Commonwealth Edison Company
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ComEd

September 30, 1998

U. S. Nuclear Regulatory Commission
ATTN: Document Control Desk
Washington, D. C. 20555-0001

Braidwood Station, Units 1 and 2
Facility Operating License Nos. NPF-72 and NPF-77
NRC Docket Nos. STN 50-456 and STN 50-457

Byron Station, Units 1 and 2
Facility Operating License Nos. NPF-37 and NPF-66
NRC Docket Nos. STN 50-454 and STN 50-455

Subject: Response to Request for Additional Information Related to Generic Letter 96-06, "Assurance of Equipment Reliability and Containment Integrity During Design-Basis Accident Conditions"

Reference:

1. NRC letter, "Request for Additional Information Related to the Generic Letter (GL) 96-06 Response for Braidwood Station, Units 1 and 2, and Byron Station, Units 1 and 2," dated April 13, 1998.
2. ComEd letter, "Response to Request for Additonal Information Related to Generic Letter 96-06 for the Byron Station and the Braidwood Station - Notification of Delay," dated June 30,1998.

In the Reference 1 letter, the Nuclear Regulatory Commission (NRC) requested that Commonwealth Edison (ComEd) Company provide additional information to allow completion of the NRC review of the response to GL 96-06 for Braidwood Station, Units 1 and 2 and Byron Station, Units 1 and 2. This additional information was to be submitted to the NRC by June 30, 1998. In the Reference 2 letter, ComEd documented that additional time was required (i.e., by August 31, 1998) to respond to the request for additional information.

The purpose of this letter is to provide the additional information requested in the Reference 1 letter. In a telephone conference held between representatives of ComEd and the NRC on August 13, 1998, it was agreed that the additional information would be provided by September 30, 1998.

1/1

A072

9810060170 980930
PDR ADOCK 05000454
P PDR

Please direct any comments or questions regarding this matter to Marcia Lesniak at 630-663-6484.

Respectfully,

K. A. Ainger for

R. M. Krich
Vice President - Regulatory Services

Attachments

cc: Regional Administrator - NRC Region III
NRC Senior Resident Inspector - Braidwood Station
NRC Senior Resident Inspector - Byron Station

ATTACHMENT A

Response to Request for Additional Information (RAI)

1. **If a methodology other than that discussed in NUREG/CR-5220, "Diagnosis of Condensation-Induced Waterhammer," was used in evaluating the effects of waterhammer, describe this alternate methodology in detail. Also, explain why this methodology is applicable and gives conservative results for both the Braidwood and Byron units (typically accomplished through rigorous plant-specific modeling, testing, and analysis)**

Response: A detailed analysis of the Reactor Containment Fan Cooler (RCFC) inlet piping, coils, and exhaust piping was performed using the RELAP5/MOD3.1.1 computer code. Stress loads on the piping were developed via post-processing of the RELAP5/MOD3.1.1 data to calculate segment wave and thrust force-time history data (Reference 1). The force-time histories were applied to a dynamic piping analysis program, PIPSYS, to determine the effect of the loads on the piping and support structures.

This approach was selected based on the geometry of the RCFC installations at Byron/Braidwood. The RCFCs and their associated piping essentially form a U-shaped geometry with the RCFCs at the low point. Void generation in the RCFC coils during service water pump coastdown will result in heating of the RCFC inlet and exhaust risers. Service water pump restart leads to sweeping of the voids with heated fluid. While dynamic effects are anticipated due to acceleration of a two phase fluid, the conditions leading to condensation induced waterhammer are not present. Therefore, a methodology to conservatively calculate the heat transfer into the coils and track the void generation/movement during the flow coastdown following loss of service water pump flow was needed. The principal loading concern is wave loads and turning loads generated in piping and coil segments due to acceleration of the two phase fluid subsequent to service water pump restart.

RELAP5 was selected to perform the thermal hydraulic portion of this analysis because of its capability to accurately model two phase flow as well as its capability to characterize heat transfer. RELAP5 has a significant validation history for a wide range of thermal hydraulic analyses, and has been extensively utilized in the industry for force-time history generation for a variety of piping problems, most notably for the PWR pressurizer safety valve exhaust lines. RELAP5 has also been extensively tested in low pressure/flow conditions as part of the advanced reactor projects. A detailed model of the inlet and outlet piping, as well as the RCFC coils, was prepared for this calculation. Conservatism was built into the model, primarily with respect to heat transfer coefficients utilized on the coil external surfaces, and also with the method of application of choked flow models, with a goal of maximizing the extent of voiding predicted. Boundary conditions were also selected to yield a rapid coastdown in the initial phase of the event, as well as to conservatively bound the pressure surge at the inlet piping due to pump start.

2. **For both the waterhammer and two-phase flow analyses, provide the following information:**

a) **Identify any computer codes that were used in the waterhammer and two-phase flow analyses and describe the methods used to benchmark the codes for the specific loading conditions involved (See Standard Review Plan Section 3.9.1). Supplement the information contained in the May 2, 1997, submittal as necessary.**

Response: The RELAP5/MOD3.1.1 computer code, as installed on the ComEd Hewlett Packard (HP) Unix platform, was utilized for the thermal-hydraulic portion of the calculations. No specific benchmark calculations were performed as part of this analysis. In the absence of applicable benchmark information to facilitate validation of the model, the model was constructed in a deliberately conservative manner, consistent with applicable user guidelines. A detailed independent review of the model inputs and results was performed as part of this effort.

The general basis for the use of the RELAP5/MOD3.1.1 code is the Development Assessment Problems as documented in NUREG/CR 5535 (Reference 2), which demonstrate that the code performs appropriately over a wide range of conditions. Additional basis for the application of RELAP5/MOD3.1.1 is the extensive body of analysis that has been performed with this code by a large number of organizations.

b) **Describe and justify all assumptions and input parameters (including those used in any computer codes) such as amplifications due to fluid structure interaction, cushioning, speed of sound, force reductions, and mesh sizes, and explain why the values selected give conservative results. Also, provide justification for omitting any effects that may be relevant to the analysis (e.g., fluid structure interaction, flow induced vibration, erosion). Information that is contained in the May 2, 1997, submittal that requires no further explanation need not be repeated.**

ATTACHMENT A

Response: Attachment B of this submittal contains two figures showing the nodalization utilized in the RELAP5/MOD3.1.1 model for the piping and RCFC coils, respectively. In addition, Appendices C and D of the ComEd calculation are provided in entirety in Attachments C and D of this submittal. Appendix C is an input listing of the RELAP5/MOD3.1.1 model. Appendix D provides a description of modeling choices and methods philosophy utilized for each element of the model as well as calculation worksheets used to develop key model inputs.
Key features of this model include:

- Highly detailed nodalization of ½ of a RCFC cooling coil arrangement and the inlet/outlet piping, including modeling of 5 coils in parallel (over 200 piping nodes plus 24 nodes per coil).
- Flow boundary conditions and modeling assumptions that yield early void initiation, and maximize the extent of voiding predicted.
- Heat transfer modeling which includes the effects of the finned surfaces.
- Use of the Uchida condensing correlation, and a heat transfer coefficient actually used that is more than double the predicted values.

The speed of sound was of particular concern in this analysis. A very small amount of air was deliberately introduced into the model. This was done for two reasons:

- The water properties routines within RELAP5 employ different methods to calculate sound speed in the presence of non-condensable gas. With non-condensable gas present, the sound speed is calculated in a volume based on the static quality. Without non-condensable gas, an equilibrium quality is employed in the expression. This implies that in a subcooled voiding situation, such as is expected as the steam exits the coils into the headers, the sound speed will be calculated more appropriately if non-condensable gas is present.
- Since the model was being exercised in very low pressure regions, a small amount of non-condensable gas was found to be beneficial in the numerical stability of the model, helping to prevent pressures from dropping below zero and causing termination of the calculation.

It should be noted that the speed of sound in the headers during the peak load period (following Essential Service Water (SX) system pump start and refi [illegible] RCFC headers) was carefully monitored to ensure that the predicted loads would not be affected by this approach. The sound speed in the headers following refill was approximately 5000 feet per second and remained high throughout the loading period.

ComEd has pursued a rigorous and detailed computational model, with emphasis on capturing all relevant physical loads in a conservative manner.

c) Provide a detailed description of the "worst-case" scenarios for waterhammer and two-phase flow, taking into consideration the complete range of event possibilities, system configurations, and parameters. For example, all waterhammer types and water slug scenarios should be considered, as well as temperature, pressure, flow rates, load combinations, and potential component failures. Additional examples include:
-the effects of void fraction on flow balance and heat transfer
-the consequences of steam formation, transport, and accumulation
-cavitation, resonance, and fatigue effects; and
-erosion considerations.

Response: The "worst-case" scenario was determined to be a design basis (DBA) loss of coolant accident (LOCA) with a concurrent loss-of-offsite power (LOOP). This combination yields the largest amount of voiding in the system since it combines a rapid flow coastdown with a high containment temperature and high heat transfer coefficient on the outside surface of the RCFC coils. Based on the use of the Uchida condensing heat transfer correlation, situations in which a high vapor-to-air mass ratio exists will yield the highest heat transfer to the coils. This is why, with the modeling methods applied in this calculation, the DBA-LOCA results in higher voiding than the main steamline break (MSLB) inside containment accident. Small and intermediate break LOCA scenarios were also considered, but are bounded by the DBA LOCA scenario analyzed, with respect to the potential for heat input to the RCFC coils.

To provide a description of the phenomena observed in the calculations, the following excerpt from the Results section of the calculation PSA-B-98-13 is provided. (The figures referred to are provided in Attachment E).

"General Information
This calculation was performed for the limiting DBA containment temperature profile, which is a double-ended pump suction (DEPS) break with maximum

safety injection (SI). The calculation employs a conservative heat transfer coefficient of 500 Btu/hr-ft^2-F to introduce additional conservatism with respect to the heat transfer and maximize the SX coil voiding experienced. The calculated value of heat transfer coefficient Uchida times the fin effect multiplier was approximately 230 Btu/hr-ft^2-F. Since the DBA LOCA mass release puts significant amounts of mass into the containment rapidly, in contrast to the MSLB, a maximum value for the heat transfer coefficient (HTC) was employed at a constant value with time.

The overall behavior observed in this analysis was a rapid initiation of voiding in the coils, with the steam generation pushing water out both sides of the coils and the header piping. Following the boiloff of fluid, the system behaves like a manometer with unequal legs, with the exhaust side piping reflooding rapidly while the inlet side stagnates. Once forward flow is established by the SX pump, reflood of the entire system occurs and single phase flow is restored. Loads on piping segments were derived for both the discharge side fallback as well as the forward flow acceleration into the inlet piping and coils.

Boundary Condition Behavior

Figure 11 shows the boundary condition pressures imposed at the time dependent volumes defining the model interfaces with the remainder of the system. As noted previously, a five second coastdown in pressure representing the loss of the SX pump starting at 1 second occurs followed by a rapid spike in pressure at 43 seconds simulating the pump restart with a 20 second decay to the steady state pressure. This profile was chosen to yield a "surge" capable of yielding two phase interactions that would bound the actual plant response. Figure 12 shows the flows at the time dependent volume pressure boundaries resulting from the forcing function defined in Figure 11. As can be seen, the flow decays rapidly following pump trip, and void generation in the coils initiates just prior to 15 seconds. As the void generation continues, fluid is pushed out both sides of the model, until the pump restart occurs. Once boiling in the coils stops, the conditions favor discharge side reflooding. Figures 13 through 17 provide the flows at the entrance and exit junctions of each coil subassembly. These plots clearly demonstrate the flow reversal occurring during void generation, as well as the discharge side reflood prior to pump startup.

RCFC Coil Behavior

To facilitate understanding of the dynamic processes occurring in the 5 coil subassemblies modeled, a series of plots were generated, based on the coil nodes at the center of each pass (4 tube passes), which essentially allows a cross-sectional view of each coil. The coils are numbered 120 through 124, with 120 being the uppermost and 124 being the lowest coil in the stack.

Figures 18 through 22 provide the liquid void fractions at the coil center node points. As can be seen, nearly complete voiding occurs in all the coils. The use of homogeneous equilibrium model (HEM) choking only at the coil exits in combination with the partial vacuum condition following pump trip allows the coils to very nearly boil dry. The coil nodes nearest the exhaust header show some recovery prior to the front side nodes. This is a consequence of reverse flow in the discharge header, which allows some water back into the coils prior to pump restart. Following pump restart, the coils refill and return to single phase liquid flow.

Figures 23 through 27 show the pressure response at the coil center node points. These plots show a double peaked behavior, which reflects the reflood of the discharge header and entry of fluid into the coils, followed by the SX pump start and establishment of forward flow. The behavior is oscillatory and is due to the unsteady generation of steam as well as the acceleration of compressible mixtures. As can be seen in the plots, the maximum pressures calculated are well below the design pressure for the coil. Peak pressures achieved are approximately 110 psig, while the design pressure of the coil assembly is 200 psig.

Figure 28 shows the input temperature profile based on the LOCA containment response, and the surface temperatures of the RCFC tubing. As can be seen, under the influence of the large heat transfer coefficient, the fluid is heated rapidly and the coils reach equilibrium with the containment atmosphere.

Inlet/Exhaust Piping Behavior

Figures 29 through 31 show the void fractions in the inlet header at several locations. The steam generation in the coils results in significant voiding in the supply piping. The vertical supply header is completely voided and water is displaced in the main horizontal supply line (represented by volumes 104010000 through 104100000). Following pump start, the header is rapidly refilled. A significant loading condition occurs as the inlet header fills and water is forced into the coils. Figure 32 shows the pressure response at a point in the middle of the vertical inlet header, with the void fraction superimposed upon the same figure. What is immediately apparent is the pressure spike that the code generates as the vapor void is closed (liquid void fraction goes to 1). This pressure spike is an artifice of the computational methods, and although mitigated by the water packing modeling option, will yield high frequency loads in the segment force calculations. While the water packing model option was selected for all hydraulic volumes, the motion of the voids during the pump start transient led to situations in which fairly rapid transition from voided to unvoided conditions were experienced. While judicious selection of time steps limited the pressure spiking considerably, in combination with the water packing model, it did not eliminate the problem completely. This is why the fast Fourier transformation filter method was employed on the developed structural loads, to ensure that "real" phenomena were addressed, eliminating numerical instability load effects that generally occurred at high frequencies incapable of inducing load on the structures.

Figures 33 through 39 show the liquid void fractions in the exhaust header as a function of time. These plots show the rapid expansion of steam out of the coil, pushing liquid out of the exhaust line. At about 43 seconds, the expansion is completed and the water falls back towards the coils. Some oscillations do occur as steam generation in the coils follows the re-introduction of fluid onto the heated coil surfaces. The calculation of piping segment loads is extended to 60 seconds to ensure that they include all possible loads up to the restoration of single phase conditions throughout the system."

d) Confirm that the analyses included a complete failure mode and effects analysis (FMEA) for all components (including electrical and pneumatic failures) that could impact performance of the cooling water system and confirm that the FMEA is documented and available for review, or explain why a complete and fully documented FMEA was not performed

Response: Since the analysis performed determined that no items or equipment would fail specifically as a result of this event (i.e., LOCA/LOOP), the FMEA in the Updated Final Safety Analysis Report (UFSAR) remains valid and appropriate.

e) Explain and justify all uses of "engineering judgment".

Response: The primary use of "engineering judgment" other than the model input determination discussed previously in response to RAI 2b, was in the development of the force- time history information. Specifically, engineering judgment was applied with respect to filtering numerical noise from the loads before applying them to the structural models. A fast Fourier transform filter was utilized to eliminate numerical noise in the loads developed. This noise was primarily the result of non-linearities that occurred in the pressure solution as a result of water-packing behavior and rapid switching of the choking models. The applicability of this assumption was confirmed by reviewing the power spectral density plots of the transformed loads to confirm that numerical noise rather than significant power terms were being eliminated. The validity of this approach was confirmed by integrating the filtered and unfiltered loads and ensuring that the total impulse remained within 2% of each other. The filtered loads were increased by 2% to ensure that total impulse was conserved.

3. **Determine the uncertainty in the waterhammer and two-phase flow analyses, explain how the uncertainty was determined, and how it was accounted for in the analyses to assure conservative results for the Braidwood and Byron units.**

   Response: The uncertainty in the analysis of the two-phase effects performed above was not explicitly quantified. Since a calculation that would conservatively represent the physical behavior was desired for load generation purposes, the model inputs were deliberately adjusted to achieve conservative results. The analysis performed was a bounding analysis as opposed to a best estimate plus uncertainty analysis. The bounding analysis has significant conservatism to bound the best estimate plus uncertainty analysis. Some examples of conservatism provided in this analysis are:

   - Use of high heat transfer rates to the coils, over 2 times the nominal value was utilized for the loads generation analysis. This ensures a high degree of conservatism with respect to the amount of void formation in the coils.
   - Use of HEM choking models in a limited number of locations to maximize the flow out of the coils.
   - Use of minimal piping pressure losses, which allows more rapid and extensive voiding than would actually be expected.
   - Bounding (rapid) coastdown of the SX pump is assumed, which leads to early void generation in the coils and extends the time for void generation.
   - SX pump restart time is based on the last SX pump diesel generator sequence start time, which also extends the void generation time to the maximum possible.

4. **Confirm that the water hammer and two-phase flow loading conditions do not exceed any design specification or recommended service**

conditions for the piping system and components, including those stated by equipment vendors; and confirm that the system will continue to perform its design-basis functions as assumed in the safety analysis report for the facility.

Response: An analysis was developed utilizing PIPSYS, Version 2.3 (Sargent and Lundy Computer Program PIP03702621o) to determine the dynamic load affects of the LOCA/LOOP concerns expressed in GL 96-06. The transient evaluation discussed in RAIs 1 through 3 above, utilized RELAP5/MOD3 to develop the fluid transient forcing functions in the RCFC supply and discharge piping. The output of the transient analysis resulted in a detailed set of force-time histories, which were used for input to PIPSYS. The critical physical parameters of the individual cooler configurations were reviewed. This review determined that the fluid transient loads developed for the Braidwood cooler 1VP01AD piping arrangement would be a conservative representation of the loads at all 4 units. Also, since the piping arrangements are very similar, the resulting dynamic response of the piping would be representative of the response that would be experienced in the other cooler piping arrangements. The analysis included piping stress and support loads, valve flange loads and accelerations, cooler nozzle stresses, cooler anchor bolt stresses, RCFC enclosure supporting steel, and containment building structural steel loads. The following describes the results of the evaluations performed for these areas:

Piping Stress – The piping stresses are very small, and meet the normal stress allowables without an increase in allowable for faulted conditions. All but eight pipe supports had loads which were enveloped by the existing design loads. For the eight pipe supports which had load increases, all loads were within Faulted condition allowables.

Valve Flanges and Accelerations – Valve flange loading was small compared to normal allowables. Additionally, the valve accelerations were well within the limits which the valve could withstand, based on the vendor qualifications.

Cooler and Cooler Nozzle Loads – As described in the response to RAI 3, the maximum pressure in the cooler coils is less than the design pressure of the coils. The calculated nozzle loads exceeded the vendor allowables. However, the vendor allowables were unreasonably low, with values that were less than 0.1 times the yield strength. Using the new loads, and using the same method of qualification as the cooler vendor, the nozzle stresses were shown to be below normal condition stress allowables for the nozzle material. The loads were then combined with operational loads and cooler deadweight and transferred to the cooler anchor bolts, which were shown to meet normal condition allowables. The attachment loads were then compared to the loads used to qualify the cooler support steel. The new loads are less severe than the cooler loads that had been used to qualify the steel. Thus, all elements in the cooler load path were shown to either meet normal allowables (with faulted condition loads) or result in loads less than those previously used in the qualification.

Structural Steel Loads – As noted above, eight of the individual pipe supports had loads which exceeded existing design loads, but met the faulted condition allowables. For completeness, the building structural steel affected by these supports was re-analyzed. For the re-analysis, the new PIPSYS loads associated with this transient were input to the Braidwood Station structural load analysis model. Concurrent with this review, an evaluation of the structural steel for Byron Station, Units 1 and 2, and Braidwood Station, Units 1 and 2, confirmed that the Braidwood Station structural re-analysis is applicable to all four units. The results of the above re-analysis confirmed that the structural loads associated with the subject transient are within existing design bases limits.

The evaluation discussed in this RAI (RAI 4) has confirmed that the LOCA/LOOP loads placed on the SX piping, pipe supports, valves, coolers and associated supports, and the containment structural steel supporting these items are within design bases limits. Consequently, the above review confirms that the system will continue to perform its design-basis functions as assumed in the safety analysis report for Braidwood Station, Units 1 and 2, and Byron Station, Units 1 and 2.

5. **Provide a simplified diagram of the system, showing major components, active components, relative elevations, lengths of piping runs, and the location of any orifices and flow restrictions.**

Response: Piping and equipment elevations are provided in Attachment F of this submittal.

References

1. "Thermal Hydraulic Behavior of RCFC System During LOCA/LOOP for Byron and Braidwood Stations," PSA-B-98-13 rev. 0, September 28,1998.
2. NUREG/CR-5535, "RELAP5/MOD3 Code Manual Vol III: Developmental Assessment Problems," June 1990.

ATTACHMENT B

NODALIZATION FIGURES

[Response to NRC RAI 2.b)]

Figure 1 Diagram of Hydraulic Model

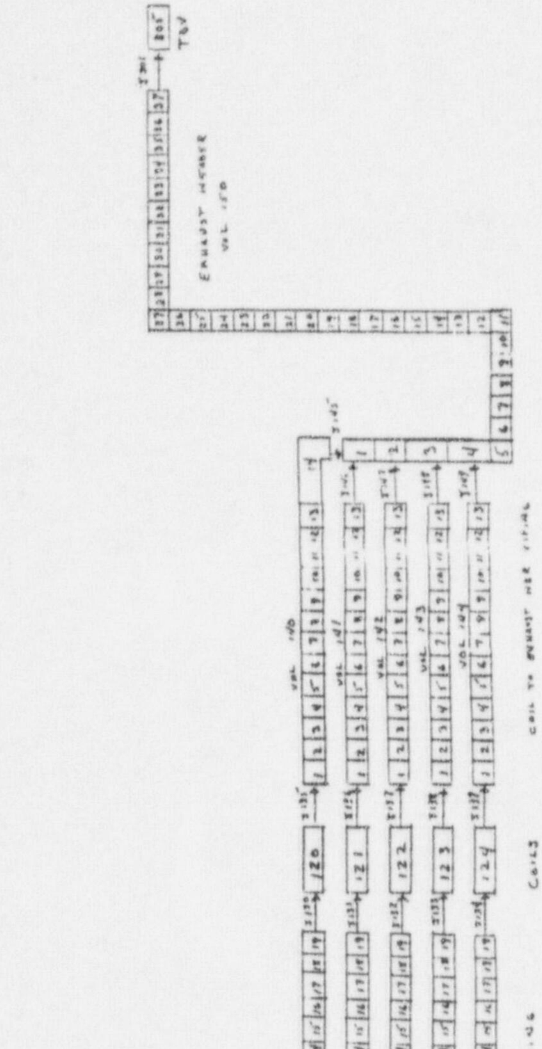
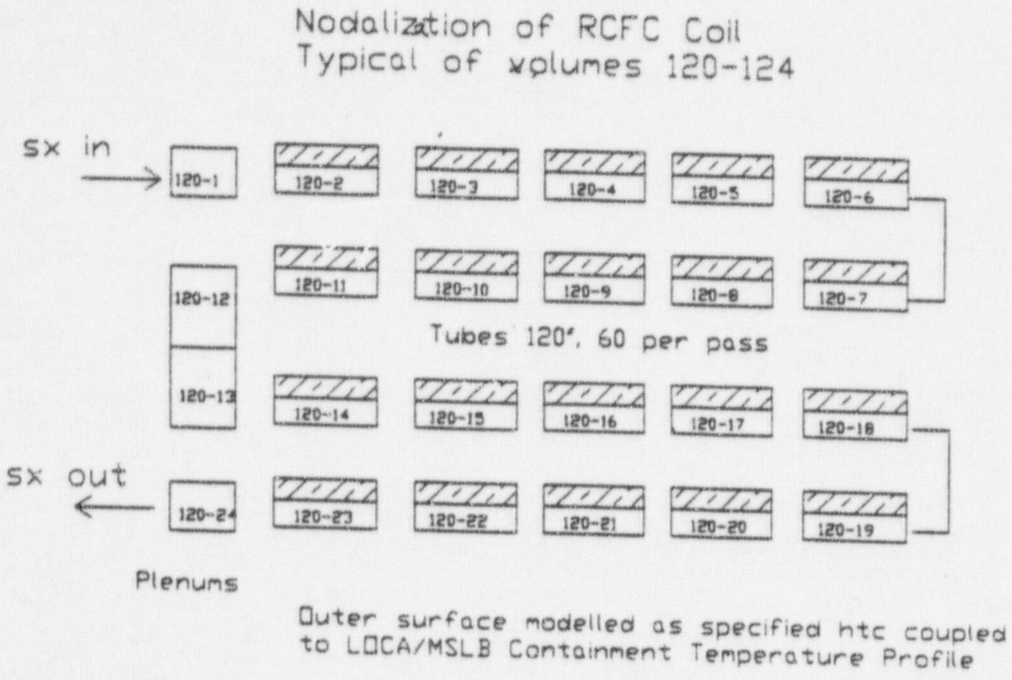


Figure 2 Diagram of RCFC Coil Model



ATTACHMENT C

APPENDIX C TO CALCULATION PSA-B-98-13
LISTING OF MODEL
[Response to NRC RAI 2.b)]

c 1

```
*byron rcfc ax model
*this deck has been modified to reflect tho guidence in Mod3.2 guides on choking
*this deck includes the 14 inch piping plus resistances
100 new transnt
*
*
102  british   british
105  90.  100.
105
110 air
*******************************************************
*                                                     *
*               time step cards                       *
*                                                     *
*******************************************************
*     end   dtmin    dtmax  opt min  maj retrt
201      12.0  1.d-7     0.01   3   100   4000 4000
202      15.  1.d-7     .005   3   500   4000 4000
203      17.  1.d-7    0.005   3   500   4000 4000
204      43.  1.d-7    0.005   3   500   4029 4000
205      60.  1.d-7    0.001   3   2   2000 2000
206      75.  1.d-7    0.005   3   500   2000 200
*205      100.  1.d-7     5.005   3   10   2000 2000
*
*******************************************************
*                                                     *
*              minor edit variables                   *
*                                                     *
*******************************************************
*
301  voidf   120090000
302  voidf   120210000
*
303  voidf   124090000
304  voidf   124210000
305  p       120090000
306  p       124090000
307  mflowj  101000000
*304  tmassv  104170000
*305  tmassv  104180000
*306  tmassv  104190000
*307  tmassv  104200000
*308  tmassv  104210000
*07  voidf  200010000
*05  mflowj 224010000
*04  voidg  345010000
*05  voidg  335060000
*06  voidg  212010000
*51  mflowj 505000000
*
*****************************************************************
*                         trip cards                            *
*                                                               *
*                       trip identifier                         *
*                                                               *
*     501   scram signal.rc pump trip.steam generator main      *
*           feed and main steam outlet trip                     *
*     502   initiate power decay curve                          *
*     503   pressure trip for si and charging initiation        *
*     504   si and charging initiation with 5.0 sec delay       *
*     505   aux feed flow initiation with 14.0 sec delay        *
*     506   break initiation                                    *
*     507   time zero trip                                      *
*     508   <*****************>                                 *
*     509   < porv trip logic >                                 *
*     601   <                 >                                 *
*     602   <*****************>                                 *
*     603   porv trip                                           *
*     510   dummy trip for main steam isolation valves          *
*     511   <*********************>                             *
*     512   <                     >                             *
*     604   < aux feed trip logic >                             *
*     605   <                     >                             *
*     606   <                     >                             *
*     607   <*********************>                             *
*     608   aux feed trip                                       *
*                                                               *
*     550  <problem stop                                        *
*     600  < cards                                              *
*                                                               *
*****************************************************************
550  time   0            ge   null    0      70.0       1
600  550
*
*
******************************************************
*                                                    *
*              hydrodynamic components               *
*                                                    *
******************************************************
*
*
*
****
 1000900   axsupply      tmdpvol
*          flowa  l     vol   azi   incl  dz   rough hyd    fe
 1000101     1.e2 1.0  0.0    0.0   0.0   0.0   0.0   0.0   10
*        ebt
 1000200  4
*          time  press   temp     qual
1000201   0.0    24.74    100.0  .00001
1000202   1.     24.74   100.0    .00001
1000203   6.     14.7   100.0  .00001
1000204   43.     14.7   100.0  .00001

1000205   44.     24.74   100.   .00001
1000206   100.     24.74   100.  .00001
*          time  press   temp     qual
1000201   0.0    27.2699    100.0   .00001
1000202   1.     27.2699   100.0    .00001
1000203   6.     14.7   100.0       .00001
1000204   43.     14.7   100.0       .00001
1000205   44.     54.5   100.0       .00001
1000206   64.     27.2699   100.0  .00001
1000207   100.     27.2699   100.  .00001
*lower the pressures
*          time  press   temp     qual
*1000201   0.0    19.07    100.0    .00001
*1000202   1.     19.07   100.0    .00001
1000201   0.0    21.9    100.0   .00001
```

C2

```
1000202   1.       21.9   100.0      .00001
1000203   6.       6.5   100.0       .00001
1000204   43.       6.5   100.      0.00001
1000205   44.       54.5   100.0    .00001
1000205   44.       41.0   100.0    .00001
1000206   64.       19.07   100.0   .00001
1000207   100.       19.07   100.   .00001
1000206   44.       21.9   100.0   .00001
1000207   100.       21.9   100.   .00001
*for steady state calc only
*1000201   0.0    22.     100.0    .00001
*1000202   1.     22.   100.0      .00001
*1000202   11.     22.   100.0      .00001
*1000203   16.     6.5   100.0       .00001
*
****
*
1010000   exratrn  engljun
1010101   100000000 104000000     .5475   0.0       0.0        00000
*add small resistance to tdv junction to simulate 14-10 inch connect
*1010101   100000000 104000000     .5475   0.5       1.0        00000
1010101   100000000 104000000     .5475   0.5       1.522        00020
1010101   100000000 104000000    1.2684   0.5       3.806        00020
*increase losses by 16 in 16 inch header to account for other cooler flows
1010101   100000000 104000000    1.2684   0.5      38.46        00020
1010101   100000000 104000003    1.2684   38.46      38.46        01000
*         flag lflow    vflow  interface flow
1010201   1    183.15       0.0       0.0
**
*1010000   junct  tmdpjun
*
*        frum        to        area
*1010101 100000000 104000000      .5475
*
*        flag
*1010200   1
*
*         time    lflow       vflow    intflow
*1010201   0.0      183.15        0.0      0.0
*1010202   1.      183.15        0.0      0.0
*1010203   6.      18.315      0.0      0.0
*1010204   11.      1.8315      0.0      0.0
*1010204   21.      0.0      0.0      0.0
*1010205   22.      0.0      0.0      0.
*1010206   43.       0.0      0.0      0.
*1010207   44.      183.15      0.0      0.
*1010208   1000.    183.15      0.0      0.
*==================
***add in 16 inch piping leg
1040000   line pipe
*         nv
1040001   22
*         flowa    nv
1040101   1.2684   10
1040102   .5475   22
*         length   nv
1040301   13.8    10
1040302   8.0    11
1040303   3.065     17
1040304   3.21875     21
1040305   1.61       22
*       incline angle  nv
1040601  0.0          11
1040602  -90.0         22
*         rough  hyd dia  nv
1040801   0.00015 0.0     22
*
*   901   fjunf   fjunr    nj
1040901    0.      0.       9
1040902    0.6     1.0       10
1040903    0.      0.       21
*         fe   nv
1041001   00   22
*         fvcahs nj
1041101   0000  21
*deactivate ccfl model on risers
1041101   001000  9
1041102   000020  10
1041103   001000  21
*        flag   p       t       x   dummy nv
1041201   4     30.   100.0     0.00001   0 0 12
1041201   4     26.25   100.0     0.00001   0 0 22
1041201   4     20.7   100.0     0.00001   0 0 11
1041202   4     28.9   100.0     0.00001   0 0 22
*         flag 1=lbm/sec
1041300   1
*         lflow    vflow  interface flow nj
1041301   183.15       0.0         0.0     21
*
1100000   catvent  engljun
1100101   104180003 105000000     .0884   0.5       1.0       01000
*         flag lflow    vflow  interface flow
1100201   1    36.63       0.0       0.0
*
1110000   catvent  engljun
1110101   104190003 106000000     .0884   0.5       1.0       01000
*         flag lflow    vflow  interface flow
1110201   1    36.63       0.0       0.0
**
1120000   catvent  engljun
1120101   104200003 107000000     .0884   0.5       1.0       01000
*         flag lflow    vflow  interface flow
1120201   1    36.63       0.0       0.0
*
1130000   catvent  engljun
1130101   104210003 108000000     .0884   0.5       1.r       01000
*         flag lflow    vflow  interface flow
1130201   1    36.63       0.0       0.
*
1140000   catvent  engljun
1140101   104220003 109000000     .0884   0.5       1.0       01000
*         flag lflow    vflow  interface flow
1140201   1    36.63       0.0       0.
*
1050000   line pipe
*         nv
1050001   19
*         flowa    nv
1050101   .0884   15
1050102   .05130  19
```

```
*          length   nv
*renodlized version
1050301    0.25     6
1050302    0.583      12
1050303    1.        15        * this and next volume arbitrarily divided
1050304     .383         18
1050305     .5          19     * this length is approximate
*        incline angle  nv
1050601  0.0             19
*          rough  hyd dia  nv
1050801    0.00015 0.0      19
*
*   901    fjunf    fjunr     nj
1050901     0.0      0.0      5     *
1050902     0.27      0.27      6     *45 deg bend
1050903     0.0      0.0      11     *
1050904     0.5      0.5      12      *std rad elbow
1050905     0.0      0.0      14     *
1050906     0.15      0.15      15   * reducer
1050907     0.0      0.0      17     *
1050908     0.5      0.5     18     * assume standard radius elbow
*          fe    nv
1051001    00   19
*          cahs nj
1051101    1000  14
1051102    0020  15
1051102    1000  15  *no choke
1051103    1000  18
*         flag    p        t         x    dummy nv
1051201    4      30.   100.0      0.00001    0 0 5
1051201    4      28.   100.0      0.00001    0 0 19
*          flag 1=lbm/sec
1051300    1
*          lflow     vflow  interface flow nj
1051301    36.63          0.0           0.0      18
*
1060000    line pipe
*          nv
1060001    19
*          flowa     nv
1060101     .0884    15
1060102     .05130  19
*          length   nv
*renodlized version
1060301    0.25     6
1060302    0.583      12
1060303    1.        15        * this and next volume arbitrarily divided
1060304     .383         18
1060305     .5          19     * this length is approximate
*        incline angle  nv
1060601  0.0             19
*          rough  hyd dia  nv
1060801    0.00015 0.0      19
*
*   901    fjunf    fjunr     nj
1060901     0.0      0.0      5     *
1060902     0.27      0.27      6     *45 deg bend
1060903     0.0      0.0      11     *
1060904     0.5      0.5      12      *std rad elbow
1060905     0.0      0.0      14     *
1060906     0.15      0.15      15   * reducer
1060907     0.0      0.0      17     *
1060908     0.5      0.5     18     * assume standard radius elbow
*          fe    nv
1061001    00   19
*          cahs nj
1061101    1000  14
1061102    0020  15
1061102    1000  15 * no choke
1051103    1000  18
*         flag    p        t         x    dummy nv
1061201    4      30.   100.0      0.00001    0 0 5
1061201    4      29.   100.0      0.00001    0 0 19
*          flag 1=lbm/sec
1061300    1
*          lflow     vflow  interface flow nj
1061301    36.63          0.0           0.0      18
*
1070000    line pipe
*          nv
1070001    19
*          flowa     nv
1070101     .0884    15
1070102     .05130  19
*          length   nv
*renodlized version
1070301    0.25     6
1070302    0.583      12
1070303    1.        15        * this and next volume arbitrarily divided
1070304     .383         18
1070305     .5          19     * this length is approximate
*        incline angle  nv
1070601  0.0             19
*          rough  hyd dia  nv
1070801    0.00015 0.0      19
*
*   901    fjunf    fjunr     nj
1070901     0.0      0.0      5     *
1070902     0.27      0.27      6     *45 deg bend
1070903     0.0      0.0      11     *
1070904     0.5      0.5      12      *std rad elbow
1070905     0.0      0.0      14     *
1070906     0.15      0.15      15   * reducer
1070907     0.0      0.0      17     *
1070908     0.5      0.5     18     * assume standard radius elbow
*          fe    nv
1071001    00   19
*          cahs nj
1071101    1000  14
1071102    0020  15
1071102    1000  15 * no choke
1071103    1000  18
*         flag    p        t         x    dummy nv
1071201    4      30.   100.0      0.00001    0 0 5
1071201    4      31.   100.0      0.00001    0 0 19
*          flag 1=lbm/sec
1071300    1
*          lflow     vflow  interface flow nj
1071301    36.63          0.0           0.0      18
*
```

c 4

```
1080000   line pipe
*         nv
1080001   19
*         flowa    nv
1080101   .0884   15
1080102   .05130  19
*         length   nv
*renodlized version
1080301   0.25    6
1080302   0.583      12
1080303   1.        15       * this and next volume arbitrarily divided
1080304   .383        18
1080305    .5        19    * this length is approximate
*       incline angle  nv
1080601  0.0           19
*         rough  hyd dia  nv
1080801   0.00015 0.0     19
*
*   901   fjunf   fjunr    nj
1080901    0.0     0.0     5    *
1080902    0.27     0.27     6    *45 deg bend
1080903    0.0     0.0     11    *
1080904    0.5     0.5     12     *std rad elbow
1080905    0.0     0.0     14    *
1080906    0.15     0.15     15  * reducer
1080907    0.0     0.0     17    *
1080908    0.5     0.5    18    * assume standard radius elbow
*         fe   nv
1081001   00   19
*         cahe nj
1081101   1000  14
1081102   0020  15
1081[illegible]   1000  15 *no choke
1081103   10[illegible]  1[illegible]
*        flag   p       t       x   dummy nv
1081201   4     30.   100.0     0.00001   0 0 5
1081201   4     32.   100.0     0.00001   0 0 19
*         flag 1=lbm/sec
1081300   1
*         lflow    vflow  interface flow nj
1081301   36.63        0.0         0.0     18
*
*
1090000   line pipe
*         nv
1090001   19
*         flowa    nv
1090101   .0884   15
1090102   .05130  19
*         length   nv
*renodlized version
1090301   0.25    6
1090302   0.583      12
1090303   1.        15       * this and next volume arbitrarily divided
1090304   .383        18
1090305    .5        19    * this length is approximate
*       incline angle  nv
1090601  0.0           19
*         rough  hyd dia  nv
1090801   0.00015 0.0     19
*
*   951   fjunf   fjunr    nj
1090901    0.0     0.0     5    *
1090902    0.27     0.27     6    *45 deg bend
1090903    0.0     0.0     11    *
1090904    0.5     0.5     12     *std rad elbow
1090905    0.0     0.0     14    *
1090906    0.15     0.15     15  * reducer
1090907    0.0     0.0     17    *
1090908    0.5     0.5    18    * assume standard radius elbow
*         fe   nv
1091001   00   19
*         cahe nj
1091101   1000  14
1091102   0020  15
1091102   1000  15  * no choke
1091103   1000  18
*        flag   p       t       x   dummy nv
1091201   4     30.   100.0     0.00001   0 0 5
1091201   4     33.   100.0     0.00001   0 0 19
*         flag 1=lbm/sec
1091300   1
*         lflow    vflow  interface flow nj
1091301   36.63        0.0         0.0     18
*
*
1300000   coilin  engljun
1300101   105010000 120000000    .0513   1.0      .5       01000
*         flag lflow    vflow  interface flow
1300201   1    36.63        0.0      0.0
**
1310000   coilin  engljun
1310101   106010000 121000000    .0513   1.0      .5       01000
*         flag lflow    vflow  interface flow
1310201   1    36.63        0.0      0.0
*
1320050   coilin  engljun
1320101   107010000 122000000    .0513   1.0      .5       01000
*         flag lflow    vflow  interface flow
1320201   1    36.63        0.0      0.
*
*
1330000   coilin  engljun
1330101   108010000 123000000    .0513   1.0      .5       01000
*         flag lflow    vflow  interface flow
1330201   1    36.63        0.0      0.
*
*
1340000   coilin  engljun
1340101   109010000 124000000    .0513   1.0      .5       01000
*         flag lflow    vflow  interface flow
1340201   1    36.63        0.0      0
*
1200000   coil pipe
*         nv
1200001   24
*         flowa    nv
1200101   .3718    1
1200102   .0908266  11
1200103   .3718    13
```

C5

```
1200104    .0908866  23
1200105    .3718     24
*          length    nv
1200301    .5    1
1200302    2.       11
1200303    .5        13        * this and next volume arbitrarily divided
1200304    2.         23
1200305     .5        24     * this length is approximate
*        incline angle  nv
1200601  0.0              24
*          rough  hyd dia  nv
1200801    0.00015 0.0      1
1200802    0.00015   .043917 11
1200803    .00015    0.0    13
1200804    0.00015   .043917 23
1200805    .00015    0.0    24
*
*   901    fjunf    fjunr     nj
1200901     0.5      1.0      1     *tube sht
1200902     0.0      0.0      10      *tubes
1200903     1.0      0.5      11  * tube sht
1200904     0.0      0.0      12
1200905     0.5      1.0      13     *tube sh
1200906     0.0      0.0      22      *tubes
1200907     1.0      0.5      23  * tube sht
*          fe    nv
1201001    00    24
*          cahs nj
1201101    1000 23
1201101    0020  1
1201102    1000  10
1201103    0020  11
1201104    1000  12
1201105    0020  13
1201106    1000  22
1201107    0020  23
*         flag    p        t         x    dummy nv
1231201    4      30.    100.0      0.00001    0 0 24
1201201    4      22.7   100.0      0.00001    0 0 24
*          flag 1=lbm/sec
1201300    1
*          lflow     vflow  interface flow nj
1201301    36.63        0.0           0.0      23
*          hyddia     beta c  m     nj
1201401  4.3917e-2  0.  1.  1.  23
*
1210000    coil pipe
*          nv
1210001    24
*          flowa     nv
1210101    .3718    1
1210102    .0908866  11
1210103    .3718     13
1210104    .0908866  23
1210105    .3718     24
*          length    nv
1210301    .5    1
1210302    2.      11
1210303    .5        13        * this and next volume arbitrarily divided
1210304    2.         23
1210305     .5        24     * this length is approximate
*        incline angle  nv
1210601  0.0              24
*          rough  hyd dia  nv
1210801    0.00015 0.0      1
1210802    0.00015   .043917 11
1210803    .00015    0.0    13
1210804    0.00015   .043917 23
1210805    .00015    0.0    24
*
*   901    fjunf    fjunr     nj
1210901     0.5      1.0      1     *tube sht
1210902     0.0      0.0      10      *tubes
1210903     1.0      0.5      11  * tube sht
1210904     0.0      0.0      12
1210505     0.5      1.0      13     *tube sh
1210906     0.0      0.0      22      *tubes
1210907     1.0      0.5      23  * tube sht
*          fe    nv
1211001    00    24
*          cahs nj
1211101    1000  23
1211101    0020  1
1211102    1000  10
1211103    0020  11
1211104    1000  12
1211105    0020  13
1211106    1000  22
1211107    0020  23
*         flag    p        t         x    dummy nv
1211201    4      30.    100.0      0.00001    0 0 24
1211201    4      24.    100.0      0.00001    0 0 24
*          flag 1=lbm/sec
1211300    1
*          lflow     vflow  interface flow nj
1211301    36.63        0.0           0.0      23
*
*          hyddia     beta c  m     nj
1211401  4.3917e-2  0.  1.  1.  23
*
1220000    coil pipe
*          nv
1220001    24
*          flowa     nv
1220101    .3718    1
1220102    .090886  11
1220103    .3718     13
1220104    .090886  23
1220105    .3718     24
*          length    nv
1220301    .5    1
1220302    2.      11
1220303    .5        13        * this and next volume arbitrarily divided
1220304    2.         23
1220305     .5        24     * this length is approximate
*        incline angle  nv
1220601  0.0              24
*          rough  hyd dia  nv
1220801    0.00015 0.0      1
1220802    0.00015   .043917 11
```

```
1220803    .00015   0.0   13
1220804    0.00015   .043917 23
1220805    .00015   0.0   24
*
*   901    fjunf    fjunr     nj
1220901     0.5      1.0      1     *tube ent
1220902     0.0      0.0      10      *tubes
1220903     1.0      0.5      11  * tube ent
1220904     0.0      0.0      12
1220905     0.5      1.0      13     *tube sh
1220906     0.0      0.0      22      *tubes
1220907     1.0      0.5      23  * tube ent
*          fe    nv
1221001    00    24
*          cahs nj
1221101    1000  23
1221101    0020  1
1221102    1000  10
1221103    0020  11
1221104    1000  12
1221105    0020  13
1221106    1000  22
1221107    0020  23
*         flag   p        t        x   dummy nv
1221201    4      30.   100.0      0.00001   0 0 24
1221201    4      25.4   100.0      0.00001   0 0 24
*          flag 1=lbm/sec
1221300    1
*          lflow    vflow  interface flow nj
1221301    36.63         0.0          0.0      23
*
*          hyddia    beta c  m     nj
1221401  4.3917e-2  0.  1.  1.  23
*
1230000    coil pipe
*          nv
1230001    24
*          flowa     nv
1230101    .3718    1
1230102    .090886  11
1230103    .3718    13
1230104    .090886  23
1230105    .3718    24
*          length    nv
1230301    .5    1
1230302    2.      11
1230303    .5       13       * this and next volume arbitrarily divided
1230304    2.        23
1230305     .5        24     * this length is approximate
*        incline angle  nv
1230601  0.0             24
*          rough  hyd dia  nv
1230801    0.00015 0.0      1
1230802    0.00015  .043917 11
1230803    .00015   0.0   13
1230804    0.00015  .043917 23
1230805    .00015   0.0   24
*
*   901    fjunf    fjunr     nj
1230901     0.5      1.0      1     *tube sht
1230902     0.0      0.0      10      *tubes
1230903     1.0      0.5      11  * tube sht
1230904     0.0      0.0      12
1230905     0.5      1.0      13     *tube sh
1230906     0.0      0.0      22      *tubes
1230907     1.0      0.5      23  * tube sht
*          fe    nv
1231001    00    24
*          cahs nj
1231101    1000  23
1231101    0020  1
1231102    1000  10
1231103    0020  11
1231104    1000  12
1231105    0020  13
1231106    1000  22
1231107    0020  23
*         flag   p        t        x   dummy nv
1231201    4      30.   100.0      0.00001   0 0 24
1231201    4      26.8   100.0      0.00001   0 0 24
*          flag 1=lbm/sec
1231300    1
*          lflow    vflow  interface flow nj
1231301    36.63         0.0          0.0      23
*
*          hyddia    beta c  m     nj
1231401  4.3917e-2  0.  1.  1.  23
*
1240000    coil pipe
*          nv
1240001    24
*          flowa     nv
1240101    .3718    1
1240102    .090886  11
1240103    .3718    13
1240104    .090886  23
1240105    .3718    24
*          length    nv
1240301    .5    1
1240302    2.      11
1240303    .5       13       * this and next volume arbitrarily divided
1240304    2.        23
1240305     .5        24     * this length is approximate
*        incline angle  nv
1240601  0.0             24
*          rough  hyd dia  nv
1240801    0.00015 0.0      1
1240802    0.00015  .043917 11
1240803    .00015   0.0   13
1240804    0.00015  .043917 23
1240805    .00015   0.0   24
*
*   901    fjunf    fjunr     nj
1240901     0.5      1.0      1     *tube ent
1240902     0.0      0.0      10      *tubes
1240903     1.0      0.5      11  * tube ent
1240904     0.0      0.0      12
1240905     0.5      1.0      13     *tube sh
1240906     0.0      0.0      22      *tubes
1240907     1.0      0.5      23  * tube sht
```

C7

```
*         fn   nv
1241001   00   24
*         cahe nj
1241101   1000  23
1241101   0020  1
1241102   1000  10
1241103   0020  11
1241104   1000  12
1241105   0020  13
1241106   1000  22
1241107   0020  23
*        flag   p        t         x   dummy nv
1241201   4      30.   100.0      0.00001   0 0 24
1241201   4      27.8   100.0      0.00001   0 0 24
*         flag 1+lbm/sec
1241300   1
*         lflow    vflow  interface flow nj
1241301   36.63        0.0          0.0     23
*
*         hyddia    beta c  m    nj
1241401  4.3917e-2  0.  1.  1.  23
*
1350000   coilout  angljun
1350101   120010000 140000000    .0513   .5      1.0        01000
*         flag lflow    vflow  interface flow
1350201   1    36.63       0.0       0.0
**
1360000   coilout  angljun
1360101   121010000 141000000    .0513   .5      1.0        01000
*         flag lflow    vflow  interface flow
1360201   1    36.63       0.0       0.0
*
1370000   coilout  angljun
1370101   122010000 142000000    .0513   .5      1.0        01000
*         flag lflow    vflow  interface flow
1370201   1    36.63       0.0       0.
*
*
1380000   coilout  angljun
1380101   123010000 143000000    .0513   .5      1.0        01000
*         flag lflow    vflow  interface flow
1380201   1    36.63       0.0       0.
*
*
1390000   coilout  angljun
1390101   124010000 144000000    .0513   .5      1.0        01000
*         flag lflow    vflow  interface flow
1390201   1    36.63       0.0       0
*
1400000   line pipe
*         nv
1400001   14
*         flowa    nv
1400101   .05130  4
1400102   .0884   14
*         length   nv
1400301   .5    1    *this length is approximate
1400302   1.15     2   * this and next volume arbitrarily divided
1400303   3.5      3
1400304   2.5       4
1400301   .5    1    *this length is approximate
1400302   0.3833     4   * this and next volume arbitrarily divided
1400303   1.167      7
1400304   0.416       13
1400305   1.609375       14    * this length is approximat
*       incline angle  nv
1400601  0.0           13
1400602  -90.0            14
*         rough  hyd dia  nv
1400801   0.00015 0.0     14
*
*   901   fjunf   fjunr    nj
1400901    0.5     0.5    1    * assume standard radius elbow
1400902    0.0     0.0     3
1400903    0.15     0.15    4  * reducer
1400904    0.0     0.0     6
1400905    0.5     0.5     7     *std rad elbow
1400906    0.0     0.0     12
1400907    0.5     0.5     13     *std rad elbow
*         fe   nv
1401001   00   14
*         cahe nj
1401101   1000  3
1401102   0020  4
1401102   1000  4  *turn off choking at reducer to limit oscillation
1401103   1000  13
*        flag   p        t         x   dummy nv
1401201   4      17.   100.0      0.00001   0 0 14
*         flag 1+lbm/sec
1401300   1
*         lflow    vflow  interface flow nj
1401301   36.63        0.0          0.0     13
*
*
1410000   line pipe
*         nv
1410001   13
*         flowa    nv
1410101   .05130  4
1410102   .0884   13
*         length   nv
1410301   .5    1    *this length is approximate
1410302   1.15     2   * this and next volume arbitrarily divided
1410303   3.5      3
1410304   2.5       4
1410301   .5    1    *this length is approximate
1410302   0.3833     4   * this and next volume arbitrarily divided
1410303   1.167      7
1410304   0.416       13
*       incline angle  nv
1410601  0.0           13
*         rough  hyd dia  nv
1410801   0.00015 0.0     13
*
*   901   fjunf   fjunr    nj
1410901    0.5     0.5    1    * assume standard radius elbow
1410902    0.0     0.0     3
1410903    0.15     0.15    4  * reducer
1410904    0.0     0.0     6
1410905    0.5     0.5     7     *std rad elbow
```

C8

```
1410906    0.0      0.0      12
*          fe   nv
1411001    00   13
*          cahs nj
1411101    1000  3
1411102    0020  4
1411102    1000  4  * no choking at reducer
1411103    1000  12
*         flag   p        t        x   dummy nv
1411201    4     18.   100.0      0.00001   0 0 13
*          flag 1=lbm/sec
1411300    1
*          lflow    vflow  interface flow nj
1411301    36.63        0.0          0.0      12
*
*
1420000    line pipe
*          nv
1420001    13
*          flowa    nv
1420101    .05130  4
1420102    .0884   13
*          length   nv
1420301    .5    1    *this length is approximate
1420302    0.3833      4   * this and next volume arbitrarily divided
1420303    1.167       7
1420304    0.416         13
*        incline angle  nv
1420601   0.0           13
*          rough  hyd dia  nv
1420801    0.00015 0.0      13
*
*   901    fjunf   fjunr    nj
1420901     0.5      0.5     1     * assume standard radius elbow
1420902     0.0      0.0      3
1420903     0.15      0.15     4  * reducer
1420904     0.0      0.0      6
1420905     0.5      0.5      7      *std rad elbow
1420906     0.0      0.0      12
*          fe   nv
1421001    00   13
*          cahs nj
1421101    0020  12
1421101    1000  3
1421102    0020  4
1421102    1000  4  *no choke
1421103    1000  12
*         flag   p        t        x   dummy nv
1421201    4     19.3   100.0      0.00001   0 0 13
*          flag 1=lbm/sec
1421300    1
*          lflow    vflow  interface flow nj
1421301    36.63        0.0          0.0      12
*
*
1430000    line pipe
*          nv
1430001    13
*          flowa    nv
1430101    .05130  4
1430102    .0884   13
*          length   nv
1430301    .5    1    *this length is approximate
1430302    0.3833      4   * this and next volume arbitrarily divided
1430303    1.167       7
1430304    0.416         13
*        incline angle  nv
1430601   0.0           13
*          rough  hyd dia  nv
1430801    0.00015 0.0      13
*
*   901    fjunf   fjunr    nj
1430901     0.5      0.5     1     * assume standard radius elbow
1430902     0.0      0.0      3
1430903     0.15      0.15     4  * reducer
1430904     0.0      0.0      6
1430905     0.5      0.5      7      *std rad elbow
1430906     0.0      0.0      12
*          fe   nv
1431001    00   13
*          cahs nj
1431101    0020  12
1431101    1000  3
1431102    0020  4
1431102    1000  4  * no choke
1431103    1000  12
*         flag   p        t        x   dummy nv
1431201    4     31.   100.0      0.00001   0 0 13
*          flag 1=lbm/sec
1431300    1
*          lflow    vflow  interface flow nj
1431301    36.63        0.0          0.0      12
*
*
1440000    line pipe
*          nv
1440001    13
*          flowa    nv
1440101    .05130  4
1440102    .0884   13
*          length   nv
1440301    .5    1    *this length is approximate
1440302    0.3833      4   * this and next volume arbitrarily divided
1440303    1.167       7
1440304    0.416         13
*        incline angle  nv
1440601   0.0           13
*          rough  hyd dia  nv
1440801    0.00015 0.0      13
*
*   901    fjunf   fjunr    nj
1440901     0.5      0.5     1     * assume standard radius elbow
1440902     0.0      0.0      3
1440903     0.15      0.15     4  * reducer
1440904     0.0      0.0      6
1440905     0.5      0.5      7      *std rad elbow
1440906     0.0      0.0      12
*          fe   nv
1441001    00   13
*          cahs nj
```

C9

```
1441101   0020  12
1441101   1000  3
1441102   0020  4
1441102   1000  4  *no choke
1441103   1000  12
*        flag   p        t        x   dummy nv
1441201   4     22.   100.0     0.00001   0 0 13
*         flag 1=lbm/sec
1441300   1
*         lflow     vflow  interface flow nj
1441301   36.63         0.0          0.0     12
*
*
*
1450000   coilout  angljun
1450101   140010000 150000000     .0884   1.0       .5       01000
*         flag lflow    vflow  interface flow
1450201   1    36.63       0.0       0.0
*
1460000   coilout  angljun
1460101   141010000 150010003     .0884   1.0       .5       01000
*         flag lflow    vflow  interface flow
1460201   1    36.63       0.0       0.0
**
1470000   coilout  angljun
1470101   142010000 150020003     .0884   1.0       .5       01000
*         flag lflow    vflow  interface flow
1470201   1    36.63       0.0       0.0
*
1480000   coilout  angljun
1480101   143010000 150030003     .0884   1.0       .5       01000
*         flag lflow    vflow  interface flow
1480201   1    36.63       0.0       0.
*
1490000   coilout  angljun
1490101   144010000 150040003     .0884   1.0       0.5       01000
*         flag lflow    vflow  interface flow
1490201   1    36.63       0.0       0.
**
*1040302   3.065     7
*1040303   3.21875    11
*1040304   1.61       12
1500000   line pipe
*         nv
1500001   37
*         flows    nv
1500101   .5475   27
1500102   1.2684   37
*         length   nv
*1500301   1.4167    1
*1500301   1.60935    1
*1500302   3.21875    4
*1500303   1.84375    5
1500301   3.21875    3
1500302   1.61    4
1500303   1.0       5
1500304   0.5       11
1500305   1.0       27
1500306   14.9       37
*      incline angle  nv
1500601   -90.0          5
1500602   0.0         11
1500603   90.0         27
1500604   0.0         37
*         rough  hyd dia  nv
1500801   0.00015 0.0     37
*
*   901   fjunf   fjunr    nj
1500901    0.      0.      4
1500902    0.26     0.26       5  *lr elbow
*1500902    0.0      0.0       5  *neglect resistance
1500903    0.      0.        10
1500904    0.26     0.26       11  *lr elbow
*1500904    0.0      0.0       11  *neglect elbow resistance
1500905    0.      0.        36
*         fe   nv
1501001   00   37
*         caha nj
1501101   0000  36
*add ccfl option
1501101   001000  26
1501102   000020  27
1501103   001000  36
*        flag   p        t        x   dummy nv
1501201   4     30.   100.0     0.00001   0 0 22
*1501201   4     16.   100.0     0.00001   0 0 37
*         flag 1=lbm/sec
1501300   1
*         lflow     vflow  interface flow nj
1501301   183.15        0.0          0.0     36
*
 3050000   sink       tmdpvol
*         flowa  l    vol   azi   incl  dz   rough hyd    fe
 3050101     1.e2 1.0  0.0   0.0   0.0   0.0   0.0   0.0   10
*        ebt
 3050200   4
*         time  temp quall
 3050201   0.0   22.3969  100.0  .00001
 3050202   10000. 22.3969  100.0  .00001
  3050201   0.0   14.2  100.0      .00001
 3050202   100.      14.2  100.0   .00001
* 3050203   6.      14.2   100.0
*3050204   43.      14.2   100.0
*3050205   44.      22.3969   100.0
*3050206   1000.      22.3969   100.0
*
*
3013000   axretrn  angljun
3010101   150010000 305000000     .5475   0.0       0.0       00000
3010101   150010000 305000000     .5475   1.0       0.5       00020
3010101   150010000 305000000     1.2684   41.       0.5       00020
3010101   150010000 305000000     1.2684   41.       0.5       01000
*add reverse flow losses as well on discharge side
*3010101   150010000 305000000     1.2684   41.       12.96       01000
*         flag lflow    vflow  interface flow
3010201   1    183.15       0.0       0.0
**
*---------- heat structure input
*
*general data
```

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```
*          nh  np   geo  ss    left coord.
11201000  20  11    2    1      0.02195833
****************************************
*mesh flags
*         location flg        format flag
11201100     0                    2
****************************************
*mesh data
*         mesh interval   int #
11201101 .00040833          10
****************************************
*composition data
*            comp. #     int #
11201201       1          10
****************************************
*heat distribution data
*         source   int #
11201301   0.0      10
****************************************
*initial temperature data
*             temp.       int #
11201401    130.0       11
************************************************************
*left bc cards
*             bvl      inc  type  surf      cyl ht/ara      struct #
11201501  120020000 10000 1       0       16.5562          10
11201502  120140000 10000 1       0       16.5562        20
************************************************************
*right bc cards
*             bvr      inc  type  surf      cyl ht      struct #
11201601      -1  00000 3002       0        19.635        10
11201602      -1 0000  3002       0        19.635        20
*11201601      -1  00000 1001       0        19.635        10
*11201602      -1 0000  1001       0        19.635        20
************************************************************
************************************************************
*source data
*           source  mult      ldh      rdh   struct #
11201701     0      0.0      0.0      0.0      20
************************************************************
*left boundary cards
*           hdiam  hlf      hlr    gridf   gridr   grdlsef grdlser lbf struct #
11201801     0.    10.0      10.0    1.5  1.5      0.0          0.0   1.   20
************************************************************
*right boundary cards
*           hdiam  hlf      hlr    gridf   gridr   grdlsef grdlser lbf struct #
11201901     0.    10.0      10.0    1.5  1.5      0.0          0.0   1.   20
************************************************************
*
*general data
*          nh  np   geo  ss    left coord.
11211000  20  11    2    1      0.02195833
****************************************
*mesh flags
*         location flg        format f'ag
11211100     0                    2
****************************************
*mesh data
*         mesh interval   int #
11211101 .00040833          10
****************************************
*composition data
*            comp. #     int #
11211201       1          10
****************************************
*heat distribution data
*         source   int #
11211301   0.0      10
****************************************
*initial temperature data
*             temp.       int #
11211401    130.0       11
************************************************************
*left bc cards
*             bvl      inc  type  surf      cyl ht/ara      struct #
11211501  121020000 10000 1       0       16.5562          10
11211502  121140000 10000 1       0       16.5562        20
************************************************************
*right bc cards
*             bvr      inc  type  surf      cyl ht      struct #
11211601      -1  00000 3002       0        19.635        10
11211602      -1 0000  3002       0        19.635        20
*11211601      -1  00000 1001       0        19.635        10
*11211602      -1 0000  1001       0        19.635        20
************************************************************
************************************************************
*source data
*           source  mult      ldh      rdh   struct #
11211701     0      0.0      0.0      0.0      20
************************************************************
*left boundary cards
*           hdiam  hlf      hlr    gridf   gridr   grdlsef grdlser lbf struct #
11211801     0.    10.0      10.0    1.5  1.5      0.0          0.0   1.   20
************************************************************
*right boundary cards
*           hdiam  hlf      hlr    gridf   gridr   grdlsef grdlser lbf struct #
11211901     0.    10.0      10.0    1.5  1.5      0.0          0.0   1.   20
************************************************************
*
*general data
*          nh  np   geo  ss    left coord.
11221000  20  11    2    1      0.02195833
****************************************
*mesh fl/gs
*         location flg        format flag
11221100     0                    2
****************************************
*mesh data
*         mesh interval   int #
11221101 .00040833          10
****************************************
*composition data
*            comp. #     int #
11221201       1          10
****************************************
*heat distribution data
*         source   int #
11221301   0.0      10
****************************************
*initial temperature data
```

C 11

```
*           temp.      int #
11221401    130.0       11
*****************************************************************
*****************************************************************
*left bc cards
*            bvl      inc  type  surf      cyl ht/ara      struct #
11221501  122020000 10000 1      0        16.5562           10
11221502  122140000 10000 1      0        16.5562           20
*****************************************************************
*right bc cards
*            bvr      inc  type  surf      cyl ht      struct #
11221601      -1  00000 3002      0        19.635       10
11221602      -1 0000  3002      0         19.635       20
*11221601      -1  00000 1001      0        19.635         10
*11221602      -1 0000  1001      0        19.635        20
****************************************************************
*****************************************************************
*source data
*          source  mult      ldh      rdh   struct #
11221701    0     0.0       0.0      0.0     20
*****************************************************************
*left boundary cards
*           hdiam  hlf      hlr    gridf   gridr   grdlsef grdlser lbf struct #
11221801    0.    10.0      10.0    1.5  1.5     0.0         0.0   1.   20
*****************************************************************
*right boundary cards
*           hdiam  hlf      hlr    gridf   gridr   grdlsef grdlser lbf struct #
11221901    0.    10.0      10.0    1.5  1.5     0.0         0.0   1.   20
*****************************************************************
*general data
*          nh  np   geo  ss    left coord.
11231000  20  11    2    1     0.02195833
****************************************
*mesh flags
*        location flg       format flag
11231100     0                   2
****************************************
*mesh data
*         mesh interval   int #
11231101 .00040833          10
****************************************
*composition data
*           comp. #     int #
11231201      1          10
****************************************
*heat distribution data
*         source   int #
11231301   0.0      10
****************************************
*initial temperature data
*            temp.      int #
11231401    130.0       11
*****************************************************************
*****************************************************************
*left bc cards
*            bvl      inc  type  surf      cyl ht/ara      struct #
11231501  123020000 10000 1      0        16.5562           10
11231502  123140000 10000 1      0        16.5562        20
*****************************************************************
*right bc cards
*            bvr      inc  type  surf      cyl ht      struct #
11231601      -1  00000 3002      0         19.635       10
11231602      -1 0000  3002      0          19.635       20
*11231601      -1  00000 1001      0         19.635       10
*11231602      -1 0000  1001      0         19.635       20
****************************************************************
*****************************************************************
*source data
*          source  mult      ldh      rdh   struct #
11231701    0     0.0       0.0      0.0     20
*****************************************************************
*left boundary cards
*           hdiam  hlf      hlr    gridf   gridr   grdlsef grdlser lbf struct #
11231801    0.    10.0      10.0    1.5  1.5     0.0         0.0   1.   20
*****************************************************************
*right boundary cards
*           hdiam  hlf      hlr    gridf   gridr   grdlsef grdlser lbf struct #
11231901    0.    10.0      10.0    1.5  1.5     0.0         0.0   1.   20
*****************************************************************
*general data
*          nh  np   geo  ss    left coord.
11241000  20  11    2    1     0.02195833
****************************************
*mesh flags
*        location flg       format flag
11241100     0                   2
****************************************
*mesh data
*         mesh interval   int #
11241101 .00040833          10
****************************************
*composition data
*           comp. #     int #
11241201      1          10
****************************************
*heat distribution data
*         source   int #
11241301   0.0      10
****************************************
*initial temperature data
*            temp.      int #
11241401    130.0       11
*****************************************************************
*****************************************************************
*left bc cards
*            bvl      inc  type  surf      cyl ht/ara      struct #
11241501  124020000 10000 1      0        16.5562           10
11241502  124140000 10000 1      0        16.5562        20
*****************************************************************
*right bc cards
*            bvr      inc  type  surf      cyl ht      struct #
11241601      -1  00000 3002      0         19.635       10
11241602      -1 0000  3002      0          19.635       20
*11241601      -1  00000 1001      0         19.635       10
*11241602      -1 0000  1001      0         19.635       20
****************************************************************
*****************************************************************
*source data
*          source  mult      ldh      rdh   struct #
11241701    0     0.0       0.0      0.0     20
```

```
*************************************************************
*left boundary cards
*          hdiam  hlf      hlr     gridf   gridr   grdlssf grdlssr lbf struct #
11241801    0.    10.0      10.0    1.5  1.5     0.0        0.0   1.   20
*************************************************************
*right boundary cards
*          hdiam  hlf      hlr     gridf   gridr   grdlssf grdlssr lbf struct #
11241901    0.    10.0      10.0    1.5  1.5     0.0        5.0   1.   20
*************************************************************
*
*----- heat structure thermal property data
*
*composition type and data format
*          material type    flag    flag
20100100       tbl/fctn      1       1
20100101       223.17
20100151       45.8
20100101       30.7           *cu-ni b/hr-f-ft
20100101       8.52778e-3   *cu-ni b/sec-f-ft
20100151       51.3488
*******************************************************
************************************
*tables
**************************************************************************
20200100  temp
20200101  0.  130.
20200102  1.0  169.
20200103  2.0 195.8
20200104  4.0 220.7
20200105  6.0 229.1
20200106  10. 241.2
20200107  15. 253.5
20200108  20. 256.7
20200109  37. 256.5
20200110  69. 262.7
20200111  1.e6  262.7
*
20200200  htc-t
20200201  0.   2.777e-1
20200202  1.e6 2.777e-1
*20200201  0.   2.777
*20200202  1.e6 2.777
*20200201  0.   2.777e-6
*20200202  1.e6 2.777e-6
*500 b/hr-ft2 htc
20200201  0.   1.3885e-1
20200202  1.e6 1.3885e-1
*250 b/hr-ft2 htc
*20200201  0.   0.6944e-1
*20200202  1.e6 0.6944e-1
**********************************************
*                                            *
* end of input deck - problem end            *
*                                            *
**********************************************
```

ATTACHMENT D

APPENDIX D TO CALCULATION PSA-B-98-13
MODEL INPUT DESCRIPTION AND SUPPORTING CALCULATIONS

[Response to NRC RAI 2.b)]

Appendix D – Model Input Description and Supporting Calculations

D1

Byron/Braidwood RCFC SX RELAP5 Model Description

Volume=100000000

Type=TDV

Description: This volume represents the SX pump/piping system up to the 16 inch piping feeding the 10 inch inlet side header which feeds the fan cooler. A TDV is used to provide an appropriate pressure boundary condition allowing back flow to occur during void formation in the RCFC coils. Experience during the development of this model has demonstrated that this pressure boundary condition is essential to prevent numerical instabilities from occurring. Use of a TDJ in conjunction with this boundary leads to an apparently too-stiff matrix that is unstable even at extremely low time steps. Therefore a pressure boundary was utilized in conjunction with a normal junction to initiate flow coastdown and simulate pump start later in the event.

Key Features: The pressure is set at 21.9 psia at the initiation of the event. This was determined by trial and error to yield the desired steady state flow of 1325 gpm through the system. Pump trip and coastdown is simulated by linearly reducing this pressure to 6.5 psia at 6 seconds, starting the decrease at 1 second. [6.5 psi is based on 14.7-(409'-390')*0.4335] Pump restart is simulated by raising this pressure over a 1 second interval, at 43 seconds (time of SX restart per vendor containment analysis timelines). To ensure a rapid void closure, this pressure is raised to the nominal pump discharge pressure corrected for elevation head and allowed to decline to the steady state pressure over a 20 second interval. This value was selected to yield a pressure sufficiently high to cause rapid flow and void collapse, and then decay to demonstrate that single phase flow would be re-established. Note that the nominal outlet pressure of the SX pumps is 180 feet of head, and flow through the RCFC is regulated by throttle valves. This model deliberately ignores the throttle valves for two reasons, 1) voiding is initiated earlier by starting at the lowest pressure possible, and 2) voiding is maximized by simulating the least resistance in the connecting piping. Calculations supporting the pressure are provided in the following Mathcad worksheet.

D2

Definition of SX Pump Startup Forcing Function

This worksheet provides the calculations and logic used to define the TDV pressure history utilized in the RCFC load calculation. The basic approach that is used is to take the rated pump head and correct for elevation losses and pressure drop through the strainers. The resulting pressure is then used as a peak value in the inlet header pressure specification. Since the model is developed to maximize voiding and doesn't include pressure drops associated with throttle valves, the maximum pressure is specified and reduced to the nominal pressure used to balance the model at design conditions. This reduction is performed over an interval of time sufficient to ensure that the dynamic effects are bounded as well as to demonstrate that single phase conditions will prevail following the return to nominal flow condition.

$Z_{sxpump} = 333$ feet elevations from attached sheet

$Z_{lake} = 390$ feet

$Z_{rcfchdr} = 409$ feet

$Pphead = 180$ rated pump head in feet, ref. Byron SX system description, ch 20

$Strloss = 3.5$ psi strainer loss at normal flow, ref. Byron SX system description, ch 20

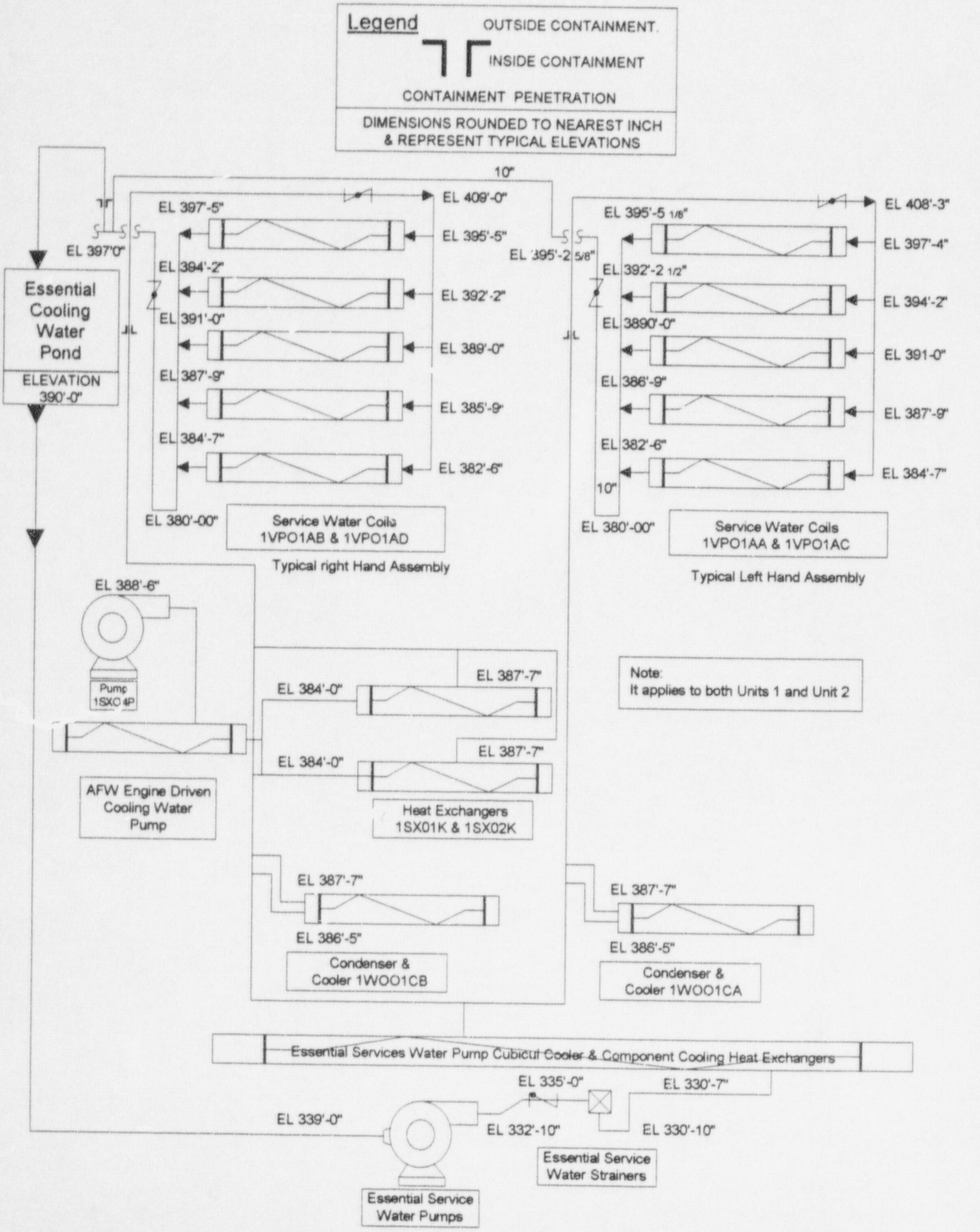
$\rho = 62.4$ density of water at standard conditions

$$HDRP = \frac{180 \cdot \rho}{144} - Strloss + \frac{\left(Z_{lake} - Z_{sxpump}\right) \cdot \rho}{144} - \frac{\left(Z_{rcfchdr} - Z_{sxpump}\right) \cdot \rho}{144} + 14.7$$

$HDRP = 80.967$ psia

D 2A

BRAIDWOOD PIPING AND EQUIPMENT ELEVATIONS



Note:
It applies to both Units 1 and Unit 2

D3

Junction: 101000000

Type: Single Junction

Description: This junction provides the connection to the inlet supply header piping. Loss coefficients were calculated for this junction to represent the minimum number of fittings in the shortest run of piping. Since this piping run is shared by three other coils, a multiplier to account for the pressure loss is applied. Details on attached Mathcad worksheet.

D4

Calculation of Reverse flow coefficients to be applied to By/Br RCFC model

These loss coefficients are based on S&L Flo Series Model data contained in Calc 90-0060 rev 0, and represent the minimum flow losses that would be incurred to get from the 10 inch riser back to the 20 inch header, where flow could potentially split.

The minimum piping length is 138.85 feet of 16 inch piping (node 670), and contains 3 LR elbows and 3 45 elbows. Based on Crane, p A30 the pipe length will equate to a K of approximately 1.4

$f_t := .013$

$K_{lr90} := 20 \cdot f_t$ $K_{lr45} := 16 \cdot f_t$

$K_{lr90} = 0.26$ $K_{lr45} = 0.208$

$K_{ex} := 1.0$ sudden expansion $K_{sc} := .5$ sudden contraction

$K_{rtot} := 3 \cdot K_{lr90} + 3 \cdot K_{lr45} + K_{ex}$ $K_{ftot} := 3 \cdot K_{lr90} + 3 \cdot K_{lr45} + K_{sc}$

$K_{rtot} = 2.404$ $K_{ftot} = 1.904$

need to multiply the loss since the model uses velocity calculated for one coil set, while the header services 4 coil sets

$K_{req} := K_{rtot} \cdot 16$ $K_{feq} := K_{ftot} \cdot 16$

$K_{req} = 38.464$ $K_{feq} = 30.464$

exhaust piping losses, based on node 561 149.5 feet of 16 inch piping with 6 LR elbows

$K_{etot} := 6 \cdot K_{lr90} + K_{ex}$ $K_{retot} := 6 \cdot K_{lr90} + K_{sc}$

$K_{etot} = 2.56$ $K_{retot} = 2.06$

$K_{exeq} := K_{etot} \cdot 16$ $K_{rexeq} := K_{retot} \cdot 16$

$K_{exeq} = 40.96$ $K_{rexeq} = 32.96$

D5

Volume=104000000

Type=Pipe

Description: This volume represents the 16 and10 inch diameter supply headers to the RCFC. 10 nodes are used to represent the 16 inch piping, with a total length of 138 feet. It employs 12 nodes to subdivide the 10 inch piping into approximately 3 foot lengths.

Reference: Braidwood Iso Spool piece dwg no. SX-66, lines SX 66-1 and SX-66-2. The 16 inch piping is assumed to be horizontal and is based on the Byron SX Flo-Series model.

Key Features: Note that no losses are modeled in for valve 1SX022D. This is intentional to minimize the overall friction losses. This model is being set up to maximize the extent of voiding and minimize the time it takes to initiate void generation. Adding additional friction here would effectively raise the TDV pressure by the pressure drop created but would delay initiation of void and throttle the pump restart. Therefore it is conservative to neglect this loss. Choking is enabled at the junction between the 10 and 16 inch piping.

D 6

Junction: 110000000, 111000000, 112000000, 113000000, 114000000

Type: Single Junction

Description: This junction provides the connection from the inlet supply header piping to the individual coil headers. It is the same diameter as the coil header. The losses associated with the transition from the vertical header are those of sudden contraction (forward) and sudden expansion (reverse) of 0.5 and 1.0 respectively.

Key Features: There are no special features selected. Note however that the ability of the code to allow connection to multiple faces of piping volumes is utilized. Additional losses could be added by selecting crossflow junction modeling, but this has been intentionally not done to minimize the overall losses for the same reasons stated previously.

D 7

Volume=105000000, 106000000, 107000000, 108000000, 109000000

Type=Pipe

Description: This volume represents the horizontal section of 4 and 3 inch diameter supply headers to the individual RCFC coils. It employs 19 nodes to subdivide the piping into three 6 node segments to allow calculation of piping segment forces. The last node is a very short node that connects into the RCFC coil. No forces are calculated for this segment due to its short length.

Reference: Braidwood Iso Spool piece dwg no. SX-66, lines SX 66-1 and SX-66-2

Key Features: The only losses associated with this piping are due to fittings. The K-values are Crane based.

Junction: 130000000, 131000000, 132000000, 133000000, 134000000

Type: Single Junction

Description: This junction provides the connection from the individual coil headers to the coil plenums. It is the same diameter as the coil header. The losses associated with the transition from the vertical header are those of sudden expansion(forward) and sudden contraction (reverse) of 1.0 and 0.5 respectively.

Key Features: There are no special features selected.

D 9

Volume=120000000, 121000000, 122000000, 123000000, 124000000

Type=Pipe

Description: This volume represents the plenums and tubing for a single RCFC coil unit. Note that heat transfer is modeled for these volumes. Each volume represents 60 tubes, and treats them as two sets of 10 foot U-bend arrangements with an intermediate plenum. The coils are assumed to be completely horizontal and no vertical displacement is modeled for simplicity. The actual vertical displacement in the tubes is less than 1 foot in actuality and is considered negligible with respect to this analysis.

Reference: Carrier Drawings 28SW405613 , 28SW405623 Rev B, 28SW405593 Rev B, and Mathcad calc sheet for RCFCs tubing model (pages attached)

Key Features: Note that the counter current flow card has been entered for these volumes to provide the junction hydraulic diameter based on an individual tube diameter. This is being done to provide the appropriate interphase drag correlation input. Heat structures 11201000 through 112410000 are associated with these volumes to provide heat transfer modeling. HEM choking is allowed at the connections between the coil tubing and the plena.

D10

Junction: 135000000, 136000000, 137000000, 138000000, 139000000

Type: Single Junction

Description: This junction provides the connection from the individual coil headers to the coil plenums. It is the same diameter as the coil header. The losses associated with the transition from the vertical header are those of sudden contraction (forward) and sudden expansion (reverse) of 0.5 and 1.0 respectively.

Key Features: There are no special features selected.

D11

Volume=140000000

Type=Pipe

Description: This volume represents the horizontal section of 4 and 3 inch diameter supply header to the uppermost RCFC coil. It employs 14 nodes to subdivide the piping into two 6 node segments to facilitate piping segment force calculation. The first node is a short run node for which forces are not calculated. The last node is the vertical run to the 10x4" reducer that starts the standpipe collecting all the coil discharge flow. This node is added to the 10inch head piping in the calculation of the vertical segment thrust load.

Reference: Braidwood Iso Spool piece dwg no. SX-63, lines SX 63-14

Key Features: The only losses associated with this piping are due to fittings. The K-values are Crane based.

Volume=141000000, 142000000, 143000000, 144000000

Type=Pipe

Description: This volume represents the horizontal section of 3 and 4 inch diameter return headers from the individual RCFC coils. It employs 13 nodes to subdivide the piping into two lengths for segment load calculation. The first node is a short run for which no forces are calculated

Reference: Braidwood Iso Spool piece dwg no. SX-63, lines SX 63-12 and SX 63-13

Key Features: The only losses are due to fittings. The K values are based on Crane methods.

D13

Junction: 145000000, 146000000, 147000000, 148000000, 149000000

Type: Single Junction

Description: This junction provides the connection to the exhaust header piping from the individual coil headers. It is the same diameter as the coil header. The losses associated with the transition from the vertical header are those of sudden contraction (forward) and sudden expansion (reverse) of 0.5 and 1.0 respectively.

Key Features: There are no special features selected. Note however that the ability of the code to allow connection to multiple faces of piping volumes is utilized. Additional losses could be added by selecting crossflow junction modeling, but this has been intentionally not done to minimize the overall losses for the same reasons stated previously.

D14

Volume=15000000

Type=Pipe

Description: This volume represents the 10 inch diameter exhaust header from the RCFC. It employs 27 nodes to subdivide the piping into approximately 1 foot lengths. It models a U-shaped geometry running down from the coil exits and then rising to the elevation at which the 10 inch pipe tees into a 16 inch header. The 16 inch header is represented by another 10 nodes, and is based on the shortest run with the fewest fittings. The piping section between the elbows is represented by 6 nodes to allow a horizontal load to be calculated. The horizontal distance is assumed to be 3 feet, based on discussion with the structural engineers.

Reference: Braidwood Iso Spool piece dwg no. SX-63

Key Features: No fitting losses are modeled in this line, other than in the 16 inch header, to minimize the potential pressure drop and allow the maximum void generation. These losses are compensated for the 16 inch header carrying three other coil flows. The losses are calculated in the worksheet attached.

D 15

Volume=30500000

Type=TDV

Description: This volume represents the SX pump/piping system exhaust boundary condition.

Key Features: The pressure is set at 14.2 psia throughout the event. This pressure represents the static pressure available from the nominal cooling lake level for this elevation. Note: the RELAP model was built from iso-dwgs and exhibited a height difference from inlet to outlet of –17.85 ft. The outlet pressure is then 14.7-(409-17.85-390)*.4335 or 14.2 psia

D 16

Junction: 301000000

Type: Single Junction

Description: This junction provides the connection to the exhaust header piping connecting to the lake. Loss coefficients were calculated for this junction to represent the minimum number of fittings in the shortest run of piping. Since this piping run is shared by three other coils, a multiplier to account for the pressure loss is applied. No reverse loss was applied to maximize the "fallback loads" that were observed to occur. Details on attached Mathcad worksheet.

Calculation of Reverse flow coefficients to be applied to By/Br RCFC model

These loss coefficients are based on S&L Flo Series Model data contained in Calc 90-0060 rev 0, and represent the minimum flow losses that would be incurred to get from the 10 inch riser back to the 20 inch header, where flow could potentially split.

The minimum piping length is 138.85 feet of 16 inch piping (node 670), and contains 3 LR elbows and 3 45 elbows. Based on Crane, p A30 the pipe length will equate to a K of approximately 1.4

$f_t := .013$

$K_{lr90} := 20 \cdot f_t$ $K_{lr45} := 16 \cdot f_t$

$K_{lr90} = 0.26$ $K_{lr45} = 0.208$

$K_{ex} := 1.0$ sudden expansion $K_{sc} := .5$ sudden contraction

$K_{rtot} := 3 \cdot K_{lr90} + 3 \cdot K_{lr45} + K_{ex}$ $K_{ftot} := 3 \cdot K_{lr90} + 3 \cdot K_{lr45} + K_{sc}$

$K_{rtot} = 2.404$ $K_{ftot} = 1.904$

need to multiply the loss since the model uses velocity calculated for one coil set, while the header services 4 coil sets

$K_{req} := K_{rtot} \cdot 16$ $K_{feq} := K_{ftot} \cdot 16$

$K_{req} = 38.464$ $K_{feq} = 30.464$

exhaust piping losses, based on node 561 149.5 feet of 16 inch piping with 6 LR elbows

$K_{etot} := 6 \cdot K_{lr90} + K_{ex}$ $K_{retot} := 6 \cdot K_{lr90} + K_{sc}$

$K_{etot} = 2.56$ $K_{retot} = 2.06$

$K_{exeq} := K_{etot} \cdot 16$ $K_{rexeq} := K_{retot} \cdot 16$

$K_{exeq} = 40.96$ $K_{rexeq} = 32.96$

D 18

Heat Structure=112010000, 112110000, 112210000, 112310000, 112410000

Type=Cylindrical geometry heat conductor

Description: These heat conductors are modeled as two sided cylindrical structures to represent the RCFC coils modeled hydraulically in volumes 120010000 through 124010000. The boundary conditions internal to the tubes are standard RELAP heat transfer map based on time dependent calculated hydraulic conditions in the tubes. The outside of the tubes is represented by a specified constant heat transfer coefficient coupled to a time dependent temperature boundary condition. This time dependent temperature is taken from vendor containment analysis results for a DBA LOCA and a 0.942 ft2 steam line break inside containment.

Reference: Carrier Drawings 28SW405613 , 28SW405623 Rev B, 28SW405593 Rev B, and Mathcad calc sheet for RCFCs tubing model (pages attached). Containment analysis data contained in Westinghouse calc CN-CRA-95-119-R0

Key Features: The specified heat transfer coefficient was arbitrarily set at 500 Btu/hr-ft2-F to provide a rapid heat transfer rate to the coil. This value is large relative to the maximum Uchida correlation value of 280 Btu/hr-ft2-F typically used in steam condensing situations with no air present. Since there is air present and this condition would be anticipated to exist throughout the initial time period of interest to this calculation, this is a clearly conservative selection, providing an overestimate of the heat input. The tubing fins are not explicitly modeled, however, a review of the calculated surface temperature of the tube shows that the tube surface is essentially equal to the outside boundary temperature, which is precisely what the fins are intended to accomplish. However, if reductions in heat transfer coefficients are contemplated, the effect of the fins must be considered in more detail, since they would tend to counter the effects of reducing surface heat transfer coefficients.

RCFC Coil Model Calculations

Reference:WTRCOIL 2.2 Data Sheet BR2P01AA.ATW dated March 24 1994 attached

$\mathrm{Rows} := 12$ number of rows in full coil

$\mathrm{Length} := 120$ length of tube row inches

$t := 0.049$ tube thickness inches

$\mathrm{ntubes} := 200$ number of tubes per row

$\mathrm{ckts} := 600$ number of tubeside circuits

$\mathrm{flow} := 2650$ total coil flow gpm

$\mathrm{OD} := 0.625$ tube diameter inches

$\mathrm{vel} := 6.5$ water velocity. fps

note that we are modeling one half of an RCFC. and are dividing it into 5 coils, versus the data above. which is for both coil stacks combined

$$\mathrm{ctubes} := \mathrm{ntubes} \cdot \frac{\mathrm{Rows}}{2 \cdot 5}$$

$\mathrm{ctubes} = 240$ =number of tubes per coil

these are divided into 4 circuits of 60 tubes with a length of 10 feet each. since:

$$\mathrm{tubckts} := \frac{\mathrm{ntubes} \cdot \mathrm{Rows}}{\mathrm{ckts}} \qquad \mathrm{tubckts} = 4$$

$$\frac{\mathrm{ctubes}}{\mathrm{tubckts}} = 60$$

Additional Coil Geometry Calculations

flow area for 60 tubes

$A_{tube} \cdot 60 = 9.08866 \cdot 10^{-2}$ ft2

hydraulic diameter for tube

$hyd_{tube} := \frac{OD - 2 \cdot t}{12}$

$hyd_{tube} = 4.39167 \cdot 10^{-2}$ ft

heat transfer area per pass

outside area

$A_{out} := \pi \cdot \frac{OD}{12} \cdot \frac{Length}{12} \cdot 60$

$A_{out} = 98.175$ ft2 for 1pass of 60 tubes

$A_{in} := \pi \cdot \frac{OD - 2 \cdot t}{12} \cdot \frac{Length}{12} \cdot 60$

$A_{in} = 82.781$ ft2 for 1pass of 60 tubes

the RELAP model splits one pass into 5 two foot long segments as an additional check, we can compare the velocity stated in the spec sheet and on the coil drawing to that calculated assuming 60 tubes per pass in a coil

$$A_{tube} := \frac{(OD - 2 \cdot t)^2}{144 \cdot 4} \cdot \pi$$

$A_{tube} = 1.514777 \cdot 10^{-3}$ tube area. ft2

$coilflow := \frac{flow}{10}$ coilflow gpm

$coilvolm := \frac{coilflow}{60 \cdot 7.4805}$ volumetric coil flow, cuft/sec

$coilvolm = 0.59042$

$vcalc := \frac{coilvolm}{A_{tube} \cdot 60}$

$vcalc = 6.496$ calculated tube water velocity fps

this calculated velocity compares very favorably with the stated tube velocity of 6.5 fps. therefore it can be concluded that the appropriate flow area and coil geometry is being applied

Δ - 22

WTRCOIL 2.2
Performance of HVAC Water Coils
S&L Program No. 03.7.274-2.2

Calc: WTRCOIL 2.2
Rev: 0
Project No.: 00072-135
Page 68

Station	Braidwood	Date	March 24, 1994
Equip. Name	RCFC SW Cooling Coils	Calculation Number	
Equip. Number	2VP01AA	Data File	BR2P01AA.ATW

Coil Conditions

Barometric Pressure, psia	14.696	Fouling Factor, hr-ft²-°F/Btu	0.00150
Water Flow, gpm	2650.0	Water Velocity, ft/sec	6.5
Coil Face Area, ft²	232.2	Face Velocity, ft/min	462
Entering Airflow, acfm	107354	Leaving Airflow, acfm	104069
Entering Mass Flow, lb mix / hr	438436	Leaving Mass Flow, lb mix / hr	438436
Entering Air Density, lb mix / cu. ft.	0.0681	Leaving Air Density, lb mix / cu. ft	0.0702
Entering Mass Flow, lb dry air / hr	435002	Leaving Mass Flow, lb dry air / hr	435002
Entering Air Density, lb dry air / cu. ft.	0.0675	Leaving Air Density, lb dry air / cu. ft	0.0697
Entering Air Dry Bulb Temp., °F	120.0	Leaving Air Dry Bulb Temp., °F	102.3
Entering Air Wet Bulb Temp., °F	74.5	Leaving Air Wet Bulb Temp., °F	69.5
Entering Air Dew Point Temp., °F	51.0	Leaving Air Dew Point Temp., °F	51.0
Entering Humidity Ratio, lb vap/lb dry air	0.0079	Leaving Humidity Ratio, lb vap/lb dry air	0.0079
Entering Air Relative Humidity, %	11	Leaving Air Relative Humidity, %	18
Entering Enthalpy, Btu/lb dry air	37.6	Leaving Enthalpy, Btu/lb dry air	33.3
Entering Water Temp., °F	100.0	Leaving Water Temp., °F	101.4

Coil Performance with 0 plugged tube circuits

Total Heat Transfer, Btu/hr	1879922
Sensible Heat Transfer, Btu/hr	1879922
Latent Heat Transfer, Btu/hr	0
Condensate Flow Rate, lb/hr	0.0

Coil Physical Data

Fin/Tube Type	Circular/Staggered	Fin Pitch, fins/inch	8.0
Fin Material	Copper	Fin Thickness, inch	0.010
Tube Material	90/10 Cupro-Nickel	Tube Length, inch	120
Tube Outside Diameter, inch	0.625	Tube Wall Thickness, inch	0.049
Number of Tube Rows	12	Number of Tubes per Row	200
Vertical Tube Spacing, inch	1.390	Horizontal Tube Spacing, inch	1.203
Coil Serpentine (passes/row)	1/3	Number of Tubeside Circuits	600

Characterization of Heat Transfer Effects of Fins on RCFC Coil Tubing

The purpose of this calculation is to demonstrate the effect of the fins on the RCFC coil tubing and develop appropriate multipliers on assumed heat transfer coefficients to ensure that the additional hea transfer due to the fins is bounded in the RELAP5 calculations. Fin effectiveness is a strong function o the outside heat transfer coefficient, with low outside heat transfer coefficients getting the greatest benefit from the fins. The overall heat transfer coefficient will be calculated for finned and unfinned tub and the results compared for a range of heat transfer coefficients. This provides a direct method of calculating appropriate multipliers for use in the RELAP5 model.

tube geometry, on an individual coil basis. Reference data sheets and input listing for wtrcoil code

$OD = \frac{.625}{12}$ outer dia, ft

$ID = \frac{.625 - 2 \cdot .049}{12}$ inner dia, ft

$l = 12 \cdot 4$ length of tube

$N = 60$ number of tubes per coil

$t = \frac{.049}{12}$ tube thickness, ft

$kw = 30.7$ tube thermal conductivity, byu/hr-ft-F

$AO = \pi \cdot OD \cdot N \cdot l$

$AO = 471.239$ Tube outside area

$AI = \pi \cdot ID \cdot N \cdot l$

$AI = 397.349$ Tube inside area

$Aw = \frac{AO + AI}{2}$ average wall area

$Rt = .0015$ design internal fouling factor fin characterization

$tfin = .01$ fin thickness, inch

$nfin = 8 \cdot 12$ fins per foot

$pitch = \frac{1.203}{12}$ based on horizontal tube spacing

$odfin = pitch$ maximize fin diameter

$$A_{1fin} = odfin^2 - OD^2 \cdot \frac{p}{4}$$

$A_{1fin} = 5.763 \cdot 10^{-3}$ area of one fin

$$A_{fintc} = A_{1fin} \cdot nfin \cdot l \cdot N$$

$A_{fintc} = 1.593 \cdot 10^{3}$ area of all fins

$$AOT = AO + A_{fintc}$$

$AOT = 2.065 \cdot 10^{3}$ area of fins plus tube

now the effect of fins can be demonstrated using the overall heat transfer relationship for a heat exchanger

key inputs to this determination are the inside and outside heat transfer coefficients and the fin efficiency.

$hin = 1000$ assume that water side ht is 1000, typical value

$hsn = 1 .. 500$ let hsn be range variable from 1 to 500

$D = pitch$ $L = odfin - OD$ $k_f = 218$

$$f(hsn) = \frac{\tanh\left(\sqrt{4 \cdot L^2 \cdot \frac{hsn}{k_f D}}\right)}{\sqrt{4 \cdot L^2 \cdot \frac{hsn}{k_f D}}}$$

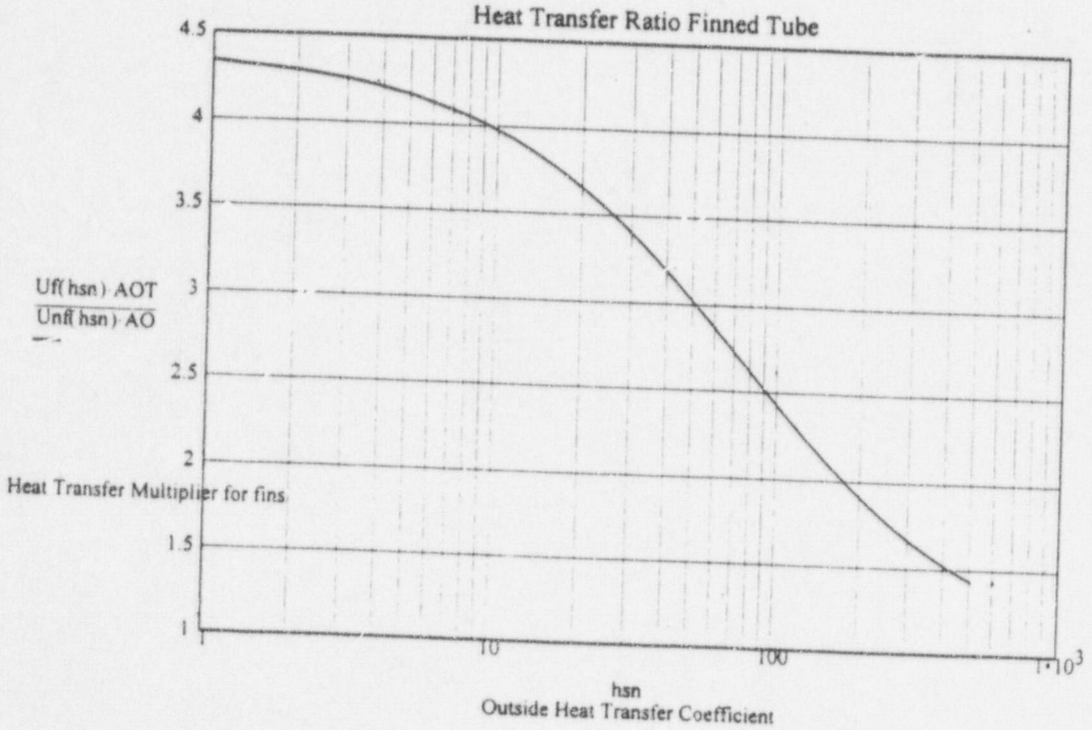
This expression defines the approximate fin efficiency. Reference: Kreith, "Principles of Heat Transfer", eqn 2-59, page 62.

the following expression provides the overall effects of heat transfer on finned and unfinned tubing. Reference: Threlkeld. "Thermal Environmental Engineering", eqn. 12.33, page 248

$$Uf(hsn) = \frac{1}{\frac{1}{hsn} + \frac{t \cdot AOT}{Aw \cdot kw} + \frac{Rt \cdot AOT}{AI} + \frac{1}{hin \cdot AI} \cdot AOT + \frac{1 - f(hsn)}{hsn \cdot \frac{AO}{A_{fintc}} - f(hsn)}}$$

$$Unf(hsn) = \frac{1}{\frac{1}{hsn} + \frac{t}{Aw \cdot kw} \cdot AO + \frac{Rt}{AI} \cdot AO + \frac{1}{hin \cdot AI} \cdot AO}$$

The following plot demonstrates the effect of the fins directly for a given delta T as a function of outside heat transfer coefficient



Application to RELAP5 RCFC Model

The RCFC coils have been modeled as pipe volumes with heat slabs. The outside temperature is specified and a constant heat transfer coefficient is applied. The heat transfer coefficient is based o the Uchida condensing correlation. To determine an appropriate htc. the air steam mass ratio is needed.

$R := 53.34$ gas constant

$P := 14.6$ minimum containment initial press

$Ti := 130$ maximum initial containment temp

$RH := 0.20$ relative humidity

$V_a := 2.758 \cdot 10^6$ containment volume

$Psat := 2.223$ saturation pressure at 130F

$$M_a := 144 \cdot \frac{(P - Psat \cdot RH) \cdot V_a}{R \cdot (Ti + 460)}$$

$M_a = 1.786 \cdot 10^5$ lbm of air

$Vapmass_{depsloca} := 201200$ approximate vapor mass per COCO results for DEPS-LOCA at t=49 sec

$Vapmass_{mslb942} := 85000$ approximate vapor mass per COCO results for .942 split rupture with MSIV failure (taken off plot)

Air/steam mass ratios at 50 seconds, can be determined and Uchida correlation table (Contempt manual can be interpolated to provide HT coefficient

$$R_{loca} := \frac{M_a}{Vapmass_{depsloca}}$$

$$R_{mslb} := \frac{M_a}{Vapmass_{mslb942}}$$

$R_{loca} = 0.888$ which would yield an Uchida coefficient of about 92 btu/hr-ft2-F

$R_{mslb} = 2.102$ which would yield an Uchida coefficient of about 41 btu/hr-ft2-F

Based on the fin effects curves calculated above, the following coefficients should be used in Relap

$$h_{loca} := 92 \cdot \frac{Uf(92) \cdot AOT}{Unf(92) \cdot AO}$$

$$h_{loca} = 229.036$$

$$h_{mslb} := 41 \cdot \frac{Uf(41) \cdot AOT}{Unf(41) \cdot AO}$$

$$h_{mslbmin} := \frac{2 \cdot Uf(2) \cdot AOT}{Unf(2) \cdot AO}$$

$$h_{mslb} = 129.576$$

$$h_{mslbmin} = 8.581$$

Note: This approach provides a value of heat transfer that is bounding for the interval in question. Since the vapor mass increases with time, it will overpredict the heat transfer early in the event. For t MSLB case, where mass addition to the vapor space is relatively slow and continues over time, a val of htc at t=0 is developed and a linear ramp to the full ht is applied over time

ATTACHMENT E

SELECT FIGURES FROM CALCULATION PSA-B-98-13

[Response to NRC RAI 2.c)]

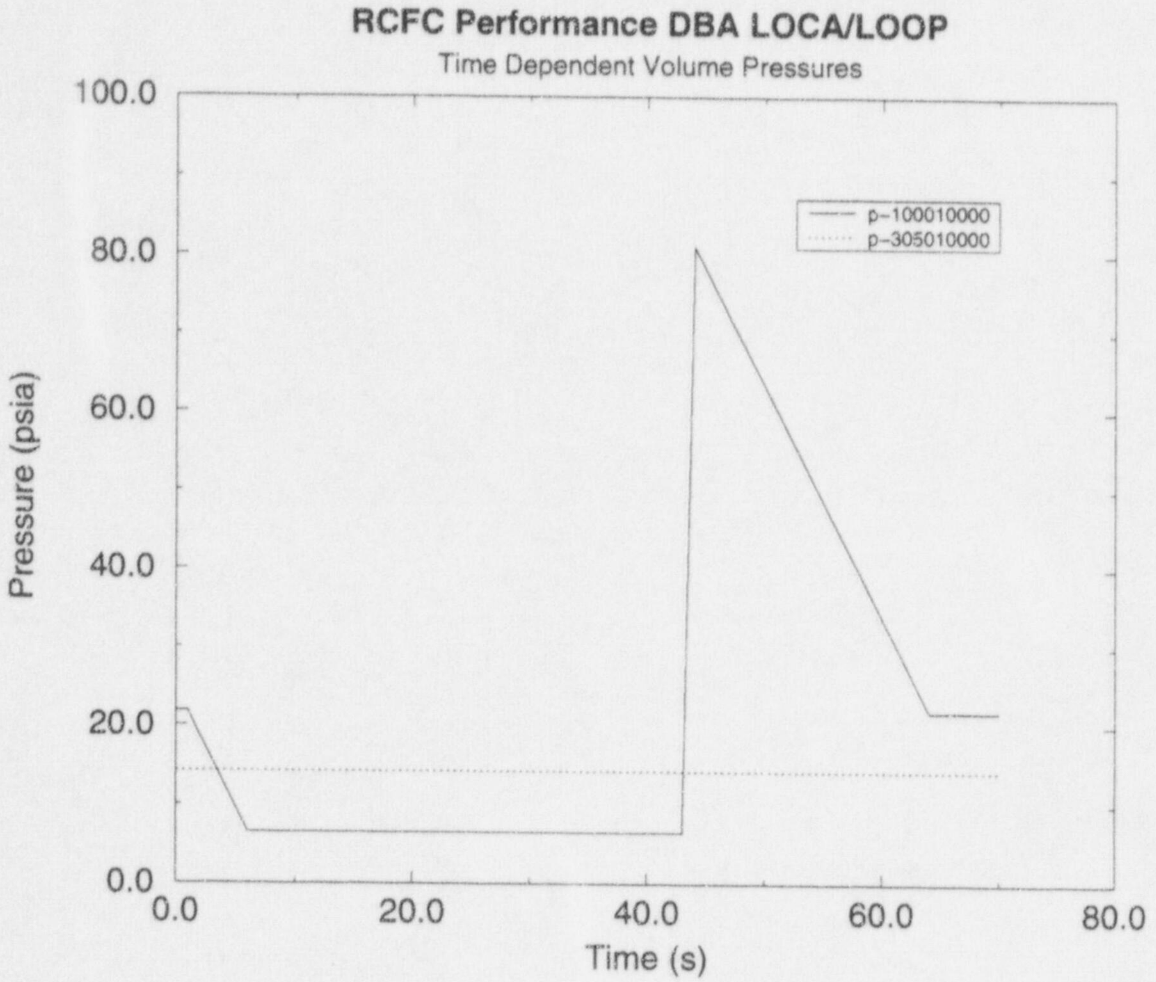


Figure 11 LOCA/LOOP TDV Boundary Condition Pressures

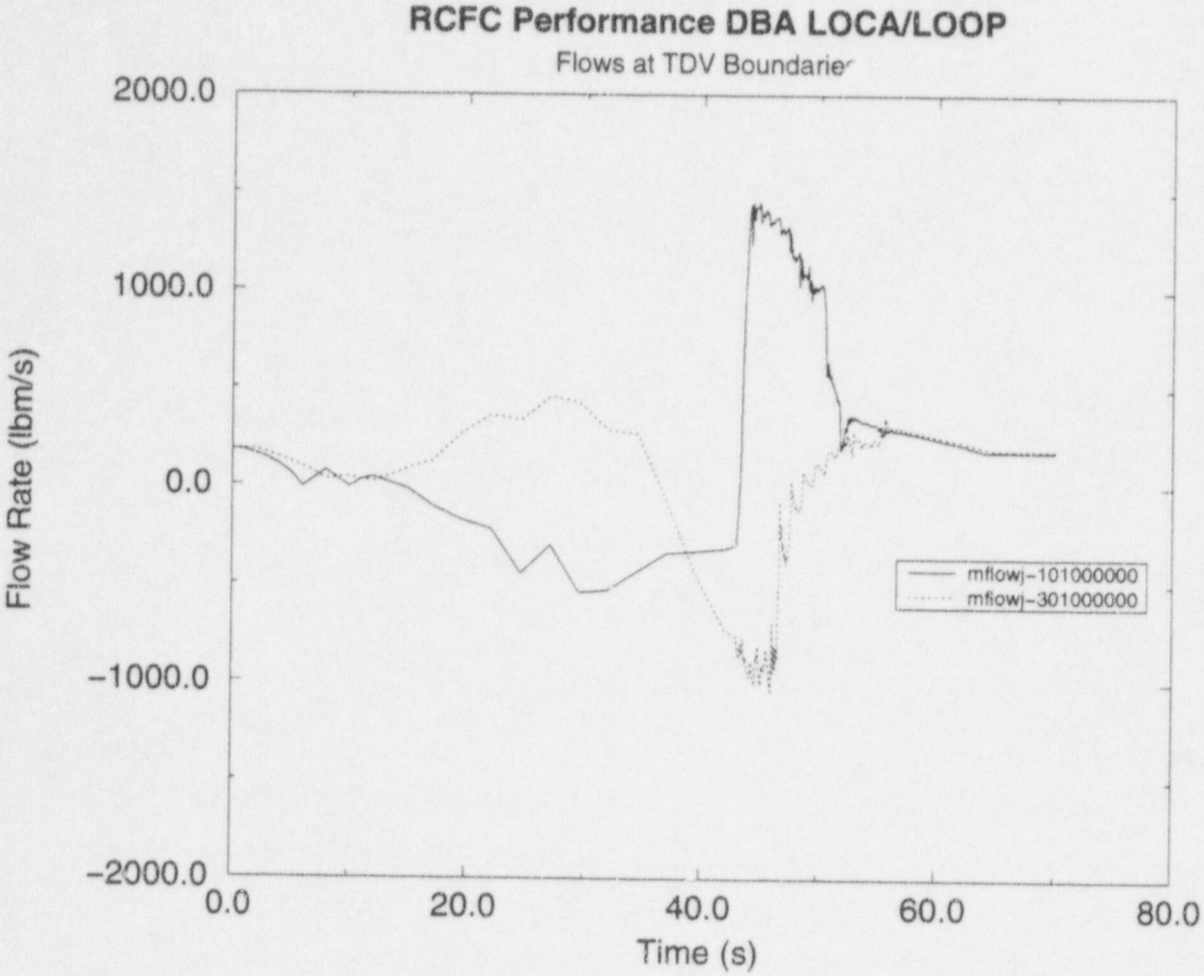


Figure 12 LOCA case flows at Model Boundaries

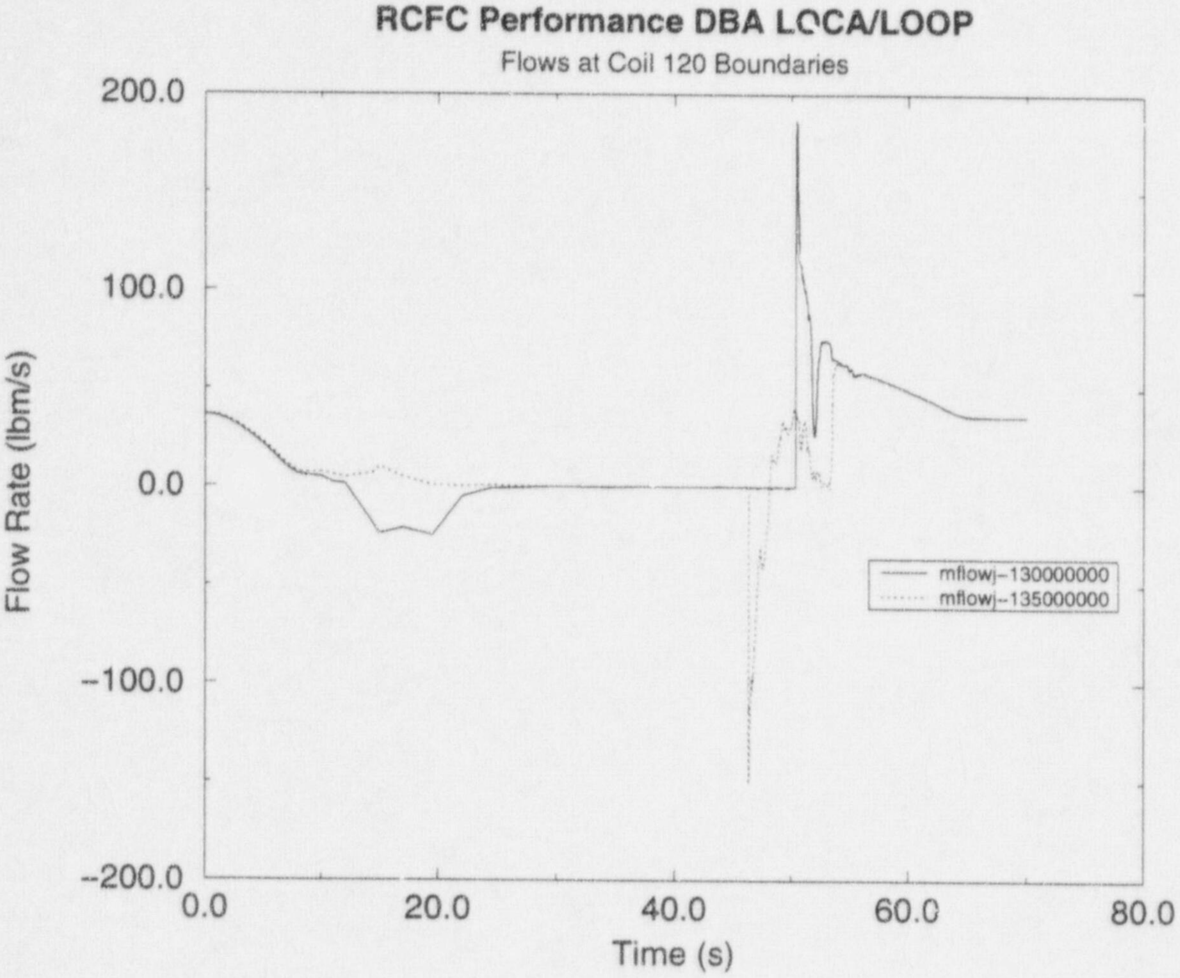


Figure 13 LOCA case flows at Coil 120

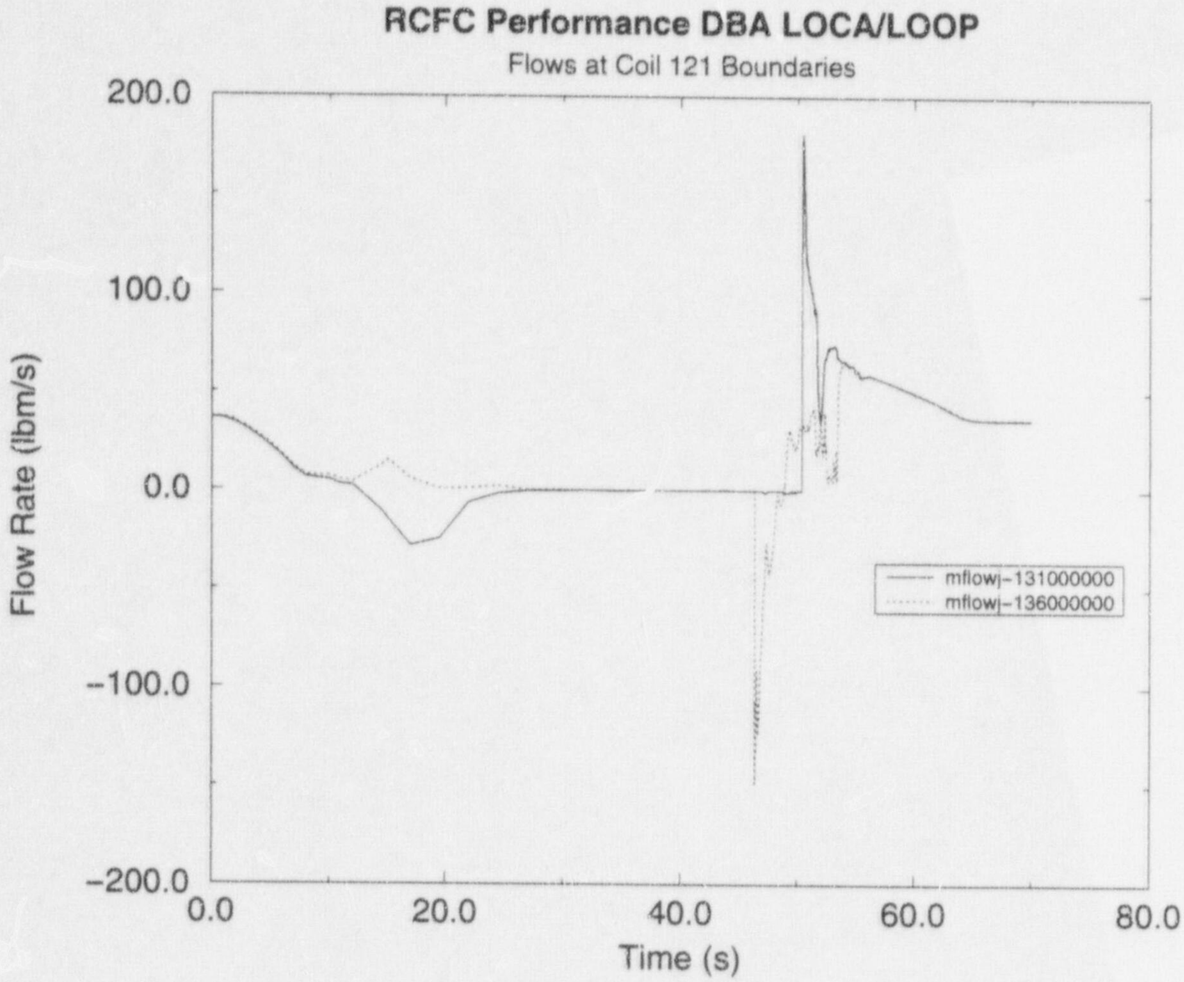


Figure 14 LOCA case flows at Coil 121

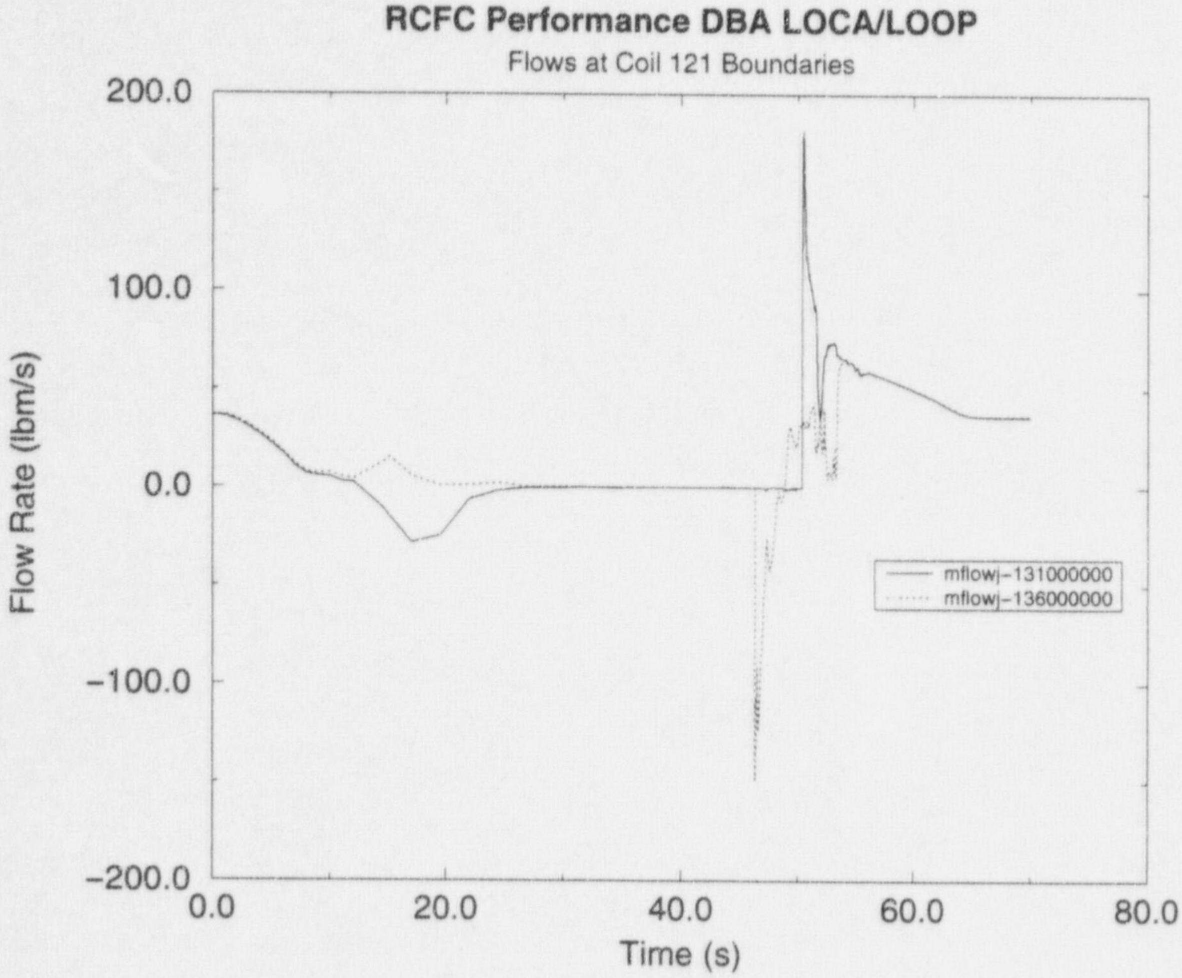


Figure 14 LOCA case flows at Coil 121

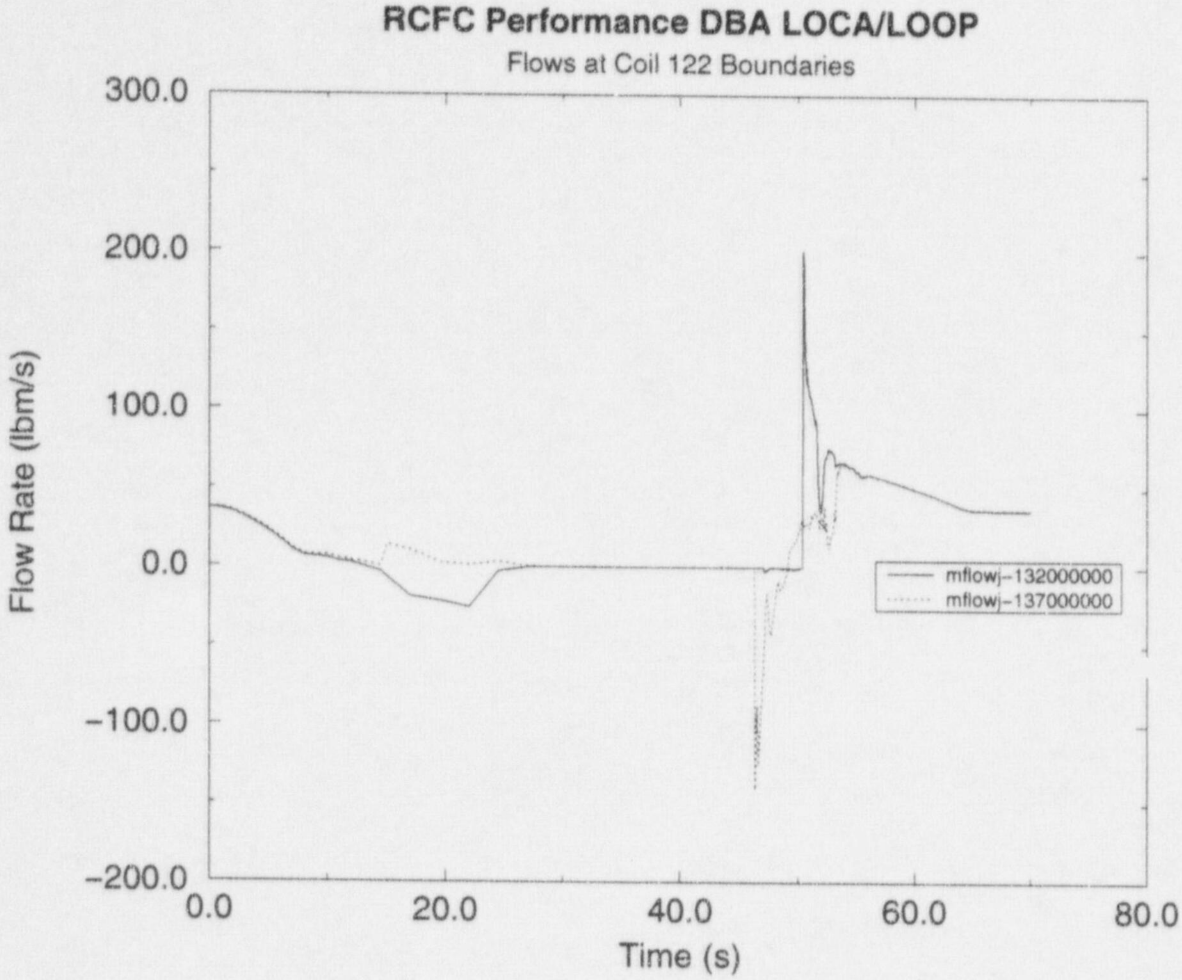


Figure 15 LOCA case flows at Coil 122

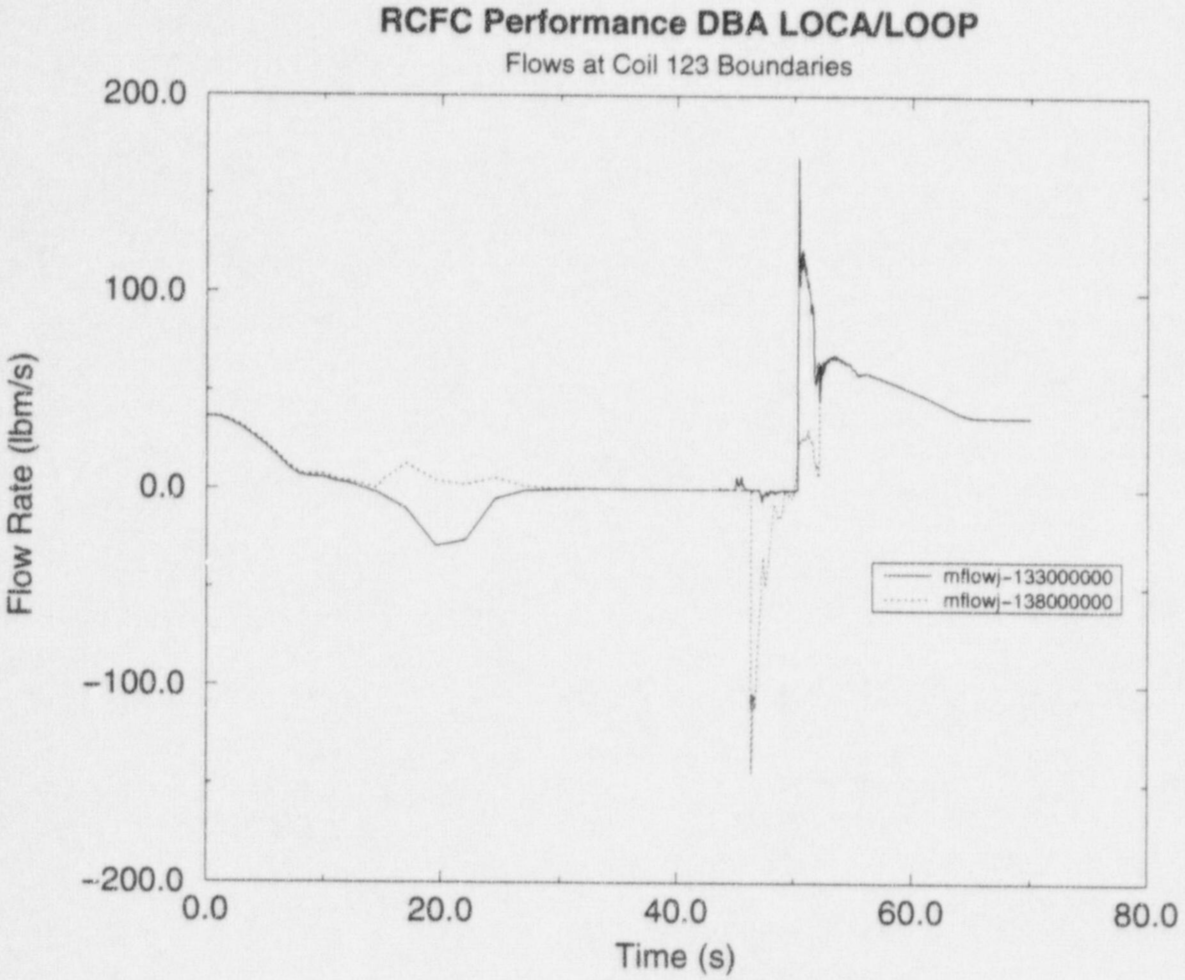
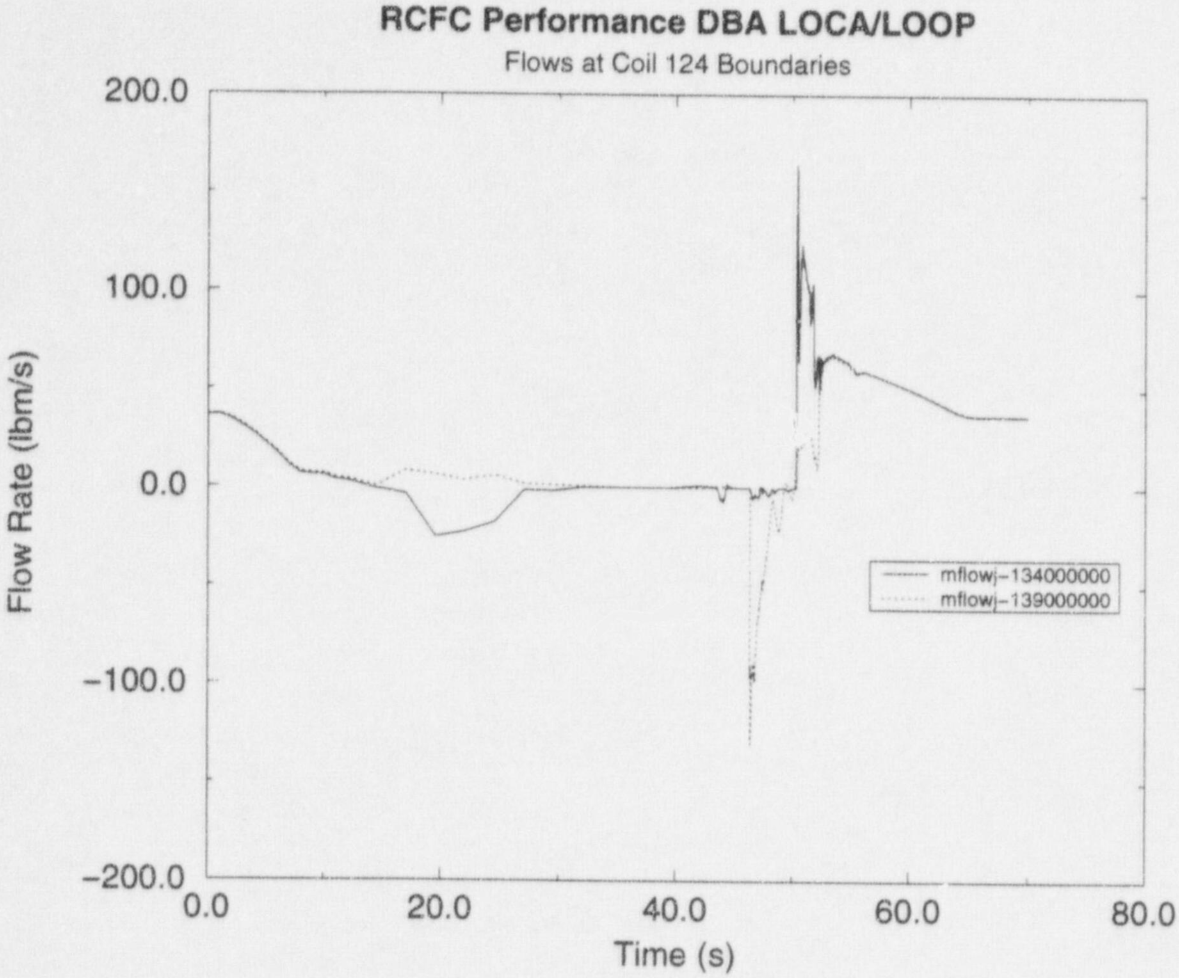


Figure 16 LOCA case flows at Coil 123



RCFC Performance DBA LOCA/LOOP

Flows at Coil 124 Boundaries

Figure 17 LOCA case flows at Coil 124

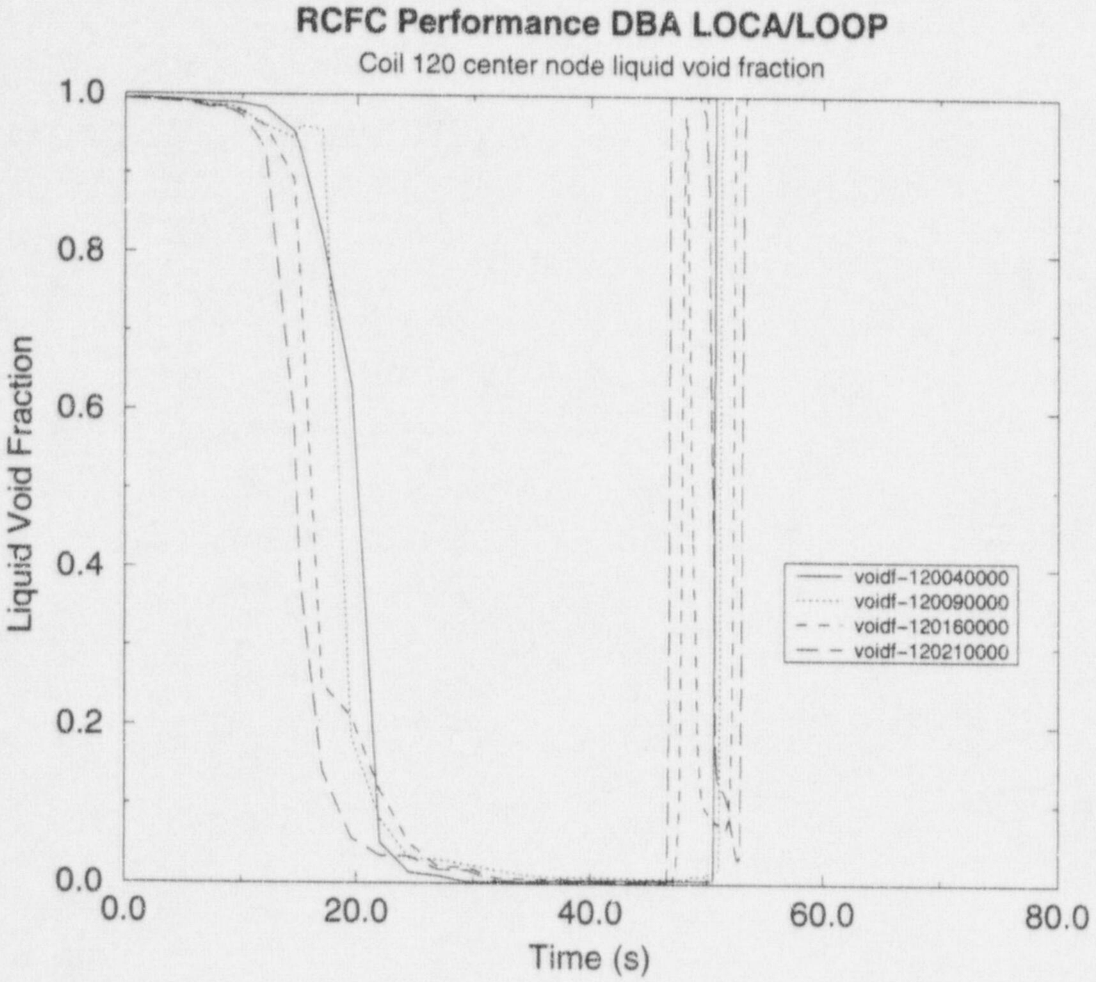


Figure 18 LOCA case void fraction in Coil 1

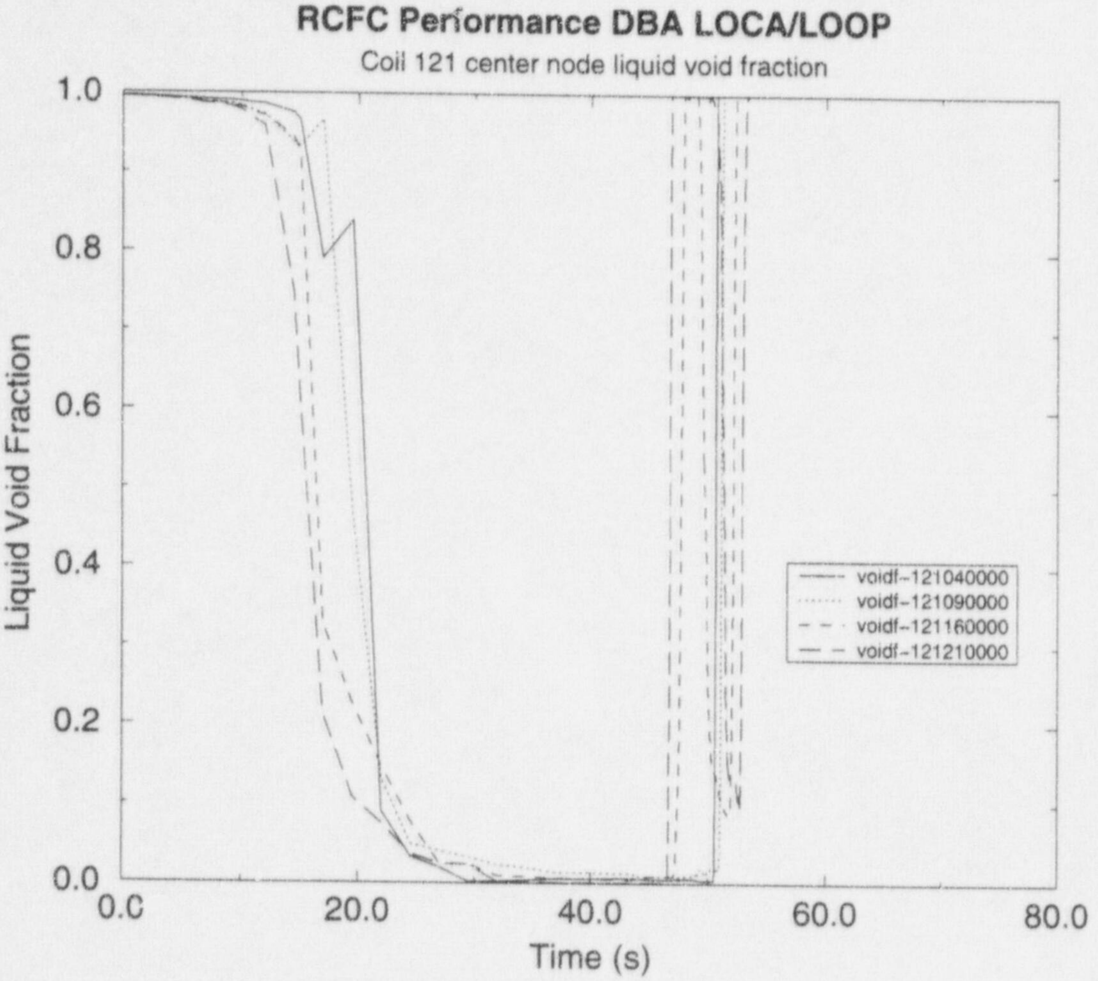


Figure 19 LOCA case void fraction in Coil 2

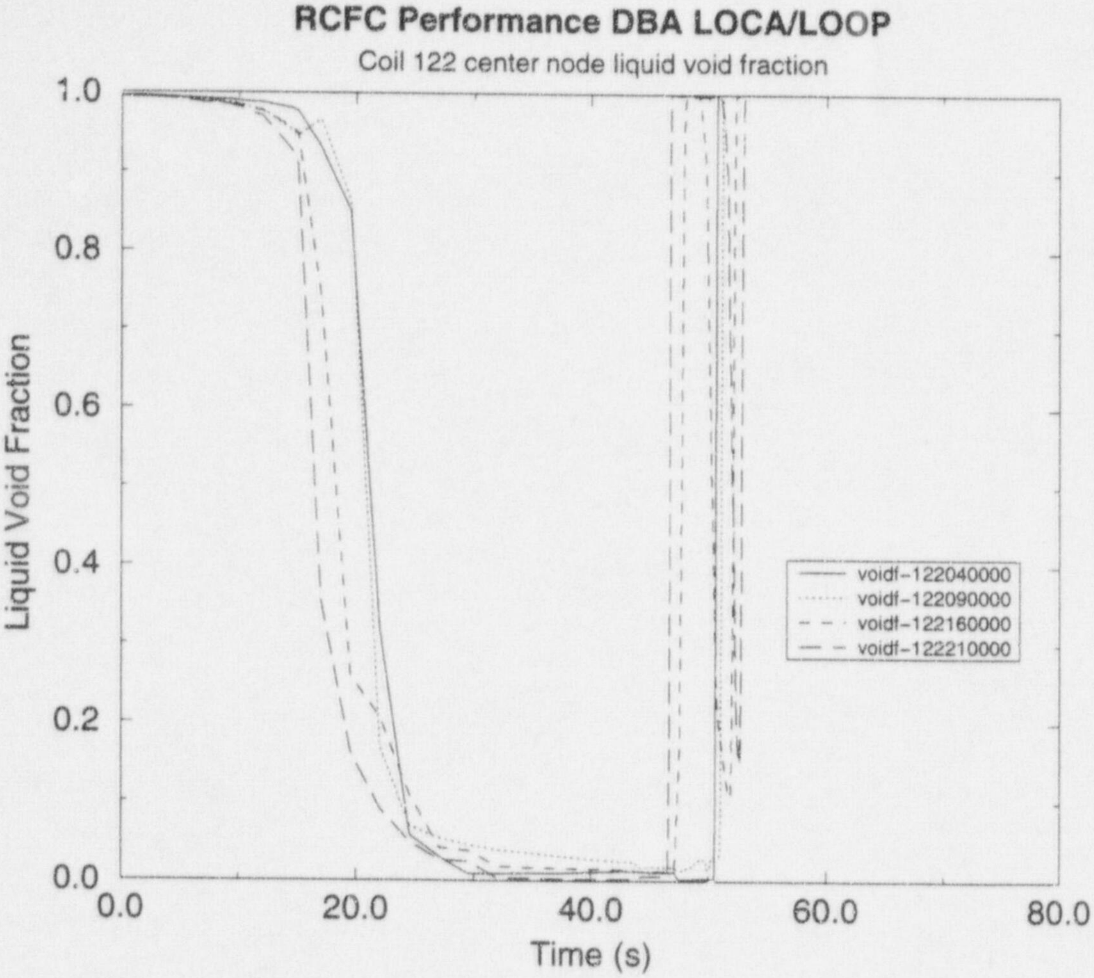


Figure 20 LOCA case void fraction in Coil 3

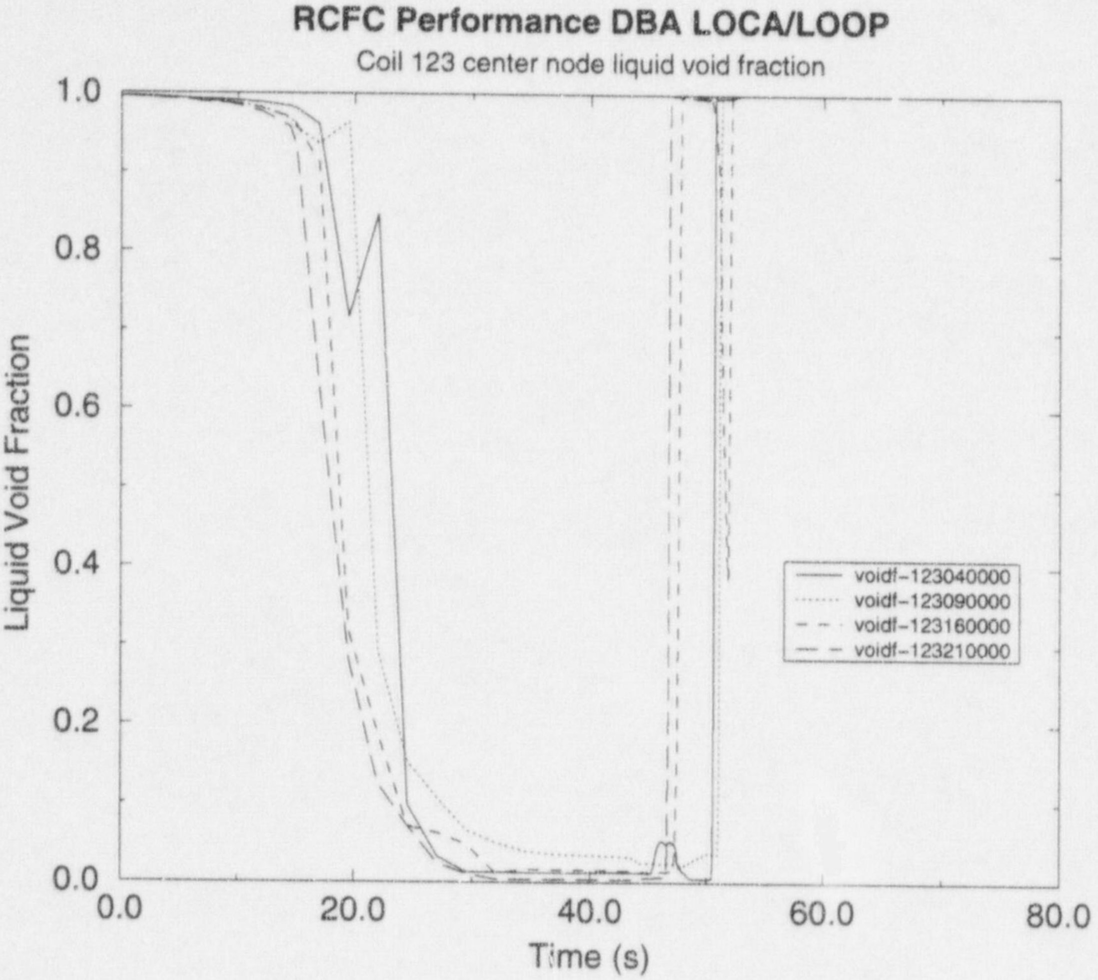


Figure 21 LOCA case void fraction in Coil 4

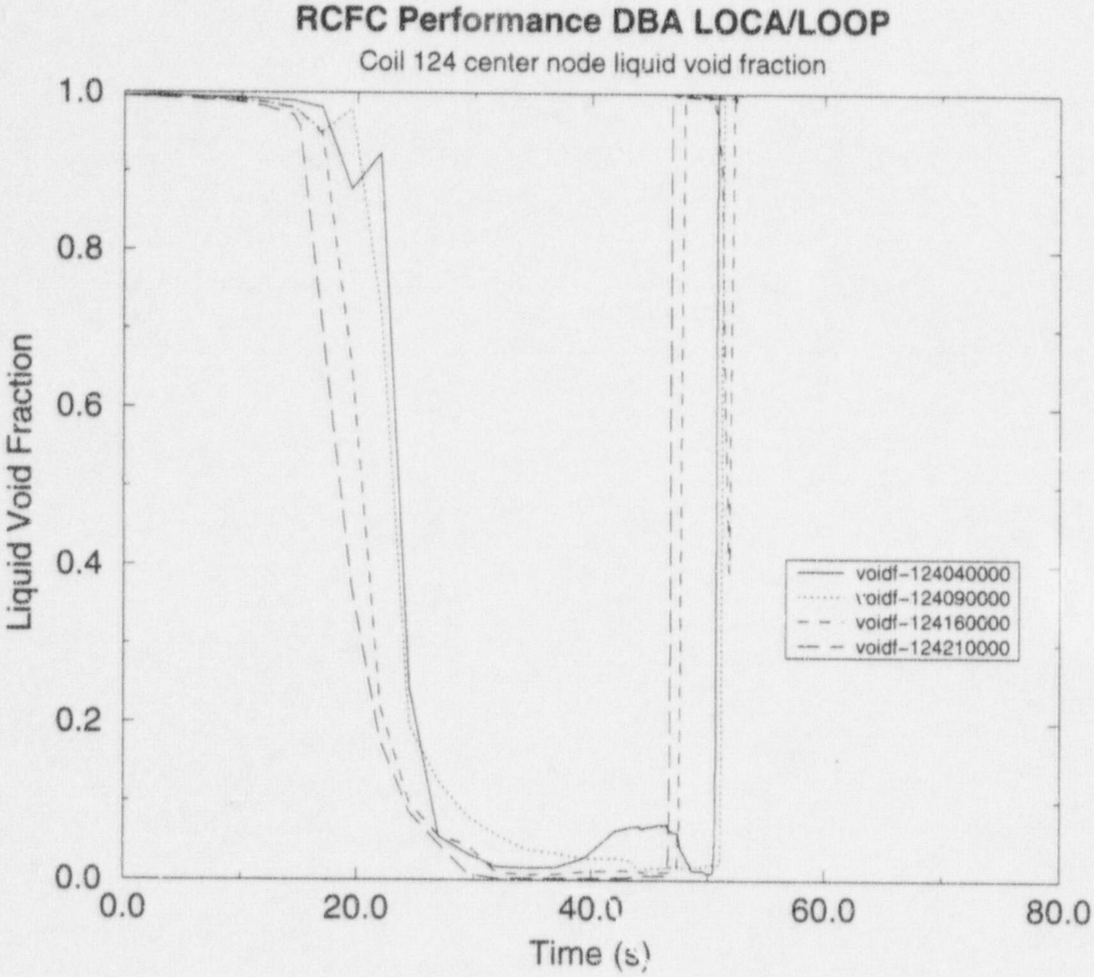


Figure 22 LOCA case void fraction in Coil 5

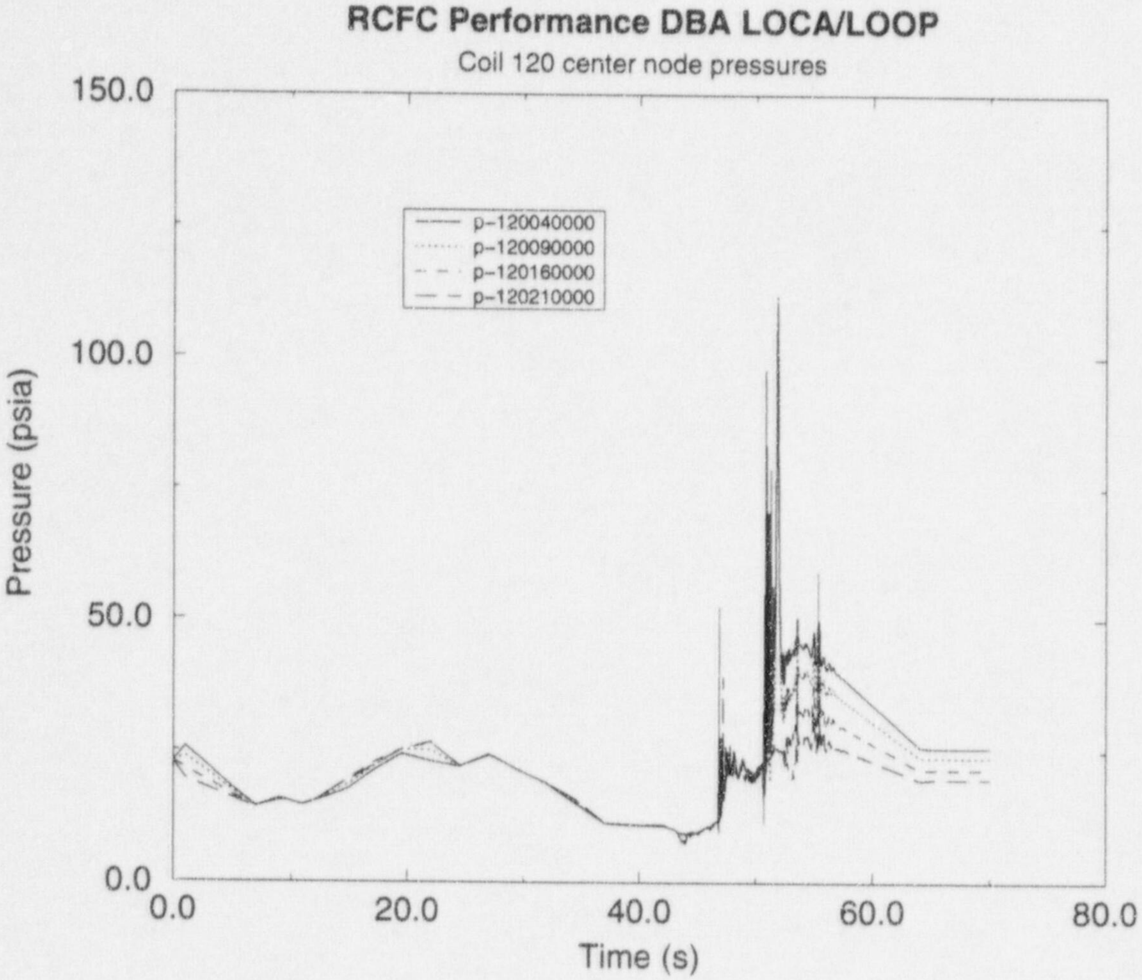


Figure 23 LOCA case pressure in Coil 1

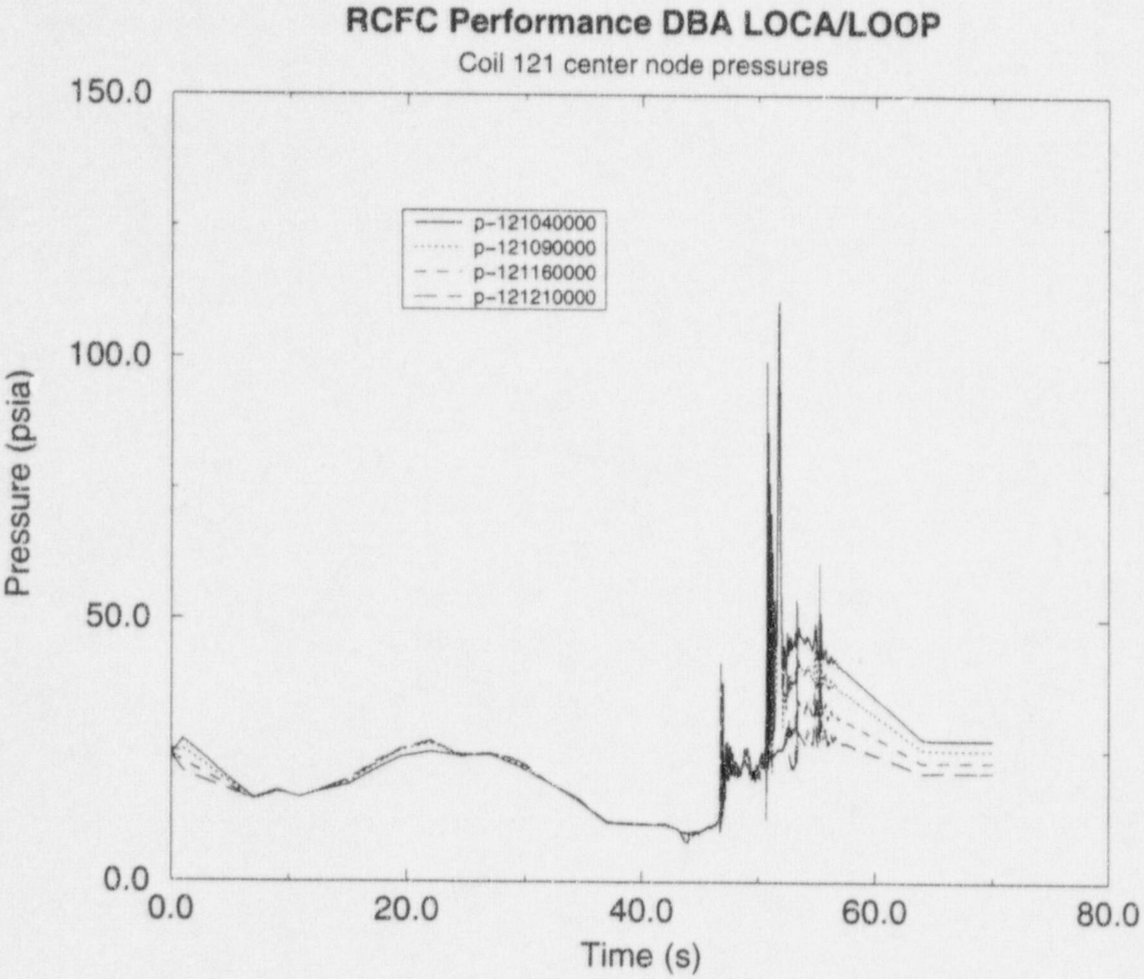


Figure 24 LOCA case pressure in Coil 2

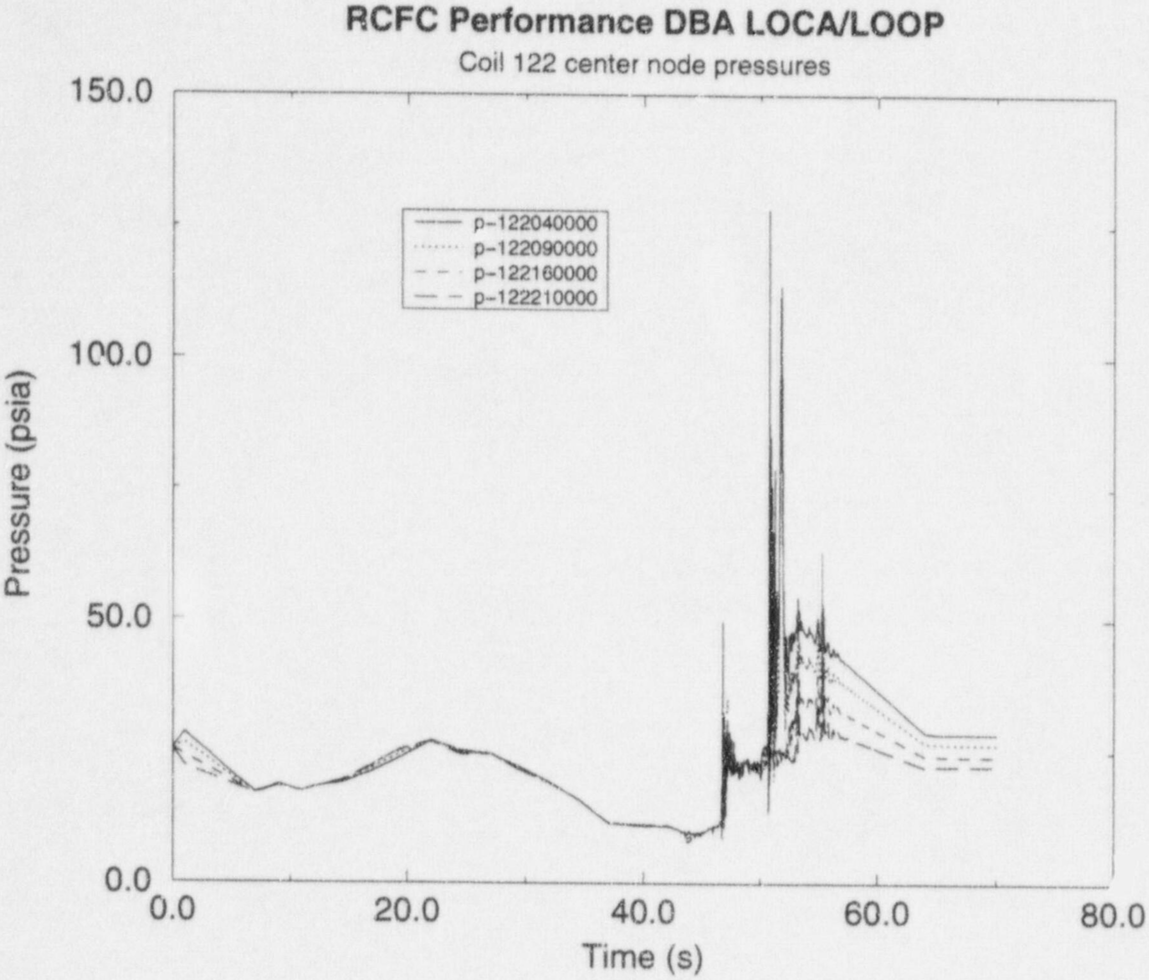


Figure 25 LOCA case pressure in Coil 3

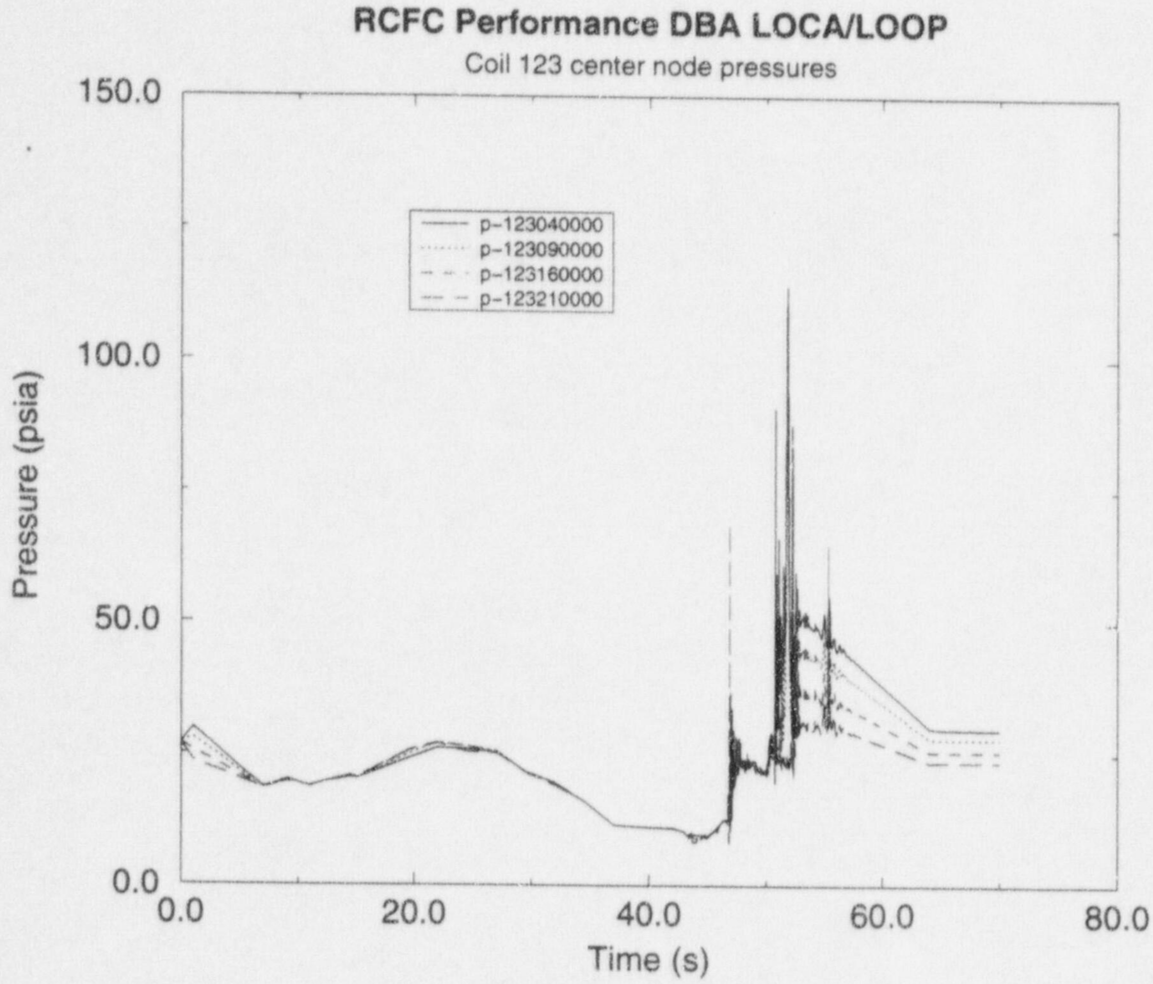


Figure 26 LOCA case pressure in Coil 4

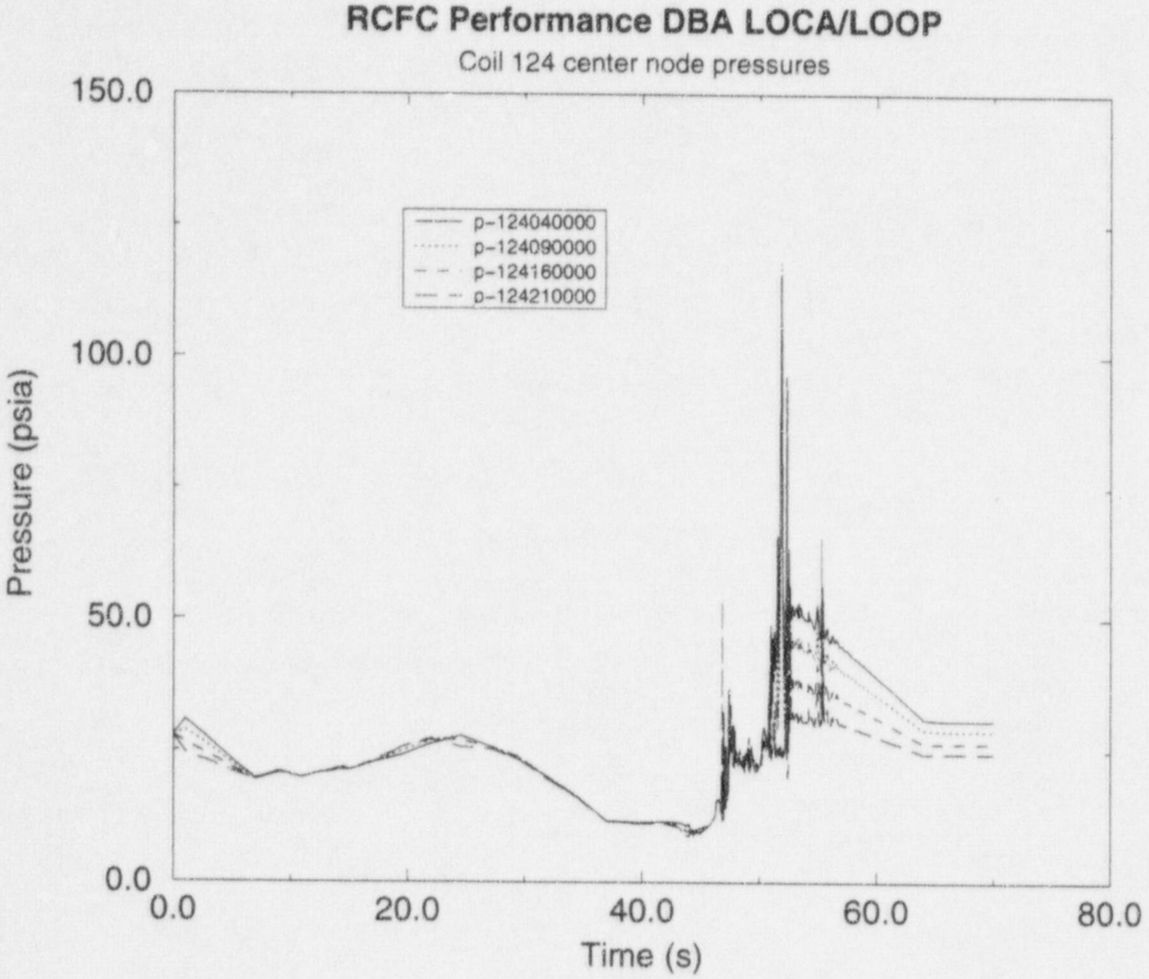


Figure 27 LOCA case pressure in Coil 5

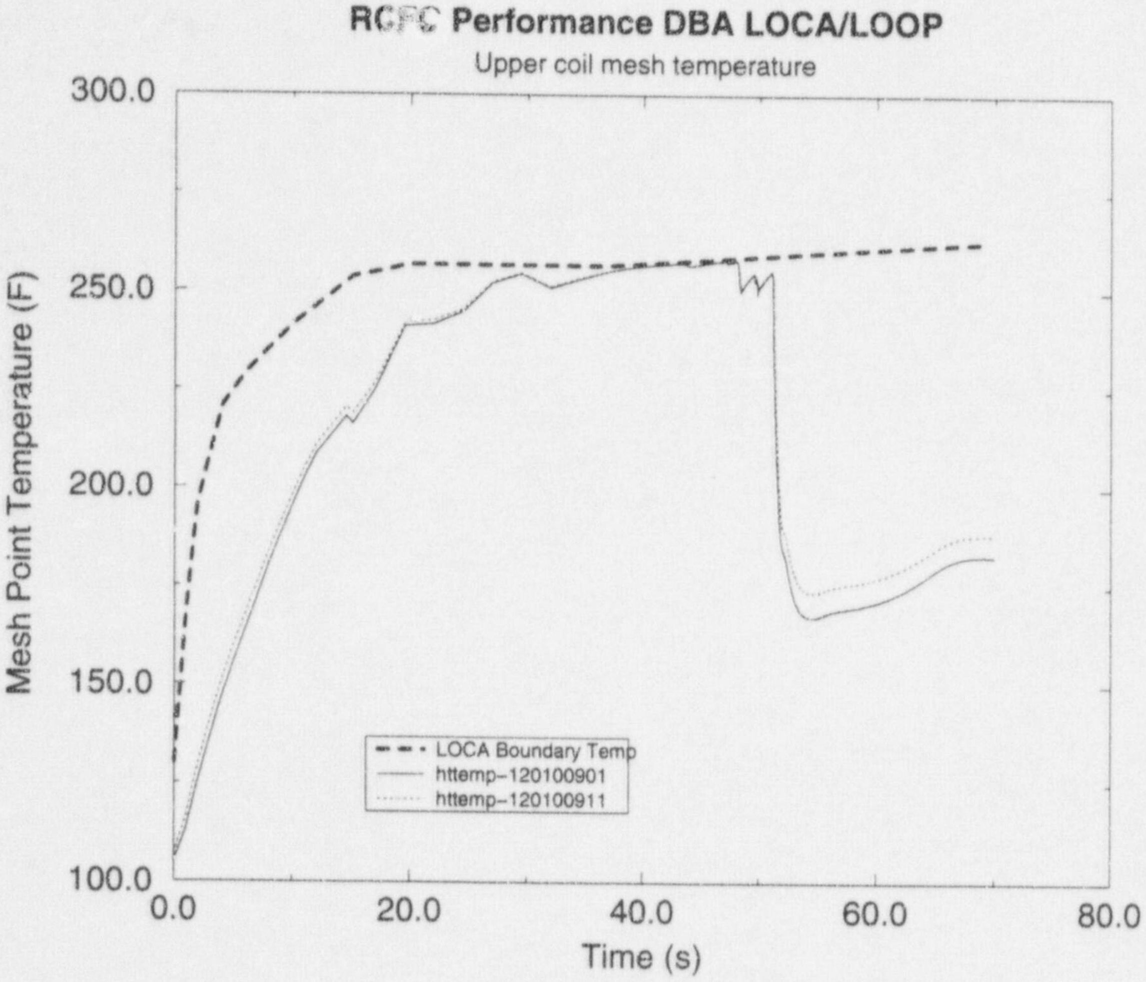


Figure 28 LOCA case containment and coil temperatures

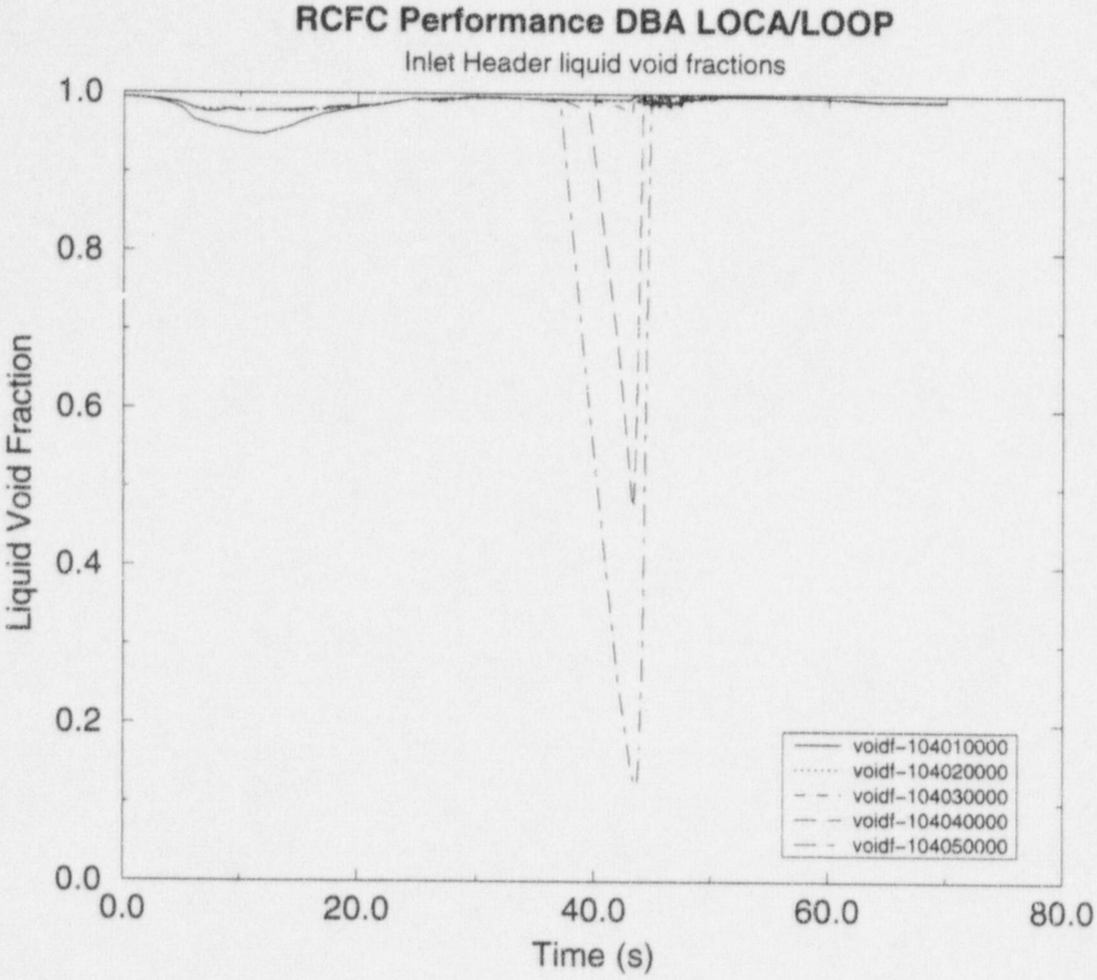


Figure 29 LOCA case Inlet Header void fractions

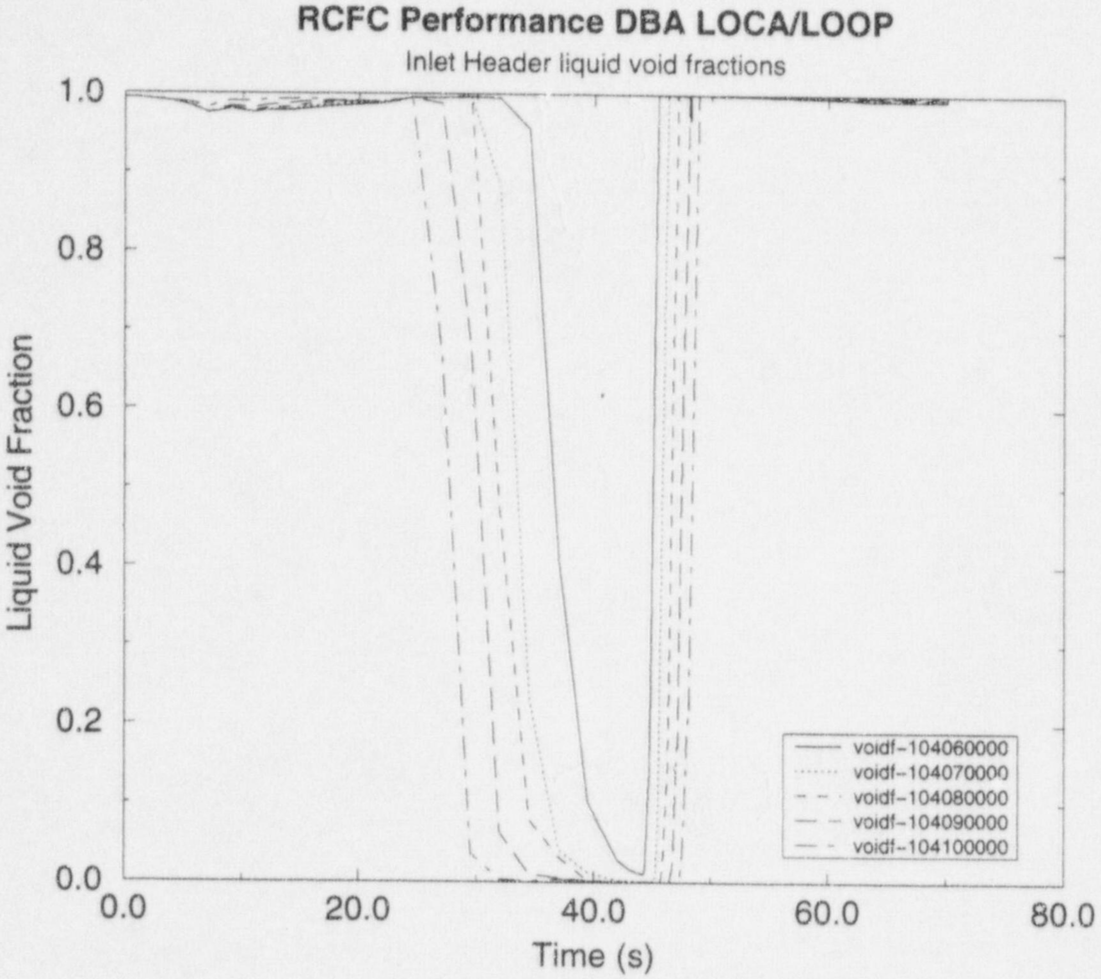


Figure 30 LOCA case Inlet Header void fractions

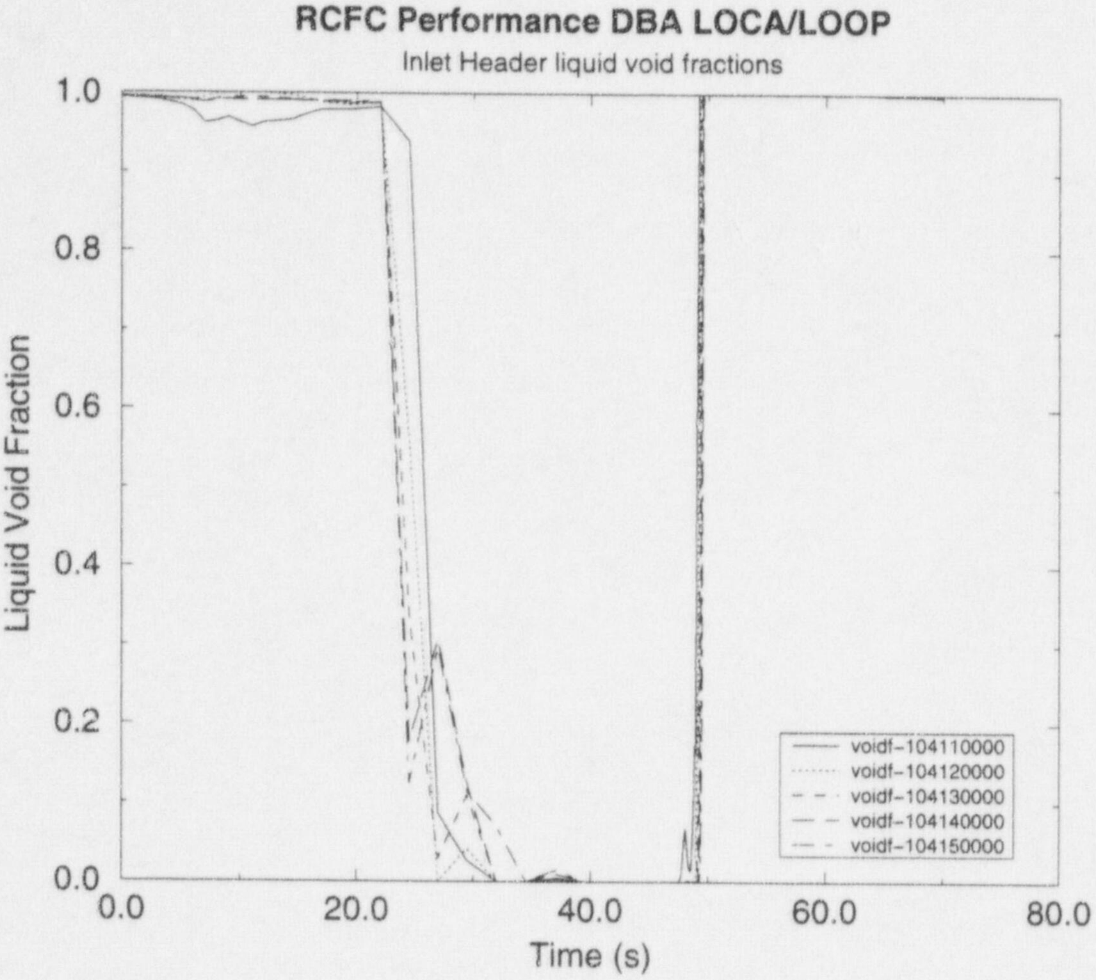


Figure 31 LOCA case Inlet Header void fractions

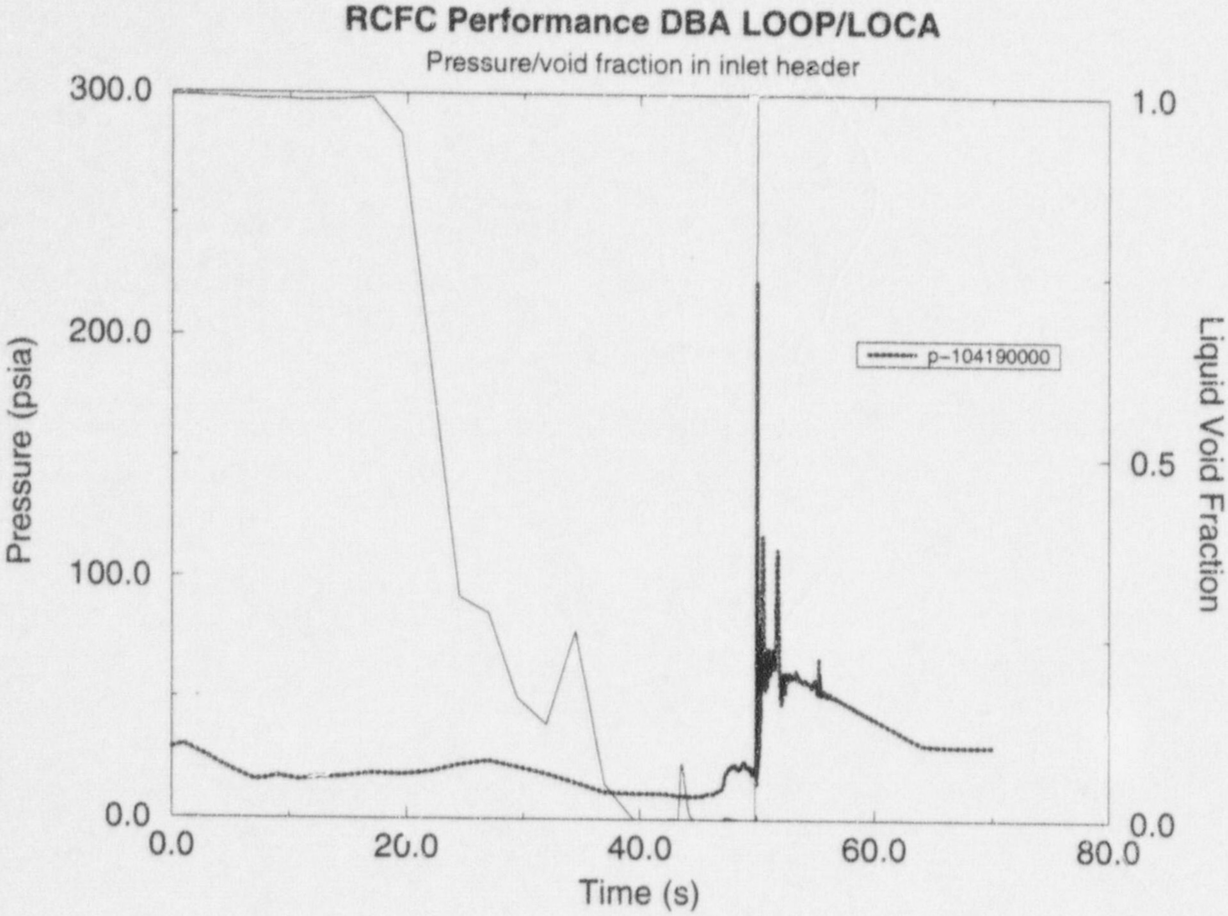


Figure 32 LOCA case Inlet Header Pressure/void behavior

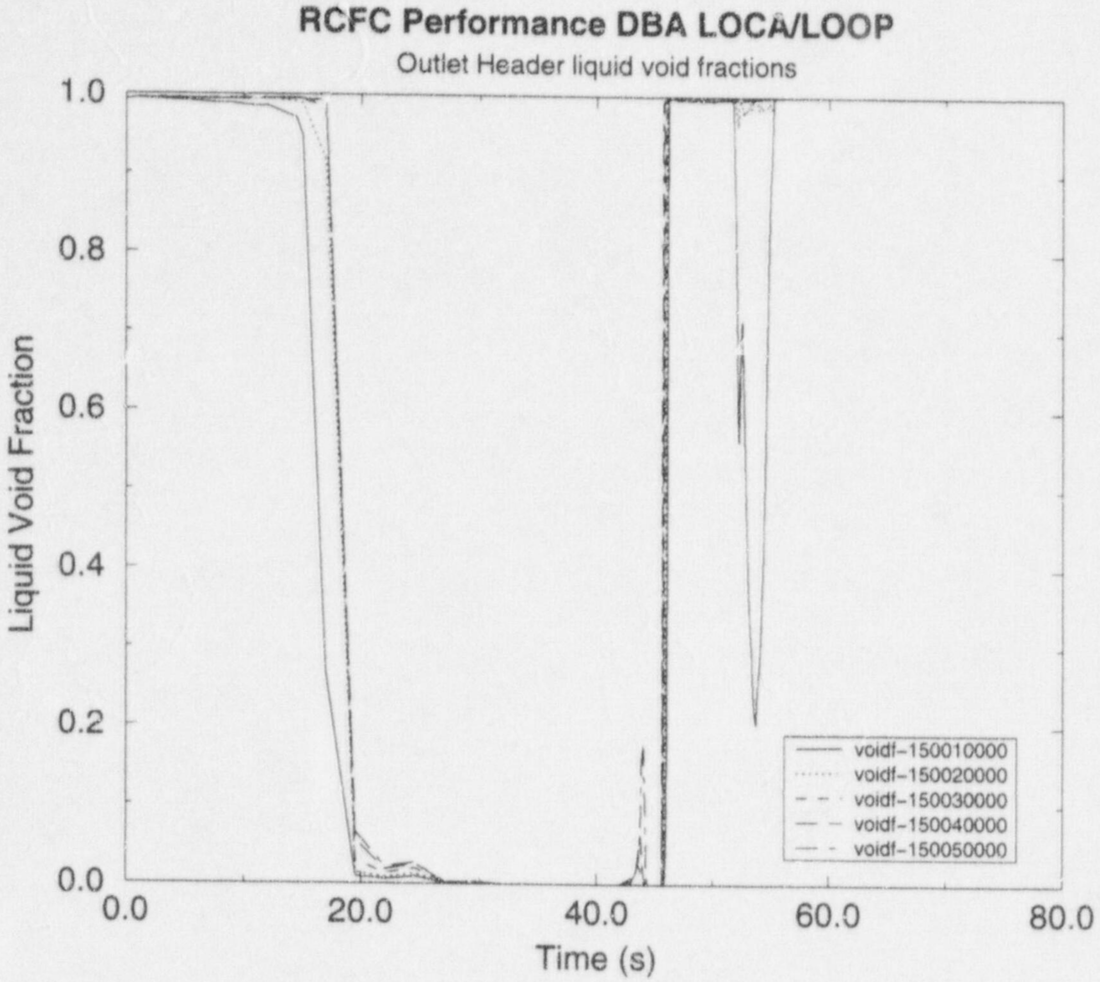


Figure 33 LOCA case Outlet Header Void fractions

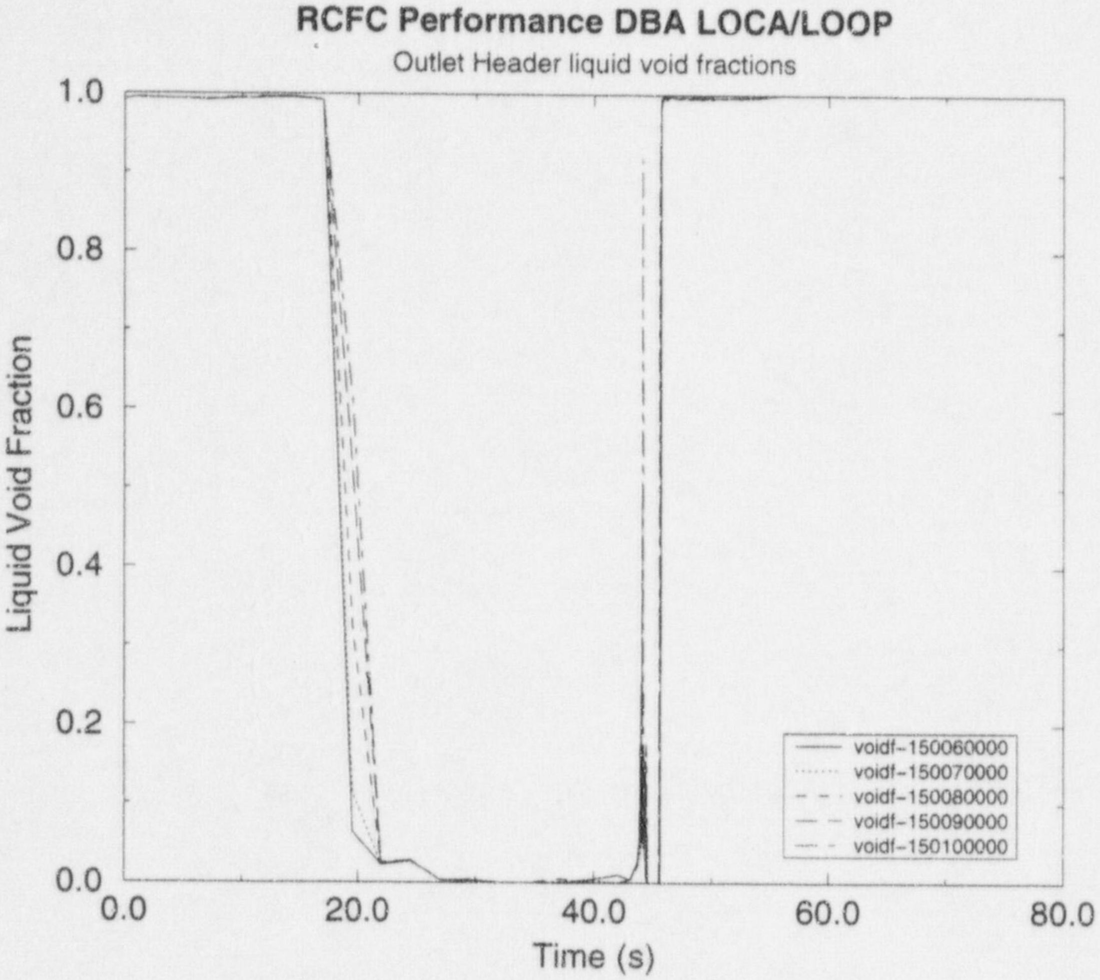


Figure 34 LOCA case Outlet Header Void fractions

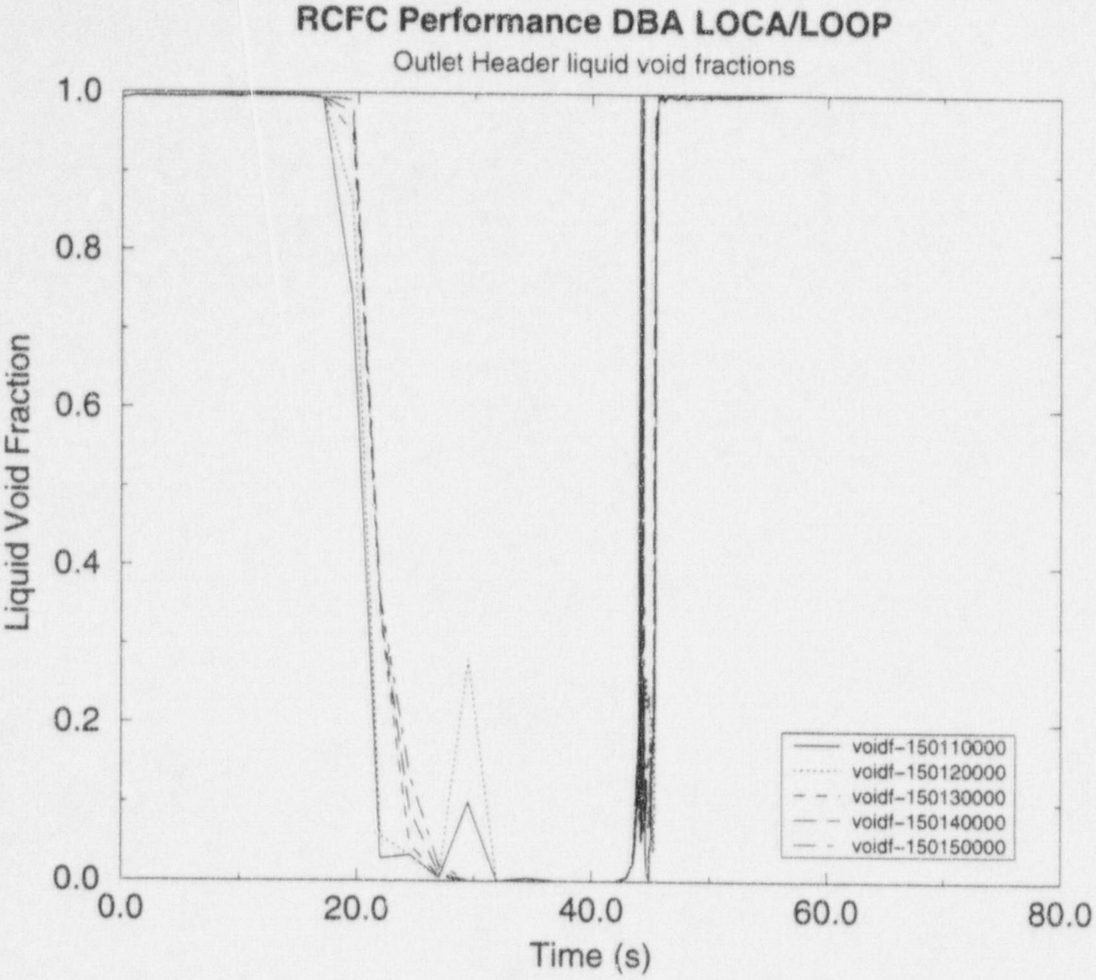


Figure 35 LOCA case Outlet Header Void fractions

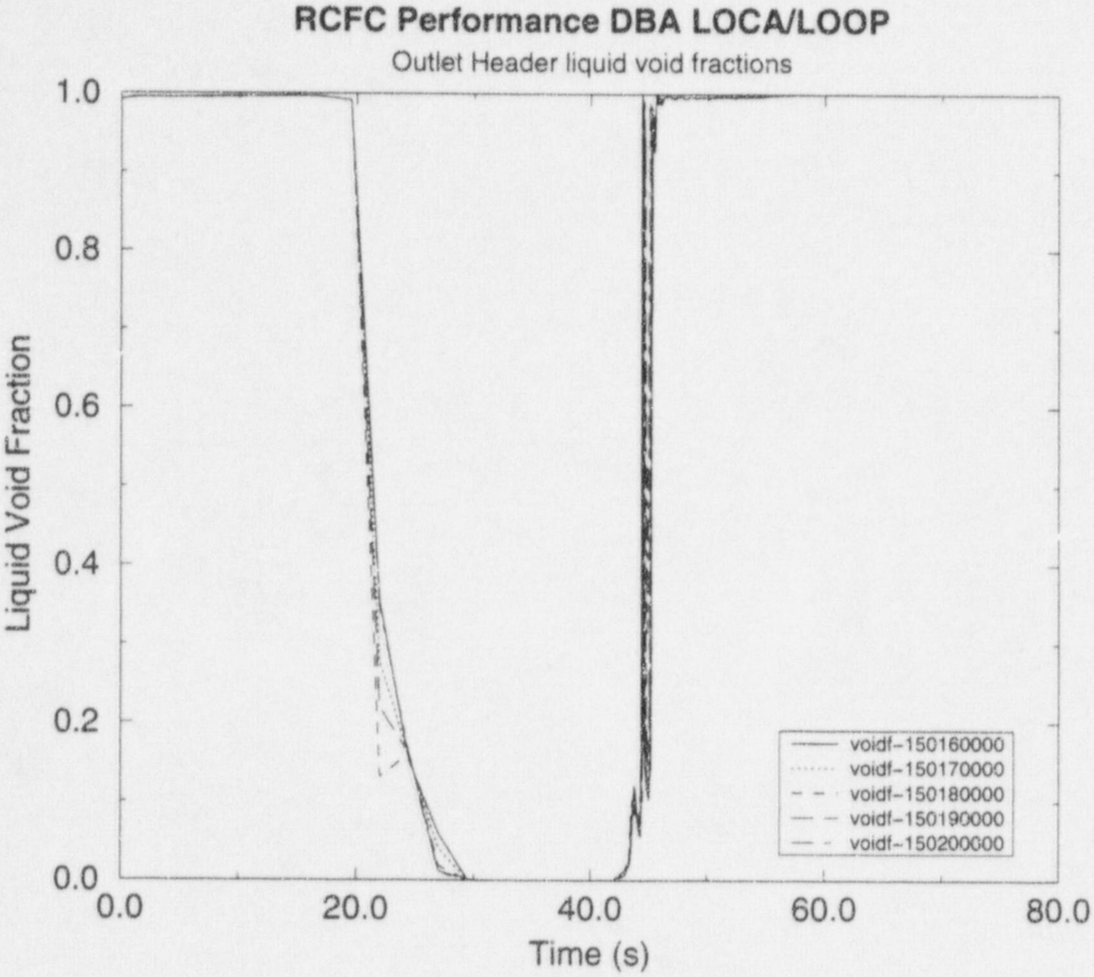


Figure 36 LOCA case Outlet Header Void fractions

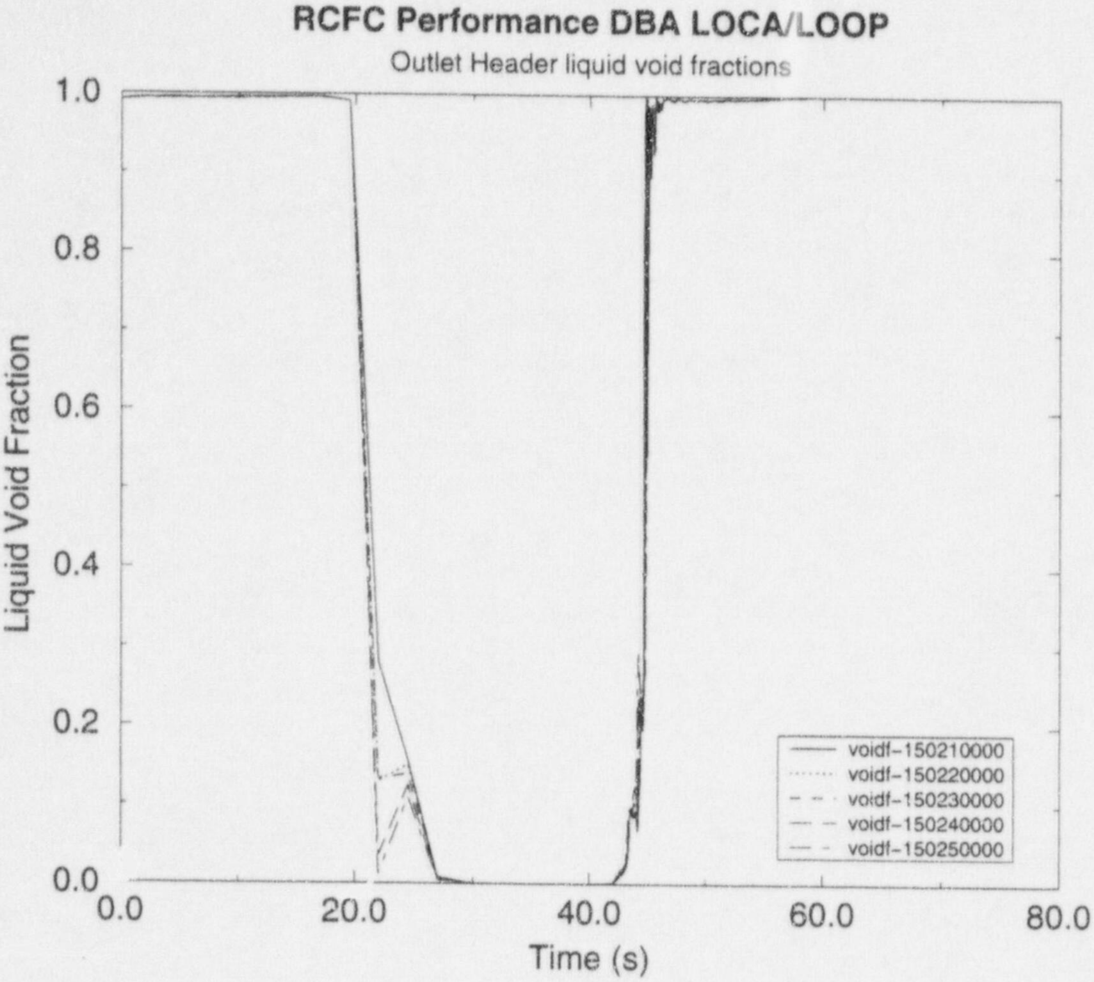


Figure 37 LOCA case Outlet Header Void fractions

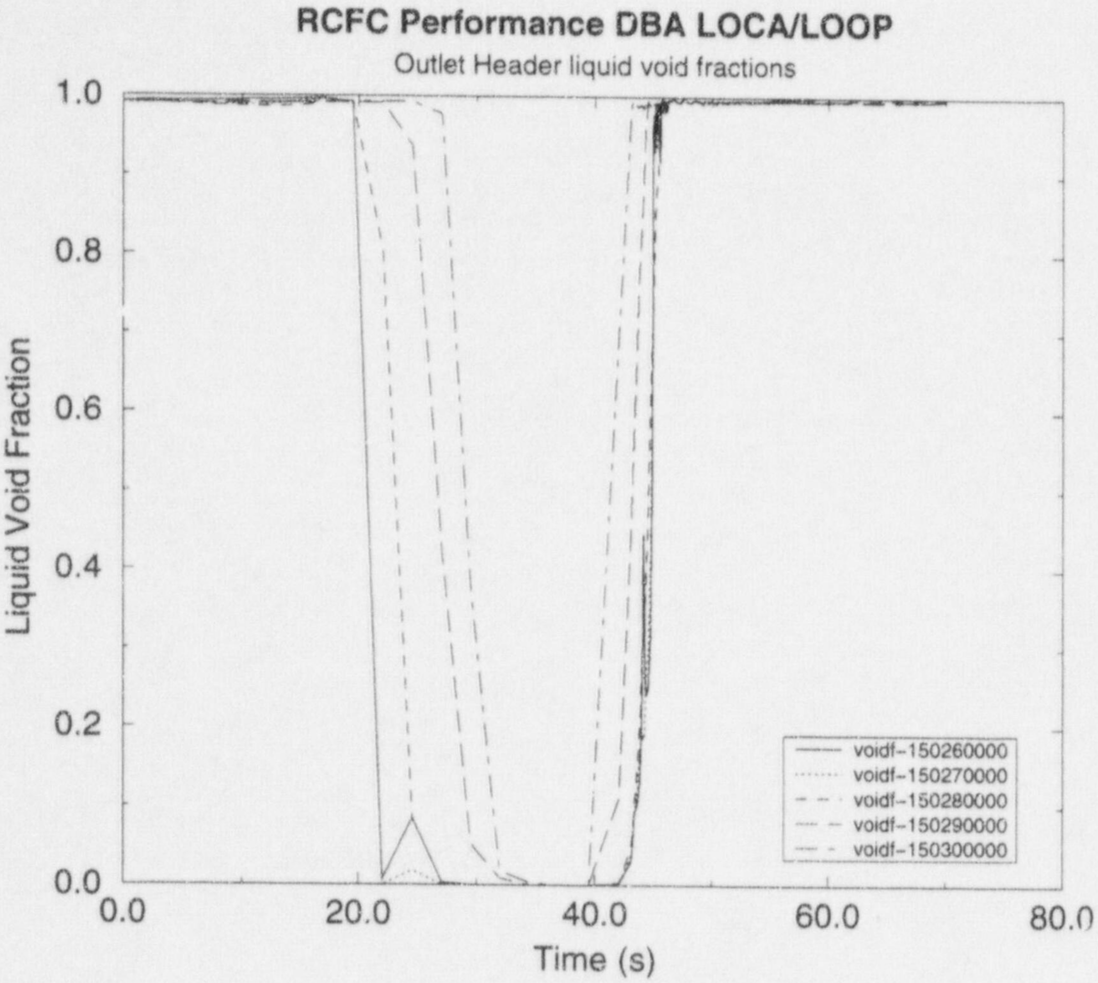


Figure 38 LOCA case Outlet Header Void fractions

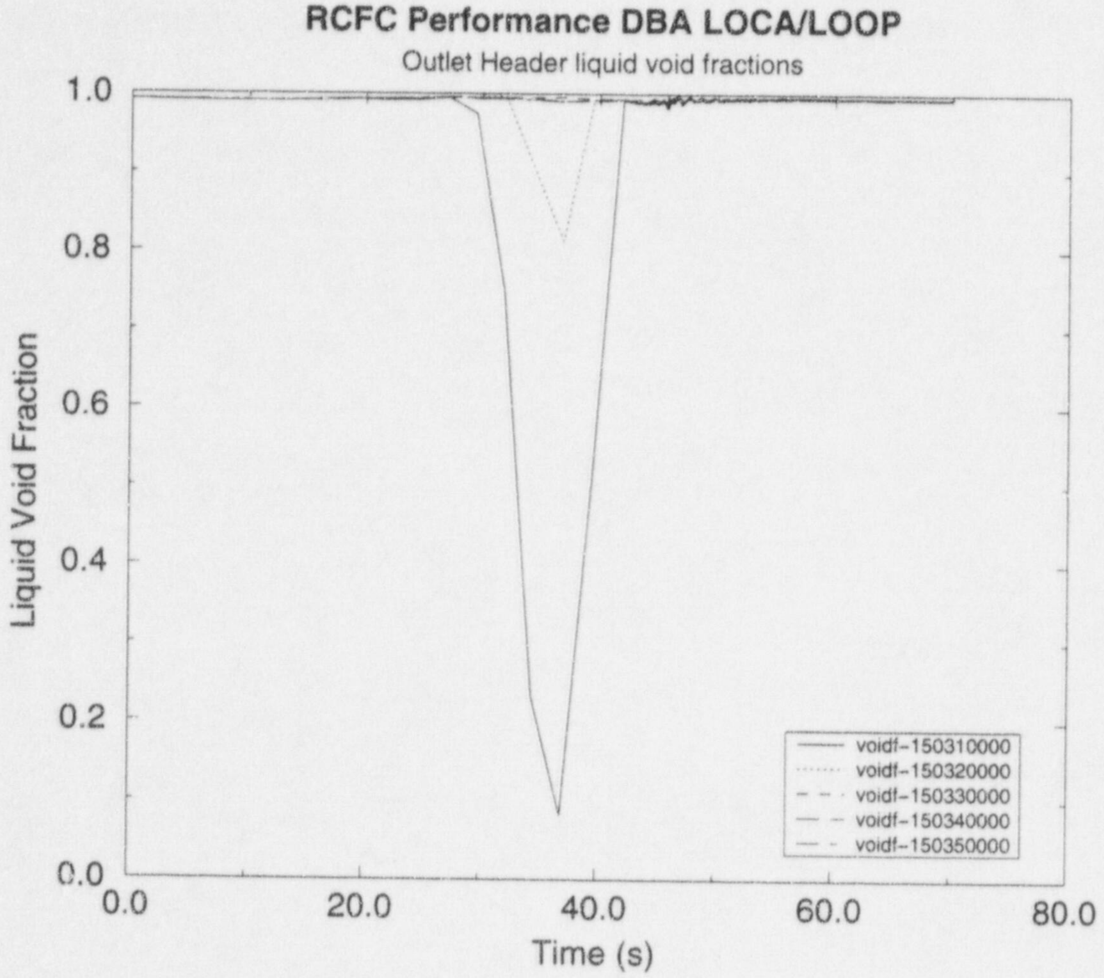
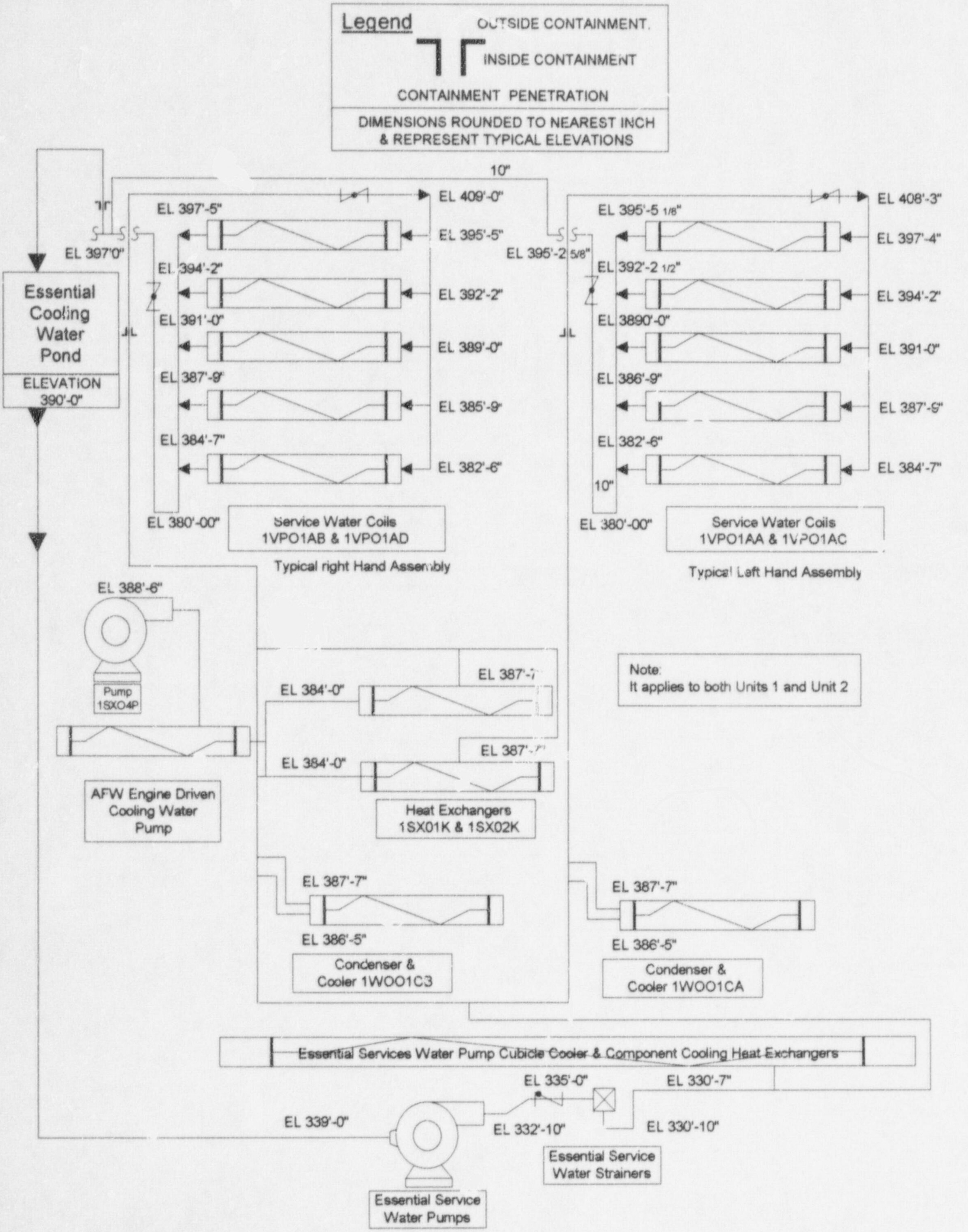


Figure 39 LOCA case Outlet Header Void fractions

ATTACHMENT F

PIPING AND EQUIPMENT ELEVATIONS
[Response to NRC RAI 5]

BRAIDWOOD PIPING AND EQUIPMENT ELEVATIONS



BYRON PIPING AND EQUIPMENT ELEVATIONS