SCE&G
A SCANA COMPANY

May 11, 2000
RC-00-0239

Document Control Desk
U. S. Nuclear Regulatory Commission
Washington, DC 20555

Attention: Ms. Karen R. Cotton

Stephen A. Byrne
Vice President
Nuclear Operations
803.345.4622

South Carolina Electric & Gas Co
Virgil C. Summer Nuclear Station
P. O. Box 88
Jenkinsville, South Carolina
29065

803.345.4344
803.345.5209
www.scana.com

Gentlemen:

Subject: VIRGIL C. SUMMER NUCLEAR STATION (VCSNS)
DOCKET NO. 50/395
OPERATING LICENSE NO. NPF-12
RESPONSE TO REQUEST FOR ADDITIONAL INFORMATION
REGARDING RESPONSE FOR GENERIC LETTER 96-06
(TAC No. M96872)
"Assurance of Equipment Operability and Containment Integrity
During Design-Basis Accident Conditions"

Reference:
1. Gary J. Taylor letter to Document Control Desk, RC-99-0080, May 28, 1999
2. Gary J. Taylor letter to Document Control Desk, RC-97-0026, January 28, 1997

The attached information is provided in response to an April 19, 2000, electronic communication from the VCSNS NRR Project Manager and a telephone conference between the Project Manager, the NRR Technical Reviewer and the contracted reviewer. These communications were in regards to the South Carolina Electric & Gas Company (SCE&G) response to Generic Letter 96-06 documented by References 1 and 2. These communications discussed three areas of report development that the contract reviewer required further information.

A072

I declare that these statements and matters set forth herein are true and correct to the best of my knowledge, information and belief.

Should you have questions, please call Mr. Jim Turkett at (803) 345-4047 or Mr. Gil Williams at (803) 345-4159.

Very truly yours,

Stephen A. Byrne

JT/GJT/dr
Attachment

c: J. L. Skolds (w/o Attachment)
T. G. Eppink (w/o Attachment)
R. J. White (w/o Attachment)
L. A. Reyes
K. R. Cotton
NRC Resident Inspector
G. G. Williams, Jr. (w/o Attachment)
J. B. Knotts, Jr.
NSRC
RTS (O-L-99-0274; w/o Attachment)
File (815.14)
DMS (RC-00-0239)

STATE OF SOUTH CAROLINA :
: TO WIT :
COUNTY OF FAIRFIELD :

I hereby certify that on the 11th day of MAY ~~19~~ 2000, before me, the subscriber, a Notary Public of the State of South Carolina personally appeared Stephen A. Byrne, being duly sworn, and states that he is Vice President, Nuclear Operations of the South Carolina Electric & Gas Company, a corporation of the State of South Carolina, that he provides the foregoing response for the purposes therein set forth, that the statements made are true and correct to the best of his knowledge, information, and belief, and that he was authorized to provide the response on behalf of said Corporation.

WITNESS my Hand and Notarial Seal

Notary Public

My Commission Expires July 13, 2005
Date

Response for

GL 96-06

REQUEST FOR ADDITIONAL INFORMATION

Included in the enclosed documentation:

Response to NRR Review Questions

Tab 1	Sargent & Lundy Report SL-5102, Rev.0, including : Sections 1-7, Table 1, Figure 1, Appendix A (excluding computer input/output)
Tab 2	FSAR Figure 6.2-7
Tab 3	Fauske and Associates Inc. Report FAI/96-75
Tab 4	Isometric drawings of relevant RBCU piping

Response to

Request for Additional Information

Regarding

GL 96-06

South Carolina Electric & Gas Company

V.C. Summer Nuclear Station

GL 96-06
RC-00-0239

SCE&G℠
A SCANA COMPANY

May 11, 2000
RC-00-0239

Document Control Desk
U. S. Nuclear Regulatory Commission
Washington, DC 20555

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phen A. Byrne
; President
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Notary Public

My Commission Expires

July 13, 2005
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Response for

GL 96-06

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Response to NRR Review Questions

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Tab 2	FSAR Figure 6.2-7
Tab 3	Fauske and Associates Inc. Report FAI/96-75
Tab 4	Isometric drawings of relevant RBCU piping

Question 1

The licensee indicated that the waterhammer analyses were performed with FORTRAN coded algorithms which directly solve the governing heat transfer and fluid motion equations for the affected piping network. However, the sufficient information about the details of this evaluation were not provided in order for us to determine whether the analyses are adequate and conservative in all respects.

Response

The analysis approach and methodology are discussed in detail in Section 4 of Sargent & Lundy (S&L) Report SL-5102, Rev.0 (see enclosed Tab 1). The governing conservative assumptions used in the evaluation are documented in Section 3, and calculational details are discussed in Section 5.
To assist in the review of the FORTRAN programs, a copy of the verification calculations (Appendices A9 and B9 of SL-5102, Rev.0) for the programs is enclosed. Included is a complete listing of the source code for each program module.

Question 2

The licensee determined that the Froude number for fluid flow was near or above unity and concluded that the potential for condensation-induced waterhammer does not exist. Sufficient information about the details of this evaluation were not provided in order for us to determine whether the analyses are adequate and conservative in all respects. Additionally, the contractor noted that pressures that result from condensation-induced waterhammer are independent of the draining Froude number.

Response

The Froude number evaluations for the analysis cases having a potential for condensation induced water hammer are discussed in Appendix A6 of the SL-5102, Rev.0 report. The following is summarized from pages A17-A18 of the report:

For analysis cases A1 and A3 the estimated range of Froude numbers is 1.23 to 1.97. For cases A2 and A4 (increased RBCU tube fouling) the range of Froude numbers is 0.89 to 1.72. The test results presented in FAI/96-75[1] *show that condensation induced water hammer will not occur for this configuration at*

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[1] Fauske and Associates Inc. Report FAI/96-75, "Evaluation of Possible Water Hammer Loads in the Service Water System for DBA Conditions", R.E. Henry, Dated October 16, 1996. Presented at the NEI GL 96-06 Industry Meeting on October 29, 1996. (See Tab 3)

Froude numbers above unity. In [the applicable] test reported in FAI/96-75, condensation induced water hammer was detected only at values of Froude number near 0.1, and characterized as multiple successive pressure peaks of low magnitude that indicated rapid and successive collapse of small scale vapor bubbles.

And from page A20:

These comparisons indicate that the RBCUs will produce sufficient steam to accelerate the water in the return line and maintain the water velocities at a value sufficient to produce Froude numbers near or above unity, thus precluding the occurrence of condensation induced water hammer.

Question 3

With regard to the two-phase flow analysis that was completed, the licensee did not address the reduction in containment cooling capacity that would result due to reduced flow caused by the increased friction of two-phase flow.

Response

The hydraulic analysis of the RBCU steam voiding transient and refill conservatively assumed single-phase friction loss coefficients because the resulting higher fluid velocities increase the calculated water hammer pressures. The decrease in RBCU heat removal capability during two phase flow conditions is not considered significant with respect to the accident analyses and design basis because:

- The estimated time to refill the steam-voided portion of the RBCU system is approximately 33 seconds (SL-5102, Rev.0, Section 5.2.6).
- RBCU cooling flow is lost after 9 seconds and Service Water Booster pump power is restored 42 seconds into the accident scenario, creating a 33 second absence of flow. Flow to the RBCUs will be re-established within 3 to 5 seconds of pump restart. (SL-5102, Rev.0, Section 5.2.4).
- Containment air temperatures peak within 18 seconds of design basis LOCA initiation and remain above 250 F for over 1000 seconds. The approximate 33 second duration reduction in heat removal caused by two-phase flow effects is considered insignificant with respect to the total integrated heat removal from containment during the accident. (FSAR Figure 6.2-7, see Tab 2)

Sargent & Lundy LLC

Report SL-5102, Rev. 0
Project 10050-003

South Carolina Electric & Gas Company
V. C. Summer Nuclear Station

Assessment for Transient Conditions in the V. C. Summer Station Service Water System During A Coincidental Loss of Coolant Accident and Loss of Off Site Power

Safety Related

Prepared by: Date 5-23-97

Reviewed by: Date 5-23-97

Approved by: H. S. Taylor Date 5-23-97

Sargent & Lundy LLC

Report SL-5102, Rev. 0
Project 10050-003

Tables

Figures

Appendices

Executive Summary

A thermal-hydraulic evaluation is performed to assess the potential for condensation induced and column separation water hammer in the V. C. Summer Nuclear Station reactor building cooling unit piping. These analyses are performed in response to the NRC's Generic Letter 96-06, "Assurance of Equipment Operability and Containment Integrity During Design-Basis Accident Conditions."

The analysis results indicate Froude numbers near or above unity, supporting the conclusion that condensation induced water hammer will not occur.

Using simplified, conservative methodology, a column separation water hammer of 274 psig is predicted to occur near Elevation 450'-0" in the 16-inch discharge lines. However, plant test data for the same scenario do not exhibit water hammer loads in the piping system.

1. PURPOSE/SCOPE

1.1. The purpose of this report is to determine the hydraulic transients which can occur in the V. C. Summer Nuclear Station (VCSNS) Service Water (SW) system inside containment during a coincidental Loss of Coolant Accident (LOCA) and Loss of Offsite Power (LOOP) events. Also, for the events that can occur, to determine the peak pressure in the piping.

The scenario being evaluated herein was originally described in Westinghouse Nuclear Safety Advisory Letter NSAL-96-003. During a postulated LOOP coincident with a design basis LOCA, power is lost to all three service water pumps, the two service water booster pumps and the four reactor building cooling unit (RBCU) fans. The service water pumps and service water booster pumps (if running) will coast down much more quickly than the RBCU fans. Accounting for diesel start times, the service water pumps will be re-energized approximately at 21.5 seconds and achieve full speed in 4.5 seconds, the RBCU fans will have power restored at 36.5 seconds and will achieve full speed in 8 seconds and the service water booster pumps will start at 41.5 seconds and achieve full speed within 5 seconds. This timing of events provides for hot, steam-laden air to be drawn over the cooling coils for approximately 42 seconds before cooling liquid flow is re-established to the coils.

1.2. During normal operation, the RBCUs are isolated from the service water system and supplied with cooling water by the closed loop industrial cooling system which operates at a pressure of 56 psig. Subsequent to a LOOP, LOCA or LOCA/LOOP, the industrial cooling water system is isolated from the RBCUs and the service water flow path is restored. See Table 1 for the timing of the events.

When containment cooling is performed by the industrial cooling water system, the RBCUs are the highest component in the system. All inlet and discharge lines slope away from the RBCUs. Following a LOCA or LOCA/LOOP, the power to the industrial cooling system will be lost. The flow in the system will subside as the circulating pump coasts down and the system will become stagnant. The pressure in the system is determined by the amount of air in the expansion tank. The system pressure is set at 20 to 30 psig at the circulating pump suction with the pump and system in operation. The RBCUs are approximately 46.3 feet above the pump suction, therefore the pressure at the RBCU is approximately 4 psig.

Upon flow stoppage, the upstream check valve (XVC-3136) will close and prevent back flow to the industrial cooling system circulating pumps. Upon the generation of an safety injection signal, the down stream industrial cooling water system isolation valve (XVG-3111) will begin to close to isolate the cooling water system from the RBCUs. As the steam in the containment condenses on the outside of the coils, the water in the

RBCUs will heat up and expand, increasing the pressure in the system. If there is sufficient volume for expansion, some vapor may form in the coils. The expansion will continue and the system temperature and corresponding saturation pressure will increase. When the pressure in the coil has increased to approximately 21 psig (saturation pressure for the accident temperature of 265°F), expansion or boiling will stop because the saturation temperature in the coil will be the same as the temperature of the steam condensing in the containment and no further heat transfer can be affected. At this point the system will remain stagnant and pressurized. A vapor bubble may be trapped in the RBCU. The system will remain in this state until the containment atmospheric temperature begins to decrease or the safety injection logic initiates the transfer of the RBCU to the service water cooling alignment.

Under this scenario, there will be minimal, if any, vapor formed in the coils. Because the coils are the high point in the system, any vapor fomed will remain in the coil or if sufficiently large, the adjacent discharge piping. Since there is no flow, there is no potential for condensation of the bubble in the hot coil and there is no potential for condensation-induced water hammer.

For VCSNS, the potential for condensation-induced water hammer is highest during periodic surveillance testing. During quarterly pump test, for example, the industrial cooling water supply to the RBCUs is valved shut (XVG-3110 and XVG-3111 are closed) and the service water system is aligned to the RBCUs when the service water booster pump is started (XVG-3106 and XVG-3107 are opened). Should a LOCA/LOOP occur during the performance of the test, the service water booster pump will coast down and the piping will depressurize into the service water discharge header. A column separation may occur in the discharge header as the pressure equalizes with the discharge lake elevation. As the steam in the containment begins to condense on the RBCU coils, the water will expand into the service water discharge header. Expansion toward the supply side of the RBCU is prevented by the check valve at the booster pump outlet (XVC-3135). Because the system is open to atmosphere through the discharge header, pressurization sufficient to prevent boiling cannot occur. As the RBCUs continue to absorb heat from the LOCA environment in the containment, the vapor formation and expansion into the discharge header is accelerated. It is during this scenario that the potential for condensation-induced water hammer is most significant and evaluated in this report.

1.3. This report addressed the potential for water hammer in the service water system RBCU piping during bounding cases where a LOOP occurs without a LOCA for the column separation water hammer during system refill and the design basis LOCA and LOOP occur coincidentally for the evaluation of condensation induced water hammer. This case is considered bounding, since:

1.3.1. Containment temperatures peak within 18 seconds of the LOCA initiation. A LOOP occurring any time after the LOCA initiation will not experience the ambient peak temperature and relative humidity.

1.3.2. Per FSAR Section 6.2, the design basis LOCA bounds the MSLB transient because the critical parameter, steam saturation temperature, dominates during the period of interest, i. e. until the service water flow is reestablished to the RBCUs.

1.4. This assessment consists of a thermal hydraulic analyses to investigate the conditions in the service water system RBCU piping during the postulated transient.

1.5. The body of this report describes the overall inputs, assumptions, methodology and results of the assessment. Detailed analyses supporting this report are provided in Appendices A and B.

1.6. The typical arrangement of the VCSNS RBCUs is shown in Figure 1. All four RBCUs are located at elevation 522 feet, approximately 110 feet above the level of the cooling lake.

1.7. Service water to each train of the RBCU is supplied by a 16-inch diameter pipe. Each of the two cooling units comprising a RBCU train is supplied by a 10-inch pipe that reduces to an 8-inch line at the RBCU nozzle. Each cooling unit consist of 8 coils that have 4 passes. Flow within the coil is through 5/8-inch diameter tubing. Similarly, the coil unit return lines are 5/8-inch diameter and the RBCU return line has diameters of 8, 10, and 16 inches.

1.8. A description of the RBCU units can be found in FSAR Section 6.2.2.2.2.

2. DESIGN INPUTS

2.1. Condensation heat transfer coefficients for metal surfaces subjected to post LOCA conditions are defined in VCSNS FSAR Figure 6.2-11. These heat transfer coefficients are based on time dependent coolant energy discharge rates for the design basis LOCA as described in FSAR Figure 6.2-7.

2.2. Containment post-LOCA temperatures are defined in VCSNS FSAR Figure 6.2-7.

2.3. Data for the cooling coil tube size and thickness, fin spacing, and physical geometry is defined in the RBCU bill of materials, specification and vendor documents (References

7.8, 7.16, 7.17, 7.18 and 7.19).

2.4. Piping system geometry is defined in the isometric drawings listed in Section 7.4 of this report.

2.5. Post LOOP sequencing of electrical loads on the diesels are defined in Reference 7.7.

2.6. Steady state friction drops in the service water system are calculated for inservice piping by standard pipe design equations given in Reference 7.6. Minimum flow requirements for the RBCUs are provided in FSAR Section 6.2.2.3.3.

2.7. Theoretical and experimental evaluation of the potential water hammer in the service water system is provided in Reference 7.5.

3. ASSUMPTIONS

3.1. The following assumptions have been made in the thermal hydraulic evaluation of the steam generation portion of the transient:

3.1.1. It is assumed that the coils are water filled at the beginning of the transient and water vaporization contributes to the evacuation of the discharge pipe.

3.1.2. The temperature effects of small and intermediate break LOCA conditions are not sufficient to produce boiling in the RBCUs prior to service water pump restart at 21.5 seconds. Therefore, the concern of condensation induced water hammer does not apply for these transients.

3.2. The following assumptions have been made in the calculation of potential water hammer forces during the system refill portion of the transient:

3.2.1. At VCSNS, there are two service water booster pumps feeding four RBCU units. Each booster pump directly supplies two RBCU units. However, only one RBCU per train is required to respond to a LOCA. Should two units in the same train be in operation at the time of the LOCA/LOOP, one unit will be valved out during the first minute of the transient. However, because the service water booster pumps initiate at 41.5 seconds, there is a potential for flow through one or two units. Therefore, water hammer loads associated with refill will be estimated for flow through one or two RBCUs, as is the more conservative configuration.

Water hammer occurring during the refill transient is due to the collapse of the column separation that occurs in the discharge piping outside of containment. Steam generated in the RBCUs has the effect of pressurizing the discharge line and cushioning the impact when the column separation collapses. This water hammer load is a maximum when there is no steam generation in the RBCU. Therefore, this water hammer load is evaluated for the case of LOOP without LOCA. This case is called the cold refill case because no heating is considered, thereby, maximizing the water density, water velocity and column collapse water hammer pressure.

3.2.2. No credit is taken for flow through the RBCU industrial cooling system valves in determining the relative refill velocities. Further, the service water booster pumps have a 6-inch bypass which serves as a minimum flow line when the pump is running and as a keep-filled line when the pump is off. This line is assumed to be closed in order to maximize the flow to the RBCUs when the booster pumps are in operation. This conservatively estimates the refill velocities and, therefore, the water hammer peak pressures.

3.2.3. To simplify the refill calculations, it is conservatively assumed that the pressure at the coil discharge remains at 0 psia during the entire refill transient.

3.2.4. No credit is taken for cushioning of the water slug due to the presence of air released from the fluid during vaporization.

3.2.5. During a non-LOCA or a non-MSLB transient, the cooler remains water solid and no water hammer is postulated. Subsequent to a LOCA and stoppage of the flow through the coolers, boiling may occur in the coils. Steam will void the coils of water.

Upon restart of the service water pumps and the service water booster pump, the service water inlet and outlet valves (XVG-3106 and XVG-3107) will open and the industrial cooling water isolation valves (XVG-3110, XVG-3111 and XVG-3112) will close. The booster pumps will provide flow to the coolers which is then directed to the service water return header to the cooling pond.

3.2.6. A review of the VCSNS industrial cooling water and service water systems indicate the design complies with single failure criteria. However, industry experience has revealed two scenarios where single failures have the potential to impact the results of these analyses. These are the failure of a fan motor breaker to open and failure of relief valves to close once opened. These scenarios are discussed below.

The failure of the fan motor breaker to open results in a potential enhancement of the heat transfer into the RBCU subsequent to the LOCA. For the evaluations performed here, this has the effect of accelerating the time at which boiling is initiated and accelerating the boiling rate once boiling is initiated. Both effects are non-conservative in terms of these evaluations, i. e. the conservative effect is to reduce the heat transfer and curtail boiling. Since more boiling and heat transfer and thus more steam volume is generated, these effects would tend to lessen the results of slug collision. Thus the current evaluations bound these effects.

Another single failure potential is for the relief valves to open and then fail to close. A single failure of this type could invalidate the assumptions about the CI system pressurization. The CI system relief valves (4203A, 4203B, 4214, and 4232) are set at 125±3 psig. The RBCU relief valves (3146A, 3146B, 3146C, 3146D) are set at 175±5 psig. The analysis indicates the pressure in the RBCUs will not exceed 30 psia. Therefore, opening of the relief valves is not considered credible during the transient.

4. APPROACH/METHODOLOGY

4.1. The possible water hammer scenarios are identified. The analysis is performed such that the bounding water hammer loads are determined for each particular scenario. The approach differs from the evaluation of one scenario to the other to ensure that bounding evaluations are performed.

4.2. NUREG/CR-5220 provides reference material and diagnostic procedures concerning condensation-induced water hammer in nuclear power plants. Five event-classes of condensation-induced water hammer, which have similar phenomena and levels of damage, are defined in NUREG/CR-5220. Additionally, NUREG/CR-5220 provides case studies to illustrate the diagnostic methods and to document past experience. The majority of the examples and case studies presented in NUREG/CR-5220 deal with high temperature and high pressure systems. The fourth case study presented in NUREG/CR-5220 has some similarities to the service water event considered herein, except that the temperature considered in the scoping study in NUREG/CR-5220 is approximately 25% higher and the refill flow rate is much higher than those in the RBCU piping. It should be noted that no pressure boundary damage was reported for this case study.

4.3. Reference 7.5 describes a series of scaled water hammer experiments performed over a range of conditions typical of the VCSNS service water system during this transient. The VCSNS geometry bears similarity to the test configuration because there is a horizontal run at the outlet of the cooler followed by a vertical leg. The steam bubble formed in the cooler can potentially collapse in the horizontal run and produce condensation-induced water hammer. Down stream of the RBCU there is also the potential for column separation to occur in the service water return header. The experiment apparatus was constructed based on Froude Number considerations and investigated the influence of void formation and steam condensation during the transient conditions. The results of these experiments demonstrate that no significant water hammer transients were observed even with significant voiding, and that peak pressures occurred during refilling of the system. Additionally, the peak pressures were substantially less than those that would be calculated using standard water hammer methodology.

4.4. Based on a review of the system configuration, potential water hammer is postulated for the RBCU outlet piping only. The service water booster pump discharge check valve and the penetration isolation check valve prevent the supply side of the cooler from draining and, therefore, forming a gas bubble.

4.4.1. During the short duration of the transient, the heat transfer will not be sufficient to boil the entire contents of the coils. As such, the only mechanisms for heat transfer to the water on the inlet side is through conduction from the coils or condensation on the outside surfaces of the pipe. This heat transfer will not be sufficient to cause voiding on the inlet side.

4.4.2. Each service water booster pump has a 6-inch bypass line with a locked open valve which allows flow into the down stream piping. The bypass line allows the service water pump to maintain the water leg between the booster pump and the XVG-3106 valve during normal operation. The booster pump outlet check valve, XVC-3135 is expected to maintain this water leg for the short duration of the transient, thus preventing water hammer from occurring in the inlet piping.

4.4.3. Friction factors for inservice piping, Reference 7.6, were used in the analysis.

4.4.4. The industrial cooling water check valves will experience a seating force associated with the flow reversal that occurs during the pump trip. The industrial cooling water supply check valve (XVC 3136) will prevent reverse flow into the industrial cooling water pump headers. The service water booster pump outlet check valve (XVC 3135) is manually closed following quarterly surveillance tests. The valve may experience additional seating force upon loss of pressure in the service water line at the beginning of the accident.

4.4.5. As heat is added to the coils, the RBCUs will pressurize, providing additional force to seat the check valves (XVC 3136 and XVC 3137).

4.5. The following water hammer scenarios could occur during the LOCA/LOOP transient:

4.5.1. A water slug striking another water slug due to condensation in the horizontal section of the 16-inch return lines prior to pump start.

4.5.2. A water slug striking another water slug in the vertical section of the 16-inch return lines during refilling.

4.6. The magnitude of water hammer loads depends upon the velocity of impact, which is a function of:

4.6.1. Inertia and friction in supply and return lines.

4.6.2. Boiling heat transfer coefficient in the coolers.

4.6.3. Condensation heat transfer coefficient and flow velocities at the fins.

4.6.4. Steam generation rate in the coolers.

4.6.5. Steam condensation rate in the return lines.

4.6.6. Volume of the vapor generated by a combination of the column separation effect and the steam generated in the coils during the transient.

4.6.7. Pressure differential across the water slug.

4.6.8. Time available to accelerate the slug.

4.7. The condensation induced water hammer, where one water slug strikes another water slug, can occur due to condensation of steam that has been generated in the coolers. The condensation can occur in the horizontal section of the 16-inch return lines located outside the containment, prior to pump start. The following approach will be used in this calculation:

4.7.1. A transient analysis will be performed to determine the steam generation rate and the steam velocity in the return line. This is based upon the heat addition rate to the RBCUs, and the steam condensation rate in the return lines, as well as the inertia and friction in the return lines.

4.7.2. The Froude Number will be determined based upon the water velocity in the 16-inch return line. If the Froude number is close to or higher than unity, horizontal legs of the return line will be filled with water and condensation induced water hammer will not occur based on the results of the testing and theoretical discussions provided in

Reference 7.5.

4.7.3. If the criteria described above is not satisfied, condensation induced water hammer can occur in the 16-inch return line. In such case, the impact velocity will be evaluated based on the methodology provided in NUREG-5220, Sec. 5.1.3, where the slug length and the vapor void length are scaled equally. The guidelines in NUREG-5220, Appendix C will be applied to more accurately determine the water hammer forces.

4.8. Water hammer due to refilling the pipe, where one water slug strikes another water slug, can occur in the vertical section of the 16-inch return lines during refilling of the system after pump restart. The following approach is used for this calculation:

4.8.1. A transient analysis will be performed to determine the vapor volume. This is based upon the heat addition rate to the RBCUs, and the steam condensation rate in the return lines, as well as the inertia and friction in the return lines.

4.8.2. The service water booster pumps start 41.5 seconds after the initiation of the accident. The back pressure at the coil outlet is fixed at 0 psia to maximize the pump flow and refill velocity and thus the water hammer pressure.

4.8.3. Inertia and friction in supply lines, as well as in RBCUs during refilling, are considered in the analysis.

4.8.4. Flow through either one or two RBCUs supplied by a booster pump will be considered to assure maximum water hammer pressures are identified.

4.8.5. Time-dependent velocities and flow rates will be determined. Based on the vapor volume determined above, the velocity at which the two water slugs strike each other will be determined.

4.9. For the calculation of steam velocities before pump start, a simplified algorithm is developed for determining the steam generation rate and the steam velocities in the return lines. This is based upon the following:

4.9.1. Containment time-dependent temperature and condensation heat transfer values are obtained from the FSAR.

4.9.2. Nucleate boiling is considered at the inside surface of the RBCU tubes. The nucleate boiling heat transfer coefficient (Reference 7.9) is:

$$h=\exp(2*P/1260)*(Tw-Tsat)/5184*10^6$$

Where P is in psia, and temperatures are in °F.

4.9.3. Thermal resistance of copper tubing is ignored. However, the thermal capacitance of both the tubing and the fins are considered.

4.9.4. The effect of fins on heat transfer is considered.

4.9.5. Inertia and friction in return lines, as well as condensation and forced convection heat transfer in the return lines are considered.

4.10. For the calculation of refill flow rate after pump start, a simplified algorithm is developed for determining the refill flow rate and water velocities after pump start. This is based upon the following:

4.11. The column separation collapse water hammer is a function of the density and velocity of the water filling the discharge piping subsequent to pump start. The velocity is maximized by the assumption of a low backpressure on the RBCU and ignoring the friction losses in the piping down stream of the RBCU. The density is a maximum for the case where no heat addition occurs, i. e. LOOP without LOCA. Taken together, these assumptions form the basis for the definition of the cold refill transient.

4.11.1. Inertia and friction in supply lines starting at time 0, as well as in coolers during refilling, are considered in the analysis.

4.11.2. The service water booster pump discharge line is maintained full of water up to the shut off valve (XVC 3106) by the service water system pressure acting through the service water booster pump bypass valve (XVG 3139). The booster pump discharge check valve is manually closed after quarterly pump surveillance testing. Therefore, void formation in the booster pump discharge line is not expected.

4.11.3. The service water booster pumps start 41.5 seconds after the initiation of the accident. For conservatism, the back pressure is fixed at 0 psia.

4.11.4. For conservatism, no credit is taken for drainage through valves during refill or for cushioning by non-condensable gas.

4.12. The input for the hydraulic transient evaluations is based on the following information:

4.12.1. Peak fluid flow rate based on the thermal/hydraulic analyses.

4.12.2. Maximum shock overpressure, based on NUREG-5220, Section 5.1.5,:

$$P = (1/2)*\rho*c*V \qquad [c = \text{sonic velocity}].$$

5. CALCULATIONS

5.1. The event scenario as outlined in NSAL-96-003 may be summarized as follows for VCSNS:

5.1.1. During normal operation, the RBCUs are cooled by an industrial cooling unit. Upon receipt of an SIS signal, the industrial cooling unit is valved out and the RBCUs are supplied with cooling water by the service water system. The flow originates at the service water pumps which supply the booster pumps on the service water header. The cooling water then returns to the lake via the service water return header.

5.1.2. As the industrial cooling system pumps lose power, flow in the RBCU circuits will begin to slow based on the coast down characteristics for the industrial cooling water circulation pumps. Pressure in the RBCU discharge piping will decrease.

5.1.3. During normal operation, the RBCU service water supply lines are pressurized by the service water header and isolated from the RBCU by the closed booster pump isolation valve (XVG-3106). A bypass of the service water booster pump is provided to assure the water leg between the booster pump and the isolation valve (XVG-3106) is maintained and no void is present. Following loss of offsite power, the service water supply header will depressurize and there is a potential for column separation to occur in these lines if the service water booster pump check valve (XVC-3135) leaks. However, the rate of leakage is expected to be small and the service water pump's power is restored in 21.5 seconds, at which time any void will slowly collapse as the piping is refilled via the booster pump bypass line. These pressures are expected to be negligible and therefore are not quantified in this evaluation.

A second scenario involves the performance of quarterly pump tests with the service water booster pump bypass valve closed. Should a loss of offsite power occur during this test, the potential for column separation is reduced from that discussed in the scenario above since the only path for discharge line drainage is through the booster pump, not the pump and bypass valve.

5.1.4. For the RBCU service water discharge lines, the pressure decreases to the point where a water column can not be supported by the back pressure in the discharge piping plus friction losses and column separation will occur and the pressure at the RBCU discharge will drop to the saturation pressure associated with the fluid temperature.

5.1.5. As the flow is decreasing, the containment temperature and relative humidity are rising. The containment reaches a peak temperature of 265°F within 18 seconds.

5.1.6. The steam in the containment atmosphere will condense on the coil outside surfaces heating the fluid in the coils. Heat transfer to the fluid is based on forced convection during pump coast down and on nucleate boiling once the inside surface of the tubes rises above the saturation temperature of the fluid.

5.1.7. The discharge side water column will be accelerated by the pressure of the generated steam.

5.1.8. When the booster pump flow is re-initiated, at approximately 41.5 seconds, water will flow through the RBCUs and fill the discharge piping and collapsing the steam bubble.

5.1.9. When the discharge lines have been filled, steady state flow will be re-established and the transient will be over.

5.2. To evaluate the impact of this transient, detailed calculations have been prepared as follows:

5.2.1. The hydraulic analyses for the steam generation portion of the transient are provided in Appendix A.

5.2.2. The thermal/hydraulic analyses for the refill portion of the transient are provided in Appendix B.

5.2.3. The time required to return the system to service is evaluated based on the results of the analyses provided in Appendix A and Appendix B as follows:

5.2.4. From the analysis in Appendix B it can be conservatively estimated that the system inertia will be overcome and flow to the RBCUs will be re-established within 3 to 5 seconds of pump restart. The pressure at the outlet of the RBCU will decrease as the steam in the bubble condenses. This will cause the flow to increase due to the lower backpressure.

5.2.5. From Reference 7.16, the minimum required flow to ensure adequate heat removal capabilities with one operable RBCU is 2000 gpm per RBCU.

5.2.6. The average water column flow rate during steam formation was conservatively calculated in Appendix A to be approximately 11 ft/sec. This flow rate is larger than the normal flow rate in the RBCU discharge piping of 4 ft/sec (based on a nominal flow rate of 2000 gpm in a 16-inch pipe). Thus it is expected that the column would be refilled in approximately the same time as required to generate the steam bubble. Based on the results of the analyses in Appendix A the steam bubble generation time is 33 seconds (generation starts at approximately 9 seconds and the pumps restart at approximately 42 seconds).

5.2.7. Once flow to the RBCUs is initiated, the service water system will begin to remove heat from the containment. When the column is filled, the pressure at the RBCU will return to the steady state value and the transient condition will be over.

5.2.8. As the system begins to refill following booster pump start, the steam in the cooling coil return lines will be swept into the return header. The following water will be heated by the piping and approach saturation temperature of the RBCU. The initial water reaching the RBCU may flash to steam and assist in pressurizing the system. In time, water will reduce the temperature of the RBCU and saturated water will begin to emerge from the cooler and push the steam bubble into the discharge header. Therefore, the collapse of the steam bubble is not expected in the RBCU and the adjacent headers.

6. RESULTS/CONCLUSIONS

6.1. The Froude Number for the flow occurring during the steam generation phase was determined to be in the range 0.89 to 1.97. The onset of steam bubble condensation occurs at or below a Froude number of 0.5 (Reference 7.5), therefore, this form of condensation will not occur.

6.2. The thermal/hydraulic analyses demonstrate that the steam generation rates and hence the water column velocities will be sufficiently high such that stratification and separated flows in horizontal runs of piping will not occur. Thus, water hammer peak overpressures for the steam generation portion of the transient will be bounded by those for the non-LOCA refill transient.

6.3. The calculated maximum flow rate during the refill portion of the transient is 13.12 ft^3/s. This flow rate is considerably higher than the normal flow of 4.46 ft^3/s and leads to a conservative estimate of the water hammer pressure.

6.4. A detailed hydraulic transient model was developed which estimated the refill rate. The estimated refill flow rate for one RBCU in service is 13.12 ft^3/s. For two RBCUs in service the refill rate is estimated as 6.64 ft^3/s. A non-LOCA (cold column separation) refill water hammer pressure was conservatively calculated to be 274 psig for the 16-inch discharge lines (for 1 or 2 RBCUs). The expected location for the water hammer is at the bottom of the column separation, near elevation 450 feet.

There is also a potential for a column closure water hammer in the piping between the RBCUs and the header. The pressure for this water hammer is estimated by assuming that the water hammer occurs at the flow velocities estimate for each piping segment without any dissipation as the water hammer wave travels through the piping system.. For the condition of one RBCU in service the corresponding water hammer pressure estimated for 8-inch, 10-inch and 12-inch piping are 265 psig, 666 psig and 456 psig, respectively. For the condition of two RBCUs in service the corresponding water hammer pressure estimates for 8-inch, 10-inch and 12-inch piping are 134 psig, 337 psig, and 456 psig, respectively.

The simplified method employed to estimate the water hammer pressure assumes that two slugs collide. The relative speed calculated for the water slugs is maximized by setting the back pressure on the coil to zero and estimating the velocity based on pump flow. Should this velocity be evaluated subsequent to a LOCA, steam bubble formation would raise the back pressure on the coil and reduce the calculated velocity, reducing the estimate for the water hammer pressure. Therefore, these calculated values, bound both the LOCA and the non-LOCA cases. These water hammer pressure values are conservative because a number of factors which have the effect of reducing the pressure (e. g. acceleration of the downstream leg after the discharge valve is opened, elevated water temperatures and correspondingly lower fluid densities, entrained non-condensables, fouling factors in the piping system flow calculations and cooling coil heat transfer calculations) have been ignored in its determination. Per Section 5.1.6 of Reference 7.3, "While an upper bound to the resulting loads is easily estimated by the methods described above, actual loads are usually lower by a factor from 2 to 10." Also, the comparison with plant data given in Appendix B indicate the water hammer loads do not propagate to the RBCUs.

7. REFERENCES

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7.2. VCSNS FSAR

7.3. NUREG-5220, "Diagnosis of Condensation-Induced Water hammer", Published October 1988

7.4. VCSNS Drawings:

E-302-221, Revision 19 System Flow Diagram - Service Water Cooling
E-302-222, Revision 33, System Flow Diagram - Service Water Cooling
E-304-252 , Revision 1, Service Water Cooling Int. Building Plan -- Below EL. 412' - 0", Col 5.2 - 9.1
E-304-253 , Revision 4, Service Water Cooling Int. Building Plan -- Below EL. 436' - 0", Col 2.8 -5.2
E-304-254 , Revision 11, Service Water Cooling Int. Building Plan -- Below EL. 454' - 0", Col 5.2 - 9.2
E-304-255 , Revision 11, Service Water Cooling PEN, Access Area Aux. Plans EL 412'-0", 436'-0", 463'-0"
E-304-256 , Revision 12, Service Water Cooling Auxiliary Plans, Sections and Details
E-304-257, Revision 3, Service Water Cooling, Reactor Building Plan and Sections Above EL 463'-0"
E-304-258, Revision 9, Service Water Cooling Reactor Building Sections and Details
C-314-251, Sheet 1, Revision 5, Service Water - To & From Comp. Cooling Heat Exchanger "A"
C-314-251, Sheet 2, Revision 3, Service Water - To & From Comp. Cooling Heat Exchanger "B"
C-314-251, Sheet 3, Revision 1, Service Water - Booster Pump "A" Suction
C-314-251, Sheet 4, Revision 5, Service Water - Booster Pump "A" Discharge to Penetration #304
C-314-251, Sheet 5, Revision 4, Service Water - Loop "A" Return From Penetration #305 To EL 412'-0"
C-314-251, Sheet 6, Revision 2, Service Water - Booster Pump "B" Suction
C-314-251, Sheet 7, Revision 6, Service Water - Booster Pump "B" Discharge to Penetration #403
C-314-251, Sheet 8, Revision 5, Service Water - Loop "B" Return From Penetration #102 To EL 412'-0"
C-314-251, Sheet 11, Revision 5, Service Water - From Penetration 403 To Reactor Building Cooling Unit, "1B" & "2B"
C-314-251, Sheet 12, Revision 3, Service Water - From Reactor Building Cooling Units "1B" & "2B" To Pen. #102
C-314-251, Sheet 13, Revision 3, Service Water -From Pen. #304 To Reactor Building Cooling Units "1A" & "2A"

C-314-251, Sheet 14, Revision 1, Service Water - From Pen #304 To Reactor Building Cooling Units "1A" & "2A" - Details
C-314-251, Sheet 15, Revision 4, Service Water - From Reactor Building Cooling Units "1A" & "2A" To Penetration #305
C-314-251, Sheet 16, Revision 3, Service Water - From Reactor Building Cooling Units "1A" & "2A" To Penetration #305- Details
C-314-251, Sheet 17, Revision 4, Service Water - Service Water Pump Discharge Line
1MS-54-098, Revision 0, V. C. Summer Coolers

7.5. Fauske and Associates Report, Inc., FAI/96-75, "Evaluation of Possible Water-Hammer Loads in the Service Water System for DBA Conditions", R. E. Henry, Dated October 16, 1996. Presented at the NEI GL 96-06 Industry Meeting on October 29, 1996.

7.6. Crane Technical Publication 410, "Flow of Fluids Through Valves, Fittings and Pipe," 1988.

7.7. VCSNS Design Basis Document, "Reactor Protection System Emergency Safeguards Load Sequencer Design Basis Document", Section 2.0(C), Revision 1.

7.8. VCSNS Bill of Materials VCS-SM-3, "Heating, Ventilating Air-conditioning and Air Handling Systems - Virgil C. Summer Nuclear Station - Unit 1", Sheets 29 to 33.

7.9. Proceedings of the Institute of Mechanical Engineers 3C180, "Boiling in Sub-Cooled Water During Flow In Tubes And Annuli," J. R. S. Thom, W. M. Walker, T. A. Fallon and G. F. S. Reising, 1966.

7.10. VCSNS System Operating Procedure, SOP-125, "Industrial Cooling Water", Revision 8, dated June 13, 1994.

7.11. VCSNS System Operating Procedure, SOP-114, "Reactor Building Ventilation System", Revision 15, dated September 4, 1996.

7.12. VCSNS System Operating Procedure, SOP-117, "Service Water System", Revision 17, dated August 12, 1996.

7.13. VCSNS Surveillance Test Procedure, STP-233.002A, "Service Water Pump Test", Revision 5, dated November 18, 1996.

7.14. VCSNS General Test Procedure, GTP-302, "Inservice Testing of Valves Second Ten Year Interval", Revision 9, dated November 25, 1996.

7.15. VCSNS-Design Basis Document, "Service Water System Design Basis Document," Revision 5, dated August 13, 1996.

7.16. VCSNS Specification, SP-534-044461-000, "Reactor Building Cooling Unit", dated October 4, 1973.

7.17. AAF Document, CoolNuc G7020M, "Containment Coolers Normal Perf. @ 50% RH (Wet Bulb Temp: 100F)" dated February 6, 1997.

7.18. AAF Document, CoolNuc G7020M, "Containment Coolers Normal Perf. @ 30% RH (Wet Bulb Temp: 89F)" dated February 6, 1997.

7.19. AAF Document, CoolNuc G7020M, "Containment Coolers Normal Perf. @ 20% RH (Wet Bulb Temp: 82F)" dated February 6, 1997.

Table 1

Sequence of Events

Time	Event
0.0	LOCA/LOOP Occur
0.5	Safety Actuation Signal generated Diesel generators signaled to start (spin up time is 10 seconds)
11.5	Diesel generators up to speed, load sequencing begins XVG-3109 receives signal to close (stroke time is 50 seconds)
21.5	Service water pumps start (spin up time is 4.5 seconds) XVG-3116 receive signal to open (stroke time is 60 seconds)
26.0	Service water pumps at full speed
36.5	RBCU fans receive start signal (spin up time is 10 seconds)
41.5	Service water booster pumps receive start signal (spin up time is 5 seconds) XVG-3106 receives signal to open (stroke time is 45 seconds) XVG-3107 receives signal to open (stroke time is 32 seconds)
46.5	Service water booster pumps at full speed
61.5	XVG-3109 fully closed
73.5	XVG-3107 fully open
81.5	XVG-3116 fully open
86.5	XVG-3106 fully open

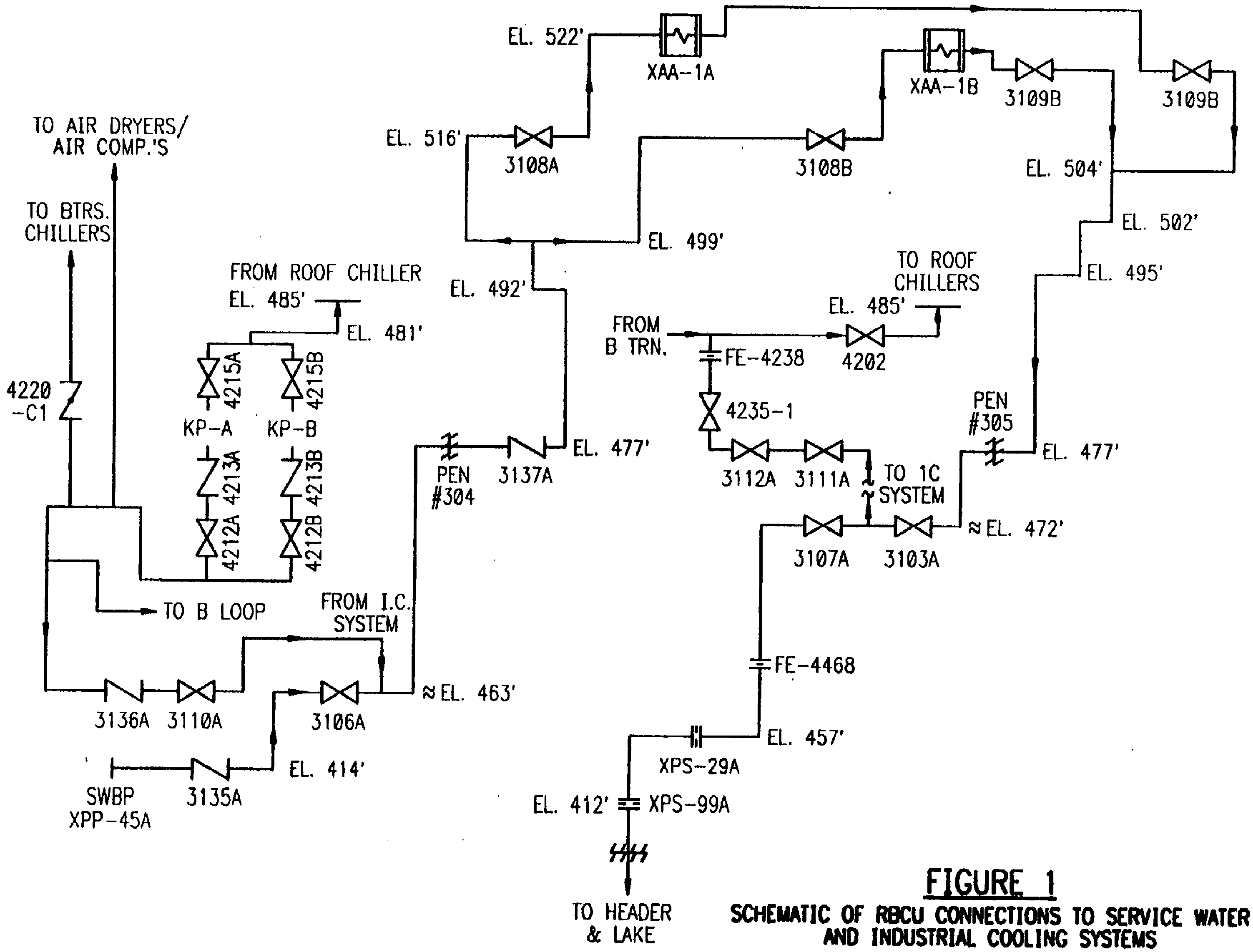


FIGURE 1

SCHEMATIC OF RBCU CONNECTIONS TO SERVICE WATER AND INDUSTRIAL COOLING SYSTEMS

Calculation MECH-0074, Rev. 0
Project 10050-003

Report SL-5102, Rev. 0
Appendix A
Page A1

APPENDIX A

LOCA/LOOP THERMAL-HYDRAULIC ANALYSIS, PRE PUMP START-UP.

for

VIRGIL C. SUMMER NUCLEAR STATION

Prepared Samir Yassin Date 5-23-97

Reviewed Date 5-23-97

Approved H. S. Taylor Date 5-23-97

A1 PURPOSE

The purpose of this calculation is to perform a thermal-hydraulic analysis of the pre-pump start-up transient for the Virgil C. Summer Nuclear Station (VCSNS). The analysis is based upon a model that includes one containment fan cooler (RBCU), as well as the corresponding return piping downstream of that cooler. XAA-1A is selected as a representative cooler since its corresponding 16-inch return line is relatively long. The pipe length results in a lower flow velocity and accordingly a lower Froude number in the return line, which increases the potential for initiating a condensation induced water hammer in the lower horizontal legs.

A2 DESIGN INPUT

A2.1 The system configuration, such as pipe diameters, wall thickness, lengths, and elevations, are based upon VCSNS isometric drawings (Reference A7.1).

A2.2 Based on References A7.2, A7.12, A7.13, A7.14, and A7.15, there are 8 heat exchanger (HX) sections in parallel per RBCU unit, 8 tube rows crossed by air flow per coil, and 16 tubes per row. The length of the finned tube exposed to air flow is 132 inches, and the number of fins per inch is 6. The outside diameter and wall thickness of RBCU copper tubing are 0.625 and 0.049 inch, respectively. The fin size is 14 inches x 24 inches x 0.007 inch thick.

A2.3 As reported in Sections 6.2 of the VCSNS FSAR (Amendment 96-02, July 1996), the containment post LOCA temperatures, $^{\circ}$F (Figure 6.2-7), and structural heat transfer coefficients, Btu/hr-ft^2-$^{\circ}$F (Figure 6.2-11), are as follows (where time is in seconds):

Table A1

Containment Post LOCA Temperatures

Time (Seconds)	Temperature (^oF)
0.0	120
0.5	142
1.0	168
2.0	203
3.0	218
4.0	227
5.0	233
6.0	237
7.0	243
8.0	247
9.0	250
10.0	253
18.0	265
20.0	264
30.0	262
40.0	260
100.0	257

Prior to the accident, the heat transfer coefficient is negligible. To provide the estimate required for the range of the analysis, the heat transfer coefficient is linearly extrapolated based on the values shown at 3.6 seconds and 10 seconds to obtain values at 0 and 1 seconds. This extrapolation is conservative because the heat transfer coefficient is over estimated early in the transient.

Table A2

Structural Heat Transfer Coefficients

Time (Seconds)	Heat Transfer Coefficient (Btu/hr-ft^2-°F)
0	10
1	50
10	180
15	220
20	100
100	90

A2.4 The 16-inch return lines downstream of the coolers have no fiberglass insulation.

A2.5 Water and steam properties used in the analysis are based upon the ASME Steam Tables (Reference A7.4). The density, specific heat and thermal conductivity of copper are 556 lb/ft^3, 0.092 Btu/lb-°F, and 227 Btu/hr-ft-°F respectively (Reference A7.5). The density, specific heat and thermal conductivity of steel are 489 lb/ft^3, 0.12 Btu/lb-°F, and 26.2 Btu/hr-ft-°F respectively (Reference A7.5).

A3 ASSUMPTIONS

A3.1 A pump coast-down of 10 seconds is assumed in the analysis. This value is representative of coast down times for service water system pumps. The sensitivity of the analysis results to this value is examined by the investigation of two identical cases with different assumed coast down times. Case 1 assumes a 10-second coast down time. Case 5 is a repeat of the transient analysis for Case 1, with an assumed pump coast down time of 5 seconds. The results of Case 1 are shown graphically in Figures A1-1 through A1-4. The results of Case 5 are shown graphically in Figures A5-1 through A5-4.

Comparing Figures A1-1 and A5-1, the effect of coast down time on the system pressure and the time to boiling is seen. The time to initiation of boiling is shifted from 9.1 seconds for Case 1 to 4.8 seconds for Case 5. The resulting pressure peaks following the initiation of boiling are 27.0 psia for Case 1 and 25.5 psia for Case 5. Also, observe there is a slower pressure build up after the initiation of boiling for Case 5. This indicates that the boiling is taking place at lower pressures (and temperatures) in the early part of the Case 5 transient.

Comparing Figures A1-2 and A5-2, the effect of coast down time on the fluid velocity is seen. The peak velocity of 12.6 feet per second occurs approximately 3 seconds after the initiation of boiling for Case 1. The peak velocity of 12.0 feet per second occurs approximately 4 seconds after the initiation of boiling for Case 5.

Comparing Figures A1-3 and A5-3, the effect of coast down time on the system temperatures is seen. Here the effect of the slower pressure buildup discussed above is seen in the lower temperatures early in the transient. However, as the transient progresses to steady state (i. e. at 20 seconds) the temperatures approach the same values. From

Figures A1-3 and A5-3 the temperatures at 20 seconds are:

Location	Case 1 Temperature °F	Case 5 Temperature °F
Containment	264	264
RBCU Tube	249	248
RBCU	241	240
Pipe w/Steam	171	176
Pipe w/Water	128	128
Return Line	97	97

Comparing of Figures A1-4 and A5-4, the effects of coast down time on the steam volume can been seen. For Case 1, the volume of steam generated, steam condensed and net steam generated at 20 seconds are 740, 576 and 164 cubic feet. These values occur at 10.9 seconds after the initiation of boiling. For Case 5, at 10.9 seconds after the initiation of boiling (15.7 seconds into the transient), the respective values are 679, 527, and 152 cubic feet.

In summary, the effect of the pump coast down time is to shift the time at which boiling in the RBCU is initiated. For comparison, a 5 second shift in coast down time resulted in a 4.3 second shift in the time to boiling. The calculated steady state system pressures, temperatures and flow velocities are not significantly different for the two cases. For Case 5, the net steam generation is slightly lower (~8%). This is attributed to the fact that the initial steam production begins at lower temperatures and pressures which tend to reduce the volume of the steam. Since the Froude number is directly dependent on the fluid velocity and the fluid properties, which are in turn functions of the temperature and pressure, it is judged by this comparison that the differences in the results due to coast down time are insignificant.

A3.2 The analysis (Case 1) is based upon the containment post LOCA temperatures and structural heat transfer coefficients provided in VCSNS FSAR (Reference A7.3), and on clean RBCU tubes. Also see Section A2.3. The effect of tube fouling is to reduce the heat transfer, and accordingly the temperature and flow velocity of the vapor which reduces the estimated water hammer pressure. Case 2 and Case 4 evaluated the effect of the manufacturer's recommended fouling factor of 0.001 in the RBCU tubing, coupled with temperatures and heat transfer coefficients 15% lower than the post LOCA values provided in the VCSNS FSAR.

A3.3 Normally, the heat transfer on the outside surface of the RBCU tubes is dominated by. condensation. During the initial phases of the LOCA, the fans serve primarily to bring additional moist air onto the coils. Therefore, only the condensation heat transfer is considered.

A3.4 The back pressure considered in this analysis is the pressure at the 12-inch return line to the industrial cooling system. This back pressure at the riser is 0.815 psia.

A4 <u>APPROACH</u>

As the LOCA/LOOP event is initiated, the service water pumps will start to coast-down, resulting in a reduced RBCU heat removal capability. Meanwhile, the containment pressure, temperature and humidity will start to rise, resulting in an increased heat flow rate to the RBCUs.

As a result, the RBCU water temperature will rise, and eventually the water will start to boil. The generated steam will start to accelerate the water column in the return line. As the generated steam is filling the return line, a fraction of that steam will condense at the pipe wall. This will result in a reduced RBCU pressure, and a lower acceleration rate of the water column in the return line. The heat transfer and fluid flow equations governing the above mechanisms are solved simultaneously using a simplified algorithm that has been developed specifically for this analysis. The algorithm is listed and validated as part of this analysis. The computational results include time dependent values of the tubing, piping and water temperatures, the RBCU pressure, the steam generation and condensation rates, and the velocity of water column in the return line.

The Froude number is determined based upon the water flow velocity in the 16-inch return line outside containment. If the Froude number approaches or exceeds unity, horizontal legs of the return line will be filled with water and a condensation induced water hammer would not occur (References A7.6 and A7.7). If the Froude number is low enough to allow stratification and separated flows in horizontal legs of the return line, condensation-induced water hammer can possibly occur in these horizontal legs (Reference A7.6).

The return lines to the header downstream of the RBCUs might experience column separation upon pump stoppage. Water columns in these return lines will start to accelerate only upon boiling and steam generation in these RBCUs. Therefore, water columns in the return lines associated with the RBCU that has the longest piping is expected to accelerate at a lower rate, which results in the lower velocities and Froude numbers. Therefore, although condensation induced water hammer can potentially occur in any return line, the return line associated with RBCU XAA-1A is more susceptible to this type of water hammer.

RBCU XAA-1A is selected as a representative cooler since its corresponding 16-inch return line is relatively long. This would result in a lower flow velocity and accordingly a lower Froude number in the return line, which increases the potential for initiating a condensation induced water hammer in the lower horizontal legs.

A5 COMPUTATIONS

A thermal/hydraulic analysis of the pre pump start-up LOCA/LOOP transient is performed in this appendix. As explained above, RBCU XAA-1A is selected as a representative cooler, and is considered in this analysis.

The RBCU parameters are given in References A7.2, A7.12, A7.13, A7.14, and A7.15. There are 8 HX sections in parallel per RBCU unit, 8 tube rows crossed by air flow per coil, and 16 tubes per row. Each coil has 4 passes. The length of the finned tube exposed to air flow is 132 inches, and the number of fins per inch is 6. The outside diameter and wall thickness of RBCU copper tubing are 0.625 and 0.049 inches, respectively. Fin size is, typically, 14 inches by 24 inches and 0.007 inches thick. Also, the flow rate of cooling water in the RBCU tubes during the accident is at least 2000 gpm (References A7.12).

Total number of tubes per unit = 8 * (8 * 16) = 1024 tubes

Number of fins / tube = 132 * 6 = 792 fins / tube

Total number of fins / unit = 8 * 792 = 6336 fins / unit

Total tube inside surface area = π * (0.527 / 12) * 1024 * (132/ 12) = 1554.07 ft^2

Total tube outside surface area (assuming no fins) = 1554.07 * (0.625 / 0.527) = 1843.07 ft^2

Total tube outside unfinned surface area = 1843.07 * (1 - 6 * 0.007) = 1765.66 ft^2

Total fin surface area = 2 * (8 / 144) * 792 [14 *24 - 128 * (π / 4) * (0.625 $)^2$] = 26112.25 ft^2

Total outside surface area = 1765.66 + 26112.25 = 27877.91 ft^2

Ratio of total outside surface area to tube outside surface area = 27877.91 / 1843.07 = 15.126

Fin Efficiency:

The fin efficiency is calculated as follows (Reference A7.8):

t = 0.007 / 12 = 5.83 E-4 ft

$r_1 = 0.625/24 = 0.026$ ft

r_2 is equivalent to $(0.5)*[((1.5*1.5/144)4/\pi]^{0.5} = 0.0705$ ft

$r_{2c} = r_2 + t/2 = 0.07079$ ft

$r_{2c}/r_1 = 2.72$

$L = r_2 - r_1 = 0.0445$ ft

$L_c = L + t/2 = 0.048$ ft

$A_p = L_c * t = 3.36\text{ E-5 ft}^2$

k for copper = 227 Btu/hr-ft-°F

h = 300 Btu/hr-ft^2-°F (an average value is considered)

$(L_c)^{1.5} * (h/(k * A_p))^{0.5} = 0.010516 * 198.325 = 2.086$

Based on the above, the fin efficiency is 33 % (Fig. 3.19, Reference A7.8)

Overall efficiency of total outside surface area (including fins)

$= (1625.21 * 100 + 24035.16 * 33) / 25660.34 = 37.24\ \%$

Ratio of volumes:

Volume of RBCU tubing = $1024 * [(\pi/4) * ((0.625/12)^2 - (0.527/12)^2) * (132/12)$

$= 6.9358\text{ ft}^3\text{/ft-pipe}$

Volume of RBCU fins = $(26112.25/2) * (0.007/12) = 7.6161\text{ ft}^3$

Ratio of total copper volume to tubing volume = (6.9358 + 7.6161.) / 6.9358 = 2.1

Velocity of water in RBCU tubes:

An initial RBCU flow of at least 2000 gpm is considered (Reference A7.12).

Initial flow of water/Unit = 2000 GPM = $(2000/60) * 0.1337 = 4.457\text{ ft}^3$/sec. = 278.12 lb/sec

Each coil has 4 passes. The water passes through one fourth of the total tubes per coil.

Initial flow / tube = $(4.457/1024) * 4 = 0.017409\text{ ft}^3$/sec

Velocity in the RBCU tube = $0.017409 / [(\pi/4) * (0.527/12)^2] = 11.493$ ft/sec

Inlet cooling water temperature = 95° F during accident.

Outlet cooling water temperature = 218.2° F during accident. (References A7.2, A7.12, A7.13, A7.14, and A7.15.)

Heat Transfer Coefficients:

Heat transfer coefficients for forced convection in the RBCU tubes and the 16-inch return pipe, and condensation in the 16-inch return line are computed below based on average temperatures and fluid velocities. These values will be verified using the results of the analysis.

Convection Heat Transfer in RBCU tubes:

The forced convection heat transfer coefficient in RBCU tubes during pump coast-down is calculated, based upon an average water temperature of $(95 + 218.2)/ 2 = 156.6\ ^{\circ}F$, as follows (Reference A7.8):

$Nu = 0.023\ Re^{0.8}\ Pr^{0.4}$

For 156.2 °F water flowing at velocity (v) 11.49265 ft/sec in a 0.527-inch tube, Nu, Re and Pr are calculated as follows:

At an average water temperature of 156.6 °F $Pr = 2.75$, $\mu = 89.9E\text{-}7$ lb.sec/ft^2, $\rho = 61.061$ lb/ft^3

$\mu / \rho = (89.9 / 1E\text{-}7) * (32.2 / 61.061) = 0.4741E\text{-}5$

$Re = v * d * \rho / \mu = 11.49265 * 0.527 / 12 * 10^5 / 0.4741 = 106459$

$Nu = 0.023 * (106459)^{0.8} * (2.75)^{0.4} = 0.023 * 10513 * 1.499 = 362.47$

$Nu = h * d / k = h * (0.527 / 12) * (1 / 0.379) = 362.47$, therefore

$h = Nu * k / d = 3128.$

This results in a forced convection heat transfer coefficient of 3128 Btu/hr-ft^2-°F. This value is adjusted with respect to Re throughout the coast-down time.

Convection Heat Transfer in the 16-inch return line:

The forced convection heat transfer coefficient in the 16-inch return line is calculated, based upon an average water temperature of 156.6° F and an average water velocity of an initial value of:

$(2000\ GPM/60) * (0.1337\ ft^3/sec/\ GPM) /(\pi/4* (15.25 / 12)) = 3.51\ ft/sec.$

The heat transfer coefficient can be calculated as follows (Reference A7.8):

$Nu = 0.023\ Re^{0.8}\ Pr^{0.4}$

For 156.6 °F water flowing at (v) 2.44 ft/sec in a 15.25-inches diameter pipe, Re and Pr are calculated as follows:

$Re = v * d * \rho / \mu = 3.51 * (15.25 / 12) * (1E5 / 0.4741) = 940862$

$Nu = 0.023 * (940862)^{0.8} * (2.75)^{0.4} = 0.023 * 60093 * 1.499 = 2072$

$h = 2072 * 0.379 / (15.25 / 12) = 618\ Btu/hr\text{-}ft^2\text{-}{}^oF$

This results in a forced convection heat transfer coefficient of 618 Btu/hr-ft^2-°F.

Condensation Heat Transfer in the 16-inch return line:

The steam generation in the coil is initiated at approximately 9 seconds and continues until the booster pump starts at approximately 42 seconds. During this time period a single containment temperature of 260°F is estimated from Table A1. Heat transfer due to condensation of steam on the inside surface of the 16-inch return line is calculated, based on an average saturation temperature of 260° F and an average surface temperature of 156.6° F, as follows:

$h_D = 0.555 [gr_f(r_f - r_v) k_f^3\ h'_{fg} / (m_f(T_{sat} - T_s) D)]^{1/4}$

where g is the acceleration of gravity, and where r, k, and m are the density, thermal conductivity, and viscosity of saturated liquid (f) and saturated vapor(g).

The modified latent heat is defined as

$h'_{fg} = h_{fg} + (3/8)\ c_{p,l} (T_{sat} - T_s)$

Based on an average saturation temperature of 260° F and an average surface temperature of 156.6° F, the above expression results in a condensation heat transfer coefficient of 731 Btu/hr-ft^2-°F.

Nucleate Boiling Heat Transfer in the 16-inch return line:

Nucleate boiling heat transfer is calculated as follows (Reference A7.9):

$Q = 10^6 * h_{n.b.} * A * (T_w - T_{sat})$

$h_{n.b.} = \exp [(2p / 1260) (T_w - T_{sat}) / 5184]$

where Q is in Btu/hr, p is in psia, $h_{n.b.}$ is the nucleate boiling heat transfer coefficient in Btu/hr-ft^2-°F, A is in ft^2, and T_w and T_{sat} are the wall and saturation temperatures respectively in °F.

The rate of heat addition to the RBCUs is determined based upon the RBCU outside surface area and temperature, the fin efficiency, and the post LOCA temperature and condensation heat transfer coefficient profiles provided in the VCSNS FSAR. The rate of heat addition to the water/steam inside the RBCUs is determined based upon the RBCU inside surface area and temperature, the water/steam temperature and pressure, and the forced convection/boiling heat transfer coefficient at the inside surface of the RBCU tubes, depending upon the surface and saturation temperatures. The difference between the above values is the rate of heat addition to the copper tubes and fins throughout the transient.

The rate of heat addition from the containment atmosphere to the 16-inch return line in contact with water is determined based upon the pipe diameter, the insulation layer thickness and material, and the post LOCA temperature and condensation heat transfer coefficient profiles provided in the VCSNS FSAR. The rate of heat addition from the 16-inch return line to the water inside that line is determined based upon the pipe inside surface area and temperature, the water temperature, and the forced convection heat transfer coefficient calculated above. The difference between the above values is the rate of heat addition to the pipe throughout the transient.

The rate of heat addition from the steam generated in the RBCUs to the 16-inch return line is determined based upon the pipe inside surface area and temperature, the saturation temperature, and the condensation heat transfer coefficient calculated above. The rate of heat addition from the containment atmosphere to the 16-inch return line in contact with steam is determined based upon the pipe diameter, the insulation layer thickness and material, and the post LOCA temperature and condensation heat transfer coefficient profiles provided in the VCSNS FSAR. The total of the above values is the rate of heat addition to the pipe throughout the transient.

The rate of steam generation in the RBCUs depends upon the RBCU pressure and the rate of heat addition to the water inside the RBCU. The net steam generation rate is the difference between the steam generation rate in the RBCU and the steam condensation rate in the 16-inch return line. This net steam generation rate will exert a force on the water column in the 16-inch return line.

The force exerted by the generated steam on the water column in the 16-inch return line should equal the total of the frictional force in the pipe, the rate of change in momentum of the water column, and the force due to the difference in elevation, in addition to the force acting on that column due to the back pressure.

The equations governing the above heat transfer and fluid flow mechanisms are solved simultaneously throughout the transient using a simplified algorithm that has been developed specifically for this analysis. The algorithm, including listing and validation, is provided in Section A9.

Cases 1 and 2 evaluate RBCU XAA-1A and differ only in the assumed LOCA temperatures, heat transfer coefficients and fouling factors. Like wise, Cases 3 and 4 evaluate RBCU XAA-1B and differ only in the assumed LOCA temperatures, heat transfer coefficients and fouling factors. The specific LOCA temperatues, heat transfer coefficients, and fouling factors are:

Cases A1 and A3:

These cases are based upon the containment post LOCA temperatures and structural heat transfer coefficients provided in the VCSNS FSAR (Reference A7.3), and on a fouling factor of 0.0 in the tubes of RBCU's XAA-1A and XAA-1B respectively. For these cases, a pump coast-down of 10 seconds is assumed.

Cases A2 and A4:

These cases are based upon temperatures and heat transfer coefficients 15% lower than the post LOCA values provided in the VCSNS FSAR, and upon a fouling factor of 0.001 in the tubing of RBCU's XAA-1A and XAA-1B respectively. This would result in a reduced heat flow to each RBCU, and accordingly a lower RBCU pressure and a lower flow velocity in the 16-inch return line.

A6 RESULTS AND DISCUSSION

The result of the calculations are shown graphically in Figures A1-1 through A4-4. Each figure shows the pertinent parameter during the pump coast down (0 to 9 seconds), onset of boiling in the coil (9 to 12 seconds) and steady flow (12 seconds to end of transient).

Cases A1 and A3:

For RBCU XAA-1A (Case A1): The maximum pressure is 26.97 psia at 16.3 seconds and decreases to 25.31 psia at 20 seconds (Figure A1-1). At 9.0 seconds, boiling of the trapped fluid begins, followed by a rapid pressurization of the system over the next 3 seconds. The maximum flow velocity of water in the 16-inch return line is 12.6 ft/sec at 12.0 seconds. This decreases to 12.0 ft/sec at 20 seconds. The results are shown in Figure A1-2. These flow velocities correspond to a Froude number within the range of 1.97 to 1.88.

Similarly, for RBCU XAA-1B (Case A3): The maximum pressure is 28.43 psia at 17.7 seconds and decreases to 27.56 psia at 20 seconds (Figure A3-1). At 8.9 seconds, boiling of the trapped fluid begins, followed by a rapid pressurization of the system over the next 3 seconds. The maximum flow velocity of water in the 16-inch return line is 9.96 ft/sec at 11.4 seconds. This decreases to 7.88 ft/sec at 20 seconds. The results are shown in Figure A3-2. These flow velocities correspond to a Froude number within the range of 1.55 to 1.23.

For cases A1 and A3 the estimated range of Froude numbers is 1.23 to 1.97. The test results presented in FAI/96-75 (Reference A7.6) show that condensation induced water hammer will not occur for this configuration at Froude numbers, above unity. In test reported in Reference A7.6, condensation induced water hammer was detected only at values of Froude number near 0.1, and characterized as multiple successive pressure peaks of low magnitude that indicated rapid and successive collapse of small scale vapor bubbles.

Cases A2 and A4:

For RBCU XAA-1A (Case 2): The velocity of water in the 16-inch return line is shown in Figure A2-2. At 9.6 seconds, boiling of the trapped fluid begins, followed by a rapid pressurization of the system over the next 3 seconds. The water in the return line is accelerated to 10.99 ft/sec until the friction forces balance with the forces exerted by the steam bubble. At this time, approximately 16 seconds of the initiation of the event, the flow decreases to 9.72 ft/sec at 20 seconds. These flow velocities correspond to a Froude number within the range of 1.72 to 1.52.

Similarly, for RBCU XAA-1B (Case 4): The velocity of water in the 16-inch return line is shown in Figure A4-2,. At 9.6 seconds, boiling of the trapped fluid begins, followed by a rapid pressurization of the system over the next 3 seconds. The water in the return line is accelerated to 8.63 ft/sec until the friction forces balance with the forces exerted by the steam bubble. At this time. approximately 20 seconds of the initiation of the event, the flow decreases to 5.72 ft/sec at 20 seconds. These flow velocities correspond to a Froude number within the range of 1.35 to 0.89.

For Cases A2 and A4 the estimated range of Froude numbers is 0.89 to 1.72. The test results presented in FAI/96-75 (Reference A7.6) show that condensation induced water hammer will not occur for this configuration, at Froude numbers, near or above unity. In test reported in Reference A7.6, condensation induced water hammer was detected only at values of Froude number near 0.1, and characterized as multiple successive pressure peaks of low magnitude that indicated rapid and successive collapse of small scale vapor bubbles.

Figures A1-4, A2-4, A3-4 and A4-4 show that all the water in the RBCU's will be evaporated before the Booster Pump starts after 41.5 seconds following initiation of the accident. The temperature of the tubes will not exceed the saturation temperature of the steam inside the containment, which is about 270° F.

The effects of tube fouling and reduced heat transfer to the RBCUs can be seen by comparing Case A1 with Case A2 and Case A3 with Case A4. These comparisons are similar, therefore the following discussion provides a comparison for Case A1 with Case A2 and the observations and conclusions apply to the other comparison. The primary effects of the reduced heat transfer and increased fouling factor are seen by comparing the results in Figures A1-1 and A2-1.

Due to the reduction in thermal gradient and the increase in the thermal resistance the time to boiling is expected to be delayed. The time to boiling is delayed approximately 0.5 seconds.

Subsequent to the onset of boiling, the pressures developed in the RBCUs is reduced as expected due to the reduction in the heat transfer. The peak pressures are reduced from approximately 25 psia to approximately 12 psia. Accordingly, the velocity of fluid being transported into the return line is reduced from approximately 13 feet per second to approximately 11 feet per second. (See Figures A1-2 and A2-2.) Comparison of the system temperatures shown in Figures A1-3 and A2-3 indicate that there is a reduction in the system temperatures of 20°F to 30°F due to the reduced heat transfer and fouling. The lower temperatures result in reduced steam production. Lower system pressure, however, tends to increase steam production, thus off setting the effect of lower temperature. As seen in a comparison of Figures A1-4 and A2-4, the net steam production is reduced from approximately 164 cubic feet to approximately 130 cubic feet at 20 seconds into the transient.

These comparisons indicate that the RBCUs will produce sufficient steam to accelerate the water in the return line and maintain the water velocities at a value sufficient to produce Froude Numbers near or above unity, thus precluding the occurrence of condensation induced water hammer. This conclusion is also valid under the degraded conditions for heat transfer expected to exist in the plant, i. e. heat transfer coefficient reduced by 15% and a fouling factor of 0.001.

If an RBCU's outlet isolation valve, i. e. XVG-3109, is closed, the RBCU will be open from the booster pump side and closed from the return side. This will result in the evaporation of the water in the affected RBCU and the steam will be forced to the supply side toward the RBCU inlet isolation valve, i. e. XVG-3108. However, when the booster pump starts at 41.5 seconds the steam in the pipe will be condensed up to the RBCU, where the tubes are still heated as a result of LOCA. The condensation of the water in the RBCU will take place gradually, without water hammer effect. This boiling of RBCU water has the same effect when the system is aligned to the industrial cooling system which assures the pressure will be relieved through the 16-inch service water return lines upon the start of the booster pump and opening the RBCU outlet valves, i. e. XVG-3107.

A7 REFERENCES

A7.1 VCSNS Drawings:

E-302-221, Revision 19 System Flow Diagram - Service Water Cooling
E-302-222, Revision 33, System Flow Diagram - Service Water Cooling
E-304-252 , Revision 1, Service Water Cooling Int. Building Plan -- Below EL. 412' - 0", Col 5.2 - 9.1
E-304-253 , Revision 4, Service Water Cooling Int. Building Plan -- Below EL. 436' - 0", Col 2.8 -5.2
E-304-254 , Revision 11, Service Water Cooling Int. Building Plan -- Below EL. 454' - 0". Col 5.2 - 9.2
E-304-255 , Revision 11, Service Water Cooling PEN, Access Area Aux. Plans EL 412'-0", 436'-0", 463'-0"
E-304-256 , Revision 12, Service Water Cooling Auxiliary Plans, Sections and Details
E-304-257, Revision 3, Service Water Cooling, Reactor Building Plan and Sections Above EL 463'-0"
E-304-258, Revision 9, Service Water Cooling Reactor Building Sections and Details
C-314-251, Sheet 1. Revision 5, Service Water - To & From Comp. Cooling Heat Exchanger "A"
C-314-251, Sheet 2. Revision 3, Service Water - To & From Comp. Cooling Heat Exchanger "B"
C-314-251, Sheet 3, Revision 1, Service Water - Booster Pump "A" Suction
C-314-251, Sheet 4, Revision 5, Service Water - Booster Pump "A" Discharge to Penetration #304
C-314-251, Sheet 5. Revision 4, Service Water - Loop "A" Return From Penetration #305 To EL 412'-0"
C-314-251, Sheet 6. Revision 2, Service Water - Booster Pump "B" Suction
C-314-251, Sheet 7. Revision 6, Service Water - Booster Pump "B" Discharge to Penetration #403
C-314-251, Sheet 8, Revision 5, Service Water - Loop "B" Return From Penetration #102 To EL 412'-0"
C-314-251, Sheet 11, Revision 5, Service Water - From Penetration 403 To Reactor Building Cooling Unit, "1B" & "2B"
C-314-251, Sheet 12, Revision 3, Service Water - From Reactor Building Cooling Units "1B" & "2B" To Pen. #102
C-314-251, Sheet 13, Revision 3, Service Water -From Pen. #304 To Reactor Building Cooling Units "1A" & "2A"

C-314-251, Sheet 14, Revision 1, Service Water - From Pen #304 To Reactor Building Cooling Units "1A" & "2A" - Details
C-314-251, Sheet 15, Revision 4, Service Water - From Reactor Building Cooling Units "1A" & "2A" To Penetration #305
C-314-251, Sheet 16, Revision 3, Service Water - From Reactor Building Cooling Units "1A" & "2A" To Penetration #305- Details
C-314-251, Sheet 17, Revision 4, Service Water - Service Water Pump Discharge Line
1MS-54-098, Revision 0, V. C. Summer Coolers

A7.2 Bill of Materials SM-3, "Heating, Ventilating Air-conditioning and Air Handling Systems", dated May 8, 1975

A7.3 VCSNS FSAR

A7.4 ASME Steam Tables, 1967.

A7.5 ASHRAE Handbook, Fundamentals Volume, 1989.

A7.6 Fauske and Associates, Inc. Report, FAI/96-75, "Evaluation of Possible Water-Hammer Loads in the Service Water System for DBA Conditions", R. E. Henry, Dated October 16, 1996. Presented at the NEI GL 96-06 Industry Meeting on October 29, 1996.

A7.7 Wallis, G. B., Crowley, C. J. and Hagi, Y., 1977, "Conditions for a Pipe to Run Full when Discharging Liquid into a Space Filled With Gas," Transactions of the ASME, Journal of Fluids Engineering, Volume 99, pp. 405-413.

A7.8 Incoropera, F. P. and DeWitt, D. P., 1990, Introduction to Heat Transfer, John Wiley & Sons, Inc., New York.

A7.9 Lahey, R. T. and Moody, F. J., 1977, The Thermal-Hydraulics of a Boiling Water Nuclear Reactor, ANS.

A7.10 Crane Technical Paper No. 410, "Flow of Fluids Through Valves, Fittings and Pipe," Twentieth Volume, 1981.

A7.11 NUREG-5220, "Diagnosis of Condensation-Induced Waterhammer", October 1988.

A7.12 VCSNS Specification, SP-534-044461-000, "Reactor Building Cooling Unit," dated October 4, 1973.

A7.13 AAF Document, CoolNuc G7020M, "Containment Coolers Normal Perf. @ 50% RH (Wet Bult Temp: 100F)" dated February 6, 1997.

A7.14 AAF Document, CoolNuc G7020M, "Containment Coolers Normal Perf. @ 30% RH (Wet Bult Temp: 89F)" dated February 6, 1997.

A7.15 AAF Document, CoolNuc G7020M, "Containment Coolers Normal Perf. @ 20% RH (Wet Bult Temp: 82F)" dated February 6, 1997.

Figure A1-1 Case1 : Pre Pump Startup - Pressures for RBCU XAA-1A
H.T.=100% , Fouling Factor =0.0

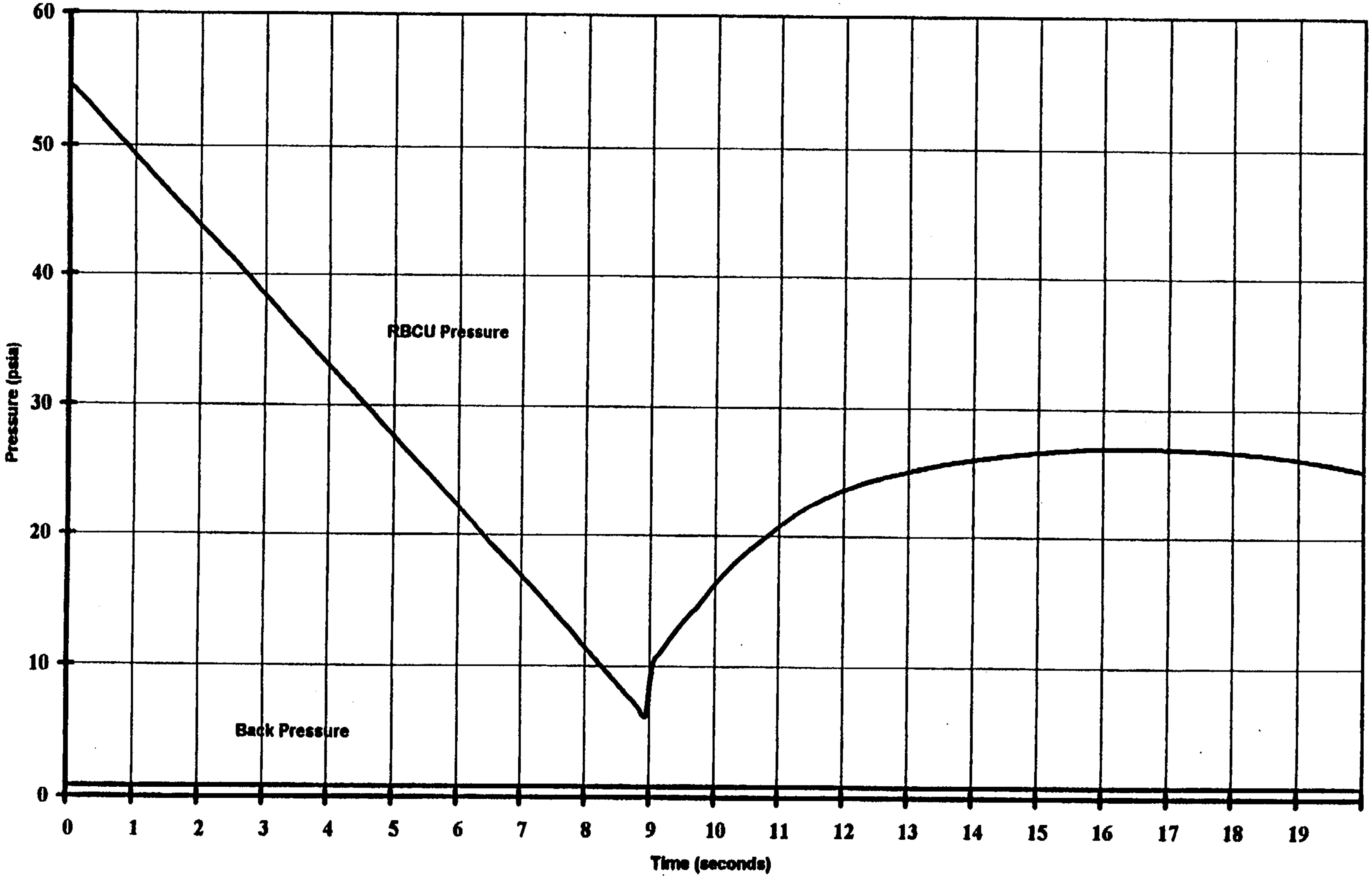


Figure A1-2 Case 1 : Pre P/P Startup - Velocity of Water in The Return Line - RBCU XAA-1A
H.T. =100%, Fouling Factor =0.0

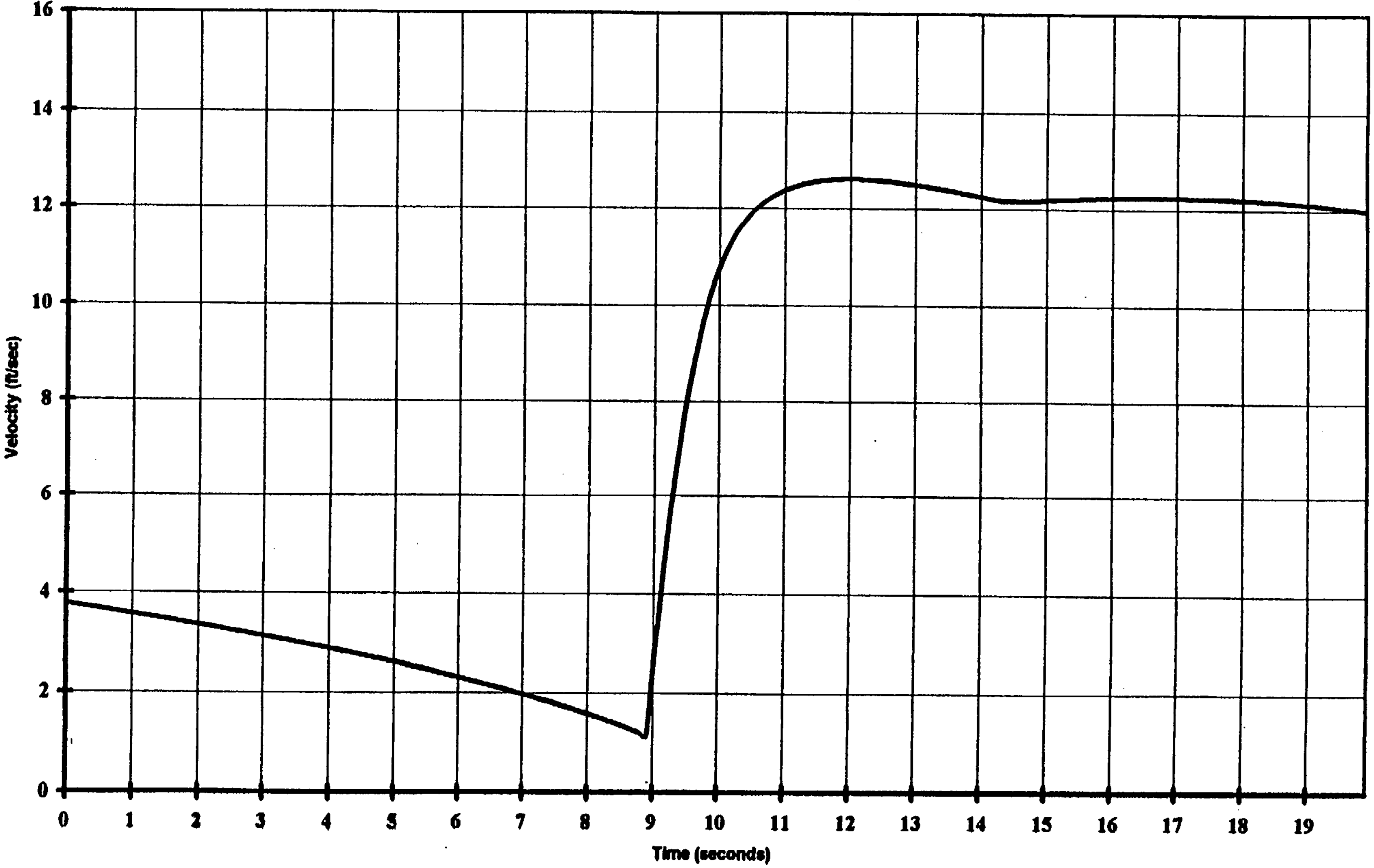


Figure A1-3 Case 1 : Pre Pump Startup - Temperatures for RBCU XAA-1A
H.T. =100% , Fouling Factor =0.0

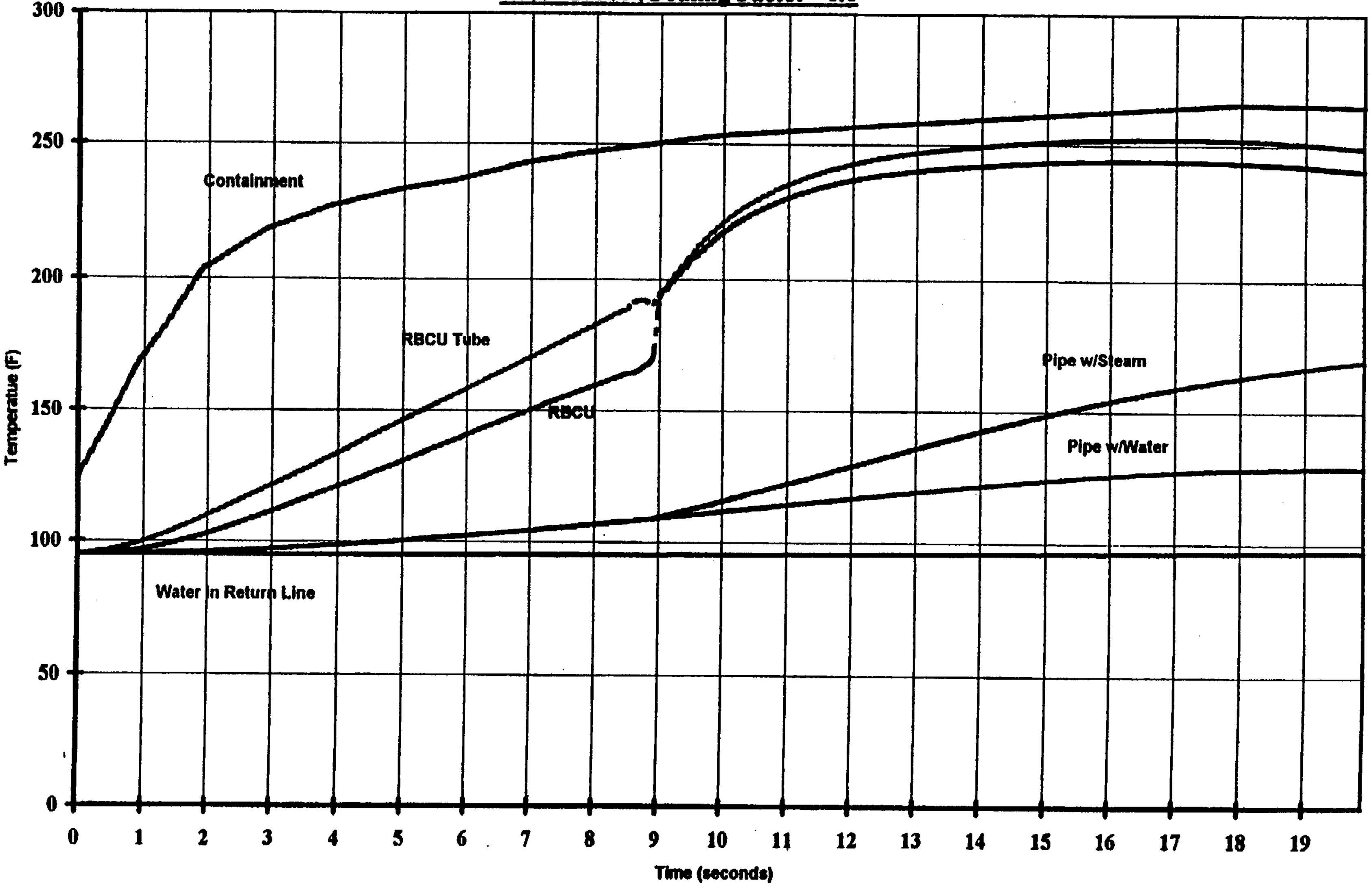


Figure A1-4 Case 1 : Pre Pump Startup - Volume of Steam - RBCU XAA-1A
H.T. =100%, Fouling Factor =0.0

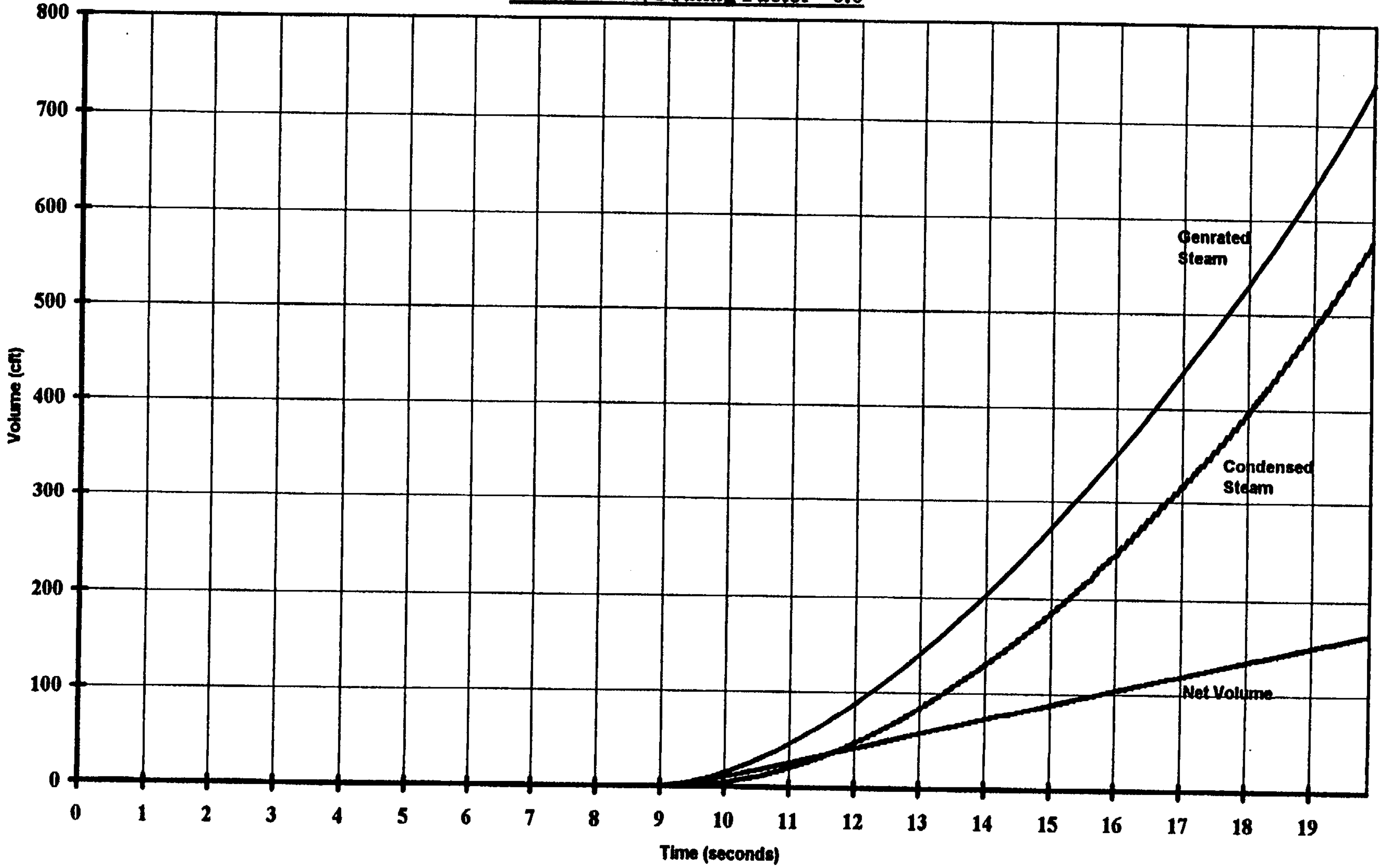


Figure A2-1 Case2 : Pre Pump Startup - Pressures for RBCU XAA-1A
H.T.=85% , Fouling Factor =0.001

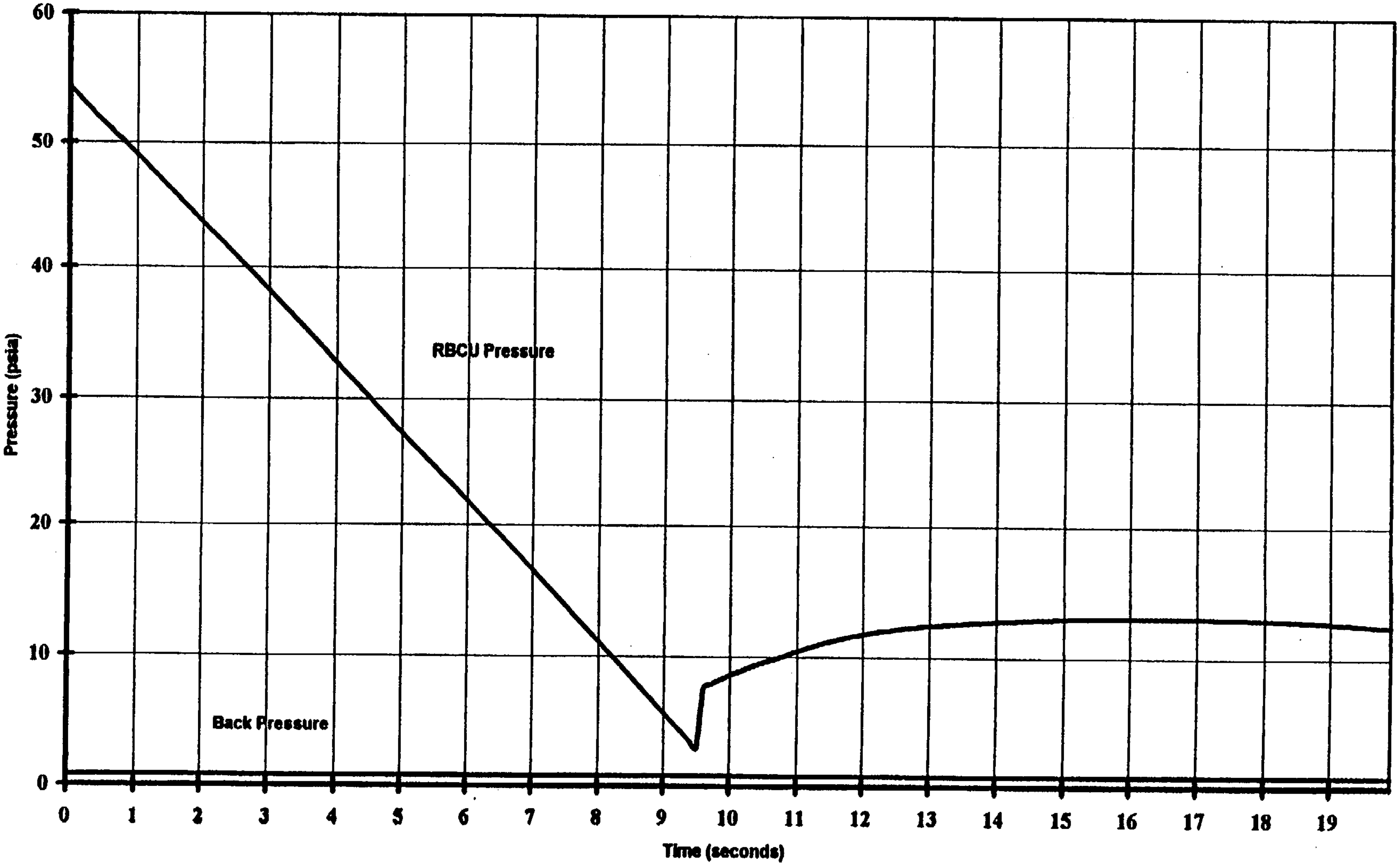


Figure A2-2 Case 2 : Pre P/P Startup - Velocity of Water in The Return Line - RBCU XAA-1A
H.T. =85%, Fouling Factor =0.001

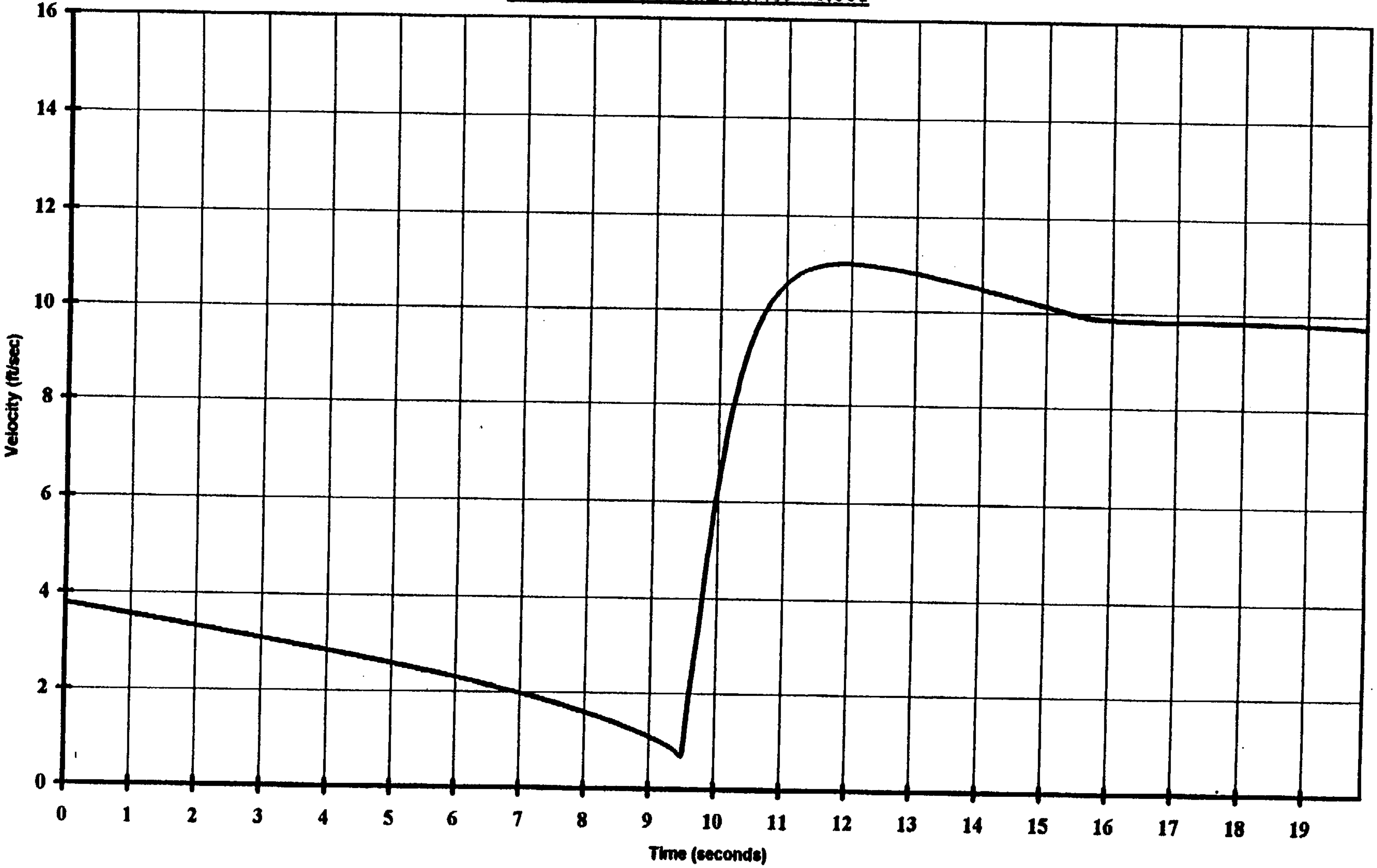


Figure A2-3 Case 2 : Pre Pump Startup - Temperatures for RBCU XAA-1A
H.T. =85% , Fouling Factor =0.001

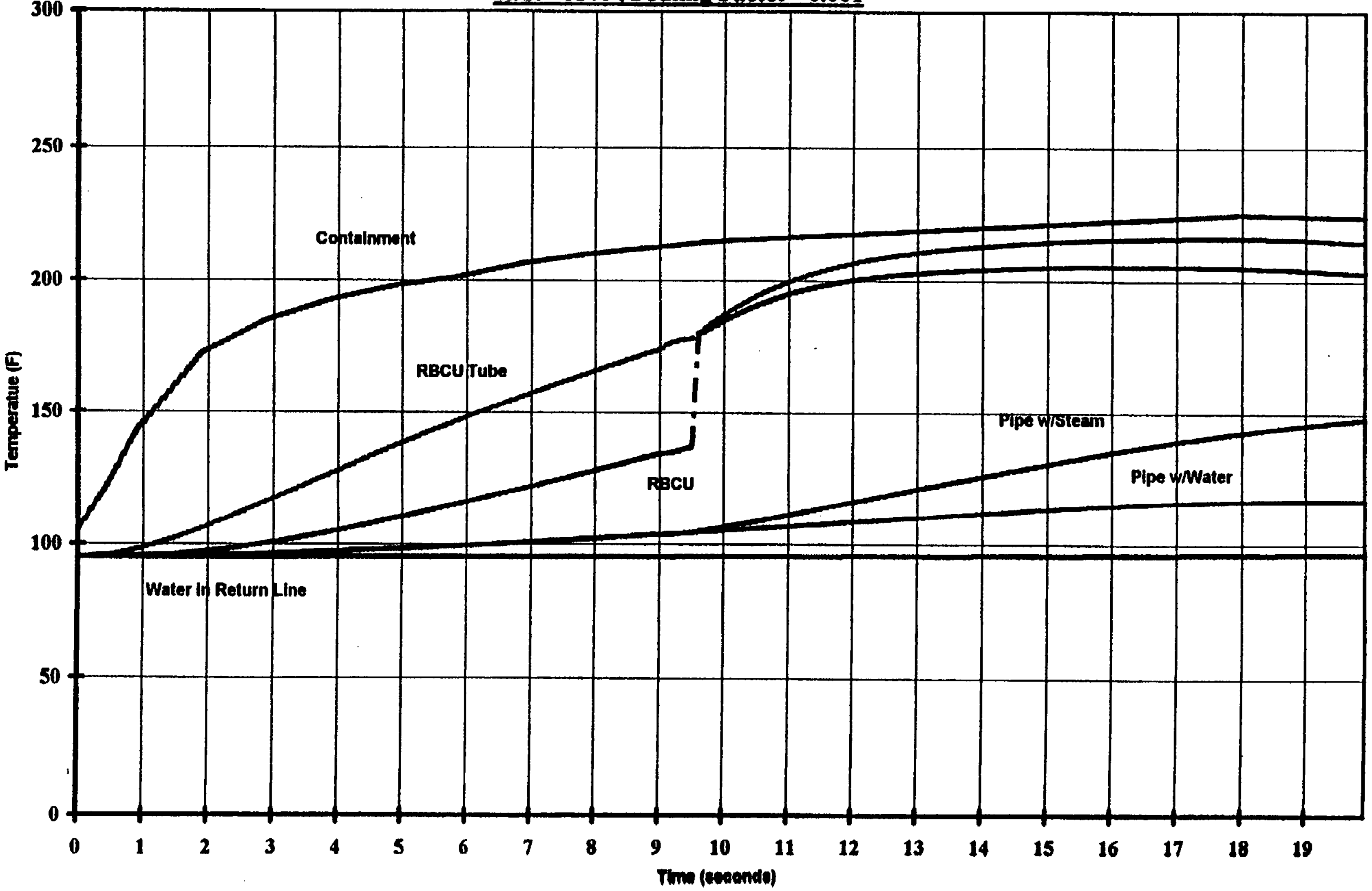


Figure A2-4 Case 2 : Pre Pump Startup - Volume of Steam - RBCU XAA-1A
H.T. =85%, Fouling Factor =0.001

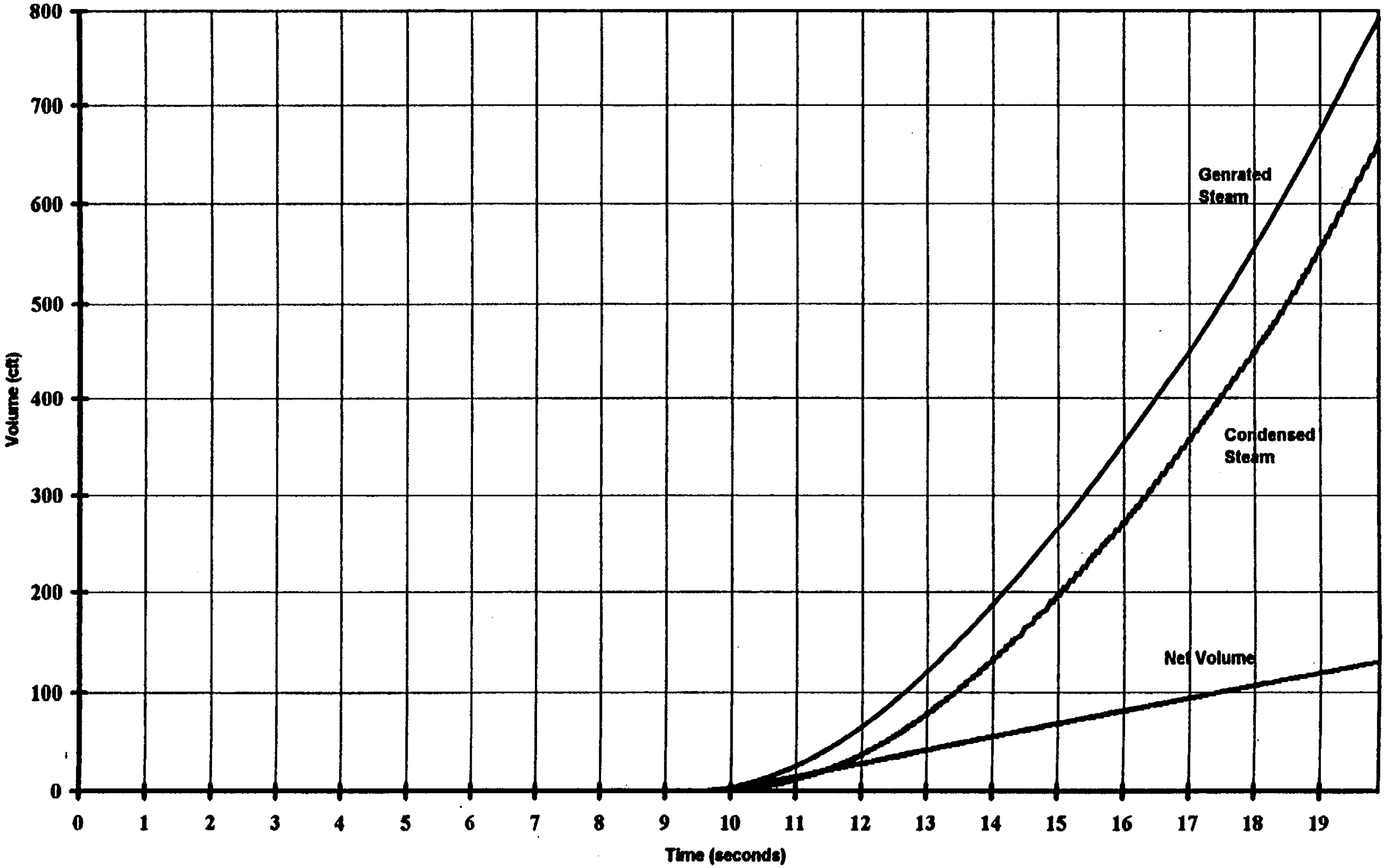


Figure A3-1 Case 3 : Pre Pump Startup - Pressures for RBCU XAA-1B
H.T.=100% , Fouling Factor =0.0

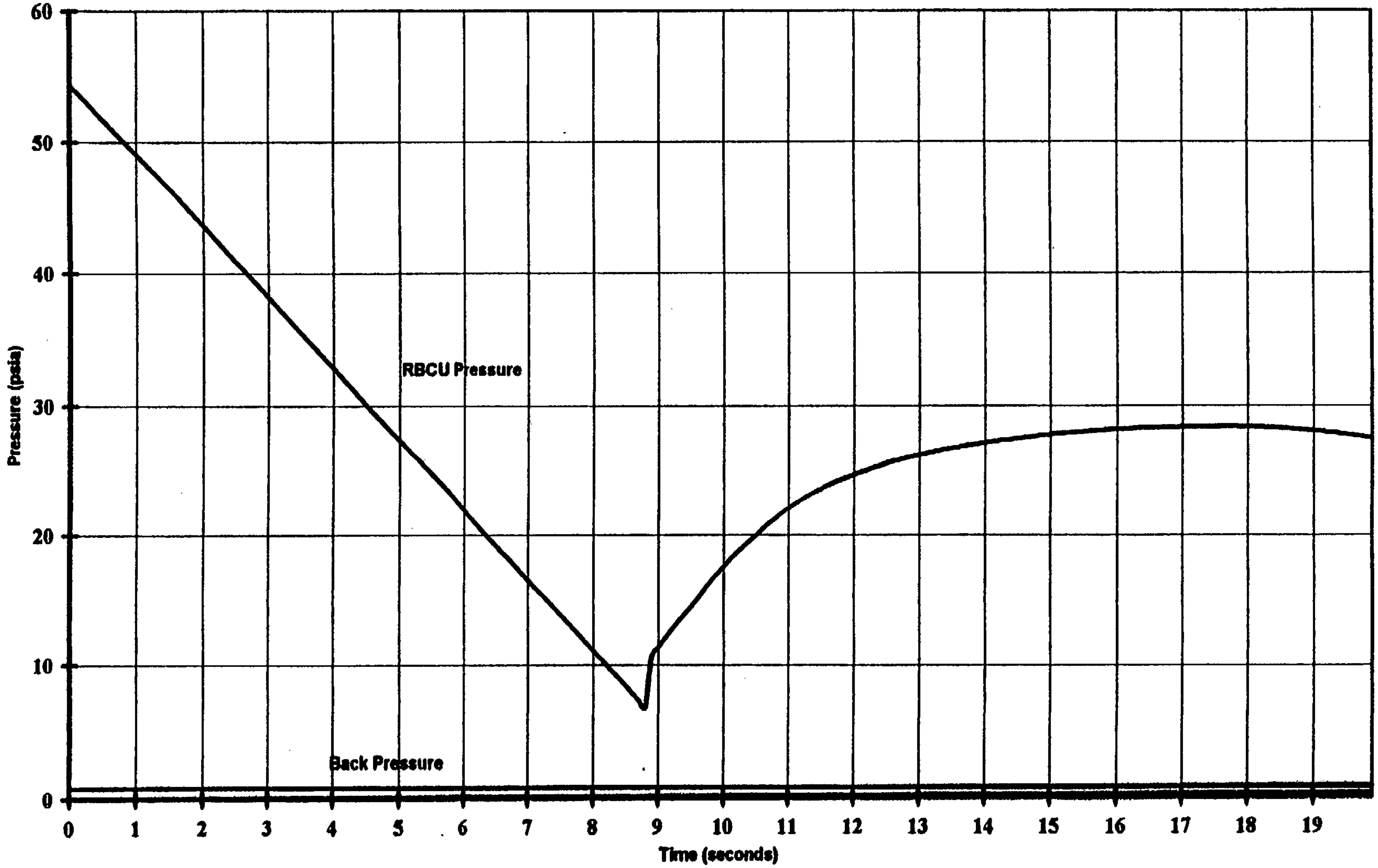


Figure A3-2 Case 3 : Pre P/P Startup - Velocity of Water in The Return Line - RBCU XAA-1B
H.T. = 100%, Fouling Factor =0.0

Figure A3-3 Case 3 : Pre Pump Startup - Temperatures for RBCU XAA-1B
H.T. =100% , Fouling Factor =0.0

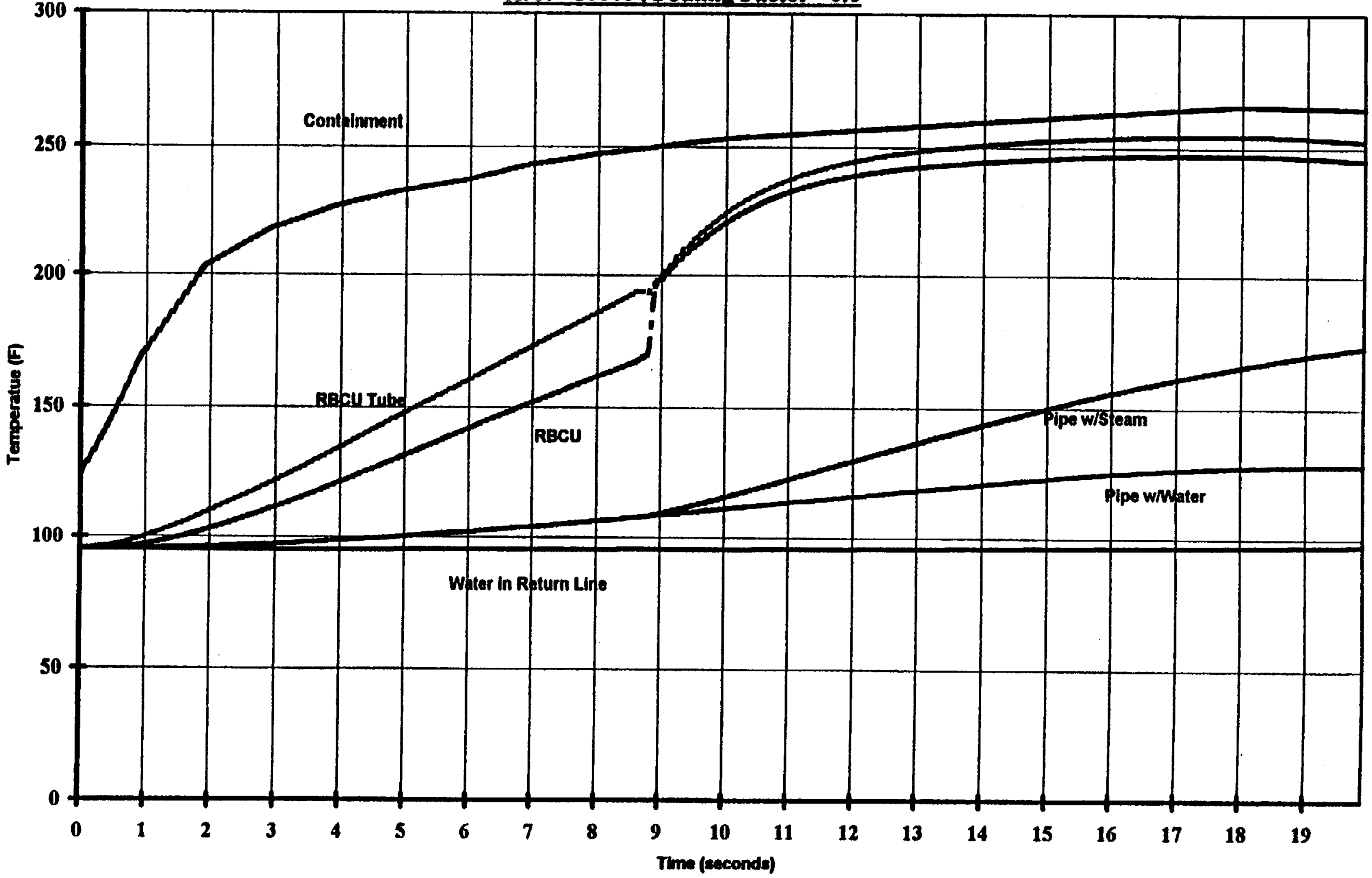


Figure A3-4 Case 3 : Pre Pump Startup - Volume of Steam - RBCU XAA-1B
H.T. =100 %, Fouling Factor =0.0

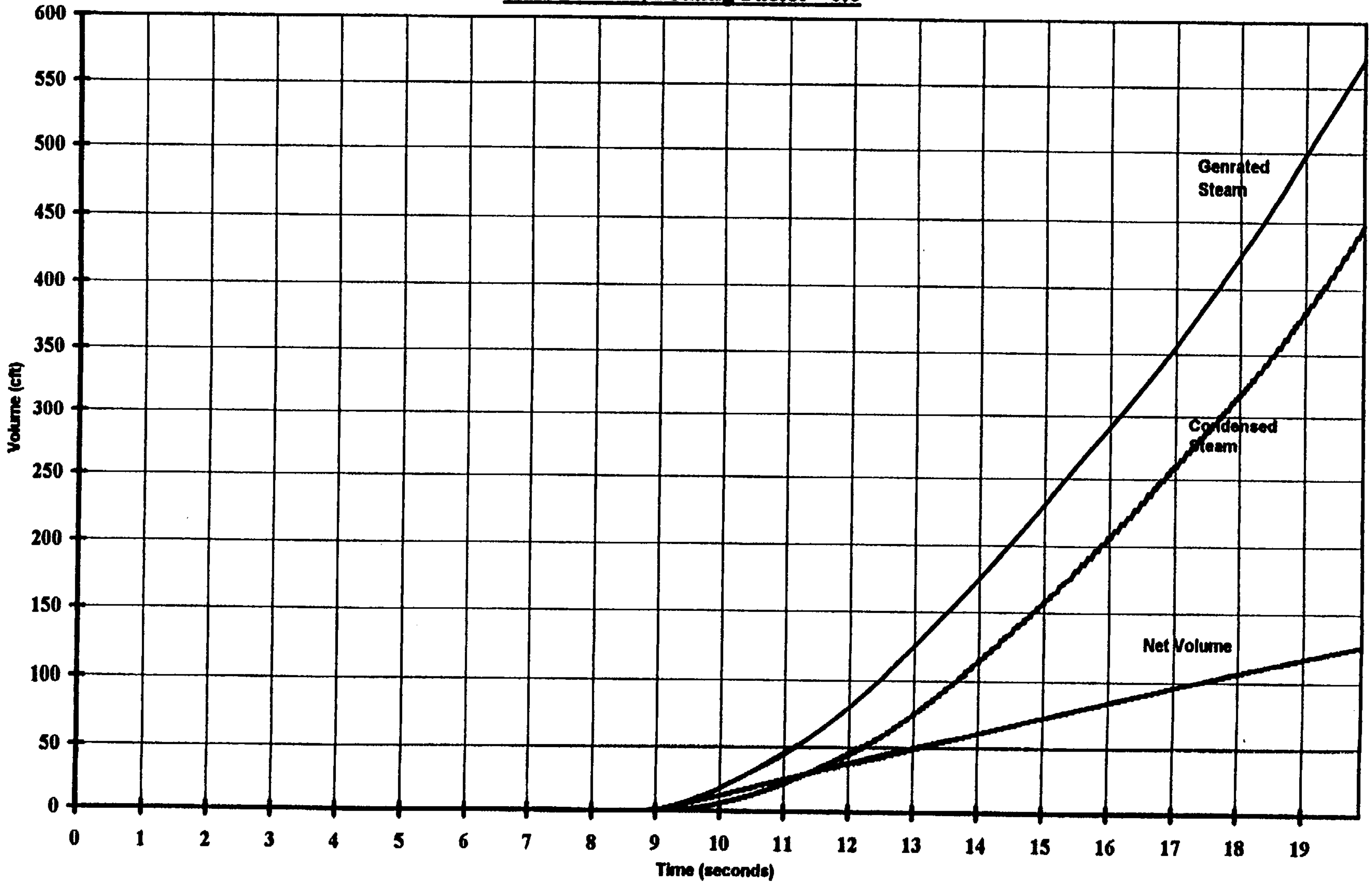


Figure A4-1 Case 4 : Pre Pump Startup - Pressures for RBCU XAA-1B
H.T.=85% , Fouling Factor =0.001

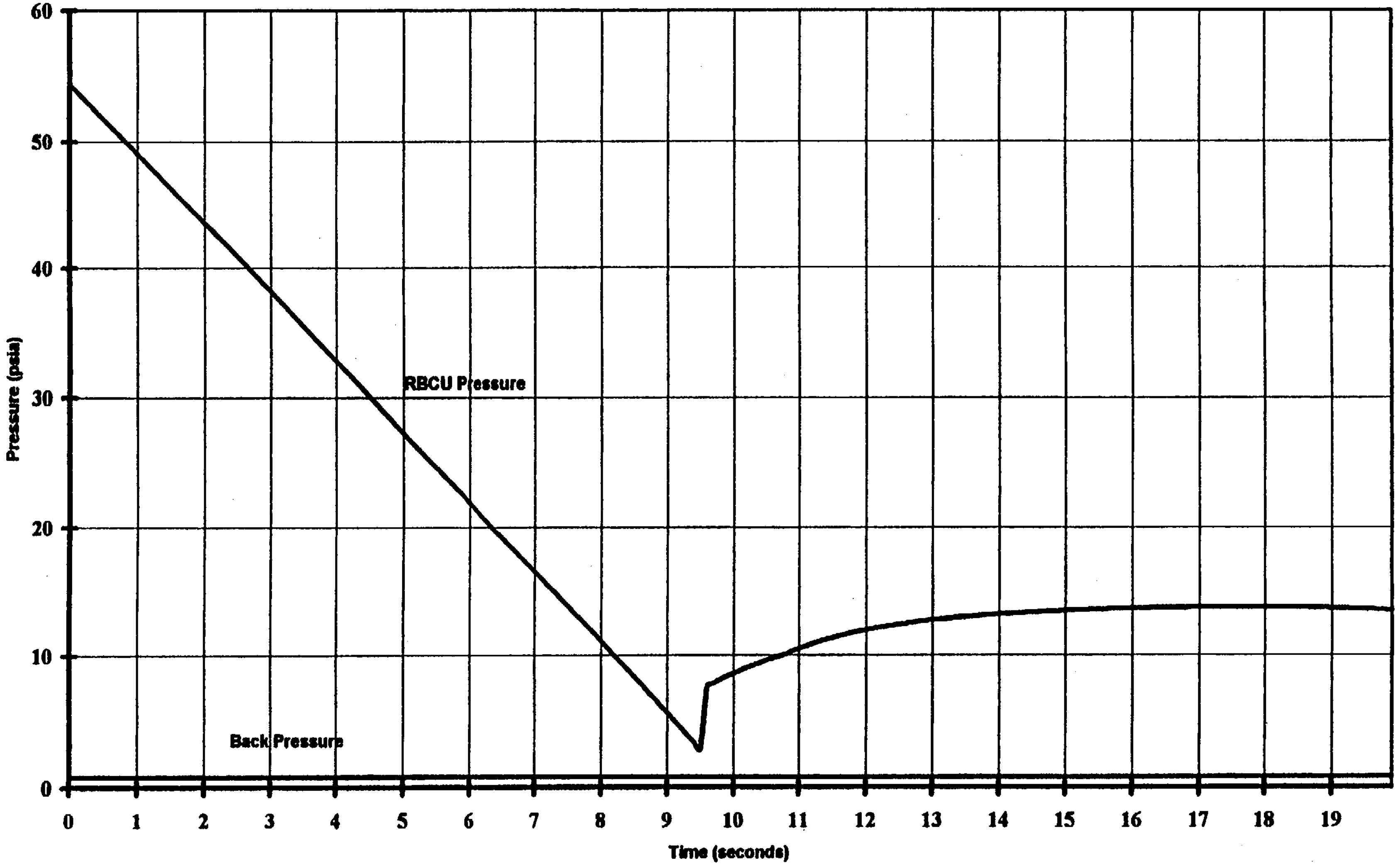


Figure A4-2 Case 4 : Pre P/P Startup - Velocity of Water in The Return Line - RBCU XAA-1B
H.T. =85%, Fouling Factor =0.001

Figure A4-3 Case 4 : Pre Pump Startup - Temperatures for RBCU XAA-1B
H.T. =85 % , Fouling Factor =0.001

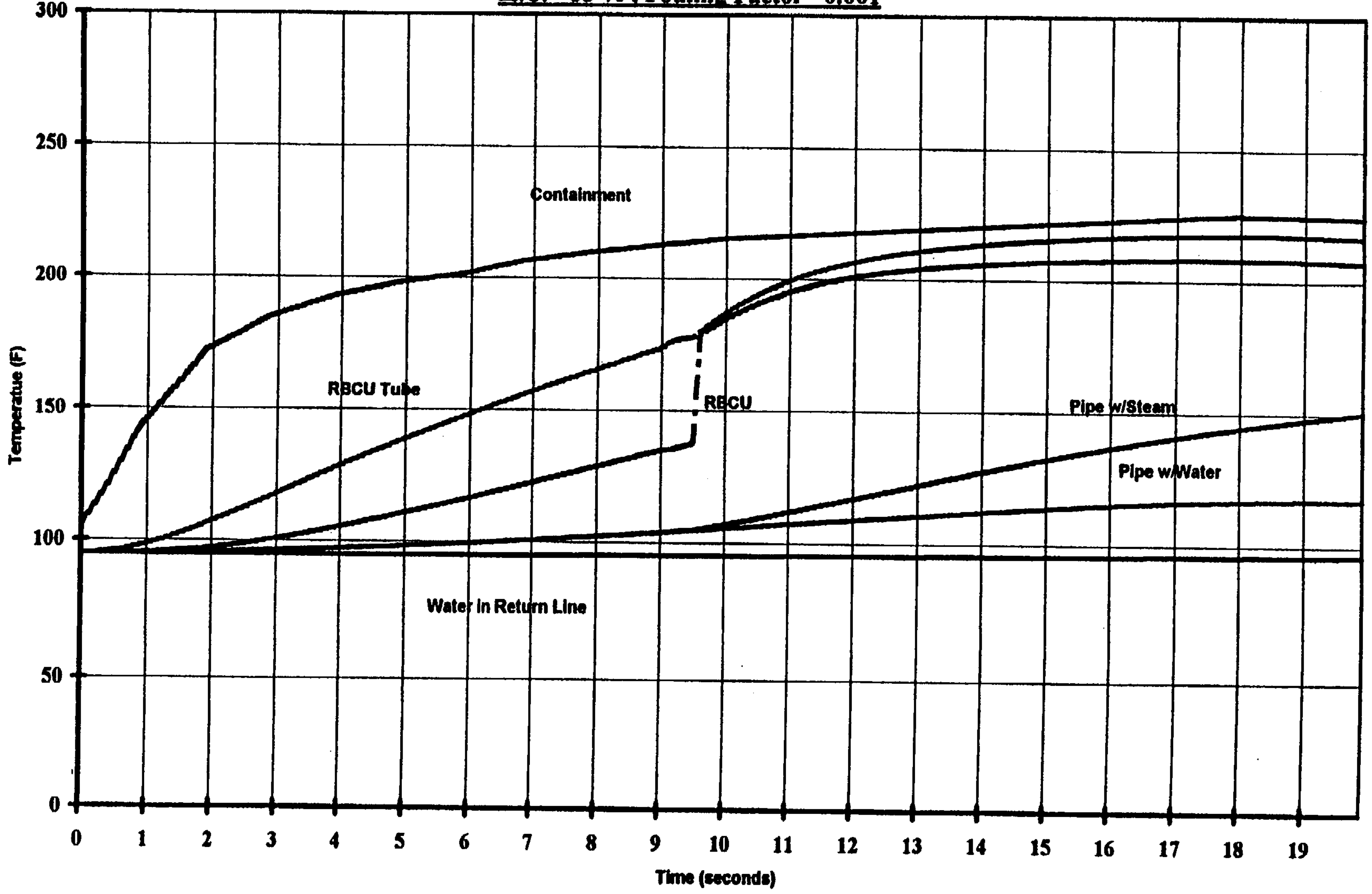


Figure A4-4 Case 4 : Pre Pump Startup - Volume of Steam - RBCU XAA-1B
H.T. =85 %, Fouling Factor =0.001

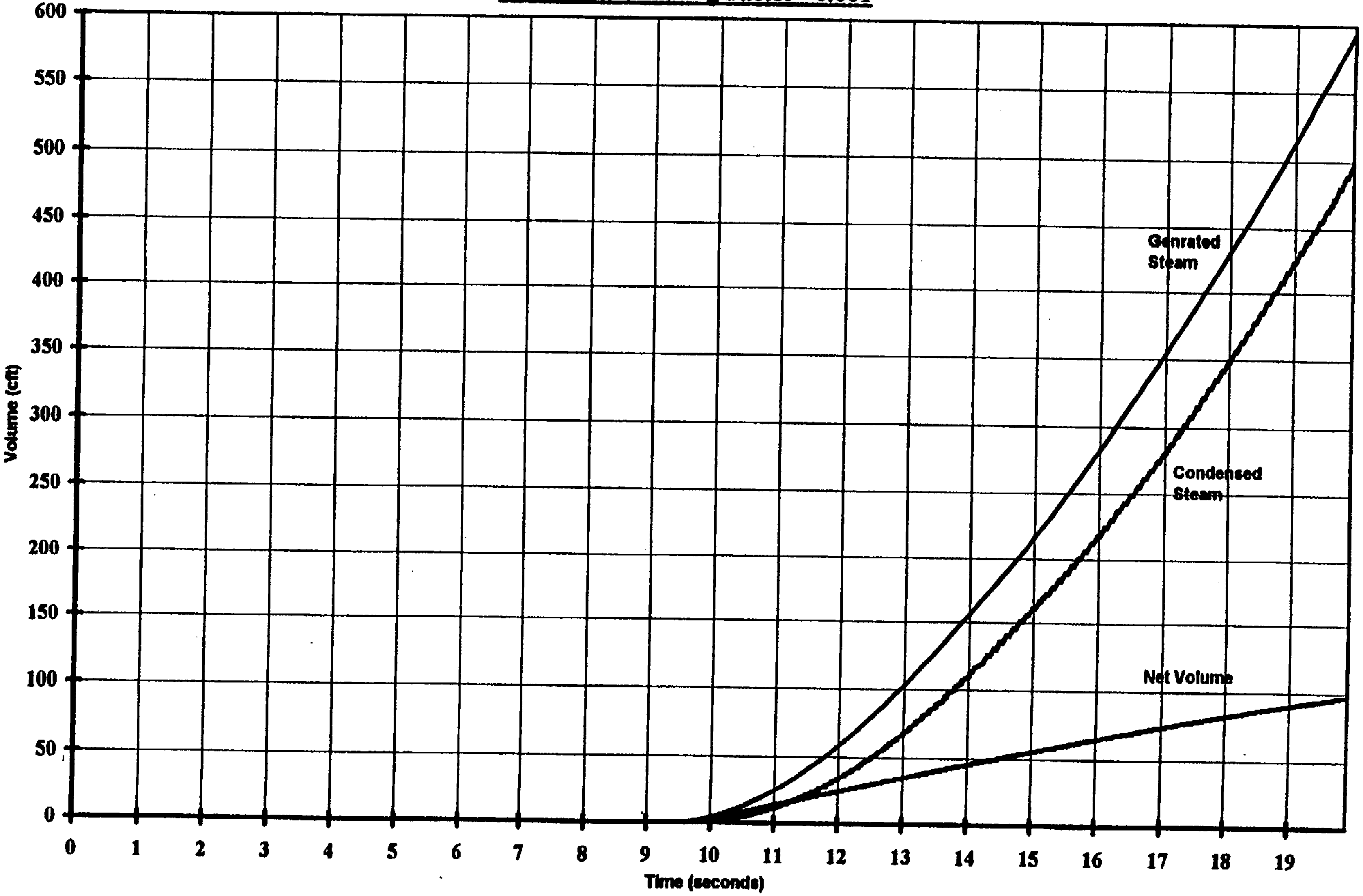


Figure A5-1 Case 5 : Pre Pump Startup - Pressure for RBCU XAA-1A
H.T.=100%, Fouling Factor =0.0

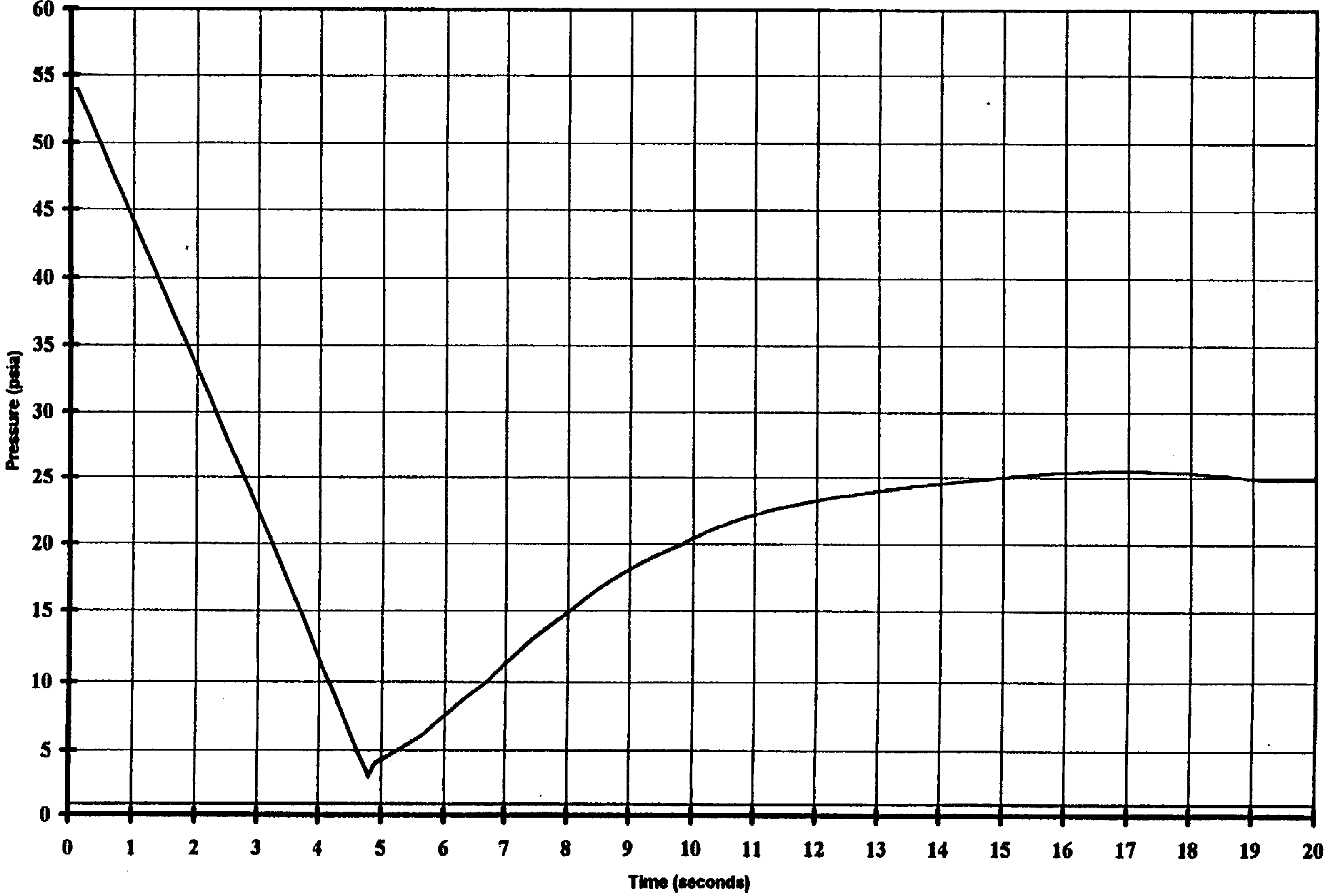


Figure A5-2 Case 5 : Pre P/P Startup - Velocity of Water in The Return Line RBCU XAA-1A
H.T.=100%, Fouling Factor =0.0

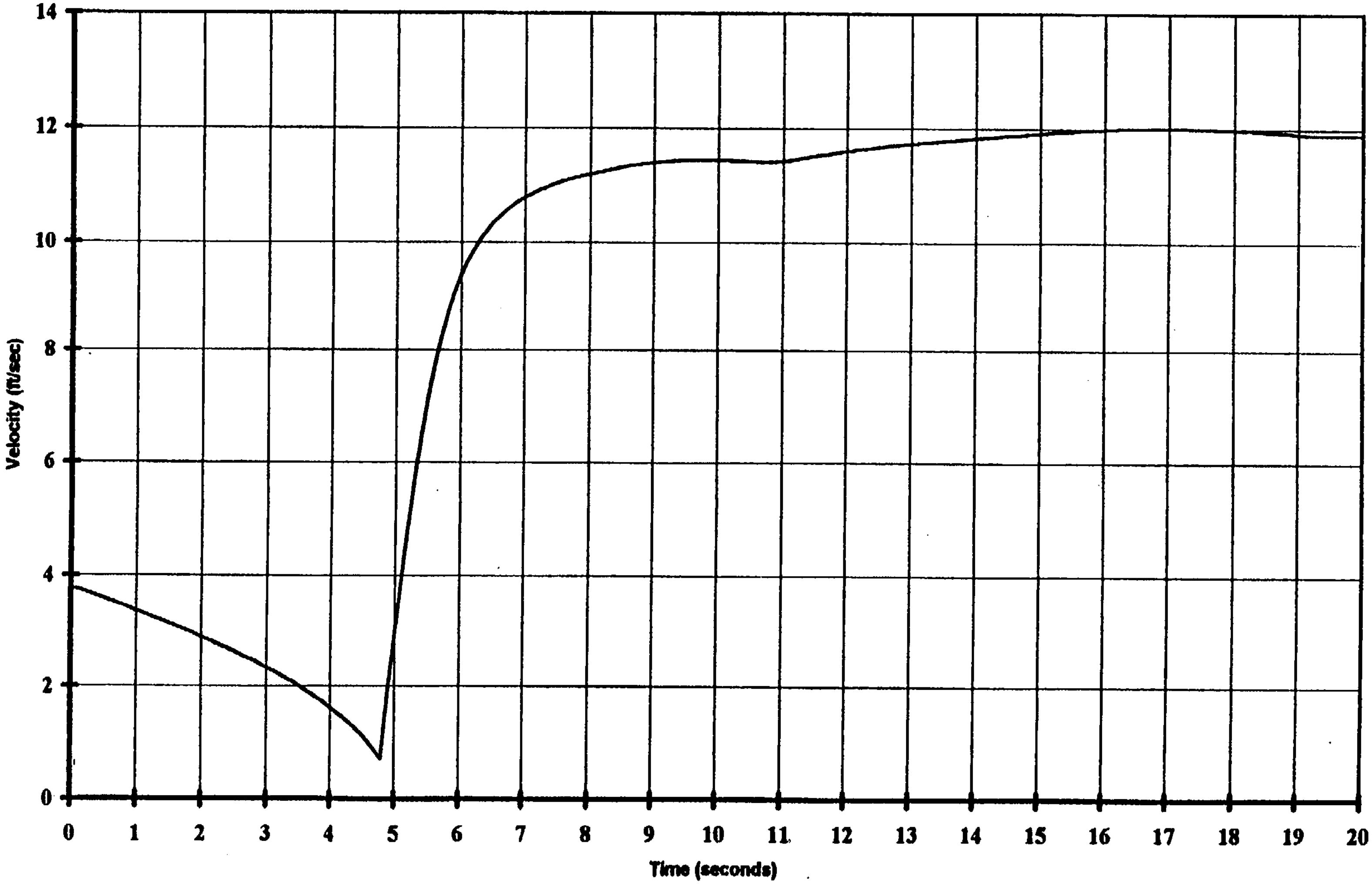


Figure A5-3 Case 5 : Pre Pump Startup - Temperatures For RBCU XAA-1A
H.T.=100%, Foouling Factor =0.0

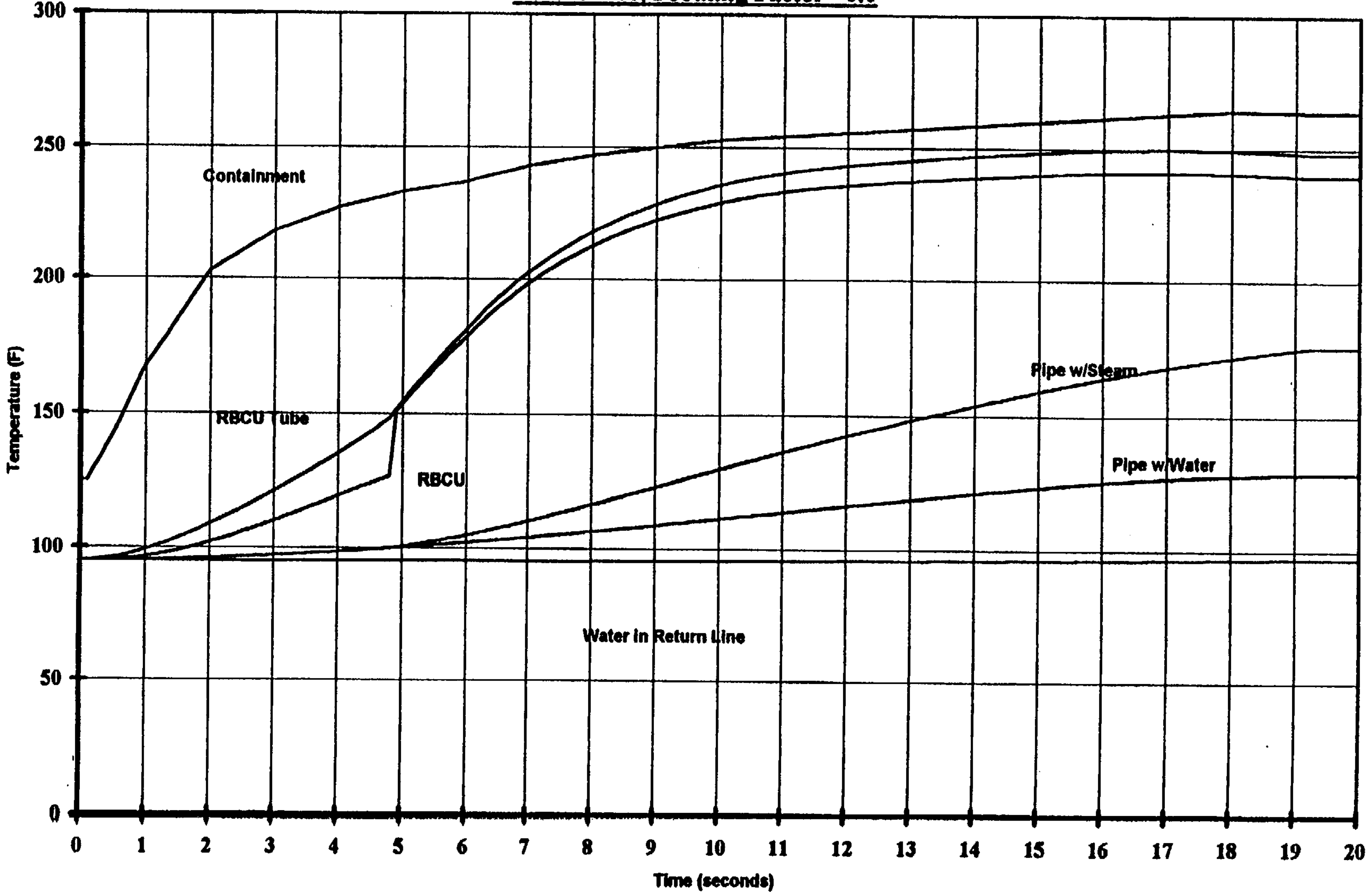
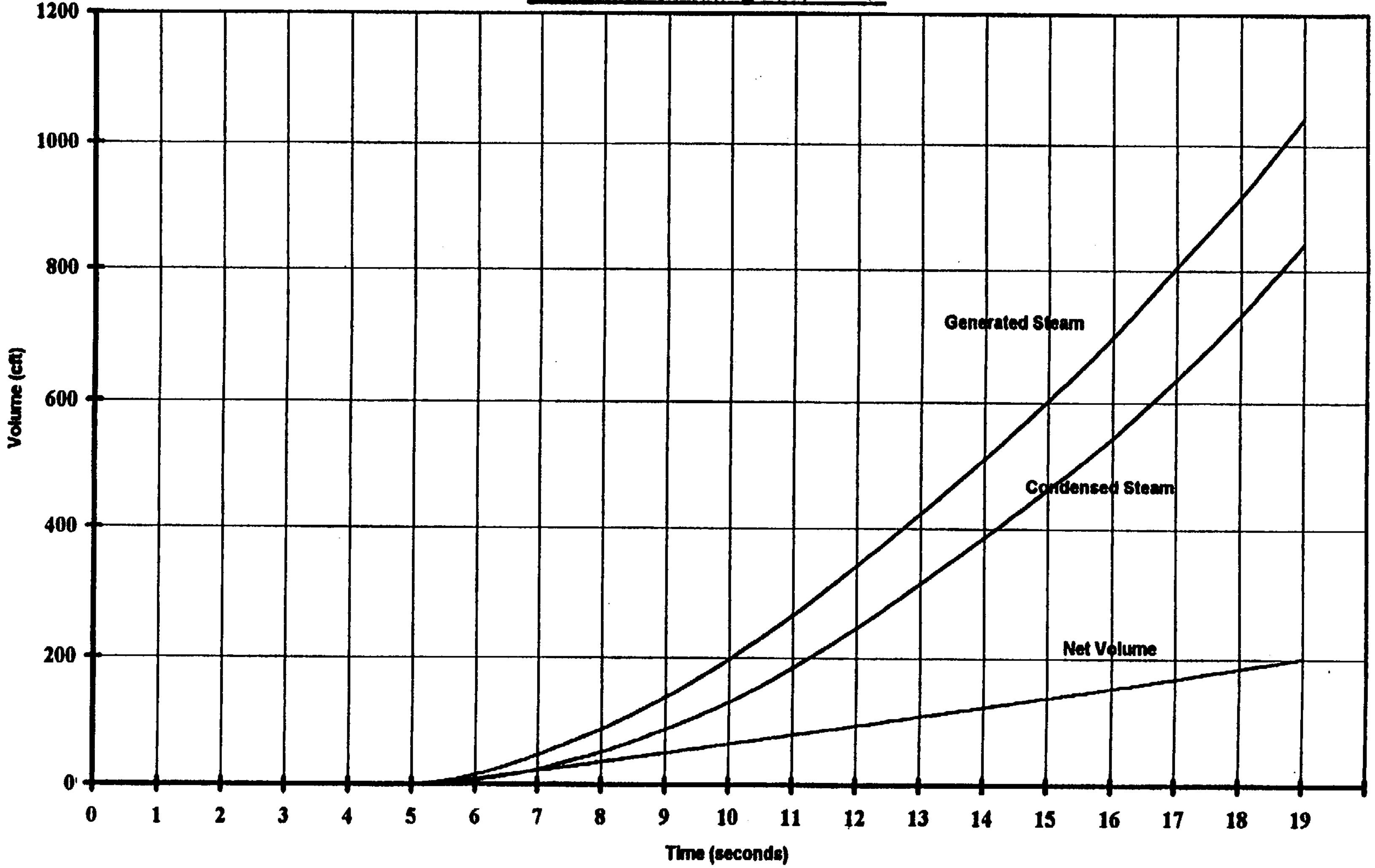


Figure A5-4 Case 5 : Pre Pump Startup - Volume of Steam - RBCU XAA-1A
H.T.=100%, Fouling Factor =0.0



VALIDATION OF COMPUTER PROGRAM PREPUMP

This section of Appendix A includes the validation documentation for the computer program PREPUMP. This code is used to predict flow conditions in the containment fan cooler piping prior to the restart of the Service Water pumps. PREPUMP is a one-shot computer program that was developed specifically for the analysis performed in this appendix.

The validation documentation includes the following items :

Listing of FORTRAN subroutines.

- prepump.for
- echo.for
- header.for
- blockio.for
- iocom.for (INCLUDED COMMON Blocks)

Listings of the program input and output for the validation case run.

A detailed spreadsheet analysis that validates the PREPUMP results.

Program Name : PREPUMP

Prepared by ______ Date 5/23/97

Reviewed by Samir Yassin Date 5/23/97

Approved by ______ Date 5-23-97

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C   PREPUMP
C
C 100 DIMENSIONS
C
      IMPLICIT REAL *8 (A-H,O-Z)
      REAL *8 MWCFC,MWCFCI,MWCFCP,MWPIP,MWPIPI,MWPIPP
C     REAL *8 MSCFC,MSCFCI,MSCFCP,MSPIP,MSPIPI,MSPIPP
      REAL *8 LWPIP1,LWPIP2,LWPIP,LWPIPI,LWPIPP,LPIP
      REAL *8 KPIP,KST,KINS
      CHARACTER *60 TITLE
      DIMENSION TPCFCT(30),PCFCT(30)
      DIMENSION TPBT(30),PBT(30)
      DIMENSION TTMPCT(30),TMPCT(30)
      DIMENSION THTCCT(30),HTCCT(30)
      DIMENSION PSATT(30),TMPSATT(30),SVWT(30),SVST(30),HWT(30),HST(30)
C
      INCLUDE 'IOCOM.FOR'
C
C   Open input and output files
C
      CALL ECHO
C
C 200 INPUT
C
      PI=3.141592654
      CALL HEADER
      READ(LIN,910)TITLE
      WRITE(LOUT,910)TITLE
      READ(LIN,*)DT,TOMIN,TOMAX,TMAX
      READ(LIN,*)VCFC,DOTUB,DITUB
      READ(LIN,*)ARFIN,VRFIN,EFFFIN,FOUL
      READ(LIN,*)RHOCU,CAPCU
      READ(LIN,*)LPIP,DOPIP,DIPIP,KPIP
      READ(LIN,*)HEADI,HEADD,HEADL
      READ(LIN,*)RHOST,CAPST,KST
      READ(LIN,*)DOINS,KINS
      READ(LIN,*)TMPCFCI,TMPCUI,TMPWPIPI,TMPSTI
      READ(LIN,*)DMDTCFCI
      READ(LIN,*)HCONV1INP,HCONV2INP,HCONDINP
      READ(LIN,*)ITPCFCTMAX,(TPCFCT(I),PCFCT(I),I=1,ITPCFCTMAX)
      READ(LIN,*)ITPBTMAX,(TPBT(I),PBT(I),I=1,ITPBTMAX)
      READ(LIN,*)ITTMPCTMAX,RTMPC,(TTMPCT(I),TMPCT(I),I=1,ITTMPCTMAX)
      READ(LIN,*)ITHTCCTMAX,RHTCC,(THTCCT(I),HTCCT(I),I=1,ITHTCCTMAX)
      READ(LIN,*)IPSATTMAX,
     &(PSATT(I),TMPSATT(I),SVWT(I),SVST(I),HWT(I),HST(I),I=1,IPSATTMAX)
C
C 300 COMPUTATIONS
C
      VTUB=(PI/4)*(DITUB/12)**2
      AOTUB=PI*(DOTUB/12)
      AITUB=PI*(DITUB/12)
      AOCFC=AOTUB*VCFC*ARFIN/VTUB
      AICFC=AITUB*VCFC/VTUB
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      VCU=(PI/4)*((DOTUB/12)**2-(DITUB/12)**2)*VCFC*VRFIN/VTUB
      AOPIP=PI*(DOPIP/12)
      AIPIP=PI*(DIPIP/12)
      APIP=(PI/4)*(DIPIP/12)**2
      VPIP=APIP*LPIP
C
      T=0
      KCOUNT=0
      PCFCI=PCFCT(1)
      PCFC=PCFCI
      PBI=PBT(1)
      PB=PBI
      DMDTCFC=DMDTCFCI
C
  310 IF((PCFC.LT.PSATT(1)).OR.(PCFC.GT.PSATT(IPSATTMAX))) THEN
       WRITE(6,*)'PCFC OUT OF RANGE'
       STOP
      ELSE
       DO 311 I=1,IPSATTMAX-1
        IF((PCFC.GE.PSATT(I)).AND.(PCFC.LE.PSATT(I+1))) THEN
         SVW=SVWT(I)+
     &        (SVWT(I+1)-SVWT(I))*
     &        (PCFC-PSATT(I))/(PSATT(I+1)-PSATT(I))
         SVS=SVST(I)+
     &        (SVST(I+1)-SVST(I))*
     &        (PCFC-PSATT(I))/(PSATT(I+1)-PSATT(I))
         RHOW=1/SVW
         RHOS=1/SVS
        ENDIF
  311  CONTINUE
      ENDIF
      TMPCU=TMPCUI
      TMPCUP=TMPCU
      TMPCFC=TMPCFCI
      TMPCFCP=TMPCFC
      TMPWPIP=TMPWPIPI
      TMPWPIPP=TMPWPIP
      TMPSTCONV=TMPSTI
      TMPSTCONVP=TMPSTCONV
      TMPSTCOND=TMPSTI
      TMPSTCONDP=TMPSTCOND
C
      VWCFCI=VCFC
      VWCFC=VWCFCI
      VWCFCP=VWCFC
      MWCFCI=VWCFCI*RHOW
      MWCFC=MWCFCI
      MWCFCP=MWCFC
      VWPIPI=VPIP
      VWPIP=VWPIPI
      VWPIPP=VWPIP
      MWPIPI=VWPIPI*62.4
      MWPIP=MWPIPI
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       MWPIPP=MWPIP
       LWPIPI=LPIP
       LWPIP=LWPIPI
       LWPIPP=LWPIP
       HEAD=HEADI
C
       HTCI=10**6
  400 T=T+DT
       KCOUNT=KCOUNT+1
C
       KERR3=0
  405 IF(LATCH1.EQ.0) THEN
        DO 807 I=1,ITPCFCTMAX-1
         IF((T.GE.TPCFCT(I)).AND.(T.LE.TPCFCT(I+1))) THEN
          PCFC=PCFCT(I)+
     &        (T-TPCFCT(I))*
     &        (PCFCT(I+1)-PCFCT(I))/(TPCFCT(I+1)-TPCFCT(I))
          GOTO 406
         ENDIF
  807   CONTINUE
       ENDIF
C
  406 CONTINUE
       DO 809 I=1,ITPCFCTMAX-1
        IF((T.GE.TPBT(I)).AND.(T.LE.TPBT(I+1))) THEN
         PB=PBT(I)+
     &     (T-TPBT(I))*
     &     (PBT(I+1)-PBT(I))/(TPBT(I+1)-TPBT(I))
         GOTO 408
        END IF
  809 CONTINUE
C
  408 CONTINUE
       DO 811 I=1,ITTMPCTMAX-1
        IF((T.GE.TTMPCT(I)).AND.(T.LE.TTMPCT(I+1))) THEN
         TMPC=TMPCT(I)+
     &     (T-TTMPCT(I))*
     &     (TMPCT(I+1)-TMPCT(I))/(TTMPCT(I+1)-TTMPCT(I))
         TMPC=TMPC*RTMPC
         GOTO 410
        ENDIF
  811 CONTINUE
C
  410 CONTINUE
       DO 821 I=1,ITHTCCTMAX-1
        IF((T.GE.THTCCT(I)).AND.(T.LE.THTCCT(I+1))) THEN
         HTCC=HTCCT(I)+
     &     (T-THTCCT(I))*
     &     (HTCCT(I+1)-HTCCT(I))/(THTCCT(I+1)-THTCCT(I))
         HTCC=HTCC*RHTCC
         GOTO 420
        ENDIF
  821 CONTINUE
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C
 420 CONTINUE
     IF((PCFC.LT.PSATT(1)).OR.(PCFC.GT.PSATT(IPSATTMAX))) THEN
      WRITE(6,*)'PCFC OUT OF RANGE'
      STOP
     ELSE
      DO 831 I=1,IPSATTMAX-1
       IF((PCFC.GE.PSATT(I)).AND.(PCFC.LE.PSATT(I+1))) THEN
        TMPSAT=TMPSATT(I)+
    &          (TMPSATT(I+1)-TMPSATT(I))*
    &          (PCFC-PSATT(I))/(PSATT(I+1)-PSATT(I))
        SVW=SVWT(I)+
    &        (SVWT(I+1)-SVWT(I))*
    &        (PCFC-PSATT(I))/(PSATT(I+1)-PSATT(I))
        SVS=SVST(I)+
    &        (SVST(I+1)-SVST(I))*
    &        (PCFC-PSATT(I))/(PSATT(I+1)-PSATT(I))
        HW=HWT(I)+
    &        (HWT(I+1)-HWT(I))*
    &        (PCFC-PSATT(I))/(PSATT(I+1)-PSATT(I))
        HS=HST(I)+
    &        (HST(I+1)-HST(I))*
    &        (PCFC-PSATT(I))/(PSATT(I+1)-PSATT(I))
        GOTO 430
       ENDIF
 831  CONTINUE
     ENDIF
C
 430 CONTINUE
C
     KERR1=0
 440 RHOW=1/SVW
     RHOS=1/SVS
     HFG=HS-HW
     HTCO=HTCC*EFFFIN
     RESO=1/(HTCO*AOCFC)
     DQDTO=(TMPC-TMPCU)/RESO
     DQDTCU=(TMPCU-TMPCUP)*RHOCU*CAPCU*VCU*3600/DT
     IF(LATCH1.EQ.1) TMPCFC=TMPSAT

     HTCITRY=10**6*EXP(4*PCFC/1260)*(TMPCU-TMPSAT)/5184
     IF(LATCH2.EQ.1) GOTO 475
     IF((TMPCU.GT.(TMPSAT+9)).AND.(HTCITRY.GT.HTCI)) LATCH2=1
 475 IF((TMPCU.GT.(TMPSAT)).AND.(LATCH2.EQ.1)) THEN
      HTCI=10**6*EXP(4*PCFC/1260)*(TMPCU-TMPSAT)/5184
      HTCI=HTCI*VWCFC/VWCFCI
      RESI=1/(HTCI*AICFC)+FOUL/AICFC
      DQDTI=(TMPCU-TMPSAT)/RESI
     ELSE
      HTCI=HCONV1INP
      HTCI=HTCI*(DMDTCFC/DMDTCFCI)**0.8
      IF(HTCI.GT.0) THEN
       RESI=1/(HTCI*AICFC)+FOUL/AICFC
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        DQDTI=(TMPCU-TMPCFC)/RESI
       ELSE
        DQDTI=0
       ENDIF
      ENDIF
C
      ERR1=2*100*(DQDTO-DQDTCU-DQDTI)/(ABS(DQDTO+DQDTCU+DQDTI)+1)
      IF(ABS(ERR1).GT.0.0001) THEN
       TMPCU=TMPCU*(1+0.000001*ERR1)
       IF(KERR1.GT.10000000) THEN
        WRITE(6,*)'KERR1 OUT OF RANGE'
        STOP
       ELSE
        KERR1=KERR1+1
        GOTO 440
       ENDIF
      ENDIF
C
      IF(LATCH1.EQ.0) THEN
       TMPCFC=TMPCFCP+DQDTI*DT/(MWCFCI*3600)
       DMDTCFC=DMDTCFCI*((PCFC-PB)/(PCFCI-PBI))**0.5
       DMCFC=DMDTCFC*DT
       TMPCFC=(DMCFC*TMPCFCI+(MWCFCI-DMCFC)*TMPCFC)/MWCFCI
      ENDIF
      IF((TMPCFCP.LE.TMPSATP).AND.(TMPCFC.GE.TMPSAT)) LATCH1=1
      IF(LATCH1.EQ.0) GOTO 705
C
      MWCFC=MWCFCP-DQDTI*DT/(3600*HFG)
      IF(MWCFC.LE.(0.01*MWCFCI)) THEN
       STOP
      ENDIF
      VWCFC=MWCFC/RHOW
C
  500 VSTEAM1=(MWCFCI-MWCFC)/RHOS
      VSTEAM2=QICOND/(HFG*RHOS)
      VSTEAM=VSTEAM1-VSTEAM2
      LWPIP1=LWPIPI-VSTEAM/APIP
C
      FORPIP=144*(PCFC-PB)*APIP
      LWPIP2=LWPIPP-UWPIPP*DT
      KERR2=0
  600 UWPIP=(LWPIPP-LWPIP2)/DT
      MWPIP=62.4*LWPIP2*APIP
      DMUDT=MWPIP*(UWPIP-UWPIPP)/(DT*32.2)
      FRICPIP=62.4*APIP*KPIP*UWPIP*ABS(UWPIP)/(2*32.2)
      IF((LWPIPI-LWPIP).LT.HEADL) THEN
       HEAD=HEADI+HEADD*(LWPIPI-LWPIP)/HEADL
      END IF
      HEADPIP=62.4*APIP*32.2*HEAD/32.2
      F=DMUDT+FRICPIP+HEADPIP
      ERR2=2*100*(FORPIP-F)/(ABS(FORPIP+F)+100)
      IF(ABS(ERR2).GT.0.001) THEN
       LWPIP2=LWPIP2*(1-0.0000001*ERR2)
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        IF(KERR2.GT.10000000) THEN
         WRITE(6,*)'KERR2 OUT OF RANGE'
         STOP
        ELSE
         KERR2=KERR2+1
         GOTO 600
        ENDIF
       ENDIF
C
  700 ERR3=2*100*(LWPIP1-LWPIP2)/(ABS(LWPIP1+LWPIP2)+1)
       IF(ABS(ERR3).GT.0.001) THEN
        PCFC=PCFC*(1-0.001*ERR3)
        IF(KERR3.GT.10000000) THEN
         WRITE(6,*)'KERR3 OUT OF RANGE'
         STOP
        ELSE
         KERR3=KERR3+1
         GOTO 405
        ENDIF
       ENDIF
       LWPIP=(LWPIP1+LWPIP2)/2
C
       VWCFCP=VWCFC
       MWCFCP=MWCFC
       VWPIPP=VWPIP
       MWPIPP=MWPIP
       LWPIPP=LWPIP
       UWPIPP=UWPIP
C
  705 AICONV=AIPIP*LWPIP
       AOCONV=AOPIP*LWPIP
       AINS=AOCONV*((DOINS+DOPIP)/(2*DOPIP))
       AACONV=(AOCONV+AICONV)/2
       KERR4=0
  710 RESOCONV=1/(HTCC*AOCONV)+(DOPIP-DIPIP)/(48*AACONV*KST)
      &+(DOINS-DOPIP)/(24*AINS*KINS)
       DQDTOCONV=(TMPC-TMPSTCONV)/RESOCONV
       RESICONV=1/(HCONV2INP*AICONV)+(DOPIP-DIPIP)/(48*AACONV*KST)
       DQDTICONV=(TMPSTCONV-TMPWPIP)/RESICONV
       DQDTSTCONV=(TMPSTCONV-TMPSTCONVP)*RHOST*CAPST*
      &(PI/4)*((DOPIP/12)**2-(DIPIP/12)**2)*LWPIP*3600/DT
       ERR4=2*100*(DQDTOCONV-DQDTSTCONV-DQDTICONV)/
      &(ABS(DQDTOCONV+DQDTSTCONV+DQDTICONV)+1)
       IF(ABS(ERR4).GT.0.0001) THEN
        TMPSTCONV=TMPSTCONV*(1+0.00000001*ERR4)
        IF(KERR4.GT.10000000) THEN
         WRITE(6,*)'KERR4 OUT OF RANGE'
         STOP
        ELSE
         KERR4=KERR4+1
C        WRITE(6,920)T,DQDTOCONV,DQDTICONV,DQDTSTCONV,ERR4
         GOTO 710
        ENDIF
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      ENDIF
C
      TMPSTCONVP=TMPSTCONV
      TMPWPIPP=TMPWPIP
      TMPWPIP=TMPWPIP+DQDTICONV*DT/(3600*MWPIP)
C
      IF(LATCH1.EQ.0) THEN
       TMPSTCOND=TMPSTCONV
       TMPSTCONDP=TMPSTCOND
       UWPIP=(DMDTCFC/RHOW)/APIP
       UWPIPP=UWPIP
       GOTO 750
      ENDIF
C
      AICOND=AIPIP*(LPIP-LWPIP)
      AOCOND=AOPIP*(LPIP-LWPIP)
      AINS=AOCOND*((DOINS+DOPIP)/(2*DOPIP))
      AACOND=(AOCOND+AICOND)/2
      KERR5=0
  720 RESOCOND=1/(HTCC*AOCOND)+(DOPIP-DIPIP)/(48*AACOND*KST)
     &+(DOINS-DOPIP)/(24*AINS*KINS)
      DQDTOCOND=(TMPC-TMPSTCOND)/RESOCOND
      RESICOND=1/(HCONDINP*AICOND)+(DOPIP-DIPIP)/(48*AACOND*KST)
      DQDTICOND=(TMPSAT-TMPSTCOND)/RESICOND
      DQDTSTCOND=(TMPSTCOND-TMPSTCONDP)*(LPIP-LWPIP)*
     &RHOST*CAPST*(PI/4)*((DOPIP/12)**2-(DIPIP/12)**2)*3600/DT
      DQDTSTST=(TMPSTCOND-TMPSTCONV)*(UWPIPP*DT)*
     &RHOST*CAPST*(PI/4)*((DOPIP/12)**2-(DIPIP/12)**2)*3600/DT
      ERR5=2*100*(DQDTOCOND+DQDTICOND-DQDTSTCOND-DQDTSTST)/
     &(ABS(DQDTOCOND+DQDTICOND+DQDTSTCOND+DQDTSTST)+1)
      IF(ABS(ERR5).GT.0.0001) THEN
       TMPSTCOND=TMPSTCOND*(1+0.00000001*ERR5)
       IF(KERR5.GT.10000000) THEN
        WRITE(6,*)'KERR5 OUT OF RANGE'
        STOP
       ELSE
        KERR5=KERR5+1
        GOTO 720
       ENDIF
      ENDIF
      TMPSTCONDP=TMPSTCOND
      QICOND=QICOND+DQDTICOND*DT/3600
C
  750 TMPCUP=TMPCU
      TMPCFCP=TMPCFC
      TMPSATP=TMPSAT
C
      WRITE(6,*)KCOUNT,LATCH1
      WRITE(6,920)T,TMPSAT,TMPSTCOND,DQDTOCOND,DQDTSTCOND,DQDTICOND
      WRITE(6,920)T,TMPWPIP,TMPSTCONV,DQDTOCONV,DQDTSTCONV,DQDTICONV
      WRITE(6,920)T,TMPC,TMPCU,TMPCFC,PCFC,MWCFC
      WRITE(6,920)T,VSTEAM1,VSTEAM2,VSTEAM,LWPIP,UWPIP
      WRITE(LOUT,*)KCOUNT,LATCH1
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      WRITE(LOUT.920)T,TMPSAT,TMPSTCOND,DQDTOCOND,DQDTSTCOND,DQDTICOND
      WRITE(LOUT,920)T,TMPWPIP,TMPSTCONV,DQDTOCONV,DQDTSTCONV,DQDTICONV
      WRITE(LOUT,920)T,TMPC,TMPCU,TMPCFC,PCFC,MWCFC
      WRITE(LOUT,920)T,VSTEAM1,VSTEAM2,VSTEAM,LWPIP,UWPIP
      WRITE(LPL1.920)T,PCFC,PB,VSTEAM,UWPIP,LWPIP
      WRITE(LPL2,920)T,TMPC,TMPCU,TMPCFC,TMPSTCOND,TMPSTCONV,TMPWPIP
      WRITE(LPL3.920)T,DQDTI,DQDTICOND,VSTEAM1,VSTEAM2.VSTEAM
      IF((T.GT.TOMIN).AND.(T.LT.TOMAX)) THEN
       WRITE(LOUT.920)T,VTUB,AOTUB,AITUB,AOCFC,AICFC,VCU
       WRITE(LOUT,920)T.AOPIP,AIPIP,APIP,VPIP,LPIP,VCFC
       WRITE(LOUT,920)T,RHOW,RHOS,HTCO,RESO,DQDTO,DQDTCU
       WRITE(LOUT,920)T,HTCI,RESI,DQDTI,TMPCU,MWCFCI,VWCFC
       WRITE(LOUT,920)T,VSTEAM1,VSTEAM2,VSTEAM,LWPIP1,LWPIP2,MWPIP
       WRITE(LOUT,920)T,FORPIP,F,FRICPIP,DMUDT,UWPIP,HEAD
       WRITE(LOUT,920)T,AICONV,AOCONV,AACONV,RESICONV,RESOCONV,
     X           TMPSTCONV
       WRITE(LOUT,920)T,AICOND,AOCOND,AACOND,RESICOND,RESOCOND,
     X           TMPSTCOND
       WRITE(LOUT,920)T,DQDTOCOND,DQDTICOND,DQDTSTCOND,DQDTSTST,
     X           QICOND.HFG
       WRITE(LOUT.920)T,DQDTOCONV,DQDTICONV,DQDTSTCONV,HTCC
      END IF

      IF(T.GT.TMAX) THEN
       STOP
      ELSE
       GOTO 400
      ENDIF
C
C 900 FORMATS
C
 910  FORMAT(A60)
 920  FORMAT(F8.2,1P6E12.4)
C
      END
```

```
SUBROUTINE ECHO
C
C   CALLED BY THE 'MAIN' PROGRAM
C
C   Routine to read input data from file assigned to LIN,
C   print copies of the input lines to the standard output
C   file LOUT and to the alternate input file ALTIN, and
C   then redirect input reads to the alternate input file.
C
    CHARACTER*4 IMAGE(20)
    INTEGER    IOCHEK,LCOUNT,LCSTRT,LCMAX
C
    INCLUDE 'IOCOM.FOR'
C
    DATA LCSTRT/5/,LCMAX/56/
C
C   Initialize the input unit number.
C
    LIN=LOCIN
C
C   Open the input file - PREPUMP.DAT.
C
    OPEN (UNIT=LIN,ACCESS='SEQUENTIAL',ERR=1900,
   X     FILE='PREPUMP.DAT',FORM='FORMATTED',STATUS='UNKNOWN')
C
C   Open the output file - PREPUMP.OUT.
C
    LOUT=LOCOUT
    OPEN (UNIT=LOUT,ACCESS='SEQUENTIAL',ERR=2000,
   X     FILE='PREPUMP.OUT',FORM='FORMATTED',STATUS='UNKNOWN')
C
C   Initialize the plot output unit numbers.
C
    LPL1=LPL1OT
    LPL2=LPL2OT
    LPL3=LPL3OT
C
C   Open the plot output files PREPUMP.PL1, PREPUMP.PL2, PREPUMP.PL3.
C
    OPEN(UNIT=LPL1,FILE='PREPUMP.PL1')
    OPEN(UNIT=LPL2,FILE='PREPUMP.PL2')
    OPEN(UNIT=LPL3,FILE='PREPUMP.PL3')
C
C   Open the alternate input file - ALTINPUT.TXT.
C
    AOUT=ALTIN
    OPEN (UNIT=AOUT,ACCESS='SEQUENTIAL',ERR=2100,
   X     FORM='FORMATTED',STATUS='SCRATCH')
C
    CALL HEADER
    LCOUNT=LCSTRT
  1 READ(LIN,3000,END=1000,ERR=1000,IOSTAT=IOCHEK) IMAGE
    IF (LCOUNT.EQ.LCMAX) THEN
```

```
        CALL HEADER
        LCOUNT=LCSTRT
      ENDIF
      WRITE(AOUT,3000) IMAGE
      WRITE(LOUT,3010) IMAGE
      LCOUNT=LCOUNT+1
      GO TO 1
C
C    End of file encountered on input
C
 1000 IF (IOCHEK.EQ.-1) THEN
        LIN=ALTIN
        REWIND LIN
        RETURN
      ELSE
        WRITE(LOUT,3100) LIN
        STOP
      ENDIF
C
C    Error attempting to open file PREPUMP.DAT
C
 1900 STOP 'STOP - Error attempting to open file PREPUMP.DAT'
C
C    Error attempting to open file PREPUMP.OUT
C
 2000 STOP 'STOP - Error attempting to open file PREPUMP.OUT'
C
C    Error attempting to open file ALTINPUT.TXT
C
 2100 STOP 'STOP - Error attempting to open file ALTINPUT.TXT'
C
C    Formats
C
 3000 FORMAT (20A4)
 3010 FORMAT (20A4)
 3100 FORMAT (/' ','I/O error encountered on input.')
      END
```

```
C
      SUBROUTINE HEADER
C
C     A subroutine to send a form feed character and
C     header line to the output file.
C
C     Declarations for local variables
C
      INTEGER     IHR, IMIN, ISEC, I100TH, IYR, IMON, IDAY
      INTEGER     PAGE
      CHARACTER* 1 FF
C
      INCLUDE 'IOCOM.FOR'
C
      DATA PAGE/0/
C      DATA FF/'1'/
      FF=CHAR(12)
C
      PAGE=PAGE+1
      CALL GETTIM(IHR,IMIN,ISEC,I100TH)
      CALL GETDAT(IYR,IMON,IDAY)
      IF (PAGE.EQ.1) THEN
        WRITE(LOUT,8000) ' ',PAGE,
     X             IMON,IDAY,IYR,
     X             IHR,IMIN,ISEC,I100TH
      ELSE
        WRITE(LOUT,8000) FF,PAGE,
     X             IMON,IDAY,IYR,
     X             IHR,IMIN,ISEC,I100TH
      ENDIF
      RETURN
C
C     Formats
C
 8000 FORMAT (A1/
     X     'Program : PREPUMP ',44X,'Page : ',I10/
     X     'Number  :            ',38X,
     X                     'Date : ',I2.2,'/',I2.2,'/',I4/
     X     62X,
     X               'Time : ',I2.2,':',I2.2,':',I2.2,'.',I2.2//)
      END
```

```
BLOCK DATA
C
   INCLUDE 'IOCOM.FOR'
C
   DATA LOCIN/8/,LOCOUT/10/,
  X    ALTIN/9/,
  X    LPL1OT/11/,LPL2OT/12/,LPL3OT/13/
C
   END
```

```
C     INCLUDE 'IOCOM.FOR'
C
C    Declarations for variables in COMMON /IOCON/
C
      INTEGER      LIN,LOCIN,LOUT,LOCOUT,
     X             AOUT,ALTIN,
     X             LPL1,LPL1OT,LPL2,LPL2OT,LPL3,LPL3OT
      COMMON/IOCON/LIN,LOCIN,LOUT,LOCOUT,
     X             AOUT,ALTIN,
     X             LPL1,LPL1OT,LPL2,LPL2OT,LPL3,LPL3OT
```

```
PREPUMP VALIDATION CASE
0.1    22     22.5   30
8.53   0.625  0.527
17.8   2.49   0.289  0.0005
556    0.092
216    8.625  7.98   228
4.5    6.5    21.5
489    0.12   26.2
10.625 0.0229
80     80     80     80
70
1040   670    690
3      0 28   10 12   100 12
2      0 12           100 12
7 0.95 0 220  0.3 250 6 268  9 269  13 280  15 280  40 272
11 0.95 0 10   1 115  2.5 180 4 225  7 300  11 385  15 345
   20 280  25 235  30 195  40 150
18    0.25    59.323  0.01603 1235.5  27.382  1067.4
      0.5     79.586  0.01607 641.5   47.623  1096.3
      1       101.74  0.01614 333.6   69.73   1105.8
      3       141.47  0.01630 118.7   109.4   1122.6
      6       170.05  0.01645 61.98   138.03  1134.2
      10      193.21  0.01659 38.42   161.26  1143.3
      14.696  212.0   0.01672 26.8    180.17  1150.5
      15      213.03  0.01673 26.29   181.21  1150.9
      20      227.96  0.01683 20.09   196.27  1156.3
      25      240.07  0.01693 16.3    208.52  1160.6
      30      250.34  0.01701 13.74   218.9   1164.1
      35      259.29  0.01708 11.9    228.0   1167.1
      40      267.25  0.01715 10.5    236.1   1169.8
      45      274.44  0.01721 9.4     243.5   1172.0
      50      281.02  0.01727 8.51    250.2   1174.1
      55      287.08  0.01733 7.785   256.4   1175.9
      60      292.71  0.01739 7.174   262.2   1177.6
      70      302.93  0.01748 6.205   272.7   1180.6
```

Validation of CFC Heat Transfer Block

	A	B	C	D	E
1					
2	Quantity	Value	Units	Source	Comparison with
3					code output
4					
5	$\text{time}_{,i}$	22.1	sec		
6	Δt	0.1	sec	input	
7	P_{CFC}	31.888	psia	output	
8	$T_{containment}$	263.84	°F	output	
9					
10					
11	d_i	0.527	inches	input	
12	d_o	0.625	inches	input	
13	L_{tube}	66.0	inches	input	
14	number tubes/unit	1024		input	
15	$A_{CFC,I}$	777.04	ft^2	calculated	776.93
16	$A_{tube,o}$	921.53	ft^2	calculated	
17	A_{ratio}	17.8		input	
18	$A_{CFC,o}$	16403.30	ft^2	calculated	16401
19					
20	h_o	71.685	Btu/hr-ft^2-°F	output	
21	h_i	1467.8	Btu/hr-ft^2-°F	output	
22	$r_{fouling}$	0.0005	hr-ft^2-°F/Btu	input	
23	T_{copper}	260.7	°F	output	
24	T_{sat}	253.85	°F	calculated	253.72
25	$Qdot_o$	3.692E+06	Btu/hr	calculated	3.689E+06
26	$Qdot_i$	4.591E+06	Btu/hr	calculated	4.594E+06
27	$Qdot_{copper}$	-8.990E+05	Btu/hr	calculated	-9.043E+05
28	ρ_{copper}	556.0	lb_m/ft^3	input	
29	c_{copper}	0.092	Btu/lb_m-°F	input	
30	Vol_{copper}	3.468	ft^3	calculated	3.467
31	ΔT_{copper}	-0.141	°F	calculated	-0.06
32	$T_{copper,previous}$	260.841	°F	calculated	260.87

Validation of CFC Heat Transfer Block

	A	B	C	D
1				
2	Quantity	Value	Units	Source
3				
4				
5	time$_i$	22.1	sec	
6	Δt	0.1	sec	input
7	P_{CFC}	32.008	psia	output
8	$T_{containment}$	263.84	°F	output
9				
10				
11	d_i	0.527	inches	input
12	d_o	0.625	inches	input
13	L_{tube}	66	inches	input
14	number tubes/unit	1024		input
15	$A_{CFC,i}$	=PI()*(B11/12)*B13/12*B14	ft^2	calculated
16	$A_{tube,o}$	=PI()*(B12/12)*B13/12*B14	ft^2	calculated
17	A_{ratio}	17.8		input
18	$A_{CFC,o}$	=B17*B16	ft^2	calculated
19				
20	h_o	71.685	Btu/hr-ft^2-°F	output
21	h_i	1447.4	Btu/hr-ft^2-°F	output
22	$r_{fouling}$	0.0005	hr-ft^2-°F/Btu	input
23	T_{copper}	260.81	°F	output
24	T_{sat}	='C:\STMFUNC.XLA'!tpsat(B7)	°F	calculated
25	Qdot$_o$	=B20*E18*(B8-B23)	Btu/hr	calculated
26	Qdot$_i$	=E15/(1/B21+B22)*(B23-E24)	Btu/hr	calculated
27	Qdot$_{copper}$	=B25-B26	Btu/hr	calculated
28	ρ_{copper}	556	lb$_m$/ft^3	input
29	c_{copper}	0.092	Btu/lb$_m$-°F	input
30	Vol$_{copper}$	=PI()/4*((B12/12)^2-(B11/12)^2)*B13/12*B14	ft^3	calculated
31	ΔT_{copper}	=B27*B6/(3600*B28*B29*E30)	°F	calculated
32	$T_{copper,previous}$	=B23-B31	°F	calculated

Validation of Force Balance Block

	A	B	C	D	E	F
1						
2	Quantity	Value	Units	Source	Comparison with	
3					code output	
4						
5	$time_{,i}$	22.1	sec			
6	Δt	0.1	sec	input		
7	P_{CFC}	31.88	psia	output		
8	P_{back}	12	psia	output		
9						
10	$d_{i,pipe}$	7.98	inches	input		
11	A_{pipe}	0.34732	ft^2	calculated	0.34732	
12	L_{water}	178.99	feet	output		
13	ρ_{water}	62.4	lb_m/ft^3	input		
14	$mass_{water}$	3879.24	lb_m	calculated	3879.3	
15	u_{water}	3.1517	ft/sec	output		
16	$u_{water,previous}$	3.1561	ft/sec	output		
17	Δu	-0.0044	ft/sec	calculated	-0.0044	
18	d(mu)/dt	-5.301	lb_f	calculated	-5.2506	
19						
20	$F_{pressure}$	994.29	lb_f	calculated	994.67	
21						
22	$K_{friction}$	228.0		input		
23	$F_{friction}$	762.17	lb_f	calculated	762.18	
24						
25	$head_{water\ column}$	10.970	feet	output		
26	F_{head}	237.75	lb_f	calculated	237.75	
27						
28	Balance of forces	0.334	lb_f	calculated	0.009	

Validation of Force Balance Block

	A	B	C	D
1				
2	Quantity	Value	Units	Source
3				
4				
5	$\text{time}_{,i}$	22.1	sec	
6	Δt	0.1	sec	input
7	P_{CFC}	32.008	psia	output
8	P_{back}	12	psia	output
9				
10	$d_{i,pipe}$	7.98	inches	input
11	A_{pipe}	=PI()/4*(B10/12)^2	ft^2	calculated
12	L_{water}	180.76	feet	output
13	ρ_{water}	62.4	lb_m/ft^3	input
14	mass_{water}	=B13*B12*B11	lb_m	calculated
15	u_{water}	3.1668	ft/sec	output
16	$u_{water,previous}$	3.1713	ft/sec	output
17	Δu	=B15-B16	ft/sec	calculated
18	d(mu)/dt	=E14*B17/(32.2*B6)	lb_f	calculated
19				
20	$F_{pressure}$	=144*(B7-B8)*E11	lb_f	calculated
21				
22	$K_{friction}$	228		input
23	$F_{friction}$	=B22*B13/(2*32.2)*B15^2*E11	lb_f	calculated
24	$\text{head}_{water\ column}$	10.918	feet	output
25	F_{head}	=B24*B13*E11	lb_f	calculated
26				
27	Balance of forces	=B18-(B20-B23-B25)	lb_f	calculated

Validation of Water Column Length Block

	A	B	C	D	E
1					
2	Quantity	Value	Units	Source	Comparison with
3					code output
4					
5	$\text{time}_{,i}$	22.1	sec		
6	Δt	0.1	sec	input	
7	P_{CFC}	31.888	psia	output	
8	ρ_g	0.07704	lb_m/ft^3	calculated	0.076656
9	h_{fg}	942.84	Btu/lb_m	calculated	942.9
10					
11	Qdot,i	4.59E+06	Btu/hr	output	
12	Δmass	0.1353	lb_m	calculated	0.13
13	$m_{CFC,previous}$	493.06	lb_m	output	
14	$m_{CFC,current}$	492.92	lb_m	calculated	492.93
15	$m_{CFC,initial}$	502.41	lb_m	input	
16	$Vol_{\text{steam produced by boiling}}$	123.74	ft^3	calculated	123.74
17	$Q_{\text{condensation}}$	8014.7	Btu	output	
18	$Vol_{\text{steam condensed}}$	110.89	ft^3	calculated	110.89
19	$Vol_{\text{steam net}}$	12.85	ft^3	calculated	12.85
20					
21	$L_{\text{water,initial}}$	216.0	feet	input	
22	$d_{i,pipe}$	7.98	inches	input	
23	A_{pipe}	0.347	ft^2	calculated	0.34732
24					
25	$L_{\text{water, boiling}}$	178.99	feet	calculated	178.99
26					
27	$L_{\text{water, force balance}}$	178.99	feet	output	
28					
29	Difference in calculated	0.00	feet		0.00
30	water column lengths				

Validation of Water Column Length Block

	A	B	C	D
1				
2	Quantity	Value	Units	Source
3				
4				
5	time$_{i}$	22.1	sec	
6	Δt	0.1	sec	input
7	P_{CFC}	32.008	psia	output
8	ρ_g	=1/'C:\STMFUNC.XLA'!vgpsat(B7)	lb_m/ft^3	calculated
9	h_{fg}	='C:\STMFUNC.XLA'!hfgpsat(B7)	Btu/lb_m	calculated
10				
11	Qdot,i	='[PREVAL.XLS]CFC Heat transfer'!E26	Btu/hr	output
12	Δmass	=B11*B6/(3600*B9)	lb_m	calculated
13	$m_{CFC,previous}$	493.82	lb_m	output
14	$m_{CFC,current}$	=B13-B12	lb_m	calculated
15	$m_{CFC,initial}$	502.41	lb_m	input
16	$Vol_{\text{steam produced by boiling}}$	=(B15-B14)/E8	ft^3	calculated
17	$Q_{\text{condensation}}$	7342.2	Btu	output
18	$Vol_{\text{steam condensed}}$	=B17/(E9*E8)	ft^3	calculated
19	$Vol_{\text{steam net}}$	=B16-B18	ft^3	calculated
20				
21	$L_{\text{water,initial}}$	216	feet	input
22	$d_{i,pipe}$	7.98	inches	input
23	A_{pipe}	=PI()/4*(B22/12)^2	ft^2	calculated
24				
25	$L_{\text{water, boiling}}$	=B21-B19/B23	feet	calculated
26				
27	$L_{\text{water, force balance}}$	='[PREVAL.XLS]Force Balance'!B12	feet	output
28				
29	Difference in calculated	=B27-B25	feet	
30	water column lengths			

Validation of Pipe Heat Transfer Block

	A	B	C	D	E	F
1						
2	Quantity	Value	Units	Source	Comparison with:	
3					code output	
4						
5	Δt	0.1	sec	input		
6	P_{CFC}	31.888	psia	output		
7	$T_{containment}$	263.84	°F	output		
8	$time_{,i}$	22.1	sec	input		
9	$U_{,wpipe,previous}$	3.1561	ft/sec	output		
10	$d_{i,pipe}$	7.98	inches	input		
11	$d_{o,pipe}$	8.625	inches	input		
12	$t_{,ins}$	1.0	inches	input		
13	$K_{,steel}$	26.2		input		
14	$K_{,ins}$	0.0229		input		
15	$LW_{,pipe}$	178.99	ft	output		
16	$L_{,pipe}$	216	ft	output		
17	$A_{pipe,i,conv}$	373.94	ft^2	calculated	373.94	
18	$A_{pipe,o,conv}$	404.16	ft^2	calculated	404.17	
19	$A_{ins,ave,conv}$	451.03	ft^2	calculated		
20	$A_{pipe,ave,conv}$	389.06	ft^2	calculated	389.06	
21	$A_{pipe,i,cond}$	77.32	ft^2	calculated	77.315	
22	$A_{pipe,o,cond}$	83.57	ft^2	calculated	83.564	
23	$A_{ins,ave,cond}$	93.25	ft^2	calculated		
24	$A_{pipe,ave,cond}$	80.44	ft^2	calculated	80.439	
25						
26	h_{tcc}	261.1	Btu/hr-ft^2-°F	calculated		
27	$R_{conv,o}$	8.079E-03	Btu/hr-ft^2-°F	calculated	8.080E-03	
28	$R_{conv,i}$	5.3096E-06	Btu/hr-ft^2-°F	calculated	5.310E-06	
29	$R_{cond,o}$	3.908E-02	Btu/hr-ft^2-°F	calculated	0.039078	
30	$R_{cond,i}$	2.5121E-05	Btu/hr-ft^2-°F	calculated	2.52E-05	
31	$T_{steel,conv}$	80.109	°F	output		
32	$T_{steel,cond}$	143.65	°F	output		
33	T_{wpip}	80.018	°F	output		
34	T_{sat}	253.85	°F	calculated	253.93	
35	$Qdot_{o,conv}$	2.274E+04	Btu/hr	calculated	2.274E+04	
36	$Qdot_{i,conv}$	1.714E+04	Btu/hr	calculated	1.721E+04	
37	$Qdot_{steel,conv}$	5.602E+03	Btu/hr	calculated	5.536E+03	
38	$Qdot_{o,cond}$	3.076E+03	Btu/hr	calculated	3.076E+03	
39	$Qdot_{i,cond}$	4.385E+06	Btu/hr	calculated	4.382E+06	
40	$Qdot_{steel,cond}$	1.918E+06	Btu/hr	calculated	1.914E+06	
41	$Qdot_{steel,steel}$	2.475E+06	Btu/hr	calculated	2.471E+06	
42	ρ_{steel}	489.0	lb_m/ft^3	input		
43	c_{steel}	0.12	Btu/lb_m-°F	input		
44	$\%BAL_{,conv}$	0.000E+00				
45	$\%BAL_{,cond}$	-5.788E-04				

Validation of Pipe Heat Transfer Block

	A	B	C	D	E	F
46						
47						
48						
49	Quantity	Value	Units	Source	Comparison with:	
50					code output	
51						
52	$Vol_{steel,conv}$	10.456	ft^3	calculated		
53	$\Delta T_{steel,conv}$	0.000	°F	calculated		
54	$Vol_{steel,cond}$	2.180	ft^3	calculated		
55	$\Delta T_{steel,cond}$	0.415	°F	calculated		
56	$T_{steel,previous,conv}$	80.109	°F	calculated	80.109	
57	$T_{steel,previous,cond}$	143.235	°F	calculated	143.23	

Validation of Pipe Heat Transfer Block

	A	B	C	D.	E
1					
2	Quantity	Value	Units	Source	Comparison with: code output
3					
4					
5	Δt	0.1	sec	input	
6	P_{CFC}	31.888	psia	output	
7	$T_{containment}$	263.84	°F	output	
8	$time_i$	22.1	sec	input	
9	$U_{wpipe,previous}$	3.1561	ft/sec	output	
10	$d_{i,pipe}$	7.98	inches	input	
11	$d_{o,pipe}$	8.625	inches	input	
12	t_{ins}	1	inches	input	
13	K_{steel}	26.2		input	
14	K_{ins}	0.0229		input	
15	LW_{pipe}	178.99	ft	output	
16	L_{pipe}	216	ft	output	
17	$A_{pipe,i,conv}$	=PI()*(B10/12)*(B15)	ft^2	calculated	373.94
18	$A_{pipe,o,conv}$	=PI()*(B11/12)*(B15)	ft^2	calculated	404.17
19	$A_{ins,ave,conv}$	=E18*(B12+B11)/B11	ft^2	calculated	
20	$A_{pipe,ave,conv}$	=(E17+E18)/2	ft^2	calculated	389.06
21	$A_{pipe,i,cond}$	=PI()*(B10/12)*(B16-B15)	ft^2	calculated	77.315
22	$A_{pipe,o,cond}$	=PI()*(B11/12)*(B16-B15)	ft^2	calculated	83.564
23	$A_{ins,ave,cond}$	=E22*(B11+B12)/B11	ft^2	calculated	
24	$A_{pipe,ave,cond}$	=(E21+E22)/2	ft^2	calculated	80.439
25					
26	h_{tcc}	=(235-280)*(B8-20)/(25-20)+280	Btu/hr-ft²-°F	calculated	
27	$R_{conv,o}$	=1/(B26*E18)+(B11-B10)/(2*12*2*E20*B13)+B12/(12*B19*B14)	Btu/hr-ft²-°F	calculated	0.0080795
28	$R_{conv,i}$	=1/(670*E17)+(B11-B10)/(2*12*2*E20*B13)	Btu/hr-ft²-°F	calculated	0.000053096
29	$R_{cond,o}$	=1/(B26*E22)+(B11-B10)/(2*12*2*E24*B13)+B12/(12*B23*B14)	Btu/hr-ft²-°F	calculated	0.039078
30	$R_{cond,i}$	=1/(690*E21)+(B11-B10)/(2*12*2*E24*B13)	Btu/hr-ft²-°F	calculated	0.00025151
31	$T_{steel,conv}$	80.109	°F	output	
32	$T_{steel,cond}$	143.65	°F	output	
33	T_{wpip}	80.018	°F	output	
34	T_{sat}	='C:\STMFUNC.XLA'!tpsat(B6)	°F	calculated	253.93
35	$Qdot_{o,conv}$	=(B7-B31)/E27	Btu/hr	calculated	22740
36	$Qdot_{i,conv}$	=(B31-B33)/E28	Btu/hr	calculated	17205
37	$Qdot_{steel,conv}$	=B35-B36	Btu/hr	calculated	5535.9
38	$Qdot_{o,cond}$	=(B7-B32)/B29	Btu/hr	calculated	3875.8
39	$Qdot_{i,cond}$	=(E34-B32)/E30	Btu/hr	calculated	4381600
40	$Qdot_{steel,cond}$	=(B32-E57)*(B16-B15)*B42*B43*PI()/4*((B11/12)^2-(B10/12)^2)*3600/B5	Btu/hr	calculated	1983500
41	$Qdot_{steel,steel}$	=(B32-B31)*B9*B5*B42*B43*PI()/4*((B11/12)^2-(B10/12)^2)*3600/B5	Btu/hr	calculated	2471200
42	ρ_{steel}	489	lb_m/ft^3	input	
43	c_{steel}	0.12	Btu/lb$_m$-°F	input	
44	$\%BAL_{conv}$	=(B35-B36-B37)/(B35+B36+B37)			
45	$\%BAL_{cond}$	=(B38+B39-B40-B41)/(B38+B39+B40+B41)			
46					
47					
48					
49	Quantity	Value	Units	Source	Comparison with: code output
50					
51					
52	$Vol_{steel,conv}$	=PI()/4*((B11/12)^2-(B10/12)^2)*B15	ft^3	calculated	
53	$\Delta T_{steel,conv}$	=B38*B5/(3600*B52*B42*B43)	°F	calculated	
54	$Vol_{steel,cond}$	=PI()/4*((B11/12)^2-(B10/12)^2)*((B16-B15)+B9*B5)	ft^3	calculated	
55	$\Delta T_{steel,cond}$	=E40*B5/(3600*B42*B43*B54)	°F	calculated	
56	$T_{steel,previous,conv}$	=B31-B53	°F	calculated	80.109
57	$T_{steel,previous,cond}$	=B32-B55	°F	calculated	143.23

APPENDIX B

LOCA/LOOP HYDRAULIC ANALYSIS, POST PUMP START-UP

for

VIRGIL C. SUMMER NUCLEAR STATION

Prepared Samir Yassin Date 5-23-97

Reviewed Date 5-23-97

Approved H. S. Taylor Date 5-23-97

B1 PURPOSE

The purpose of this calculation is to perform a hydraulic analysis of the post pump start-up transient for the Virgil C. Summer Nuclear Station (VCSNS). The analysis is based upon a model that includes two containment fan cooler (RBCUs) XAA-1A and XAA-2A, as well as the booster pump XPP-45A and the corresponding supply piping upstream of both coolers are selected for this analysis. The configuration and piping arrangements of RBCUs XAA-1B and XAA-2B are similar to those of XAA-1A and XAA-2A respectively.

B2 DESIGN INPUT

B2.1 The system configuration, such as pump curves, pipe diameters, lengths, and elevations, are based upon VCSNS isometric drawings (Reference B7.1). Booster pump curves are given in Reference B7.2. Service water pump curves are given in Reference B7.8.

B2.2 The booster pump start time in this analysis is 0 second, which corresponds to approximately 41.5 seconds after the LOOP (Reference B7.3).

B2.3 Water and steam properties used in the analysis are based upon the ASME Steam Tables (Reference B7.4).

B3 ASSUMPTIONS

B3.1 For conservatism, it is assumed that all flow from the booster pump will be supplied to one or two RBCUs.

B3.2 The piping downstream of the RBCU outlet valves XVG-3107 contains a separated column at the beginning of this transient. When outlet valve XVG-3107 begin to open, the discharge side of the RBCU will be exposed to this pressure until the return line fills with water. For conservatism, a zero back pressure is assumed throughout the refill transient.

B4 APPROACH

The refilling process will start approximately 41.5 seconds after the LOOP. The analysis is based upon a booster pump starting at 30 seconds after the diesel generator is ready for loading which is 11.5 seconds after the LOOP.

One booster Pump (XPP-45A) and the two RBCUs (XAA-1A and XAA-2A) are considered in the analysis. In train B, where booster pump (XPP-45B) supplies water to the RBCUs XAA-1B and XAA-2B, the piping configurations are similar to those in loop A above. Due to this similarity, the results of the analysis will be applicable to both loops.

In the analysis, the momentum equations governing the flow to the RBCUs are solved simultaneously using a simplified algorithm that has been developed specifically for this analysis. The algorithm is listed and validated in Section B9. The computational results include time dependent values of flow rates and integrated flows.

B5 COMPUTATIONS

The force exerted by the pumps on the water column in the 16-inch return line should equal the total of the frictional force in the pipe, the rate of change in momentum of the water column, and the force due to difference in elevation, in addition to the force acting on that column due to the back pressure. The back pressure in this analysis is that at the discharge of the downstream of the RBCUs. For conservatism, a zero back pressure is assumed.

The momentum equations governing the flow in different pipe segments of the supply line upstream of the RBCUs are solved simultaneously throughout the transient using a simplified algorithm that has been developed specifically for this analysis

B6 RESULTS AND DISCUSSION

The results of the analysis are presented in Figures B1-1, B1-2 and B1-3.

The results show that the maximum flow rate through the RBCUs is less than 13.12 ft^3/sec (5888 gpm) if it was assumed that the flow from the Booster Pump 45A would be directed to one RBCU only (RBCU XAA-1A).

However, the results also shows that the maximum flow rate through each RBCU is less than 6.64 ft^3/sec (2980 gpm) if it is assumed that the flow from the booster pump would be directed to two RBCUs.

Because the flow is directed through the piping in a different manner for these two potential alignments, the water velocities and water hammer pressure values are calculated for each line size for each flow condition. This will address the potential alignments that can occur during normal, infrequent, accident and test conditions. The more limiting of the two conditions is the system requirement.

Time-dependent values of flow rates and integrated flows are shown in Figures B1-1 and B1-2.

Sonic velocity (a) of shock wave in the 10-inch line (O.D. = 10.75 inches , Thickness (t) = 0.365 inches, I.D. = 10.02 inches, Flow Area = 0.548 ft^2) is calculated as follows :

$$a = 4660 / ((1 + 0.01 * (I.D./t))^{0.5} = 4127.7 \text{ ft/sec}$$

<u>For the case where the flow from the booster pump is directed to one RBCU only :</u>

The velocity of water in the 10-inch line at 31.12 ft^3/sec will be 13.12 / 0.548 = 23.94 ft / sec. Therefore, the maximum expected water hammer pressure wave (P) in the 10-inch line can be calculated as follows:

$$P = 0.5 * a * v * (\gamma / g) / 144 = 0.5 * 4127.7 * 23.94 * (62.4 / 32.2) / 144 = 666 \text{ psig.}$$

This is the expected maximum water hammer pressure in the return side, 10-inch line as a result of LOOP or LOCA/LOOP.

Similarly, the maximum expected water hammer pressure in the return side, 8-inch lines and 16-inch lines is 265 psi and 274 psi, respectively (see Figure B1-3).

<u>For an alternate case where the flow from the booster pump goes to two RBCUs:</u>

The velocity of water in the 10-inch line at 6.64 ft^3/sec will be 6.64 / 0.548 = 12.12 ft / sec.

Therefore, the maximum expected water hammer pressure wave (P) in the 10-inch line can be calculated as follows:

$$P = 0.5 * a * v * (\gamma / g) / 144 = 0.5 * 4127.7 * 12.12 * (62.4 / 32.2) / 144 = 337 \text{ psig.}$$

In this less conservative case, the expected maximum water hammer pressure in the return side, 10-inch line as a result of LOOP or LOCA/LOOP is 337 psig.

Similarly, the maximum expected water hammer pressure in the return side 8-inch lines and 16-inch lines is 134 psi and 274 psi, respectively (see Figure B1-3).

The maximum water hammer pressure that would occur in the 16-inch return line is 274 psi after the RBCU outlet valves, XVG-3107, begin to open followed by the flow from the booster pump. The water hammer will strike the water column at or near Elevation 450.

The simplified method employed to estimate the water hammer pressure assumes that two water slugs collide. The relative speed calculated for the water slugs is maximized by setting the back pressure on the coil to zero and estimating the velocity based on pump flow. Should this velocity be evaluated subsequent to a LOCA, steam bubble formation would raise the back pressure on the coil and reduce the calculated velocity, reducing the estimate for the water hammer pressure. Therefore, the values calculated above bound both the LOCA and the non-LOCA cases. This water hammer pressure values are conservative because a number of factors which have the effect of reducing the pressure (e. g. acceleration of the downstream leg after the discharge valve is opened, elevated water temperatures and correspondingly lower fluid densities, entrained non-condensables, fouling factors in the piping system flow calculations and cooling coil heat transfer calculations) have been ignored in its determination.

At VCSNS, data are available from MOVATS tests (Reference B7.9) that allow examination of the cold-restart transient and comparison with the analytical results. In these data, the RBCUs are aligned to the service water system and placed in standby mode. The service water pumps are in operation and the header is pressurized. The service water booster pump is off and valves XVG-3106 and XVG-3107 are closed. This allows the column separation to form downstream of XVG-3107.

The test is initiated by starting the service water booster pump, which in turn signals XVG-3106 and XVG-3107 to open. Figures B2-1 through B2-4 show the pressure measured upstream and downstream of XVG-3106A, XVG-3107A, XVG-3106B and XVG-3107B for such tests. The pressure traces are given in the lower two curves of these figures.

The analytical results for the flow during this scenario is given in Figure B1-1. The flow rises from zero at pump start to full flow in approximately 2 seconds. The comparable traces are the upstream pressure for XVG-3106 (Figures B2-1 and B2-3). In these figures the pressure rises sharply at pump start, reaching a peak value at approximately 3 to 5 seconds. The pressure then settles to a steady state value less than the peak value. For the downstream valves, Figures B2-2 and B2-4, the pressure signature is similar but the pressure rise occurs over a longer period of time, approximately 5 seconds for Figure B2-2 and approximately 12 seconds for Figure B2-4. The important observation is that the fast rise predicted analytically leads to higher velocities and water hammer pressures and is therefore conservative.

An important result is shown in the pressure traces downstream of the XVG-3107 valves. (See the lower curve in Figures B2-2 and B2-4.) The pressure traces rise from the static pressure to a peak value in 10 to 15 seconds. However, there is no evidence of a column separation water hammer event propagating from the return line into the piping during these tests. This is important as these tests are performed under the scenario expected to produce the maximum water hammer pressure from closure of the column separation.

B7 REFERENCES

B7.1 VCSNS Drawings:

E-302-221, Revision 19 System Flow Diagram - Service Water Cooling
E-302-222, Revision 33, System Flow Diagram - Service Water Cooling
E-304-252 , Revision 1, Service Water Cooling Int. Building Plan -- Below EL. 412' - 0", Col 5.2 - 9.1
E-304-253 , Revision 4, Service Water Cooling Int. Building Plan -- Below EL. 436' - 0", Col 2.8 -5.2
E-304-254 , Revision 11, Service Water Cooling Int. Building Plan -- Below EL. 454' - 0", Col 5.2 - 9.2
E-304-255 , Revision 11, Service Water Cooling PEN, Access Area Aux. Plans EL 412'-0", 436'-0", 463'-0"
E-304-256 , Revision 12, Service Water Cooling Auxiliary Plans, Sections and Details
E-304-257, Revision 3, Service Water Cooling, Reactor Building Plan and Sections Above EL 463'-0"
E-304-258, Revision 9, Service Water Cooling Reactor Building Sections and Details
C-314-251, Sheet 1, Revision 5, Service Water - To & From Comp. Cooling Heat Exchanger "A"
C-314-251, Sheet 2, Revision 3, Service Water - To & From Comp. Cooling Heat Exchanger "B"
C-314-251, Sheet 3, Revision 1, Service Water - Booster Pump "A" Suction
C-314-251, Sheet 4, Revision 5, Service Water - Booster Pump "A" Discharge to Penetration #304
C-314-251, Sheet 5, Revision 4, Service Water - Loop "A" Return From Penetration #305 To EL 412'-0"
C-314-251, Sheet 6, Revision 2, Service Water - Booster Pump "B" Suction
C-314-251, Sheet 7, Revision 6, Service Water - Booster Pump "B" Discharge to Penetration #403
C-314-251, Sheet 8, Revision 5, Service Water - Loop "B" Return From Penetration #102 To EL 412'-0"
C-314-251, Sheet 11, Revision 5, Service Water - From Penetration 403 To Reactor Building Cooling Unit, "1B" & "2B"
C-314-251, Sheet 12, Revision 3, Service Water - From Reactor Building Cooling Units "1B" & "2B" To Pen. #102

C-314-251, Sheet 13, Revision 3, Service Water -From Pen. #304 To Reactor Building Cooling Units "1A" & "2A"

C-314-251, Sheet 14, Revision 1, Service Water - From Pen #304 To Reactor Building Cooling Units "1A" & "2A" - Details

C-314-251, Sheet 15, Revision 4, Service Water - From Reactor Building Cooling Units "1A" & "2A" To Penetration #305

C-314-251, Sheet 16, Revision 3, Service Water - From Reactor Building Cooling Units "1A" & "2A" To Penetration #305- Details

C-314-251, Sheet 17, Revision 4, Service Water - Service Water Pump Discharge Line

1MS-54-098, Revision 0, V. C. Summer Coolers

B7.2 Gould Pumps, Incorporated Certified Test Sheet for Gould Model 3405-L, Serial Numbers N238B455-1 and N238B455-2, dated April 14, 1978.

B7.3 VCSNS FSAR.

B7.4 ASME Steam Tables, 1967.

B7.5 Fauske and Associates Report, Inc., FAI/96-75, "Evaluation of Possible Water-Hammer Loads in the Service Water System for DBA Conditions", R. E. Henry, Dated October 16, 1996. Presented at the NEI GL 96-06 Industry Meeting on October 29, 1996.

B7.6 Crane Technical Paper No. 410, "Flow of Fluids Through Valves, Fittings and Pipe," Twentieth Volume, 1981.

B7.7 NUREG-5220, "Diagnosis of Condensation-Induced Water hammer", Published October 1988

B7.8 Gould Pumps, Incorporated Certified Test Sheet for Gould Model 24 x 30 BHC Deep Well Turbine Pump, Serial Numbers N302996-1, N302996-2 and N302996-3, dated June 21, 22 and 23, 1978, respectively.

B7.9 VCSNS Modification Package MFR-22362, "Service Water Actuator, Valve and Logic Change"

Figure B1-1 : Flow Rates from Pump 45A

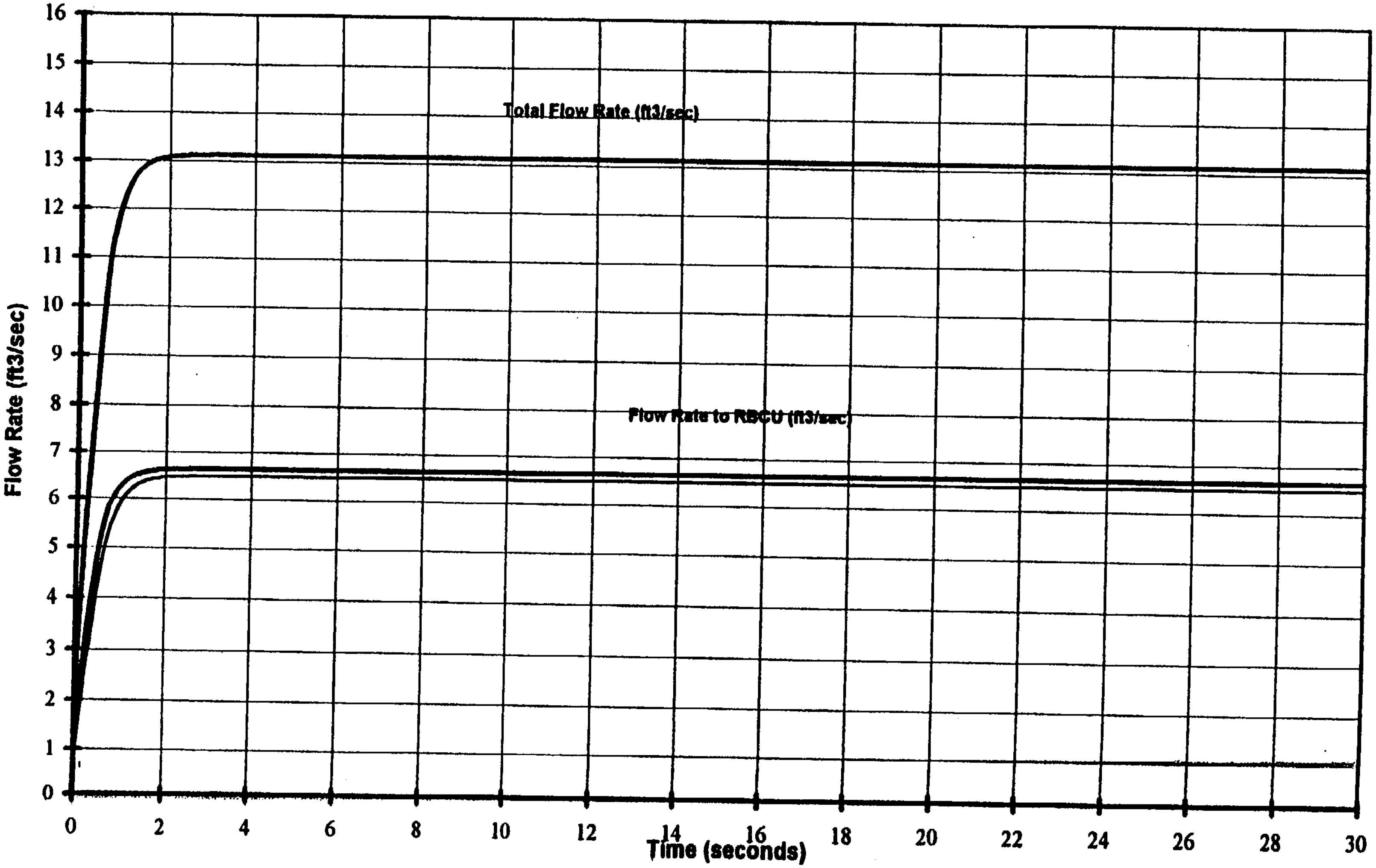


Figure B1-2 : Integrated Flows Through The RBCU's

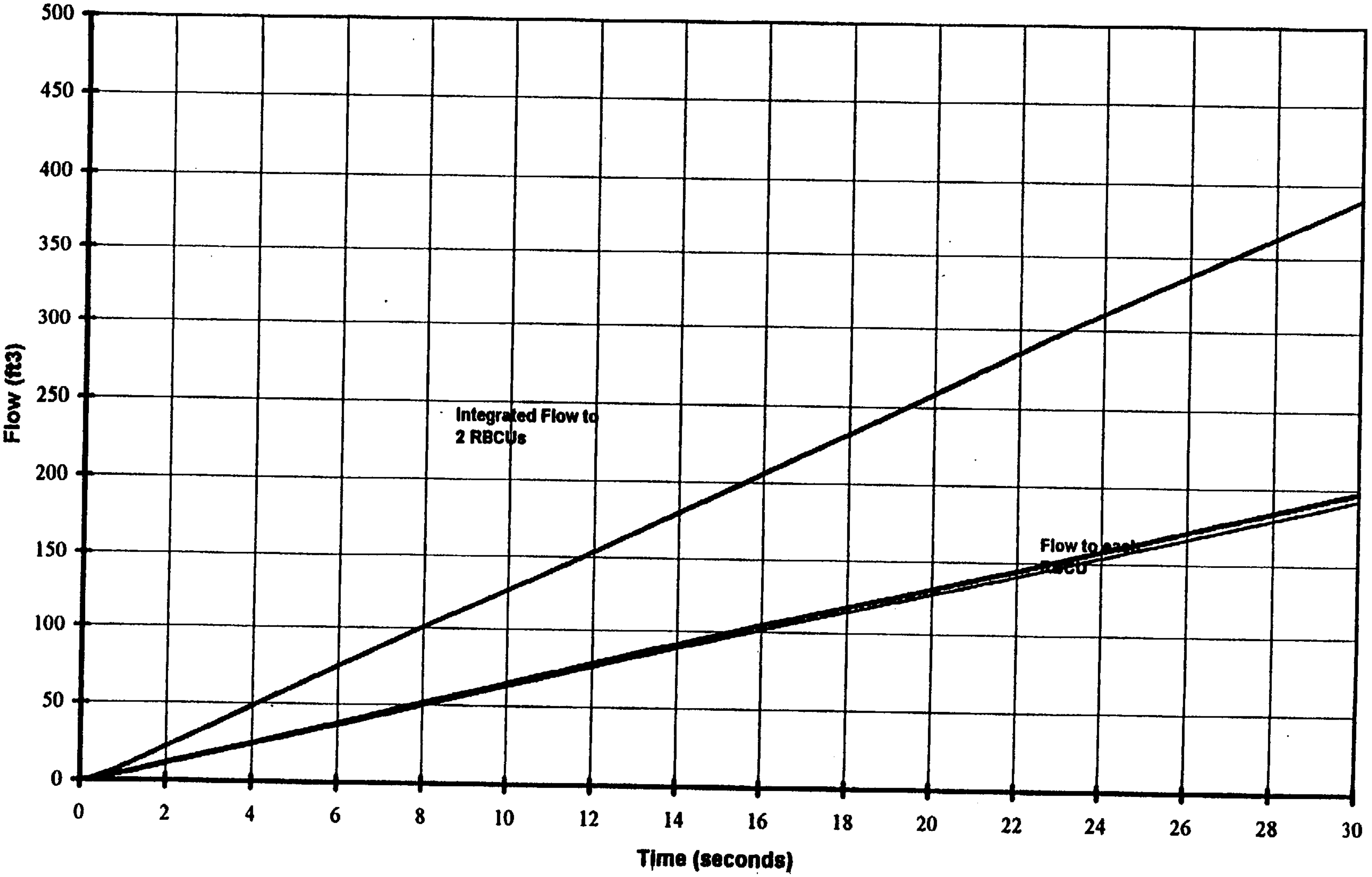
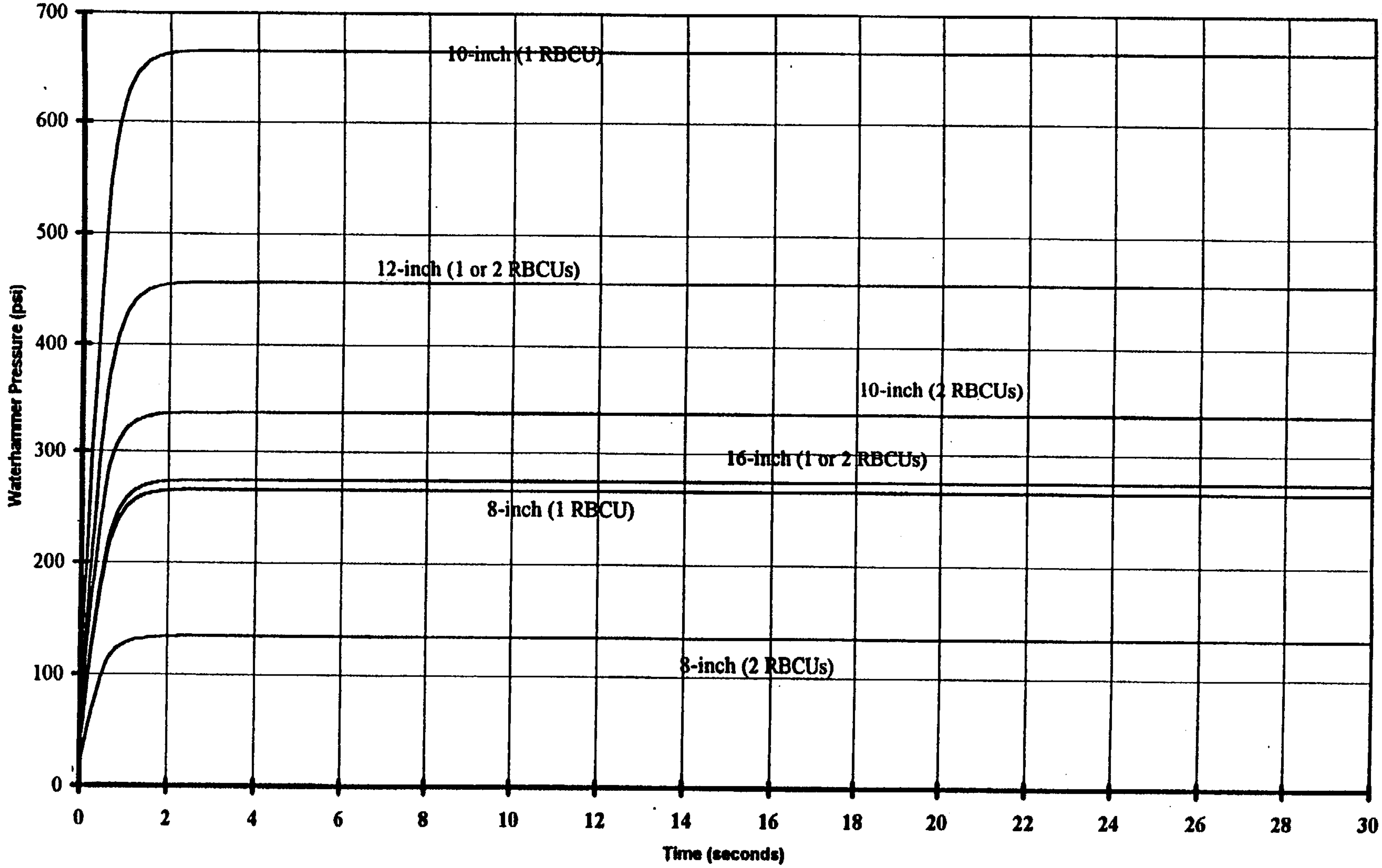
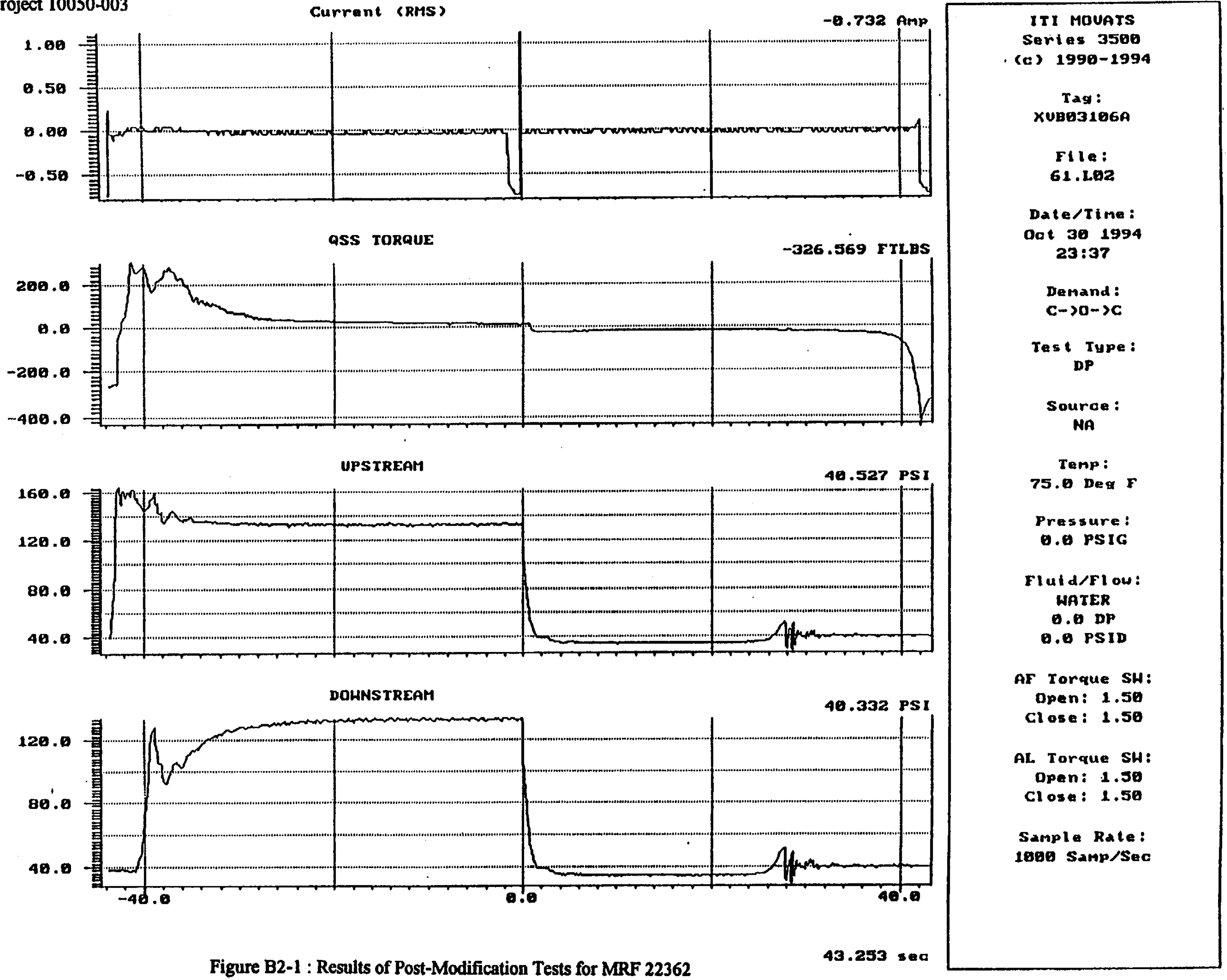


Figure B1-3 : Maximum Expected Waterhammer Pressures in Service Water System Piping





ITI MOVATS
Series 3500
(c) 1990-1994

Tag:
XVB03106A

File:
61.L02

Date/Time:
Oct 30 1994
23:37

Demand:
C->O->C

Test Type:
DP

Source:
NA

Temp:
75.0 Deg F

Pressure:
0.0 PSIG

Fluid/Flow:
WATER
0.0 DP
0.0 PSID

AF Torque SW:
Open: 1.50
Close: 1.50

AL Torque SW:
Open: 1.50
Close: 1.50

Sample Rate:
1000 Samp/Sec

Figure B2-1 : Results of Post-Modification Tests for MRF 22362

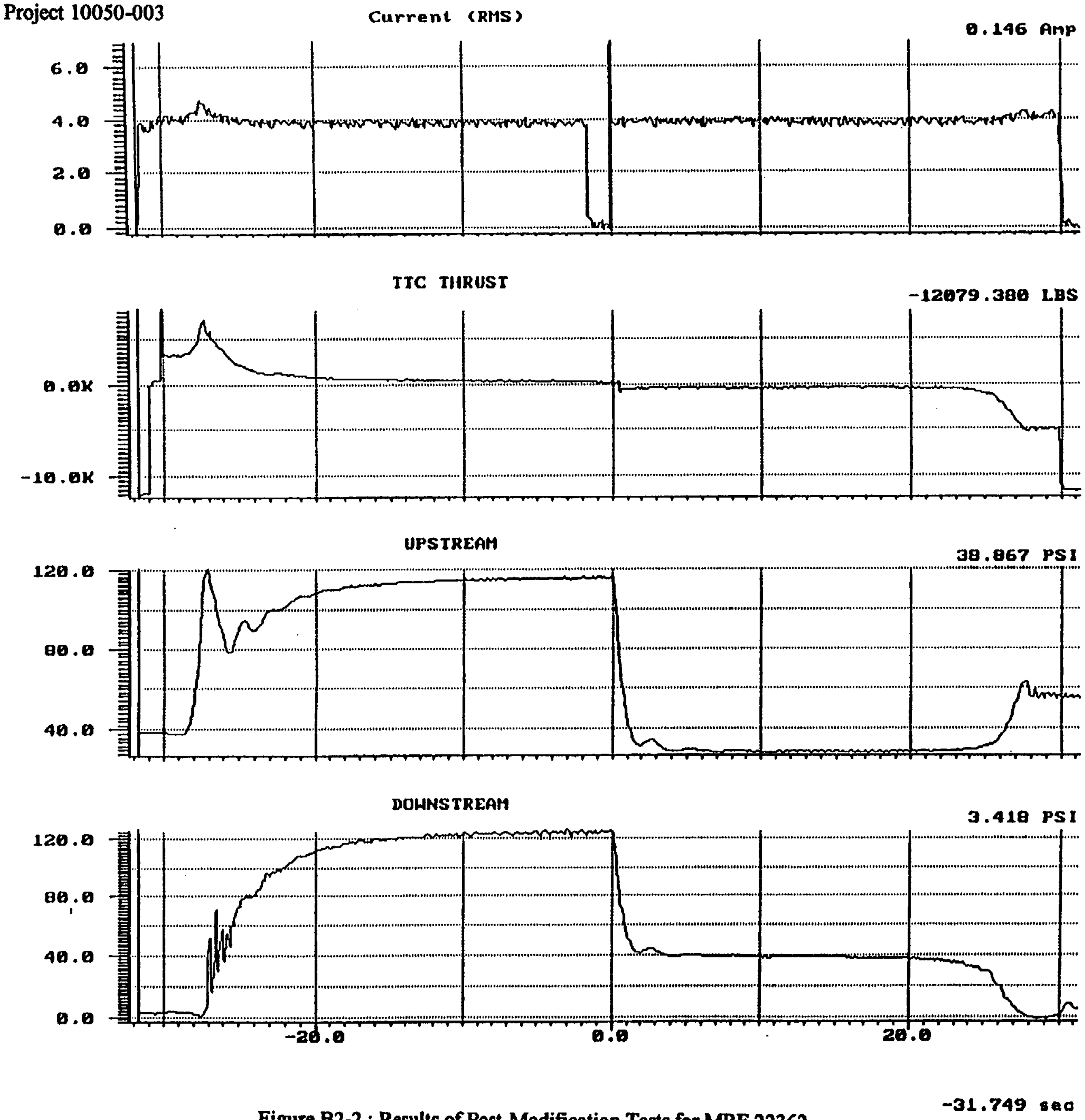


Figure B2-2 : Results of Post-Modification Tests for MRF 22362

ITI MOVATS
Series 3500
(c) 1990-1994

Tag:
XVG03107A

File:
139.L04

Date/Time:
Oct 31 1994
00:39

Demand:
C->O->C

Test Type:
DP

Source:
SW PUMP

Temp:
0.0 Deg F

Pressure:
0.0 PSIG

Fluid/Flow:
WATER
0.0 DP
0.0 PSID

AF Torque SW:
Open: 1.00
Close: 1.00

AL Torque SW:
Open: 1.00
Close: 1.00

Sample Rate:
1000 Samp/Sec

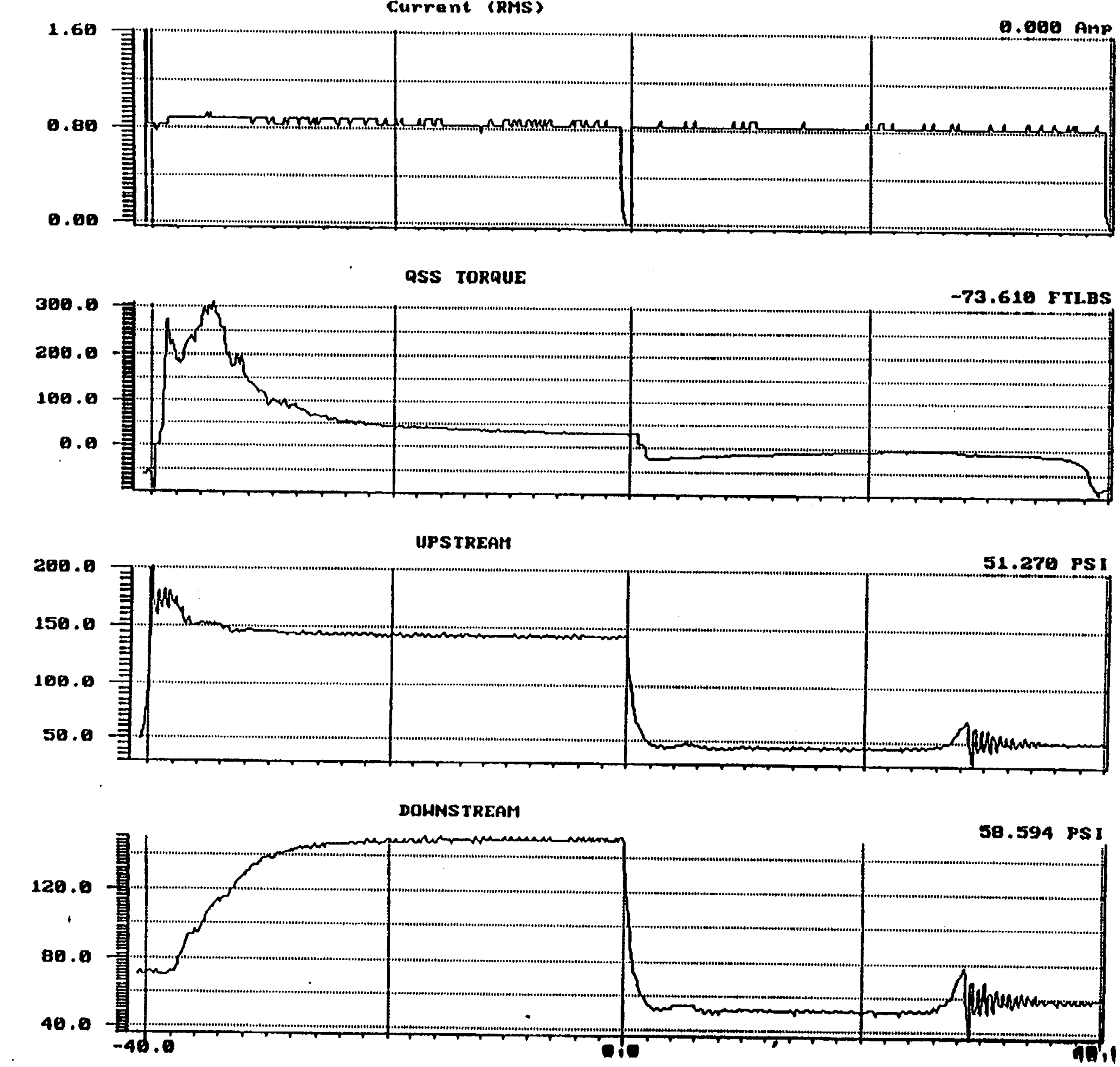


Figure B2-3 : Results of Post-Modification Tests for MRF 22362

40.254 sec

ITI MOVATS
Series 3500
(c) 1990-1994

Tag:
XVB03106B

File:
62.L03

Date/Time:
Oct 31 1994
03:10

Demand:
C->O->C

Test Type:
DP

Source:
SWBP

Temp:
75.0 Deg F

Pressure:
0.0 PSIG

Fluid/Flow:
WATER
0.0 DP
0.0 PSID

AF Torque SW:
Open: 1.00
Close: 1.00

AL Torque SW:
Open: 1.00
Close: 1.00

Sample Rate:
1000 Samp/Sec

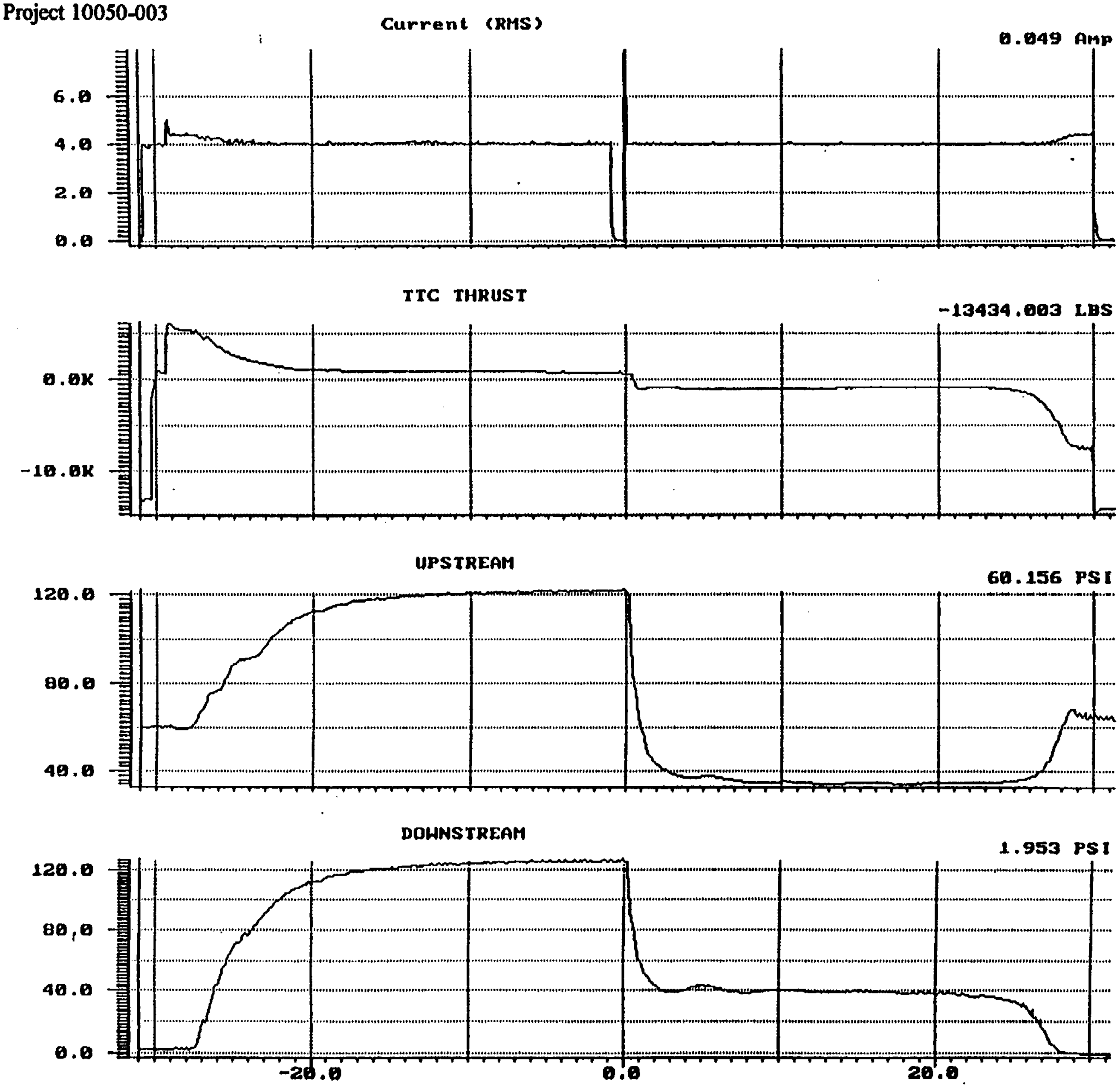


Figure B2-4 : Results of Post-Modification Tests for MRF 22362

ITI MOVATS
Series 3500
(c) 1990-1994

Tag:
XVG03107B

File:
140.L05

Date/Time:
Oct 31 1994
04:13

Demand:
C->O->C

Test Type:
DP

Source:
B. PUMP

Temp:
0.0 Deg F

Pressure:
0.0 PSIG

Fluid/Flow:
WATER
0.0 DP
0.0 PSID

AF Torque SW:
Open: 1.00
Close: 1.25

AL Torque SW:
Open: 1.00
Close: 1.25

Sample Rate:
1000 Samp/Sec

VALIDATION OF COMPUTER PROGRAM POSTPUMP

This section of Appendix A includes the validation documentation for the computer program POSTPUMP. This code is used to predict flow conditions in the containment fan cooler piping after the restart of the Service Water pumps. POSTPUMP is a one-shot computer program that was developed specifically for the analysis performed in this appendix.

The validation documentation includes the following items :

Listing of FORTRAN subroutines.

- postpump.for
- echo.for
- header.for
- blockio.for
- iocom.for (INCLUDED COMMON Blocks)

Listings of the program input and output for the validation case run.

A detailed spreadsheet analysis that validates the POSTPUMP results.

Program Name : POSTPUMP

Prepared by ______________________ Date 5/23/97

Reviewed by Samir Yassin Date 5/23/97

Approved by ______________________ Date 5-23-97

```
C    POSTPUMP - Post Pump Start-Up LOCA/LOOP Hydraulic Analysis
C
C 100 DIMENSIONS
C
      IMPLICIT REAL *8 (A-H,O-Z)
      REAL *8 LAA,LAAT,KAA,KAAT
      REAL *8 LAB,LABT,KAB,KABT
      REAL *8 LA,LAT,KA,KAT
      CHARACTER *60 TITLE
      DIMENSION PSTIME(10)
      DIMENSION QAT(100),PPT(100)
      DIMENSION DAAT(1000),LAAT(1000),KAAT(1000),H1AAT(1000),H2AAT(1000)
      DIMENSION DABT(1000),LABT(1000),KABT(1000),H1ABT(1000),H2ABT(1000)
      DIMENSION DAT(1000), LAT(1000), KAT(1000), H1AT(1000), H2AT(1000)
      DIMENSION UCAA(1000),UCAB(1000),UCA(1000),
     X        UPAA(1000),UPAB(1000),UPA(1000)
C
      INCLUDE 'IOCOM.FOR'
C
C    Open input and output files
C
      CALL ECHO
C
C 200 INPUT
C
      CALL HEADER
      PI=3.141592654
      GRAV=32.2
      RHO=62.4/32.2
C
C    TITLE (A60)
C
      READ(LIN,910)TITLE
C
C    Time limit parameters
C
C    DT     - Time step increment (seconds)
C    TOMIN  - Time at which output to print file begins (seconds)
C    TOMAX  - Time at which output to print file ends (seconds)
C    TMAX   - Time at which the analysis ends (seconds)
C
      READ(LIN,*)DT,TOMIN,TOMAX,TMAX
C
C    Initial conditions
C
C    QAI    - Initial total flow rate (gpm)
C    RAI    - Initial fraction of flow rate through line AA
C    PBAA   - Backpressure in line AA (psi)
C    PBAB   - Backpressure in line AB (psi)
C
      READ(LIN,*)QAI,RAAI,PBAA,PBAB
C
C    Pump Phased Start Time Data
C
```

```
C    IPUMPS    - Number of Pumps >=1
C    PSTIME(I) - Pump start time (seconds)
C
      READ(LIN,*)IPUMPS,(PSTIME(I),I=1,IPUMPS)
C
C    Pump Curve Data - Single Pump
C
C    QAT(I) - Pump discharge flow rate (gpm)
C    PPT(I) - Pump head pressure (feet)
C
      READ(LIN,*)IQATMAX,(QAT(I),PPT(I),I=1,IQATMAX)
C
C    SW Pump Discharge Line from Pumps to CFC Supply Headers Parameters
C    Line AA (1HX-15A)
C
C    IAAMAX   - Number of segments in the line
C    DAAT(I)  - Pipe internal diameter (inches)
C    LAAT(I)  - Pipe length (feet)
C    KAAT(I)  - Total line resistance
C    H1AAT(I) - Starting elevation (feet)
C    H2AAT(I) - Ending elevation (feet)
C
      READ(LIN,*)IAAMAX,
     &(DAAT(I),LAAT(I),KAAT(I),H1AAT(I),H2AAT(I),I=1,IAAMAX)
C
C    SW Pump Discharge Line from Pumps to CFC Supply Headers Parameters
C    Line AB (1HX-15B)
C
C    IABMAX   - Number of segments in the line
C    DABT(I)  - Pipe internal diameter (inches)
C    LABT(I)  - Pipe length (feet)
C    KABT(I)  - Total line resistance
C    H1ABT(I) - Starting elevation (feet)
C    H2ABT(I) - Ending elevation (feet)
C
      READ(LIN,*)IABMAX,
     &(DABT(I),LABT(I),KABT(I),H1ABT(I),H2ABT(I),I=1,IABMAX)
C
C    SW Pump Discharge Line from Pumps to CFC Supply Headers Parameters
C    Line A
C
C    IAMAX   - Number of segments in the line
C    DAT(I)  - Pipe internal diameter (inches)
C    LAT(I)  - Pipe length (feet)
C    KAT(I)  - Total line resistance
C    H1AT(I) - Starting elevation (feet)
C    H2AT(I) - Ending elevation (feet)
C
      READ(LIN,*)IAMAX,
     &(DAT(I),LAT(I),KAT(I),H1AT(I),H2AT(I),I=1,IAMAX)
      QA1=QA1/(60*7.48)
      QA=QA1
      RAA=RAA1
      PBAA=PBAA*144
```

```
      PBAB=PBAB*144
      DO 10 I=1,1000
       UPAA(I)=0
       UPAB(I)=0
       UPA(I)=0
   10 CONTINUE
C
      T=-DT
C
C     Time Loop Entry
C
   90 T=T+DT
C
C     Use Pump Curve to Determine Pressure (PP2)
C     for Single Pump Flowrate (QA1PMP)
C
      QA1PMP=QA*60*7.48
      IF (IPUMPS.GT.1) THEN
       DO 20 I=2,IPUMPS
        IF (T.GE.PSTIME(I-1).AND.T.LT.PSTIME(I)) THEN
         QA1PMP=QA1PMP/(I-1)
         GOTO 25
        ENDIF
   20  CONTINUE
       QA1PMP=QA1PMP/IPUMPS
      ENDIF
   25 CONTINUE
C
      IF(QA1PMP.GT.QAT(IQATMAX)) THEN
       WRITE(6,*)'QA OUT OF RANGE'
       STOP
      ELSE
       DO 30 I=1,IQATMAX-1
        IF((QA1PMP.GE.QAT(I)).AND.(QA1PMP.LE.QAT(I+1))) THEN
         PP2=PPT(I)+
     X       (QA1PMP-QAT(I))*(PPT(I+1)-PPT(I))/(QAT(I+1)-QAT(I))
         PP2=PP2*RHO*GRAV
         GOTO 35
        ENDIF
   30  CONTINUE
      ENDIF
   35 CONTINUE
C
      KERR2=0
  100 CONTINUE
C
      KERR1=0
  110 CONTINUE
C
C     AA LOOP
C
      QAA=QA*RAA
      DO 120 IAA=IAAMAX,1,-1
       DAA=DAAT(IAA)/12
```

```
      LAA=LAAT(IAA)
      KAA=KAAT(IAA)
      H1AA=H1AAT(IAA)
      H2AA=H2AAT(IAA)
      IF(IAA.EQ.IAAMAX) THEN
       P2AA=PBAA
      ELSE
       UDAA=UAA
       AAA=(PI/4)*DAA**2
       UAA=QAA/AAA
       P2AA=P1AA+RHO*(UDAA**2-UAA**2)/2
      END IF
      QAA=QA*RAA
      AAA=(PI/4)*DAA**2
      UAA=QAA/AAA
      DMUDT=RHO*LAA*(UAA-UPAA(IAA))/DT
      FRIC=RHO*KAA*UAA*ABS(UAA)/2
      HEAD=RHO*GRAV*(H2AA-H1AA)
      P1AA=P2AA+DMUDT+FRIC+HEAD
      UCAA(IAA)=UAA
C      IF((T.GT.TOMIN).AND.(T.LE.TOMAX)) THEN
C        WRITE(LOUT,*)'AA LOOP'
C        WRITE(LOUT,920)T,UDAA,UAA,AAA,P2AA,P1AA,PBAA
C        WRITE(LOUT,920)T,DMUDT,UPAA,FRIC,HEAD,UCAA,H2AA
C      END IF
C
 120 CONTINUE
    DA=DAT(IAMAX)/12
    UDA=UAA
    AA=(PI/4)*DA**2
    UA=QA/AA
    P2A1=P1AA+RHO*(UDA**2-UA**2)/2
C       WRITE(LOUT,*)'AA LOOP'
C       WRITE(LOUT,920)T,P2A1,P1AA,RHO,UDA,UA
C
C   AB LOOP
C
    RAB=1-RAA
    QAB=QA*RAB
    DO 130 IAB=IABMAX,1,-1
     DAB=DABT(IAB)/12
     LAB=LABT(IAB)
     KAB=KABT(IAB)
     H1AB=H1ABT(IAB)
     H2AB=H2ABT(IAB)
     IF(IAB.EQ.IABMAX) THEN
      P2AB=PBAB
     ELSE
      UDAB=UAB
      AAB=(PI/4)*DAB**2
      UAB=QAB/AAB
      P2AB=P1AB+RHO*(UDAB**2-UAB**2)/2
     END IF
     QAB=QA*RAB
```

```
        AAB=(PI/4)*DAB**2
        UAB=QAB/AAB
        DMUDT=RHO*LAB*(UAB-UPAB(IAB))/DT
        FRIC=RHO*KAB*UAB*ABS(UAB)/2
        HEAD=RHO*GRAV*(H2AB-H1AB)
        P1AB=P2AB+DMUDT+FRIC+HEAD
        UCAB(IAB)=UAB
C        IF((T.GT.TOMIN).AND.(T.LE.TOMAX)) THEN
C          WRITE(LOUT,*)'AB LOOP'
C          WRITE(LOUT,920)T,UDAB,UAB,AAB,P2AB,P1AB,PBAB
C          WRITE(LOUT,920)T,DMUDT,UPAB,FRIC,HEAD,UCAB,H2AB
C        END IF
C
  130 CONTINUE
      DA=DAT(IAMAX)/12
      UDA=UAB
      AA=(PI/4)*DA**2
      UA=QA/AA
      P2A2=P1AB+RHO*(UDA**2-UA**2)/2
C        WRITE(LOUT,*)'AB LOOP'
C        WRITE(LOUT,920)T,P2A2,P1AB,RHO,UDA,UA
C
      PHEADMIN=RHO*GRAV*(H2AAT(IAAMAX)-H1AAT(1))
      ERR1=2*100*(P2A2-P2A1)/(ABS(P2A2+P2A1)+1)
C      WRITE(6,'(F8.2,I12,1P5E12.5)')
C    *          T,KERR1,PHEADMIN,P2A1,P2A2,ERR1,RAA
C      WRITE(LOUT,'(F8.2,I12,1P5E12.5)')
C    *          T,KERR1,PHEADMIN,P2A1,P2A2,ERR1,RAA
      IF((P2A2.GT.PHEADMIN).AND.(ABS(ERR1).GT.0.1)) THEN
        RAA=RAA+0.0001*ERR1
        IF(KERR1.GT.100000) THEN
          WRITE(6,*)'KERR1 OUT OF RANGE'
          STOP
        ENDIF
        KERR1=KERR1+1
C         WRITE(6,'(F8.2,I12,1P5E12.5)')
C    *          T,KERR1,PHEADMIN,P2A1,P2A2,ERR1,RAA
C         WRITE(LOUT,'(F8.2,I12,1P5E12.5)')
C    *          T,KERR1,PHEADMIN,P2A1,P2A2,ERR1,RAA
C         IF ( KERR1.EQ.2 ) STOP
        GOTO 110
      END IF
      PBA=P2A2
C
C     A LOOP
C
      DO 140 IA=IAMAX,1,-1
       DA=DAT(IA)/12
       LA=LAT(IA)
       KA=KAT(IA)
       H1A=H1AT(IA)
       H2A=H2AT(IA)
       IF(IA.EQ.IAMAX) THEN
        P2A=PBA
```

```
        ELSE
         UDA=UA
         AA=(PI/4)*DA**2
         UA=QA/AA
         P2A=P1A+RHO*(UDA**2-UA**2)/2
        END IF
        AA=(PI/4)*DA**2
        UA=QA/AA
        DMUDT=RHO*LA*(UA-UPA(IA))/DT
        FRIC=RHO*KA*UA*ABS(UA)/2
        HEAD=RHO*GRAV*(H2A-H1A)
        P1A=P2A+DMUDT+FRIC+HEAD
        UCA(IA)=UA
C        IF((T.GT.TOMIN).AND.(T.LE.TOMAX)) THEN
C          WRITE(LOUT,*)'A LOOP'
C          WRITE(LOUT,920)T,UDA,UA,AA,P2A,P1A,PBA
C          WRITE(LOUT,920)T,DMUDT,UPA,FRIC,HEAD,UCA,H2A
C        END IF
C
 140  CONTINUE
      PP1=P1A
C
C       WRITE(6,'(F8.2,I12,1P5E12.5)')
C     *           T,KERR2,PP2,PP1,ERR2,QA
C       WRITE(LOUT,'(F8.2,I12,1P5E12.5)')
C     *           T,KERR2,PP2,PP1,ERR2,QA
      ERR2=2*100*(PP2-PP1)/(ABS(PP2+PP1)+1)
      IF(ABS(ERR2).GT.0.1) THEN
       QA=QA+0.0001*ERR2
       IF(KERR2.GT.1000000) THEN
        WRITE(6,*)'KERR2 OUT OF RANGE'
        STOP
       ENDIF
       KERR2=KERR2+1
C       WRITE(6,'(F8.2,I12,1P5E12.5)')
C     *           T,KERR2,PP2,PP1,ERR2,QA
C       WRITE(LOUT,'(F8.2,I12,1P5E12.5)')
C     *           T,KERR2,PP2,PP1,ERR2,QA
C       IF ( KERR2.EQ.1000 ) STOP
       GOTO 100
      END IF
      PP=(PP1+PP2)/2
C
      QTOTA=QTOTA+QA*DT
      QTOTAA=QTOTAA+QAA*DT
      QTOTAB=QTOTAB+QAB*DT
      DO 150 I=1,1000
       UPAA(I)=UCAA(I)
       UPAB(I)=UCAB(I)
       UPA(I)=UCA(I)
 150  CONTINUE
C
      WRITE(6,920)T,PP,QA,QAA,QAB,QTOTAA,QTOTAB
      WRITE(LOUT,920)T,PP,QA,QAA,QAB,QTOTAA,QTOTAB
```

```
   WRITE(LPL1,920)T,QTOTA,QA,QAA,QAB,QTOTAA,QTOTAB
C
   IF((T.GT.TOMIN).AND.(T.LE.TOMAX)) THEN
    WRITE(LOUT,920)T,QAA,AAA,UAA.P1AA,P2AA,P2A1
    WRITE(LOUT,920)T,QAB,AAB,UAB,P1AB.P2AB,P2A2
    WRITE(LOUT,920)T,QA,AA,UA.P1A.P2A
    WRITE(LOUT,920)T,DMUDT,FRIC.HEAD,PP1,PP2
   END IF
C
C   Check for Time Limit, Otherwise Continue Time Loop
C
   IF(T.GT.TMAX) THEN
    STOP
   ELSE
    GOTO 90
   ENDIF
C
 910 FORMAT(A60)
 920 FORMAT(F8.2,1P6E12.4)
C
   END
```

```
SUBROUTINE ECHO
C
C   CALLED BY THE 'MAIN' PROGRAM
C
C   Routine to read input data from file assigned to LIN,
C   print copies of the input lines to the standard output
C   file LOUT and to the alternate input file ALTIN, and
C   then redirect input reads to the alternate input file.
C
    CHARACTER*4 IMAGE(20)
    INTEGER   IOCHEK,LCOUNT,LCSTRT,LCMAX
C
    INCLUDE 'IOCOM.FOR'
C
    DATA LCSTRT/5/,LCMAX/56/
C
C   Initialize the input unit number.
C
    LIN=LOCIN
C
C   Open the input file - POSTPUMP.DAT.
C
    OPEN (UNIT=LIN,ACCESS='SEQUENTIAL',ERR=1900,
   X     FILE='POSTPUMP.DAT',FORM='FORMATTED',STATUS='UNKNOWN')
C
C   Open the output file - POSTPUMP.OUT.
C
    LOUT=LOCOUT
    OPEN (UNIT=LOUT,ACCESS='SEQUENTIAL',ERR=2000,
   X     FILE='POSTPUMP.OUT',FORM='FORMATTED',STATUS='UNKNOWN')
C
C   Initialize the plot output unit numbers.
C
    LPL1=LPL1OT
C
C   Open the plot output file POSTPUMP.PL1
C
    OPEN(UNIT=LPL1,FILE='POSTPUMP.PL1')
C
C   Open the alternate input file - ALTINPUT.TXT.
C
    AOUT=ALTIN
    OPEN (UNIT=AOUT,ACCESS='SEQUENTIAL',ERR=2100,
   X     FORM='FORMATTED',STATUS='SCRATCH')
C
    CALL HEADER
    LCOUNT=LCSTRT
  1 READ(LIN,3000,END=1000,ERR=1000,IOSTAT=IOCHEK) IMAGE
    IF (LCOUNT.EQ.LCMAX) THEN
     CALL HEADER
     LCOUNT=LCSTRT
    ENDIF
    WRITE(AOUT,3000) IMAGE
    WRITE(LOUT,3010) IMAGE
```

```
      LCOUNT=LCOUNT+1
      GO TO 1
C
C     End of file encountered on input
C
 1000 IF (IOCHEK.EQ.-1) THEN
        LIN=ALTIN
        REWIND LIN
        RETURN
      ELSE
        WRITE(LOUT,3100) LIN
        STOP
      ENDIF
C
C     Error attempting to open file POSTPUMP.DAT
C
 1900 STOP 'STOP - Error attempting to open file POSTPUMP.DAT'
C
C     Error attempting to open file POSTPUMP.OUT
C
 2000 STOP 'STOP - Error attempting to open file POSTPUMP.OUT'
C
C     Error attempting to open file ALTINPUT.TXT
C
 2100 STOP 'STOP - Error attempting to open file ALTINPUT.TXT'
C
C    Formats
C
 3000 FORMAT (20A4)
 3010 FORMAT (20A4)
 3100 FORMAT (/' ','I/O error encountered on input.')
     END
```

```
C
      SUBROUTINE HEADER
C
C  A subroutine to send a form feed character and
C  header line to the output file.
C
C  Declarations for local variables
C
      INTEGER     IHR, IMIN, ISEC, I100TH, IYR, IMON, IDAY
      INTEGER     PAGE
      CHARACTER* 1 FF
C
      INCLUDE 'IOCOM.FOR'
C
      DATA PAGE/0/
C      DATA FF/'1'/
      FF=CHAR(12)
C
      PAGE=PAGE+1
      CALL GETTIM(IHR,IMIN,ISEC,I100TH)
      CALL GETDAT(IYR,IMON,IDAY)
      IF (PAGE.EQ.1) THEN
        WRITE(LOUT,8000) ' ',PAGE,
     X             IMON,IDAY,IYR,
     X             IHR,IMIN,ISEC,I100TH
      ELSE
        WRITE(LOUT,8000) FF,PAGE,
     X             IMON,IDAY,IYR,
     X             IHR,IMIN,ISEC,I100TH
      ENDIF
      RETURN
C
C  Formats
C
8000 FORMAT (A1/
     X   'Program : PostPump',44X,'Page : ',I10/
     X   'Number  :           ',38X,
     X                      'Date : ',I2.2,'/',I2.2,'/',I4/
     X   62X,
     X              'Time : ',I2.2,':',I2.2,':',I2.2,'.',I2.2//)
      END
```

```
BLOCK DATA
C
     INCLUDE 'IOCOM.FOR'
C
     DATA LOCIN/8/,LOCOUT/10/,
    X    ALTIN/9/,
    X    LPLIOT/11/
C
     END
```

```
C     INCLUDE 'IOCOM.FOR'
C
C     Declarations for variables in COMMON /IOCON/
C
      INTEGER    LIN,LOCIN,LOUT,LOCOUT,
     X          AOUT,ALTIN,
     X          LPL1,LPL1OT
      COMMON/IOCON/LIN,LOCIN,LOUT,LOCOUT,
     X          AOUT,ALTIN,
     X          LPL1,LPL1OT
```

```
POSTPUMP VALIDATION CASE
 0.1 19.8 20.0 20.0
  0   0   0   0
  3   0.  5.  10.
  8
    0.0    287.9
  2060.7   237.9
  3059.3   214.8
  4047.5   196.2
  4952.7   177.1
  5994.7   155.7
  6915.0   125.4
  7668.3    72.0
3   10.02    30.33   2.734    33.16   33.16
     7.98    74.5    2.815    33.16   67.5
     7.98    50.    38.268    67.5    67.5
3   10.02    33.     3.014    33.16   33.25
     7.98   173.     4.327    33.25   47.5
     7.98    50.    36.921    47.5    47.5
5   15.25    10.5    3.094     8.25   11.04
    23.25    23.58   1.899    11.04   -1.125
    29.25    94.     0.877    -1.125   9.
    23.25   175.5    1.392     9.     36.
    13.25   112.     0.754    36.     33.16
```

Validation of Pump Startup Analysis

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
1															
2				Δt =	0.1										
3				ρ =	62.4	lb_m/ft^3									
4		t = 0.2	t = 0.3												
5	Segment	$Q_{previous}$	Q	d	L	K	ΔA	friction	sub-total	head	sub-total	Δu	inertia	sub-total	head loss / segment
6		*(ft3/sec)*	*(ft3/sec)*	*(in)*	*(feet)*		*(feet)*	*(feet)*	*(feet)*	*(feet)*	*(feet)*	*(ft/sec)*	*(feet)*	*(feet)*	*(feet)*
7															
8	A	4.168	5.1812	15.25	10.5	3.094	-0.21	0.80		2.79		0.80	2.61		
9		4.168	5.1812	23.25	23.58	1.899	-0.03	0.09		-12.165		0.34	2.52		
10		4.168	5.1812	29.25	94	0.877	0.029	0.02		10.125		0.22	6.34		
11		4.168	5.1812	23.25	175.5	1.392	0.407	0.07		27		0.34	18.74		
12		4.168	5.1812	13.25	112	0.754		0.34	1.32	-2.84	24.91	1.06	36.82	67.03	93.45
13															
14	AA	2.379	2.907	10.02	30.33	2.734	0.65	1.20		0		0.96	9.08		
15		2.379	2.907	7.98	74.5	2.815	0	3.06		34.34		1.52	35.15		
16		2.379	2.907	7.98	50	38.268		41.63	45.89	0	34.34	1.52	23.59	67.82	148.70
17															
18	AB	1.788	2.2742	10.02	33	3.014	0.40	0.81		0.09		0.89	9.10		
19		1.788	2.2742	7.98	173	4.327	0	2.88		14.25		1.40	75.18		
20		1.788	2.2742	7.98	50	36.921		24.58	28.27	0	14.34	1.40	21.73	106.00	149.01
21															
22															
23			Developed head at pump taken from code output:												
24												Pressure drop in path A-AA			242.15
25			15126.0	(lb_f/ft^2)		242.4	*(feet)*								
26												Pressure drop in path A-AB			242.46
27			Q_A =	1870.4	*gpm*										
28			$Q_{per\ pump}$ =	1870.4	*gpm*										
29															
30			**Interpolated from pump curve data:**												
31			head =	242.52	*feet*										

Validation of Pump Startup Analysis

	A	B	C	D	E	F	G
1							
2				Δt =	0.1		
3				ρ =	62.4	lb_m/ft^3	
4		t = 0.2	t = 0.3				
5	Segment	$Q_{previous}$	Q	d	L	K	ΔA
6		(ft3/sec)	(ft3/sec)	(in)	(feet)		(feet)
7							
8	A	4.1675	5.1812	15.25	10.5	3.094	=1/(2*32.2)*(C8/(PI()/4*(D8/12)^2))^2*((D8/D9)^4-1)
9		4.1675	5.1812	23.25	23.58	1.899	=1/(2*32.2)*(C9/(PI()/4*(D9/12)^2))^2*((D9/D10)^4-1)
10		4.1675	5.1812	29.25	94	0.877	=1/(2*32.2)*(C10/(PI()/4*(D10/12)^2))^2*((D10/D11)^4-1)
11		4.1675	5.1812	23.25	175.5	1.392	=1/(2*32.2)*(C11/(PI()/4*(D11/12)^2))^2*((D11/D12)^4-1)
12		4.1675	5.1812	13.25	112	0.754	
13							
14	AA	2.3793	2.907	10.02	30.33	2.734	=1/(2*32.2)*(C14/(PI()/4*(D14/12)^2))^2*((D14/D15)^4-1)
15		2.3793	2.907	7.98	74.5	2.815	=1/(2*32.2)*(C15/(PI()/4*(D15/12)^2))^2*((D15/D16)^4-1)
16		2.3793	2.907	7.98	50	38.268	
17							
18	AB	1.7882	2.2742	10.02	33	3.014	=1/(2*32.2)*(C18/(PI()/4*(D18/12)^2))^2*((D18/D19)^4-1)
19		1.7882	2.2742	7.98	173	4.327	=1/(2*32.2)*(C19/(PI()/4*(D19/12)^2))^2*((D19/D20)^4-1)
20		1.7882	2.2742	7.98	50	36.921	
21							
22							
23			Developed				
24							
25			15126	(lb_f/ft^2)		=C25/62.4	(feet)
26							
27			Q_A =	=B8*60*7.48	gpm		
28			$Q_{per\ pump}$ =	=D27/1	gpm		
29							
30			Interpolate				
31			head =	=(237.9-287.9)/2060.7*D28+287.9	feet		

Validation of Pump Startup Analysis

	H	I	J	K
1				
2				
3				
4				
5	friction	sub-total	head	sub-total
6	*(feet)*	*(feet)*	*(feet)*	*(feet)*
7				
8	=F8/(2*32.2)*(C8/(PI()/4*(D8/12)^2))^2		2.79	
9	=F9/(2*32.2)*(C9/(PI()/4*(D9/12)^2))^2		-12.165	
10	=F10/(2*32.2)*(C10/(PI()/4*(D10/12)^2))^2		10.125	
11	=F11/(2*32.2)*(C11/(PI()/4*(D11/12)^2))^2		27	
12	=F12/(2*32.2)*(C12/(PI()/4*(D12/12)^2))^2	=SUM(H8:H12)	-2.84	=SUM(J8:J12)
13				
14	=F14/(2*32.2)*(C14/(PI()/4*(D14/12)^2))^2		0	
15	=F15/(2*32.2)*(C15/(PI()/4*(D15/12)^2))^2		34.34	
16	=F16/(2*32.2)*(C16/(PI()/4*(D16/12)^2))^2	=SUM(H14:H16)	0	=SUM(J14:J16)
17				
18	=F18/(2*32.2)*(C18/(PI()/4*(D18/12)^2))^2		0.09	
19	=F19/(2*32.2)*(C19/(PI()/4*(D19/12)^2))^2		14.25	
20	=F20/(2*32.2)*(C20/(PI()/4*(D20/12)^2))^2	=SUM(H18:H20)	0	=SUM(J18:J20)
21				
22				
23				
24				
25				
26				
27				
28				
29				
30				
31				

Validation of Pump Startup Analysis

	L	M	N	O
1				
2				
3				
4				
5	Δu	inertia	sub-total	head loss
6	*(ft/sec)*	*(feet)*	*(feet)*	/ segment *(feet)*
7				
8	=(C8-B8)/(PI()/4*(D8/12)^2)	=1/32.2*E8*L8/$E$2		
9	=(C9-B9)/(PI()/4*(D9/12)^2)	=1/32.2*E9*L9/$E$2		
10	=(C10-B10)/(PI()/4*(D10/12)^2)	=1/32.2*E10*L10/$E$2		
11	=(C11-B11)/(PI()/4*(D11/12)^2)	=1/32.2*E11*L11/$E$2		
12	=(C12-B12)/(PI()/4*(D12/12)^2)	=1/32.2*E12*L12/$E$2	=SUM(M8:M12)	=SUM(G8:G12)+I12+K12+N12
13				
14	=(C14-B14)/(PI()/4*(D14/12)^2)	=1/32.2*E14*L14/$E$2		
15	=(C15-B15)/(PI()/4*(D15/12)^2)	=1/32.2*E15*L15/$E$2		
16	=(C16-B16)/(PI()/4*(D16/12)^2)	=1/32.2*E16*L16/$E$2	=SUM(M14:M16)	=SUM(G14:G16)+I16+K16+N16
17				
18	=(C18-B18)/(PI()/4*(D18/12)^2)	=1/32.2*E18*L18/$E$2		
19	=(C19-B19)/(PI()/4*(D19/12)^2)	=1/32.2*E19*L19/$E$2		
20	=(C20-B20)/(PI()/4*(D20/12)^2)	=1/32.2*E20*L20/$E$2	=SUM(M18:M20)	=SUM(G18:G20)+I20+K20+N20
21				
22				
23	Pressure drop in path A-AA			=O12+O16
24				
25	Pressure drop in path A-AB			=O12+O20
26				
27				
28				
29				
30				
31				

Validation of Refill Analysis at Near Steady-State Conditions

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
1															
2															
3															
4				Δt =	0.1										
5				ρ =	62.4										
6		t = 20.0													
7	Segment	$Q_{previous}$	Q	d	L	K	ΔA	friction	sub-total	head	sub-total	Δu	inertia	sub-total	head loss /segment
8		(ft3/sec)	(ft3/sec)	(in)	(feet)		(feet)	(feet)	(feet)	(feet)	(feet)	(ft/sec)	(feet)	(feet)	(feet)
9															
10	A	11.69	11.69	15.25	10.5	3.094	-1.07	4.08		2.79		0.00	0.00		
11		11.69	11.69	23.25	23.58	1.899	-0.15	0.46		-12.165		0.00	0.00		
12		11.69	11.69	29.25	94	0.877	0.15	0.09		10.125		0.00	0.00		
13		11.69	11.69	23.25	175.5	1.392	2.07	0.34		27		0.00	0.00		
14		11.69	11.69	13.25	112	0.754		1.75	6.71	-2.84	24.91	0.00	0.00	0.00	32.62
15															
16	AA	5.702	5.702	10.02	30.33	2.734	2.50	4.60		0		0.00	0.00		
17		5.702	5.702	7.98	74.5	2.815	0.00	11.78		34.34		0.00	0.00		
18		5.702	5.702	7.98	50	38.268		160.15	176.54	0	34.34	0.00	0.00	0.00	213.38
19															
20	AB	5.9878	5.9878	10.02	33	3.014	2.76	5.60		0.09		0.00	0.00		
21		5.9878	5.9878	7.98	173	4.327	0.00	19.97		14.25		0.00	0.00		
22		5.9878	5.9878	7.98	50	36.921		170.39	195.96	0	14.34	0.00	0.00	0.00	213.06
23															
24															
25			Developed head at pump taken from code output:									Pressure drop in path A-AA			246.00
26															
27			15310.0	(lb_f/ft^2)		245.4	(feet)					Pressure drop in path A-AB			245.68
28															
29			Q_A =	5246.5	gpm										
30			$Q_{per\ pump}$	1748.8	gpm										
31															
32			Interpolated from pump curve data:												
33			head =	245.47	feet										

Validation of Refill Analysis at Near Steady-State Conditions

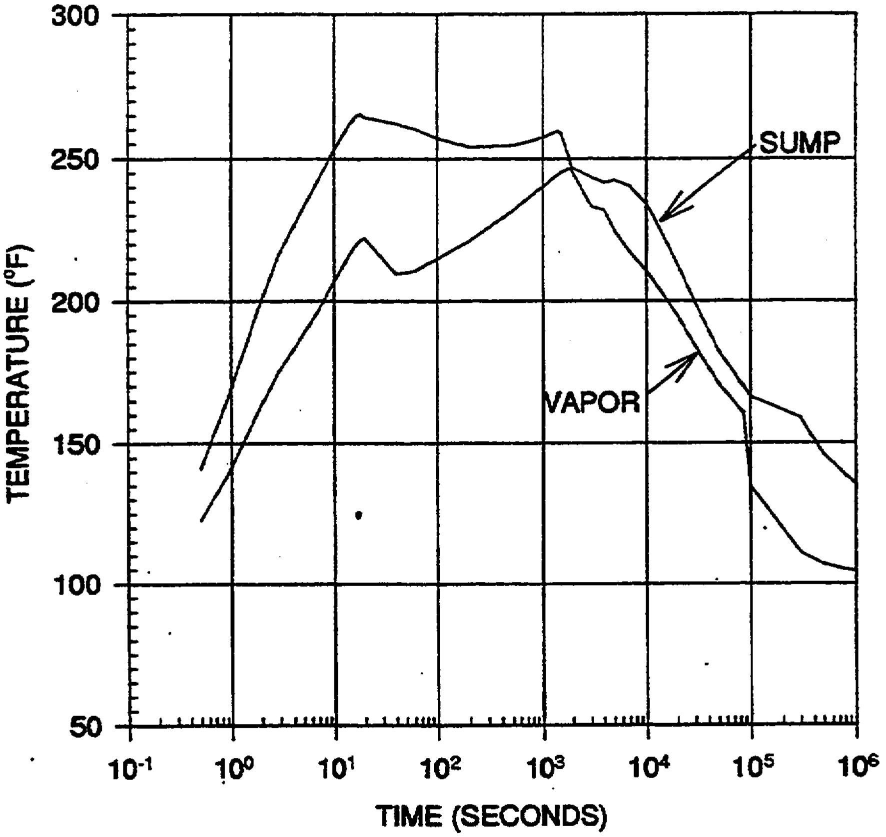
	A	B	C	D	E	F	G
1							
2							
3							
4				Δt =	0.1		
5				ρ =	62.4		
6		t = 20.0					
7	Segment	$Q_{previous}$	Q	d	L	K	ΔA
8		*(ft3/sec)*	*(ft3/sec)*	*(in)*	*(feet)*		*(feet)*
9							
10	A	11.69	11.69	15.25	10.5	3.094	=1/(2*32.2)*(C10/(PI()/4*(D10/12)^2))^2*((D10/D11)^4-1)
11		11.69	11.69	23.25	23.58	1.899	=1/(2*32.2)*(C11/(PI()/4*(D11/12)^2))^2*((D11/D12)^4-1)
12		11.69	11.69	29.25	94	0.877	=1/(2*32.2)*(C12/(PI()/4*(D12/12)^2))^2*((D12/D13)^4-1)
13		11.69	11.69	23.25	175.5	1.392	=1/(2*32.2)*(C13/(PI()/4*(D13/12)^2))^2*((D13/D14)^4-1)
14		11.69	11.69	13.25	112	0.754	
15							
16	AA	5.702	5.702	10.02	30.33	2.734	=1/(2*32.2)*(C16/(PI()/4*(D16/12)^2))^2*((D16/D17)^4-1)
17		5.702	5.702	7.98	74.5	2.815	=1/(2*32.2)*(C17/(PI()/4*(D17/12)^2))^2*((D17/D18)^4-1)
18		5.702	5.702	7.98	50	38.268	
19							
20	AB	5.9878	5.9878	10.02	33	3.014	=1/(2*32.2)*(C20/(PI()/4*(D20/12)^2))^2*((D20/D21)^4-1)
21		5.9878	5.9878	7.98	173	4.327	=1/(2*32.2)*(C21/(PI()/4*(D21/12)^2))^2*((D21/D22)^4-1)
22		5.9878	5.9878	7.98	50	36.921	
23							
24							
25			Developed				
26							
27			15310	(lb_f/ft^2)		=C27/62.4	*(feet)*
28							
29			Q_A =	=B10*60*7.48	*gpm*		
30			$Q_{per\ pump}$ =	=D29/3	*gpm*		
31							
32			Interpolate				
33			head =	=(237.9-287.9)/2060.7*D30+287.9	*feet*		

Validation of Refill Analysis at Near Steady-State Conditions

	H	I	J	K
1				
2				
3				
4				
5				
6				
7	friction	sub-total	head	sub-total
8	*(feet)*	*(feet)*	*(feet)*	*(feet)*
9				
10	=F10/(2*32.2)*(C10/(PI()/4*(D10/12)^2))^2		2.79	
11	=F11/(2*32.2)*(C11/(PI()/4*(D11/12)^2))^2		-12.165	
12	=F12/(2*32.2)*(C12/(PI()/4*(D12/12)^2))^2		10.125	
13	=F13/(2*32.2)*(C13/(PI()/4*(D13/12)^2))^2		27	
14	=F14/(2*32.2)*(C14/(PI()/4*(D14/12)^2))^2	=SUM(H10:H14)	-2.84	=SUM(J10:J14)
15				
16	=F16/(2*32.2)*(C16/(PI()/4*(D16/12)^2))^2		0	
17	=F17/(2*32.2)*(C17/(PI()/4*(D17/12)^2))^2		34.34	
18	=F18/(2*32.2)*(C18/(PI()/4*(D18/12)^2))^2	=SUM(H16:H18)	0	=SUM(J16:J18)
19				
20	=F20/(2*32.2)*(C20/(PI()/4*(D20/12)^2))^2		0.09	
21	=F21/(2*32.2)*(C21/(PI()/4*(D21/12)^2))^2		14.25	
22	=F22/(2*32.2)*(C22/(PI()/4*(D22/12)^2))^2	=SUM(H20:H22)	0	=SUM(J20:J22)
23				
24				
25				
26				
27				
28				
29				
30				
31				
32				
33				

Validation of Refill Analysis at Near Steady-State Conditions

	L	M	N	O
1				
2				
3				
4				
5				
6				
7	Δu	inertia	sub-total	head loss
8	(ft/sec)	(feet)	(feet)	/segment (feet)
9				
10	=(C10-B10)/(PI()/4*(D10/12)^2)	=1/32.2*E10*L10/$E$4		
11	=(C11-B11)/(PI()/4*(D11/12)^2)	=1/32.2*E11*L11/$E$4		
12	=(C12-B12)/(PI()/4*(D12/12)^2)	=1/32.2*E12*L12/$E$4		
13	=(C13-B13)/(PI()/4*(D13/12)^2)	=1/32.2*E13*L13/$E$4		
14	=(C14-B14)/(PI()/4*(D14/12)^2)	=1/32.2*E14*L14/$E$4	=SUM(M10:M14)	=SUM(G10:G14)+I14+K14+N14
15				
16	=(C16-B16)/(PI()/4*(D16/12)^2)	=1/32.2*E16*L16/$E$4		
17	=(C17-B17)/(PI()/4*(D17/12)^2)	=1/32.2*E17*L17/$E$4		
18	=(C18-B18)/(PI()/4*(D18/12)^2)	=1/32.2*E18*L18/$E$4	=SUM(M16:M18)	=SUM(G16:G18)+I18+K18+N18
19				
20	=(C20-B20)/(PI()/4*(D20/12)^2)	=1/32.2*E20*L20/$E$4		
21	=(C21-B21)/(PI()/4*(D21/12)^2)	=1/32.2*E21*L21/$E$4		
22	=(C22-B22)/(PI()/4*(D22/12)^2)	=1/32.2*E22*L22/$E$4	=SUM(M20:M22)	=SUM(G20:G22)+I22+K22+N22
23				
24				
25	Pressure drop in path A-AA			=O14+O18
26				
27	Pressure drop in path A-AB			=O14+O22
28				
29				
30				
31				
32				
33				



SOUTH CAROLINA ELECTRIC & GAS CO.
VIRGIL C. SUMMER NUCLEAR STATION

Double Ended Pump Suction Break
Minimum Safety Injection
Reactor Building Vapor and Sump Temperature

Figure 6.2-7

AMENDMENT 96-02
JULY 1996

EVALUATION OF POSSIBLE WATER HAMMER LOADS IN THE POINT BEACH SERVICE WATER SYSTEM FOR DBA CONDITIONS

Robert E. Henry
Fauske & Associates, Inc.

Presented to
The International Joint Power
Generation Conference and Exposition

October 16, 1996

CONDENSATION INDUCED WATERHAMMER

- **This process is governed by the potential for generating a large interfacial area between highly subcooled water and steam.**

- **For a large interfacial area to exist, the conditions must be consistent with a stratified flow pattern in the pipe.**

- **In the Point Beach cooling circuits, the piping is generally 8″ diameter and the nominal water velocity is 5 to 7 ft/sec.**

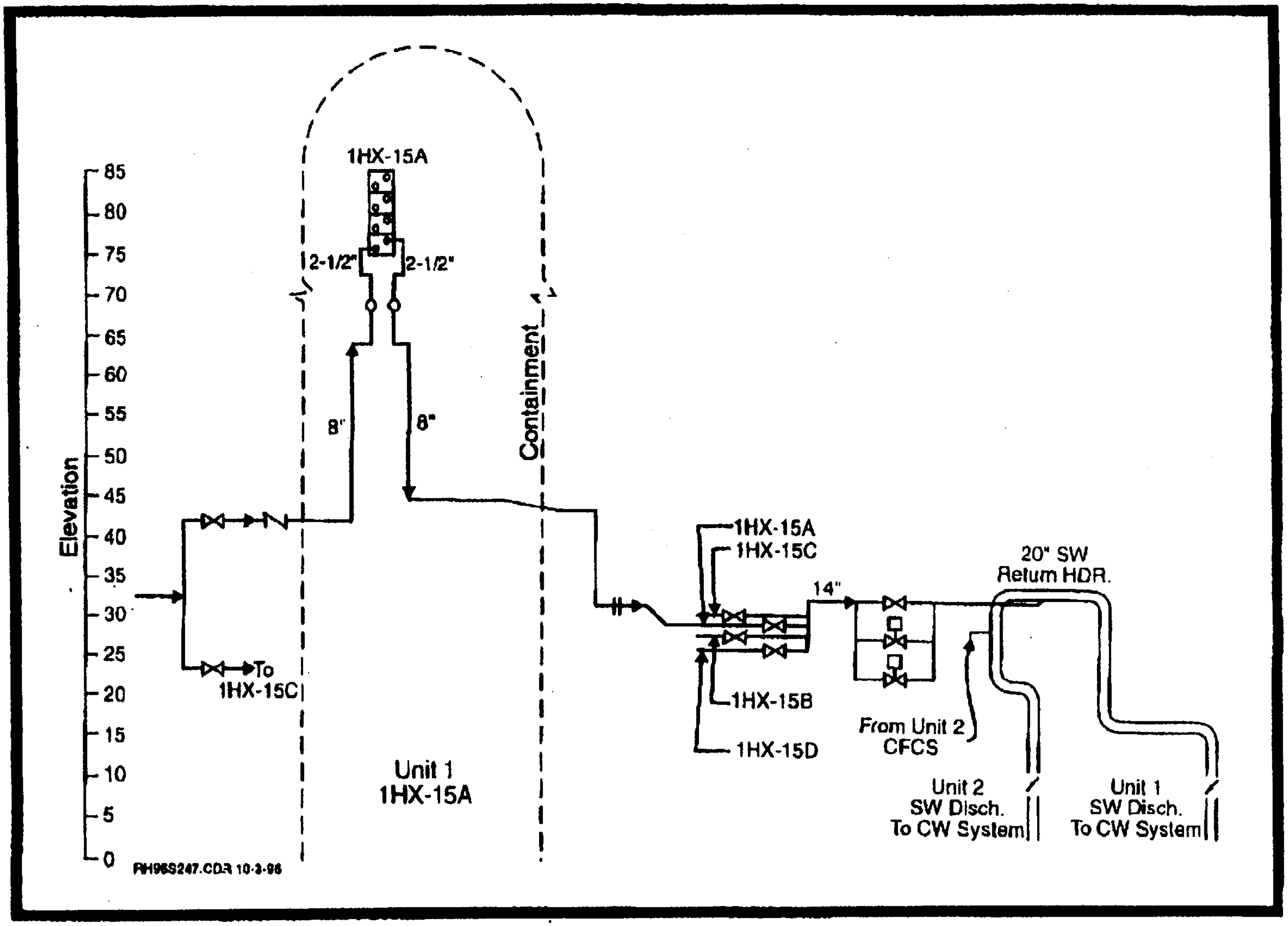

Elevation
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
1HX-15A
2-1/2"
2-1/2"
8"
8"
Containment
To
1HX-15C
Unit 1
1HX-15A
1HX-15A
1HX-15C
14"
1HX-15B
1HX-15D
20" SW
Return HDR.
From Unit 2
CFCS
Unit 2
SW Disch.
To CW System
Unit 1
SW Disch.
To CW System
RH96S247.CDR 10-3-96

Figure 4

DURING THE VOIDING TRANSIENT

- Consider the heat transfer in a fan cooler to be 10 MW (34 MBTU/hr).
- The resulting steam velocity in the 8″ pipe is about 416 ft/sec (127 m/sec) which is an order of magnitude greater than the entrainment velocity (56.8 ft/sec / 17.3 m/sec)

$$U_{ent} = \frac{3.7 \sqrt[4]{g\sigma (\rho_f - \rho_g)}}{\sqrt{\rho_g}}$$

- Thus, unless the energy transfer is very low or condensation on the heat sinks is very high, there will be no stratification during the voiding transient.

VOIDING IN THE FAN COOLER

- Sustained steam generation in the fan cooler requires the presence of water.
- If the voiding rate is too high, the steam would "flood" the water in the cooling coils and dynamically remove the water. This would terminate the voiding leaving only column separation and rejoining.
- The maximum energy transfer that could occur in the fan cooler coils with water remaining to support continued steaming is about 1 MW.
- Thus, high voiding rates can not be sustained.

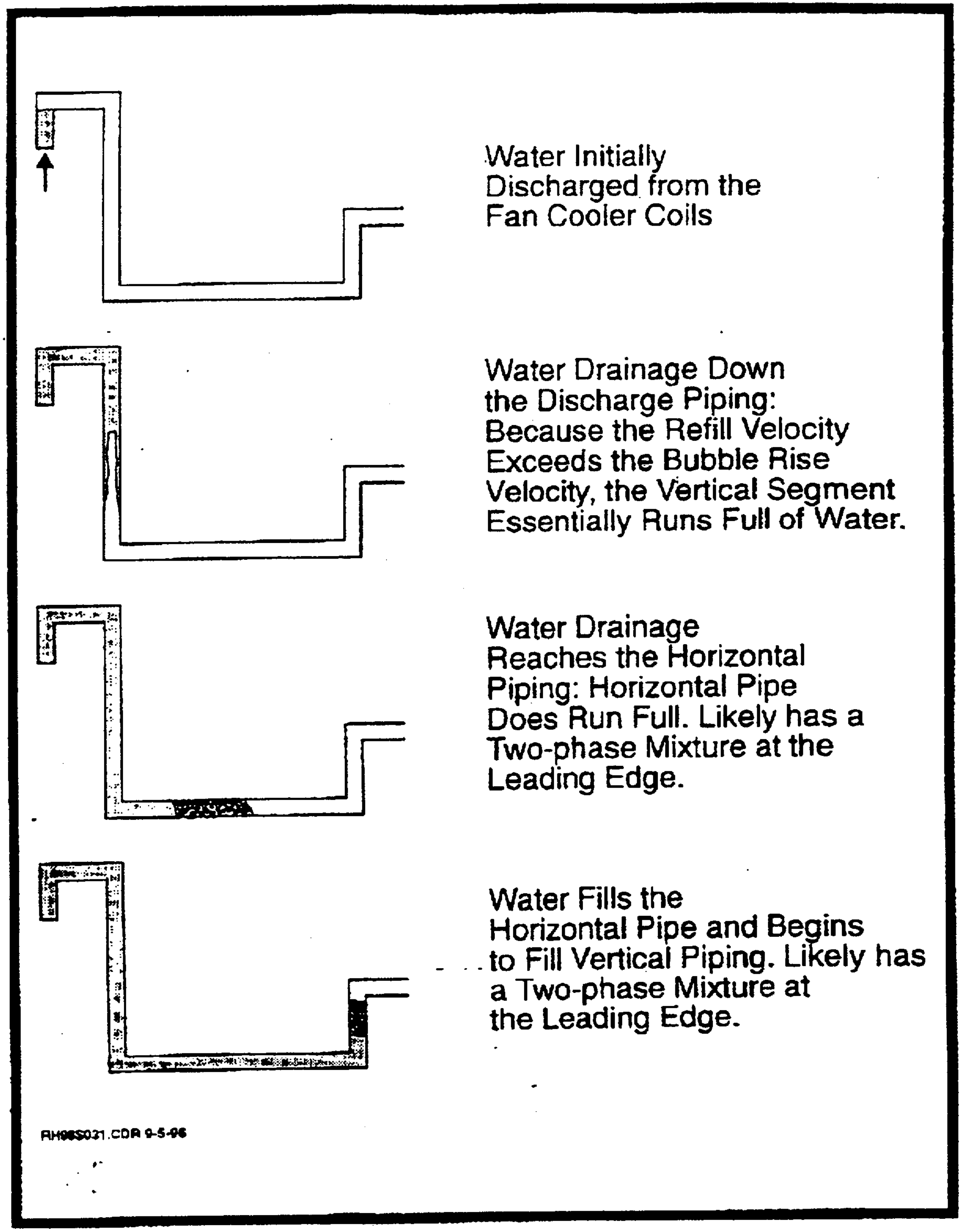


Figure 2-3 **Two-phase flow patterns during refill of the discharge piping.**

TWO-PHASE FLOW PATTERN CONSIDERATIONS

For a Horizontal Pipe to Run Full

$$\text{Froude No. (Fr)} > 0.5 = U/U^*$$

$$U^* = \sqrt{gD}$$

If D = 8 in. (0.2 m), U* = 4.6 ft/sec (1.4 m/sec).

For a Vertical Pipe to Run Full

$$U > U_{B,rise}$$

$$U_{B,rise} = 0.345 \left[\frac{gD\,(\rho_f - \rho_g)}{\rho_f}\right]^{1/2} \approx 0.345\,\sqrt{gD}$$

$$U_{B,rise} = 0.345\,U^*$$

For D = 8 in., $U_{B,rise}$ = 1.6 ft/sec (0.5 m/sec).

TWO-PHASE FLOW PATTERN CONSIDERATIONS
(Continued)

* **Conclusion:** For the conditions of interest, the Froude Number greater than unity a stratified flow pattern will not exist in the horizontal piping segments during the refill transient.

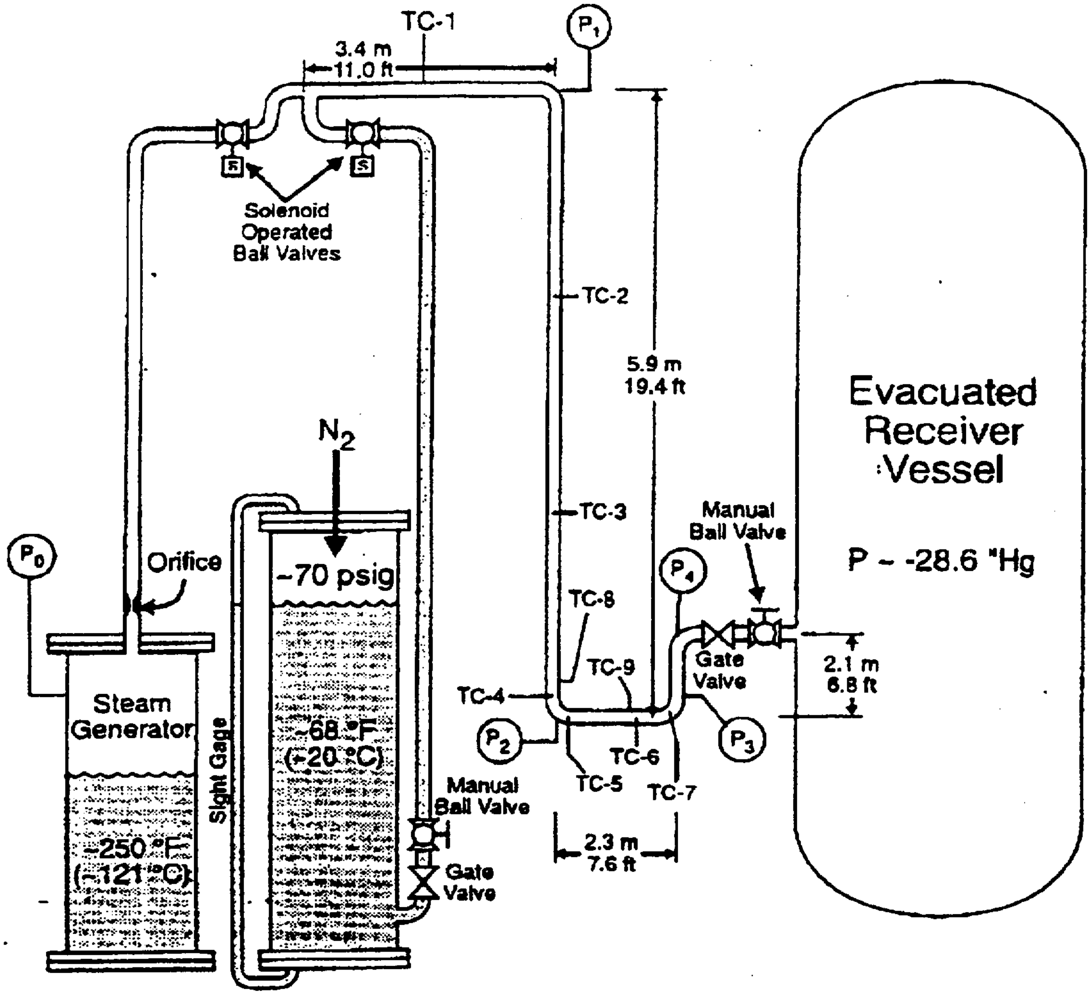
CONCLUSIONS

- High steaming rates could not be supported for more than a few seconds. Without high steaming rates, there is only a limited void and the issue reduced to column rejoining, i.e. determined by the refill rate.

- Assuming high steaming rates gives velocities much greater than the entrainment velocity. Thus, a stratified condition could only exist due to the pipe wall heat sink.

- Scaled experiments show only limited waterhammer during the voiding period as well as during the refill transient.

- The pressurization when the refill water reaches the throttle valve is very mild.

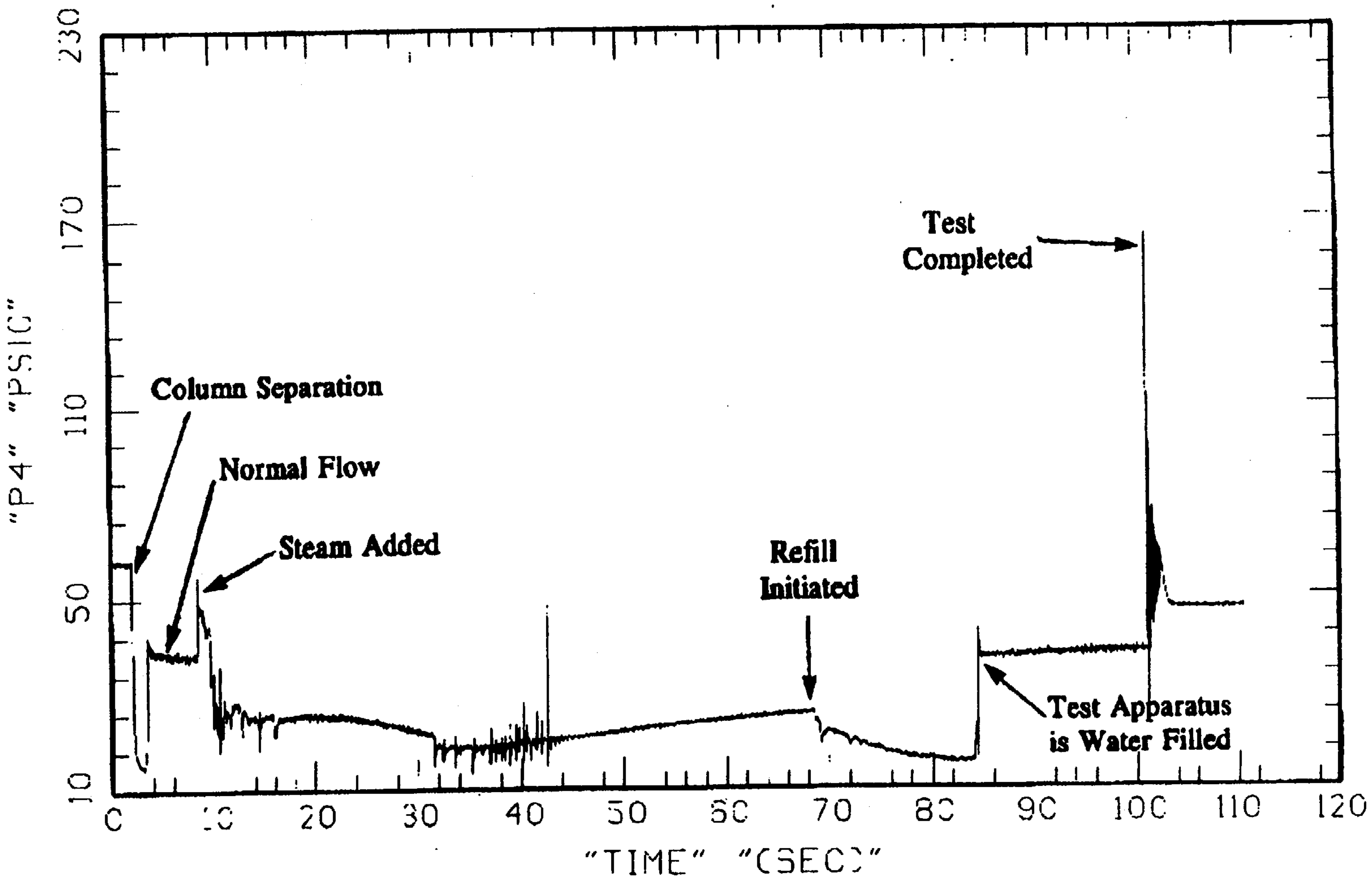


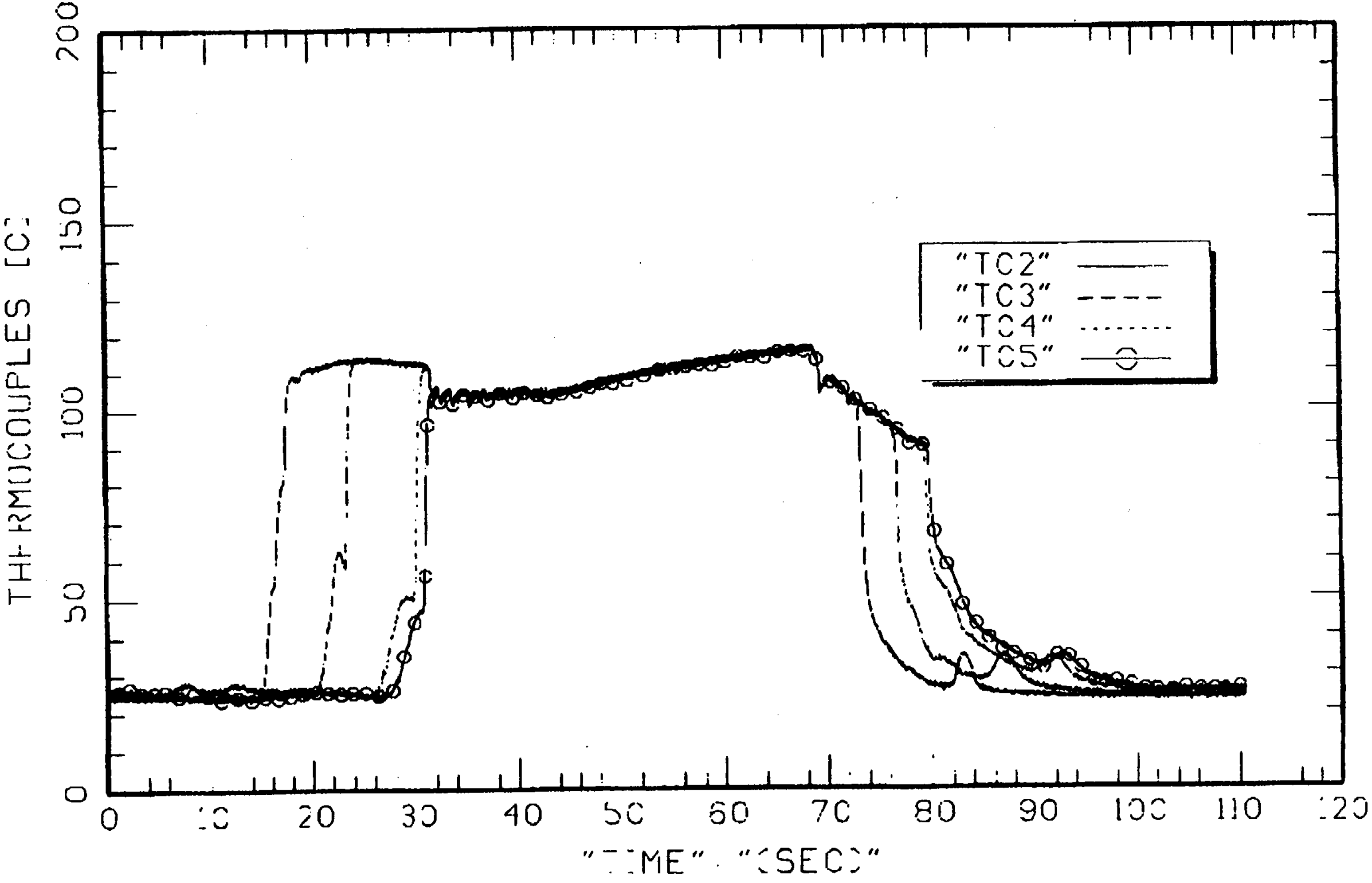
WB96A117.CDR 9-4-96

Note: TC's 1,8, and 9 are surface mounted on the pipe all others are sensing internal to the pipe.

Waterhammer experiment.

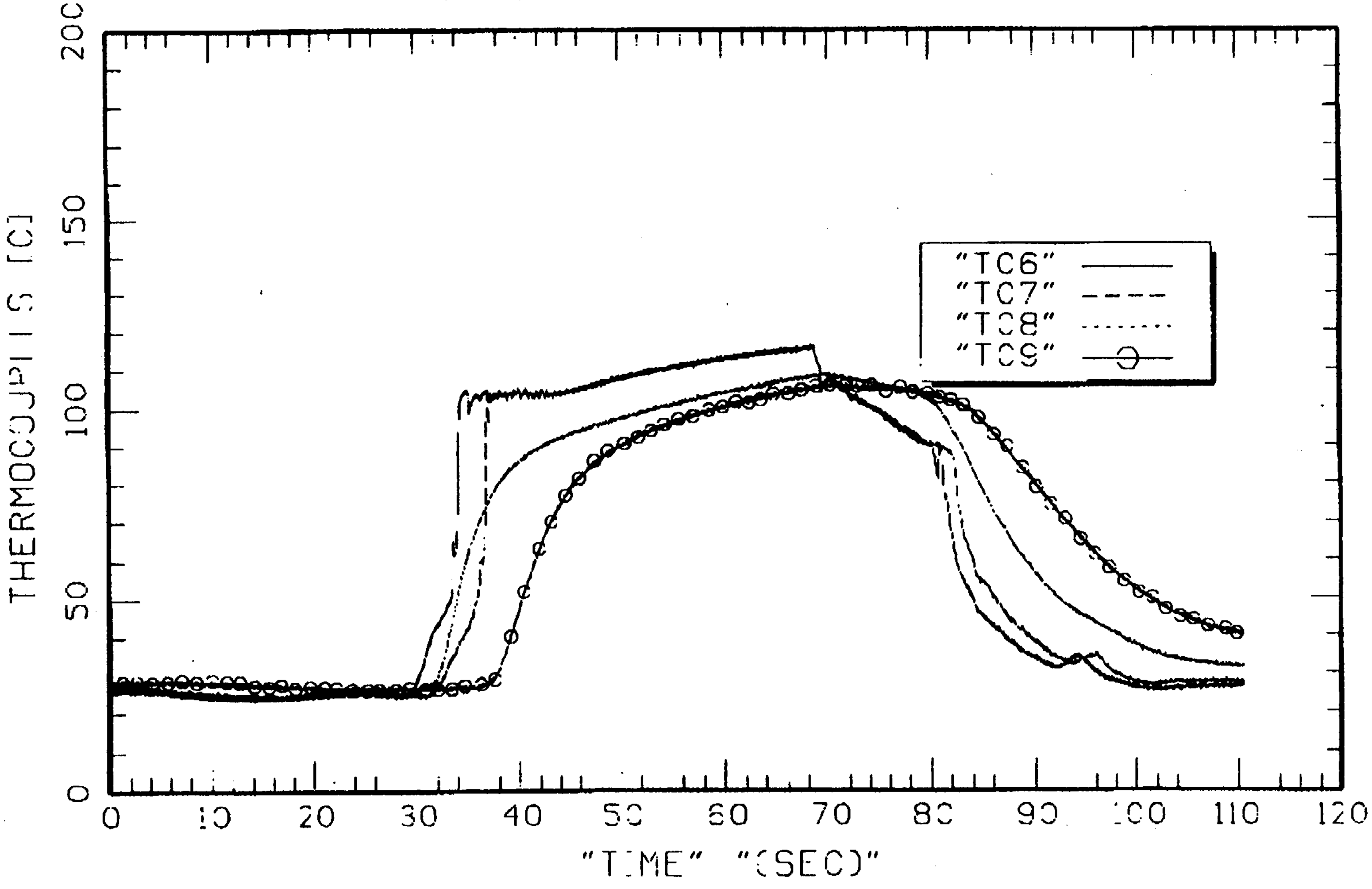
WATER HAMMER TEST #21
test5.ol: -





WATER HAMMER TEST #21

WATER HAMMER TEST #21



Drawings included with submittal:

- C-314-251, Sht. 11
- C-314-251, Sht. 12
- C-314-251, Sht. 13
- C-314-251, Sht. 15

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D4