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Quad Cities Nuclear Power Station
Units 1 and 2
Evaluation of the Minimum Post-LOCA Heat Removal Requirements To Assure Adequate NPSH For the Core Spray and LPCI/Containment Cooling Pumps

Prepared by: S. Mintz
S. Mintz
Plant Performance Analysis Projects

Approved by: J. E. Torbeck
J. E. Torbeck
Project Manager,
ECCS & Containment Analysis Projects

IMPORTANT NOTICE REGARDING

CONTENTS OF THIS REPORT

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ABSTRACT

This report provides the results of an evaluation of the Quad Cities containment response during a design basis loss-of-coolant accident (DBA-LOCA). The containment response was evaluated for a range of heat removal values for the residual heat removal (RHR) system heat exchanger. The results of the Quad Cities containment pressure and temperature response analysis described in this report were used to determine the trend of peak suppression pool temperature with RHR heat exchanger performance and to determine the minimum acceptable heat removal capability of the Quad Cities RHR heat exchanger which will assure there is adequate NPSH available for the core spray and LPCI/Containment Cooling pumps which take suction from the suppression pool.

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1.0 DESCRIPTION OF WORKSCOPE

The purpose of this evaluation is to determine the minimum acceptable heat removal capability of the Quad Cities Residual Heat Removal (RHR) Systems heat exchanger (HX) which will assure there is adequate NPSH available for the core spray and LPCI/Containment Cooling pumps which take suction from the suppression pool during a design basis loss-of-coolant accident (DBA-LOCA). The DBA-LOCA for Quad Cities is the postulated double-ended guillotine break of a recirculation suction line. The results in this report also show the sensitivity of the peak suppression pool temperature following a DBA-LOCA to the RHR HX heat removal capability. The results of this evaluation can be used to support an operability assessment of the RHR HX.

The workscope of this report involves analysis of the primary containment performance following a DBA-LOCA for Quad Cities. Specifically, analysis of the containment long-term pressure and temperature response following the DBA-LOCA was performed. Long-term is defined here as beginning at 600 seconds into the event which is when containment cooling is initiated and proceeding through the time of the peak suppression pool temperature. This analysis uses the GE SHEX computer code and current standard assumptions for containment cooling analysis including use of the ANS 5.1 decay heat model. The analysis is performed for a range of RHR heat exchanger (HX) heat transfer coefficient, 'K', values. The analysis results are compared against containment conditions (pool temperature and wetwell airspace pressure) required for adequate NPSH for the LPCI/Containment Cooling pumps and Core Spray pumps. The suppression pool temperature and wetwell airspace pressure required for adequate NPSH were provided by Commonwealth Edison Company (CECo) in Reference 1.

An additional analysis was performed to bench mark the SHEX code with the original Quad Cities USAR analysis. The benchmark analysis used key inputs and assumptions used originally to analyze Case e of USAR Table 6.2.3. These included May Witt decay heat (Reference 2), an initial suppression pool temperature of 90°F, no feedwater addition and a RHR HX heat removal rate of

84.5 million Btu/hr (corresponding to a suppression pool temperature-to-service water temperature difference of 85°F). The benchmark analysis is provided in Appendix C of this report.

2. RESULTS/CONCLUSION

2.1 SUMMARY OF RESULTS:

Pressure and Temperature Containment Response Dependence on K

The results of the Quad Cities containment pressure and temperature response analysis for a DBA-LOCA are summarized in Table 1. Table 1 gives the peak suppression pool temperature and the wetwell pressure at the time of the peak suppression pool temperature vs RHR HX K with 1 and 2 LPCI/Containment Cooling pumps. Table 1 also gives the RHR HX heat removal at the time of the peak suppression pool temperature. This is the maximum heat load for each case. Figures 1, 2 and 3 show the containment pressure and temperature response for Case 3 which is typical of the response for all cases.

Figure 4 compares curves of the peak suppression pool temperature vs K for 1 LPCI/Containment Cooling pump and 2 LPCI/Containment Cooling pumps. The peak suppression pool temperature with 2 LPCI/Containment Cooling pumps are slightly higher than the temperatures with 1 LPCI/Containment Cooling pump due to a higher pump heat.

NPSH Evaluation

Figure 5 compares curves of the calculated wetwell pressure at the time of the peak suppression pool temperature vs. peak suppression pool temperature for 1 LPCI/Containment Cooling pump and for 2 LPCI/Containment Cooling pumps. The wetwell pressures with 1 LPCI/Containment Cooling pump are approximately 2 psi less than the wetwell pressures with 2 LPCI/Containment Cooling pumps for a given suppression pool temperature. This is attributed mainly to a lower total flow rate through the RHR heat exchanger which produces a lower spray temperature. There is also a minor effect due to the lower pump heat added to the containment spray with one LPCI/Containment Cooling pump. These two effects together result in lower drywell and wetwell airspace temperatures with 1 LPCI/Containment Cooling Pump and consequently lower pressures in the wetwell airspace.

The results in Figures 6 and 7 compare the calculated wetwell pressure and pool temperature at the time of the peak pool temperature with the values of required wetwell pressure for adequate NPSH reported in Reference 1 for 1 and 2 LPCI/Containment Cooling pumps respectively. The required wetwell pressures shown in Figures 6 and 7 which were provided by CECo in Reference 1 are for the LPCI/Containment Cooling pumps. However, Reference 1 noted that the wetwell pressure requirements for the LPCI/Containment Cooling pumps are more limiting than the wetwell pressure requirements for the core spray pumps.

Table 2 which was developed from the data in Figures 6 and 7 shows the maximum allowable pump flow as a function of HX K value for 1 and 2 LPCI pumps. Table 2 shows that for pump flow rates less than 5300 gpm for one LPCI/Containment Cooling Pump and for pump flow rates less than 10600 gpm for 2 LPCI/Containment Cooling pumps, the predicted wetwell pressures will be greater than the required wetwell pressures for adequate NPSH for the range of RHR HX K values evaluated (100 to 500 Btu/sec-°F). For flow rates greater than approximately 5300 gpm per pump (for 1 or 2 pumps), the results of the current analysis predicts wetwell pressures which are less than the required wetwell pressure.

Benchmark Analysis

The results of the analysis performed to bench mark the current analysis with the analysis documented in the USAR are provided in Appendix C. The analysis in Appendix C used key input assumptions which are consistent with the inputs used in the analysis for Case e of USAR Table 6.2-3. This included the use of May Witt decay heat (Reference 2), an initial suppression pool temperature of

90°F, no feedwater addition and a RHR HX heat removal rate of 84.5 million Btus/hr (referenced to a suppression pool temperature-to-service water temperature difference of 85°F). The peak suppression pool temperature obtained with the GE SHEX code is 181°F which is 4°F higher than the value of 177°F given in USAR Table 6.2-3. This confirms that SHEX predicts peak suppression pool temperatures for Quad Cities which are higher than those predicted in the USAR for the same input conditions.

2.2 CONCLUSIONS

The sensitivity of pool temperature on the RHR HX K value is given in Figure 4. Based on Figure 4, a minimum RHR HX K value of 277 Btu/°F-sec will assure that the calculated peak suppression pool temperature following a DBA-LOCA will not exceed the maximum value of 177°F given in Table 6.2-3 of the USAR.

Based on the results shown in Figures 6, 7 and 8 it was determined that for LPCI/Containment Cooling pump flow rates less than 5300 gpm per pump, there will be adequate NPSH for the core spray pump and the LPCI/Containment Cooling pumps which take suction from the suppression pool for the full range of K values analyzed here. CECo should consider uncertainties in the measured pump flow when determining if adequate NPSH is available.

3.0 DESIGN ASSUMPTIONS AND ENGINEERING JUDGEMENTS

Input assumptions were used which maintain the overall conservatism in the NPSH evaluation by maximizing the suppression pool temperature and minimizing the wetwell pressure. The following key input assumptions were used in performing the Quad Cities containment LOCA pressure and temperature response analysis:

1. The reactor is assumed to be operating at 102% of the rated thermal power.

   (The inputs used to model the reactor vessel are the same as used in the Dresden containment analysis described in Reference 4 This is since Dresden and Quad Cities have the same vessel design (BWR-3, 251" diameter vessel). The difference in rated power level between Dresden and Quad Cities was accounted for in the analysis inputs.)

2. Vessel blowdown flowrates are based on the Homogeneous Equilibrium Model (Reference 5).

3. The core decay heat is based on ANSI/ANS-5.1-1979 decay heat (Reference 6).

4. Feedwater flow into the RPV continues until all the feedwater above 180°F is injected into the vessel.

   (The feedwater inputs used for the analysis were developed originally for the Dresden containment analysis of Reference 4. Per Reference 1, there are no major differences in the feedwater systems between the two plants. Therefore the use of the Dresden FW system inputs will not have a significant impact on the results.)

5. Thermodynamic equilibrium exists between the liquids and gases in the drywell. Mechanistic heat and mass transfer between the suppression pool and the suppression chamber airspace was modeled.

6. To minimize the containment pressure for this NPSH evaluation it is assumed that there is only partial heat transfer to the fluids in the drywell from the liquid flow from the break which does not flash. To model partial heat transfer in the analysis, a fraction of the non-flashing liquid break flow is assumed to be held up in the drywell and to be fully mixed with the drywell fluids before flowing to the suppression pool. Thermal equilibrium conditions are imposed between this held up liquid and the fluids in the drywell as described in Assumption No. 5 above. The liquid not held up is assumed to flow directly to the suppression pool without heat transfer to the drywell fluids. For the

analysis it is assumed that only 20% of the non-flashing liquid flow from the break is held up in the drywell airspace. Because the liquid flow from the break is at a higher temperature than the drywell fluid, this minimizes the drywell temperature and consequently minimizes the drywell and wetwell pressure.

7. The vent system flow to the suppression pool consists of a homogeneous mixture of the fluid in the drywell.

8. The initial suppression pool volume is at the minimum Technical Specification (T/S) limit to maximize the calculated suppression pool temperature.

9. The initial drywell and wetwell pressure were at the minimum expected operating values to minimize the containment pressure used to evaluate available NPSH.

10. The maximum operating value of the drywell temperature of 150°F and a relative humidity of 100% were used to minimize the initial non-condensible gas content and minimize the long-term containment pressure for the NPSH evaluation.

11. The initial suppression pool temperature is at the maximum T/S value to maximize the calculated suppression pool temperature.

12. Consistent with the NPSH evaluation in USAR Section 6.3, containment sprays are available to cool the containment. Once initiated at 600 seconds it is assumed that containment sprays are operated continuously with no throttling of the LPCI/Containment Cooling pumps.

13. Passive heat sinks in the drywell, suppression chamber airspace and suppression pool are conservatively neglected to maximize the suppression pool temperature.

14. All Core Spray and LPCI/Containment Cooling system pumps have 100% of their horsepower rating converted to a pump heat input which is added either to the RPV liquid or suppression pool water.

15. The LPCI/Containment Cooling pump flow rates used in the analysis are based on the nominal rated values: 5000 gpm with one pump and 10000 gpm with two pumps.

16. Heat transfer from the primary containment to the reactor building is conservatively neglected.

17. Although a containment atmospheric leakage rate of 5% per day was used to determine the available NPSH in USAR Section 6.3.3.2.9, containment leakage is not included in this current analysis. Including containment leakage has no impact on the peak suppression pool temperature, but will slightly reduce the calculated containment pressure. A leakage rate of 5% per day is considered to be unrealistically large since the T/S limit for allowable leakage is 1% per day. Use of the leakage rate of 1% per day would result in less than a 0.1 psi reduction in the pressures calculated in the analysis. This effect is negligible considering all other input conditions have been chosen at their limiting values to minimize containment pressure and the assumption of only 20% holdup of the non-flashing liquid flow from the break in the drywell (see assumption no. 6). Therefore containment atmospheric leakage was not included in the analysis.

4.0 INPUT DOCUMENTATION

4.1 Inputs

The initial conditions and key input parameters used in the long-term containment pressure and temperature analysis are provided in Table 3. These are based on the current Quad Cities containment data which were confirmed by CECo in Reference 3.

Appendix A provides the core decay heat based on ANS 5.1 used in the analysis.

Appendix B provides the values of required wetwell pressure versus suppression pool temperature for the LPCI/Containment Cooling pumps which was provided by CECo in Reference 3.

4.2 Industry Codes and Standards

The core decay heat used in the analysis (see Attachment A) is based on ANSI/ANS-5.1-1979 decay heat (Reference 6).

5.0 REGULATORY REQUIREMENTS

The analysis were performed per Regulatory Guide 1.49.

Pertinent sections of the USAR for this report include USAR Section 6.2 and 6.3.

6.0 LIMITATIONS OF APPLICABILITY

The results of the proposed analysis can be used to support an operability assessment of the RHR heat exchanger. However, CECo should confirm that adequate NPSH is the limiting concern in determining the minimum RHR heat exchanger requirements for Quad Cities. Examples of other issues which may be affected by RHR heat exchanger performance and are not addressed in this report include: temperature limits for pump seals, local pool temperature limits specified in NUREG-0783, reactor shutdown cooling times and dynamic loads defined during the Mark I Containment Long Term Program (LTP).

In addition, if CECo chooses to update the Quad Cities USAR based on this analysis it should be noted that the results of the analysis in this report are not sufficient by themselves to provide a complete basis for updating the USAR. The analysis results contain the information required to revise the NPSH evaluation in USAR Section 6.3. However, to update the long-term containment analysis in USAR Section 6.2 this analysis will need to be performed again with assumptions which maximize the long-term containment pressure response. Also, additional analyses may be required to revise the USAR analysis results for the different containment cooling configurations described in USAR Section 6.2.1.3.3. Finally, the USAR should be reviewed to ensure that all appropriate USAR sections are revised where necessary, e.g. Section 6.2 (LOCA long-term containment cooling, NUREG-0783 and Mark I Containment LTP), Section 6.3 (NPSH evaluation) and Section 5.4.7 (reactor shutdown cooling).

The results of the analysis described in this report are based on the inputs described in Section 4.0. Any changes to these inputs should be reviewed to determine the impact on the results and conclusions reported here.

Finally, the results presented in this report, specifically the results in Table 2 and Figures 6 and 7 are based on the values of required wetwell pressure for adequate NPSH given in Reference 1 for the LPCI/Containment Cooling pump flow rates. Uncertainties in the pump flow rate should be considered by CECo in applying these results to determine the maximum LPCI/Containment Cooling pump flow rate or Core Spray pump flow rate which maintains an adequate NPSH.

7.0 CALCULATIONS AND COMPUTER CODES

7.1 Calculation Record

The calculations used this report are contained in the GE design record file DRF T23-00711.

7.2 Model Description

The GE computer code SHEX was used to perform the analysis of the containment pressure and temperature response. The SHEX code has been validated in conformance with the requirements of the GE Engineering Operational Procedures (EOPs). In addition, a benchmark analysis to validate the code for a plant specific application to Quad Cities was performed. This analysis is included in Appendix C to this report.

SHEX uses coupled reactor pressure vessel and containment model, based on the Reference 7 and Reference 8 models, to calculate the transient response of the containment during the LOCA. This model performs fluid mass and energy balances on the reactor primary system and the suppression pool, and calculates the reactor vessel water level, the reactor vessel pressure, the pressure and temperature in the drywell and suppression chamber airspace and the bulk suppression pool temperature. The various modes of operation of all important auxiliary systems, such as SRV's, the MSIV's, ECCS, the RHR system and feedwater are modeled. The model can simulate actions based on system setpoints, automatic actions and operator-initiated actions.

7.3 Analysis Approach

The long-term pressure and temperature response was analyzed for the DBA-LOCA which is identified in the USAR as an instantaneous double-ended break of a recirculation suction line. Sensitivity analyses were performed for a range of

K values assuming 1 and 2 LPCI/Containment Cooling pumps are available. As described in Section 3, these sensitivity analyses used input assumptions which maximized the suppression pool temperature and minimized the containment pressure response. The purpose of these analyses were to determine the trend of peak suppression pool temperature and wetwell pressure at the time of the peak suppression pool temperature with K.

Note, that for this analysis the K value is independent of the LPCI/Containment Cooling pump flow rate. In actuality, the K value is a function of several parameters including the LPCI/Containment Cooling pump flow rate with a higher pump flow rate resulting in a higher value of K. Therefore the results of the analysis at the lower K values are more representative of operation with 1 LPCI/Containment Cooling pump. Similarly, the results of the analysis with the higher values of K are more representative of operation with 2 LPCI/Containment Cooling pumps. This should be considered in the operability assessment to be performed by CECo.

The core spray flow rate, number of RHR loops and number of LPCI/Containment Cooling pumps corresponding to USAR Cases c & e of USAR Table 6.2.3 were used for the analysis. Continuous containment spray operation (starting at 600 seconds) with no throttling was assumed for the analysis to minimize containment pressure. Nominal values of the containment spray flow rate for 1 LPCI/Containment Cooling pump (5,000) gpm and 2 LPCI/Containment Cooling pumps (10,000 gpm) were used.

Six values of K were selected for each of the two LPCI/Containment Cooling pump configurations described above, for a total of 12 cases. Table 4 summarizes the LPCI/Containment Cooling pump and core spray pump parameters for each case.

The USAR benchmark analysis is described in Appendix C.

8. Q/A RECORDS

All work performed to produce this document and supporting background information is contained in the GE design record file DRF T23-00711.

9.0 References

1) Letter, C. A. Moerke (CECo) to J. E. Torbeck, "Minimum Wetwell Pressure Required for Evaluation of the Minimum Post-LOCA Heat Removal Requirements for Quad Cities Units 1 and 2," August 5, 1993, (CHRON# 0121389)

2) NEDO-10625, "Power Generation in a BWR Following Normal Shutdown or Loss-Coolant Accident Conditions," March 1973.

3) Letter, C. A. Moerke (CECo) to J. E. Torbeck, "Verification of Key Containment Parameters to be used in Evaluation of the Minimum Post-LOCA Heat Removal Requirements for Quad Cities Units 1 and 2," August 4, 1993, (CHRON# 0121386).

4) GENE-770-26-1092, "Dresden Nuclear Power Station, Units 2 and 3, LPCI/Containment Cooling System Evaluation," November 1992.

5) NEDO-21052,"Maximum Discharge of Liquid-Vapor Mixtures from Vessels," General Electric Company, September 1975.

6) "Decay Heat Power in Light Water Reactors," ANSI/ANS 5.1 - 1979, Approved by American National Standards Institute, August 29, 1979.

7) NEDM-10320,"The GE Pressure Suppression Containment System Analytical Model," March 1971.

8) NEDO-20533,"The General Electric Mark III Pressure Suppression Containment System Analytical Model," June 1974.

Table 1 - Peak Suppression Pool Temperature and Wetwell Pressure at time of Peak Suppression Pool Temperature vs RHR HX Heat Transfer Coefficient - K

K CASE	RHR HX K (Btu/Sec-°F)	No. of LPCI/Cont Cooling Pumps	PEAK POOL TEMP. (°F)	WW* PRES. (PSIA)	Max. RHR HX Heat Load** (million Btu/hr)
1	150	1	208	24.0	61.0
2	200	1	191	20.1	69.1
3	250	1	180	18.2	76.5
4	300	1	172	17.1	83.2
5	400	1	164	15.8	99.4
6	500	1	160	15.2	117.0
7	150	2	210	26.5	62.1
8	200	2	192	22.1	69.8
9	250	2	180	19.9	76.5
10	300	2	173	18.7	84.2
11	400	2	164	17.3	100.8
12	500	2	160	16.5	117.0

*Wetwell (WW) pressures shown here are at the time of the peak suppression pool temperature.

** The maximum heat load occurs at the time of the peak suppression pool.

Table 2 - Maximum Allowable LPCI/Containment Cooing Pump Flow Rate for Adequate NPSH vs. RHR HX K.

RHR HX K (Btu/Sec-°F)	No. of LPCI/Containment Cooling Pumps	Max. Allowable LPCI/Containment Cooling Pump Flow (gpm)
150	1	5300
200	1	5300
250	1	5400
300	1	5400
400	1	5300
500	1	5300
150	2	10800
200	2	10800
250	2	10800
300	2	10800
400	2	10800
500	2	10600

Table 3 - Input Parameters Used for Containment Analysis

Parameter	Units	Value Used in Analysis
Core Thermal Power	MWt	2578
Vessel Dome Pressure	psia	1020
Drywell Free (Airspace) Volume (including vent system)	ft^3	158236
Initial Suppression Chamber Free (Airspace) Volume		
Low Water Level (LWL)	ft^3	119963
Initial Suppression Pool volume		
Min. Water Level	ft^3	111500
Initial Drywell Pressure	psig	0.0
Initial Drywell Temperature	°F	150
Initial Drywell Relative Humidity	%	100
Initial Suppression Chamber Pressure	psig	0.0
Initial Suppression Chamber Airspace Temperature	°F	95
Initial Suppression Chamber Airspace Relative Humidity	%	100
Initial Suppression Pool Temperature	°F	95
No. of Downcomers		96
Total Downcomer Flow Area	ft^2	301.6
Initial Downcomer Submergence (LWL)	ft	3.21

Table 3 - Input Parameters Used for Containment Analysis

Parameter	Units	Value Used in Analysis
Downcomer I.D.	ft	2.00
Vent System Flow Path Loss Coefficient (includes exit loss)		5.17
Supp. Chamber (Torus) Major Radius	ft	54.50
Supp. Chamber (Torus) Minor Radius	ft	15.00
Suppression Pool Surface Area in contact with suppression chamber air space)	ft^2	9971.4
Suppression Chamber-to-Drywell Vacuum Breaker Opening Diff. Press.		
- full open	psid	0.5
Supp. Chamber-to-Drywell Vacuum Breaker Flow Area (Total)	ft^2	18.85
Supp. Chamber-to-Drywell Vacuum Breaker Flow Loss Coefficient (including exit loss)		3.47
LPCI/Containment Cooling Heat Exchanger K in Containment Cooling Mode	Btu/s-°F	See Table 2
LPCI/Containment Cooling Service Water Temperature	°F	95

Table 3 - Input Parameter Used for Containment Analysis

Parameter	Units	Value Used in Analysis
LPCI/Containment Cooling Pump Heat (per pump)	hp	600
Core Spray Pump Heat (per pump)	hp	850
Time for Operator to turn on LPCI/Containment Cooling System in Containment Cooling mode (after LOCA signal)	sec	600
Feedwater Addition (to RPV after start of event; mass and energy)		

Feedwater Node **	Mass (lbm)	Enthalpy * (Btu/lbm)
1	34658	308.0
2	96419	289.2
3	145651	268.7
4	91600	219.8
5	65072	188.4

* Includes sensible heat in the feedwater system pipe metal.

** Feedwater mass and energy data combined to fit into 5 nodes for use in the analysis.

Table 4 - Flow Rates Used in Containment Response Analysis

Case	RHR Loops	RHR Pumps Per Loop	Containment Spray Flow (gpm)	RHR HX K (BTU/°F-sec)	Core Spray Flow Rate (gpm)
1	1	1	5,000	150	4,500
2	1	1	5,000	200	4,500
3	1	1	5,000	250	4,500
4	1	1	5,000	300	4,500
5	1	1	5,000	400	4,500
6	1	1	5,000	550	4,500
7	1	2	10,000	150	4,500
8	1	2	10,000	200	4,500
9	1	2	10,000	250	4,500
10	1	2	10,000	300	4,500
11	1	2	10,000	400	4,500
12	1	2	10,000	500	4,500

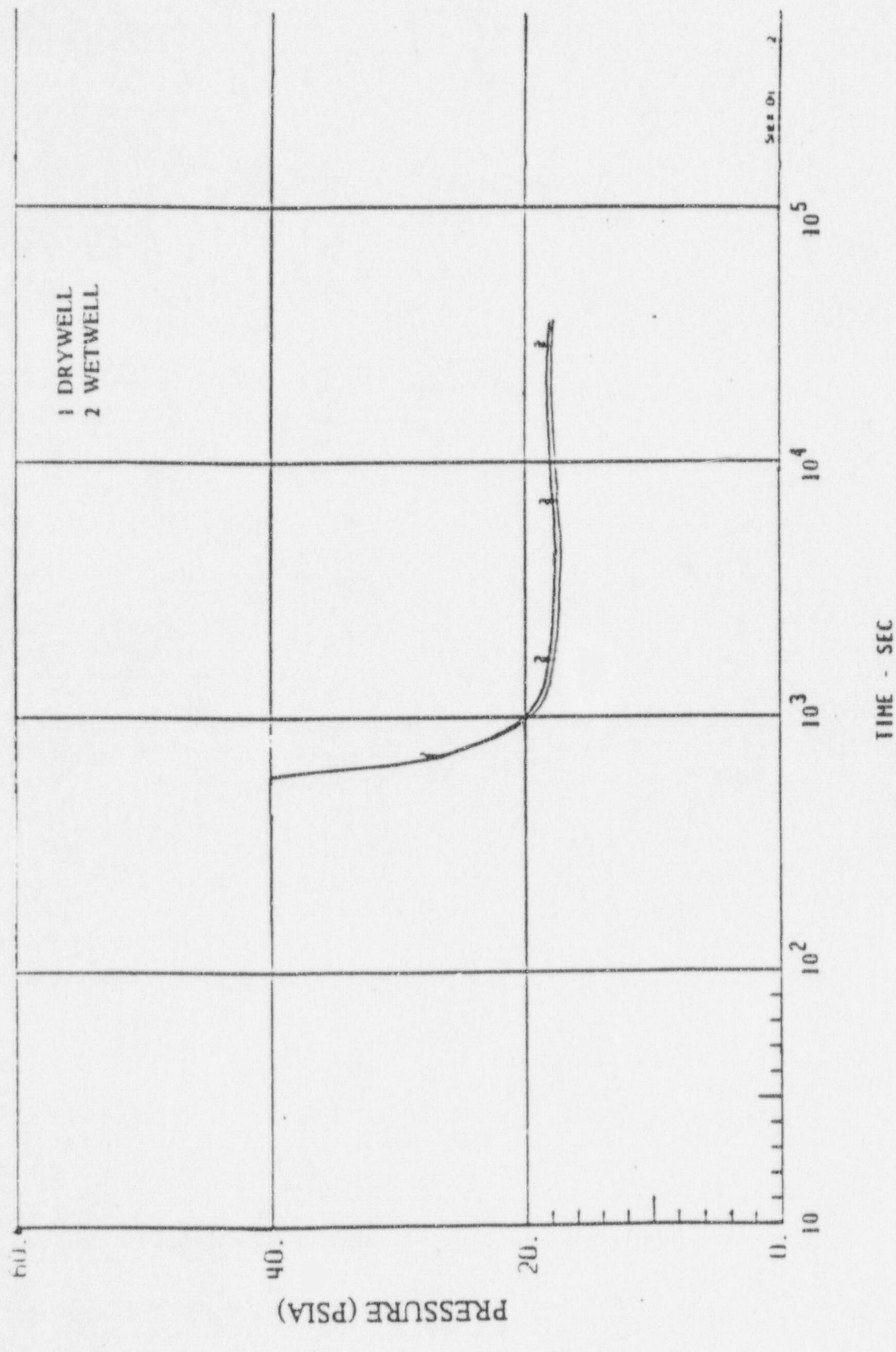


Figure 1 - Long-Term DBA-LOCA Drywell and Wetwell Pressure Response for Case 3

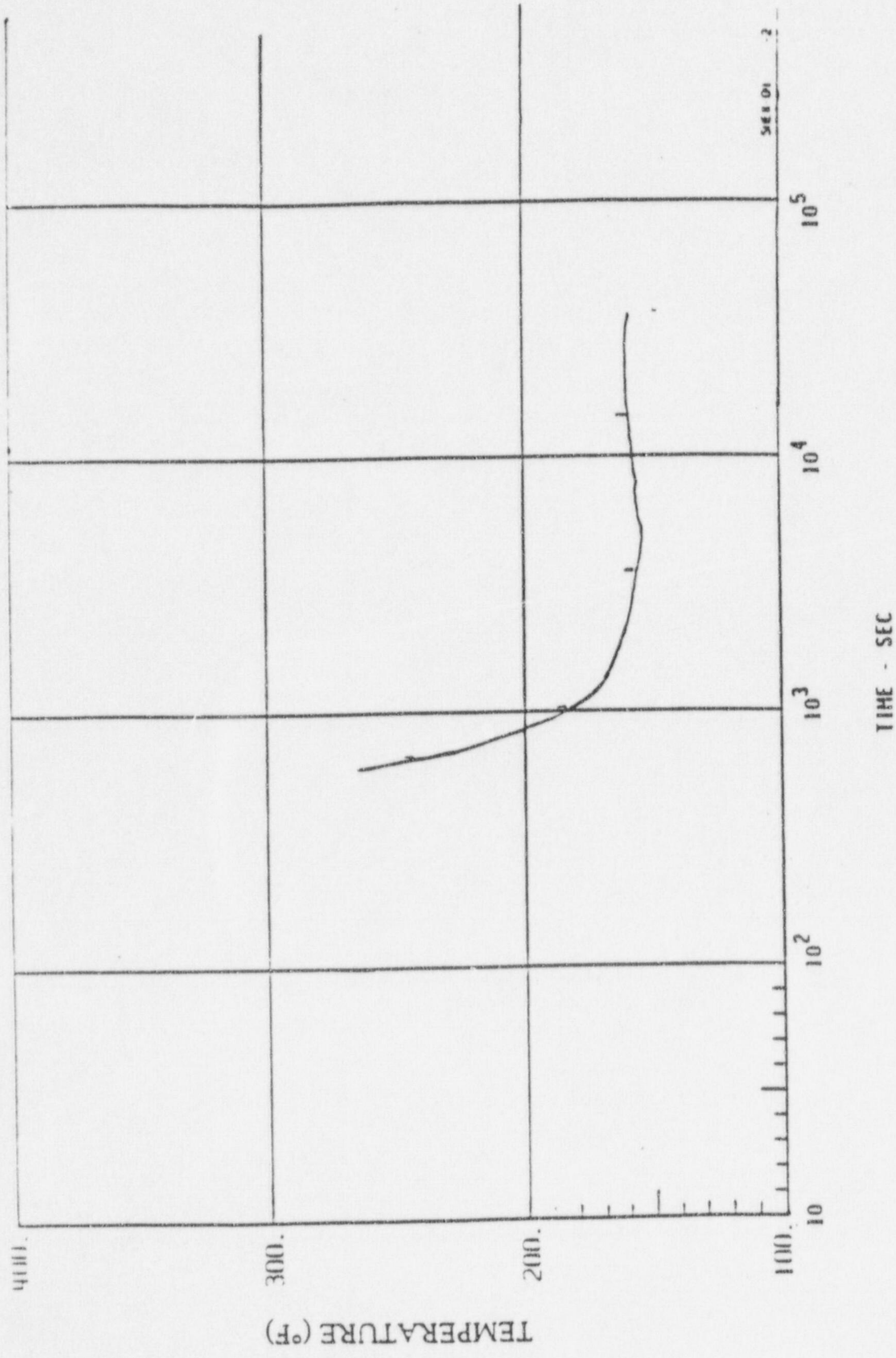


Figure 2 - Long-Term DBA-LOCA Drywell Temperature Response for Case 3F

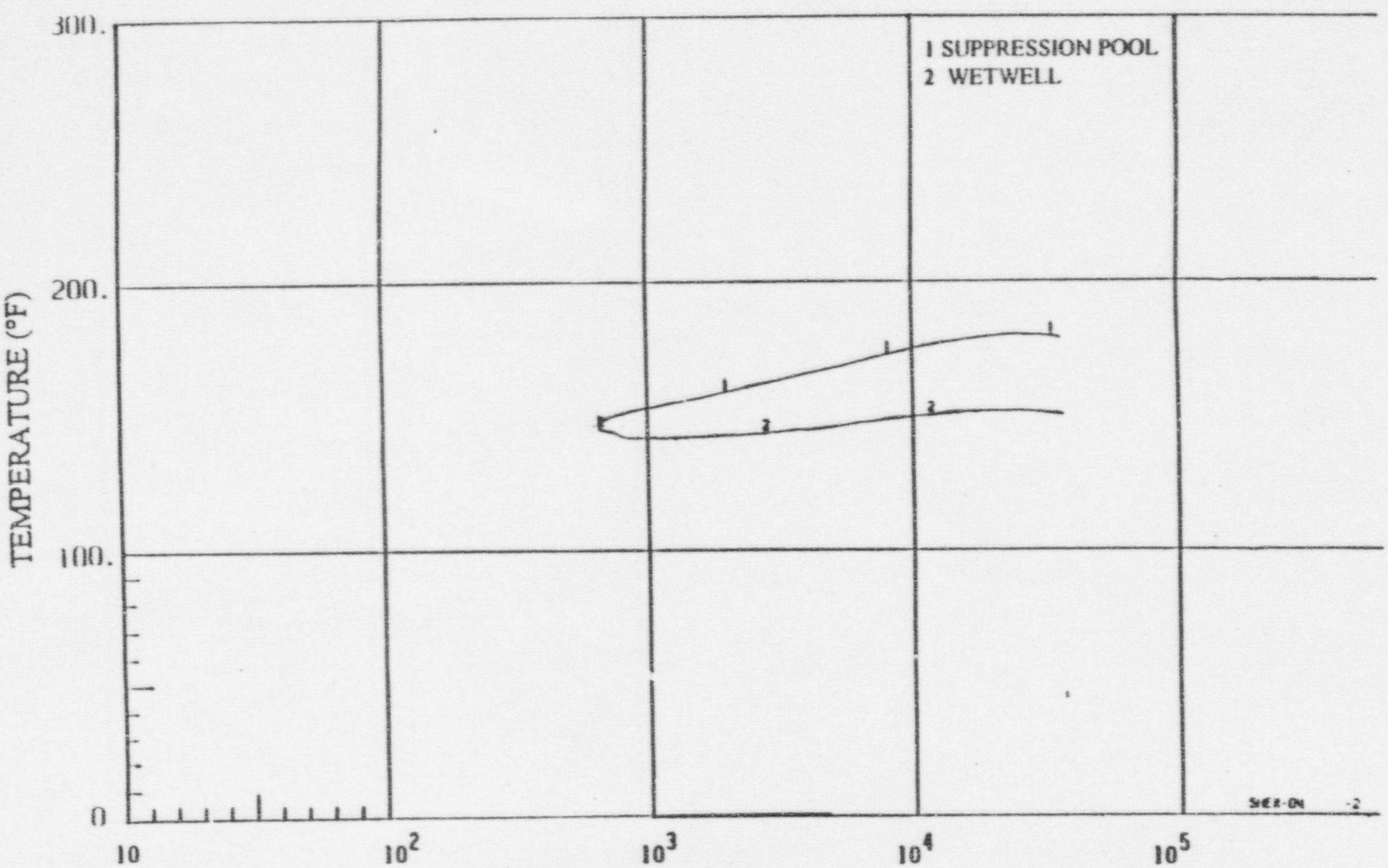


Figure 3 - Long-Term DBA-LOCA Suppression Pool and Wetwell Temperature Response for Case 3

FIGURE 4

PEAK POOL TEMPERATURE VS RHR HEAT EXCHANGER COEFFICIENT 'K'

1 & 2 LPCI/CONTAINMENT COOLING PUMPS

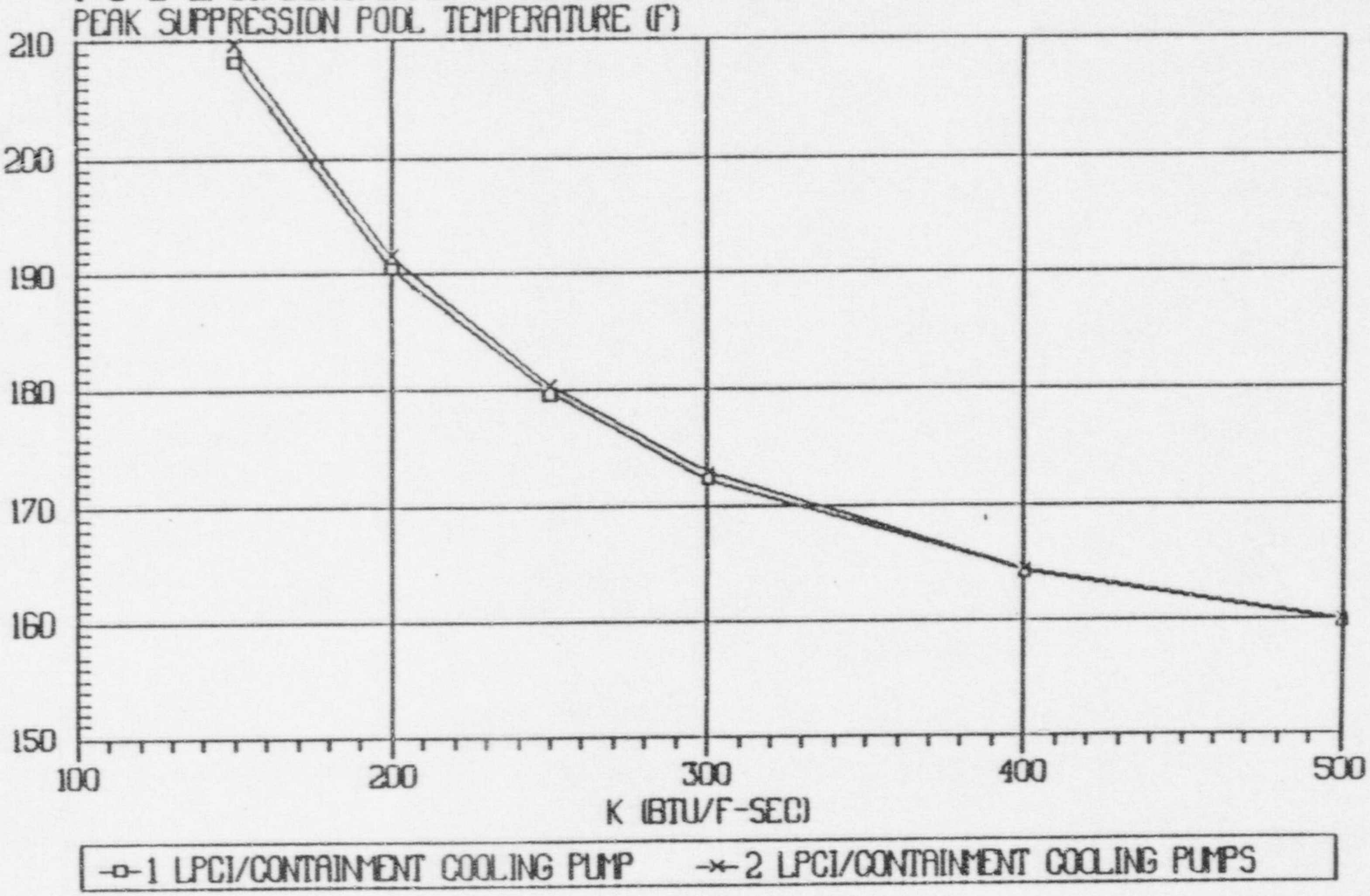


FIGURE 5

WETWELL PRESSURE VS POOL TEMPERATURE

1 & 2 LPCI/CONTAINMENT COOLING PUMPS
SHEX

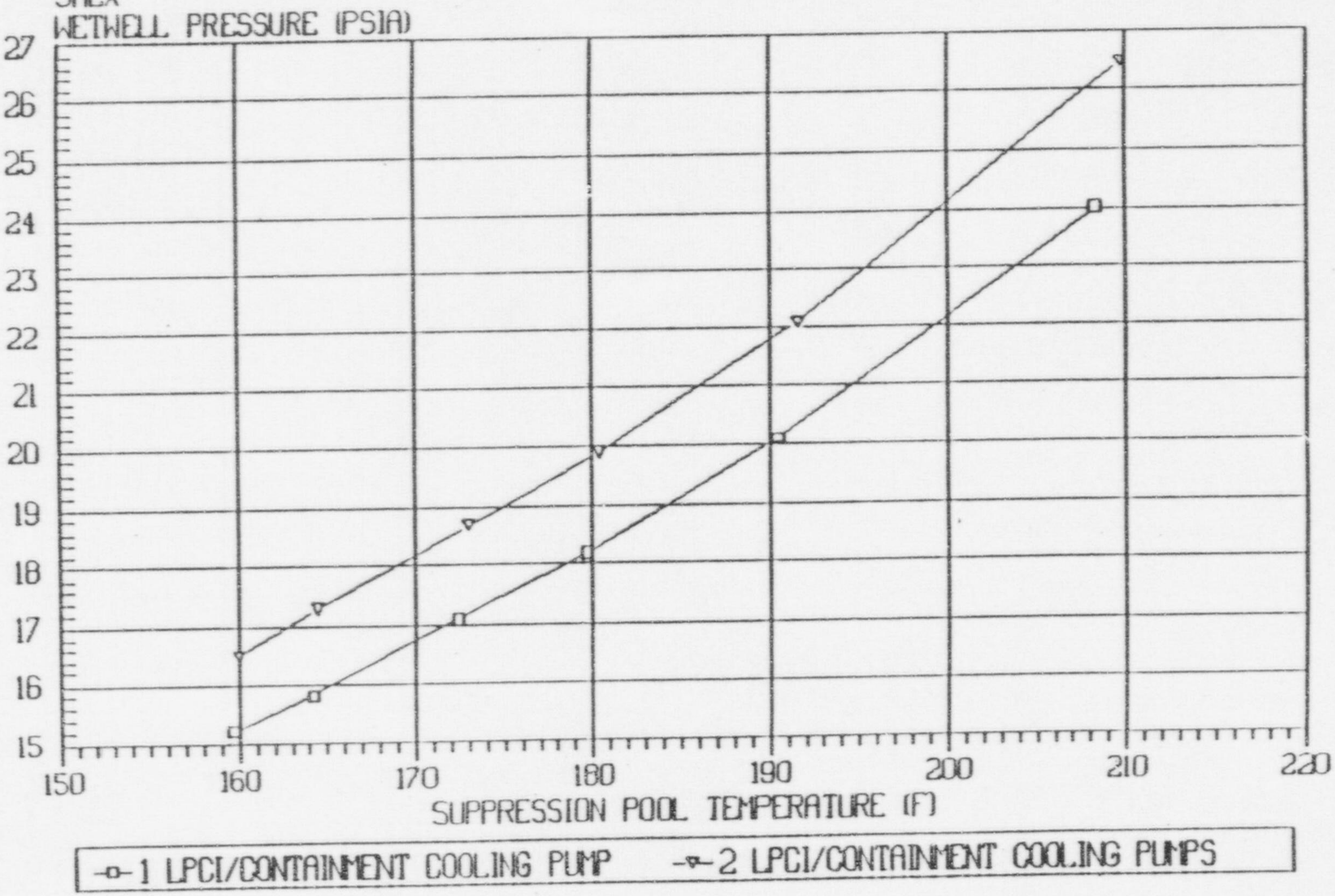


FIGURE 6

WETWELL PRESSURE VS POOL TEMPERATURE

CALCULATED VS REQUIRED WETWELL PRESSURE
FOR ADEQUATE NPSH (1 LPCI/CONT. COOL. PUMP)

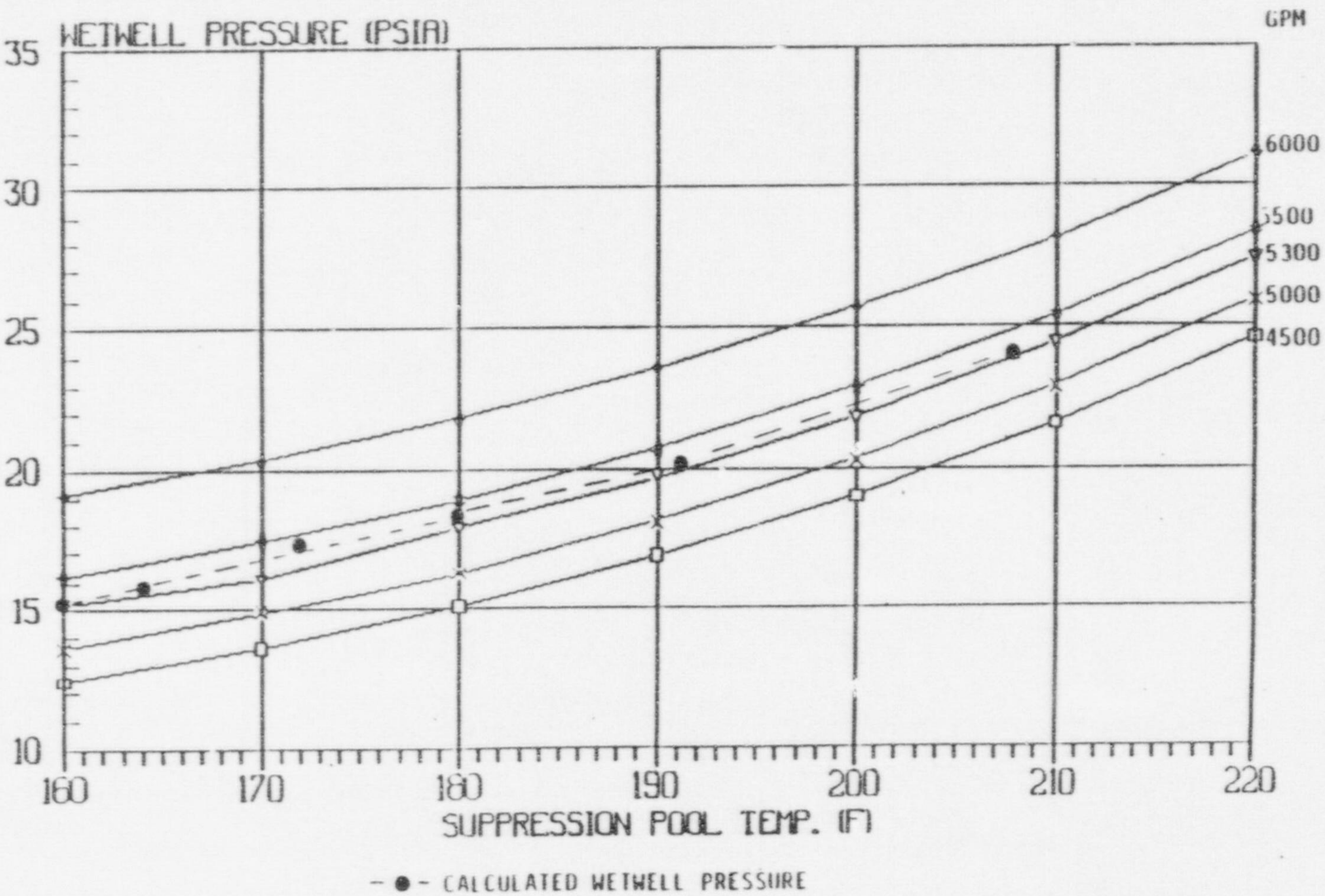
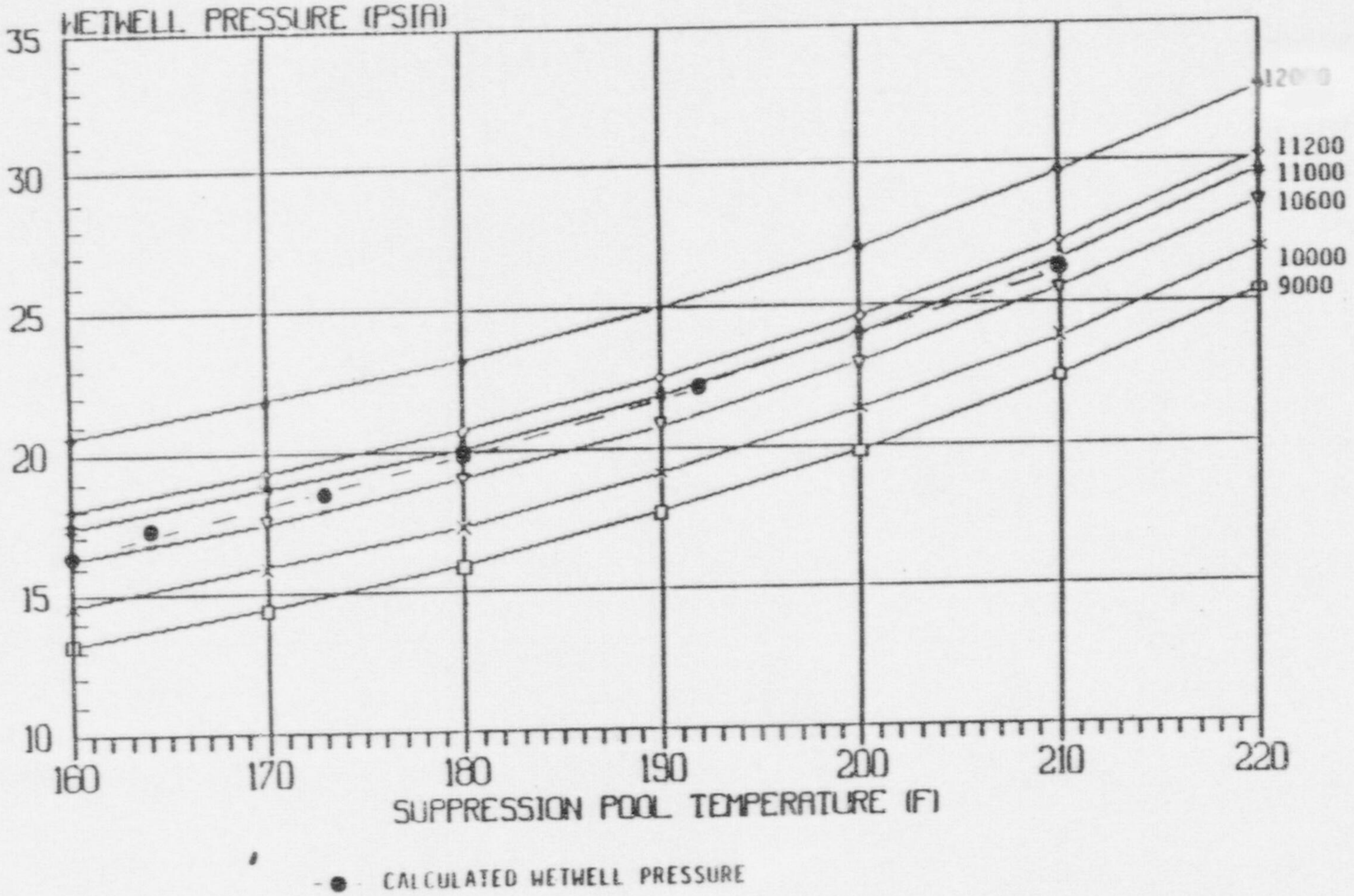


FIGURE 7

WETWELL PRESSURE VS POOL TEMPERATURE

CALCULATED VS REQUIRED WETWELL PRESSURE
FOR ADEQUATE NPSH (2 LPCI/CONT. COOL. PUMPS)



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10.0 APPENDICES

A. CORE HEAT DATA

B. MINIMUM WETWELL PRESSURES FOR EVALUATION OF REQUIRED NPSH

C USAR BENCHMARK ANALYSIS

APPENDIX A

CORE HEAT DATA

Table A.1 provides the core heat (Btu/sec) and integrated core heat (Btu) used in the analysis of Section 7.0. The core heat includes decay heat, metal-water reaction energy, fission power and fuel relaxation energy. The core decay heat used for the analysis was obtained from Reference A.1. This reference provides the shutdown power considering delayed neutron induced fissions, actinide decay heat and the fission production decay (including effects of delayed neutrons) based on the ANSI/ANS 5.1 decay heat model (Reference A.2) assuming an exposure of 25.7 GWD/st. The core heat in Table A.1 is normalized to the initial core thermal power of 2561 mwt.

TABLE A.1 - CORE HEAT

Time (sec)	Core Heat*
0.0	1.006
1.0	.5634
4.0	.5319
10.	.3479
20.	.1092
40.	.0563
60.	.04050
80.	.0385
120.	.0363
120.**	.0303
200.	.0274
400.	.0241
600.	.0221
1000.	.0196
2000.	.0160
4000.	.0127
6000.	.0112
8000.	.0103
10000.	.00972
14400.	.00928
18000.	.00881
20000.	.00859
28800.	.00788
36000.	.00748
60000.	.00658

*Core Heat (normalized to the initial core thermal power of 2561 mwt)
= decay heat + fission power + fuel relaxation energy + metal-water reaction energy

** Metal-water reaction heat is assumed to end at 120 seconds.

REFERENCES:

A.1 GE Design Specification 23A6938, "Decay Heat Requirements," August 1991.

A.2 "Decay Heat Power in Light Water Reactors," ANSI/ANS 5.1 - 1979, Approved by American National Standards Institute, August 29, 1979.

APPENDIX B

MINIMUM WETWELL PRESSURES FOR EVALUATION OF REQUIRED NPSH

Since both the RHR and Core Spray pumps have similar elevations and NPSHR curves, the Core Spray pumps are bounded in this analysis by the RHR pumps due to the difference in suction losses. To determine the frictional losses at any one or two pump flow, the quadratic relationship between head loss and flow establishes the following:

$$\text{head loss}_2 = \text{head loss}_1 \times (\text{flow}_2/\text{flow}_1)^2 \qquad (3)$$

Therefore, the suction losses for the flows to be analyzed are:

One Pump Flow (gpm)	Suction Losses (ft)	Two Pump Flow (gpm)	Suction Losses (ft)
4,500	4.36	9,000	6.28
5,000	5.38	10,000	7.75
6,000	7.75	12,000	11.16

Table 2

Calculations

The minimum required wetwell pressure is determined for a range of wetwell temperatures using Equation 2. Three different single pump flow values are analyzed, including the rated RHR pump flow of 4500 gpm. Table 4 documents the results of this calculation.

Summary and Conclusions

This calculation developed the minimum required wetwell airspace pressure to provide adequate NPSH to the RHR and Core Spray pumps when suction is taken from the torus. Wetwell pressures were developed for both one and two pump RHR and Core Spray operation at Quad Cities Station. Required pressures for Core Spray pumps are bounded by those determined for the RHR pumps based on similar pump elevations and NPSHR curves, and lower Core Spray suction losses. It should be noted that there is no common suction piping for the Core Spray pumps so that the required wetwell pressures for one ECCS pump operation apply to both one and two Core Spray pump operation.

Quad Cities RHR/Core Spray
Minimum Wetwell Pressure Required

TABLE 4

Torus Temp (°F)	Vapor Pressure (psia)	Specific Volume (ft3/lb)	One Pump Operation: @4500 gpm Min Wetwell Pressure (psia)	One Pump Operation: @5000 gpm Min Wetwell Pressure (psia)	One Pump Operation: @6000 gpm Min Wetwell Pressure (psia)	Two Pump Operation: @9000 gpm Min Wetwell Pressure (psia)	Two Pump Operation: @10000 gpm Min Wetwell Pressure (psia)	Two Pump Operation: @12000 gpm Min Wetwell Pressure (psia)
90	0.698	0.01610	8.46	9.75	15.35	9.28	10.77	16.82
100	0.949	0.01613	8.69	9.99	15.57	9.51	11.01	17.04
110	1.275	0.01617	8.99	10.29	15.86	9.82	11.31	17.33
120	1.693	0.01620	9.39	10.69	16.25	10.22	11.70	17.71
130	2.223	0.01625	9.90	11.19	16.74	10.72	12.21	18.20
140	2.889	0.01629	10.55	11.84	17.38	11.37	12.85	18.82
150	3.718	0.01634	11.35	12.64	18.15	12.17	13.64	19.60
160	4.741	0.01640	12.35	13.63	19.13	13.17	14.64	20.57
170	5.993	0.01646	13.58	14.85	20.33	14.39	15.85	21.77
180	7.511	0.01651	15.07	16.34	21.80	15.88	17.34	23.23
190	9.340	0.01657	16.87	18.14	23.57	17.67	19.13	25.00
200	11.526	0.01664	19.03	20.29	25.70	19.83	21.28	27.12
210	14.123	0.01671	21.59	22.85	28.24	22.39	23.83	29.66
220	17.186	0.01678	24.63	25.88	31.24	25.42	26.86	32.68

Torus Level = 13.52 ft.
(Dresden min torus level post-LOCA w/ 1 ft. drawdown)

@ 4500 gpm
NPSHR = 28 ft.
Z = 14.39 ft.
hL = 4.36 ft.

@ 5000 gpm
NPSHR = 30 ft
Z = 14.39 ft.
hL = 5.38 ft.

@ 6000 gpm
NPSHR = 40.6 ft.
Z = 14.39 ft.
hL = 7.75 ft

@ 9000 gpm
NPSHR = 28 ft
Z = 14.39 ft.
hL = 6.28 ft.

@ 10000 gpm
NPSHR = 30 ft.
Z = 14.39 ft
hL = 7.75 ft.

@ 12000 gpm
NPSHR = 40.6 ft.
Z = 14.39 ft.
hL = 11.16 ft.

Calculation No. NED-M-MSD-59 Rev. 0
Quad Cities ECCS NPSH - Minimum Required Wetwell Pressure

Purpose/Objective

Calculate the minimum required wetwell airspace pressure as a function of suppression pool temperature which is needed to provide adequate Net Positive Suction Head (NPSH) to the RHR and Core Spray pumps taking suction from the suppression pool. This calculation includes analysis of both one and two ECCS pump operation.

Assumptions/Inputs

In addition to the assumptions made in Reference 1, the following assumptions and inputs are utilized in this calculation:

1) One set of wetwell pressures will be generated for both the RHR and Core Spray pumps. Since both pumps have similar elevations and NPSH curves, and since suction losses to the Core Spray pumps are less than those for the RHR pumps (Reference 2), then the pressures determined for the RHR pumps bound the Core Spray pumps.

2) Torus level elevation is assumed to be 14.39' above pump centerline, or 570.02'. This corresponds to the post-LOCA minimum torus level elevation used in the Dresden LPCI NPSH calculations (Reference 4). Assumed Quad Cities post-LOCA minimum torus level elevation to be the same.

3) RHR/CS pump centerline elevation = 555.625' (Reference 2).

4) RHR/CS NPSHR values shown in Table 3 (Reference 1).

5) RHR/CS one and two pump suction losses shown in Table 1 (References 1 and 2).

6) This analysis includes single pump flows of 4500, 5000 and 6000 gpm, and two pump flows of 9000, 10000 and 12000 gpm.

References

1. "Quad Cities ECCS NPSH Temperature Limits", Nuclear Engineering and Technology Services Calculation #NED-M-MSD-58 Rev. 0, CHRON# 202807, dated 7/24/93.

2. "Base Suppression Pool Level required for proper operation of the RHR/LPCI and Core Spray Pumps during plant cold shutdown and refueling conditions", NUTECH Calculation No. CWE097.0200.40, January 7, 1992.

3. ASME Steam Tables, 1967.

4. "Dresden Post-LOCA LPCI/Core Spray Pumps NPSH Evaluation," Nuclear Engineering and Technology Services Calculation #NED-M-MSD-54 Rev. 0, CHRON# 200691, dated 4/30/93.

Equations

Net Positive Suction Head Available (NPSHA) in feet is determined using the following equation:

$$NPSHA = 144\, v\, (Pt - vp) + z - hL \qquad (1)$$

where:
- Pt = Torus Pressure (psia)
- vp = Saturation Pressure (psia)
- hL = suction losses (feet)
- v = specific volume (ft^3/lb)
- z = head of water above pump inlet (feet)
  - = torus water elev - pump centerline elev
  - = 570.02' - 555.625'
  - = 14.39'

Solving Equation 1 in terms of the wetwell (torus) pressure provides the following:

$$Pt = \frac{NPSHR - z + hL}{144\, v} + vp \qquad (2)$$

For a given flow, the required NPSH (NPSHR), the head of water above the pump (z) and the suction losses (hL) are constant. The specific volume (v) and vapor pressure (vp) are a function of wetwell temperature.

Suction Losses

Suction losses for one pump operation (Reference 2) and two pump operation (Reference 1) of RHR and Core Spray are provided in Table 1 below:

	Total Suction Losses (feet)	
Pump	One Pump @ 4500 gpm	Two Pumps @ 9000 gpm
RHR	4.36	6.28
Core Spray	2.4	2.4

Table 1

Since both the RHR and Core Spray pumps have similar elevations and NPSHR curves, the Core Spray pumps are bounded in this analysis by the RHR pumps due to the difference in suction losses. To determine the frictional losses at any one or two pump flow, the quadratic relationship between head loss and flow establishes the following:

$$\text{head loss}_2 = \text{head loss}_1 \times (\text{flow}_2/\text{flow}_1)^2 \qquad (3)$$

Therefore, the suction losses for the flows to be analyzed are:

One Pump Flow (gpm)	Suction Losses (ft)	Two Pump Flow (gpm)	Suction Losses (ft)
4,500	4.36	9,000	6.28
5,000	5.38	10,000	7.75
6,000	7.75	12,000	11.16

Table 2

Calculations

The minimum required wetwell pressure is determined for a range of wetwell temperatures using Equation 2. Three different single pump flow values are analyzed, including the rated RHR pump flow of 4500 gpm. Table 4 documents the results of this calculation.

Summary and Conclusions

This calculation developed the minimum required wetwell airspace pressure to provide adequate NPSH to the RHR and Core Spray pumps when suction is taken from the torus. Wetwell pressures were developed for both one and two pump RHR and Core Spray operation at Quad Cities Station. Required pressures for Core Spray pumps are bounded by those determined for the RHR pumps based on similar pump elevations and NPSHR curves, and lower Core Spray suction losses. It should be noted that there is no common suction piping for the Core Spray pumps so that the required wetwell pressures for one ECCS pump operation apply to both one and two Core Spray pump operation.

Quad Cities RHR/Core Spray Pumps NPSH Required
(Reference 1)

Flow (gpm)	NPSHR (ft)	Flow (gpm)	NPSHR (ft)
3,500	25	5,500	35
3,800	25.5	5,600	36.1
4,000	26	5,700	37.2
4,500	28	5,800	38.4
5,000	30	5,900	39.5
5,300	33	6,000	40.6

Table 3

APPENDIX C

USAR BENCHMARK ANALYSIS

A benchmark case was performed with the SHEX code using the same input assumptions as those used for the USAR analysis for Case e of USAR Table 6.2-3. Table C.1 summarizes the changes made to the key inputs and assumptions of Section 3 and 4. The core heat used in the analysis, which is shown in Table C.2, was based on the May-Witt decay heat model.

RESULTS:

Figure C.1 shows the long-term suppression pool temperature response for the USAR bench mark case. The calculated peak suppression pool temperature with SHEX for the USAR bench mark case is 181°F which is 4°F higher than the value of 177°F reported in Table 6.2-3 of the USAR for Case e.

Table C.1 - Key Parameters used for the USAR Bench Mark Analysis

Parameter	Value
Decay Heat	May-Witt
Feedwater	None
Initial Pool Temperature (°F)	90
RHR HX Heat Transfer Coefficient (Btu/Sec-°F)	276.1
RHR HX Heat Removal (million Btu/hr)	*84.5

* Referenced to a Suppression Pool Temperature of 180°F and a Service Water Temperature of 95°F ($\Delta T = 85$°F)

TABLE C.2 - CORE HEAT BASED ON MAY WITT DELAY HEAT MODEL

Time (sec)	Core Heat*
0.0	1.0232
0.1	1.0092
0.2	.9785
0.6	.7467
0.8	.6966
1.0	.5860
2.0	.5541
3.0	.5921
4.0.	.5830
6.0	.5486
8.0	.4733
10.	.3859
20.	.08943
30.	.07161
40.	.05378
60.	.04937
80.	.04727
100.	.04588
120.	.04499
121.**	.03718
200.	.03365
600.	.02549
1000.	.02229
2000.	.01841
4000.	.01512
6000.	.01353
10000.	.01201
20000.	.01008
40000.	.008125
60000.	.007394

*Core Heat (normalized to the initial core thermal power of 2561 mwt)
= decay heat + fission power + fuel relaxation energy + metal-water reaction energy

** Metal-water reaction heat is assumed to end at 120 seconds.

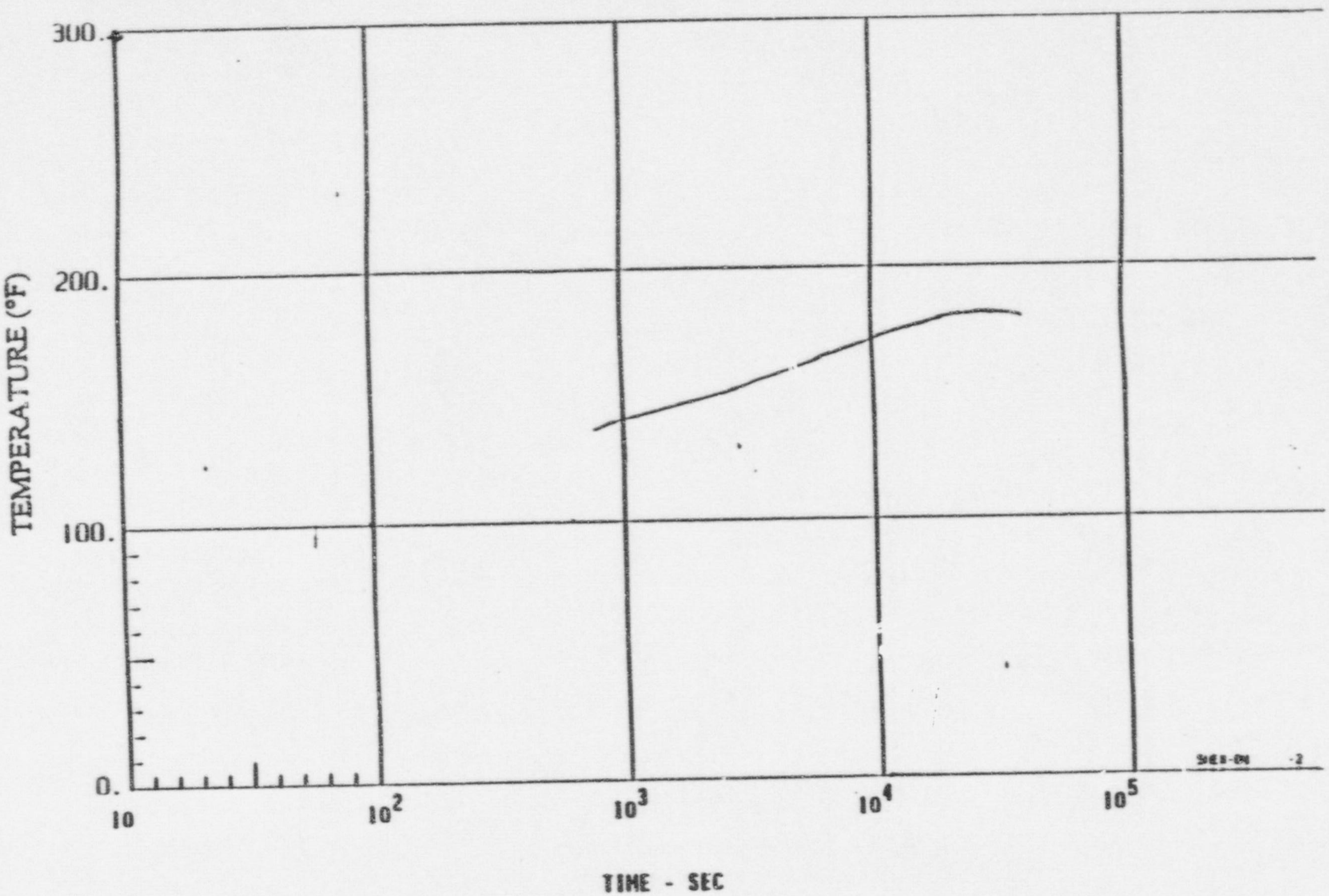

Figure C.1 - Long-Term DBA-LOCA Suppression Pool Temperature Response for FSAR Case e Bench Mark