     2.074
       a3       =     1.268
       a4       =     0.2006
       acst     =  1250.0
       cvf042   = 20700.0
       cvf004   = 20700.0
       cvf031   =  2300.0
       cvf010   =  2300.0
       d1       =     1.625
       d3       =     1.271
       d4       =     0.5054
       efcst    =   672.10
       ebcstsp  =     0.84
       ebsp     =   648.0
       etvb     =     2.573
       g        =    32.2
       gc       =    32.2
       k12      =     5.35
       k23p     =     2.16
       k24p     =     5.20
       k53p     =     9.56
       k54p     =     9.52
       p1       =  2116.8
       p5       =  2116.8
       z3       =   653.25
       z4       =   648.7
       z5       =   670.0
       rhos     =    61.38
       rhoc     =    62.00
       rcictr   =    36.0
       tf042    =   115.
       tf031    =    44.
C.... Design Case for Vortex Formation
C      tf004    =   108.
C      tf010    =    44.
C.... Limiting Case for NPSH Evaluation
       tf004    =    53.6
       tf010    =    25.5
C.... specify convergence criterion
       err0 = 1.E-07
C.... specify the time step size (sec)
       dt    = 0.1D0
C.... specify initial CST water level (inches)
       cstL = 40.5
C.... specify initial time, end time, and time step size (sec)
       t     = 0.D0
       tend = 150.0
```

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```
      npr  = DINT( dt/dt )
      np   = 0

C.... Initialize tank level, loss coefficients,flow rates,
C.... and pressures
      k23 = fk23(t)
      k24 = fk24(t)
      k53 = fk53(t)
      k54 = fk54(t)
      z1 = efcst + cstL/12.0
      qhc = 5100./449.
      qrc = 625./449.
      qhs = 0.0
      qrs = 0.0
      p3  = g*z1/gc + p1/rhoc
     &    - g*z3/gc - qhc**2/(2*gc*a3**2)
     &    - k12*(qhc+qrc)**2/(2*gc*a1**2)
     &    - k23*qhc**2/(2*gc*a3**2)
      p3  = p3*rhoc
      p4  = g*z1/gc + p1/rhoc
     &    - g*z4/gc - qrc**2/(2*gc*a4**2)
     &    - k12*(qhc+qrc)**2/(2*gc*a1**2)
     &    - k24*qrc**2/(2*gc*a4**2)
      p4  = p4*rhoc

C.... initialize t1 and t2 (sec)
C     t1 = time at which F031 valve starts to open (sec)
C        = time when CST level drops to allowable value (36.0")
C          for RCIC suction transfer
C        = t at instant when cstL = 36.0
C     t2 = time when F010 valve starts to close (sec)
C        = t1 + tf031 (F010 starts to close when F031 is full open)
      t1 = 1.D+09
      t2 = 1.D+09

C.... set RCIC suction transfer flag
C     irtr = 0 prior to transfer
C     irtr = 1 after transfer
      irtr = 0

C.... print the initial conditions
C.... calculate flows and pressures
      CALL flow(t)
C.... compute vortex limit
      CALL vortex
      WRITE(5,111)
      WRITE(5,113)
      WRITE(5,101) t,cstL,vxL,qhc*449,qhs*449,qrc*449,qrs*449
      WRITE(*,101) t,cstL,vxL,qhc*449,qhs*449,qrc*449,qrs*449
      WRITE(7,115)
      WRITE(7,117)
      WRITE(7,103) t,k12,k23,k24,k53,k54,p3/144.,p4/144.
      WRITE(9,119)
      WRITE(9,120)
  101 FORMAT(3F12.4,4F12.2)
  103 FORMAT(F12.4,1P5E12.4,0P2F12.4)
  105 FORMAT(F12.4,F12.2,5X,F12.2)
  111 FORMAT(8X,'t',9X,'cstL',8X,'vxL',8X,'Qhc',9X,'Qhs',
     &       9X,'Qrc',9X,'Qrs')
  113 FORMAT(7X,'sec',9X,'in',9X,'in',9X,'gpm',9X,'gpm',
     &       9X,'gpm',9X,'gpm')
  115 FORMAT(8X,'t',9X,'K12 ',8X,'K23',8X,'K24',9X,'K53',
     &       9X,'K54',9X,'P3 ',9X,'P4 ')
```

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```
  117 FORMAT(7X,'sec',9X,'  ',9X,'  ',9X,'   ',9X,'   ',
     &       9X,'   ',9X,'psia',8X,'psia')
  119 FORMAT(8X,'t',5X,'NPSHA_HPCI',9X,'NPSHA_RCIC')
  120 FORMAT(8X,'sec',5X,'  (ft)            (ft)  ')


   20 CONTINUE
C.... Calculate the hpci and rcic flows and pressures p3, p4
      CALL flow(t)

C.... Integrate the CST mass balance
      z1 = z1 - dt*( qhc + qrc )/acst
      t  = t + dt
      cstL = (z1-efcst)*12.

C.... check if RCIC suction transfer should initiate
      IF ( cstL .LT. rcictr .AND. irtr .EQ. 0 ) THEN
        t1   = t
        t2   = t1 + tf031
        irtr = 1
        WRITE(8,151) t1
        WRITE(8,153) t2
  151   FORMAT(' t1(sec) = ', F15.5,3X,'F031 begins to open' )
  153   FORMAT(' t2(sec) = ', F15.5,3X,'F010 begins to close' )
      END IF


C.... print the results
      CALL vortex
      CALL hnpsh(t,hnpsha)
      CALL rnpsh(t,rnpsha)
      np = np + 1
      IF ( np .EQ. npr ) THEN
      IF ( vxL .GE. cstL ) THEN
        PAUSE 'CST level less than Vortex Limit--STOP'
        STOP
      END IF
      WRITE(5,101) t,cstL,vxL,qhc*449,qhs*449,qrc*449,qrs*449
      WRITE(*,101) t,cstL,vxL,qhc*449,qhs*449,qrc*449,qrs*449
      WRITE(7,103) t,k12,k23,k24,k53,k54,p3/144.,p4/144.
      WRITE(9,105) t,hnpsha,rnpsha
      np = 0
      END IF

      IF ( t .LT. tend ) GOTO 20
      STOP
      END



      SUBROUTINE flow(t)
      IMPLICIT REAL*8(A-H,O-Z)
      REAL*8 k12,k23,k24,k53,k54,k23p,k24p,k53p,k54p
      COMMON /SET1/ a1,a3,a4,acst,cvf042,cvf004,cvf031,cvf010,
     &              d1,d3,d4,efcst,ebcstsp,ebsp,etvb,g,gc,
     &              k12,k23,k24,k53,k54,k23p,k24p,k53p,k54p,
     &              p1,p3,p4,p5,qhc,qhs,qrc,qrs,t1,t2,tf042,
     &              tf004, tf031,tf010,z1,cstL,z3,z4,z5,
     &              rcictr,rhoc,rhos,err0,vxL

      KOUNT = 0
   10 CONTINUE
C.... calculate time-dependent loss coeff k23, k24, k53, and k54
```

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```
      k23 = fk23(t)
      k24 = fk24(t)
      k53 = fk53(t)
      k54 = fk54(t)
      KOUNT = KOUNT + 1
      IF ( KOUNT .GT. 1500 ) THEN
C....    WRITE(*,*) KOUNT,qrs
      END IF
      IF ( KOUNT .GT. 75000 ) THEN
        PAUSE 'iter failed in flow--STOP'
        STOP
      END IF

C.... save p3 and p4 in order to apply under-relaxation
      y2 = qhc
      y3 = qrc
      y4 = qhs
      y5 = qrs
      y6 = p3
      y7 = p4


C.... check size of k's to maintain stable interation scheme
      IF ( k53 .GE. k23 ) THEN
C....    calc qhs from Eq. 3
         qhs = g*(z5-z3)/gc + (p5-p3)/rhos
         qhs = qhs*(2*gc*a3**2)/(1.D0+k53)
         qhs = DSQRT(qhs)
C....    calc qhc from Eq. 5
         qhc = 5100./449. - qhs
C....    calculate p3 from Eq. 1
         p3 = g*(z1-z3)/gc + p1/rhoc
     &       - qhc**2/(2*gc*a3**2)
     &       - k12*(qhc+qrc)**2/(2*gc*a1**2)
     &       - k23*qhc**2/(2*gc*a3**2)
         p3 = p3*rhoc
      ELSE IF ( k53 .LT. k23 ) THEN
C....    calc qhc from Eq. 1
         qhc = g*(z1-z3)/gc + (p1-p3)/rhoc
     &        - k12*(qhc+qrc)**2/(2*gc*a1**2)
         qhc = qhc*(2*gc*a3**2)/(1+k23)
         qhc = DSQRT(qhc)
C....    calc qhs from Eq. 5
         qhs = 5100./449. - qhc
C....    calc p3 from Eq. 3
         p3 = g*(z5-z3)/gc + p5/rhos
     &       - (1.D0+k53)*qhs**2/(2*gc*a3**2)
         p3 = p3*rhos
      END IF

      IF ( k54 .GT. k24 ) THEN
C....    calc qrs from Eq. 4
C.... Look for solution with qrs > 0
         qrs = g*(z5-z4)/gc + (p5-p4)/rhos
         qrs = qrs*(2*gc*a4**2)/(1.D0+k54)
        IF ( qrs .LT. 0.D0 ) THEN
          k54 = fk54(t)
           qrs = g*(z5-z4)/gc + (p5-p4)/rhos
           qrs = qrs*(2*gc*a4**2)/(1.D0-k54)
          qrs = -DSQRT(qrs)
          GOTO 50
         END IF
         qrs = DSQRT(qrs)
```

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```
   50     CONTINUE
C....     calc qrc from Eq. 6
          qrc = 625./449. - qrs
C....     calculate p4 from Eq. 2
          p4 = g*(z1-z4)/gc + p1/rhoc
     &        - qrc**2/(2*gc*a4**2)
     &        - k12*(qhc+qrc)**2/(2*gc*a1**2)
     &        - k24*qrc**2/(2*gc*a4**2)
          p4 = p4*rhoc
       ELSE IF ( k54 .LE. k24 ) THEN
C....     calc qrc from Eq. 2
          qrc = g*(z1-z4)/gc + (p1-p4)/rhoc
     &          - k12*(qhc+qrc)**2/(2*gc*a1**2)
          qrc = qrc*(2*gc*a4**2)/(1.D0+k24)
          qrc = DSQRT(qrc)
C....     calc qrs from Eq. 6
          qrs = 625./449. - qrc
C....     calc p4 from Eq. 4
          p4 = g*(z5-z4)/gc + p5/rhos
     &        - 1.D0*qrs**2/(2*gc*a4**2)
     &        - k54*qrs*DABS(qrs)/(2*gc*a4**2)
          p4 = p4*rhos
        ELSE
       END IF

C.... compute the error
      err = ferr(t)

C.... apply under-relaxation
      IF ( err .GT. err0 ) THEN
           ep = 5.E-04
         qhc = ep*qhc + (1.D0-ep)*y2
         qrc = ep*qrc + (1.D0-ep)*y3
         qhs = ep*qhs + (1.D0-ep)*y4
         qrs = ep*qrs + (1.D0-ep)*y5
          p3 = ep*p3 + (1.D0-ep)*y6
         p4 = ep*p4 + (1.D0-ep)*y7
         GOTO 10
      END IF
C.... Solution has converged--return to Main
      RETURN
      END


      FUNCTION ferr(t)
C.... computes rms error for governing equations
      IMPLICIT REAL*8(A-H,O-Z)
      REAL*8 k12,k23,k24,k53,k54,k23p,k24p,k53p,k54p
      COMMON /SET1/ a1,a3,a4,acst,cvf042,cvf004,cvf031,cvf010,
     &              d1,d3,d4,efcst,ebcstsp,ebsp,etvb,g,gc,
     &              k12,k23,k24,k53,k54,k23p,k24p,k53p,k54p,
     &              p1,p3,p4,p5,qhc,qhs,qrc,qrs,t1,t2,tf042,
     &              tf004,tf031,tf010,z1,cstL,z3,z4,z5,
     &              rcictr,rhoc,rhos,err0,vxL
C.... Equation 1
      er1 = g*z1/gc
     &    + p1/rhoc
     &    - g*z3/gc
     &    - p3/rhoc
     &          - qhc**2/(2*gc*a3**2)
     &    - k12*(qhc+qrc)**2/(2*gc*a1**2)
     &    - k23*qhc**2/(2*gc*a3**2)
C.... Equation 2
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```
      er2 = g*z1/gc
     &     + p1/rhoc
     &     - g*z4/gc
     &     - p4/rhoc
     &     - qrc**2/(2*gc*a4**2)
     &     - k12*(qhc+qrc)**2/(2*gc*a1**2)
     &     - k24*qrc**2/(2*gc*a4**2)
C.... Equation 3
      er3 = g*z5/gc
     &     + p5/rhos
     &     - g*z3/gc
     &     - p3/rhos
     &     - qhs**2/(2*gc*a3**2)
     &     - k53*qhs**2/(2*gc*a3**2)
C.... Equation 4
      er4 = g*z5/gc
     &     + p5/rhos
     &     - g*z4/gc
     &     - p4/rhos
     &     - qrs**2/(2*gc*a4**2)
     &     - k54*qrs*DABS(qrs)/(2*gc*a4**2)
C.... Equation 5
      er5 = qhc + qhs - 5100./449.
C.... Equation 6
      er6 = qrc + qrs - 625./449.
      ferr =DSQRT( (er1**2 + er2**2 + er3**2
     &      + er4**2 + er5**2 + er6**2)/6.D0 )
      RETURN
      END


      FUNCTION fk23(t)
      IMPLICIT REAL*8(A-H,O-Z)
      REAL*8 k12,k23,k24,k53,k54,k23p,k24p,k53p,k54p
      COMMON /SET1/ a1,a3,a4,acst,cvf042,cvf004,cvf031,cvf010,
     &              d1,d3,d4,efcst,ebcstsp,ebsp,etvb,g,gc,
     &              k12,k23,k24,k53,k54,k23p,k24p,k53p,k54p,
     &              p1,p3,p4,p5,qhc,qhs,qrc,qrs,t1,t2,tf042,
     &              tf004,tf031,tf010,z1,cstL,z3,z4,z5,
     &              rcictr,rhoc,rhos,err0,vxL
C.... F004 valve starts to close at t=0
C.... and is fully closed at t=tf004
      IF ( t .LE. tf004 ) THEN
         x = 1.D0 - t/tf004
      ELSE
        x = 0.D0
      END IF
      cv = cvf004*( 0.9602*x**4 - 0.1689*x**3
     &   - 0.1857*x**2 + 0.3952*x )
      cv = DMAX1( cv, 1.D-06 )
      k23 = k23p + 891.*(12.*d3)**4/cv**2
      fk23 = k23
      RETURN
      END


      FUNCTION fk24(t)
      IMPLICIT REAL*8(A-H,O-Z)
      REAL*8 k12,k23,k24,k53,k54,k23p,k24p,k53p,k54p
      COMMON /SET1/ a1,a3,a4,acst,cvf042,cvf004,cvf031,cvf010,
     &              d1,d3,d4,efcst,ebcstsp,ebsp,etvb,g,gc,
     &              k12,k23,k24,k53,k54,k23p,k24p,k53p,k54p,
     &              p1,p3,p4,p5,qhc,qhs,qrc,qrs,t1,t2,tf042,
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     &              tf004,tf031,tf010,z1,cstL,z3,z4,z5,
     &              rcictr,rhoc,rhos,err0,vxL
C.... F010 valve starts to close at t=t2 and is fully
C.... closed at t=t2+tf010
      IF ( t .LE. t2 ) THEN
        x = 1.D0
      ELSE IF ( t .GT. t2 .AND. t .LE. t2+tf010 ) THEN
          x = 1.D0 - (t-t2)/tf010
      ELSE IF ( t .GT. t2+tf010 ) THEN
        x = 0.D0
      END IF
      cv  = cvf010*( 0.9602*x**4 - 0.1689*x**3
     &    - 0.1857*x**2 + 0.3952*x )
      cv  = DMAX1( cv, 1.D-06 )
      k24 = k24p + 891.*(12.*d4)**4/cv**2
      fk24= k24
      RETURN
      END


      FUNCTION fk53(t)
      IMPLICIT REAL*8(A-H,O-Z)
      REAL*8 k12,k23,k24,k53,k54,k23p,k24p,k53p,k54p
      COMMON /SET1/ a1,a3,a4,acst,cvf042,cvf004,cvf031,cvf010,
     &              d1,d3,d4,efcst,ebcstsp,ebsp,etvb,g,gc,
     &              k12,k23,k24,k53,k54,k23p,k24p,k53p,k54p,
     &              p1,p3,p4,p5,qhc,qhs,qrc,qrs,t1,t2,tf042,
     &              tf004,tf031,tf010,z1,cstL,z3,z4,z5,
     &              rcictr,rhoc,rhos,err0,vxL
C.... F042 valve starts to open at t=0 and is
C.... fully open at tf042
      IF ( t .LE. tf042 ) THEN
          x = 0.D0 + t/tf042
      ELSE
        x = 1.D0
      END IF
      cv = cvf042*( 0.9602*x**4 - 0.1689*x**3
     &    - 0.1857*x**2 + 0.3952*x )
      cv = DMAX1( cv, 1.D-06 )
      k53 = k53p + 891.*(12.*d3)**4/cv**2
      fk53 = k53
      RETURN
      END


      FUNCTION fk54(t)
      IMPLICIT REAL*8(A-H,O-Z)
      REAL*8 k12,k23,k24,k53,k54,k23p,k24p,k53p,k54p
      COMMON /SET1/ a1,a3,a4,acst,cvf042,cvf004,cvf031,cvf010,
     &              d1,d3,d4,efcst,ebcstsp,ebsp,etvb,g,gc,
     &              k12,k23,k24,k53,k54,k23p,k24p,k53p,k54p,
     &              p1,p3,p4,p5,qhc,qhs,qrc,qrs,t1,t2,tf042,
     &              tf004,tf031,tf010,z1,cstL,z3,z4,z5,
     &              rcictr,rhoc,rhos,err0,vxL
C.... F031 valve starts to open at t=t1 and is fully
C.... open at t=t1+tf031
      IF ( t .LE. t1 ) THEN
        x = 0.D0
      ELSE IF ( t .GT. t1 .AND. t .LE. t1+tf031 ) THEN
          x = 0.D0 + (t-t1)/tf031
      ELSE IF ( t .GT. t1+tf031 ) THEN
        x = 1.D0
      END IF
```

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```
      cv = cvf031*( 0.9602*x**4 - 0.1689*x**3
     &   - 0.1857*x**2 + 0.3952*x )
      cv = DMAX1( cv, 1.D-06 )
      k54 = k54p + 891.*(12.*d4)**4/cv**2
      fk54 = k54
C.... If reverse flow in RCIC SP suction line add large
C.... resistance to simulate closure of check valve 149F030
      IF ( qrs .LT. 0.D0 ) fk54 = k54 + 1.D+12
      RETURN
      END


      SUBROUTINE vortex
      IMPLICIT REAL*8(A-H,O-Z)
      REAL*8 k12,k23,k24,k53,k54,k23p,k24p,k53p,k54p
      COMMON /SET1/ a1,a3,a4,acst,cvf042,cvf004,cvf031,cvf010,
     &              d1,d3,d4,efcst,ebcstsp,ebsp,etvb,g,gc,
     &              k12,k23,k24,k53,k54,k23p,k24p,k53p,k54p,
     &              p1,p3,p4,p5,qhc,qhs,qrc,qrs,t1,t2,tf042,
     &              tf004,tf031,tf010,z1,cstL,z3,z4,z5,
     &              rcictr,rhoc,rhos,err0,vxL
C.... compute the vortex limit
      Fr = ( (qhc+qrc)/a1 )/DSQRT(g*d1)
      IF ( Fr .GE. 0.D0 .AND. Fr .LT. 0.35D0 ) THEN
         s = 2.087*Fr**(0.670)
         hh = s*d1
         vxL = (hh + 672.94 - efcst)*12.
         vxL = DMIN1( vxL, 32.D0 )
      ELSE IF ( Fr .GE. 0.35D0 .AND. Fr .LE. 1.40D0 ) THEN
         s = 1.363*Fr**(0.261)
         hh = s*d1
         vxL = (hh + 672.94 - efcst)*12.
         vxL = DMIN1( vxL, 32.D0 )
      ELSE
         vxL = 32.0
        write(*,*) Fr
         PAUSE 'froude # out of range--STOP'
        STOP
      END IF
      RETURN
      END


      SUBROUTINE hnpsh(t,hnpsha)
      IMPLICIT REAL*8(A-H,O-Z)
      REAL*8 k12,k23,k24,k53,k54,k23p,k24p,k53p,k54p
      COMMON /SET1/ a1,a3,a4,acst,cvf042,cvf004,cvf031,cvf010,
     &              d1,d3,d4,efcst,ebcstsp,ebsp,etvb,g,gc,
     &              k12,k23,k24,k53,k54,k23p,k24p,k53p,k54p,
     &              p1,p3,p4,p5,qhc,qhs,qrc,qrs,t1,t2,tf042,
     &              tf004, tf031,tf010,z1,cstL,z3,z4,z5,
     &              rcictr,rhoc,rhos,err0,vxL
      rhobar = (rhoc*qhc + rhos*qhs)/(qhc + qhs )
      hvpac = 2.2
      hvpas = 6.8
      hvpa   = (hvpac*qhc + hvpas*qhs)/(qhc + qhs )
      a16 = 1.27
      a14 = 0.958
      ak16 = 2.2
      ak14 = 0.052
      hnpsha = p3/rhobar
     &       + 1.75
     &       - ( ak16/A16**2 + ak14/A14**2 )
```

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```
&        * ( ( qhc + qhs )**2 )/(2*g)
&        - hvpa
 RETURN
 END


 SUBROUTINE rnpsh(t,rnpsha)
 IMPLICIT REAL*8(A-H,O-Z)
 REAL*8 k12,k23,k24,k53,k54,k23p,k24p,k53p,k54p
 COMMON /SET1/ a1,a3,a4,acst,cvf042,cvf004,cvf031,cvf010,
&              d1,d3,d4,efcst,ebcstsp,ebsp,etvb,g,gc,
&              k12,k23,k24,k53,k54,k23p,k24p,k53p,k54p,
&              p1,p3,p4,p5,qhc,qhs,qrc,qrs,t1,t2,tf042,
&              tf004, tf031,tf010,z1,cstL,z3,z4,z5,
&              rcictr,rhoc,rhos,err0,vxL
 rhobar = (rhoc*qrc + rhos*qrs)/(qrc + qrs )
 hvpac = 2.2
 hvpas = 6.8
 hvpa   = (hvpac*qrc + hvpas*qrs)/(qrc + qrs )
 a6 = 0.201
 ak6 = 2.5
 rnpsha = p4/rhobar
&        - ( ak6/A6**2 )*( ( qrc + qrs )**2 )/(2*g)
&        - hvpa
 RETURN
 END
```

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Attachment 2: Verification of FORTRAN Results

Calculations for Case 1 are verified by substituting numerical results at a particular time (t=100 sec) back into Eqs. (1)-(6) to demonstrate that the governing equations are satisfied. From the FORTRAN output for Case 01 included on CD, the CST level and the HPCI and RCIC suction flows at t=100 seconds are (Note: because temporal integration is first-order explicit, FORTRAN output at any particular time actually corresponds to the indicated time minus one time step except for CST water level which corresponds to the actual indicated time.)

CST Level = 31.3109 inches
CST Level at previous time step = 31.3149 inches

HPCI suction from CST =	1324.8012 gpm =	2.95056 ft^3/sec
HPCI suction from SP =	3775.1990 gpm =	8.40802 ft^3/sec
RCIC suction from CST =	537.0097 gpm =	1.19601 ft^3/sec
RCIC suction from SP =	87.9903 gpm =	0.195969 ft^3/sec

$A_C = 1{,}250\ ft^2$
P_3 = 18.6864 psia = 2690.84 psfa
P_4 = 23.7112 psia = 3414.41 psfa
$K_{1\text{-}2}$ = 5.3500E+00
$K_{2\text{-}3}$ = 1.4016E+02
$K_{2\text{-}4}$ = 7.6021E+00
$K_{5\text{-}3}$ = 9.8354E+00
$K_{5\text{-}4}$ = 9.7475E+00
t_1 = 40.70000 sec
dt = 0.1 sec (time step)
Z_1 = 672.10 ft + (31.3109 inches)/12.0 = 674.7092 ft
Z_1 = 672.10 ft + (31.3149 inches)/12.0 = 674.7096 ft (at previous time step)

Other input data consist of
P_1 = 2116.8 psfa
P_5 = 2116.8 psfa
$A_1 = 2.074\ ft^2$
$A_3 = 1.268\ ft^2$
$K_{1-2} = 5.35$

$$K_{2-3} = 2.16 + \frac{891(12\,x1.271)^4}{\left[C_{V,F004}(t)\right]^2}$$

$$x_{F004} = 1 - t/108\text{sec for } t \le 108\text{sec}$$

$$x_{F004} = 1 - 99.9/108 = 0.075$$

$$C_{V,F004}(t) = (20{,}700)[0.9602(0.075)^4 - 0.1689(0.075)^3 - 0.1857(0.075)^2 + 0.3952(0.075)]$$

$$C_{V,F004}(t) = 591.079$$

$$K_{2-3} = 2.16 + \frac{891(12\,x1.271)^4}{[591.079]^2} = 140.165$$

$$K_{2-4} = 5.20 + \frac{891(12\,\text{x}0.5054)^4}{\left[C_{V,F010}(t)\right]^2}$$

$$t_2 = t_1 + 44\,\text{sec} = 40.7 + 44 = 84.7\,\text{sec}$$

$$x = 1 - (t - t_2)/44\,\text{sec for } 0 < t - t_2 \le 44\,\text{sec}$$

$$x = 1 - (99.9 - 84.7)/44 = 0.6545$$

$$C_{V,F010}(t) = (2{,}300)[0.9602(0.6545)^4 - 0.1689(0.6545)^3 - 0.1857(0.6545)^2 + 0.3952(0.6545)] = 708.293$$

$$K_{2-4} = 5.20 + \frac{891(12\,\text{x}0.5054)^4}{[708.293]^2} = 7.6028$$

$$K_{5-3} = 9.56 + \frac{891(12\,\text{x}1.271)^4}{\left[C_{V,F042}(t)\right]^2}$$

$$x = 0 + t/115\,\text{sec for } t \le 115\,\text{sec}$$

$$x = 0 + 99.9/115 = 0.86870$$

$$C_{V,F042}(t) = (20{,}700)[0.9602(0.86870)^4 - 0.1689(0.86870)^3 - 0.1857(0.86870)^2 + 0.3952(0.86870)]$$

$$C_{V,F042}(t) = 13232.81$$

$$K_{5-3} = 9.56 + \frac{891(12\,\text{x}1.271)^4}{[13232.81]^2} = 9.8353$$

$$K_{5-4} = 9.52 + \frac{891(12\,\text{x}0.5054)^4}{\left[C_{V,F031}(t)\right]^2}$$

$$x = 1 \text{ for } t - t_1 > 44\,\text{sec}$$

$$C_{V,F031}(t) = (2{,}300)\left[0.9602(1)^4 - 0.1689(1)^3 - 0.1857(1)^2 + 0.3952(1)\right]$$

$$C_{V,F031}(t) = 2301.84$$

$$K_{5-4} = 9.52 + \frac{891(12\,\text{x}0.5054)^4}{[2301.84]^2} = 9.7475$$

<u>Check of Eq. (1)</u>:

$$\left(\frac{g}{g_C} Z_1 + \frac{P_1}{\rho_C}\right) - \left(\frac{g}{g_C} Z_3 + \frac{P_3}{\rho_C} + \frac{Q_{HC}^2}{2 g_C A_3^2}\right) - K_{1-2} \frac{(Q_{HC} + Q_{RC})^2}{2 g_C A_1^2} - K_{2-3} \frac{Q_{HC}^2}{2 g_C A_3^2} = 0$$

$$\left(\frac{g}{g_C} Z_1 + \frac{P_1}{\rho_C}\right) = 674.7096 + \frac{2116.8}{62.00} = 708.8515$$

$$\left(\frac{g}{g_C} Z_3 + \frac{P_3}{\rho_C} + \frac{Q_{HC}^2}{2 g_C A_3^2}\right) = 653.25 + \frac{2690.84}{62.00} + \frac{(2.95056)^2}{(2)(32.2)(1.268)^2} = 696.7347$$

$$K_{1-2}\frac{(Q_{HC}+Q_{RC})^2}{2g_C A_1^2}=(5.35)\frac{(2.95056+1.19601)^2}{(2)(32.2)(2.074)^2}=0.332069$$

$$K_{2-3}\frac{Q_{HC}^2}{2g_C A_3^2}=(140.165)\frac{(2.95056)^2}{(2)(32.2)(1.268)^2}=11.78485$$

708.8515 – 696.7347 – 0.332069 – 11.78485 = –0.0001 (Eq. 1 is satisfied)

Check of Eq. (2):

$$\left(\frac{g}{g_C}Z_1+\frac{P_1}{\rho_C}\right)-\left(\frac{g}{g_C}Z_4+\frac{P_4}{\rho_C}+\frac{Q_{RC}^2}{2g_C A_4^2}\right)-K_{1-2}\frac{(Q_{HC}+Q_{RC})^2}{2g_C A_1^2}-K_{2-4}\frac{Q_{RC}^2}{2g_C A_4^2}=0$$

$$\left(\frac{g}{g_C}Z_1+\frac{P_1}{\rho_C}\right)=674.7096+\frac{2116.8}{62.00}=708.8515$$

$$\left(\frac{g}{g_C}Z_4+\frac{P_4}{\rho_C}+\frac{Q_{RC}^2}{2g_C A_4^2}\right)=648.7+\frac{3414.41}{62.00}+\frac{(1.19601)^2}{(2)(32.2)(0.2006)^2}=704.3231$$

$$K_{1-2}\frac{(Q_{HC}+Q_{RC})^2}{2g_C A_1^2}=(5.35)\frac{(2.95056+1.19601)^2}{(2)(32.2)(2.074)^2}=0.332069$$

$$K_{2-4}\frac{Q_{RC}^2}{2g_C A_4^2}=7.6028\frac{(1.19601)^2}{(2)(32.2)(0.2006)^2}=4.19658$$

708.8515–704.3231–0.332069–4.19658 = -0.00025 (Eq. 2 is satisfied)

Check of Eq. (3):

$$\left(\frac{g}{g_C}Z_5+\frac{P_5}{\rho_S}\right)-\left(\frac{g}{g_C}Z_3+\frac{P_3}{\rho_S}+\frac{Q_{HS}^2}{2g_C A_3^2}\right)-K_{5-3}\frac{Q_{HS}^2}{2g_C A_3^2}=0$$

$$\left(\frac{g}{g_C}Z_5+\frac{P_5}{\rho_S}\right)=670+\frac{2116.8}{61.38}=704.4868$$

$$\left(\frac{g}{g_C}Z_3+\frac{P_3}{\rho_S}+\frac{Q_{HS}^2}{2g_C A_3^2}\right)=653.25+\frac{2690.84}{61.38}+\frac{(8.40802)^2}{(2)(32.2)(1.268)^2}=697.7718$$

$$K_{5-3}\frac{Q_{HS}^2}{2g_C A_3^2}=(9.8353)\frac{(8.40802)^2}{(2)(32.2)(1.268)^2}=6.71507$$

704.4868–697.7718–6.71507 = –0.00007 (Eq. 3 is satisfied)

Check of Eq. (4):

$$\left(\frac{g}{g_C}Z_5+\frac{P_5}{\rho_S}\right)-\left(\frac{g}{g_C}Z_4+\frac{P_4}{\rho_S}+\frac{Q_{RS}^2}{2g_C A_4^2}\right)-K_{5-4}\frac{Q_{RS}^2}{2g_C A_4^2}=0$$

$$\left(\frac{g}{g_C}Z_5+\frac{P_5}{\rho_S}\right)=670+\frac{2116.8}{61.38}=704.4868$$

$$\left(\frac{g}{g_C}Z_4+\frac{P_4}{\rho_S}+\frac{Q_{RS}^2}{2g_C A_4^2}\right)=648.7+\frac{3414.41}{61.38}+\frac{(0.195969)^2}{(2)(32.2)(0.2006)^2}=704.3422$$

$$K_{5-4}\frac{Q_{RS}^2}{2g_C A_4^2}=(9.7475)\frac{(0.195969)^2}{(2)(32.2)(0.2006)^2}=0.14445$$

704.4868–704.3422–0.14445 = 0.00015 (Eq. 4 is satisfied)

Check of Eq. (5):

$$Q_{HC}+Q_{HS}-\left(\frac{5{,}100}{449}\right)=0$$

2.95056+8.40802–5100/449 = 5.4E-06 (Eq. 5 is satisfied)

Check of Eq. (6):

$$Q_{RC}+Q_{RS}-\left(\frac{625}{449}\right)=0$$

1.19601+0.195969–625/449 = –0.000003 (Eq. 6 is satisfied)

Check of Eq. (7):

$$A_C\frac{dZ_1}{dt}+Q_{HC}+Q_{RC}=0$$

Validation of the solution to Eq. 7 is accomplished by checking numerical integration consistency against Euler's method for one time step. From FORTRAN output for Case 01 at t=99.9 seconds and t=100 seconds,

t =99.9000 sec, CST Level = 31.3149 in, Z_1 = 672.10 ft + (31.3149 in)/12.0 = 674.7096 ft

t = 100.0000 sec, CST Level = 31.3109 in, Q_{HC} = 1324.8012 gpm = 2.95056 ft^3/sec, Q_{RC} = 537.0097 gpm = 1.19601 ft^3/sec, Z_1 = 672.10 ft + (31.3109 in)/12.0 = 674.7092 ft

Integrating Eq. 7 from t=100 sec – Δt to t=100 sec gives

$$Z_1(100) = Z_1(99.9) - (0.1)[Q_{HC}(99.9) + Q_{RC}(99.9)]/1250$$
$$Z_1(100) = 674.7096 - (0.1)[2.95056 + 1.19601]/1250 = 674.7093$$

This value is consistent (to within the number of available significant digits) with the computer code calculated value of 674.7092 ft.

Note: As discussed above, because temporal integration is first-order explicit, FORTRAN output at any particular time actually corresponds to the indicated time minus one time step except for CST water level which corresponds to the actual indicated time.

Attachment 3: Peer Check of FORTRAN Results

An additional peer check of the results is provided in this Attachment by comparison of the results presented in §6 against an independently developed, but unverified, Excel spreadsheet model of CST level response during HPCI/RCIC suction transfer. The Excel model was developed by Station system engineer John Vandenberg. The Excel model and associated documentation is included on CD. Basic assumptions used in the Excel model consist of

Condensate storage tank water is 100°F.
Suppression Pool water is 140°F.
Suppression pool level is constant through the transient.
Suppression Pool pressure is constant through the transient.
The RCIC CST set point is lower than the HPCI CST set point.
Total HPCI and RCIC flow is constant.

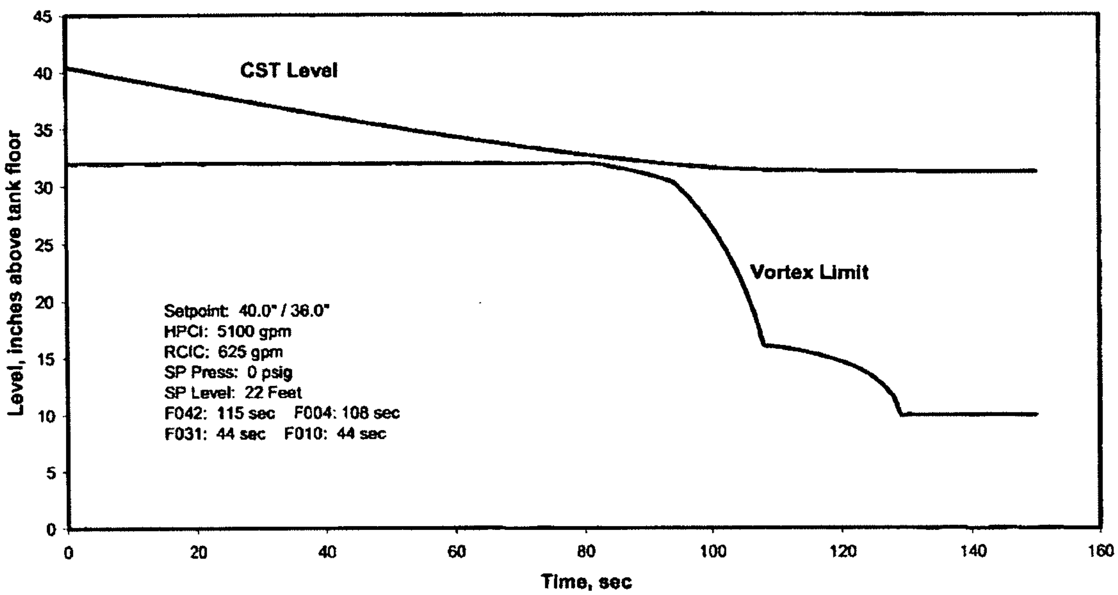
The valve stroke times are taken from EC-VALV-0509 for the limiting stroke time. These inputs are
HPCI F042 = 115 seconds
HPCI F004 = 108 seconds
RCIC F031 = 44 seconds
RCIC F010 = 44 seconds

HPCI and RCIC suction line loss coefficients are derived from pressure drops given in Calculations EC-052-0002, "High Pressure Coolant Injection DP Calculations," Rev. 2 and EC-050-0001, "Reactor Core Isolation Cooling Pressure Drop Calculations," Rev. 2.

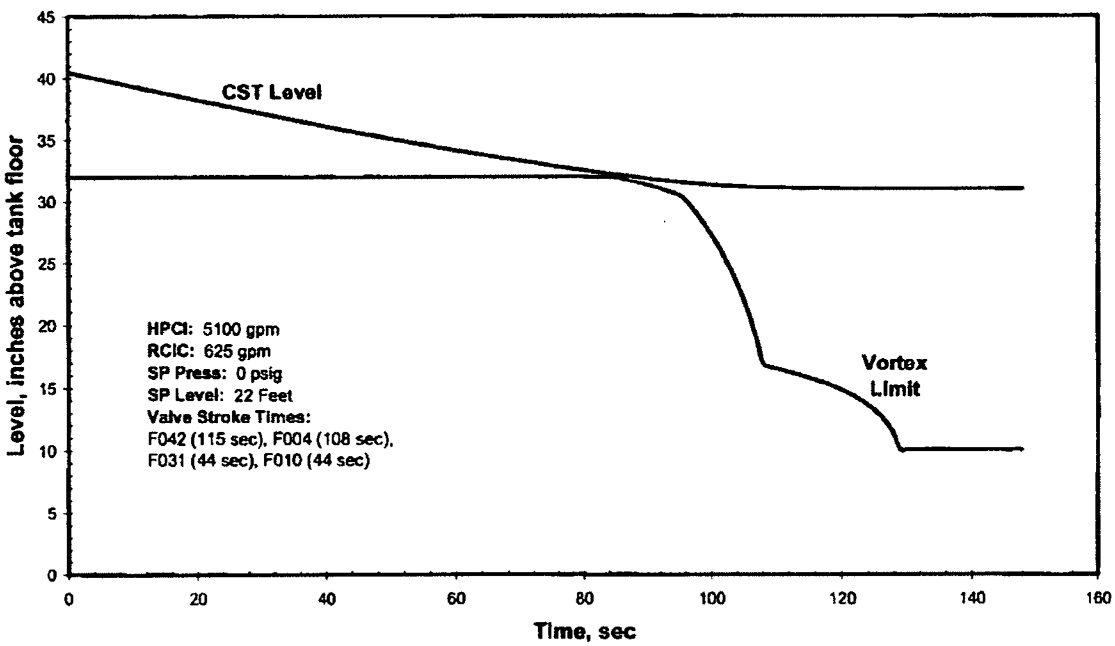
As shown by comparison of the following plots, results obtained with the FORTRAN code listed in Attachment 1 are slightly conservative with respect to the independently developed Excel model, but overall the two models show good agreement.

For Information Only

Excel Calculation of CST Water Level vs Vortex Limit
Suction Transfer Setpoint: 40.5" (HPCI), 36.0" (RCIC)



FORTRAN Calculation of CST Water Level vs Vortex Limit
Suction Transfer Setpoints: 40.5" (HPCI), 36.0" (RCIC)



Attachment 4: Validation of Acceptance Criteria for Vortex Formation

Per FSAR Section 6.3.2.2.1, preoperational testing demonstrated that vortex formation did not occur in the CST under low water level conditions and suction flow equal to 6000 gpm. TP 2.18 (microfilm Roll G5393, Frame 316) and QCIR No. 81-3263 (microfilm Roll 4065, Frame 705) verified by visual inspection that no vortex formation occurred with water level 3" above the vortex breaker.

It is therefore given that vortex formation will not occur at a flow rate of 6000 gpm, as long as CST water level is maintained 3" above the top of the vortex breaker, which is located 30.875" ≈ 31" above the CST floor (see Table 4-1). In the present analysis it is assumed that vortex formation does not occur as long as CST level is greater than or equal to 32" (see Assumption 13 and discussion in §5.3). As discussed below, the preoperational test result can be used in conjunction with the vortex correlation in §5.3 to validate this assumption.

Inputs:

Based on test data, vortex formation does not occur with CST water level at 31" + 3" = 34" and CST suction flow equal to 6,000 gpm.

From the computer output for Case 1, the suction flow from the CST is 3,050 gpm when water level drops to 32".

Method:

The Froude number at the test condition (34" and 6000 gpm) and at the low-level operating condition (32" and 3050 gpm) will be calculated (see §5.3). Based on the range of calculated Froude numbers, the appropriate correlation from section 5.3 will be selected. A first-order Taylor series expansion for the dimensionless suction pipe submergence S, corresponding to the onset of air ingestion, will then be developed about the test condition, and the value of S corresponding to 3050 gpm will be calculated. If the tank level associated with this value of S is less than or equal to 32", then the assumption of no vortex formation with tank level ≥ 32" (Assumption 13) is validated.

Fluid velocities and Froude numbers are (Refer to §5.3)

$$V \text{ at 6000 gpm} = \frac{6000\,\text{gal}}{\text{min}} \times \frac{1\,\text{min}}{60\,\text{sec}} \times \frac{\text{ft}^3}{7.48\,\text{gal}} \times \frac{1}{2.074\,\text{ft}^2} = 6.45\frac{\text{ft}}{\text{sec}}$$

$$V \text{ at 3050 gpm} = \frac{3050\,\text{gal}}{\text{min}} \times \frac{1\,\text{min}}{60\,\text{sec}} \times \frac{\text{ft}^3}{7.48\,\text{gal}} \times \frac{1}{2.074\,\text{ft}^2} = 3.28\frac{\text{ft}}{\text{sec}}$$

$$\text{Fr at 6000 gpm} = \frac{6.45\,\text{ft}}{\text{sec}} \Big/ \sqrt{\frac{32.2\,\text{ft}}{\text{sec}^2} \times 1.625\,\text{ft}} = 0.89$$

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$$\text{Fr at 3050 gpm} = \frac{3.28\,\text{ft}}{\text{sec}} \bigg/ \sqrt{\frac{32.2\,\text{ft}}{\text{sec}^2} \times 1.625\,\text{ft}} = 0.45$$

For this range of Froude numbers, the appropriate air-ingestion correlation is

$$S = 1.363(\text{Fr})^{0.261}.$$

At the test condition (Fr = 0.89) the value of *S* = 1.32. The first derivative of *S* with respect to Fr is

$$\frac{dS}{d(\text{Fr})} = 0.356\,\text{Fr}^{-0.739}.$$

Evaluating this derivative at the test condition (Fr = 0.89) gives

$$\left.\frac{dS}{d(\text{Fr})}\right|_{\text{Fr}=0.89} = 0.356\,\text{Fr}^{-0.739} = 0.388$$

Evaluating *S* at Fr = 0.45, the Froude number when CST water level falls to 32", gives

$$S|_{\text{Fr}=0.45} \approx S|_{\text{Fr}=0.89} + \left.\frac{dS}{d(\text{Fr})}\right|_{\text{Fr}=0.89} (0.45-0.89) = 1.32 + 0.388 \times (0.45-0.89) = 1.15.$$

The change in *S* corresponding to a change in Froude number from 0.89 to 0.45 is

$\Delta S = 1.15 - 1.32 = -0.17.$

Since $H = D\,S$, where *H* = submergence of CST suction pipe entrance (see §5.3) and *D* is the CST suction pipe diameter,

$\Delta H = D\Delta S = (1.625\text{ ft}) \times (-0.17) = -0.28\text{ ft} = -3.4$ inches.

Therefore, the water level at which vortex formation could occur is
34 inches - 3.4 inches = 30.6 inches, which is significantly below the assumed value of 32 inches. **Therefore, the assumption of no vortex formation with tank level ≥ 32" is valid.**

Note that the assessment provided in this Attachment implicitly assumes that the test condition (tank level of 34" and suction flow of 6000 gpm) corresponds to the threshold of vortex formation.

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